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Rerearch paper

Manual calibration of TETIS model in the Mar Menor lagoon subcatchment

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Abstract: Hydrological models can simulate water balance and predict water behaviors in any catchments; however, accuracy of model always is questioned. Therefore, calibration and validation processes are required for any models to acquire realistic expectations. TETIS model is a conceptual distribution model applied to simulate dynamic of hydrology based on water balance calculation, sediment erosion, and other constituents. As many other hydrological models, calibration and validation are important to evaluate the accuracy. Thus, an appropriate calibration facilitates the model effectiveness. Recently, auto calibration approach has been promoted due to availability of the optimization algorithm. In contrast, manual calibration requires time consuming, expert knowledge and calculation effort. But manual calibration is suitable for unconventional calibration, such as lack of streamflow observation and specific conditions. In this study, a manual calibration has been employed to evaluate how water balance changed under assumptions that there are partial irrigation and without irrigation activity. The results showed that there are considerable effects from different irrigation scenarios on the water balances, but the stream flow is insignificantly affected.

Keywords: Hydrological model; Irrigation; TETIS model; The Mar Menor lagoon; Water balance.

1. Introduction

Hydrological models have been developed in decades. Many researchers divided the models into different types based on the model approaches. According to Hrachowitz & Clark [1], there have been four main classifications so far, including spatial simplification, system simplification, model refinement scaling strategies, and model architecture. Spatial simplification relates to spatially distributed capacity of hydrological models while system simplification refers to physically based models and conceptual based models. Although hydrological models are capable to simulate water behavior in any catchment, the accuracy of the outputs is always quested. And thus, the calibration and validation of model are considered a necessity in hydrological simulation in any catchment [1–2].

Generally, calibration aims to identify the values of parameters so that the simulated results can be the best performance in comparison to observed results. Then, the precision of parameters will be evaluated through a validation process [3]. According to Boyle et al, there are three levels of calibration. The first is the simplest approach named ‘zero level’ since the calibrated values can be borrowed from similar watershed or sub-catchment [3]. Particularly, Cuenca 45, which will be elaborated in the study areas, is a case in point. The second is a level one with identifying an individual parameter which is the most sensitivity parameter. The third is level two which is a very challenging process revolving the complexity between parameters, parameter weighting judgement in model, and how these parameters impact the output [3].

Undoubtedly, calibration and validation are important to evaluate the accuracy. Thus, the appropriate calibration facilitates the model effectiveness. Recently, auto calibration approach has been promoted for availability of the optimization algorithm. In contrast, manual calibration requires time consuming and calculation effort, but it is suitable for unconventional calibration, such as lack of streamflow observation and specific conditions [3]. TETIS model is a conceptual distributed hydrological model. In TETIS model, corrections factors are very important in calibration process since they correct the input parameter maps before simulation [4–6]. The corrections factors can be considered the temporal, spatial and errorless representatives for static storage, evapotranspiration, infiltration, overland flow, percolation, interflow, deep aquifer flow, base flow, and river flow velocity [5]. These corrections factors will be calibrated so that simulation returns in optimal result. These correcting factors equally treat all pixels in each parameter maps [4] [5]. Most importantly, in TETIS model, the corrections factors can be extrapolated from calibrated subbasin to ungauged subbasin [4].

The Mar Menor is a lagoon between land areas of Murcia, Spain and the Mediterranean sea. With a special location, the Mar Menor has unique characteristics of geohydrology and ecosystem and also plays an important meaning in agriculture and economic development. Several previous studies illustrated that the lagoon suffers environmental issues, and one of them is eutrophication consequences [7–9]. These studies indicated that the water quality of lagoon not only depends on surface water but also the groundwater and demonstrated that contribution of groundwater into the lagoon is a dominant process resulting in eutrophication [7, 9, 10]. Importantly, these results illustrated mechanisms of nitrogen leaching from groundwater every year through aquifers is abundant. Ultimately, the dynamic underlying geohydrology processes leads to the fluctuation of nitrogen leaching to the lagoon. This leaching is still a challenging in biogeochemical models, particularly in this study area. From these viewpoints, it is urgent to simulate the leaching of nitrogen in hydrological processes either in groundwater or in surface water to improve the water quality in the lagoon. These issues demand the accuracy of water balance simulation, not only stream flow.

According to Moriasi et al, most of hydrology model employed stream flow to calibrate and validate due to the available of long-term observation data for stream flow, while it was barely for sediment and nitrogen long-term monitoring results [11]. However, it was not applicability in this study area, which was defined as semi-arid climate associate with tremendous anthropogenic influences, such as horticulture, irrigation, and drainage system, resulted in non-permanent stream flow [8, 12, 13]. The volume of surface runoff is infrequently high due to climate conditions varying from semiarid to arid climate conditions and soil characteristics which are mainly sandy soil of coastal areas. Runoff generation extremely depends on intension of rainfall, while the groundwater elevation was significantly affected from intensive irrigation serving agriculture in this area [8, 13]. In addition, the research of Hesse et al. pointed out that the calibration for the entire of the Mar Menor lagoon catchment is difficult due to insufficiently observed data [13]. Therefore, all the constituents of water balance such as evapotranspiration, percolation and runoff are also necessary to be considered in calibration, not only stream flow.

From this perspective, TETIS model, a conceptual distribution hydrology model is an optimal in this study areas in terms of conceptual model and initially calibrated [9]. Therefore, the objective in this short-term study is how to calibrate TETIS model in this sub-catchment. The research question of this study is how the water balance change when applying the initially calibrated factors in the nearby sub-catchment. In this short-term study, these calibrated correcting factors will be evaluated by manual calibration at the simplest level which is "zero level".

2. Materials and Methods

2.1. Study area

Subcatchment 45 (Cuenca 45) of the Mar Menor lagoon is a small basin with the area of 18 km^2. The entire catchment of the Mar Menor lagoon and particular study area are mainly agricultural area with semi-arid climate. From previous study, baseline scenario was the long-term mean annual water balance in which total inflows include precipitation and irrigation and total outflows include evapotranspiration, percolation, and surface runoff. In this simplification, the water balance was described as a function of inflows and outflows which is "Precipitation (280.9 mm) + Irrigation (178.9 mm) = Total Evapotranspiration (392.6 mm) + Percolation (34.2 mm) + Surface runoff (32.9 mm)". The specific values of contributed components are as in the table 1 [9]. This water balance is the sufficient irrigation scenario which will be the baseline.

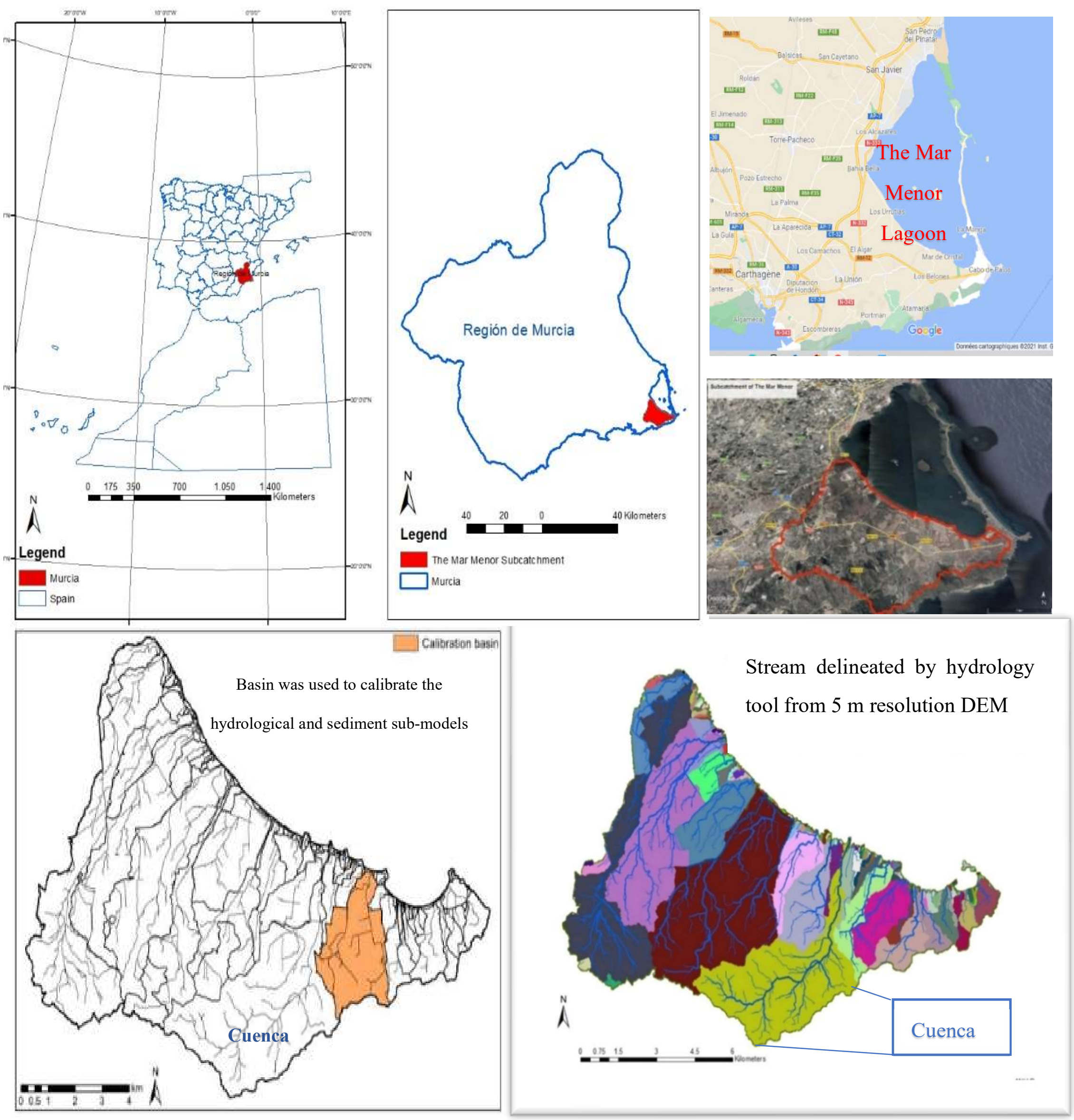

Figure 1. (a) The adopted calibrated catchment; (b) Study area – Cuenca 45 – the Mar Menor subcatchment [9].

**Reproduced from partially previous data source with ArcGIS 10.5, ArcHydrology Tool, Bui, 2020*

Table 1. Adopted water balance of sufficient irrigation scenario [9].

Water balance (mm)	
Precipitation	280.9
Irrigation	178.9
Evapotranspiration	392.6
Percolation	34.2
Surface runoff	32.9

2.2. Materials

Study area was a sub-catchment of the Mar Menor lagoon named Cuenca 45. According to previous study, a calibrated sub-catchment was utilized to derive the effective parameters for TETIS hydrological sub-model. The location of catchment was as in the figure 1. The calibrated model was conducted to obtain the long-term mean annual water balance which is adopted as baseline for this study. Input map of Cuenca 45 is a sub-catchment of the Mar Menor lagoon was generated by ArcGIS from DEM 5m from national geography database, Spanish Centro Nacional de Información Geográfica (CNIG). The topographical parameter maps such as slope, flow direction, flow accumulation, and overland flow velocity were derived by ArcGIS toolbox. The hydraulic conductivity in soil parameters relating to hydraulic conductivity of soil, rate of infiltration and percolation were extracted from soil profile information and adopted from previous study [9]. DEM was reconditioned by stream network which were generated from previous study to eliminate the error from derived maps, including slope, velocity of overland flow, flow accumulation, and flow direction. Parameters maps including hydraulic conductivity, static storage, percolation rate, infiltration rate, deep percolation rate, and soil types were adopted from .ascii files (American Standard Code for Information Interchange) from previous study [9].

According to Puerter et al, precipitation and temperature data were derived from the V4 version of the SPAIN02 dataset from 1971 to 2008, and 2009 to 2016 period were extended by the Agencia Estatal de Meteorologia (AEMET) of a near meteorological station in Cartagena. Irrigation data was provided by the Hydrological Watershed Plan of the Segura Region. Evapotranspiration was indirectly calculated from the temperature values with proposed method from Hargreaves and Samani. These meteo-hydrology dataset was produced from 2002 to 2016 and from 1971 to 2016 and adopted from previous study [9]. Potential evapotranspiration was estimated from 800 mm – 1200 mm at the entire Mar Menor every year in many researches [10, 14] . Irrigation dataset in this study area was adopted from previous study [9–10].

2.3. Methodology

TETIS model is hydrological model with capacity to describe the temporal and spatial distribution, conceptually based model which is facilitated by physical parameters with physical characteristics of a catchment [5–6]. Subsequently, TETIS model is completed with capacity to simulate sediment in water erosion through sub-models of TETIS sediment [6]. Water balance of TETIS sub-hydrological model is summarized as in the general formulation "inflow = outflow + flux + storage". These are three main components of hydrological models in which inflows are precipitation and irrigation; outflows are overland flow (direct runoff), interflow (sub-surface runoff), and connected aquifer flow (baseflow); fluxes are evapotranspiration, infiltration, and percolation. This general formulation can be modified as "inflow = outflow + flux" since storage capacity is assumed to be stable through daily time step. Finally, water balance can be defined as "total inflow = total outflow + total flux", in which total inflow is precipitation and irrigation; total outflow is direct runoff, sub-surface runoff and connected aquifer flow; total flux in downward direction is percolation and flux in upward direction is evapotranspiration. Overland flow and interflow are surface runoff and sub-surface runoff which end up in contributing to stream flow.

3. Results and Discussions

3.1. Reapplying adopted baseline with sufficient irrigation and partial irrigation

In the sufficient irrigation scenario, total ET was higher than precipitation, which can be explained that irrigation activity is required for annual water balance. In the Mar Menor, precipitation and irrigation are two main inflows. Evapotranspiration, percolation, and surface runoff are all the outflows in water balance. Irrigation is an important supply in agriculture in this area [7, 15]. Thus, irrigation strongly influences water behavior. From comparison between baseline and partial irrigation, a relation between irrigation and evapotranspiration was delineated. This interaction can be explained as watering demand in plantation and agriculture which urged the irrigation increase from May to July. Furthermore, irrigation was modeled in a manner that it rarely infiltrated downward into deeper soil, but it is more likely to evaporate through topsoil and to transpiration in plants [9]. With partial irrigation, the water balance was recalculated as in the Table 2.

Table 2. Water balance of partial irrigation which is simulated in insufficient irrigation scenario.

Water balance (mm)	
Precipitation	282.4
Irrigation	113.7
Total Evapotranspiration (Real ET + ET from vegetation)	348.8
Percolation	18.64
Surface runoff (Direct runoff + Subsurface runoff)	28.7

*Recalculated in TETIS and R by Bui, 2020

The water balance of partial irrigation indicated the annual evapotranspiration is higher than precipitation, while the amount of irrigation is approximately 113.7 mm in every year from 1971 to 2016. To maintain this long-term annual water balance, the irrigation is expected to reach 178 mm every year to obtain yearly evapotranspiration at 393.7 mm. Obviously, the annual pattern of irrigation and evapotranspiration from 1971 to 2016 were similar, while runoff, percolation and precipitation indicated the correlation. In other word, evapotranspiration highly correlates with irrigation, while runoff and percolation highly correlate with precipitation. This conclusion is very important for the next step calibration because it directs the identifying of the parameters which are needed to calibrate in the subsequent steps.

Overall, precipitation was more intensive from September to December in autumn and spring with average annual rainfall approximately 275 mm – 300 mm [10, 14]. The lowest amount of precipitation every year was from May to July. Mean long-term daily precipitation and total ET indicated a different tendency from May to July. Precipitation was lower, while total ET showed a higher estimation. This can be explained that high temperature from May to July every year resulted in high rate of total ET. Furthermore, under high temperature condition and the rainfall scarcity, irrigation was urged to maintain horticulture. From this point view, there would be an uncertainty in hydrology model at the Mar Menor lagoon since water yield strongly depends on the amount of precipitation, irrigation, evapotranspiration, infiltration, and percolation.

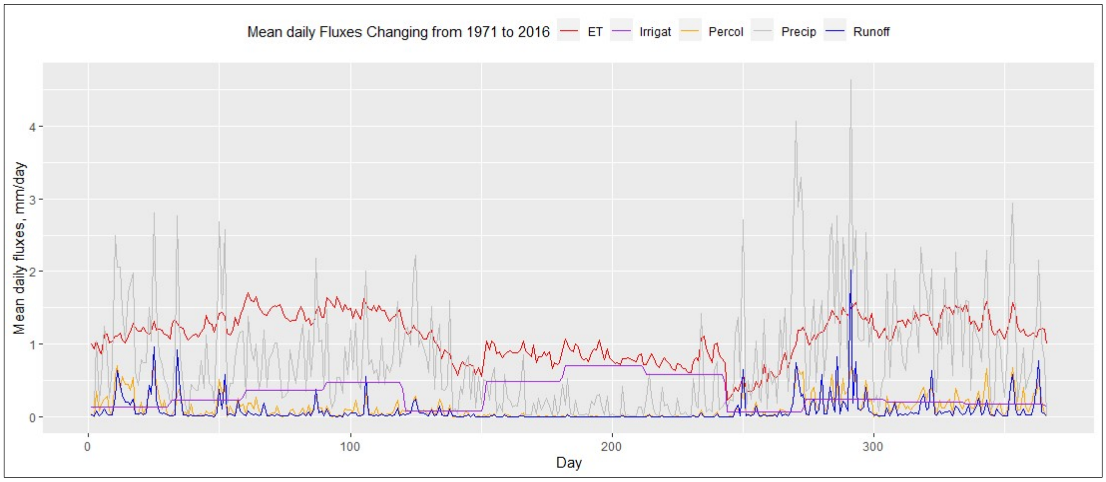

Figure 2. Mean daily long–term inflow and outflow of partial irrigation.

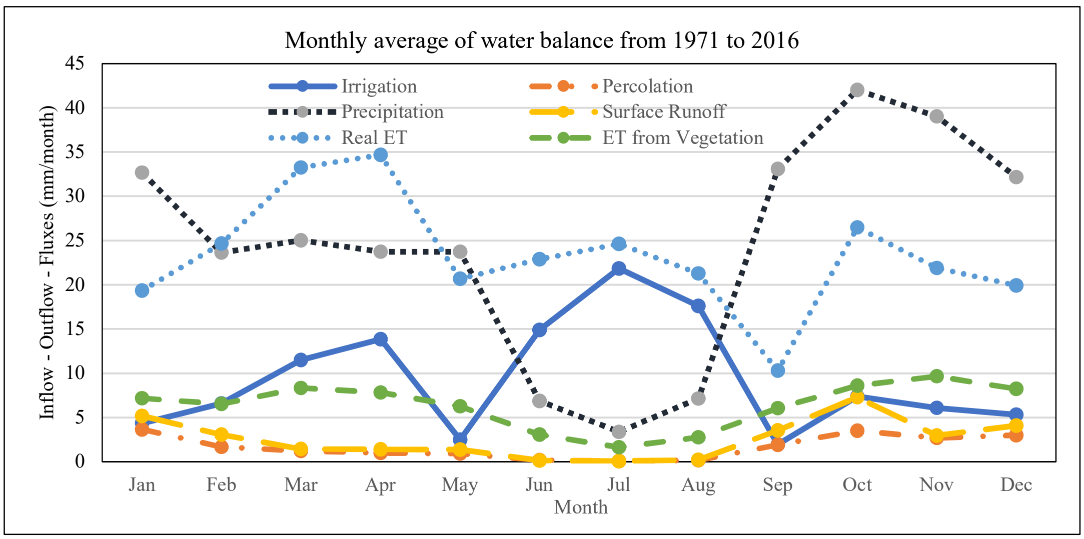

Figure 3. Monthly average of water balance from 1971 to 2016 of partial irrigation.

TETIS simulated the interaction between irrigation and evapotranspiration which have a rational correlation. Even though, there are many potential situations with irrigation. Water from irrigation can be evaporated, transferred to overland flow, or infiltrated to shallow aquifers, or percolated to deeper aquifers. The dominant process depends on specific conditions of driving factors such as the amount of irrigation, irrigation techniques, and hydraulic conductivity of soil, type of covering plants, water capacity of soil, and initial moisture condition of soil. In this situation, the amount of annual mean sufficient irrigation was estimated approximately 178.9 mm, while irrigation varies through seasonal horticulture, soil types, techniques, and seasonal meteo-hydrological conditions.

3.2. Water balance without irrigation

Water balance comparison between partial irrigation and without irrigation illustrated that without irrigation, the amount of real ET had a significant change. Accordingly, ET from vegetation gradually change from 75 mm/year to 78 mm/year. On the contrary, real ET significantly decrease from 273 mm/year to 164 mm/year. It means that it is not precipitation contributing to real ET, but the irrigation. Without irrigation, direct runoff slightly declined from 24 mm/year to 20 mm/year, percolation diminished from 18.6 mm/year to 16 mm/year.

Table 3. Water balances comparison between partial irrigation and without irrigation.

Inflows & Outflows (mm/year)	PPT	Irrigation	ET from Veg	Real ET	Percolation	Subsurface runoff	Direct Runoff
With partial irrigation	282	114	75	273	18.6	4	24
Without irrigation	282	0	78	164	16	4	20

Without irrigation, the only inflow is precipitation. In both of scenarios, the precipitation was unchanged, but the water balance was considerably different from the water balance with partial irrigation. Generally, the higher precipitation is, the higher other outflow and fluxes are. When the precipitation is very low from May to July, other outflow and fluxes are also at minimum values (figure 4). Among three distinct degrees of irrigation, sufficient irrigation (178 mm/year), partial irrigation (113 mm/year) and non-irrigation, ET is the most affected fluxes. Percolation and surface runoff were slightly varied among three scenarios. With this set of parameters and correcting factors, the model simulated that evapotranspiration process was the most affecting factor. Therefore, it is notable that the next step of calibration should focus on the correcting factor – FC2 of evapotranspiration under the without irrigation assumption. Under sufficient irrigation, other factors should be considered such as correcting factor – FC5 of percolation and FC3 of infiltration. This water balance under the assumption of without irrigation aims to examine the contribution of precipitation to surface runoff and percolation.

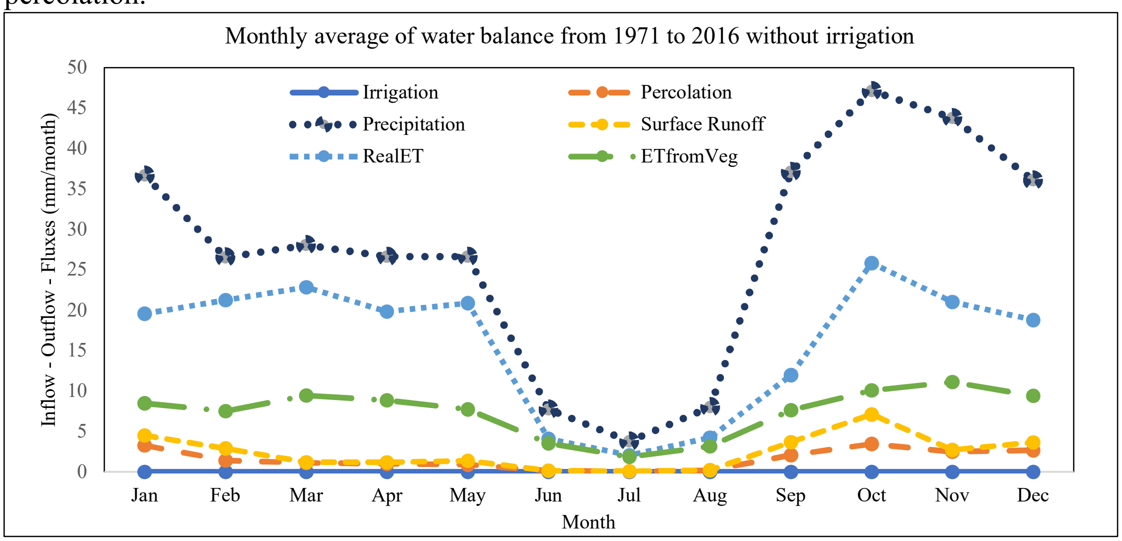

Figure 4. Monthly average of water balance from 1971 to 2016 without irrigation.

In the stream flow comparison in figure 5 between partial irrigation and non-irrigation, daily Nash-Sutcliffe (NSE) and monthly NSE are 0.96 and daily PBIAS and monthly PBIAS are 19.8. NSE and PBIAS for the period 1971 to 2016 demonstrated the similar simulation between the two scenarios. Without irrigation, stream flow was diminished in compare to partial irrigation. The daily simulation and monthly simulation of stream flow in partial irrigation and without irrigation were not different since NSE were the same at 0.96. It can be explained that the changing of irrigation did not significantly affect the stream flow in the scenario of insufficient irrigation. In other words, the stream flow highly depends on extreme weather and intensive rainfall events. When these extreme events occur, the stream flow will be established and increased. This triggering increase, which considerably influents subsequent simulations, results in increase of water erosion processes such as sediment erosion, while percolation mainly affect the leaching of nitrogen and phosphorus processes.

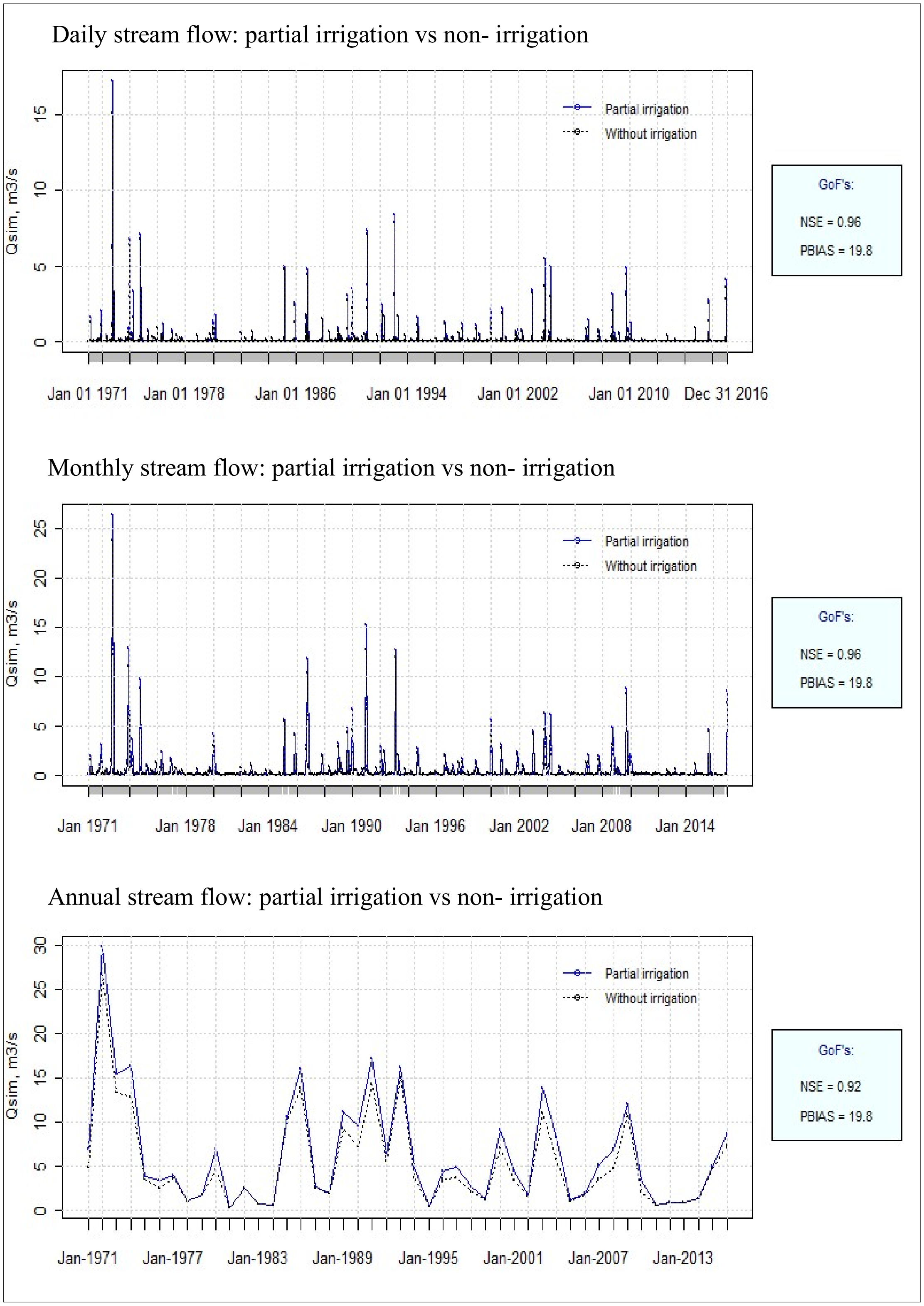

Figure 5. Daily, monthly, and annual NSE and PBIAS stream flow between partial irrigation and non-irrigation.

4. Conclusions

In conclusion, at calibration level zero, reapplying from adopted previous result is meaningful to explore the hydrological dynamic at the study area. From this result, TETIS model inherit correcting factors and execute simulation for the nearby sub-basin which share the similar physical characteristic. This approach is suitable for ungauged catchment. Though water balance is significantly different between partial irrigation and non-irrigation, the stream flow vigorously depends on precipitation in both partial irrigation and non-irrigation. For the TETIS model, correcting factor estimation highly depends on the understanding of naturally water processes and interaction between natural processes and anthropogenic encountering. The first level of manual calibration facilitates to reveal the main pattern of water behavior in the catchment and identify the potential sensitive parameters for the next calibration.

With this insight, in a short-term research, the study focuses on clarifying the first question how water balance will be simulated under solely precipitation influence. The long–term objectives of water resource management is to simulate the interaction between surface water and groundwater under either anthropogenic effects or climate effects. Furthermore, this study proposed a potential approach in hybrid calibration so that hydrological TETIS model can extend to larger area of the entire catchment. In the future, the research question is how to develop a hybrid calibration for TETIS to emerge the natural process of water behavior at the Mar Menor lagoon.

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