Replies to Referee #1

We are very grateful to the reviewers for reading the manuscript extremely carefully and forwarding the valuable suggestions for improvement. Point-by-point responses to the reviewers' comments are listed below.

1. General comment

The reviewer's comment 1: …but the poor writing make it hard to be understood well. …However, the manuscript was not well written...

The authors' Answer: Thanks for the kind advice. We have invited a professional organization to help modify the language. The confusing, conflict, and unclear technical details has been stated clearly.

2. Specific comments

The reviewer's comment 1: The abstract was not well written. (1) 'To estimate streamflow without observation, the authors extend existing techniques . . .', but it is not clear what is the existing one and what is extended one? A simple 'coupling hydrological model with a hydrodynamic model' is not far clear. (2) L13-15: It is hard to understand. What is land covered area? (3) L15-17: I still did not get what the original and adjusted scenarios are. (4) it is not that convincing to say R^2 with higher values and bias with lower values, it would be better to use numbers or a range (e.g., 0.7～0.8).

The authors' Answer:

(1)The sentence may be not clearly written. It has been revised as follows:

To solve the problem of estimating and verifying streamflow without direct observation data, we estimated streamflow in ungauged zones by coupling a hydrological model with a hydrodynamic model, using the Poyang Lake Basin as a test case. To simulate the streamflow of the ungauged zone, we built a SWAT model for the entire catchment area covering the upstream gauged area and ungauged zone; and then calibrated the SWAT model using the data in the gauged area. To verify the results, we built two hydrodynamic scenarios (the original and adjusted scenarios) for Poyang Lake using the Delft3D model. In the original scenario, the upstream boundary condition is the observed streamflow from the upstream gauged area, while it is the sum of the observed from the gauged area and the simulated from the ungauged zone in the adjusted scenario.

(2) Land covered area means the area which is not covered by water body. Seen in Figure 1, the land covered area of the ungauged zone is the area inside the yellow line and outside the boundary of Poyang Lake. Originally, the Poyang Lake ungauged zone includes two parts: the land covered area and the Poyang Lake. As streamflow should be considered by the lake dynamic model (Delft3D model), we do not need to calculate the streamflow of Poyang Lake and set the streamflow as the input of the lake dynamic model. So we redefined region of the ungauged zone as the area inside the yellow line and outside the Poyang Lake (Figure 1(a)). The area does not include the Poyang Lake. L13-15 is revised as the follows.

To simulate the streamflow of the ungauged zone, we built a SWAT model for the entire catchment area covering the upstream gauged area and ungauged zone; and then calibrated the SWAT model using the data in the gauged area.

(3) Thank you for the valuable suggestion. There may exist some writing problems here.

The method should be described in details. The procedures of the manuscript are as follows.

Procedure 1: we first calculated the streamflow produced by the Poyang Lake ungauged zone (PLUZ). Procedure 2: we compared the model result (water level and discharge in outlet (Hukou)) of the dynamic model with and without the ungauged streamflow. For Procedure 1, to simulate the streamflow in the Poyang Lake ungauged zone we build a SWAT model for the entire catchment covering the upstream gauged zone and the ungauged zone. The parameters were calibrated using the observed streamflow from the gauges located in the upper streams.

For Procedure 2, the simulated streamflow in PLUZ were used as part of the inflows for hydrodynamic model to simulate the water level and other hydrodynamic characteristics of Poyang Lake. In this processing, two lake hydrodynamic scenarios (Adjusted Scenario, Original Scenario) are constructed. In Adjusted Scenario, the upper inflow boundary of hydrodynamic

model is the summation of the simulated ungauged streamflow and the upstream gauged streamflow. In Original Scenario, the upper inflow boundary of the hydrodynamic model is the upstream gauged streamflow. The modeled results (water level and ouflow) in Adjusted Scenario and Original Scenario were compared.
In summary, the Adjusted Scenario take the ungauged streamflow into consideration while the Original Scenario does not. In Adjusted Scenario, inflows for hydrodynamic model is the summation of simulated streamflow in PLUZ and the observed streamflow from gauges located in the upper streams. In Original Scenario, inflows for hydrodynamic model is the observed streamflow from gauges located in the upper streams. The model in Original Scenario has been calibrated and validated. The model in Adjusted Scenario use the same parameter as that in Original Scenario.
(4)The sentence has been deleted. The similar sentence is written as you comment.

The reviewer's comment 2: L29- 33: it does not read well, the connection seems not logical.
The authors' Answer: The sentences are revised as follows:
To reduce the damage to the population, agriculture and economy, we should attempt to predict floods and droughts precisely. However, in watersheds, there is ungauged zones lack streamflow observations. The ungauged streamflow is difficult to estimate and is usually neglected in water yield estimations, which can result in floods/droughts predictions being not accurate enough.

The reviewer's comment 3: L66-67: What does 'Usually, there are stream flow observation at the lower boundary of the ungauged zone.' Mean?
The authors' Answer: The sentence may not be written clearly. The sentence is revised as follows:
Usually, a water body (a lake, a river, or an ocean) exists downstream of the ungauged zone. The water body is gauged by streamflow gauging stations at the outlet and water level gauging stations on the water surface.

The reviewer's comment 4: L72-75: Dargahi and Setegn combined a hydrological model (SWAT) with a 3D hydrodynamic model (GEMSS) .... Bellos and Tsakiris . . .. However, . . . there is no clear and specific method of coupling hydrological and hydrodynamic models in space and time. It is really hard for readers to get what problems or drawbacks others have, and what the novelty of the authors' method is.
The authors' Answer: The sentences should be clearer. They has been revised as follows:
Dargahi and Setegn (2011) combined a watershed hydrological (SWAT) model with a 3D hydrodynamic model (GEMSS) to simulate the Tana Lake Basin to address the impact of climate change. Bellos and Tsakiris (2016) combined hydrological and hydrodynamic techniques for flood simulation in the Halandri catchment. However, the method combing a hydrological model and a hydrodynamic model is rarely applied in such ungauged zone. As the ungauged zone is usually located in flat topography with turbulent flow, it is difficult to draw watersheds in the ungauged zone. In addition, allocating the ungauged streamflow to the inflow boundary of a hydrodynamic model is not easy. The ways to drawing watersheds and allocating the streamflow are not mentioned in the previous studies. The details of coupling hydrology and hydrodynamic models in the ungauged are presented in the study.

The reviewer's comment 5: L101-103: 'We established . . . model was established to . . .' Grammar issue.
The authors' Answer: The sentences has been revised as follows:
We established two lake hydrodynamic scenarios to further verify the streamflow simulation results.

The reviewer's comment 6: L103-106: It is strange the end of Introduction was repeating the abstract.
The authors' Answer: The related sentences has been deleted.

The reviewer's comment 7: L121-124: It reads awkward, and it seems SWAT doesn't need temperature? Were all the data downloaded from Jiangxi hydro info website?
The authors' Answer:

(1) The sentences may be confused. They has been revised as follows:

Data required by the SWAT model include the forcing elements of daily rainfall, evapotranspiration, temperature, relative humidity and wind from 1980 to 2014 collected at 16 national meteorological stations. The stations are distributed uniformly across the area (Fig. 1a). This data was downloaded from China Meteorological Data Sharing Service System (http://data.cma.cn/).

(2) No. Daily rainfall, evapotranspiration, temperature, relative humidity and wind data were downloaded from China Meteorological Data Sharing Service System. Streamflow data at 7 gauging stations (Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan, and Dufengkeng), daily observation for water level at water surface stations (Xingzi, Duchang and Kangshan), and outflow discharges at Hukou were downloaded from Jiangxi hydro info website.

The reviewer's comment 8: Methodology section is too short and lack details.

The authors' Answer: The section should be clearer. We have added more details and reorganize the methodology section clearly.

The reviewer's comment 9: SWAT and Delft3D are the two major approaches of the study; however, there was no description of the two models.

The authors' Answer: The descriptions for the two models have been added in the manuscript.

The part described for SWAT is as follows:

We used a SWAT (Soil and Water Assessment Tool) (Arnold et al., 1993) model to simulate streamflow in the PLUZ. SWAT is a physically-based, semi-distributed and river basin-scale hydrological model. It is developed to assess the impact of land management practices on streamflow, sediment and agricultural yields in complex basins with changing soil types, land use and management over long periods of time. For the purpose of modelling, an entire watershed is divided into sub-watersheds based on rivers and DEM data. Sub-watersheds are portioned into Hydrological Response Units (HRUs), the minimum research units. Water balance is the driving force of hydrological processes. The hydrological cycle includes two divisions: runoff-producing on land and flow-routing in channels. The surface runoff volume is calculated using the SCS method (USDA Soil Conservation Service, 1972). Flow routed through the channel is calculated by the variable storage coefficient method (Williams et al., 1969). SWAT has already been widely applied to watersheds around the world for streamflow simulation (Douglas-Mankin et al., 2010; Arnold et al., 2012; Luo et al., 2016).

The part described for Delft3D is as follows:

Delft3D simulates the hydrodynamic pattern via the Delft3D-FLOW (Roelvink and van Banning, 1994) module. Delft3D-FLOW is a multi-dimensional (two-dimension or three-dimension) hydrodynamic and transport simulation program. The program can calculate unsteady flow by building linear or curvilinear grids suitable for the water boundary, which is forced by tidal and meteorological data. Delft3D-FLOW is based on the Reynolds-Averaged Navier-Stokes (RANS) equations, which are simplified for an incompressible fluid under shallow water and Boussinesq assumptions. The RANS equations are solved by the alternative direction implicit finite difference method (ADI) on a spherical or orthogonal curvilinear grid. Delft3D has ability to simulate water-level variations and flows on surface water bodies in response to forcing elements of inflow discharges and climate factors, which has been proven by applications on many surface water bodies around the world. Delft3D is considered appropriate for the wide and shallow characteristics of Poyang Lake.

The reviewer's comment 10: L146-147: to simulated ?

The authors' Answer: As the PLUZ does not include Poyang Lake. The sentence has been revise as follows:

We used SWAT model to simulate stream flows in the land covered area of the PLUZ.

The reviewer's comment 11: The results and discussion seems just result description and no discussion was provided.

The authors' Answer: We have revise the discussion part. The intra-annual and inter-annual variation of the ungauged streamflow will be discussed, as well as the impact to the lake water balance.

The reviewer’s comment 12: There are many grammar issues here and there, and I believe they need a professional editing service before resubmission.

The authors’ Answer: We have invited a professional editing service to revise the grammar issues.

Replies to Referee #2

We are very grateful to the reviewer for reading the manuscript extremely carefully and forwarding the valuable suggestions for improvement. Point-by-point responses to the reviewers' comments are listed below.

1. General Comments

The reviewer's comment 1: However, the writing is very poor. Most of sentences are too awkward to be understood even though the grammar of the sentence is correct. After reading the whole of methodology, I could not proceed with the rest of the manuscript, not only because of the poor English writing but also because of the confusing, conflict, and unclear technical details.

The authors' Answer: Thanks for the kind advice. We have invited a professional organization to modify the language.

The reviewer's comment 2: Based on my understanding, the methods in this study should be very clear: authors firstly simulated the streamflow of inlets for Poyang Lake using SWAT model; the parameters were calibrated using the observed streamflow from gauges located in the upper streams; then, the simulated streamflow were used as the inflows for hydrodynamic model to simulate the water level and other hydrodynamic characteristics of Poyang Lake; finally, modeled water level and discharge in outlet (Hukou) with and without SWAT simulated inflows were compared. If my understanding is correct…

The authors' Answer: The reviewer is almost right. The procedures of the manuscript are as follows. Procedure 1: we first calculated the streamflow produced by the Poyang Lake ungauged zone (PLUZ). Procedure 2: the modeled water level and discharge in outlet (Hukou) with and without PLUZ streamflow were compared.

For Procedure 1, the Poyang Lake ungauged zone including two parts. One is the land cover area of PLUZ, the other one is water covered area (It has been revised as Poyang Lake). The water covered area is Poyang Lake. So in the next step, we calculate the streamflow for the land covered area and Poyang lake separately.

The streamflow for the land covered are of PLUZ is simulated by SWAT model. The parameters were calibrated using the observed streamflow from gauges located in the upper streams. The streamflow in the land coved area of PLUZ is calculated as the difference value of simulated streamflow at inlets of Poyang Lake and the observed streamflow of the upstream gauged area.

The streamflow for the Poyang Lake is calculated by a simplified equation (Eq (1)). As the reviewer comments, the equation is not serious for not considering the lake storage change (This will be discussed in **the reviewer's comment 4 in General Comments**).

The steamflow of PLUZ is the summation of streamflow produced by the land coved area and Poyang Lake.

For Procedure 2, the calculated streamflow in PLUZ were used as part of the inflows for hydrodynamic model to simulate the water level and other hydrodynamic characteristics of Poyang Lake. In this processing, two lake hydrodynamic scenarios (Adjusted Scenario, Original Scenario) are built. In Adjusted Scenario, inflows for hydrodynamic model is the summation of simulated streamflow in PLUZ and the observed streamflow from gauges located in the upper streams. In Original Scenario, inflows for hydrodynamic model is the observed streamflow from gauges located in the upper streams. The modeled results (water level and discharge) in Adjusted Scenario and Original Scenario were compared.

The details is in section 3 in the manuscript.

The reviewer's comment 3: …I don't understand why authors used more than five pages to describe this simple procedure and the procedure hasn't been clarified ultimately. For example, I didn't see any coupling of hydrological and hydrodynamic models in sections 3.3

The authors' Answer: Thank you for the valuable suggestion. The coupling is in L197-252. The writing of manuscript may confuse you.

In the manuscript, it is loosen coupling. In the Adjusted Scenario, the output of SWAT model is the input of Delft3D model. The streamflow of PLUZ is used as part of the upper inflows for hydrodynamic model.

In the Original Scenario when the streamflow of PLUZ is not considered, there are 9 inflow points (*d1, d2, d3, d4, d5, d6, d7, d8 and d9*) for the lake (Figure 1(b)). Inflows to the points comes from the 7 gauging stations (Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan and Dufengkeng). In the Adjusted Scenario, we should solve the problem: how to allocate the ungauged streamflow in to different inflow points.

As the ungauged zone is usually in flat topography with turbulent flow, it is difficult to draw watersheds in the ungauged zone. What's more, allocating the streamflow in the ungauged zone to inflow boundary of hydrodynamic model is not an easy work. The coupling sections (section 3.4) describe the content: how to drawing watersheds in the ungauged zone and allocating the ungauged streamflow to the lake model properly.

The section may confuse you. We have reorganized the coupling section.

The reviewer's comment 4: …but a lot of confusing water balance equations (i.e., Equation (2-4)), especially for equation (3). Where is the water level change (i.e., surface water storage) in equation (3)? If the water level change is too small to be negligible authors may need to verify it and clarify it in the manuscript. In my opinion, all the Equation (2-4) can be written in one if considering the Poyang Lake as the control volume: QHukou = P+Qinflows-E-ΔSWSsimulated where QHukou is the discharge in the outlet of Poyang lake; P is the precipitating in Poyang Lake; Qinflows is the summation of the streamflow in all inlets of Poyang Lake; E is the evaporation in Poyang Lake; ΔSWSsimulated is the water level changes in Poyang Lake.

The authors' Answer: Thank you very for the valuable suggestion. The writing of manuscript may confuse you.

In Section 3.3 (Equation (2-4)), we intended to calculated the inflow at different inflow points of the lake in the Adjusted Scenario. The inflow at the point was the summation of three parts: the streamflow in land covered PLUZ, the streamflow in Poyang Lake, and the streamflow from the upper gauged stream (the 7 gauging stations: Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Dufengkeng and Hushan).

However, originally I was confused by the concept of STREAMFLOW in Poyang Lake. The streamflow in Poyang Lake should take the lake level change into consideration. However, the hydrodynamic model modeled the changed lake level and outflow in long time series. The streamflow of the lake should not be the upper inflow boundary of the Lake hydrodynamic model, it should be considered by the hydrodynamic model. But the hydrodynamic model is developed without considering evaporation. And we estimated the evaporation on the surface of the lake as less than 2% of the total water resource. Thus, in our study, we have ignored the evaporation on the surface of the lake.

So we revise the inflow of the lake as the summation of two parts: the streamflow in land covered area of PLUZ, and the streamflow from the upstream gauged area (the 7 gauging stations).

As the lake hydrodynamic model can model the changed lake level and outflow, we have decided not to take Poyang Lake as part of the ungauged zone. So the PLUZ is redefined the area inside the yellow line and outside the boundary of Poyang Lake (Figure 1(a)).

The reviewer's comment 5: …Given the authors' methodology is correct, I have another two concerns: has the hydrodynamic model been calibrated? If yes, the bias and error of the simulated ungauged streamflow can be corrected during the calibration of hydrodynamic model which means the verification of simulated streamflow in ungagged zone may be spurious;

The authors' Answer: Thank you very for the valuable suggestion. The writing of manuscript may make you confused.

We construct two scenarios (Adjusted Scenario, Original Scenario) for the lake hydrodynamic model. Adjusted Scenario take the ungauged streamflow into consideration while Original Scenario does not. The model in Original Scenario has been calibrated and validated. The model in Adjusted Scenario use the same parameter as that in Original Scenario.

The reviewer's comment 6: the other concern is I don't think it's necessary to use SWAT simulation as the results shown in Figure 4 since the discrepancy of two scenarios with and without SWAT is relatively small which may be smaller than the uncertainties in SWAT simulations as shown in Figure 3.

The authors' Answer: Thank you for the comments. The writing may confuse you. If the writing is more clear, your comments is as follows: the other concern is I don't think it's necessary to use SWAT simulation as the results shown in Figure 4 since the discrepancy of two scenarios with and without ungauged streamflow is relatively small which may be smaller than the uncertainties in SWAT simulations as shown in Figure 3.

The SWAT and Delft3D are two different models and applied in different specific fields. The acceptable simulation accuracies are different too. In general, SWAT model simulation can be judged as satisfactory if Ens (Nash-Sutcliffe efficiency) > 0.50 and absolute PBIAS (percent bias) < 25% for streamflow (Van Liew et al. 2007), while for water level (or tide level) simulation by Delf3D model Ens can be larger than 0.90 (some can reach 0.99) and absolute PBIAS can be smaller than 5% (Qi et al., 2016; Zhang et al., 2015). The Delf3D model is steady and the uncertainty is relatively small. Therefore, it is not easy to improve the simulation result of Delft3D model. If the simulated accuracy of Delft3D model can be increased, the increased range should be small and may be smaller than the uncertainty of SWAT model.

However, it is valuable to improve the Delft3D model, although the increased range is small. In the previous research for Poyang Lake dynamic model, the simulated streamflow at the outlet (Hukou) is smaller than the observed in average (Qi et al., 2016; Zhang et al., 2015). This may result from not taking the ungauged streamflow into consideration. So it is valuable and important to test if ungauged streamflow can increase the Poyang Lake dynamic model. And we are curious about what the results would be. It is important to get the result: the ungauged zone improves the Delft3D model accuracy although the increase range of the accuracy is small.

You comment means the discrepancy should be bigger than the SWAT uncertainty if we want to validate the simulation result of the ungauged streamflow by Delft3D model. That is because the increased discrepancy may be caused by the uncertainty of the SWAT model?

If my understanding is right, what we should do is to demonstrate that the discrepancy (the increased accuracy) is not the random fluctuation result of the SWAT uncertainty. We statistic the annual R^2 (determination coefficient) and monthly RMSE (root mean square error) in section 4.2. Mostly R^2 is bigger and RMSE is smaller in Adjusted Scenario than that in Original Scenario. Furthermore, in section 4.4 the ungauged streamflow did improve the lake water balance. The evidences show the improvement in Adjusted Scenario is not random. It suggested the ungauged streamflow is reasonable.

2. Specific Comments

The reviewer's comment 1: Line 15: Is the water covered area of the ungauged zone the Poyang Lake? If yes, please revise or it is very confusing.

The authors' Answer: Yes. It will been revised in the manuscript.

The reviewer's comment 2: Line 18: how do you conclude "narrower discrepancy"? Please provide some quantification. The same for Line 23 "higher value"

The authors' Answer: Yes. It has been revised in the manuscript.

The reviewer's comment 3: Line 29-30: Please rewrite this sentence.

The authors' Answer: The sentence is revised in the manuscript.

To reduce the damage to the population, agriculture and economy, we should attempt to predict floods and droughts precisely. However, in watersheds, there is ungauged zones lack streamflow observations. The ungauged streamflow is difficult to estimate and is usually neglected in water yield estimations, which can result in floods/droughts predictions being not accurate enough.

The reviewer's comment 4: Line 40: Please delete the second "stream flow".

The authors' Answer: It has been delete.

The reviewer's comment 5: Line 51-52: Please revise this sentence. Awkward.

The authors' Answer: Some researchers use regionalization methods to simulate streamflow in ungauged zones. The parameters in the gauged areas are calibrated. Then, the parameters are transformed from gauged to ungauged areas.

The reviewer's comment 6: Line 60: Where is the citation for Ma's study?

The authors' Answer: It is an article in Chinese. The reference is as follows:

Ma, X., Liu, D.: Modeling of interval runoff in the region of Dongting Lake[J]. Journal of Hydroelectric Engineering, 30(5):10-15, 2011.

The reviewer's comment 7: Line 124: Please provide the spatial resolution for DEM.

The authors' Answer: The spatial resolution for DEM is 90 m.

The reviewer's comment 8: Line 131: Please provide some examples about the topographic data.

The authors' Answer: The following examples of topographic data have been added. The reference is as follows:

Qi, H., Lu, J., Chen, X., et al. Water age prediction and its potential impacts on water quality using a hydrodynamic model for Poyang Lake, China. Environmental Science and Pollution Research, doi:10.1007/s11356-016-6516-5, 23(13):13327-13341, 2016.

Zhang, P., Lu, J., Feng L., et al. Hydrodynamic and inundation modeling of China's largest freshwater lake aided by remote sensing data. Remote Sensing, doi:10.3390/rs70404858, 7(4): 4858-4879, 2015.

The reviewer's comment 9: Line 134-135: Please provide the temporal scales for water level and discharge.

The authors' Answer: Daily scale. The sentence has been revised as follows:

The daily observation for water level (at stations of Xingzi, Duchang and Kangshan), and outflow discharges (at Hukou) from 2000 to 2011 were got from Web of hydrological information in Jiangxi.

The reviewer's comment 10: Line 142: What does "sing" mean here?

The authors' Answer: It is a spelling mistake. It should be "using".

The reviewer's comment 11: Line 163: Where is the water level change (i.e., surface water storage change) in equation (1) and (3)? If the water level change can be negligible please verify it and clarify it. (???)

The authors' Answer: The lake water level change has been taken into consideration in the lake hydrodynamic model. As there are observed stations gauging the water level and lake hydrodynamic model can model the streamflow in Poyang Lake, Poyang Lake is not considered as ungauged zone. (more details in **Comment 4 in General Comments**)

The reviewer's comment 12: I didn't read the Result section word by word please carefully read it and revise it based on the revised methodology.

The authors' Answer: Thank you for the suggestion. We have modified it based on the the methodology.

The reviewer's comment 13: Line 440: Please delete Table 3.

The authors' Answer: We have deleted Table 3 in the revised version.

The reviewer's comment 14: Line 444: Please switch the Figure 1a and 1b; put figure 1a in left hand side; delete the "Meteorological stations" in legend of Figure 1b since there is no meteorological station; add the scale bar in Figure 1b.

The authors' Answer: There is a meteorological station of Boyang. And the rest have been revised in Figure 1.

The reviewer's comment 15: Line 450: Figure 2 is confusing, and please revise it. (???)

The authors' Answer: It has been revise as the comment (Figure2).

The reviewer's comment 16: Please provide the line number for figure 3 and also the captions for the subfigures.

The authors' Answer: We will provide the line number for Figure 3. The added captions is as follows: Subfigures (a),(b),(c),(d),(e) and (f) are the calibration and validation result for stations at Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan, and Dufengkeng separately.

The reviewer's comment 17: Based on Figure 4, I don't think it's necessary to use SWAT simulation. The discrepancy of two scenarios is relatively small which may be smaller than the uncertainties in SWAT model as shown in Figure 3.

The authors' Answer: We have made more analysis (more details in **the reviewer's comment 6 in General Comments**).

The reviewer's comment 18: Please delete the figures 5-7.

The authors' Answer: We have deleted the figures 6-7.

Stream flow simulation and verification in ungauged zones by coupling hydrological and hydrodynamic models: a case study of the Poyang Lake ungauged zone

Ling Zhang [1], Jianzhong Lu [1,*], Xiaoling Chen [1,2], Sabine Sauvage [3], José-Miguel Sanchez Perez [3]

[1]State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China

[2]Key Laboratory of Poyang Lake Wetland and Watershed Research, Ministry of Education, Jiangxi Normal University, Nanchang 330022, China

[3]ECOLAB, Université de Toulouse, CNRS, INPT, UPS, 31400 Toulouse, France

* *Correspondence to*: Jianzhong Lu (lujzhong@whu.edu.cn)

Abstract. To solve the problem of estimating and verifying ~~stream flows~~streamflow without direct observation data~~;~~, we ~~extend existing techniques for estimating stream flows~~estimated streamflow in ungauged zones~~,~~ by coupling a hydrological model with a hydrodynamic model, using the Poyang Lake ~~basin~~Basin as a test case. ~~We simulated stream flows in the land covered area~~To simulate the streamflow of the ungauged zone~~ by building~~, we built a SWAT model for the entire catchment area covering the upstream gauged ~~stations~~area and ~~the land covered area; then estimated stream flows in the water covered area of the~~ ungauged zone; and then calibrated the SWAT model using the ~~simplified water balance equation~~data in the gauged area. To verify the results, we built two hydrodynamic scenarios (the original and adjusted scenarios) for Poyang Lake using the Delft3D model. In ~~this study,~~ the original scenario~~ did not take stream flows in the~~ , the upstream boundary condition is the observed streamflow from the upstream gauged area, while it is the sum of the observed from the gauged area and the simulated from the ungauged zone ~~into consideration, unlike~~in the adjusted scenario~~ that accounts for the ungauged zones. Experimental~~. The experimental results ~~show~~showed that there ~~was~~are a ~~narrower discrepancy~~stronger correlation and lower bias (R^2 = 0.81, PBIAS = 10.00%) between the ~~stream flows~~ observed ~~at the outlet of the lake~~ and ~~the~~ simulated ~~stream flows~~streamflow in the adjusted scenario~~.~~ compared to that (R^2 = 0.77, PBIAS = 20.10%) in the original scenario, suggesting the simulated streamflow of the ungauged zone is reasonable. Using ~~our technique~~this method, we estimated ~~that~~ the ~~ungauged zone~~streamflow of the Poyang Lake ~~produces stream flows of approximately 180~~ungauged zone as 16.4 ± 6.2 billion m^3~~;~~/a, representing ~~about 11.4%~~ $\sim$11.24% of the annual total water yield of the ~~total inflow from the~~ entire watershed. ~~We also analysed the impact of the stream flows~~Of the annual water yield, 70% (11.48 billion m^3/a) concentrates in ~~ungauged zone on~~the wet season, while 30% (4.92 billion m^3/a) comes from the dry season. The ungauged streamflow significantly improves the water balance ~~between inflow and outflow~~with the closing error decreased by 13.48 billion m^3/a (10.10% of the total annual water resource) from 30.20 ± 9.1 billion m^3/a (20.10% of the ~~lake. These results, incorporating the estimated stream flow in ungauged zone, significantly improved the water balance as indicated by R^2 with higher value and percent bias with lower~~

~~value, as compared to the results when the stream flows in the ungauged zone were not taken into account, R^2 with lower value and percent bias with higher value.~~total annual water resource) to 16.72 ±8.53 billion m^3/a (10.00% of the total annual water resource). The method can be extended to other lake, river, or ocean basins where observation data is unavailable.

1 Introduction

In recent years, floods and droughts have occurred frequently (Cai et al., 2015; Tanoue et al., 2016), threatening lives and health, reducing crop ~~yield~~yields and hindering economic development (Lesk et al., 2016; Smith et al., 2014). ~~If we know the water yield of watersheds, we can predict and prevent droughts and floods. Therefore, it is necessary to fully understand the water yield of watersheds, in order to~~ To reduce the damage ~~of floods and droughts~~ to the population, agriculture and economy~~.~~, we should attempt to predict floods and droughts precisely. However, in watersheds, there is ~~an~~ ungauged ~~zone lacking stream flow~~zones lack streamflow observations. ~~Hydrological model is used~~The ungauged streamflow is difficult to estimate ~~water yields; and stream flow observations are used to calibrate the model and verify the estimation results. Therefore, lacking stream flow observations~~ and is usually ~~makes ungauged zones~~ neglected in water yield ~~estimation~~estimations, which can result in floods/droughts predictions being not accurate enough.

These ungauged zones ~~is~~are an area of interest in Ungauged Basins (Sivapalan et al., 2003). Ungauged zones, which stretch from the ~~most~~ downstream boundary of a gauged basin to the ~~lower~~upper boundary of an adjacent water body, ~~existing~~exist in river, lake and ocean catchments universally. An ungauged zone usually occupies a large proportion of an entire watershed (Dessie et al., 2015; Li et al., 2014); thus, ~~the neglect of~~neglecting ungauged zones adds uncertainty in models ~~for~~ of estimating the water yield ~~estimation. Therefore, stream flow simulations~~. In addition, the ungauged zone is usually located in ~~ungauged zones are necessary to reduce uncertainty~~flat topography with a dense river-net, resulting in ~~accurate~~turbulent flow without a fixed direction. The dense river-net and ~~reliable predictions of water yields and droughts-floods.~~

~~The simulation of stream flows in stream~~turbulent flow make it difficult to observe and estimate streamflow in the ungauged zone.

The streamflow simulation in ungauged zones is one area of interest in the Prediction ~~in~~of Ungauged Basins (PUB) research program (Hrachowitz et al., 2013; Sivapalan et al., 2003). In the PUB research program, data acquisition techniques (Hilgersom and Luxemburg, 2012), ~~and~~ experimental studies (McMillan et al., 2012; Ali et al., 2012), advanced models and strategies (Harman, 2008), and new hydrological theory (Kleidon et al., 2013) have been developed to improve hydrological prediction results ~~in prediction in the ungauged area. These advanced methods aid in stream flow simulations of~~for ungauged zones.

In the PUB research, methods for ~~stream flow~~streamflow prediction in ~~stream flow~~streamflow ungauged zones focus on simple water balance equations and the transformation of hydrological information ~~transformation~~ (Dessie et al., 2015; Song et al., 2015). For~~ the~~ simple water balance equations, there are no parameters to be calibrated. Feng et al. (2013) defined ~~stream flow~~streamflow as the difference between precipitation and evapotranspiration. SMEC (2008) determined the ~~stream flow~~streamflow of the ungauged zone based on a lake water balance equation~~,~~ using measured lake water levels and inflow discharges from the upstream gauged catchment. This method is ~~too rough~~not suitable for ~~stream flow~~accurate streamflow simulation~~. For some hydrological models, we need to calibrate the hydrological parameters. The ~~ in the ungauged zone. Some researchers use regionalization methods to simulate streamflow in ungauged zones. The parameters in the gauged areas are calibrated. Then, the parameters ~~in the gauged areas similar to the ungauged areas. Then transform the parameters~~are transformed from gauged to ungauged areas. Wale et al. (2009) constructed a ~~reginal~~regional model ~~of~~for the relationship between the hydrological model parameters and the catchment characteristics. Based on this ~~reginal~~regional model, the hydrological parameters in the gauged area were transformed to the ungauged zone~~ for stream flow simulations.~~. However, ~~these researches rarely take ~~verification ~~into consideration~~of the ungauged streamflow is not shown in these studies. ~~Verification of stream flow simulations in ~~Yet other researchers do verification for the ungauged ~~zones is however, the focus in some studies.~~streamflow simulation. Wang et al. (2007) computed ~~stream flow~~the streamflow in an ungauged zone by classifying the underlying surface. The ~~stream flow~~streamflow of each type of surface was calculated based on the ~~corresponding ~~surface characteristics. Wang verified the ~~prediction~~estimation results by comparing the simulated and observed lake water ~~level~~levels. The verification in Ma's study (2011) was based on the water balance of yearly inflow and outflow of the lake. ~~These verification methods were coarse.~~The time resolution is not high enough. Dessie et al. (2015) simulated ~~stream flows~~streamflow in ungauged zones using a rainfall-runoff model and ~~runoff coefficient.~~a runoff coefficient. Dessie ~~analyse~~analyzed the effect of the ungauged zone on the water balance of the lake, which ~~was ~~indirectly verified ~~for ~~the ~~hydrological prediction~~streamflow simulation result of the ungauged ~~zones~~zone. However, the water balance ~~of inflow and outflow is too rough to~~for indirect verification does not represent the ~~hydrodynamic characteristics of the lake. Verification in these studies was indirect or too coarse for accurate and precise prediction results. ~~water conservation exactly.

An approach coupling hydrology ~~and~~with hydrodynamics could be used to solve the simulation and verification ~~problem~~problems. Usually, ~~there are stream flow observation~~a water body (a lake, a river, or an ocean) exists downstream of the ungauged zone. The water body is gauged by streamflow gauging stations at the ~~lower boundary of the ungauged zone. The observation~~outlet and water level gauging stations on the water surface. The observations can be used to verify the ~~stream flow simulation of the whole watershed and furtherly verify stream flow simulation of the ungauged zone,~~streamflow simulation result by building a hydrodynamic model for the water ~~covered area of the ungauged zone.~~body. The method coupling ~~of ~~hydrology ~~and~~with hydrodynamic models is widely used to represent the catchment ~~-~~water system and the interaction between catchments and water bodies. Inoue et al. (2008) combined hydrology and hydrodynamic models to simulate the hydrological cycle and hydrodynamic characteristics in a coastal wetland of the Mississippi River ~~delta, and~~Delta, with an effective model performance ~~when predicting stream flows~~. Dargahi and Setegn (2011) combined a watershed hydrological (SWAT) model with a 3D hydrodynamic model (GEMSS) to simulate the Tana Lake Basin ~~that addressed~~to address the impact of climate change. Bellos and Tsakiris (2016) combined ~~a~~ hydrological and hydrodynamic techniques for flood simulation in the Halandri catchment. However, ~~in the researches there is no clear and specific~~ the method ~~of coupling~~combing a hydrological model and a hydrodynamic ~~models in space and time. Extending the existing research,~~model is rarely applied in such ungauged zone. As the ~~method~~ungauged zone is usually located in flat topography with turbulent flow, it is difficult to draw watersheds in the ungauged zone. In addition, allocating the ungauged streamflow to the inflow boundary of a hydrodynamic model is not easy. The ways to drawing watersheds and allocating the streamflow are not mentioned in the previous studies. The details of coupling hydrology and hydrodynamic models in ~~space and time~~the ungauged are presented ~~in detail~~ in the study.

The Poyang Lake Ungauged Zone (PLUZ~~),~~) is a ~~typical~~typical example of ungauged zones. The PLUZ is adjacent to Poyang Lake. There are ~~stream flows~~streamflow observations at the outlet of the ~~entire watershed.~~lake. The ~~stream flow~~streamflow from the PLUZ is usually estimated as the difference ~~of~~between the streamflow at the outlet of the lake and the observed ~~stream flow from~~ streamflow gauging the upstream ~~stations and that at the outlet of the lake.~~ area. However, the ~~observation~~observations at the outlet of the lake ~~can not~~cannot respond to the variation of the watershed hydrology ~~in time~~quickly and accurately~~,~~ due to ~~the function of~~ water storage and flood regulation ~~in~~of the lake, which makes the ~~stream flow~~streamflow peak clipped and time-lagged. ~~This~~Traditional method is too coarse for ~~stream flow~~streamflow simulation in the PLUZ.

~~Attempts has~~More attempts have been made for ~~accurate and precise stream flow~~streamflow simulation ~~results~~ in the PLUZ. Huang et al. (2011) developed a runoff-~~fluex~~flux model especially for the plain area of the PLUZ. The simulation results were verified by comparing ~~the outflow observation~~ observed streamflow at Hukou with the ~~summation~~sum of the simulated streamflow in the PLUZ and the ~~measured~~gauged streamflow of the gauged upstream~~, on the yearly~~ in an annual scale. The time scale ~~of the verification~~ was coarse~~;~~. Furthermore, the water storage and flood regulation function of the lake were not taken into consideration. Guo et al. (2011) simulated the daily runoff of the PLUZ ~~by~~using the Variable Infiltration Capacity (VIC) and multiple-input single-~~out put~~output system (~~MSIO~~MISO) models. The verification was performed by comparing the simulated results with the estimated results. However, the estimated result was derived from the time-lag equation, so it could not replace the observed value exactly, for the following two reasons~~. The~~: (1) the time-lag equation was a simple hydrodynamic model for the lake, which is not very accurate~~. In~~; (2) in the equation, the streamflow at Hukou was adjusted by a modified coefficient at the annual scale, which is not reasonable to ~~be applied in~~apply at the daily scale. Most recently, Li et al. (2014) combined the hydrological model (WATLAC) and hydrodynamic model (MIKE), where the streamflow in the ungauged area~~,~~ was ~~roughly~~ calculated by the runoff coefficient ~~method~~. However, ~~the ungauged area did not take the water~~

~~covered area into consideration. Further,~~ there was no verification. In summary, there have ~~has~~ been ~~no study including~~few studies that include effective verification ~~of stream flow~~for streamflow simulations in the PLUZ. In the study, the method of combining hydrological and hydrodynamic models is introduced to solve the simulation ~~results for the PLUZ~~and verification problem in the PLUZ. Our specific objectives are to: (1) simulate and the verify the streamflow in the PLUZ; (2) analyse the inter-annual and intra annual variations of the ungauged streamflow; (3) analyse the impact of the ungauged streamflow on the lake water balance.

~~The object of this study was to solve the verification problem in stream flow simulation in the PLUZ by combining hydrological and hydrodynamic models. The stream flow simulation of the land-covered area in the ungauged zone was conducted by building a SWAT model for the whole catchment covering the gauging stations and the land covered area; while the stream flow in the water covered area of the PLUZ was calculated by a simplified water balance equation. We established two lake hydrodynamic model (Delft3D) to further verify the streamflow simulation results. The hydrological and hydrodynamic models were coupled in both space and time. We estimated that the ungauged zone of Poyang Lake produces stream flows of approximately 180 billion m³; representing about 11.4% of the total inflow from the entire watershed. The impacts of stream flows in the PLUZ on the water balance of the catchment-lake system were analysed; and the importance of ungauged zones in hydrological prediction for the whole watershed were verified.~~

2 Study area and data

2.1 Study area

Poyang Lake is the largest freshwater lake in China~~,~~ and is connected with the Yangtze River in the north of Jiangxi ~~province~~Province. The catchment is covered by the five major river sub-catchments and the ungauged zone ~~shown~~, in Fig. 1~~.~~(a).

As shown in Fig. ~~1a, stream flow produced by~~1(a), the Poyang Lake basin includes three parts: the gauged area (the five major river catchments ~~are~~), ungauged zone (the PLUZ) and Poyang Lake. The streamflow of the gauged area was measured by ~~the~~ seven ~~stream flow~~streamflow stations~~.~~ (Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan and Dufengkeng). The PLUZ is a plain area and stretches from the ~~stream flow gauging~~seven streamflow stations to the ~~outlet~~boundary of ~~the lake~~Poyang Lake. The PLUZ covers an area of 19,867 km², and amounts to 12% ~~area~~ of the lake catchment. ~~The stream flow from the sub-catchments and the PLUZ~~ The discharges from the gauged area and the PLUZ flow into the lake~~; then this~~. Then the water ~~flows~~discharges into the Yangtze River at Hukou.

~~As shown in Fig. 1b, the lake received water from the gauged area (the five major river catchments) and the PLUZ. The lake topography~~The Poyang Lake basin, with an area of 162,000 km², has a subtropical wet climate characterized by a mean annual precipitation of 1680 mm and annual average temperature of 17.5 ℃. The topography of the Poyang Lake basin varies from upstream hills at an elevation of approximately 2,100 m to downstream plain areas at an elevation of almost 35 m above sea level. The topography of the ~~land covered area in the~~ PLUZ is flat, with a slope ~~at~~of less than five degrees~~. The Poyang Lake basin with an area of 162,000 km^2 has a subtropical wet climate characterized by a mean annual precipitation of 1680 mm and annual average temperature of 17.5℃~~.

The elevation of the lake bed generally decreases from south to the north, with differences of approximately 7 m, as shown in Fig. 1(b). The discharges from the gauged area and the ungauged zone flow into the lake at 11 points ($d_1 \ldots d_{11}$). The water level is controlled by the representative stations of Kangshan, Duchang and Xingzi.

2.2 Data

We provide data for SWAT and Delft3D models. Data required by the SWAT model include the forcing elements of daily rainfall~~ and potential~~, evapotranspiration~~ for~~, temperature, relative humidity and wind from 1980 to 2014 collected at 16 national meteorological stations~~,~~. The stations are distributed uniformly across the area (Fig. ~~1a). This~~1(a)). These data ~~was~~were downloaded from the ~~hydrological information website of Jiangxi (http://www.jxsw.cn/).~~China Meteorological Data Sharing Service System (http://data.cma.cn/). The digital elevation model (DEM) of the catchment ~~origins~~originates from SRTM (Shuttle Radar Topography Mission) in 2000. The spatial resolution of the DEM is 90 m. The land-use data ~~was~~were obtained from Landsat TM and ETM+ images in 2000 (Chen el at. 2007). Land-use was categorized into forest (54%), farmland (25%), pasture (10%), water bodies (5%), bare land (3%), urbanization (2%), and wetland (1%). The soil data ~~is~~were generated from HWSD (FAO, 1995). The soil ~~have~~has the following catchment-aggregated proportions: Haplic Acrisols (55%), Cumulic Anthrosols (22%), Humic Acrisols (11%), Haplic Alisols (3%), Haplic Luvisols (2%), and others (7%). The long time series daily~~/monthly~~ discharges at seven gauging stations (Qiujin, Wanjiabu, Waizhou, Lijiadu, Meigang, Dufengkeng, Hushan) from 2000 to 2011 were ~~get~~obtained from the web of hydrological information in Jiangxi. Data required by Delft3D Model included the lake shoreline~~ of lake~~, topographic data (Qi et al., 2016; Zhang et al., 2015) and hydrological ~~observation~~observations. The shoreline ~~were~~was delineated based on the remote sensing image of Poyang Lake during the flood period in 1998, which is the maximum surface area of the lake~~ surface~~. The topographic data ~~is~~were measured by the Changjiang Water Resources Commission of China (http://www.cjw.gov.cn). ~~The long time series observation for~~The daily water level at the stations of Xingzi, Duchang and Kangshan, and ~~outflow~~ discharges at Hukou from 2000 to 2011 were ~~got~~downloaded from ~~Web of hydrological information in~~ Jiangxi~~.~~ hydro info website (http://www.jxsw.cn/).

3 Methodology

~~To solve the problem of estimating~~The procedure for the ungauged streamflow simulation and ~~verifying stream flows without direct observation data; we extend existing techniques for estimating stream flows in catchment-water systems, coupling a~~

~~hydrological model with a hydrodynamic model using the~~ verification, contains three parts (Fig. 2): (1) hydrologic modelling for the Poyang Lake ~~basin as a test case. We simulated stream flows in the land covered area of the ungagged zone by building~~ ungauged zone; (2) hydrodynamic modelling for Poyang Lake in two scenarios with or without considering the ungauged streamflow; (3) coupling of hydrological and hydrodynamic models.

In Procedure 1, we built a SWAT model for the entire catchment ~~area~~ covering the ~~seven~~ gauged ~~stations and the land covered area; then estimated stream flows in the water covered area of~~ area and the ungauged zone to simulated streamflow in the PLUZ; and calibrated and validated the SWAT model using the ~~simplified water balance equation. To verify the results~~gauged streamflow in the gauged area. In Procedure 2, we built ~~two scenarios representing~~ the original and adjusted ~~stream flows sings~~scenarios for the ~~Delft3D~~lake hydrodynamic model~~. In this study,~~ to further verify the ungauged streamflow. The original scenario did not take ~~stream flows in~~ the ungauged ~~zone~~streamflow into consideration, unlike the adjusted scenario ~~that includes a hydrodynamic model that accounts~~, which accounted for the ungauged zones. In the adjusted scenario, the hydrological and hydrodynamic modes were coupled. In Procedure 3, we described the coupling of river hydrological and lake hydrodynamic models in details.

In order to analyse the impact of ungauged streamflow on the lake water balance, we described the water balance equation in section 3.4.

3.1 Hydrology modelling

We used ~~SWAT model to simulated stream flows in the land covered area of the PLUZ and a simple water balance equation to simulated stream flows in the water covered area of the PLUZ.~~

~~The stream flow simulation in the land covered area of the PLUZ was performed by building a SWAT model for the entire catchment area including gauged stations and the land covered area.~~a SWAT (Soil and Water Assessment Tool) (Arnold et al., 1993) ~~was physically-based and semi-distributed hydrological model. It~~ model to simulate streamflow in the PLUZ. SWAT is a physically-based, semi-distributed and river basin-scale hydrological model. It is developed to assess the impact of land management practices on streamflow, sediment and agricultural yields in complex basins with changing soil types, land use and management over long periods of time. For the purpose of modelling, an entire watershed is divided into sub-watersheds based on rivers and DEM data. Sub-watersheds are portioned into Hydrological Response Units (HRUs), the minimum research units. Water balance is the driving force of hydrological processes. The hydrological cycle includes two divisions: runoff-producing on land and flow-routing in channels. The surface runoff volume is calculated using the SCS method (USDA Soil Conservation Service, 1972). Flow routed through the channel is calculated by the variable storage coefficient method (Williams et al., 1969). SWAT has already been widely applied to watersheds ~~widely in~~around the world for ~~stream flow~~streamflow simulation (Douglas-Mankin et al., 2010; Arnold et al., 2012; Luo et al., 2016).

A SWAT model ~~used for prediction must~~should be calibrated and validated by the measured data. The ~~land covered area of the~~ PLUZ is ungauged for ~~stream flow~~streamflow, while there are streamflow gauging ~~station~~stations (the seven gauging stations) at the upstream boundary of the PLUZ~~. So~~, controlling the upstream gauged area (Fig. 1(a)). Thus, we ~~can establish~~established a SWAT model for a larger ~~catchment. The large catchment excludes the land covered area of the PLUZ,~~area, more than just the ungauged zone. The modelled area covers the ~~gauging station and the~~ upstream gauged area ~~to calculate streamflow in the PLUZ indirectly.~~and the ungauged zone (the PLUZ), excluding Poyang Lake (Fig. 1(a)). We use the long time series of monthly discharges at six gauging stations (Wanjiabu, Waizhou, Lijiadu, Meigang, Dufengkeng~~,~~ and Hushan) to perform the calibration from 2000 to 2005 and validation from 2006 to 2011. The ~~performance indexes is~~ determination coefficient (R^2), Nash-Sutcliffe efficiency coefficient (Ens), ~~and~~ percent bias (PBIAS~~).~~

~~Since runoff produced by the water covered area was not taken into consideration by the hydrodynamic model (Delft3D), we calculated the stream flow by a simple water balance equation. The stream flow produced by water covered area of the PLUZ (~~$\cancel{Q'_{uw}}$~~) was assumed as the difference of the precipitation and the evapotranspiration in the lake area. The methodology is based on the assumptions that the ground water were ignored.~~ $\cancel{Q'_{uw}}$ ~~was calculated by the following formula:~~

$$\cancel{Q'_{uw} = P - E} \qquad \cancel{(1)}$$

~~Where P is the precipitation and E represents the evapotranspiration in the water area. Long time series precipitation and evapotranspiration data was derived from the nearby meteorological station to the lake—Boyang station~~) and root mean square error (RMSE) are used as the performance indices.

3.2 Hydrodynamics modelling

To verify the streamflow simulation results in the PLUZ, we ~~use Delft3D to build the~~built two hydrodynamic ~~model~~scenarios for the lake~~.~~

using the Delft3D model. Delft3D simulates the hydrodynamic pattern via the Delft3D-FLOW (Roelvink and van Banning, 1994) ~~was used to simulate the hydrodynamic pattern of the lake. It~~module. Delft3D-FLOW is a multi-dimensional (two-dimension or three-dimension) hydrodynamic and transport simulation program. The program can calculate unsteady flow by building linear or curvilinear grids suitable for the water boundary, which is forced by tidal and meteorological data. Delft3D-FLOW is based on the Reynolds-Averaged Navier-Stokes (RANS) equations, which are simplified for an incompressible fluid under shallow water and Boussinesq assumptions. The RANS equations are solved by the alternative direction implicit finite difference method (ADI) on a spherical or orthogonal curvilinear grid. Delft3D has ability to simulate water~~–~~-level variations and flows on surface water bodies in response to forcing elements of inflow discharges and climate factors, which has been proven by ~~application~~applications on many surface water bodies around the world. Delft3D is considered appropriate for the wide and shallow characteristics of Poyang Lake.

In the model, the shoreline of lake ~~were~~was delineated as the maximum area of the lake surface to ~~make sure~~ensure that the dynamic changes in the lake's~~ water~~ surface area did not surpass the inundation area. To better capture the rapid dynamic of inundation area and minimize the ~~computing~~computational effort, the size of the model grids ranged from ~~200m~~200 m to 300 m. The topographic data ~~was~~were interpolated into each computational node of the model grids. The water level was initialized as the mean of the three hydrological stations in Poyang Lake on 1 January, 2001, which are Xingzi, Duchang and Kangshan. The corresponding velocities were initialized as zero. The upper open boundary was set as the upstream discharges. The lower open boundary was specified as the observed long time series of the daily water level at Hukou station. The model was run from January 1, 2001 to December 31, 2010 and the time ~~steps~~step was set as five minutes ~~in order~~ to meet the Courant-Friedrich-Levy criteria for a stable condition. The long time series of observed data for water ~~level~~levels at Xingzi, Duchang, ~~Tangying,~~and Kangshan~~ and Longkou~~ gauging stations, and outflow discharges at Hukou gauging station, were used for calibration from 2001 to 2005 and validation from 2006 to 2010.

Two ~~Scenarios was~~scenarios were established, the adjusted scenario (Adjusted Scenario) and the original scenario (Original Scenario).

~~In this study,~~ Original Scenario did not take ~~stream flows~~streamflow in the ~~ungauged zone~~ PLUZ into consideration, unlike Adjusted Scenario~~ that accounts~~, which accounted for the ungauged zones. In Original Scenario, the upper open boundary was the ~~long time series observed~~ streamflow from the gauged area, set as the daily discharges ~~at~~from the seven gauging stations~~, in which the streamflow produced by the PLUZ is ignored. There~~; and there are 9 inflow points—d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8~~,~~ and d_9 ~~located at the upper boundary of the lake, representing the upper boundary condition for the lake model~~ (Fig. 1b~~). The inflow into d_1, d_6, d_8 and d_9 points comes from Xiushui River, Fuhe River, one of Raohe River tributaries, the other one of Raohe River tributaries, respectively. The inflow into d_6, d_8, d_9 and d_1 were set as the observed streamflow at Lijiadu station, Meigang station, Hushan station, Dufengkeng station, the sum from Wanjiabu and Qiujin, respectively. The inflow into d_2, d_3, d_4 and d_5, which come from Gangjiang River, is set as 50%, 10%, 20%, 20% of the total observed stream flow at Waizhou station.~~) for the lake model. In Adjusted Scenario, the upper boundary was the ~~summation~~streamflow from the gauged and ungauged areas, set as the sum of the ~~total~~ measured ~~discharge~~discharges at the seven gauging stations and the simulated streamflow in the PLUZ~~. It will be discussed in the next section~~; and there are 11 inflow points—*d1, d2, d3, d4, d5, d6, d7, d8, d9, d10*, and *d11* (Fig. 1b) for the lake model. The specific upstream conditions for the two scenarios are listed in Table 1.

3.3 Models coupling

As the ungauged zone is usually in low and flat topography with turbulent flow, it is difficult to draw watersheds in the ungauged zone. What's more, allocating the streamflow in the ungauged zone to inflow boundary of hydrodynamic model is not an easy work.

3.3.1. Drawing the watersheds for the ungauged zone

The upper boundary condition of the hydrodynamic model in the Adjusted Scenario ~~are~~is the ~~summation~~sum of the gauged streamflow from the ~~hillslopes and the PLUZ. The PLUZ includes the land covered~~gauged area and the ~~water covered area. The~~ simulated streamflow from the ~~hillslopes are represented by the summation observed streamflow of the seven gauging stations. The streamflow from the land covered area in the PLUZ are simulated result by the SWAT model; the streamflow from the water covered area in the PLUZ are estimated by a simplified water balanced equation. In order to~~ ungauged zone (the PLUZ). To determine the upper boundary condition in Adjusted Scenario, we ~~couples~~coupled the hydrological model and hydrodynamic model in space and time.

To make sure the hydrological model and hydrodynamic model ~~was~~were coupled perfectly in space, the delineated sub-basins ~~delineation~~, rivers and the outlets of ~~each sub-~~the PLUZ basin ~~definition~~ should ~~satisfy~~follow the following constraints~~.~~: (1) The ~~five major rivers~~river nets in the PLUZ must be delineated ~~flowing from~~to link the five ~~sub-catchments (~~major rivers and the ~~gauged basins), through the land area~~inflow points of ~~the PLUZ, into~~ the lake~~ at last.~~. (2) The seven gauging stations were set as the outlets of the gauged basins and the inlets of the ~~land covered~~PLUZ basin~~ of the PLUZ.~~; and the most downstream boundary of the gauged basins should coincide with the most upstream boundary of the PLUZ basin. (3) The outlets of the ~~land covered basin in the~~ PLUZ must ~~be~~ completely ~~coincided~~coincide with the inflow points of the lake in the hydrodynamic model~~ for the lake. The stream flows in the inflow points is the upper boundary of Poyang Lake. The most downstream boundary of the gauged basins and the most upstream boundary of the PLUZ land area basin should be coincided with each other; the~~; and the most downstream boundary of the PLUZ ~~land area~~ basin ~~and~~should coincide with the boundary of the lake ~~are coincided with each other too. Only in this way can~~. (4) The sub-basins of the PLUZ should cover the whole area of the PLUZ. Following the principles, the catchment hydrological model can be ~~seamless coupled~~seamlessly coupling with the lake hydrodynamic model in space. We first drew the sub-basins, rivers and outlets using the SWAT model. Since the delineated results by the SWAT model may not satisfy these constraints, we edited the rivers, the boundary of sub-basins and the outlets to meet the constraints (Fig. 2).

~~In this study~~As shown in Fig. 2, the ~~land covered area of the~~ PLUZ was divided to ~~15~~14 sub-basins (b_1, b_2...b_i...b_{14}), and the ungauged area was divided ~~to~~into 25 sub-basins (b_{15}, b_{16}...b_i...b_{39}). Consequently, 11 outlets of the whole catchment were produced for Adjusted Scenario, coinciding with the lake inflow points—d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, d_{11}.~~ The inflow at the 11 points are the upper boundary in Adjusted Scenario.~~

~~In order to calculate the stream flow discharging into each~~ The calibration and validation of the SWAT model was conducted at a monthly scale. However, hydrodynamic model simulation is at a daily scale. To coupling the two models in the same time scale, we use the same parameters of the monthly SWAT model to simulate the ungauged streamflow at the daily scale.

3.3.2. Allocating streamflow

To allocate the ungauged streamflow to different inflow ~~point~~points of the lake, the sub-basins were sorted ~~to~~into 11 groups (*group*$_1$, *group*$_2$, *group*$_3$...*group*$_i$...*group*$_{11}$) ~~according to the~~ (Fig. 3). As shown in Fig. 3, the sub-basins in the same group (*gourp*$_i$) drain to the same inflow point (~~d_1, d_2, d_3...~~d_i).

Based on~~…d$_{11}$). The sub-basins, of which~~ the ~~stream flow flows into~~sub-basin groups, we determined the ~~same~~ungauged streamflow gathering to each inflow point ~~(d_i) at last, are divided into the same group (*group*$_i$). The gauging station were divided into the same group, as the sub-basins it measures are in. Wanjibu and Qiujing, Waizhou, Lijiadu, Meigang, Hushan, Dufengkeng are in *group*$_1$, *group*$_2$, *grourp*$_6$, *group*$_7$, *group*$_8$, *group*$_9$. The group number and the inflow point number are one-to-one corresponded to each other.~~

~~The inflow at point di is the total stream flow~~ of the lake. The streamflow produced by the ~~sub-basins in *group*$_i$, including stream flow produced by the sub-basins in land covered area and water covered of the~~ PLUZ~~, and the gauged area. The streamflow from the sub-basins in the gauged area was represented by the observed stream flows at the gauging stations in *group*$_i$. For example, the streamflow produced by the sub-basins flowing into d_1 is the sub-basins of b_{16} and b_{18}. The stream flow flowing into d_1 was presented by the total observed outflow of Qiujing and Wanjiabu gauging stations (Fig. 2). Specially, in the model, 50%, 30%, 10%, 10% of the streamflow from sub-basins in Ganjiang Basin was set as inflows of points d_4, d_5, d_6 and d_7 respectively.~~

~~For model coupling in time, the calibration and validation of the SWAT model is conducted at monthly scale. However, the upper boundary conditions of the hydrodynamic model are the daily discharge. The same parameters from the SWAT model were used to perform the streamflow prediction at daily scale.~~

~~The daily streamflow produced by the land covered area of the the PLUZ (Q_{ul}), contributing to the lake at the inflow point~~ gathering to d_i, is calculated as the difference between the SWAT simulated outflows at the outlets of the whole catchment and ~~outflows at the outlets of the hillslopes. It was calculated by the following formula:~~the gauged area. The ungauged streamflow contributing to each lake inflow point is listed in Table 2.

$$\cancel{Q_{\mathrm{ul}} = Q_{\mathrm{whole\_out}} - Q_{\mathrm{hp\_out}} \qquad (2)}$$

~~Where, $Q_{\mathrm{whole\_out}}$ is the simulated outflows at point *di*, and $Q_{\mathrm{hp\_out}}$ is the total simulated outflows at the gauging station points in *group*$_i$.~~

~~For daily streamflow simulation in the water covered area of the PLUZ, the calculated streamflow was separated to different parts, allocated to the corresponding inflow points. As the lake area is small and almost in the same elevation, the precipitation and evapotranspiration could be considered distributed uniformly in space. So the runoff in the water covered area was divide into 11 parts equally. The streamflow (Q_{uw}) produced by the lake area contributing to the inflow point di is calculated by the following formula:~~

~~$Q_{uw} = \left(P - E\right)/n$ (3)~~

~~Where P is the daily precipitation, E represents the daily evapotranspiration in the lake, *n*, the total number of inflow points of the lake in lake hydrodynamic model Adjusted Scenario (Fig. 2), equals 11. Long time series precipitation and evapotranspiration data was derived from the nearest meteorological station to the lake, Boyang Station.~~

~~The total daily inflow (Q_{total}) contributing to the lake at the inflow point (d_i) produced by the whole watershed is the summation daily streamflow from the hillslopes (Q_{hp_obs}), the land covered area in the PLUZ (Q_{ul}) and water covered area in the PLUZ (Q_{uw}), the sub-basins of which are in $group_i$. Q_{total} is calculated by following formula:~~

~~$Q_{total} = Q_{ul} + Q_{uw} + Q_{hp\_obs}$ (4)~~

~~Where, Q_{hp_obs}, the daily streamflow from the hillslopes. It is calculated as the summation daily observed streamflow of the gauging stations in $group_i$. Specially, daily streamflow from the hillslopes contribute to the lake at inflow points d_4, d_5, d_6, d_7 are defined as 50%, 30%, 10%, 10% of the streamflow from sub-basins in Ganjiang sub-catchment, respectively.~~

~~The total simulated streamflow produced by the land covered area of the PLUZ (Q'_{ul}) was calculated by subtracting the total streamflow of the hillslopes from the whole catchment. Q'_{ul} is the summation of Q_{ul} at each inflow point. The total daily simulated streamflow produced by the PLUZ (Q'_{ul}) is the summation of streamflow produced the land covered area of the PLUZ (Q'_{ul}) and that produced the water covered area of the PLUZ (Q'_{uw}).~~

3.4 Analysis of lake water balance

In order to analysis the effect of ungauged zone on the lake balance. We construct water balance equations for the lake based on water conservation principles that the difference between of input and output streamflow equals storage change of the lake, as the follows.

$$Q_{in} + P - E + G + \triangle S + \varepsilon' = Q_{out} \qquad (1)$$

where, Q_{in} denotes the inflow from the river basins, P is the precipitation in the lake, $\triangle S$ is the storage change of the lake, and Q_{out} represents the observed outflow at Hukou of the lake. Ɛ' represents the uncertainties in the water balance, which arise from errors in observed data and other components, such as the ungauged streamflow and model uncertainty. E represents the evapotranspiration of the lake, less than 2% of the lake outflow. The E data are obtained from Nachang climatology station. G represents the ground water exchange, only 1.3% of the total water balance (Zhang et al. 2014). Thus, we combine the E, G, and Ɛ' as the closing error Ɛ. As the summation of Q_{in}, P, and $\triangle S$ can be simulated by the hydrodynamic model, the summation is set as the simulated streamflow at Hukou. Traditionally (in Original Scenario), the Q_{in} omits the ungauged streamflow. The water balance equation can be describe as follows.

$$Q_{SimOut,org} + \varepsilon_{org} = Q_{out} \qquad (2)$$

where $Q_{SimOut,org}$ represents the simulated streamflow at Hukou from the hydrodynamic model in Original Scenario. ε_{org} represent the uncertainty of the equation, which arising from the ungauged streamflow, E, G, the error in the observe data, and uncertainty of the hydrodynamic model. As the ungauged zone occupies 12% of the total water balance (Li et al. 2014), much larger than the other components (E and G, less than 3.3%), the closing error should be large than zero if the observe data and hydrodynamic model are sufficient accuracy.

When the ungauged streamflow is taken account (in Adjusted Scenario), the O_{in} contains the gauged and the ungauged streamflow. The water balance equation can be describe as follows.

$$Q_{SimOut,adj} + \varepsilon_{adj} = Q_{out} \qquad (3)$$

where $Q_{SimOut,adj}$ represents the simulated streamflow at Hukou from the hydrodynamic model in Adjusted Scenario. ε_{adj} represent the uncertainty, which doesn't include the ungauged streamflow. Thus, the absolute value of ε_{adj} should be smaller than that of ε_{org}, if the observe data and hydrodynamic model are sufficient accuracy.

4 Results and discussion

4. 1 Calibration and validation of SWAT model and Delft3D model

~~In order to~~To adjust the models to be applied in the Poyang Lake ~~Basin~~basin availably, we ~~undertake~~undertook calibration and validation for the SWAT model and the Delft3D model. Table ~~1~~3 and Fig. ~~3 shows~~4 show the calibration and validation ~~result~~results for the SWAT model. The observations and simulations at the six gauging stations (Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan and Dufengkeng~~,) comes~~) come to a satisfactory agreement, with an R^2 or Ens larger than 0.70 and ~~the~~an absolute ~~value of~~ PBIAS less than 20%, except for Wanjiabu Station. The agreement ~~are fourthly~~is also supported by the ~~highly consistence~~high consistency between the ~~observation~~observations and the simulation~~,~~ in terms of amplitude and phase, although the simulated peak streamflow ~~was~~did not accurately ~~matched~~match the ~~observed~~observations, producing underestimation and overestimation (Fig. ~~3~~4). Nevertheless, the calibration and validation ~~result demonstrates~~results demonstrate that the SWAT model is generally capable of simulating the streamflow of the catchment.

Table ~~2~~4 and Fig. ~~4 shows~~5 show the calibration and validation ~~result~~results for the Delft3D model. The observations and simulations at the four gauging stations (Xingzi, Duchang, Kangshan~~,~~ and Hukou) ~~comes~~come to a satisfactory agreement, with an R^2 or Ens larger than 0.70 and ~~the~~an absolute ~~value of~~ PBIAS less than 25%. The agreement ~~are fourthly~~is also supported by the ~~highly consistence~~high consistency between the observation and simulation, although there ~~is an~~are obvious ~~discrepancy~~discrepancies during the low water level period (Fig. ~~4a~~5a, Fig. ~~4b~~5b, Fig. ~~4c~~5c) and ~~high~~the highly changed flow velocity period (Fig. ~~4d). This outcome~~5d). The mismatch probably arises from the decreased elevation of lake bed from the south to the north and the dynamic variation between wetlands and lake areas. The dynamic variation ~~makes~~causes the lake to be a river in dry ~~period~~periods and ~~turned to be~~turn into a lake in flood ~~period~~periods, which is ~~difficulty~~difficult to ~~be~~

accurately ~~modelled~~model. Nonetheless, model calibration and validation results demonstrate that the Delft3D model has the capability to simulate the hydrodynamic characteristics of Poyang Lake.

4.2 ~~Stream flows~~Streamflow verification in the ungauged zone

~~We~~ To further verify the streamflow simulation results in the ungauged zone, we compared the two hydrodynamic simulation results ~~of the~~from Adjusted Scenario and ~~that from the~~ Original Scenario~~, to take a further verification for the stream flows simulation result in the ungauged zone~~. The Adjusted Scenario took the streamflow in the PLUZ into consideration, while Original Scenario ~~neglected~~omitted the streamflow in the PLUZ. The hydrodynamic simulation result in Adjusted Scenario is improved compared to the Original Scenario, shown in Table 4 and Fig. 6.

Table 4 ~~also~~ shows the ~~comparison of the~~ results ~~from~~of the two scenarios~~,~~ in ~~terms of~~two aspects: the lake water level and outflow. ~~For the~~ For the lake water level, the absolute PBIAS decreases from 0.85%, 3.18%, and 1.56% in Original Scenario to 0.48%, 2.67%, and 1.21% in the Adjusted Scenario while the R^2 keeps the same. The water level simulated result is only a bit improved when inflow to the lake increase by ~10%, due to the large area of the lake. In fact, the simulated water level is already good enough (R^2> 0.85, the absolute of PBIAS < 4%) in Original Scenario. It is not easy to improve the water level simulated result by adding the inflow, only ~10% of the total water resource. However, for the lake outflow discharges, the simulated results in Adjusted Scenario ~~produced high value of~~ produce a higher R^2 (0.81) and ~~low~~lower absolute ~~value of~~ PBIAS (10.00 %), compared to that (R^2 = 0.77 and PBIAS = 20.01%) in Original Scenario~~ with lower value of R^2 (0.77) and higher absolute value of PBIAS(18.88%). And~~ . The evidence suggests an improved simulation result in the ~~discrepancy between the observed and the simulated in~~ Adjusted Scenario when the ungauged streamflow is ~~narrower~~taken into account, compared to that in Original Scenario when the ungauged streamflow is neglected. The result indicates the ungauged simulated result is reasonable.

Figure 6 show the comparison of the streamflow simulated accuracy in Adjusted Scenario and Original Scenario. The R^2 is larger and RMSE is smaller in Adjusted Scenario than that in Original Scenario during the ~~most period. For the lake water level, the absolute value of PBIAS is decreased from 0.85%, 3.18%, 1.56% in Original Scenario to 0.48%, 2.67%, 1.21% in Original Scenario. The figures suggests obviously improved simulated result in Adjusted Scenario when the PULZ was taken into consideration, compared to that in Original Scenario when the PULZ was neglected. And the improvement demonstrates the reasonability of the streamflow simulation result in the PLUZ and the significance of the PLUZ on the water balance of the catchment-lake system~~period from 2001 to 2009. The larger R^2 and smaller RMSE indicates a more significant correlation and narrower discrepancy between the simulated and observed streamflow in Adjusted Scenario. The improved simulated result of the hydrodynamic model in Adjusted Scenario indicates that the ungauged simulated streamflow is reasonable. Although in 2010 the simulated result in Adjusted Scenario is not better than that in the Original Scenario (red shadow in the

Fig. 6), the opposite result may cause by the dike burst in the Fuhe basin (Feng et al. 2011) since the SWAT model and Delft3D model don't consider the dike burst. Thus, it doesn't demonstrate the ungauged streamflow is unreasonable in 2010.

4.3 Stream flows simulation result of the ungauged zone

~~We calculate the cumulative monthly discharge in the PLUZ from 2000 to 2010. Fig. 5 show the statistic result. Seasonal and inter-annual variations can be seen in the long time series data. The seasonal and inter-annual variations was consist of the change of the precipitation. Monthly water yield reaches maximum in flooding period from March to July, then decrease in the later month. After that, it arrives at the minimum in dry period from December to next January, finally increases. The water yields in 2002, 2003 and 2010 are abundant, indicating rich rainfall and possibility of flood event. Severe drought in 2001, 2006, 2007 and 2009 could be observed indicating relatively deficient precipitation.~~

~~The cumulative~~We do monthly (Fig. 7) and annual (Fig. 8(b)) statistic for the ungauged streamflow, to study the intra-annual and inter-annual variations. As shown in Fig. 7, water yield show clearly seasonality. In a particular year, the maximum monthly water yield varies from 1.676 to 7.712 billion m^3/month, occurring between April and July (Fig. 7 (a) and (b)); and the minimum monthly water yield varies from 0 to 0.508 billion m^3/month, occurring between November and the next February (Fig. 7 (a) and (b)). In the Poyang Lake basin, the precipitation mainly concentrates in the period from March to July (the wet season) and there is less rain during the period from September to next March (the dry season) (Fig. 7 (c)). Nearly 70% of the annual streamflow and nearly 65% of the annual precipitation, come from the wet season. The ungauged streamflow seasonal variations are consistent with the change of the precipitation, as precipitation is one of the import driving forces for streamflow. Inter-annual variation is also apparent. Both the month and amount of maximum monthly water yield appear different in different years, as well as that of minimum monthly water yield. For the ten years (2001-2010), the maximum monthly water yield occurred in 2010, when five of twelve month maintained high amount of streamflow (Fig. 7 (a)). Indeed, a flooding event happened in June 2010 due to the dike burst, causing more than 10 thousand people exposed their lives in danger. The minimum monthly water yield reached the minimum in 2007. In fact, in 2007 Jiangxi province experience severe drought (Feng et al. 2011). The severe flood and drought can also be suggested in Fig. 8. As the water yield is affected by the extreme climate, the long time series of water yields can also reflect flood/drought conditions in Poyang Lake area, in reverse.

Annual streamflow shows a clear declining trend ($P<0.05$, from t-test), at a rate of -1.02 billion m^3/a (dashed line in Fig. 8) during the period from 2001 to 2009. The annual streamflow in the dry and wet season is are decreased by -0.67 billion m^3/a and -0.34 billion m^3/a respectively from 2001 to 2009. In 2010, the annual streamflow recovered to a high level of 28.07 billion m^3/a.

The mean annual water yield in the PLUZ totals ~~15~~16.4 ± 6.2 billion m^3, ~~occupying~~encompassing 11.24% of that from the whole Poyang Lake watershed ~~averagely (Table 3), which~~. The result is close to ~~the result by~~ that from Li's research (Li et al.

~~(~~2014), where the ungauged streamflow ~~produced by~~amounts to ~12%. The similar results indicate that the ~~PLUZ land area amount 12%, indicating the hydrological prediction~~streamflow simulation result of the PLUZ is reasonable. Of the annual water yield, nearly 70% (11.48 billion m^3) concentrates in the wet season while 30% (4.92 billion m^3) comes from the dry season. Such a great contribution to the inflow of Poyang Lake~~, which has a great influence on drought/flood in the Poyang Lake basin, could make~~ could have a great effect on the water balance of the ~~catchment~~ lake~~ system~~.

4.4 The impact of the ungauged zone on the water balance

In order to ~~analyse~~analyze the impact of the ~~PLUZ~~ungauged streamflow on the lake water balance ~~of~~ (seen in section 3.4), we calculate the ~~lake-catchment system, we compare~~closing errors based on the ~~consistence of the inflow (or the simulated outflow)~~equation 2 and ~~outflow in two cases. In one case, the inflow (or the simulated outflow) incorporated the streamflow produced by the PLUZ; in the other case, the inflow neglected the~~ 3: ε_{adj} when the ungauged streamflow ~~produced by the PLUZ. Fig. 6, Fig. 7 and Fig. 8 shows the comparison in yearly, monthly and daily scales, respectively.~~

~~In Fig. 6, PBIAS between the Observed and the Estimated~~ is ~~19.13%; PBISA between the Observed and the Adjusted Estimation1 is 7.94%. The discrepancy between the Observed and the Estimated is narrower than that between the Observed and the Adjusted Estimation1. The Estimated represent the total streamflow of the seven gauging stations, and the Adjusted Estimation1 represent the summation of streamflow in the PLUZ and total streamflow of the seven gauging stations. PBIAS is decreased and the discrepancy is narrowed, when streamflow in the PLUZ neglected. The result suggests the streamflow in the PLUZ improves the water balance of inflow and outflow of the lake, in yearly scale.~~

~~In Fig. 7, PBIAS between the Observed and the Estimated is 19.13% while PBISA between the Observed and the Adjusted Estimation1 is 7.94%; the discrepancy between the Observed and the Estimated is narrower than that between the Observed and the Adjusted Estimation1. PBIAS is decreased and the discrepancy is narrowed, when streamflow in the PLUZ neglected. The result suggests the streamflow in the PLUZ improves the water balance of inflow and outflow of the lake, in monthly scale.~~

~~However, in monthly scale R^2 is decreased from 0.74 when streamflow in the PLUZ is neglected to 0.72 when streamflow in the PLUZ is taken into account. That seem to get a worse relationship between the inflow and the outflow when the PLUZ is taken into account. The result arise from the water storage and flood regulation function of the Poyang Lake in daily scale. So we built hydrodynamic model for the lake, considering the lake function of water storage and flood regulation. The result was shown in Fig. 8.~~

~~In Fig.8, PBIAS between the Observed and the Estimated is 19.13% while PBISA between the Observed and the Adjusted Estimation2 is 7.94%; R^2 between the Observed and the Estimated is 19.13% while R^2 between the Observed and the Adjusted Estimation2 is 7.94%; the discrepancy between the Observed and the Estimated is narrower than that between the Observed~~

~~and the Adjusted Estimation2 in most period. The Adjusted Estimation2 represent the prediction result from the hydrodynamic model in~~ considered (Adjusted Scenario~~. The PBIAS is decreased, R^2 is increased~~) and ~~the discrepancy is narrowed~~ε_{org} when the ungauged streamflow is omitted (Original Scenario), in ~~the PLUZ was considered. And~~Fig. 9. As shown in Fig. 9, for ~~Adjusted Estimation2 when~~most months (nearly 83%), the absolute value of ε_{adj} is smaller than that of ε_{org}, which can demonstrate the ungauged streamflow ~~in the PLUZ is considered, the blocking effects of Yangtze River are reproduced reasonably. In summary, the streamflow in the PLUZ improve the~~ improves the lake water balance ~~of the lake obviously.~~.

However, there are some exceptional dot pairs colored in red (outlier, only 17%) in Fig. 9. For the exceptional, the absolute ε_{adj} is not less than the absolute ε_{org} as the above. All the exceptional almost concentrates in the high flow period from July to October (Fig. 9). That is an unstable stage when backward flow from Yangtze River usually appears and the water level of Yangtze River usually keeps high (David et al. 2006), which can result in high dynamical changed flow. Thus, more uncertainties would be added to the measured data and the hydrodynamic model during unstable season (July to October) compared to the stable season (January to June, December to November). High dynamic changed flow may cause the streamflow overestimated randomly. High water level of Yangtze River also can leads to overestimated streamflow at Hukou, compared to the conditions in normal water level. What's more, frequent water abstraction for irrigation from July to October can also strength the overestimation situation. The accumulative estimation can even lead the closing error less than zero between July and October (Fig. 9), which is opposite to that the closing error should be more than zero described in section 3.4. The evidence suggests that the hydrodynamic model is not accuracy enough to simulate the streamflow during the unstable season. During the time, the added input component could make the ever overestimated streamflow larger. Thus, the closing error will be extended. That's why when ε_{org} is less than zero, the ε_{adj} will be more less than zero (the red dot pairs in Fig. 9). The evidence just demonstrates that the hydrodynamic model is not accuracy enough to simulate the lake input components during the unstable season from July to October. It doesn't deny the role of ungauged simulated streamflow in improving the lake water balance.

The ungauged streamflow decreases the annual average closing error of water balance by 13.48 billion m^3/a (10.10% of the total annual water resource) from 30.20 ± 9.1 billion m^3/a (20.10% of the total annual water resource) to 16.72 ± 8.53 billion m^3/a (10.00% of the total annual water resource) for 2001-2010. The evidence also suggests the ungauged simulated streamflow is reasonable.

5 Conclusions

~~Method~~A method coupling hydrology and ~~hydrodynamic~~hydrodynamics can be used to simulate and verify ~~stream flows~~streamflow in ungauged zones, solving the simulation and verification ~~problem~~problems caused by ~~no~~ the unavailability of streamflow observations.

~~Ungauged zones lacks stream flow observations for calibration and verification for stream flow simulation. The couple hydrological models for the water body of ungauged zones, can verify the stream flow simulation result of ungauged zones using stream flow observations at the lower boundary of the water body. Due to the verification, the method can demonstrate the reliable of stream flow simulation result of ungauged zone. In the study, discrepancy between the observed and the simulated stream flows of the hydrodynamic model when the ungauged zones was taken into consideration, is narrower than that when the ungauged zones was ignored. The result suggests that the stream flow simulation of the ungauged zone is reliable, verifying the simulation result furtherly.~~

The hydrological and hydrodynamic models are coupled ~~seamless~~seamlessly in both space and time. The method of coupling the models ~~in detail~~ was presented in detail for the first ~~try. Sub-basins in the ungauged zones and the gauged zones must be coupled in space. Inflow to the water body is sum of stream flow from the gauged and ungauged zone in daily scale. The method is~~time and was applied in the case study successfully. Using ~~the~~this method, we estimated that the ungauged zone of Poyang Lake produces ~~stream flows~~a streamflow of approximately ~~180~~16.4 billion m^3~~;~~, representing ~~about~~approximately 11.4% of the total inflow from the entire watershed. ~~We also analysed the impact of the stream flows in~~The ungauged ~~zone on~~streamflow significantly improves the water balance ~~between inflow and outflow of the lake. These results, incorporating the estimated stream flow in ungauged zone, significantly improved the water balance as indicated by R^2~~ with ~~higher value and percent bias with lower value, as compared to the results when the stream flows in the ungauged zone were not taken into account, R^2 with lower value and percent bias with higher value.~~the closing error decreased by 13.48 billion m^3/a (10.10% if the total annual water resource) from 30.20 billion m^3/a (20.10% of the total annual water resource) to 16.72 billion m^3/a (10.00% of the total annual water resource).

The method can be extended to other lake, river, or ocean basins where ~~stream flow~~streamflow observation data ~~is~~are unavailable, ~~thus~~ producing ~~relatively accurate stream flow~~reasonable streamflow simulation results in ungauged zones. Reliable ~~stream flow~~streamflow simulation results in ungauged zones contribute to more accurate and reliable water yield predictions, ~~water balance analysis and floods-droughts predictions. The reliable prediction and analysis provide~~which provides a deep understanding of hydrology for hydrological engineers and scientists~~,~~ and helps ~~a~~governments develop better ~~plan making of~~ water management ~~for governments. Furtherly, as~~plans. Furthermore, this method is an area of interest of Prediction in Ungauged Basins~~, stream flow~~ (PUB) and provides streamflow prediction and validation aids in PUB research.

Data availability

All data can be accessed as described in Sect. 2.2.

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Tables

Table 1. ~~Quantitative Assessment of Calibration and Validation for SWAT Model~~The upstream boundary conditions of the Delft3D model in the Original and Adjusted Scenarios. Od1, Od2, Od3, Od4, Od5, Od6, Od7, Od8, and Od9 represent the streamflow set at *d1*, *d2*, *d3*, *d4*, *d5*, *d6*, *d7*, *d8* and *d9*, respectively, in the Original Scenario. Ad1, Ad2, Ad3, Ad4, Ad5, Ad6, Ad7, Ad8, Ad9, Ad10, and Ad11 represent the streamflow set at *d1*, *d2*, *d3*, *d4*, *d5*, *d6*, *d7*, *d8* , *d9*, *d10*, and *d11*, respectively, in the Adjusted Scenario. *B1*, *b2*…and *b13* represent the subbasins in the PLUZ (Fig. 2(b)). $Q_{gau,di}$ and $Q_{ungau,di}$ represent the gauged and ungauged streamflow gathering to the point of *di*, respectively. $Q_{ungau,di}$ will be calculated in the model linking section (seen table 2).

~~Gauging Station~~Scenarios	~~Index~~Inflow Points	~~Model Calibration (Jan.2000 - Dec.2005)~~Streamflow set at different points	~~Model Validation (Jan.2006- Dec.2011)~~

Original Scenario	*d1*	~~R^2~~Od1: the observed streamflow at the Qiujin station ($Q_{gau,d1}$)	~~Ens~~	~~PBIAS(%)~~	~~R^2~~	~~Ens~~	~~PBIAS(%)~~
	d2	Od2: 50% of the observed streamflow at the Wanjiabu station ($Q_{gau,d2}$)					
	d3	Od3: 10% of the observed streamflow at the Wanjiabu station ($Q_{gau,d3}$)					
	d4	Od4: 20% of the observed streamflow at the Wanjiabu station ($Q_{gau,d4}$)					
	d5	Od5: 20% of the observed streamflow at the Wanjiabu station ($Q_{gau,d5}$)					
	d6	Od6: the observed streamflow at the Lijiadu station ($Q_{gau,d6}$)					
	d7	Od7: the observed streamflow at the Meigang station ($Q_{gau,d7}$)					
	d8	Od8: the observed streamflow at the Hushan station ($Q_{gau,d8}$)					
	d9	Od9: the observed streamflow at the Dufengkeng station ($Q_{gau,d9}$)					
Adjusted Scenario	*d1*	Ad1: the summation of $Q_{ungau,d1}$ and $Q_{gau,d1}$					
	d2	Ad2: the summation of $Q_{ungau,d2}$ and $Q_{gau,d2}$					
	d3	Ad3: the summation of $Q_{ungau,d3}$ and $Q_{gau,d3}$					
	d4	Ad4: the summation of $Q_{ungau,d4}$ and $Q_{gau,d4}$					
	d5	Ad5: the summation of $Q_{ungau,d5}$ and $Q_{gau,d5}$					
	d6	Ad6: the summation of $Q_{ungau,d6}$ and $Q_{gau,d6}$					
	d7	Ad7: the summation of $Q_{ungau,d7}$ and $Q_{gau,d7}$					
	d8	Ad8: the summation of $Q_{ungau,d8}$ and $Q_{gau,d8}$					
	d9	Ad9: the summation of $Q_{ungau,d9}$ and $Q_{gau,d9}$					
	d10	Ad10: $Q_{ungau,d10}$					
	d11	Ad11: $Q_{ungau,d11}$					

Table 2. The ungauged streamflow allocated to the lake inflow points of the dynamic model in the Adjusted Scenario. $Q_{ungau,di}$ represent the ungauged streamflow gathering to the inflow point of di. d1, d2, d3… d11 are the inflow points in the Delft3D model and the outlets in the SWAT model (Fig. 1(b) and Fig. 3). b1, b2, b3…b11 are the subbasins in the PLUZ (Fig. 3(b)). $Q_{swat,di}$ represent the simulated discharges at the outlet (di) from the SWAT model. $Q_{swat,Qiujin}$, $Q_{swat,Wanjiabu}$, $Q_{swat,Waizhou}$, $Q_{swat,Lijiadu}$, $Q_{swat,Meigang}$, $Q_{swat,Hushan}$, and $Q_{swat,Dufengkeng}$ represent the simulated discharges at the outlets of Qiujin, Waizhou, Lijiadu, Meigang, Hushan and Dufengkeng respectively, from the SWAT model.

the lake inflow point (d_i)	the subbasins draining to d_i	the ungauged streamflow gathering to di
d1	b12, b13 and b14	$Q_{ungau,d1}$: $Q_{swat,d1}$- $Q_{swat,Qiujin}$- $Q_{swat,Wanjiabu}$
d2	b11	$Q_{ungau,d2}$: $Q_{swat,d2}$- 50%*$Q_{swat,Waizhou}$
d3	b10	$Q_{ungau,d3}$: $Q_{swat,d3}$- 10%*$Q_{swat,Waizhou}$
d4	b9	$Q_{ungau,d4}$: $Q_{swat,d4}$- 20%*$Q_{swat,Waizhou}$
d5	b8	$Q_{ungau,d5}$: $Q_{swat,d5}$- 20%*$Q_{swat,Waizhou}$
d6	b7	$Q_{ungau,d6}$: $Q_{swat,d6}$- $Q_{swat,Lijiadu}$
d7	b6	$Q_{ungau,d7}$: $Q_{swat,d7}$- $Q_{swat,Meigang}$
d8	b4 and b5	$Q_{ungau,d8}$: $Q_{swat,d8}$- $Q_{swat,Hushan}$
d9	b3	$Q_{ungau,d9}$: $Q_{swat,d9}$- $Q_{swat,Dufengkeng}$
d10	b2	$Q_{ungau,d10}$: $Q_{swat,d10}$
d11	b1	$Q_{ungau,d11}$: $Q_{swat,d11}$
total	b1, b2, b3, b4, b5, b6, b7, b8, b9, b10, b11	$Q_{ungau,total}$: ($Q_{swat,d1}$+$Q_{swat,d2}$+$Q_{swat,d3}$+$Q_{swat,d4}$+$Q_{swat,d5}$

		$+Q_{swat,d6}+Q_{swat,d7}+Q_{swat,d8}+Q_{swat,d9}+Q_{swat,d10}+Q_{swat,d11})-(Q_{swat,Qiujin}+Q_{swat,Wanjiabu}+Q_{swat,Waizhou}+Q_{swat,Lijiadu}+Q_{swat,Meigang}+Q_{swat,Hushan}+Q_{swat,Dufengkeng})$

Table 3. Quantitative Assessment of Calibration and Validation for SWAT Model.

Gauging Station	Index	Model Calibration (2000-2005)			Model Validation (2006-2011)		
		R^2	Ens	PBIAS (%)	R^2	Ens	PBIAS (%)
Wanjiabu	monthly discharge	0.63	0.61	-0.2	0.78	0.76	9.4
Waizhou	monthly discharge	0.94	0.93	3.2	0.95	0.93	6.5
Lijiadu	monthly discharge	0.84	0.82	-9.4	0.88	0.85	-16.8
Meigang	monthly discharge	0.89	0.89	1.1	0.91	0.90	10.0
Hushan	monthly discharge	0.81	0.78	14.2	0.76	0.75	13.9
Dufengkeng	monthly discharge	0.80	0.80	-4.7	0.83	0.80	9.4

Table ~~2~~4. Quantitative assessment of calibration and validation for streamflow simulation for the Delft3D model.

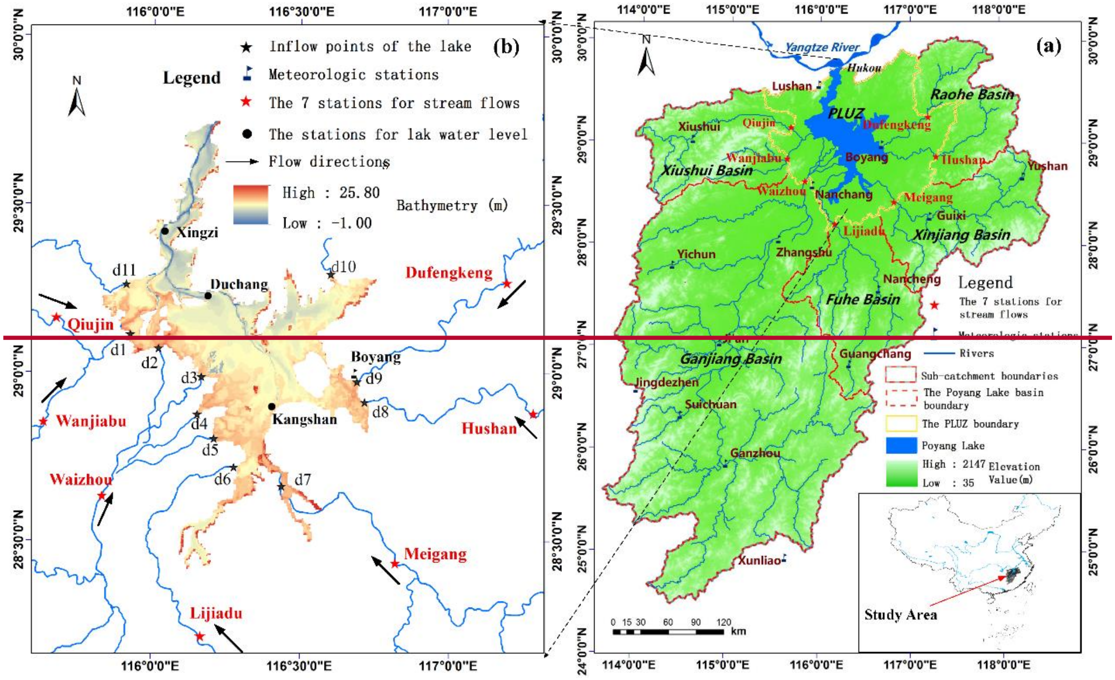
Gauging Station	Index	Original Scenario						Adjusted Scenario	
~~Gauging Station~~	~~Index~~	Calibration (~~Jan.~~2001-~~Dec.~~2005)		Validation (~~Jan.~~2006-~~Dec.~~2010)		All (2001-2010)		All (2001-2010)	
		R^2	PBIAS (%)	R^2	PBIAS (%)	R^2	PBIAS (%)	R^2	PBIAS (%)
Xingzi	Lake water level	0.99	1.~~20~~2	0.99	0.45	0.99	0.85	0.99	0.48
Duchang	Lake water level	0.97	4.74	0.99	2.78	0.97	3.18	0.97	2.67
Kangshan	Lake water level	0.85	2.86	0.88	1.72	0.86	1.56	0.86	1.21
Hukou	Lake outflow discharge	0.75	19.46	0.80	21.47	0.77	20.10	0.81	10.00

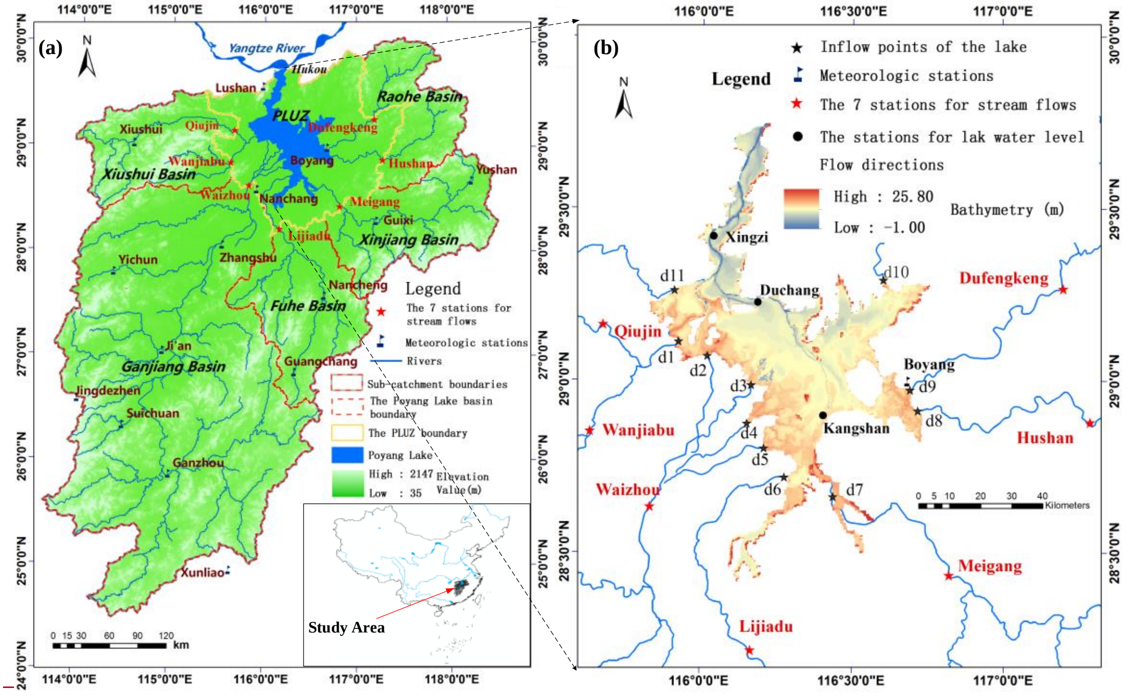
~~Table 3. Annual water yields produced by the PLUZ (Q_{PLUA}) from 2000 to 2009. The table includes the whole Poyang Lake catchment (Q_{whole}), and the ratio between Q_{PLUA} and Q_{whole}.~~

~~Year~~	~~Q_{PLUA}($10^8 m^3$)~~	~~Q_{whole}($10^8 m^3$)~~	~~Q_{PLUA}/Q_{whole}(%)~~
~~2000~~	~~157.18~~	~~1421.28~~	~~11.06%~~

~~2001~~	~~141.74~~	~~1477.88~~	~~9.59%~~
~~2002~~	~~216.10~~	~~1856.29~~	~~11.64%~~
~~2003~~	~~220.90~~	~~1404.69~~	~~15.73%~~
~~2004~~	~~113.95~~	~~921.54~~	~~12.36%~~
~~2005~~	~~187.83~~	~~1471.95~~	~~12.76%~~
~~2006~~	~~155.76~~	~~1560.27~~	~~9.98%~~
~~2007~~	~~72.41~~	~~1012.19~~	~~7.15%~~
~~2008~~	~~133.71~~	~~1291.85~~	~~10.35%~~
~~2009~~	~~115.70~~	~~1057.66~~	~~10.94%~~
~~The Average~~	~~151.53~~	~~1347.56~~	~~11.24%~~

Figures





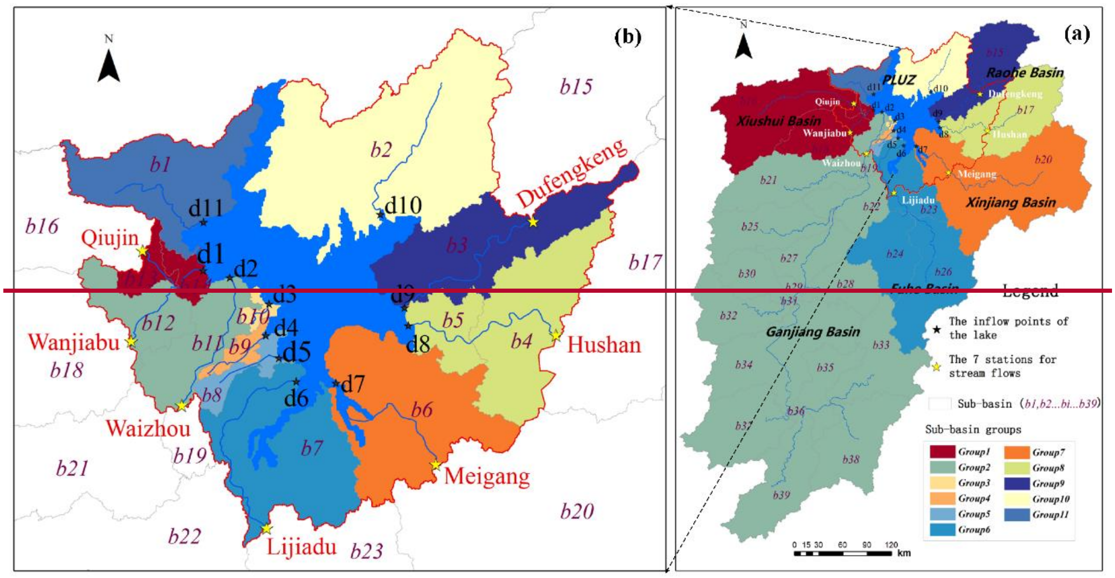


Figure 1. Study area and the related data. (a) The location of the Poyang Lake watershed ~~location~~, PLUZ ~~location~~, five major river ~~system~~sub-catchments, meteorological stations, and hydrological stations; (b) ~~Lake~~ location of the lake, inflow points ~~location, hydrologic stations for lake~~, and water level~~.~~ stations.

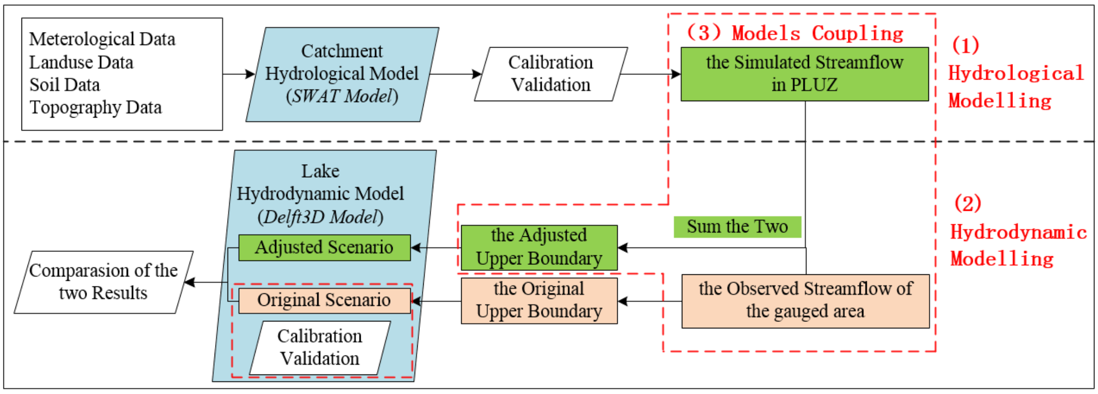


Figure 2. Conceptual flow chart for streamflow simulation and verification in ungauged zones by coupling hydrological and hydrodynamic models. The flow chart includes three parts: Hydrological modelling, Hydrodynamic modelling, Models Coupling.

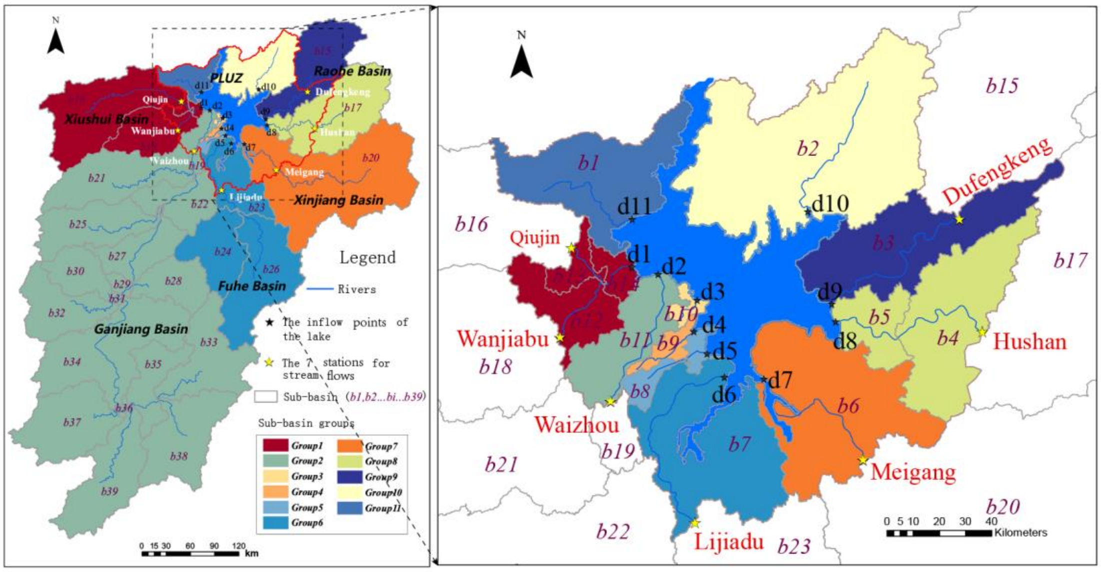
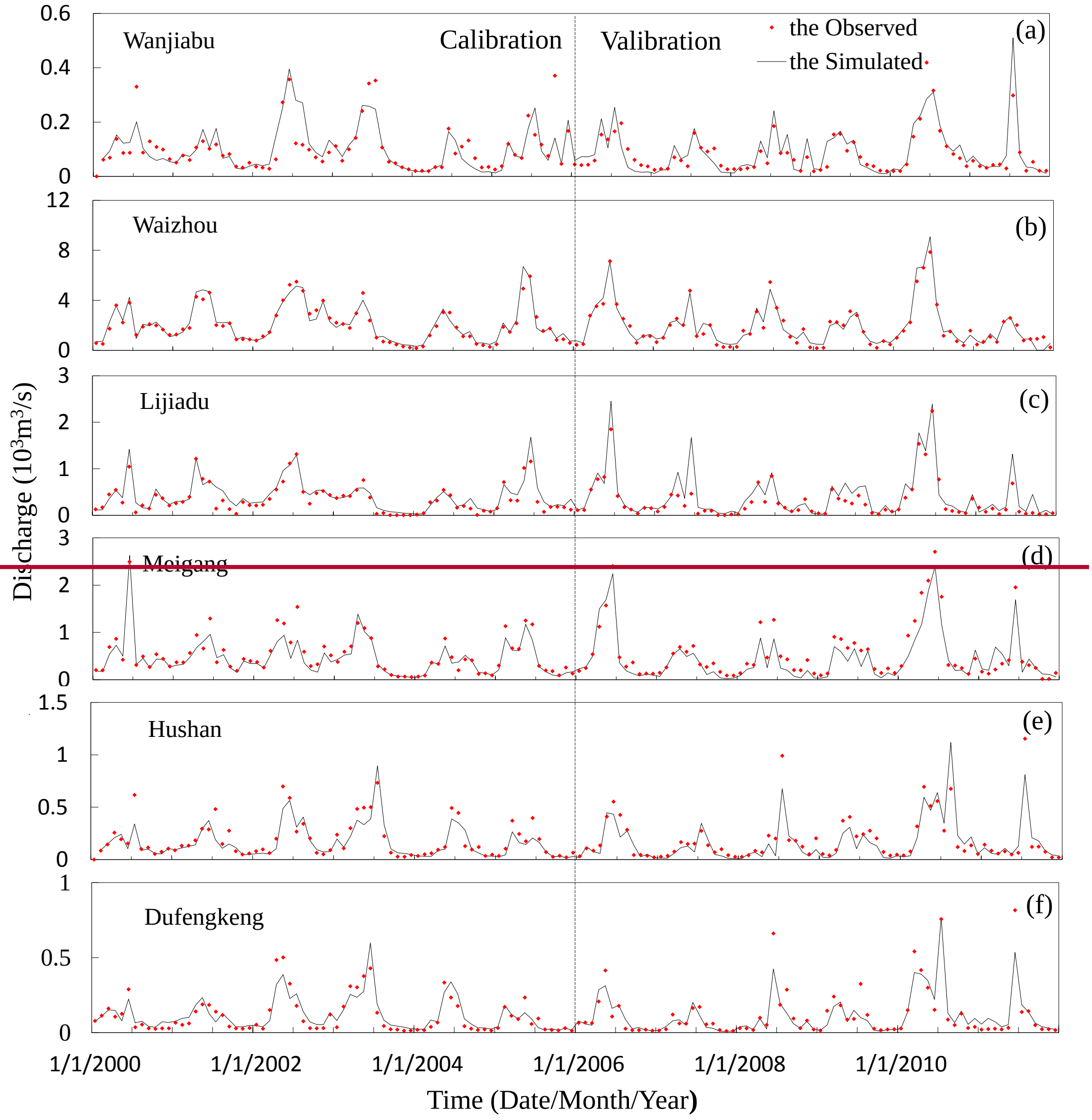


Figure 3. The abridged general view ~~of the~~ coupling ~~between~~ the catchment ~~model~~ and lake ~~model.~~models in space: (a) ~~and (b) shows the sub-~~streamflow partition scheme from the whole basin ~~groups. The streamflow produced by the~~ to the inflow points ($d_1, d_2...d_i...d_9$) of the lake; (b) streamflow partition scheme from the PLUZ to the inflow points ($d_1, d_2...d_i...d_{11}$) of the lake. The sub-basins in the same group ($group_i$~~) flow into~~ colored the same) drains to the same inflow point (d_i) of the lake. Specially, in the model, 50%, 30%, 10%, 10% of the streamflow from sub-basins in Ganjiang sub-catchment was ~~defined~~set to ~~discharges~~flow into ~~inflow~~the lake at points d_2, d_3, d_4, and d_5~~, d_6, d_7~~ respectively.


Wanjiabu
Calibration
Valibration
the Observed
the Simulated
(a)
Waizhou
(b)
Lijiadu
(c)
Meigang
(d)
Hushan
(e)
Dufengkeng
(f)
Discharge ($10^3m^3/s$)
1/1/2000
1/1/2002
1/1/2004
1/1/2006
1/1/2008
1/1/2010
Time (Date/Month/Year)

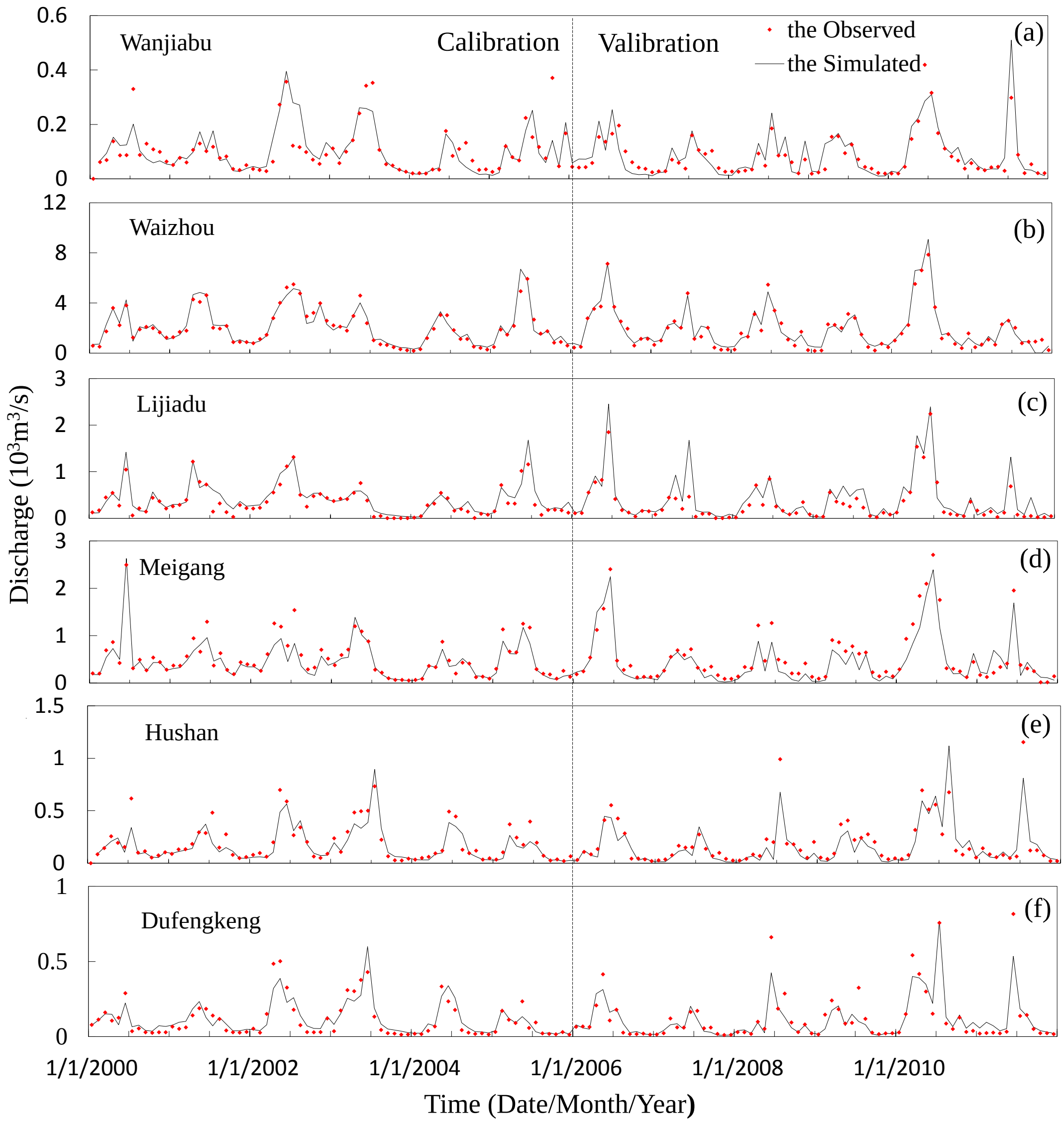
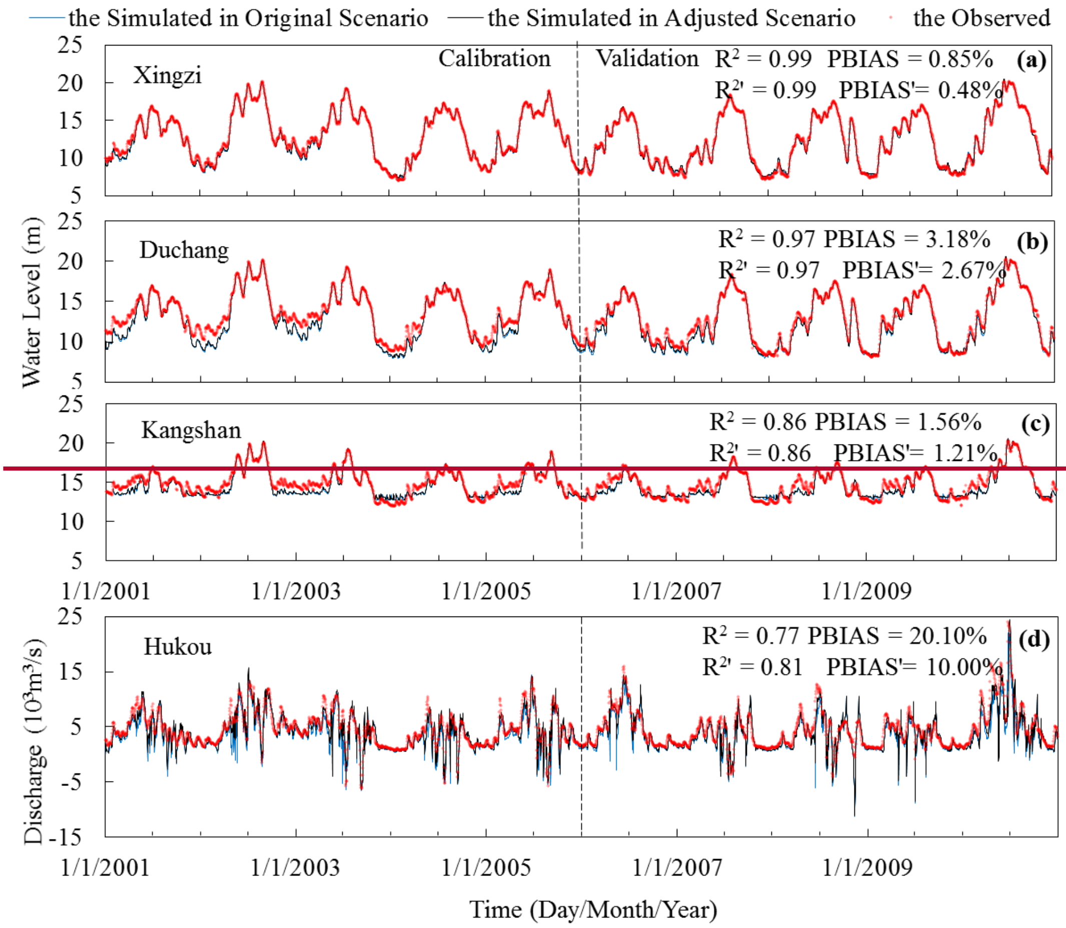


Figure ~~3~~4.

Comparison of ~~the observed~~observations and the simulated results by the SWAT Model for calibration (2000-2005) and validation (2006-2011). Subfigures (a), (b), (c), (d), (e) and (f) are the calibration and validation results for stations at Wanjiabu, Waizhou, Lijiadu, Meigang, Hushan, and Dufengkeng, respectively.


the Simulated in Original Scenario
the Simulated in Adjusted Scenario
the Observed
Calibration
Validation
Xingzi
R² = 0.99 PBIAS = 0.85% (a)
R²' = 0.99 PBIAS'= 0.48%
Duchang
R² = 0.97 PBIAS = 3.18% (b)
R²' = 0.97 PBIAS'= 2.67%
Kangshan
R² = 0.86 PBIAS = 1.56% (c)
R²' = 0.86 PBIAS'= 1.21%
Hukou
R² = 0.77 PBIAS = 20.10% (d)
R²' = 0.81 PBIAS'= 10.00%
Water Level (m)
Discharge (10³m³/s)
1/1/2001
1/1/2003
1/1/2005
1/1/2007
1/1/2009
Time (Day/Month/Year)

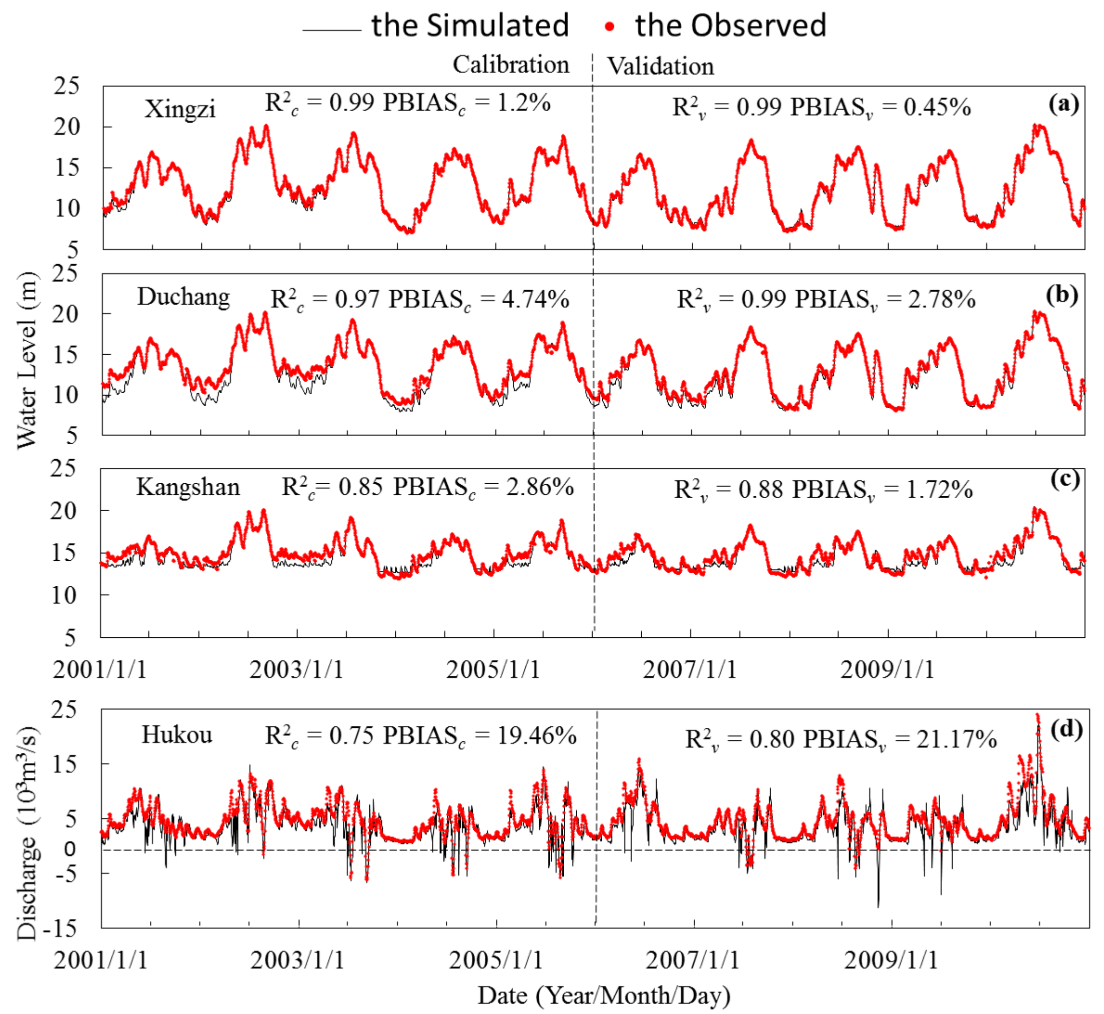
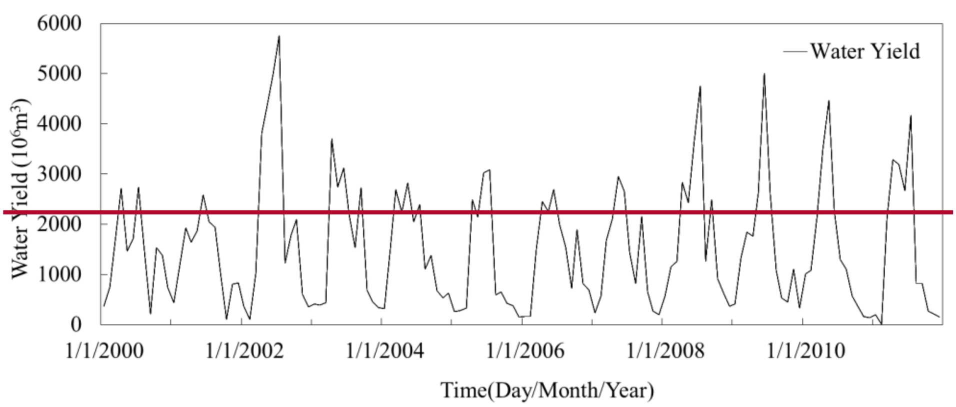
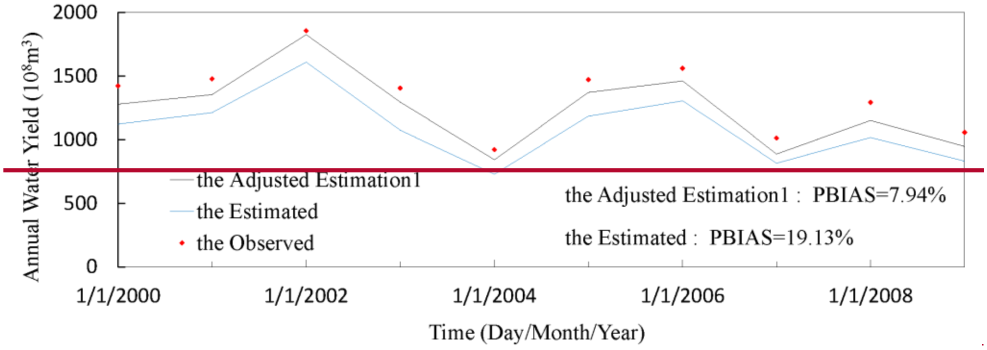


Figure ~~4~~5. Comparison of the observed (red dotted line) and simulated (black solid line ~~for the result in Adjusted Scenario, blue solid line for the result in Original Scenario~~) lake water level at Xingzi, Duchang, and Kangshan ~~station,~~stations and ~~lake~~ outflow discharges at Hukou ~~station~~ by the Delft3D Model. ~~For the Original Scenario, the~~The calibration period and validation period ~~is~~are from 2001 to 2005, 2006 to 2010, respectively. ~~R^2 and PBIAS, R^{2}', and PBIAS' is the prediction result of Delft3D model in Original Scenario and~~ R^2_c, $PBIAS_c$ and R^2_v, $PBIAS_v$ are the calibaration (from 2001-2005) and validation (from 2001-2005) results~~Adjusted Scenario~~, respectively.



~~Figure 5. Monthly water yield in the PLUZ from 2000 to 2010.~~



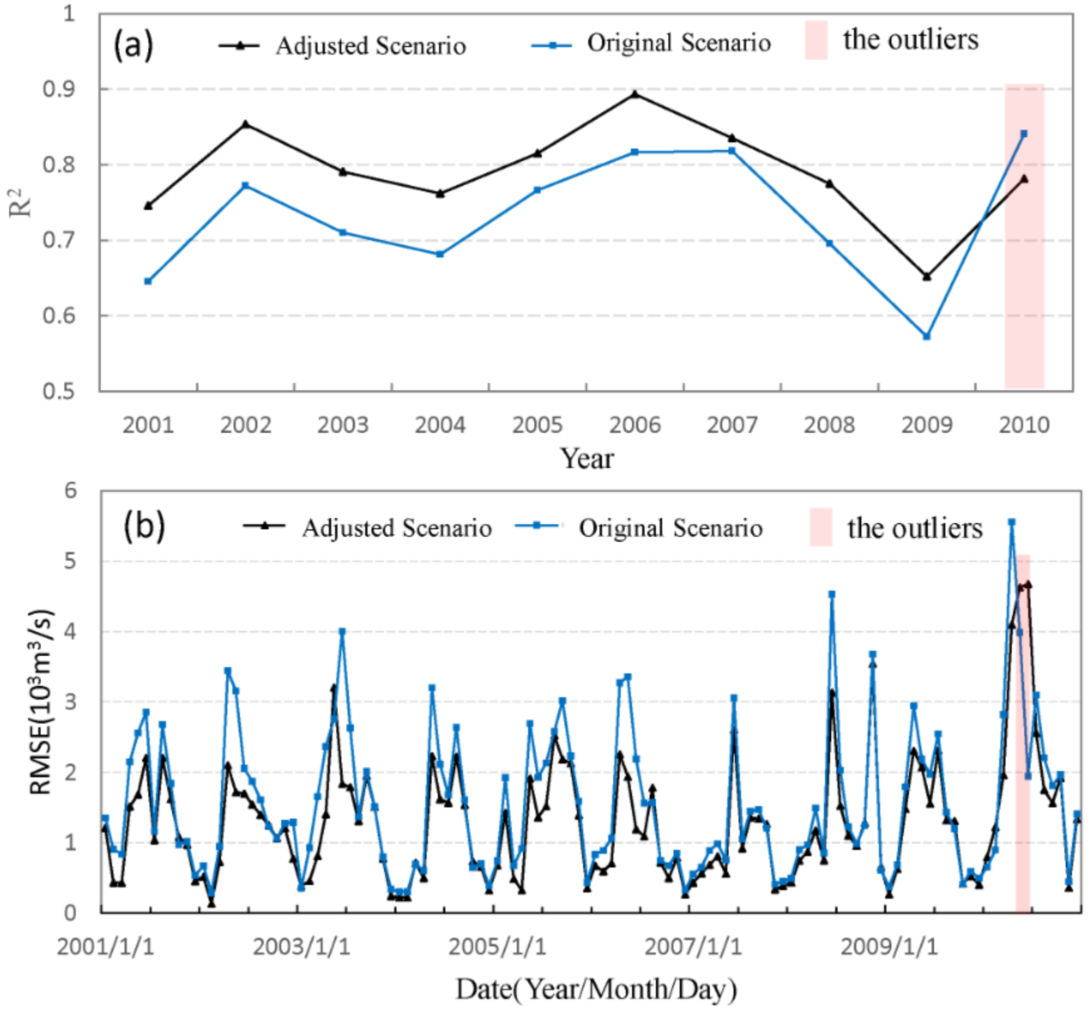


Figure 6. Comparison of the ~~simulated inflow (solid line) and the observed outflow (dotted line) at Hukou gauging station~~streamflow simulated results at Hukou, in Adjusted Scenario and Original Scenario. The outlier is the data which may affected by the dike burst in 2010.

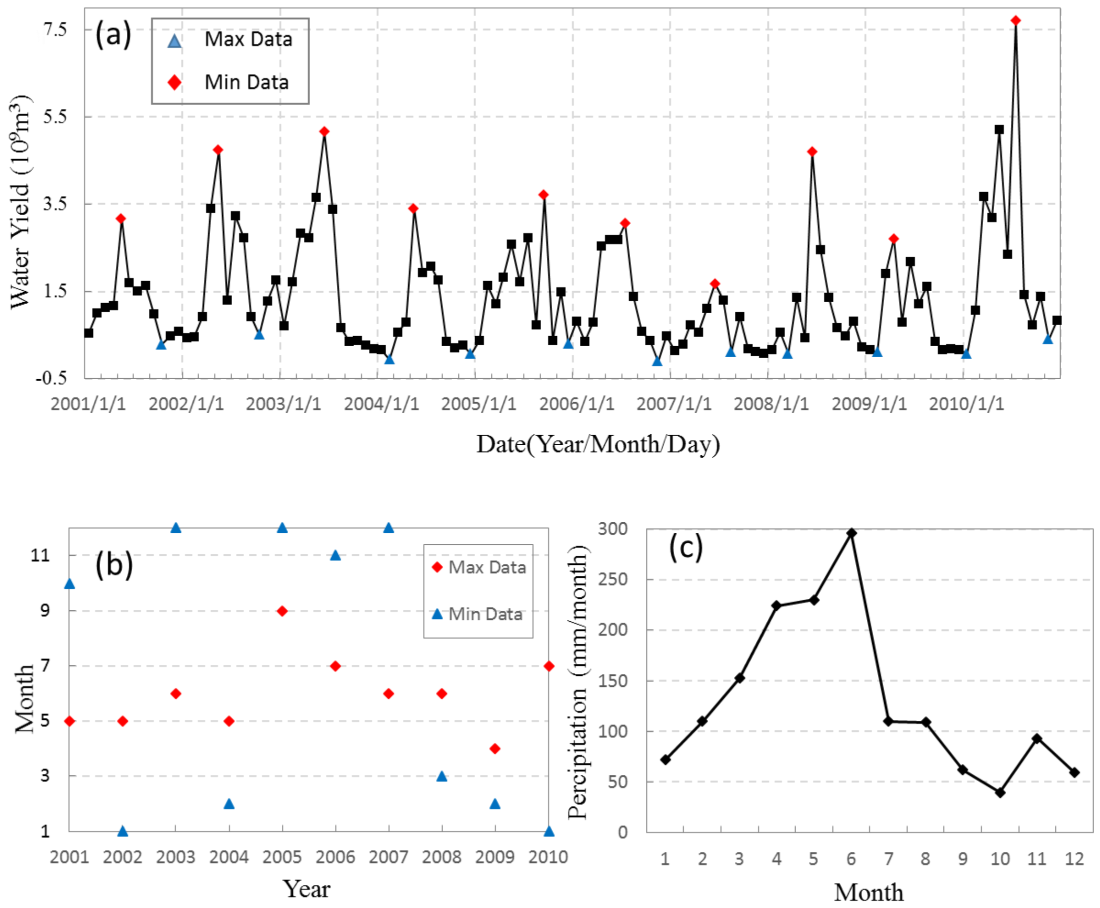


Figure 7. (a)The monthly mean water yield for each month from January 2001 to December 2010 produced by the PLUZ; (b)Maximum and minimum water yield month distributed from ~~2000 to 2009~~2001to 2010; (c) The mean monthly precipitation from 2001 to 2010 at ~~monthly scale, where the Estimated~~Nanchang meteorological station derived from China's meteorological nets. Max Data and Min Data represent the ~~total streamflow of the seven gauging stations, and the Adjusted Estimation1 represent~~monthly maximum water yield and monthly minimum water yield in the particular year respectively.

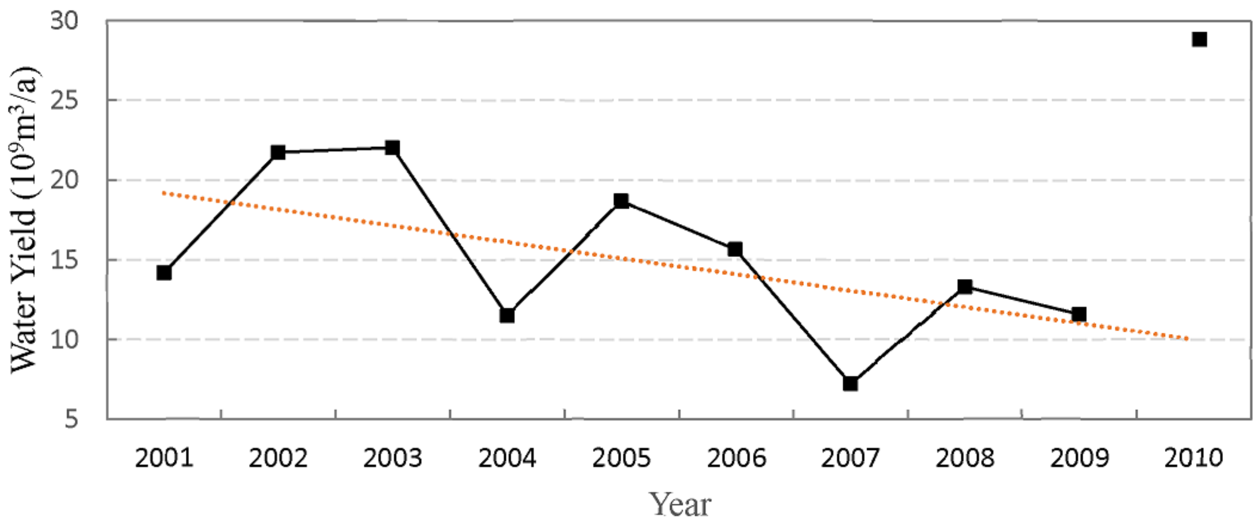


Figure 8. The variation trend of the annual water yield from 2001 to 2009. It shows declining trend at an rate -1.02 of billion m3/a ($P < 0.05$).

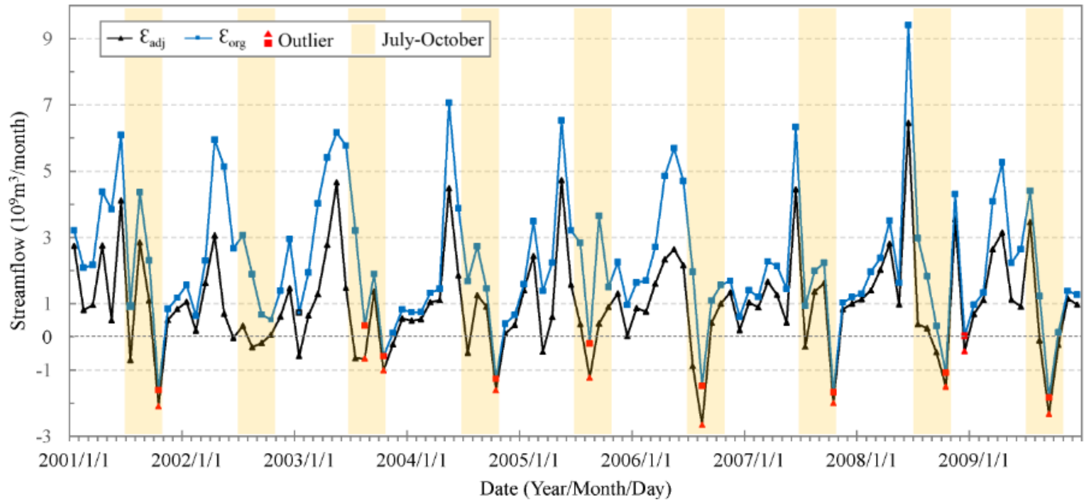
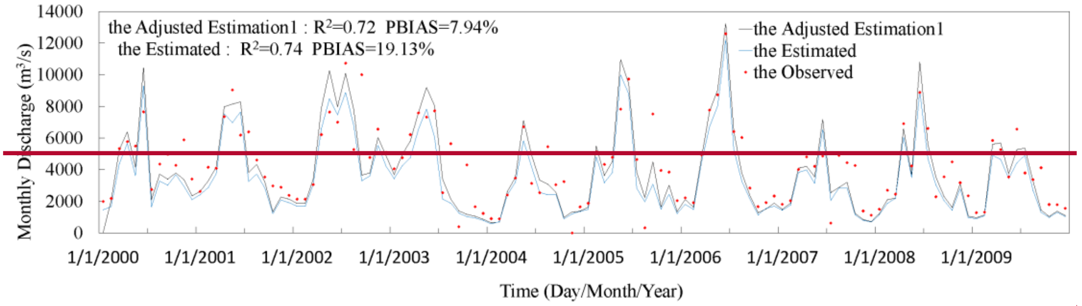
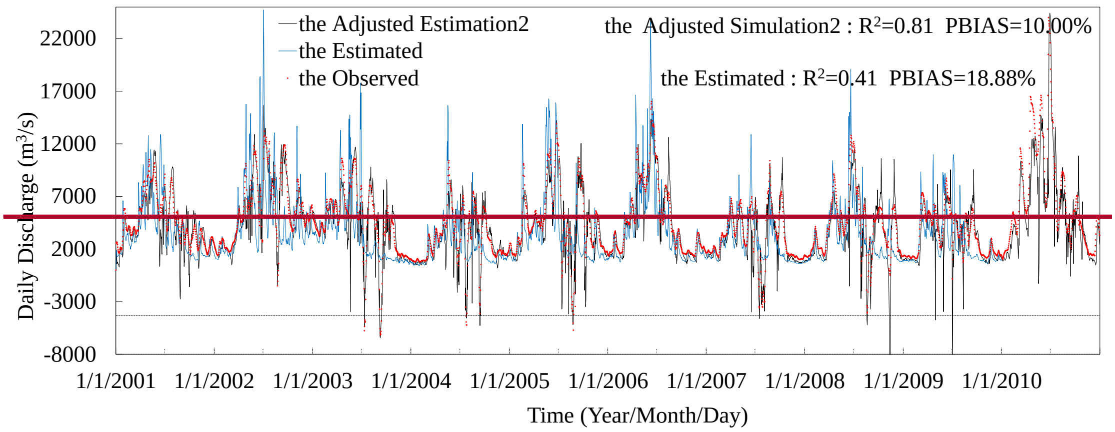


Figure 9. Closing errors of lake water balance: $\mathcal{E}_{org}$ and $\mathcal{E}_{adj}$. $\mathcal{E}_{org}$ is the ~~summation of~~ closing error when the ungauged streamflow ~~in the PLUZ and total~~is considered and $\mathcal{E}_{adj}$ is the closing error when the ungauged streamflow ~~of the seven gauging stations. PBIAS presents the percent bias between~~is omitted. Outliers are the ~~Observed and the Estimated (or the Adjusted Estimation1).~~point pairs, of which the $\mathcal{E}_{org}$ is samll than $\mathcal{E}_{adj}$, expected abnormal.



~~Figure 7. Comparison of the simulated inflow (solid line) and the outflow (dotted line) at Hukou gauging station from 2000 to 2009 at daily scale, where the Estimated represent the total streamflow of the seven gauging stations, and the Adjusted Estimation1 represent the summation of streamflow in the PLUZ and total streamflow of the seven gauging stations. PBIAS presents the percent bias between the Observed and the Estimated (or the Adjusted Estimation1).~~ ~~R^2 presents the determinated coefficient between the Observed and the Estimated (or the Adjusted Estimation1).~~



~~Figure 8. Comparison between the observed (dotted line) and the simulated (solid line) lake outflow discharge at Hukou, where the Estimated represent the total streamflow of the seven gauging stations, and the Adjusted Estimation2 represent the prediction result from the hydrodynamic model in Adjusted Scenario. PBIAS presents the percent bias between the Observed and the Estimated (or the Adjusted Estimation2). R^2 presents the determinate coefficient between the Observed and the Estimated (or the Adjusted Estimation2).~~