water

MDPI

Article

Water Management Balance as a Tool for Analysis of a River Basin with Conflicting Environmental and Navigational Water Demands: An Example of the Warta Mouth National Park, Poland

Dorota Pusłowska-Tyszewska

Chair of Environment Protection and Management, Faculty of Building Services, Hydro and Environmental Engineering, Warsaw University of Technology, Nowowiejska 20, 00-663 Warszawa, Poland; dorota.puslowska@pw.edu.pl

Abstract: Allocating finite water resources between different water uses is always a challenging task. Searching for a solution which satisfies the water needs (requirements) of all water users without compromising the water requirements of river ecosystems calls for analyzing different water management options and their expected consequences. Water management balances are usually used for comparison of water resources with the needs of water users. When aquatic and water dependent ecosystems are considered in a similar manner as other users, searching for the optimum water resources allocation, without neglecting requirements of the natural environment, is possible. This paper describes basic modeling assumptions and methodological solutions, which allow for taking into account some tasks related to the protection of aquatic and water dependent ecosystems. The water balance model, developed for a catchment comprising the Warta Mouth National Park, was applied to find out whether supplying adequate amounts of water for conservation (or restoration) of wet meadows and wetland habitats in the area is possible, while still satisfying the demands of other water users.

Keywords: water requirements of aquatic and water dependent ecosystems; water resources allocation; water balance model

Citation: Pusłowska-Tyszewska, D. Water Management Balance as a Tool for Analysis of a River Basin with Conflicting Environmental and Navigational Water Demands: An Example of the Warta Mouth National Park, Poland. *Water* **2021**, *13*, 3628. https://doi.org/10.3390/w13243628

Academic Editors: Andrzej Walega and Tamara Tokarczyk

Received: 26 October 2021
Accepted: 14 December 2021
Published: 16 December 2021

1. Introduction

The issue of allocating sufficient volumes of water for aquatic and water-dependent terrestrial ecosystems has been analyzed for many years, but, in 2000, the Water Framework Directive (WFD [1]) introduced new and ambitious objectives to protect and restore these ecosystems as a basis for ensuring the long-term sustainable use of water for people, businesses, and nature. The key objective of the WFD is to achieve a good status for all water bodies. This comprises the objectives of good ecological and chemical status for surface waters and good quantitative and chemical status for groundwater. This becomes a priority task of water management. Maintenance of the appropriate environmental flows is mentioned often as one of the basic conditions to achieve good status of surface water bodies [2]. There are many methods of defining the environmental flows required for an aquatic environment—at least 200 of them have been identified [3–5]. These methods differ considerably from one another as regards the method of determination, scope of application, the hydrological regime elements taken into account [6–8], interactions with groundwater [9,10], and the socio-economic objectives of water use [11–13]. The flow magnitude and characteristics of the hydrological regime, such as variability of flows, their distribution during high- and low-water periods, duration, and frequency of occurrence, are treated as the key parameters [7]. Other parameters, such as water velocity and depth of the stream, river bed morphology, and connection with floodplains, are also mentioned in the context of quantitative requirements of river ecosystems [14–16]. For water dependent ecosystems, including a variety of wetlands, water requirements pertain to hydrological feeding types, time distribution and dynamics of water level changes, soil moisture content, and frequency of droughts [17,18].

Identification of water requirements of ecosystems or protected organisms is the first basic condition of their protection. Other conditions are related to the ability of meeting these requirements—in view of the existing socio-economic tasks of water management [19,20]. The search for a compromise fits into the concept of sustainable development. What has fundamental importance is the possibility of analyzing the potential alternatives of water resources allocation in a specific location and time [21,22].

At the current level of economic development, in Poland and Europe alike, and with the effected anthropogenic changes of the environment as a whole, one can hardly approve the idea of preservation or reconstruction of the natural hydrological conditions that originally formed the existing aquatic and water-dependent ecosystems. One should focus instead on allocation of sufficient (or appropriate) volume of water, which—in a specific situation as regards to water use, anthropogenic transformation of the basin, and social expectations, e.g., those related to flood risk—at least partly meet the ecosystems' requirements and secure a sufficient level of protection [23]. One of the tools for analyzing the water resources allocation alternatives is the model of water management balance (e.g., [24]). Since the water management balance means comparison of water resources with the needs of their users, both the resources and the needs should be described with sufficient precision. A dynamic balance takes into account data that change over time and the calculations are based on a simulation of the functioning of the water management system, usually a river basin [25,26].

In the Warta Mouth National Park (WMNP) there are conflicting objectives of water resources management: agricultural areas located in the park require at least periodical drainage, while protection of the Park's natural values requires maintenance of high humidity of habitats. The use of water resources of the Warta River to improve habitats' moisture conditions is limited due to the necessity to provide adequate flows for inland navigation. The aim of the study was to answer the question if it was possible for effective protection of wetland habitats, navigation, and agriculture to coexist in the area. In order to answer this question, a water management balance of part of the Warta catchment was performed, in which tasks related to maintaining appropriate moisture conditions in the WMNP area were taken into account. In this paper special emphasis is put on methodological solutions for these elements of water balances, which are of crucial value for adequate representation of the quantitative requirements of water dependent ecosystems. The balance model, which takes into account the specific features of a catchment comprising The Warta Mouth National Park, was applied to find out whether supplying an adequate volume of water for conservation or restoration of the marshy meadow ecosystems is possible, while still satisfying the demands of other water users. The present balance model assumptions, methodological solutions, and calculations are the effects of a study: "Water management optimization model for the Warta Mouth National Park" [27] undertaken within the preparations of a draft protection plan for the Park and Natura 2000 site PLC 080001, implemented by MGGP S.A. in 2013.

In the following part of the article a short description of the Warta Mouth National Park is presented, the applied water management balance methodology is discussed, and then the way in which the specific uses of the studied area were included in the balance model is described. The results of simulation calculations are presented on the example of a selected habitat that is protected in the WMNp. In the discussion, attention is paid to possible sources of uncertainty of the obtained results. Conclusions formulated in the final part concern both the usefulness of the applied approach in assessing the possibility of obtaining a compromise in case of conflicts between water management tasks and the scope of information necessary for an adequate description of tasks related to ecosystem protection.

2. Materials and Methods

2.1. Study Area

The Warta Mouth National Park (WMNP) lies in the lower part of the Warta River basin and comprises the right-hand part of the Warta valley and a fragment of the area between the Odra and Warta rivers. The WMNP covers an area of 8037.6 hectares. It is one of the most important refuges of water birds and marsh birds, as well as birds of prey, both in Poland and in Europe [28]. Due to its natural values, it has been entered on the list of the RAMSAR Sites and included in the Natura 2000 network (PLC 080001). The prevalent land cover consists of meadows with various moisture contents, some of them being used for agricultural purposes. The southern part of the park is regularly flooded during the spring freshets of Warta and the swelling of its waters at the mouth of the Odra River. The northern, right-hand part of the valley, located behind flood dikes, is not hydrologically connected with the Warta River today. The water conditions are shaped by small watercourses flowing down from the edge of the valley, and—first of all—by a system of drainage canals and ditches, as well as pumping stations, that drain water from the area [28]. The nature of the WMNP water conditions is one of the key elements for the protection of open meadow and marsh habitats, as well as nesting and resting areas of valuable bird species.

Besides meeting water needs related to the WMNP protection, the water management tasks in the Warta mouth catchment include: maintenance of the environmental (hydrobiological) flows in Warta and its tributaries; ensuring navigation flows in the Warta River (II class navigable route stretch); and water supply to the existing agricultural users.

2.2. Water Management Balance

The water management balance of surface water is a comparison of water resources with the needs of water users, which takes into account the requirements of the natural environment, the hierarchy of users, the effects of hydrotechnical facilities, and the impact of water abstractions and wastewater discharges on the volume of surface water resources, as well as the interactions with groundwater [29,30]. The balance calculations are performed as a simulation of water resources allocation among the users, for all time steps of the selected multi-annual period, taking into account the time variability of the input data (water resources, water needs and wastewater discharges, operation rules of hydrotechnical facilities, etc.). Simulation analyses shall cover the longest possible period for which reliable data on resources and needs are available. The allocation of water resources is carried out according to the adopted hierarchy of water use, which represents the priorities prevailing in the analyzed area and denotes the order in which users receive access to water. Water abstraction for a user placed lower in the hierarchy must not cause the occurrence or worsening of the deficit of the more important user. The comparison of water resources and water users' needs is carried out at control cross-sections, which are important for determining the quantity of water at main rivers above and below the mouth of significant tributary; at tributaries above the mouth to a higher-order river; at locations of significant water abstraction and sewage discharge, or hydrotechnical facilities (storage reservoirs, transfer channels); and at places important for the assessment of the amount of water resources due to protected ecosystems/habitats.

Time series of mean periodic flow (weekly, 10-day, monthly) at water gauge cross-sections are the basis for determining surface water resources. The flow series should be continuous, synchronous, and homogeneous, and should be free from the water use impact. Ensuring the last condition can be achieved, subject to data availability, by naturalizing water gauge flows (e.g., [31,32]). Flows at control cross-sections are computed by interpolation and extrapolation methods on the basis of water gauge observations, or, results of a hydrological model can be imported.

The needs of water users are represented by time series of average water demands (e.g., municipal or industrial users), or flow requirements at specific river cross sections (environmental flows, navigation flows, etc.). However, for water users capable of retaining water, such as fishponds, irrigated facilities, or certain nature conservation tasks, whose needs depend on the current water retention (including the amount of water supplied in previous time steps) and current hydrometeorological conditions, they are calculated during balance analyses. This approach allows for considering the build-up of demand volumes that have not been met in previous time steps. The simulation of users retaining water is carried out in two steps: first, user needs are calculated based on retention volumes and hydrometeorological conditions. Then, after the allocation of water resources in a given time step, the final state of retention is calculated based on the allocated water. This retention becomes the initial state in the next time step of simulation.

The wastewater discharges of groundwater users represent an additional source of water in the river. Discharges (return flows) of surface water users are calculated during water resources allocation, based on the amount of water allocated to the user.

The impact of groundwater use on river flows is described by pseudo-users of surface water, whose needs represent the reduction in groundwater discharge to rivers due to groundwater use. The volumes of pseudo-user needs are determined at the balance cross-sections either on the basis of the results of a groundwater model, or in a simplified way, according to the assumption that the reduction of groundwater discharge to a river is proportional to the area of groundwater filtration to the wells located in the catchment. However, the possibility to take into account the impact of groundwater use depends on the availability of results of hydrogeological analyses and groundwater use data.

The water system under study is modeled as a flow network of arcs and nodes. It reflects the spatial structure of the system: the layout of the river network, the routes of water transfer, the location of hydrotechnical structures, and the points of water intake and sewage discharge. The nodes of the network correspond to control cross-sections, water users, and hydrotechnical structures and the arcs represent the routes of water movement between the nodes: along river or water transfer stretches and between rivers or hydrotechnical structures and water users.

The basic task of the model is the multi-period simulation of the allocation of water resources between users. The flows calculated in the network arcs for each simulation time step must satisfy two basic conditions: flow compliance with the arc constraints (e.g., the water intake for a user must not exceed the amount of needs and must be a non-negative value) and preservation of the mass balance at the nodes (the sum of water inflows to a node must be equal to the sum of outflows). Allowing variability of flows within the constraints indicates that many different combinations that satisfy the constraints are possible. If in a time step there is a surplus of resources over demand, the solution is to assign to the intake arcs a flow equal to demand; the flows in the other arcs result from a simple summation (balance). In case of water scarcity, a combination of flows corresponding to the adopted hierarchy of water resource use is determined. The criterion for optimizing flows in the network is to minimize the sum of losses caused by failure to satisfy the needs of water users or to provide the required flows in river sections. The values of unit loss coefficients for water users and river reaches represent the water use hierarchy. The Out-of-Kilter network programming algorithm [33] is used to solve the water allocation task thus defined. The results of the calculations consist of the time series of: water intakes and wastewater discharges by users, volumes of water in storage reservoirs and at users that retain water, and flows in transfer channels and in all river reaches. From these, assessment criteria, such as time reliability, volume guarantee, maximum depth, maximum volume, and maximum duration of continuous deficit, are calculated. Criteria for users retaining water are usually based on the frequency of occurrence of a given retention condition [22,32]. Moreover, reserves of available water resources with assumed guarantees of occurrence are determined in all control cross-sections.

Balancing calculations often consider several water management variants, i.e., system operation is simulated for different sets of input data and model parameters. These variants may include: the occurrence, parameters and water management principles of hydrotechnical facilities (storage reservoirs, transfer channels), environmental flows, and water needs of users, as well as the hierarchy of water resource use.

2.3. Model Concept

The developed balance model allows for the consideration of the specificity of the area and identifies water users and their water needs related to WMNP protection—the basic scheme used to construct the model is shown in Figure 1. The following has been taken into account to assure the appropriate water conditions in the WMNP area: (i) satisfying the Northern Polder's water needs from the Old Warta River (N Polder PU4); (ii) supplementary Warta water supplies to the Northern Polder (N Polder PU4*); (iii) appraisal of the volume and time distribution of Warta water reserves for potential supplementary supplies to the southern part of the WMNP (Słoński Basin). The most important assumptions pertain to the method of modeling water requirements of the Northern Polder, the estimation of water volumes available for supplementary supplies to the Słoński Basin, and the method of representing water needs for navigation purposes (PU5).

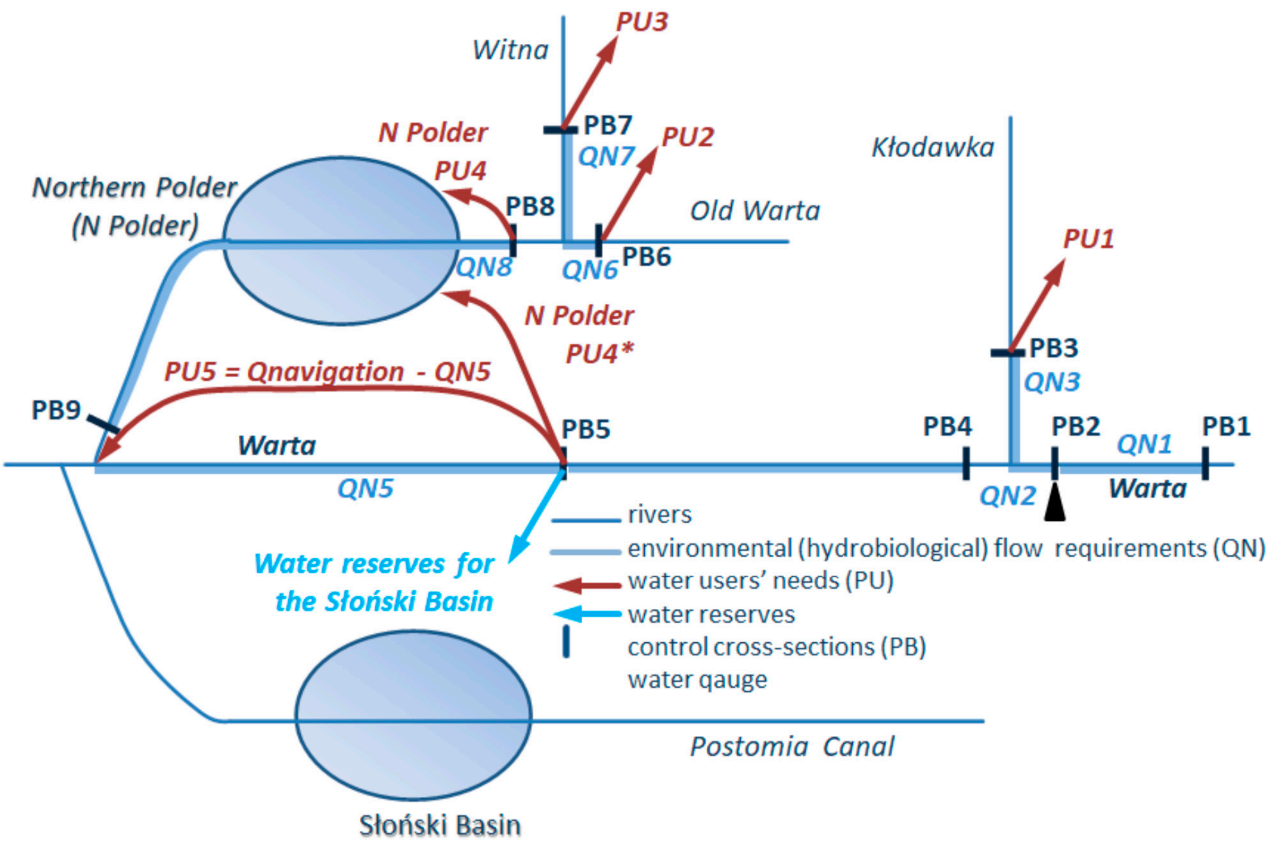

Figure 1. Water management system scheme.

Environmental (hydrobiological) flows (QN) were determined at control cross-sections (PB1-PB8) by the hydrological method defined by the Regional Water Management Authority, based on the method of Kostrzewa [34,35]. According to this method, the environmental flow is equal to the higher of two values: the product of the multi-year average of the annual minimum flows and the parameter of the method (k coefficient), or the lowest flow in the multi-year period. The k coefficient depends on the hydrological type of the river (lowland, transitional, mountain), which is selected on the basis of the average specific runoff and on the catchment area to the cross-section under consideration. The existing agricultural uses included fishpond complexes and areas of irrigated grassland, the needs of which were determined on the basis of water permits. The needs of these users were represented in the model as aggregated water demands PU1–PU3.

2.3.1. Northern Polder

The protection of the natural values of the Northern Polder WMNP aims to prevent the degradation of organic soils and vegetation and should, therefore, consist in maintaining the highest possible moisture content of the local hydrogenic habitats [28]. The habitats have been classified into three types based on their moisture conditions, and their respective uses have been defined:

- Marshy habitats, including reed fields not used for agricultural purposes, located in the southern part of the Polder—between Old Warta and the flood bank (area of marshy habitats Fmarsh = 500 hectares),
- Moist habitats, including extensively utilized once-mowed meadows (Fmeadow = 1050 hectares),
- Moderately moist habitats, including pastures (Fpasture = 1000 hectares).

The task of ensuring the habitats' high moisture content has been formulated as follows [28]:

- Admission of spring floods to the marshy and moist areas (until the end of June);
- Avoidance of excessive drainage when used for agricultural purposes (the groundwater level may be reduced to 50–60 cm below the ground from early June to mid-October in the case of pastures, and in July-August in the case of extensive meadows);
- Stopping of drainage and reconstructing of water retention in the soil profile after agricultural utilization ceases.

To maintain the habitats' high moisture content, the own waters and Old Warta's resources should be used first of all, with Warta waters used only in case of shortage of such resources. To represent water requirements of the Polder mentioned above, simplified water balance in the soil profile has been used to develop a model of the habitat's water needs, and the required parameters have been determined for each habitat moisture type (the desired water retention in the soil profile by seasons, the possibility of drainage or irrigation, and the occurrence of floods). According to the modeling method of water retaining user, the water needs of each habitats were calculated based on the soil water balance and the desired retention. Then, after solving the water allocation task, the final retention state was calculated, which became the initial state in the next simulation step.

2.3.2. Słoński Basin

No model of the Słoński Basin's water needs has been developed, due to insufficient exploration of the site and inventory/survey works carried out during the balance analyses. Instead, the volume of water resources (reserves) available for use as supplementary supplies for the area was estimated. The available reserves were determined based on the assumption that they are equal to the volume of water that remained after the needs of all users located downstream of the examined cross-section had been satisfied. Of crucial importance for the allocation of water for the potential supplementary supplies to the Słoński Basin, has been a discussion concerning satisfaction of the inland navigation water requirements.

2.3.3. Navigation

As follows from the information obtained from the Regional Water Management Authority in Poznań, the navigation season along the analyzed stretch of the Warta River comprises the whole year. The proper (standard) navigation conditions require water levels exceeding a specific threshold value (Hnav_stand). At the same time, navigation may take place, with some limitations, already at a specific lower water level (Hnav_min). Below that level, navigation is impossible. After preliminary balance analyses, it has been arranged with the Regional Water Management Authority in Poznań, that no resources are reserved for navigation purposes in the periods with water levels below Hnav_min. Therefore, current water requirements for navigation purposes (Qnavigation) have been modeled as:

- Equal to the navigable flow at water levels exceeding Hnav_stand,

- Equal to the actual flow within water level range ⟨Hnav_min–Hnav_stand⟩, and
- Equal to 0 at water levels below Hnav_min.

The water demand for navigation (PU5) is represented in the balance model as the excess flow over the environmental flow (PU5 = QNavigation − QN5).

2.4. Simulation

The balance analyses have been carried out in accordance with the methodology described in Section 2.2 by simulation of the catchment's functioning. The balance model was developed in an MS Excel workbook with Visual Basic Application macro support enabled. The model developed for the Warta mouth catchment consisted of 16 nodes and 81 arcs. The following hierarchy of water use was assumed in the balance calculations: maintaining environmental flows, maintaining navigation conditions, supplying existing agricultural users, and providing adequate moisture conditions for wetland habitats in the Northern Polder. The balancing covered the years 1984–2012, and the simulation based on 10 days' time steps. The interpolation and extrapolation method was used to determine the magnitude of flows at control cross-sections.

3. Results

On the basis of the balance simulation results, the criteria for assessing the degree to which users' water needs were met were calculated. In the system under analysis, water supply problems occurred in the basins of small watercourses—tributaries of Warta or Old Warta. With respect to those rivers, relatively low time reliability of maintenance of the environmental (hydrobiological) flows and satisfying water users demands were determined: QN8—58%, QN6 and QN7—60%, and PU1–PU3, respectively, 61%, 77%, and 23%. The volumetric guarantee, defining the ratio between the volume of water supplied and that required, was approximately 85% for maintaining environmental flows. The volumetric guarantee of water supply to agricultural users was in the range of 30–75%. Environmental flows in the Warta River, on the other hand, were 100% guaranteed, and navigable conditions occurred in 82% of the analyzed time steps (standard conditions—47%, minimum acceptable conditions—35%). The estimated water reserves are quite large and occur during periods when flows in the Warta River are greater than the environmental flow, but smaller than the minimum navigable flow, or they are above the standard navigable level. A considerable part of these reserves occurs in the spring period from March to May. The flow volumes determined in the control cross-section PB5, in which both environmental flow and the task of maintaining adequate navigable conditions were determined, are shown in Figure 2 (in hydrological years, that start in the 1 November). The volumes of water reserves that can be used for additional supply of the Słoński Basin are also included there. As can be seen from this figure, water reserves are not available all the time. They occur in about 50% of the time steps.

The water retention time series in the Northern Polder habitats demonstrate the habitats' satisfactory moisture content for most of the time. Considerable drying was found most often (18% of the time) in the moderately moist pasture areas. These are the driest of the habitats considered, with the smallest desired retention, which is related to their natural conditions and actual land use. Due to problems with maintaining appropriate humidity conditions, Figure 3 presents the water retention time series in this habitat in the studied multi-year period. Apart from the retention, the available water resources in the Old Warta River and water intakes to improve water conditions in this habitat are presented. Figure 4 shows the water retention and meteorological parameters for a selected year (2000), where relatively unfavorable moisture conditions were observed. Winter season retention was high, but drainage at the start of the grazing season, the subsequent period of high temperatures, lack of rainfall, and deficit of water resources for irrigation resulted in significant drying of the habitat, which lasted from early August to late October. In November the restoration of retention began.

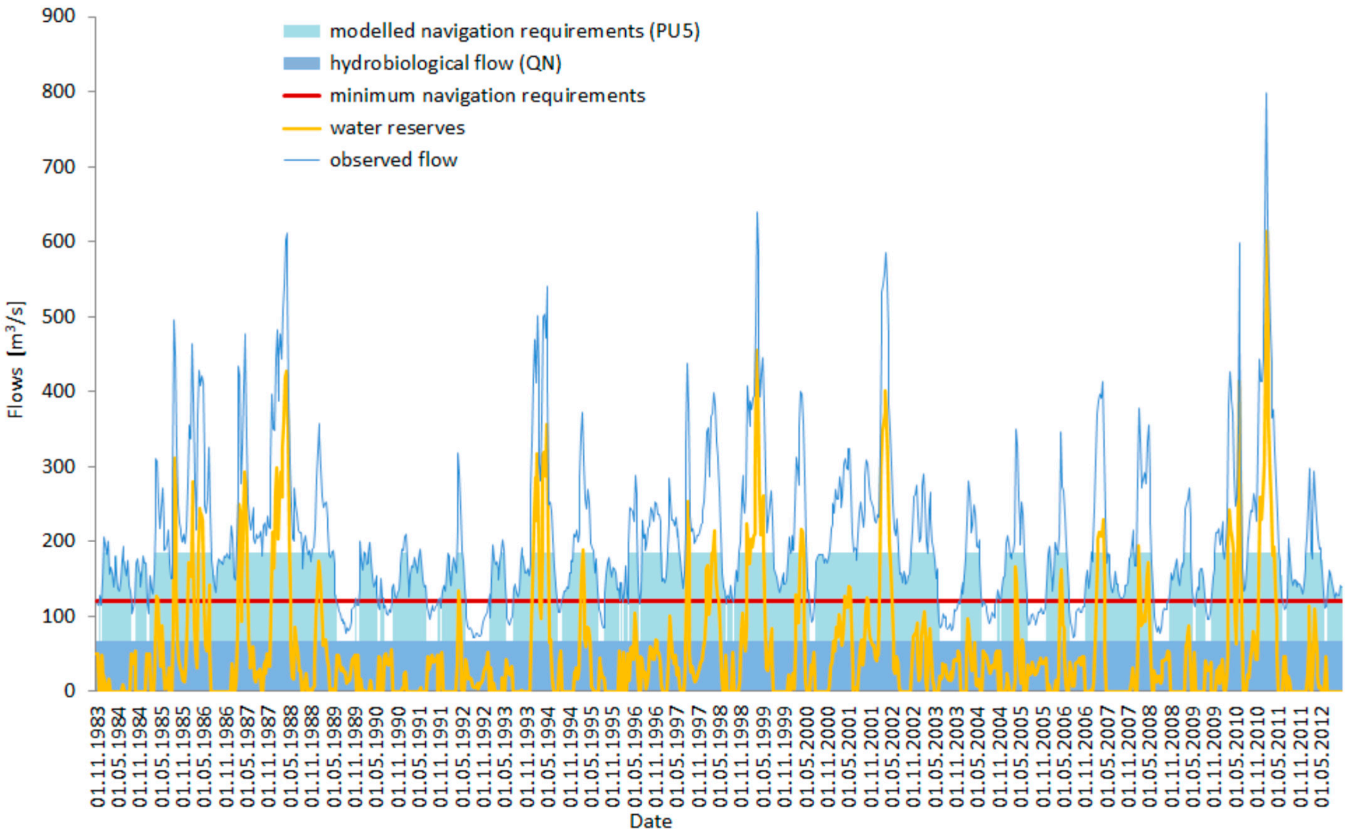

Figure 2. Balance flows of the Warta River at the cross-section PB5 with appraisal of the navigation conditions and water reserves.

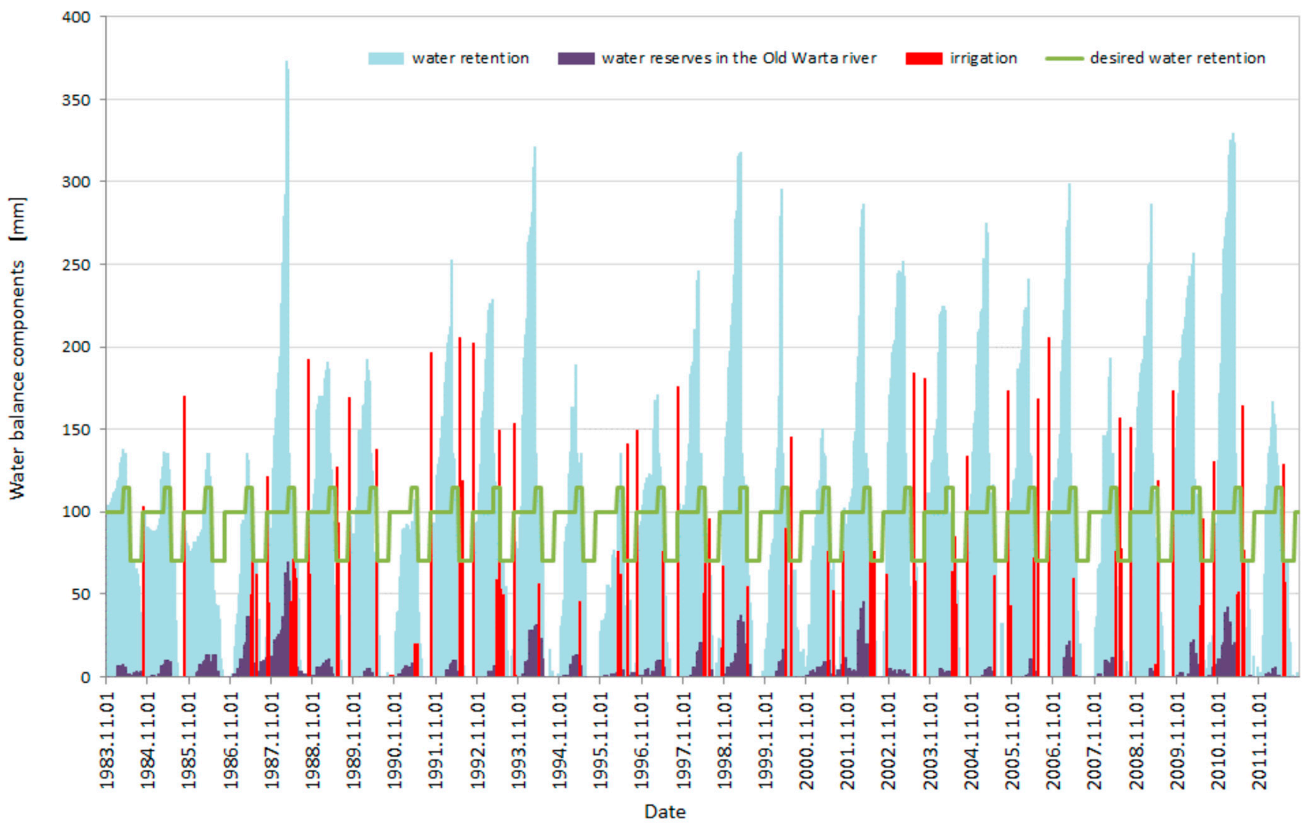

Figure 3. Water retention in moderately moist habitats in the analyzed multiple years' period.

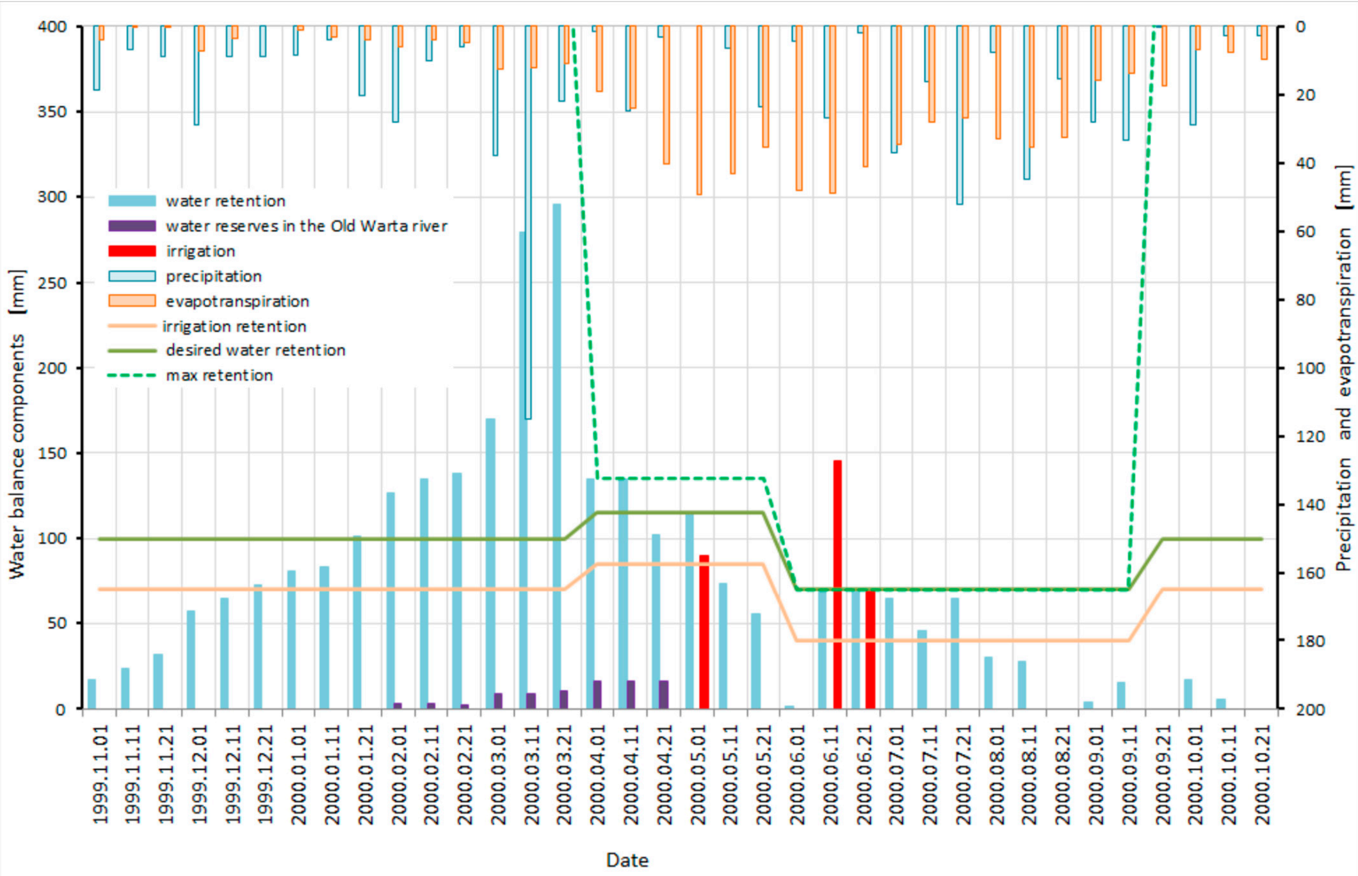

Figure 4. Water retention and other water balance elements in moderately moist habitats in 2000.

In moist habitats (meadows) water retention below the assumed irrigation threshold, i.e., overdrying threshold, was observed only 5% of the time. In marshy habitats, such a situation occurred more frequently, i.e., in about 12% of time steps, which is related to higher humidity of these habitats.

The resources of the Old Warta River were mainly used for irrigation. The task of providing suitable conditions for navigation limited the supply to the Polder from the Warta River.

4. Discussion

As identified within the water balance analyses, the problems with maintenance of the environmental hydrobiological flows—and, thus, with meeting the users' water requirements—in small water courses of the analyzed basin, are related to the high values of the required flows, determined in some of the still valid documents [34], much exceeding those determined in earlier studies [28]. Since maintenance of environmental flows was defined as the most important task in the modeled system, low values of its implementation criteria indicate the need for verification of the determined requirements. Verification, ideally preceded by research of the existing water ecosystems and definition of their specific quantitative requirements, would lead to a more reliable appraisal of any potential problems with maintaining appropriate flows, possibly threatening the good ecological status.

Furthermore, a more precise determination of the water resources of small watercourses would certainly contribute to a better recognition of the relevant catchment problems. The water flow data used in the balance calculations are subject to high uncertainty—the flows in all rivers were estimated on the basis of observations from the water gauge on the Warta River. For higher reliability of resource determination, it is advisable to establish at least periodic water gauges, which would provide data to improve the relationships used to transfer hydrological data, or to calibrate hydrological models [36]. Similar problems concerning availability, reliability of hydrological data, and the necessity to strive for their improvement, were also raised by other authors dealing with modeling for decision support in water management (e.g., [37–39]).

The problem of reliability of input data to the balance appears again when analyzing results for the habitats of the Northern Polder. In 7 years out of the 29 analyzed, water retention was not restored to the assumed optimum level during the winter season. Reasons for such results could be:

- too low values of groundwater recharge for habitats in the valley edge zone and of infiltration from the Warta River to habitats located near its bed, based on estimates and other studies' data [28] and
- the applied method of determining reference evapotranspiration (Penman's method), for which overestimation of calculation results was reported in other studies [40].

Field measurements and modeling aimed at identifying the best method of estimation of actual evapotranspiration from the area, and monitoring of groundwater levels permitting estimation of the inflow of waters from the upland and from the Warta River, would improve the accuracy of the habitats' water balance modeling.

In spite of the discussed inaccuracies in the description of some elements of habitats' water balance, it can be concluded from the results for the Northern Polder that a possibility to irrigate and retain water in the polder (prohibition of land drainage) in spring is of key importance for the occurrence of high moisture content in hydrogenic habitats. Water reserves of the Old Warta River might be used to ensure appropriate moisture conditions in the Northern Polder (Figures 3 and 4), however, due to their time distribution, the use of these reserves depends on the possibility of water retention in the area. The application of hydrotechnical solutions, e.g., trough damming devices, is one of the options, whose expediency and effectiveness should be further considered.

Another thing worth considering is the task of ensuring adequate navigation conditions. The proposed concept of giving up resources' preservation, in periods when the river flow is below the minimum navigable requirements, yields considerable volumes of water for other tasks. For the practice of water resources management, this way of meeting the navigation requirements, negotiated on the basis of the preliminary balance results, is an advantageous option for the environment. In the context of modeling the navigation requirements in balance analyses, the proposed approach is recommended where the needs depend on the defined threshold values and the current river flow.

5. Conclusions

This paper presents the application of water management balances to the search for a compromise between socio-economic water use and the tasks of protecting water and water-dependent ecosystems. The water management balance model proved to be a useful tool for such analyses. A necessary condition for including the tasks of protecting water and water-dependent ecosystems in the balance analyses is treating the water needs of these ecosystems as one of the water users. Only then can the impact of water management priorities on the amount of water available to both ecosystems and socio-economic users be analyzed. However, the possibility to model the water needs of ecosystems depends on the recognition of their water needs, which is necessary to define the model parameters.

For a complete description of the water needs of ecosystems it is necessary to provide not only the desired values that ensure optimum conditions for the development of ecosystems, but also the threshold values, beyond which significant changes in the ecosystems' functioning occur. The determination of desirable and threshold values has, for years, been an important research problem in the field of water management and protection of water-dependent ecosystems. The accuracy with which the requirements of aquatic and water-dependent ecosystems are represented in a water balance model depends on the recognition of their functioning and the role of flow for ecosystem sustainability and conservation.

The balance model was developed for the part of the Warta River catchment comprising the Warta Mouth National Park. The low availability of hydrological data and the resulting inaccuracy of water resources assessment, together with the uncertainty of input data for modeling the requirements of protected habitats in the WMNP, contributed to the limited reliability of the balance results. Nevertheless, it can be concluded that it is possible to satisfy both the needs of water users—agriculture and navigation—and, to a considerable extent, the requirements of protected wetlands. The abandonment of drainage in spring and the possibility of irrigation in late summer are both key to ensuring high moisture content of the Northern Polder habitats. As navigation requirements limit the use of the Warta River flows, and due to the unfavorable time distribution, the Old Warta River resources do not allow for fully meeting the water needs of the protected habitats, and the increase of water quantity for the Northern Polder would depend on the implementation of retention measures in the area. The developed balance model can be used to help determine the location and technical parameters of potential facilities.

The possibilities to improve the reliability of the balance results depend primarily on improving the quality of the input data. The coupling of water user models with the balance model allows for the correct determination of water needs and the proper assessment of the degree to which water needs are being met.

Funding: This research received no external funding.

Data Availability Statement: The source hydrological and meteorological data were collected by the Institute of Meteorology and Water Management National Research Institute and are available here: https://danepubliczne.imgw.pl/data/dane_pomiarowo_obserwacyjne/ (accessed on 26 October 2021). On their basis, the time series of mean 10-day values used in the study were calculated.

Acknowledgments: I would like to acknowledge T. Okruszko and S. Tyszewski for the work that fostered me to write this article. I would also like to thank the Regional Water Management Authority in Poznań and the Warta Mouth National Park staff for provision of necessary information and insight into respective water management issues as well as MGGP S.A. for the experience which I gained owing to cooperation. I would also like to thank the Anonymous Reviewers who have contributed to improving the quality of the article.

Conflicts of Interest: The author declares no conflict of interest.

References

1. *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy, OJ L 327*; 2000; pp. 1–73. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:en:NOT (accessed on 26 October 2021).
2. Acreman, M.C.; Ferguson, A. Environmental flows and the European Water Framework Directive. *Freshw. Biol.* **2010**, *55*, 32–48. [CrossRef]
3. Tharme, R.E. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Res. Appl.* **2003**, *19*, 397–441. [CrossRef]
4. Acreman, M.; Dunbar, M.J. Defining environmental river flow requirements—A review. *Hydrol. Earth Syst. Sci.* **2004**, *8*, 861–876. [CrossRef]
5. Piniewski, M.; Acreman, M.C.; Stratford, C.S.; Okruszko, T.; Giełczewski, M.; Teodorowicz, M.; Rycharski, M.; Oświecimska-Piasko, Z. Estimation of environmental flows in semi-natural lowland rivers—The Narew basin case study. *Pol. J. Environ. Stud.* **2011**, *20*, 1281–1293.
6. Richter, B.D.; Baumgartner, J.V.; Wigington, R.; Braun, D.p. How much water does a river need? *Freshw. Biol.* **1997**, *37*, 231–249. [CrossRef]
7. Poff, N.L.; Allan, J.D.; Bain, M.B.; Karr, J.R.; Prestegaard, K.L.; Richter, B.D.; Sparks, R.E.; Stromberg, J.C. The natural flow regime. *BioScience* **1997**, *47*, 769–784. [CrossRef]
8. Poff, N.L.; Richter, B.D.; Arthington, A.H.; Bunn, S.E.; Naiman, R.J.; Kendy, E.; Acreman, M.; Apse, C.; Bledsoe, B.P.; Freeman, M.C.; et al. The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshw. Biol.* **2010**, *55*, 147–170. [CrossRef]
9. Hendriks, D.M.D.; Kuijper, M.J.M.; van Ek, R. Groundwater impact on environmental flow needs of streams in sandy catchments in the Netherlands. *Hydrol. Sci. J.* **2014**, *59*, 562–577. [CrossRef]
10. Streetly, M.J.; Bradley, D.C.; Streetly, H.R.; Young, C.; Cadman, D.; Banham, A. Bringing groundwater models to LIFE: A new way to assess water resources management option. *Hydrol. Sci. J.* **2014**, *59*, 578–593. [CrossRef]

11. Acreman, M.; Aldrick, J.; Binnie, C.; Black, A.; Cowx, I.; Dawson, H.; Dunbar, M.; Extence, C.; Hannaford, J.; Harby, A.; et al. Environmental flows from dams: The Water Framework Directive. *Eng. Sustain.* **2009**, *162*, 13–22. [CrossRef]
12. Shafroth, P.B.; Wilcox, A.C.; Lytle, D.A.; Hickey, J.T.; Andersen, D.C.; Beauchamp, V.B.; Hautzinger, A.; McMullen, L.E.; Warner, A. Ecosystem effects of environmental flows: Modelling and experimental floods in a dryland river. *Freshw. Biol.* **2010**, *55*, 68–85. [CrossRef]
13. Yin, X.A.; Yang, Z.F.; Petts, G.E. Optimizing environmental flows below dams. *River Res. Appl.* **2012**, *28*, 703–716. [CrossRef]
14. Verdonschot, P.F.M.; Nijboer, R.C. Towards a decision support system for stream restoration in The Netherlands: An overview of restoration projects and future needs. *Hydrobiologia* **2002**, *478*, 131–148. [CrossRef]
15. Gostner, W.; Parasiewicz, P.; Schleiss, A.J. A case study on spatial and temporal hydraulic variability in an alpine gravel-bed stream based on the hydromorphological index of diversity. *Ecohydrology* **2013**, *6*, 652–667. [CrossRef]
16. Parasiewicz, P.; Rogers, J.N.; Gortazar, J.; Vezza, P.; Wiśniewolski, W.; Comglio, C. The MesoHABSIM Simulation Model–development and applications. In *Ecohydraulics: An Integrated Approach*; Maddock, I., Harby, A., Kemp, P., Wood, P., Eds.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2013; pp. 109–124.
17. Godyń, I.; Indyk, W.; Jarząbek, A.; Owsiany, M.; Pusłowska-Tyszewska, D.; Sarna, S.; Stańko, R.; Tyszewski, S. *Good Practices for Water Management Planning in the Sites of High Natural Values. Guidance*; Regional Water Management Authority: Kraków, Poland, 2011; p. 139. (In Polish)
18. Okruszko, T. *Hydrologic Criteria for Wetlands' Conservation*; Warsaw University of Life Sciences SGGW: Warsaw, Poland, 2005; p. 151. (In Polish)
19. Loucks, D.P.; Van Beek, E. *Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications*; UNESCO: Paris, France, 2005; p. 681.
20. Acreman, M. Linking science and decision-making: Features and experience from environmental river flow setting. *Environ. Model. Softw.* **2005**, *20*, 99–109. [CrossRef]
21. Holmes, M.G.R.; Young, A.R.; Grew, R. A catchment-based water resource decision support tool for the United Kingdom. *Environ. Model. Softw.* **2005**, *20*, 197–202. [CrossRef]
22. Bonenberg, J.; Drużyńska, E.; Kindler, J.; Nachlik, E.; Pusłowska-Tyszewska, D.; Tyszewski, S. Basis for planning and water resources allocation. In *Methodological Basis and Standards for Integrated Planning in Water Management*; Environmental Engineering Series, 341, Nachlik, E., Drużyńska, E., Eds.; Krakow University of Technology: Kraków, Poland, 2006; pp. 56–78. (In Polish)
23. Acreman, M.; Arthington, A.H.; Colloff, M.J.; Couch, C.; Crossman, N.D.; Dyer, F.; Overton, I.; Pollino, C.A.; Stewardson, M.J.; Young, W. Environmental flows for natural, hybrid, and novel riverine ecosystems in a changing world. *Front. Ecol. Environ.* **2014**, *12*, 466–473. [CrossRef]
24. Jha, M.K.; Das Gupta, A. Application of Mike Basin for Water Management Strategies in a Watershed. *Water Int.* **2003**, *28*, 27–35. [CrossRef]
25. Draper, A.; Jenkins, M.; Kirby, K.; Lund, J.; Howitt, R. Economic-engineering optimization for California Water Management. *J. Water Resour. Plan. Manag.* **2003**, *129*, 155–164. [CrossRef]
26. Dai, T.; Labadie, J. River basin network model for integrated water quantity/quality management. *J. Water Resour. Plan. Manag.* **2001**, *127*, 295–305. [CrossRef]
27. Pusłowska-Tyszewska, D.; Tyszewski, S.; Okruszko, T. *Water Management Optimization Model for the Warta Mouth National Park*; Project Report; MGGP S.A.: Kraków, Poland, 2013; p. 101. (In Polish)
28. Chormański, J.; Giełczewski, M.; Kardel, I.; Malinowski, R.; Szporak, S. *Concept of Revitalization of Meadow and Marsh Habitats in the Warta Mouth National Park-Northern Polder*; Project Report; Nature Conservation Society Ptaki Polskie: Warsaw, Poland, 2009; p. 189. (In Polish)
29. Kloss, A.; Łaski, A.; Rutkowski, M.; Sokołow, W.; Tyszewski, S. *Methodology for Water Management Balances*; Hydroprojekt-Warszawa: Warsaw, Poland, 1992; p. 123. (In Polish)
30. Tyszewski, S.; Herbich, P.; Indyk, W.; Jarząbek, A.; Pusłowska-Tyszewska, D.; Rutkowski, M. *Methodology for Developing Conditions for Water Use in Water Regions and in Catchments*; Water Management Lab Pro-Woda–Guidance Document Prepared for the National Water Management Authority; Water Management Lab.: Warsaw, Poland, 2008; p. 66. (In Polish)
31. Stewardson, M.J.; Acreman, M.; Costelloe, J.F.; Fletcher, T.D.; Fowler, K.J.A.; Horne, A.C.; Liu, G.; McClain, M.E.; Peel, M.C. Chapter 3. Understanding Hydrological Alteration. In *Water for the Environment. From Policy and Science to Implementation and Management*; Horne, A.C., Webb, J.A., Stewardson, M.J., Richter, B., Acreman, M., Eds.; Academic Press: Cambridge, MA, USA; Elsevier: London, UK, 2017; pp. 37–64.
32. Pusłowska-Tyszewska, D.; Dybkowska-Stefek, D.; Relisko-Rybak, J. Analysis of Surface Water Resources Availability in the Area of the Planned Silesian Canal. Water-Management Balances of Surface Waters of the Ruda, Bierawka, Gostynia and Pszczynka Catchment areas. *Gospod. Wodna* **2021**, *13*, 10–24.
33. Ford, L.R.; Fulkerson, D.R. *Flows in Networks*, 1st ed.; PWN: Warsaw, Poland, 1969; p. 256. (In Polish)
34. Conditions for Water Use of the Warta Water Region, Official Journal of the Lubuskie Voivodeship No. 810 of 02.04.2014. Available online: http://dzienniki.luw.pl/WDU_F/2014/810/akt.pdf (accessed on 3 September 2014). (In Polish).
35. Kostrzewa, H. *Verification of Criteria and Magnitude of Environmental Flow for Polish Rivers*; IMGW Research Materials, Series: Water Management and Protection; IMGW: Warsaw, Poland, 1977. (In Polish)

36. Pusłowska-Tyszewska, D.; Tyszewski, S. Water management balance as a basis for conditions for water use in river catchments–the Jeziorka river case study. In *Monographs of the Committee on Water Resources Management of the Polish Academy of Sciences XX*; Banasik, K., Hejduk, L., Kaznowska, E., Eds.; KGWPAN: Warsaw, Poland, 2014; pp. 259–270. (In Polish)
37. Wurbs, R.A. Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites. *J. Hydrol. Eng.* **2006**, *11*, 55–64. [CrossRef]
38. Bangash, R.F.; Passuello, A.; Hammond, M.; Schuhmacher, M. Water allocation assessment in low flow river under data scarce conditions: A study of hydrological simulation in Mediterranean basin. *Sci. Total Environ.* **2012**, *440*, 60–71. [CrossRef] [PubMed]
39. Cai, X. Implementation of holistic water resources-economic optimization models for river basin management–reflective experiences. *Environ. Model. Softw.* **2008**, *23*, 2–18. [CrossRef]
40. Kasperska-Wołowicz, E.; Łabędzki, L. A comparison of reference evapotranspiration according to Penman and Penman-Montheith in various regions in Poland. *Water-Environ.-Rural Areas* **2004**, *11*, 123–136. (In Polish)