

## **General thanks:**

We very much appreciate the general attention given to our manuscript and the constructive remarks of all reviewers and try to answer them here. Special Thanks to Referee #3, who gave very detailed comments and essentially contributed to improve the text.

## **General remark:**

Changes concerning Referee comments are marked **YELLOW** in the marked-up-version, all other changes are marked in **GREEN**!

A mistake in writing is corrected in Fig. 3.

## **Reply to Anonymous Referee #1**

1. R#1: "Introduction. The authors give the aim and hypothesis, but it would be remarkable to clearly address the main goals/objectives."

A: Thank you very much for a very constructive remark. Indeed, we clearly defined the aim or the goal of our study – to show that using both literature and locally measured values of parameters "LAI", "Rsc" and "leaf unfolding date" introduces the uncertainty in hydrological modelling, and to quantify these uncertainties. The objectives were also formulated, but definitely not clearly enough. Therefore, we will complement the Introduction and formulate the objectives inserting following sentence after hypothesis:

"In our study the following objectives should be met: 1) to quantify the WaSim response (sensitivity) to variations of following parameters: LAI, Rsc and leaf unfolding date, caused by different measurement methods and modelling approaches; 2) to estimate the most sensitive parameter and 3) to evaluate quantitatively whether it is advisable to implement the locally point-measured values of sensitive parameters directly. We used GWR and plant available water as indicators. **[included in introduction]**"

2. R#1: "Discussion. This section could be improved whether the authors discussed their results regarding other studies conducted in similar/different environments and conditions."

A: To our knowledge there are no comparable studies. Of course there are investigations of the water budget of SRC, but most studies do not present the precise parameterization. Furthermore, other studies used different models, mostly plot-model approaches like SWAT or BROOK90 that have different sensitivities. We used the regional model approach WaSim on a plot model domain here, because we use the model and parameterization for catchment analyses in other related studies (not shown here). The comparison of different models applied at different locations (different soils and climate) is definitely out of scope of our study and the discussions on comparability of results would considerably expand the size of the manuscript. Of course we could compare hydrological quantities of SRC like evapotranspiration or percolation rates, but such quantities are related to the local conditions. We decided to evaluate our model's sensitivity using local soil water measurements. The comparison to other studies would be interesting for further investigations on the catchment level. Thus we would like to focus our study on WaSim sensitivity to different parameterizations and avoid the comparison to different models and locations. We are aware that the effects we are showing and discussing in this paper are relevant to WaSim based studies and should be considered with care for other hydrological models and environments.

**[no change]**

3. R#1: "Conclusions. This section is quite long in my opinion. Please, be more concise and follow the scheme i) ii) iii) giving answer to the study goals."

A: In the conclusions we showed the complexity of the topic and gave the answer to the aims and objectives. Generally the numbered conclusions are not the common practice, however to be more concise and to correspond to the main aim of study as well as to newly formulated objectives (Remark 1): we will add following sentences like:

L16; "Sources of model parameters for the vegetation cover are local measurements or scientific literature. The analysis shows simulation uncertainties evolving from the use of model parameters that are derived from i) non-local measurements or ii) some appropriate literature values."

Thus, we reached the main goal of our study and demonstrated the uncertainties in modelling results caused by variations in modelling parameters.

Changes answering the objectives according to the introduction are implemented.

"Answering objective 1..."

"Answering objective 2: in our study LU was the most sensitive parameter by analysing GWR, especially when inter annual variations and hydrological extreme conditions are of interest."

**[changed according to numbered objectives in the introduction]**

## Reply to Anonymous Referee #2

1. R#2: "General Comments: The paper titled "How to predict hydrological effects of local land use change: how the vegetation parameterisation for short rotation coppices influences model results" by F. Richter et al. deals with the influences of three different parameters on the results of hydrological models. Specifically authors implemented WaSim hydrological model for their simulations. The paper does not have problems in the structure and English is good. Nevertheless some improvements are needed in the title and in the statement of the aim. The authors refer to Land Use Change with the intention of underlying the importance of their results, but there is not an evaluation of the change, quantifying it for example. But this is not a criticism of the paper itself but it is just a suggestion to help readers in the comprehension of the aim and consequently of the results."

A: Thank you very much for a good comment. We have to state as much in the manuscript and suggest the following addition to introduction: "The overarching aim of our research was the evaluation of land use change effects. However, this study does not focus on land use change effects in any way but rather on the evaluation of a suitable tool." [included in introduction]

2. R#2: "A general improvement has to be given to materials section, improving the description of which data authors have used for their study (the use of data from another sites or species). Authors will find more explanations in the following specific comments. Specific Comments Abstract: I suggest a general revision of the text, the aim has to be clearly stated. Authors declare that they want to test which parameter plays a major role in the general assessment of what? Line 6-10: I suggest a change in this sentence, authors did not apply a hydrological model to assess land use change, as a matter of fact there is no comparison with other crop."

A: We agree about the land use change. We will insert the sentence stating the main aim of the study: "The aim of present study is to assess the effect of parameter uncertainties of the land use type poplar SRC on modelling results". [included in introduction] We would retain the sentence in lines 6-9 as it shows the motivation of the present study.

3. R#2: "Introduction Page 407 Line3 and 5: Please add some references for this statement

A: We will add: DJOMO, S. N., KASMIQUI, O. E. and CEULEMANS, R. (2011), Energy and greenhouse gas balance of bioenergy production from poplar and willow: a review. GCB Bioenergy, 3: 181–197. [reference included p407 I5]

4. R#2: "Line 18: Please state clearly the assessment of what?

A: This clearly refers to previous sentence, i.e. the negative effects on ground water recharge. The repetition is unnecessary in our opinion. [no change]

5. R#2: "Page 408 Line 1 to 28: please be more concise, try to focus more on your research aim this part.

A: We added the formulation of research objectives – see answer to Referee#1 - Comments.

6. R#2: "Materials and methods Pag. 410 line 9 Please can you give more explanations about why you can consider these data in your research, I've seen that a better explanations is given in the Discussion section but I think has to be anticipated here.

A: We agree. We will include the following sentences: "Because the estimation of leaf unfolding (LU), as used in this study is based on meteorological measures, the parameterisation should hold true for the same poplar clone in the same age, if other environmental factors are of minor importance. The results will confirm this." [included p416 l11]

"The IPG-data are used for long term comparison, because there were no long term investigations of leaf unfolding available on the research plots of the BEST project or nearby." [included p416 l14]

7. R#2: "line 9: Please give some references about BEST research project and give an explanation about why you are using data from another site

A: we will include the following sentences about BEST-Project at the beginning of the Materials and methods section, to clearly state which data are out of BEST:

"The site Reiffenhausen was established as part of the interdisciplinary investigations of SRC by the joint integrated project BEST ("Bioenergie-Regionen stärken" - Boosting Bioenergy Regions), which ran from 2010 until 2014 and was funded by the German Ministry of Education and Research (BMBF). The aim of BEST was to develop regionally appropriate concepts and innovative solutions for the production of biomass, with focus on SRC, and to evaluate ecological and economic impacts." [included p410 l7]

8. R#2: "Pag. 415: Line 11: Maybe it is better "according to (2), (3), (4) and (5)".

A: Accepted, we will change the text accordingly. [changed]

9. R#2: "Pag. 416 Line 3 Please introduce the IPG235 (pag 427 line 23)

A: We agree. We will include following explanation: "IPG235" is the acronym of the parameterisation for *Populus tremula* used by Menzel (1997). We decided to retain this acronym to make it comparable to published results, and also because it is an

acronym used in the data provided by the phenological garden network.” [included p416 l14]

10. R#2: “Results Pag 421 Line 7: please revise “2012 –1014”

A: You are right, thanks for the correction! [changed]

11. R#2: “Pag 422: Line 1-5: this seems more a motivation of your work- Maybe it is has to be moved in the Introduction

A: Thank you – we will implement the suggestion. [introduction changed accordingly]

12. R#2: “Pag 425 Line 1-7: please give a better explanation of what you have done. Have you used or not data on so long period?

A: To make it more clearly we will add following explanation in text, after the sentence in Page 425 line 12:

....the Max1 and IPG235 parameter set, respectively. “Results in Fig. 7 show the last two years from the long term simulations 1969-2013, mean values for ETR and GWR for the whole period 1969-2013 are presented in Tab. 5.” [included p425 l12]

13. R#2: “Pag 427 Line 23: This sentence maybe has to be replaced where you mention for the first time IPG235 [changed p416 l14]

A: Yes, this sentence is also an explanation for the goals and objectives of this paper.

14. R#2: “Figure 1, 2, 4, 5 and 6 can you use a better format for x-axis? You can use Jan-Feb ecc. or remove the full stop at the end of the data.”

A: header in Fig.3 is changed: typing error “loacal” to “local” [no change in fig. 1, 2, 4, 5 and 6]

15. R#2: “Technical corrections No technical corrections are needed

### **Reply to Anonymous Referee #3**

1. R#3: "General comments The paper parameterises the hydrological model system WaSim (Schulla and Jasper 2013) using of Leaf Area Index (LAI), stomatal resistance (Rsc) and leaf unfolding (LU) date. Data were collected in a short rotation coppice (SRC) plantation of a poplar clone (Max 1, *Populus nigra* x *P. maximowiczii*) in the 2nd (2012) and 3rd (2013) years of the mono-stem cycle. With the aim to assess the effect of parameterisation uncertainties of poplar SRC land use on modelling results, the hypothesis tested is that the variables measured (LAI, Rsc and LU) fit better than values extracted from literature. The paper is too long and its different sections are not easy to understand. Some paragraphs which are not closely related to the topic could be eliminated (see also Technical corrections). In particular, data on long term phenological estimate of *Populus tremula* could be left out. In fact, due to different microclimate patterns the phenology of adult plants in the forest is not the same as the one of the younger plants of SRC cultivation.

A: We disagree and would like to retain the paragraph. The comparison to the long term phenological estimate of *Populus tremula* is of particular importance. We explained in the paper that phenological data and parameters for poplar Max1 are hard to find. Therefore, for the modelling they are either measured directly on site or taken from literature. In the latter case due to the mentioned scarcity of data for clones like Max1, the parameters sets from similar plants are adopted, e.g. from *Populus tremula* which is well observed, even over long periods and at different sites. Such adoptions are the cause of uncertainty, which we demonstrated by comparing the modelling results with two different parameter sets of these certainly different species (Max1 and *Populus tremula*). As the differences in estimating of leaf unfolding (LU) have to be analysed on longer time scales to show the effects under extreme climate conditions (e.g. early or late spring) we employed the long-term time series from Tharandt, which is the nearest, comparable IPG site.

It is also true that microclimate influences phenology, but for commonly used estimations of LU from temperature sums the meteorological data are seldom taken from direct onsite measurements. More often the data from nearest meteorological stations (installed on short grass/lawn) are used which almost always has definitely different microclimate than the vegetation stand. So, micrometeorological effects are mostly neglected when LU is estimated from temperature sums.

2. R#3: "The main result emerging in this work concerns the exact knowledge on the precise growing period the beginning of which is affected by the species/clone utilized, local environmental parameters and plantation density. SRC cultivation during the first 1-2 years have not yet developed a full canopy closure. This can have

1 a strong effect on local microclimate and on energy fluxes between canopy and  
2 atmosphere and soil and atmosphere.

3 A: It is not quite clear from these statements what should be improved in the  
4 manuscript. It is true – generally the best way would be to use locally measured or  
5 derived parameters for modelling. As we already stated in the manuscript, this is not  
6 always possible, and this is exactly the motivation of present study: to show the  
7 uncertainty of results caused by the use of transferred or even insufficient parameter  
8 sets. The poplar SRC we investigated was 3 years old when LAI and Rsc were  
9 measured. We explained in the paper that this SRC can be seen as hydrologically  
10 fully developed. In WaSim land use types are parameterized with rooting depth, LAI,  
11 Rsc, albedo and canopy closure. All parameters of the poplar SRC Reiffenhausen  
12 are comparable to estimates of other poplar SRC's – if not necessarily the same  
13 clone or age.  $LAI_{max}$  is 6-8  $m^2 m^{-2}$ , depending on the measurement technique.  
14 Difficulties of Rsc are discussed, canopy closure is almost maximal (plant height is  
15 already 6 m and due to the planting design in double rows plant density is high). So,  
16 all parameters influencing the hydrology in the model are in the order of a fully  
17 developed SRC, although it is in mono-stem cycle. [changed/included p409 l27]

- 18 3. R#3: "Plant available soil water is not coherent with stomatal resistance values (Rsc)  
19 implemented in WaSim (Figures 5 and 6), because these values are not compatible  
20 with the SRC canopy behavior on a daily and monthly basis. The absolute minimum  
21 Rsc value measured of 80  $s m^{-1}$  cannot be maintained during the entire growing  
22 season and since it is reduced to its half, it becomes even more unrealistic, because of  
23 the isohydric behaviour of poplar clones (see Tardieu and Simonneau 1998, Journ.  
24 Exp. Bot. 49:419-432).

25 A: The Rsc value used in WaSim, represented the minimal resistance for a state  
26 when plants are fully supplied with water. So the model needs the minimal  
27 resistance. The real transpiration is further influenced by meteorological boundary  
28 conditions and the available soil water. [sentence included p414 l13] Therefore,  
29 one could not see a clear coherence of PAW and Rsc in figures 5 and 6, as also not  
30 in figure 4. In the reality the minimum of Rsc does not occur every day, but this is not  
31 the value that has to be parametrized in WaSim. And of course the reduction of the  
32 measured minimum Rsc to 40  $s m^{-1}$  is not realistic (at least we could not measure this  
33 value) but this was a specific model-adaptation to improve the model fit to measured  
34 soil water contents. Additionally, more drought-tolerant, anisohydric water use  
35 strategies are also reported from greenhouse experiments for poplar clones

(Ceulemans et al., 1988; Larchevêque et al., 2011). Schmidt-Walter et al. (2014) reported also a poor stomatal control of water loss estimated from field measurements of a poplar SRC.

“One might interpret the reduction of  $R_{sc}$  from  $80 \text{ s m}^{-1}$  to  $40 \text{ s m}^{-1}$  as a shift from the often reported isohydric behaviour of poplar clones (Tardieu and Simonneau, 1998) to a more anisohydric behaviour. But the diurnal or seasonal variations of leaf water potential that are characteristic for anisohydric plants are not expressed by the  $R_{sc}$  value in WaSim, which represents the minimal resistance for a state when plants are fully supplied with water. The reduction of transpiration in drought stress situations is done in a different way in WaSim. Furthermore, there are also more drought-tolerant, anisohydric water use strategies reported from greenhouse experiments for poplar clones (Ceulemans et al., 1988; Larchevêque et al., 2011). Schmidt-Walter et al. (2014) reported also a poor stomatal control of water loss estimated from field measurements of a poplar SRC.” **[included p427 I5]**

4. R#3: “Local land use change with poplar SRC indicates high levels of ETR and GWR (Table 5). It is suitable to compare these estimated values with alternative crops and other poplar plantations of the same region (see Petzold et al. 2011, Eur. J. Forest Res 130:695-706).

A: The comparison to other crops is not the focus of this study; the land use change aspect serve as motivation for investigating the parameterisation of poplar SRC, to be used for land use change analysis in a next step.

The mentioned study of Petzold et al. (2011) reported ~470 mm of transpiration, our model results showed 425-527 mm total evapotranspiration (ETR, Tab. 5). So, transpiration of SRC is not high compared to Petzold et al. As precipitation (especially the inter-annual distribution) and soil types are not comparable between the different locations, we would like to avoid such comparisons. Additionally we would compare measured and modelled values of different locations. Petzold et al. also reported maximum daily transpirations rates of 6.7 mm/d (2.2 mm/d in average), these values are comparable to our model results(max. 6.9 mm/d, mean ~1.7 mm/d; April-September for the period 1969-2013), but as already stated we would like to avoid thus comparisons of different location, years and sources of data.

**[comparison to other studies are not included]**



5. R#3: "Specific comments Figure 1 is repeated in panel (a) of Figure 4 and therefore has to be deleted from the latter.

A: Figure 1 is in the sections where measurements are presented, here additional information is provided. Of course figure 4 is partly repeating information of figure 1, but it presents the model parameterisation for the simulation. To facilitate for a reader the interpretation of figures 5 and 6 we decided to include the LAI information also in figure 4 to enlarge overview and comparability. **[no change]**

6. R#3: "Figure 2 lower panel. In my opinion the Vapour Pressure Deficit (VPD) of the air, calculated from meteorological data recorded in situ, rather than the maximum daily temperature, could better explain the seasonal variation of stomatal resistance.

A: It is correct. However, the purpose of the presented maximum daily temperature was not the explanation of seasonal variations of Rsc, but the demonstration of daily effects due to high air temperatures. Compare local measurements of June 14 and 18. At these particular dates soil water availability is quite comparable, the dominant difference are from meteorology, especially maximum air temperature, effecting Rsc values and/or measurements.

**"This shows the effect of local environmental conditions to measurements, possibly influencing derived model parameters."** **[sentence included p419 l14]**

7. R#3: "Figure 3 panels a-c. Please specify Temperature in the upper titles. Long term estimates of panels (e) and (f) do not add information on SRC phenology characterised by repeated rotations within very few years.

A:

- a) What temperatures do you mean? The degree-days? **[no change]**
- b) "Long-term estimations..." - This is true, but the rotation aspect of SRC is not the focus here. **[no change]**

8. R#3: "Technical corrections Please insert a glossary of Abbreviations

A: We explained all abbreviations when they are used for the first time. Difficult abbreviations like for the different model simulations are explained in table 3. If a glossary is desired by the editor, it could be included. **[no list of abbreviations included]**

9. R#3: "Page 406 - line 17 delete "the description of"

A: OK **[changed]**

10. R#3: "Page 407 - line 21 "perennial" rather than "all year"

1 A: OK **[changed]**

2 11. R#3: "Page 407 - line 22 "combined " rather than "in combination"

3 A: OK **[changed]**

4 12. R#3: "Page 407 – line 23 "compared" rather than "comparing"

5 A: OK **[changed]**

6 13. R#3: "Page 407 - line 24 "canopy interception evaporation" rather than "interception

7 evaporation"

8 A: OK **[changed]**

9 14. R#3: "Page 408 - lines 22 and 26 "growing season" rather than "growing period"

10 A: OK **[changed]**

11 15. R#3: "Page 408 - line 27 "values reported in literature" rather than "literate values"

12 A: OK **[changed]**

13 16. R#3: "Page 409 - line 3 delete "most extensive investigations were carried out at the"

14 and continue with "study site is"

15 A: OK **[changed]**

16 17. R#3: "Page 409 - line 15 after "...Max1 (Populus...)" insert ", hereinafter Max1"

17 A: OK **[changed]**

18 18. R#3: "Page 409 - line 22 "low: only" rather than "low – only"

19 A: OK **[changed]**

20 19. R#3: "Page 409 - line 23 "(...for the long term mean value of the same period of the

21 year)" rather than "(...for the long term mean)"

22 A: OK **[changed]**

23 20. R#3: "Page 409 - line 24 "... for the mono-stem cycle of the poplar SRC" rather than

24 "...for the poplar SRC"

25 A: OK, but in our opinion the poplar SRC is fully developed in hydrological terms, as

26 already explained, therefore results should also be valid in the non-mono-stem cycle.

27 **[changed here, but the explained aspect is also added in the text: p409 l27]**

28 21. R#3: "Page 410 – lines 4-11 delete from "Comparing to ..." up to "...et al., 2014"

29 A: OK **[changed]**

30 22. R#3: "Page 410 – line 13 "Meteorological and local soil measurements" rather than

31 "Micrometeorological and local soil measurements"

32 A: OK **[changed]**

23. R#3: "Pages 411-412 delete from line 10 of page 411 "The Tharandter .." up to line 5 of page 412 "...climatological measurements." Specify briefly the source of long term meteorological records of Wildacker and Grillenburg.

A: As long term phenological observations from Tharandt are important we suggest reformulating the paragraph as follows:

"Additionally to the data of Reiffenhausen, meteorological and phenological data are used from region of Tharandter Wald (Tharandt Forest) being located in the federal state Saxony (Germany), 15km southwest of city of Dresden. As, climate characteristic of this region is comparable with Reiffenhausen, a proper set of comparison data are provided. Detailed information about measurement programs of Tharandter Wald can be found, i.a., in Bernhofer (2002) and Spank et al. (2013). In frame of this study, phenological observation data from the International phenological garden Tharandt-Hartha (IPG) and meteorological measurement data (air temperature, air humidity and precipitation) from climate stations Grillenburg and Wildacker have special importance. Grillenburg and Wildacker are the nearest meteorological long-term measurements sites from IPG and are situated approx. 3 km away. Both stations provide meteorological and climatological information since 1958. The station Grillenburg represents a standard climate station fulfilling all guidelines and standards of World Meteorological Organisation (WMO) for large-scale representativeness of climatological observations. However, measurements on this site sometimes does not represent micro-scale climatic characteristic of the region, particularly related to daily minimum and maximum of air temperature. In contrary, climate station Wildacker, being not fulfill WMO standards of fetch and horizon heightening, better represent local climatic situation." **[changed]**

24. R#3: "Page 412 – lines 11 and the following: correct LI191SA with LI-191 SA and LAI2000 with LAI-2000 all in the text

A: This is actually the page 413. Correct. Initially we used the abbreviations in the manuscript draft, because they correspond to the simulation acronyms. However, the correct instrument names (LI-191SA and LAI-2000) should be used. We will change it in text and explain the simulation acronyms, **[changed in text and also in Tab 3]**

25. R#3: "Page 412 – line 22 "...of short-wave (400-700 nm)" rather than "...of short-wave"

1 A: The remark is not quite correct. Different instruments use different spectral ranges.  
2 E.g. Li-Cor plant canopy analyser uses the short wave radiation below 490 nm.  
3 Therefore, we would like to use the general term: “short-wave radiation”. **[no**  
4 **change]**

5 26. R#3: “Page 412 – line 25 “...below the canopy” rather than “...for the vegetation  
6 layer”

7 R#3: “Page 412 – line 26 “...above the canopy” rather than “...to the  
8 vegetation layer” and “... below the canopy” rather than “at the lower bound of  
9 vegetation layer”

10 A: These corrections are not necessary – here we are using the general definition:  
11 the LAI could be estimated for any vegetation layer including the whole canopy. **[no**  
12 **change]**

13

14 27. R#3: “Page 413 – lines from 23 to 28: any specification on view cap used for LAI-  
15 2000, rings analyzed and sampling method used with LI-191 SA

16 A: We will include this explanation in manuscript. “The LAI-2000 was used in two-  
17 instrument mode with 25% view restriction caps to eliminate the influence of  
18 observer. The measurements with line quantum sensors LI-191SA were also carried  
19 out in two-instrument mode; the measurement design was absolutely identical to LAI-  
20 2000.” **[changed p413 l28]**

21 28. R#3: “Page 414 line 8 “its” rather than “it’s”

22 A: OK **[changed]**

23 29. R#3: “Page 414 line16 “every week or two weeks” rather than “every week”

24 A: OK, We will replace it with “were carried out weekly or fortnightly” **[changed]**

25 30. R#3: “Page 414 line 18 “plots” rather than “...locations in the poplar SRC”

26 A: OK **[changed]**

27 31. R#3: “Page 414 lines 19-20 delete “so called”, “to be measured at different times”  
28 rather than “to measure the same leaf at different times”. Please specify the number  
29 of sun leaves marked.

30 A:

31 a) OK, we will delete it **[changed]**  
32 b) 3 sun leaves were marked at every plot. We will include the information in text  
33 **[changed]**

1

2 32. R#3: "Page 416 lines 19-23 delete from "This IGP ..." to "Seidler (1995)" and thus

3 citation from References section, too.

4 A: OK **[changed; Seidler (1995) and Volkert and Schnelle (1968) are deleted**

5 **from reference list]**

6 33. R#3: "Page 417 line 4 "a poplar SRC in the 3rd growing season of its mono-stem

7 cycle" rather than "an approx. 3 year-old poplar SRC". The mono-stem cycle

8 specification indicates that the roots have the same age of the stems!

9 A: OK **[changed]**

10 34. R#3: "Page 417 line 25 "from 1969 to ..." rather than "of 1969 to .."

11 A: OK **[changed]**

12 35. R#3: "Page 418-419 lines 23-24 and 1 of page 419. Delete from "Maximal.." to "(not

13 shown)"

14 A: OK **[changed]**

15 36. R#3: "Page 419 line 9 delete "at the poplar SRC Reiffenhausen"

16 A: OK **[changed]**

17 37. R#3: "Page 419 line 10 "SD" rather than "SDs"

18 A: OK, but this was done by HESS, I would also like to introduce the abbreviation SD

19 at the first time it is used. **[!!! Please note – HESS !!!]**

20 38. R#3: "Page 419 line 25 "We used in situ phenological" rather than "We used

21 phenological". Delete "in Reiffenhausen"

22 A: first OK **[changed]**; second "in Reiffenhausen" was inserted to clearly distinguish

23 between the different sources of phenological data. **[no change]**

24 39. R#3: "Page 420 line 7 "from" rather than "to"

25 A: OK **[changed]**

26 40. R#3: "Page 420 line 8 insert "(Table 2) after "respectively"

27 A: OK **[changed]**

28 41. R#3: "Page 421 line 7 "2012-2014" rather than "2012-1014"

29 A: OK **[changed]**

30 42. R#3: "Page 421 line 14 "Goettingen and Wildacker, respectively" rather than

31 "Goettingen and Wildacker"

32 A: OK **[changed]**

1 43. R#3: "Page 422 line 2 "(LAI-2000 and LI-191 SA using Rsc80 in both cases)" rather  
2 than "LAI200 Rsc80 and LI191SA Rsc80"

3 A: These are not the names of instruments but the names of corresponding  
4 experiments that's why we would prefer the use of the introduced abbreviations. **[no**  
5 **change]**

6 44. R#3: "Page 422 line 9 and line 16 "measured" rather than "observed"

7 A: OK **[changed]**

8 45. R#3: "Page 422 line 17 "plant available water (PAW)" rather than PAW

9 A: PAW is introduced already at page 422 line14 **[no change]**

10 46. R#3: "Page 422 line 18 "Nash-Sutcliffe criterion (NSC)" rather than "Nash-Sutcliffe  
11 criterion"

12 A: OK **[changed]**

13 47. R#3: "Page 424 line 23 "PBIAS" rather than "PBAIS"

14 A: OK **[changed]**

15 48. R#3: "Page 425 line 2 "longest meteorological period without missing data" rather  
16 than "longest period meteorological forcing data are available without missing data"

17 A: OK **[changed]**

18 49. R#3: "Page 426 line 23 "affected" rather than "effected"

19 A: OK **[changed]**

20 50. R#3: "Page 426 line 26 "Populus species" rather than "populus clones" and "(Populus  
21 grandidentata, P. tremula and P. tremuloides)" rather than "(Populus grandidenata,  
22 Populus tremula and Populus tremuloides)"

23 A: OK **[changed]**

24 51. R#3: "Page 427 line 28 "... shows a wide variability in the date of leaf unfolding"  
25 rather than "...shows a wide spread in the date leaf unfolding started"

26 A: OK **[changed]**

27 52. R#3: "Page 428 line 5 "evident" rather than "visible"

28 A: OK **[changed]**

29 53. R#3: "Page 428 line 15 "ground water recharge (GWR)" rather than "GWR"

30 A: GWR is already introduced in the introduction; of course we can repeat it here  
31 once again. **[changed]**

32 54. R#3: "Page 428 line 27 "... occurring thermal inversion" rather than "...occurring  
33 inversion conditions"

1 A: OK **[changed]**

2 55. R#3: "Page 431 line 18 "... local soil water budget" rather than "local water budget"

3 A: We are also showing ETR for the long term simulations, that's why we talk about  
4 water budget in general. **[no change]**

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# How to predict hydrological effects of local land use change: how the vegetation parameterisation for short rotation coppices influences model results

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## Abstract

Among the different bioenergy sources short rotation coppices (SRC) with poplar and willow trees are one of the mostly promising options in Europe. SRC not only provide woody biomass, but often additional ecosystem services. However, one known shortcoming is the potentially lower groundwater recharge, caused by the potentially higher evapotranspiration compared to annual crops. The complex feedback between vegetation cover and water cycle can be only correctly assessed by application of well parameterized and calibrated numerical models. An assessment of land use change by means of hydrological models and taking into account the changing climate can help to minimize negative and maximize positive ecological effects at regional and local scales, e.g. to regional climate and/or to adjacent ecosystems. The present study implements the hydrological model system WaSim for the assessment of water balance. The special focus is the analysis of simulation uncertainties caused by the use of guidelines or transferred parameter sets from scientific literature compared to ‘actual’ parameterisations derived from local measurements of leaf area index (LAI), stomatal



1 resistance (Rsc) and date of leaf unfolding (LU). The hydrological analysis requires the  
2 adequate description of the vegetation cover to simulate the processes like soil evaporation,  
3 interception evaporation and transpiration. It is clearly shown that uncertainties in  
4 parameterisation of vegetation lead to implausible model results. The present study shows that  
5 LAI, Rsc as well as the LU and length of the growing season are the most sensitive plant  
6 physiological parameters when investigating the effects of an enhanced cultivation of SRC on  
7 water budget or on groundwater recharge. Mostly sensitive is the beginning of the growing  
8 season, i.e. LU. When this estimation is wrong, the accuracy of LAI and Rsc description plays  
9 a minor role. The analyses done here illustrate that the use of locally measured vegetation  
10 parameters like maximal LAI and meteorological variables like air temperature, to estimate  
11 LU, produce better results than literature data or data from remote network stations. However,  
12 the direct implementation of locally measured data is not always advisable or possible, e.g.  
13 Rsc. In case of Rsc the adjustment of local measurements shows the best model evaluation.  
14 Especially if local investigations are in focus local measurements of model sensitive  
15 parameters like LAI, Rsc and LU are valuable information. The derivation of these model  
16 parameters based on local measurements show the best model fit. Additionally the adjusted  
17 seasonal course of LAI and Rsc is less sensitive to different estimates for LU. The different  
18 parametrisations, as they are all eligible either from local measurements or from scientific  
19 literature, can result in modelled ground water recharge to be present or completely absent in  
20 certain years under poplar SRC.

## 21 1 Introduction

22 In the scope of climate change mitigation and reduction of greenhouse gases (GHGs)  
23 emissions bioenergy is one of the possible alternatives for fossil fuels. Among the different  
24 bioenergy sources short rotation coppices (SRC) with mainly poplar and willow trees are one  
25 of the mostly promising options in Europe (Djomo et al., 2011). SRC not only provide woody  
26 biomass, but also additional ecosystem services. Additionally Seepage water quality is  
27 enhanced, due to lower fertilizer requirements and higher nutrient use efficiency (Aronsson et  
28 al., 2000; Schmidt-Walter and Lamersdorf, 2012). Compared to conventional annual crops  
29 SRC sequester more carbon and emit less N<sub>2</sub>O (Don et al., 2012), which is one of the most  
30 important GHGs. As structural landscape elements in rural areas SRC might also contribute  
31 positively to biodiversity (Baum et al., 2012).

32 Yet SRC are not without some disadvantages.

1 However, SRC are not without disadvantages. The most quantitatively assessable  
2 disadvantage is the potentially lower groundwater recharge (GWR) being caused by higher  
3 evapotranspiration of poplar and willow plantations in comparison to annual crops (Lasch et  
4 al., 2010; Schmidt-Walter and Lamersdorf, 2012). An assessment using hydrological models  
5 can help to minimize negative and maximize positive ecological effects due to the land use  
6 change from arable land to SRC at regional and local scales, e.g. to regional climate and/or to  
7 adjacent ecosystems. To quantify effects of this land use change and to provide an adequate  
8 assessment, suitable hydrological models are required, correctly reproducing hydrological  
9 feedback effects of vegetation and land use management. However, in the same way as a  
10 proper model approaches are required, carefully executed parameterization of land use and  
11 vegetation is mandatorily needed to obtain reliable simulation results. The aim of present  
12 study is to assess the effect of parameter uncertainties of the land use type poplar SRC on  
13 modelling results.

14 The planting of SRC causes the occurrence of new factors and complex factor interactions  
15 influencing site water fluxes. One factor is the perennial vegetation cover with higher leaf  
16 area index (LAI,  $\text{m}^2 \text{m}^{-2}$ ) combined with a longer growing season compared to annual crops  
17 (Petzold et al., 2010).

18 The LAI directly affects canopy interception due to an almost linear correlation between LAI  
19 and canopy storage (Rutter et al., 1971). Outside the growing season LAI, more precisely plant  
20 area index, additionally provide canopy storage by woody biomass, i.e., stems and branches.  
21 Furthermore, the transpiration is positively correlated with the LAI, i.e., higher LAI causes  
22 higher transpiration rates. However, LAI is negatively correlated with soil evaporation as  
23 higher LAI means more shadowing and therefore less solar radiation input, and in  
24 consequence less evaporation below vegetation cover. Other important parameters controlling  
25 the water balance are the stomatal resistance ( $R_{sc}$ ), rooting depth and roots distribution. The  
26 structural and biophysical parameters, however, do not remain stable during the year, but have  
27 a seasonal or even annual course. The most intensive changes occur during the growing  
28 period. Thus, the beginning and length of the growing season should be known for adequate  
29 description of seasonal dynamic of vegetation parameters.

30 The smaller the scale of interest the more detailed time-dependent parameterisation of land  
31 use and vegetation is necessary to capture the spatial and temporal variability of effects. There  
32 are two possibilities to obtain the required information: the first one, the labour- and time-

consuming way, is to measure the parameters like LAI or Rsc directly at the investigated site. The other possibility is to apply parameters from scientific literature. This information is quite rare for SRC, due to the fact that this land use scarcely came into focus of investigation as a part of the renewable energy discussion during the last years (Surendran Nair et al., 2012). Very often not the annual course, but only one value is given **in literature**, e.g. the maximum value for LAI, or the minimum value for Rsc, describing together the maximum transpiration. In such cases the annual course for these parameters has to be estimated for hydrological modelling. **Hence**, the question on transferability of published results obtained in a certain area and **a specific** year to other regions and years has to be solved in each study separately. However, it is well known that neither literature values nor direct measurements provide the true values of model parameters, but more or less representative approximations, because of spatial and temporal heterogeneity of vegetation stands including SRC.

The overarching aim of our research was the evaluation of land use change effects. However, this study does not focus on land use change effects in any way but rather on the evaluation of **a suitable tool**. In this study we used the results of our own measurements of LAI, Rsc and the estimation of leaf unfolding date (LU), determining the beginning of growing **season**, for a poplar SRC to parameterise the hydrological model system WaSim (Schulla and Jasper, 2013). The aim of **the** present study is to assess the effect of parameterisation uncertainties of the land use type poplar SRC on modelling results. The hypothesis, that the parameterization of LAI, Rsc and **LU the beginning of growing period** based on measurements shows a better model fit than the use of **values reported in literature** in combination with approximation about the annual course should be proofed. In our study the following objectives should be met: 1) to quantify the WaSim response (sensitivity) to variations of following parameters: LAI, Rsc and LU, caused by different measurement methods and modelling approaches; 2) to estimate the most sensitive parameter and 3) to evaluate quantitatively whether it is advisable to implement locally point-measured values of sensitive parameters directly. We used GWR and plant available water as indicators.

## 2 Material and methods

### 2.1 Study site

The ~~most extensive investigations were carried out at the~~ study site Reiffenhausen (51.67 °N, 10.65°E, 325 m a.s.l.) **is** located south of Göttingen, central Germany. According to the

1 meteorological data provided by the German Weather Service (Deutscher Wetterdienst,  
2 DWD), for the station Göttingen (DWD Station-ID: 01691), nearest to the study site, the  
3 climate is characterized by an average temperature of 9.1 °C ( $\pm$  0.7 °C) and a mean annual  
4 precipitation sum of 635 mm ( $\pm$  122 mm) for the period 1971-2010. The site Reiffenhausen  
5 was established as part of the interdisciplinary investigations of SRC by the joint integrated  
6 project BEST ("Bioenergie-Regionen stärken" - Boosting Bioenergy Regions), which ran  
7 from 2010 until 2014 and was funded by the German Ministry of Education and Research  
8 (BMBF). The aim of BEST was to develop regionally appropriate concepts and innovative  
9 solutions for the production of biomass, with focus on SRC, and to evaluate ecological and  
10 economic impacts.

11 The soil in Reiffenhausen is characterized by a sedimentary deposits of Middle and Upper  
12 Buntsandstein, like sandstone, siltstone and clay stone. The main soil types present at the field  
13 level are stagnic cambisol and haplic stagnosol with a soil quality (Ackerzahl) of  
14 approximately 45 points. The maximum available points are 100 for very good agriculture  
15 fields (Blume et al., 2010). The soil texture is dominated by loamy sand or silty clay.

16 The plantation Reiffenhausen was established at a former arable field in March 2011 with the  
17 poplar clone Max1 (Populus nigra x Populus maximowiczii), hereafter Max1. The poplar SRC  
18 were planted with 0.2 m long cuttings on 0.4 ha in a double row system with alternating inter-  
19 row distances of 0.75 m and 1.50 m, and a spacing of 1.0 m within the rows, yielding an  
20 overall planting density of 8800 cuttings per hectare. A detailed site description, including  
21 soil chemistry and biomass information is given by Hartmann et al. (2014). In 2011 the  
22 weather conditions at Reiffenhausen were unfavourably dry for the initial growth after  
23 planting. During the first months in 2011, from February to May, the precipitation sum was  
24 unusually low: only 42 % of the long term (1971-2010) precipitation (78 mm of 188 mm for  
25 the long term mean value of the same period of the year). This led to dry soil conditions,  
26 especially in the upper soil, and resulting in a survival rate of only 63 % for the mono-stem  
27 cycle of the poplar SRC. In 2013, when the most measurements and investigations took place  
28 the poplar SRC reached a height of 5-6 m, indicating that the unfavourable initial conditions  
29 were somewhat improved. All parameters influencing the hydrology in the model are in the  
30 order of a fully developed SRC, although it is in mono-stem cycle. The development of the  
31 rooting system was eventually enforced by the dry conditions during the initial phase  
32 (Broeckx et al., 2013). Rooting depth was more than 1 m in the second year after planting,

exploiting the main part of soil layer above the bedrock (Kalberlah, 2013). The LAI reached 5 in 2012 and 6-7 in 2013, which is typical for a fully grown poplar SRC (Schmidt-Walter et al., 2014). ~~Comparing to another poplar SRC nearby established in 2012 under more favourable initial conditions, the poplars in Reiffenhausen are characterized by a higher share of woody material (more branches) and somewhat smaller but numerous leaves.~~ Observations for LU are also used from the site Großfahner, which is also part of the BEST-research project. Großfahner is located near Erfurt, Thuringia, Germany and was also established in 2011 with the poplar clone Max1 (Hartmann et al., 2014).

## 2.2 Measurements

### 2.2.1 Meteorological and local soil measurements

In Reiffenhausen the micrometeorological measurements were carried out in the centre of the SRC stand; the instruments were installed above the vegetation on a 10 m mast. The air temperature and humidity were measured using Hmp45C (Campbell Sci.; Loughborough, UK); wind speed and wind direction (wind sensor compact and wind direction sensor compact, both ThiesClima; Göttingen, Germany), atmospheric pressure (pressure sensor, Theodor Friedrichs & Co.; Schenefeld, Germany) and solar radiation (CMP3, Kipp & Zonen, Delft, The Netherlands) were measured continuously with 1 Hz frequency and averaged over 15 minutes. 5 minutes precipitation sums were obtained using an ombrometer (Precipitation Transmitter, ThiesClima; Göttingen, Germany). The values were averaged and stored by a CR1000 data logger (Campbell Sci.; Loughborough, UK). Additionally to the meteorological measurements in the centre of the poplar SRC, a reference station was similarly equipped and installed approximately 500 m to the north from the stand in the open place (short-grass meadow) to measure the climate variables unaffected by the poplar SRC.

The soil moisture was measured continuously every 15 minutes using tensiometers and soil water content probes in 20, 60 and 120 cm depth, by six (tensiometers) and three (probes) sensors in every depth. Tensiometers were constructed in the Department of Soil Science for the study using the PCFA6D pressure sensor (Honeywell; Morristown, NJ, USA) and a P-80 ceramic (CeramTec AG; Marktreidwitz, Germany). Volumetric soil water content and soil temperature were measured using SM-300 probes (Delta-T Devices Ltd; Cambridge, UK). Additionally, descriptions of soil horizons and soil texture were assessed using a soil pit near the SRC.

1 Additionally to the data of Reiffenhausen, meteorological data and data of phenological  
2 observations from Tharandter Wald (Tharandt Forest) are used. The Tharandter Wald is the  
3 biggest contiguous woodland in the federal state Saxony (Germany) being located 15 km  
4 southwest of city of Dresden. Geologically, the Tharandt Forest is part of the forelands of the  
5 Ore Mountains. The climate of this region can be classified as sub-oceanic. The average  
6 annual temperature and the average annual total of precipitation are 7.2 °C and 850 mm  
7 respectively measured in the centre of Tharandter Wald at climate station Grillenburg, climate  
8 period 1961-1990 (Spank, 2010).

9 The Technische Universität Dresden (University of Technology Dresden) operates numerous  
10 test sites and outdoor laboratories within the Tharandter Wald as well as in its near vicinity  
11 (Bernhofer, 2002; Spank, 2010; Spank et al., 2013). In frame of this study, data of the  
12 International phenological garden Tharandt-Hartha (IPG), being located at eastern edge of the  
13 Tharandter Wald (50.59 °N, 13.32 °E, 360m a.s.l.), have special importance. The IPG was  
14 established by initiative of creation of a standardized European phenological monitoring  
15 network in 1959 (Volkert and Schnelle, 1968). A complete site description as well as detailed  
16 information about observation standards and monitored species can be found in Seidler  
17 (1995).

18 Meteorological variables (air temperature, air humidity, precipitation, wind speed at 2 m  
19 height and incoming solar radiation) are measured at this site only since May 2005. However,  
20 two neighbouring sites (Wildacker and Grillenburg), being located in distance of  
21 approximately 3 km away from IPG, provide meteorological and climatological information  
22 since 1958. The station Wildacker belongs to the micro-meteorological and silvicultural  
23 outdoor laboratory Anchor Station Tharandt Forest. The site Wildacker is located on a small  
24 clearance in a coniferous forest. It was established to provide open land information for  
25 comparison with internal forest climate being measured at the Anchor Station Tharandt  
26 Forest. In contrary to that, the station Grillenburg represents a standard climate station. This  
27 site fulfils all World Meteorological Organisation guidelines and standards for large scale  
28 representative climatological measurements.

29 Additionally to the data of Reiffenhausen, meteorological and phenological data are used  
30 from region of Tharandter Wald (Tharandt Forest) being located in the federal state Saxony  
31 (Germany), 15 km southwest of city of Dresden. As, climate characteristic of this region is  
32 comparable with Reiffenhausen, a proper set of comparison data are provided. Detailed

information about measurement programs of Tharandter Wald can be found, i.a. in Bernhofer (2002) and Spank et al. (2013). In frame of this study, phenological observation data from the International phenological garden Tharandt-Hartha (IPG) and meteorological measurement data (air temperature, air humidity and precipitation) from climate stations Grillenburg and Wildacker have special importance. Grillenburg and Wildacker are the nearest meteorological long-term measurements sites from IPG and are situated approx. 3 km away. Both stations provide meteorological and climatological information since 1958. The station Grillenburg represents a standard climate station fulfilling all guidelines and standards of World Meteorological Organisation (WMO) for large-scale representativeness of climatological observations. However, measurements on this site sometimes does not represent micro-scale climatic characteristic of the region, particularly related to daily minimum and maximum of air temperature. In contrary, climate station Wildacker, being not fulfil WMO standards of fetch and horizon heightening, better represent local climatic situation.

### 2.2.2 Leaf area index

For the present study we use the definition of leaf area index by Watson (1947) cited in Breda (2003) as the total one-sided area of leaf tissue per unit ground surface area with the dimension of  $\text{m}^2 \text{m}^{-2}$  (or dimensionless). There are numerous ground-based as well as remote sensing-based techniques to estimate LAI. An extensive overview of ground-based methods is given by Breda (2003). Direct methods: allometric, litter collection and harvesting are based on statistically significant sampling of phytoelements and phytoelement dimensions. Among them only the harvesting can provide the information on the seasonal dynamic of LAI for the whole season or year. The obvious disadvantages of harvesting as destructive method, however, are that it is very time- and labour-consuming, that the canopy is irreversibly damaged and further statistically representative LAI-measurements for seasonal dynamics are affected.

Indirect ground-based methods are non-destructive and based on the inversion of the Beer-Lambert law, i.e. on measurements of the extinction of short-wave solar radiation by the canopy. The extinction is related to the vegetation structure parameters including LAI (Eq. 1).

$$\text{LAI} = \frac{\ln(I_0/I)}{k} \text{ with } k = \frac{G(\theta, \alpha)}{\cos \theta} \quad (1)$$

where LAI is the leaf area index for the vegetation layer,  $I_0$  is the radiation intensity incident to the vegetation layer,  $I$  – radiation intensity at the lower bound of vegetation layer and  $k$  is



1 the extinction coefficient (Breda, 2003). The function  $G$  is the projection of unit foliage area  
2 on the plane normal to the direction  $\theta$ ,  $\theta$  – zenith angle and  $\alpha$  is the leaf angle distribution. It  
3 should be also noted that indirect methods estimate not LAI but Plant Area Index (PAI) as the  
4 light attenuation is caused not only by leaves but by branches and tree stems as well. To  
5 derive LAI either the correction factors are applied which subtract the share of woody  
6 material from PAI, or the assumption is made (especially for dense canopies) that the  
7 attenuation is caused for the most part by leaves. The underlying assumptions, e.g. on stand  
8 homogeneity and small black opaque phytoelements that have to be considered to ensure the  
9 applicability of indirect methods, as well as advantages and disadvantages of various methods  
10 are presented, e.g. in LAI-2000 Manual (LI-COR INC, 1992), in Breda (2003) and  
11 (Jonckheere et al., 2004).

12 For the present study the data of one direct and two indirect methods for the estimation of  
13 LAI of the poplar SRC in Reiffenhausen were used. For the indirect method we used two  
14 different types of instruments. First - two LI-191 SA Line Quantum Sensors (LI-COR Inc.,  
15 USA) were used to measure incident ( $I_{0,PAR}$ ) and within-stand photosynthetic active radiation  
16 ( $I_{PAR}$ ) to calculate the LAI using Eq. (1). The  $k = 0.5$  for mixed broadleaved species was  
17 accepted in our study (Breda, 2003). Second - two plant canopy analysers LAI-2000 (LI-COR  
18 Inc., USA) were implemented in Two-Sensor mode (LI-COR INC, 1992) to obtain LAI and  $k$ .  
19 Measurements were performed weekly whenever possible from May till November 2013  
20 under homogenous illumination, i.e. at days with overcast conditions or during morning or  
21 evening hours. Sensor pairs were cross-validated at the beginning of each measurement day.

22 In the homogeneous poplar SRC ten evenly distributed plots were selected. To account for the  
23 double row planting of the SRC 3 m x 3 m square grids with 1 m distance between grid points  
24 were marked at every plot so that 16 grid points per plot were obtained for measurements. At  
25 each grid point two measurements were performed with instrument oriented along and  
26 perpendicularly to SRC rows. Thus 32 measurements were performed at each of ten plots  
27 during every measurement day. The LAI-2000 was used in two-instrument mode with 25 %  
28 view restriction caps to eliminate the influence of observer. The measurements with line  
29 quantum sensors LI-191SA were also carried out in two-instrument mode; the measurement  
30 design was absolutely identical to LAI-2000.

31 To obtain the reference values for leaf area the direct destructive sampling – harvesting were  
32 carried out. All phytoelements within the square column of 1 m<sup>2</sup> surface area were collected



and measured with leaf area meter (LI-3100; LI-COR Inc., USA). The sampling was carried at 26 August 2013 at three plots within the investigated stand.

### 2.2.3 Stomatal resistance

The dominant factor controlling both the water loss from plant leaves and the uptake of CO<sub>2</sub> for photosynthesis is the resistance of stomata, regulated by the plant in response to environmental conditions. Stomatal resistance, or its reciprocal the stomatal conductance, is an important parameter in hydrological modelling, controlling the rate of transpiration for the different vegetation types. The version of WaSim applied in present study uses the Penman-Monteith approach for calculating evapotranspiration and requires a parameter of minimal surface resistance for a state when plants are fully supplied with water (Schulla, 1997; Schulla and Jasper, 2013). The real transpiration modelled is further influenced by meteorological boundary conditions and the available soil water.

For the Rsc measurements in poplar SRC we used the SC-1 leaf porometer (Decagon Devices Inc.; Pullman, WA, USA). The measurements took place in Reiffenhausen in 2013 and were carried out weekly or fortnightly from May till September only under favourable weather conditions promising minimal resistances: preferable sunny, but at least without rain and with dry leaves. The same 10 plots in the poplar SRC as for the LAI measurements were used, where so-called 3 sun-leaves were marked to be measured at different times. All 10 locations were measured during one hour to minimize the effects of changing weather conditions. Measurements were started in the morning, when leaves are dry and continued till afternoon, or as long as weather conditions were appropriate.

### 2.2.4 Phenology – start of growing season

The phenological phases of plants, e.g., leaf unfolding, leaf colouring and fall of leaves, are controlled by environmental conditions and internal genetic characteristics of plants. Thus, the site and species specific phenological state is a result of complex interference between length of light period, meteorological drivers (mainly temperature and radiation), soil properties, plant provenance, age and height (Menzel, 2000).

Within WaSim a modified approach for estimating LU according to Cannell and Smith (1983) is implemented and used here. A detailed description of this model as presented in Eq. (2-5), as well as parameterisation examples (Tab. 1) is given by Menzel (1997).

The model has four parameters:  $T_0$ ,  $T_l$ ,  $a$  and  $b$  which are the threshold temperatures for chilling units and for forcing units and two tree specific regression parameters, respectively. The starting day for leaves unfolding is calculated according to Eq. (2), (3), (4) and (5).

$$T_S = \sum_{i=0}^n \begin{cases} T(t_1 + i\Delta t) - T_1 & T(t_1 + i\Delta t) \geq T_1 \\ 0 & T(t_1 + i\Delta t) < T_1 \end{cases} \quad (2)$$

Here  $T_S$  is the temperature sum,  $T$  is the daily mean temperature for a day  $t_l + i\Delta t$ ,  $t_l$  is set as 1 February in present study and time step,  $\Delta t$ , as one day. The daily mean temperature is calculated according to Eq. (3).

$$T = \frac{T_{\min} + T_{\max}}{2} \quad (3)$$

Here  $T_{\min}$  is the daily minimum temperature and  $T_{\max}$  the daily maximum temperature. The LU occurs when  $T_S$  reaches the critical value  $T_{S,\text{crit}}$  (Eq. 4 and 5).

$$T_{S,\text{crit}} = a + b \ln(CD_n), \text{ with} \quad (4)$$

$$CD_n = \sum_{i=0}^n \begin{cases} 1 & T(t_0 + i\Delta t) \leq T_0 \\ 0 & T(t_0 + i\Delta t) > T_0. \end{cases} \quad (5)$$

$CD$  is the number of chilling days, i.e. when  $T < T_0$ , between days  $t_0$  and  $t_l$ . The date  $t_0$  was set as 1 November in present study. Values for  $T_0$ ,  $T_l$ ,  $a$  and  $b$  for *Populus tremula* (IPG235) are given by Menzel (1997) (Tab. 1).

Using these numbers as initial values we fitted the parameters  $T_0$ ,  $T_l$ ,  $a$  and  $b$  to observed LU for the poplar clone Max1 in Reiffenhausen for the years 2012 and 2013 using least squares method. Finally we evaluated the obtained model parameters against the independent observations in Reiffenhausen (for 2014), and observation in Großfahner for the years 2012 and 2013 (Lorenz and Müller, 2013) and 2014 (Lorenz, 2014). The observed LU in Reiffenhausen and Großfahner is comparable to the recommendations according to Volkert and Schnelle (1966). Because the estimation of LU, as used in this study is based on meteorological measures, the parameterisation should hold true for the same poplar clone in the same age, if other environmental factors are of minor importance. The results will confirm this.

For a long term comparison the data from the international phenological observation networks (IPG) are used (Chmielewski et al., 2013), namely LU of *Populus tremula* (IPG235) at the IPG station Tharandt-Hartha. For poplar clone Max1 we could not find parameter sets in literature, so we used for comparison the IPG235 parameters of Menzel (1997) for *Populus*

tremula, which is better investigated. The IPG-data are used for long term comparison, because there were no long term investigations of LU available on the research plots of the BEST project or nearby. IPG235 is the acronym of the parameterisation for Populus tremula used by (Menzel, 1997). We decided to retain this acronym to make it comparable to published results, and also because it is an acronym used in the data provided by the phenological garden network. The phenological phase of leaf unfolding is defined as the stage UL, according to the IPG webpage (International Phenological Gardens of Europe, 2014) and is obtained by daily observations of plant's development state. The IPG station Tharandt-Hartha is located at the eastern border of the Tharandter Wald (50.59 °N; 13.32 °E; 360 m a.s.l.). It is the nearest IPG station to the site Reiffenhausen, and comparable in climate and altitude. ~~This IPG station was established in 1959 by the initiative to create a standardized European phenological monitoring network (Volkert and Schnelle, 1968). A list about species and phenological items, being monitored at this site, as well as a comprehensive description of station's history is offered by Seidler (1995).~~

## 2.3 Modeling approach

For simulation, the deterministic spatially distributed hydrological catchment model system WaSim (version 9.05.04) was used. Complete and comprehensive descriptions of this model and its internal structure can be found inter alia in (Schulla, 1997; Schulla and Jasper, 2013). The setup of physically based parameters, such as LAI and Rsc as well as phenological state (date of leaf unfolding - LU here), are predicated on direct measurements and observations. Thus, physical nexus between model image and reality is reproduced as best as possible. The SRC described with these measurements and observations represents a poplar SRC in the 3rd growing season of its mono-stem cycle, which can be seen as a hydrological fully developed canopy, concerning LAI, Rsc and root development. The simulated local soil water contents were compared and evaluated with measurements.

Different model simulations are done to show the suitability of the direct use of specific plant physiological measurements, as well as the effects of an approximated parameter description in the model, i.e. the annual course and the quantity of LAI, Rsc and phenology.

All these model approaches were done on a plot model domain, which are 3x3 raster cells based on a digital elevation model with a spatial resolution of 12.5 m (LGLN - Landesbetrieb Landesvermessung und Geobasisinformation, 2013), provided by the project partner NW-

1 FVA<sup>1</sup>. All topographic information, needed by the model is derived by the model itself. The  
2 research site, providing the measured soil water contents for model calibration is located in  
3 the centre of the domain. A retention curve required in hydrological modelling for the  
4 description of soil physical properties was taken from Van Genuchten (1980). The Van  
5 Genuchten retention parameters from Blume et al. (2010) were accepted based on a  
6 characterization of soil texture and soil horizons in Reiffenhausen.

7 The meteorological forcing data were taken from own measurements for the period 2011-  
8 2013, whereas the first two years were used for the model spin up. Analyses and the  
9 evaluation to measured local soil water contents were done for the year 2013, only. To show  
10 the effects of different parameterisations under various climate conditions the simulations  
11 were performed for the period from 1969 to 2013 using the forcing meteorological data from  
12 DWD station Göttingen. The period was chosen as the longest period without missing values.  
13 The parameterisation of land use is kept constant for the whole period. A WaSim control file  
14 including all information about parameterization and model setup is provided as  
15 supplementary material.

## 16 **2.4 Data analysis**

17 All measured and applied meteorological, soil physical and eco physiological parameters have  
18 been checked for plausibility and measurement errors.

19 The data has been numerically analysed and graphically presented with the free software  
20 package GNU Octave, version 3.6.2 (Octave community, 2012). Parts of the statistical  
21 analysis were performed using the hydroGOF package (Mauricio Zambrano-Bigiarini, 2014)  
22 within the R software environment (R-Studio under Windows, version 0.98.501) for statistical  
23 computing and graphics (R Development Core Team, 2011).

24 The evaluation of model performance was done according to objective criteria of Moriasi et  
25 al. (2007). Important quality criterions of simulation runs are the Nash-Sutcliffe model  
26 efficiency criterion (NSC), the percent bias (PBIAS), and the ratio of the root mean square  
27 error to the standard deviation of measured data (RSR).

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## 3 Results

### 3.1 Measurements

#### 3.1.1 Leaf area index

Figure 1 shows the annual course of LAI, derived from two different indirect optical and one direct destructive method. LU started shortly before the first measurement at the 1 May 2013. Until the 1 August there is almost a linear increase of LAI up to 7.3 and 5.5 for the LI191SA and the LAI2000 measurements, respectively. Maximal observed values out of all 160 measurements are  $10.5 \text{ m}^2 \text{ m}^{-2}$  and  $6.5 \text{ m}^2 \text{ m}^{-2}$ , respectively (not shown). After that LAI starts to decrease, with a more rapid decline toward the end of August 2013. Leaf fall was almost finished at the 25 October.

Differences between devices, i.e. LI191SA vs. LAI2000, are large. The LAI values obtained with the LI191SA are systematically  $\approx 2 \text{ m}^2 \text{ m}^{-2}$  higher ( $\approx 2 \text{ m}^2 \text{ m}^{-2}$ ). The values obtained by direct destructive sampling at the 26 August are rather on the level of the LAI2000 estimates.

#### 3.1.2 Stomatal resistance

Figure 2 shows the stomatal resistance ( $R_{sc}$ ) as measured on well illuminated leaves at the poplar SRC Reiffenhausen in 2013. Values are ranging from  $100 \text{ s m}^{-1}$  to  $300 \text{ s m}^{-1}$  until August 2013. At the 18 June  $R_{sc}$  is higher with larger standard deviations as the previous measurement at the 14 June. Soil water supply is sufficient on both days. The two days significantly differ in temperature, although the 14 June is relatively colder with a daily maximum temperature of approximately  $17^\circ \text{C}$  and the 18 June is quite hot, reaching a maximum temperature of  $33^\circ \text{C}$ . This shows the effect of local environmental conditions to measurements, possibly influencing derived model parameters. Starting from August both mean  $R_{sc}$  and standard deviation are steadily increasing. This period is characterized by decreasing soil water availability leading to severe drought stress conditions. Due to higher  $R_{sc}$  the trees counteracting the drought stress to avoid water loss and xylem damage, e.g. embolism of xylem vessels. The increase of standard deviation is an expression of stand heterogeneity, single trees still have access to water, and other may already be limited or stressed. In September 2013 we stopped measurements because leaves were visibly affected by the drought stress event. The correlation of plant available soil water and plant regulation

via stomata seems to be consistent, increasing confidence in the distinct measurements. The minimum observed stomatal resistance is  $80 \text{ s m}^{-1}$ .

### 3.1.3 Phenology – start of growing season

We used in situ phenological observations of the two years 2012 and 2013 in Reiffenhausen to calibrate the modified approach for estimating LU according to Cannell and Smith (1983), which is used in WaSim. In 2012 LU for Max1 in Reiffenhausen started at day of year (DOY) 88, i.e. the 28 March 2012 (Tab. 2). In 2013 LU was delayed by approximately 4 weeks due to low temperatures in spring and started at DOY 115 (25 April 2013). Our calibration resulted in values of  $10^\circ\text{C}$  and  $2^\circ\text{C}$  for  $T_0$  and  $T_l$ . The regression parameters  $a$  and  $b$  are 2200 and -403, respectively (Tab. 1). Estimates of LU using these values for  $T_0$ ,  $T_l$ ,  $a$  and  $b$  show deviations from the observed dates of +3 and -3 days for Reiffenhausen in 2012 and 2013, respectively (Tab. 2). Then the phenological model results with the obtained parameter set and local temperatures were compared to phenological observations in Reiffenhausen in 2014 and in Großfahner in 2012 and 2013. Observed LU in Großfahner are almost equal to that in Reiffenhausen, also showing the delay of ~~approx. 4 weeks~~ in 2013 compared to 2012. The phenological model using the Max1 parameters result in differences of -1 day for Reiffenhausen in 2014 and of +1 and -1 days for Großfahner in 2012 and 2013 compared to observations. Tab. 2 also shows the application of the IPG235 parameter set provided by Menzel (1997) for *Populus tremula*. Parameters of  $a$  and  $b$  for IPG235 are both smaller in magnitude and threshold temperatures for chilling and forcing units,  $T_0$  and  $T_l$  show smaller differences. Due to this wider spread between  $T_0$  and  $T_l$  the Max1-model is able to describe extreme values and therefore a higher variability of LU, which was observed in 2012 and 2013. The model estimations of LU with Max1 and with the IPG235 parameters differ considerably. The IPG235 set produces systematically later dates. Differences to observations are +31 (2012), +10 (2013) and +28 (2014) days for Reiffenhausen and +23 (2012) and +7 (2013) days for Großfahner using the local temperatures (Tab. 2, column: local).

To assess the effects of non-local micrometeorological data sources, the model was driven by temperature measurements from the nearest DWD stations, namely Göttingen for Reiffenhausen and Dachwig for Großfahner. Expectedly, the use of DWD data instead of the local measurements produces mostly larger estimation errors for both the Max1 and the IPG235 parameter set (Tab. 2, column: nearest DWD).

We will use the varying parameter sets, i.e. our Max1 model and the IPG235 parameter set (Tab. 1) to analyse the effect for hydrological modelling for the year 2013, where soil hydrological measurements are available to evaluate the hydrological model results.

To analyse the species-dependence of LU estimations the model with Max1 and IPG235 parameters was also driven by temperature measurements during 2012-2014 at the phenological station Tharandt. Figure 3 (a-d) illustrates that, expectedly, the parameter sets correspond better to the observations at species for which they were calibrated: Max1 parameters to Reiffenhausen and the IPG235 parameters to Tharandt observations, which were part of its calibration dataset. The differences between estimated and observed DOY of LU are smaller when local temperature measurements are used (Fig. 3a vs. 3b and Fig. 3c vs. 3d).

Figure 3 (e-f) show the long term courses of estimated DOY of LU for Reiffenhausen and Tharandt using the temperatures of the nearest DWD stations (Göttingen and Wildacker, respectively). The model with IPG235 is systematically later and shows less variability than with Max1 parameters. For Reiffenhausen no long term phenological observations are available. However, the average DOY of LU in Reiffenhausen is  $\text{DOY } 97 \pm 9$  using Max1 and  $\text{DOY } 124 \pm 5$  for IPG235. The long term phenological observations in Tharandt fit well to the IPG235 estimates, but showing less variability than observed. The average DOY of LU in Tharandt as observed is  $\text{DOY } 123 \pm 10$  days, estimated using Max1  $\text{DOY } 101 \pm 9$  days and with IPG235  $\text{DOY } 124 \pm 7$  days. In general estimates fit best to observations when the corresponding parameters are used, i.e. Max1 for Reiffenhausen and IPG235 for Tharandt. But variability is underestimated by IPG235 compared to observations.

### 3.2 Hydrological model simulations

Several model simulations were performed with different parameterisations of LAI, Rsc and LU. Table 3 summarizes the eight performed model simulations and introduces their abbreviations. The detailed descriptions of model simulations are given in text.

First the measured values of LAI, Rsc and LU are implemented for hydrological modelling (LAI2000 Rsc80 and LI191SA Rsc80). Starting from here we changed the parameter sets: i) to improve the model fit; ii) to adjust the suitability of applied parameterisations and iii) to show the effects of different parameterisations on hydrological model results.



### 3.2.1 Simulation using observed parameters and adaptation of stomatal resistance

First we used the measured annual courses of LAI for hydrological modelling.  $R_{sc}$  is set to the measured minimum of  $80 \text{ s m}^{-1}$ , when LAI is larger than 1. LU is not calculated for measured LAI from air temperature using the approach of Cannell and Smith (1983), because this information is already imprinted in LAI measurements and therefore fixed for the year 2013.

Figure 4 shows the applied model parameterisations for LAI and  $R_{sc}$ , as well as the plant available water (PAW), calculated until 1 m soil depth from measured and modelled soil water contents.

For all simulations using the measured value for  $R_{sc}$  (i.e.  $80 \text{ s m}^{-1}$ ) model results for soil water content were higher than measured values, resulting in larger PAW-values than observed. This is also reflected by the Nash-Sutcliffe criterion (NSC) calculated from PAW (Tab. 4). The annual course of PAW is captured quite well by the model, but the drying up in summer is not sufficient, neither for the LI191SA, nor for the LAI2000 measurements. The NSC is better for the experiments with LAI measured by LI191SA (0.69) than with LAI2000 (0.44) because of the higher LAI values (Tab. 4).

As, especially the maximum of LAI measures using the LAI2000 showed better agreement with direct destructive measurements, we halved the value of  $R_{sc}$  from  $80 \text{ s m}^{-1}$  to  $40 \text{ s m}^{-1}$  to reach the low PAW values observed. This decision has two reasons. First it can be assumed that the measured  $R_{sc}$  is always higher than the minimum value needed for parameterisation, because the conditions by measuring  $R_{sc}$  are not satisfying the requirements for the parameter to be used in the model, i.e. optimal conditions for transpiration and no water stress. Another way to get lower PAW values would be to increase the LAI, as can be seen by comparing the results for LI191SA and LAI2000. However, in our experiment LAI has to be increased to unrealistically high values to minimize the differences to observed PAW. Additionally LAI is also affecting other processes in hydrological models, like interception evaporation and soil evaporation. Together the decrease of  $R_{sc}$  is a consistent way to minimize the deviations to observations and to improve the model fit.

The reduction of  $R_{sc}$ , from  $80 \text{ s m}^{-1}$  to  $40 \text{ s m}^{-1}$ , improved the NSC from 0.69 and 0.44 to 0.89 and 0.87 for the LI191SA and LAI2000, respectively (Tab. 4).



### 3.2.2 Approximation and adaptation of annual course of leaf area and stomatal resistance

In many cases when hydrological models should be applied for analyses involving vegetation there are no locally measured data on LAI and/or Rsc. Often only the literature data for the maximum and minimum values of LAI and Rsc are available. Then the annual course for these parameters has to be derived or approximated for modelling. The simplest approximation is a stepwise function, where the increase from minimum to maximum or decrease from maximum to minimum occurs within one time step. We applied this form to the LAI and Rsc as shown in Fig. 5. Here the maximum of LAI is set to  $6 \text{ m}^2 \text{ m}^{-2}$ , which is the observed maximum plus standard deviation of the LAI2000 measurements. The minimum of Rsc is set to  $40 \text{ s m}^{-1}$ . For this kind of approximation the start, and therefore the length of the growing season becomes important, because the maximum transpiration rate occurs immediately after LU. In Fig. 5 we compare two different parameterisations for dynamical estimating LU, i.e. the Max1 and the IPG235 parameter set (Tab. 1).

The NSCs for both simulations are 0.89 (Tab. 4), which is even a bit better than for applying the direct LAI measurements. However, PBIAS values are negative for the step function simulations, where they are positive for the simulations using LAI measurements. Negative PBIAS values indicate a stronger drying signal.

Differences in PAW are only visible in the period when parameterisation is different (Fig. 5). The year 2013 shows no drought event in spring, where effects would be more obvious. There are small differences in May, where the step function simulation using the Max1 parameters are closer to observations.

However, the abrupt increase to the maximum transpirations rate immediately after LU is rather unrealistic as already shown by the LAI measurements. Unfolding of leaves in nature can happen very quickly, as everybody can observe when spring comes late in the year, followed by favourable growth conditions. When spring starts early the full leaf development can take much longer. To account for this and to further improve our model fit we changed the annual development of LAI and Rsc by using these parameters for manual model calibration, guided by the course of LAI measurements mainly (Fig. 6). Major changes are higher LAI and lower Rsc values at the date of leaf unfolding, i.e.  $2 \text{ m}^2 \text{ m}^{-2}$  and  $150 \text{ s m}^{-1}$ , respectively. LU is estimated with the dynamic approach like in the step function simulations. This resulted in modelled higher transpiration rates in spring. Besides the annual course of

LAI and Rsc is described more detailed and more similar to the observed LAI dynamics - the LAI increase and decline is smoother but also starts a bit earlier in the year and last a bit longer in autumn. Due to that smoother increase in spring the sensitivity to deviations in estimating LU is reduced.

Due to these changes the NSC increased to 0.90 for both Max1 and IPG235 parameter sets. This is the best fit obtained in manual calibration procedure (Tab. 4). PBIAS values are positive for the adjusted models, which is a slightly too small drying signal. However, the magnitudes of PBIAS and RSR values are smaller than for the step function simulations, indicating better agreement with observations and lower root mean square errors or residual variations (Moriassi et al., 2007).

### 3.2.3 Long term simulations

In all simulations shown for the year 2013, the effects on PAW caused by changes in estimated LU are quite low, due to the high soil water contents in spring 2013. Therefore, we applied all simulations for the years 1969-2013, which was the longest meteorological period without missing data. A focus is set to the year 2012, which was characterized by an early drought event in May. Because of missing data there is no complete set of soil water content information available for this year and there is no information about LAI and Rsc for 2012 that can be used to parameterise the hydrological model. So no evaluation of model fit is possible for 2012 or the other years of the period 1969-2013, like it is done for 2013.

To illustrate the effects for the different courses of LAI and Rsc development as well as the estimation of LU, Fig. 7 shows the precipitation, the plant available water and the GWR for the step function and for the adjusted simulations combined with the estimates of LU, i.e. the Max1 and IPG235 parameter set, respectively. Results in Fig. 7 show the last two years from the long term simulations 1969-2013, mean values for ETR and GWR for the whole period 1969-2013 are presented in Tab. 5. In 2012 and 2013 as well as for both estimations of LU, the adjusted simulation shows the highest GWR and the step function simulations results in the lowest GWR. The reason for this is the change in transpiration in spring, as described due to the different parameterisations of the step function and adjusted course for LAI and Rsc. However, the largest effects on GWR are caused by the different estimation of LU (Fig. 7). In the step function experiments GWR is zero in 2012 with both the Max1 and the IPG235 parameterisations of LU. Plant available water is reduced stronger for the Max1

parameterisation, due to the early start of the growing season. However, this early LU fits better to the observations in Reiffenhausen. For the adjusted simulations GWR in 2012 is only zero for the Max1 parameterisation. ~~GWR in May and July 2012 only occurs in the simulation using the adjusted courses for LAI and Rsc as well as for all simulations using the IPG235 parameterisation for LU.~~ For the year 2012 data of the matrix potential (tensiometer measurements) in 20 cm, 60 cm and 120 cm soil depth are available. These data show a drought period in May 2012, where the tensiometers in 20 cm soil depth run out the measuring range, i.e. a matrix potential was lower than approx. -800 hPa. Starting from May 2012 the tensiometers in 60 cm and 120 cm soil depth indicated a consistent drying signal (not shown). Additionally the poplar SRC in 2012 is younger and therefore less water demanding than the poplar SRC parameterised in the model, applied for these analyses. This indicates that GWR after May 2012 is very unlikely in these simulations.

The parameterisation using the adjusted course for LAI and Rsc, based on the measured course of LAI, in combination with the Max1 parameterisation for LU, calibrated at local observations, seems to be the most realistic model simulation (**LAIadjusted Rsc40 Max1**). By comparing all four model parameter combinations shown in Fig. 7, one can switch completely from GWR present in 2012 to absent.

Table 5 summarizes the evapotranspiration (ETR) and GWR for all simulations, averaged over all years for the period 1969-2013, as well as for the 5 driest and 5 wettest years of this period. GWR averaged over all years varies from 80 mm year<sup>-1</sup> to 145 mm year<sup>-1</sup> depending on the approximation of the annual course of LAI and Rsc and the estimation of LU. The ratio of maximum and minimum of the all year averages of GWR for the different simulations is approx. 1.8. This factor is approx. 3 for the 5 driest years and approx. 1.7 for the 5 wettest years, showing that especially the model results for dry years are sensitive to the parameterisations used.

## 4 Discussion

Not all necessary model parameters for WaSim could be measured in detail. One example is the implemented assumption on rooting depth which was measured in 2012, and was set to 1 m for modelling which is comparable to the commonly used values presented in Raissi et al. (2009).

Measuring Rsc in the field is rather challenging. For hydrological modelling we are interested in more theoretically minimum values, indicating optimal transpiration. These conditions are

1 hardly found in reality. In addition the measurements are affected by soil water availability as  
2 well as rapidly changing atmospheric conditions. Breuer et al. (2003) summarises values for  
3 minimal stomatal resistance for various plants. Values for *Populus* clones (*Populus*  
4 *grandidenata*, *P. tremula* and *P. tremuloides*) are ranging from  $102 \text{ s m}^{-1}$  to  $400 \text{ s m}^{-1}$ . Our  
5 measured minimum of  $R_{sc}$  for poplar clone Max1 (*Populus nigra* x *Populus maximowiczii*) is  
6 lower:  $80 \text{ s m}^{-1}$ . Yet we needed to further reduce  $R_{sc}$  to  $40 \text{ s m}^{-1}$  for modelling in order to  
7 match the observed soil water contents. On the one hand the low observed minimum of  $80$   
8  $\text{ s m}^{-1}$  shows that specific measurements of  $R_{sc}$  are helpful. On the other hand the  
9 measurements of  $R_{sc}$  were still too high to produce plausible results with WaSim. One might  
10 interpret the reduction of  $R_{sc}$  from  $80 \text{ s m}^{-1}$  to  $40 \text{ s m}^{-1}$  as a shift from the often reported  
11 isohydric behaviour of poplar clones (Tardieu and Simonneau, 1998) to a more anisohydric  
12 behaviour. But the diurnal or seasonal variations of leaf water potential that are characteristic  
13 for anisohydric plants are not expressed by the  $R_{sc}$  value in WaSim, which represents the  
14 minimal resistance for a state when plants are fully supplied with water. The reduction of  
15 transpiration in drought stress situations is done in a different way in WaSim. Furthermore,  
16 there are also more drought-tolerant, anisohydric water use strategies reported from  
17 greenhouse experiments for poplar clones (Ceulemans et al., 1988; Larchevêque et al., 2011).  
18 Schmidt-Walter et al. (2014) reported also a poor stomatal control of water loss estimated  
19 from field measurements of a poplar SRC.

20 The LAI measurements show a systematic difference between the two measurement devices,  
21 whereas the LI191SA seems to overestimate LAI taking the destructive method as a  
22 reference. In situ measurements of LAI are helpful to determine the maximum value, but  
23 differences due to the different estimation methods including underlying assumptions should  
24 be considered. The annual development of LAI is indispensable information to adjust and  
25 improve the model parameterisation of annual course. The measured LAI development  
26 represents local conditions and is therefore valid for the measurement site and time period  
27 only. Approximations of seasonal course are advisable to enable the transferability to other  
28 sites and years. A crucial factor here is LU, determining the start of LAI increase. For the  
29 determination of this date phenological stages have been defined. To describe LU various  
30 models are available, based on air temperature, soil temperature, photoperiod, day length or  
31 radiation. All models have to be calibrated for specific plants species. There is also evidence  
32 that local conditions like latitude or altitude of observations are influencing the calibration of  
33 the phenological model. Furthermore the derivation of parameters for the phenological model

1 will depend on the observed data, e.g. the detection of extremely early or late LU as well as  
2 the climate data, which has to be appropriate for the observed site. For poplar clone Max1 we  
3 could not find parameter sets in literature, so we used for comparison the IPG235 parameters  
4 of Menzel (1997) for *Populus tremula*, which is better investigated. The period of parameter  
5 adjustment used by Menzel (1997) is 1959-1993, and is based on several phenological  
6 stations, whereas our derived parameters are based on 2 years at one site. However, these two  
7 years show a wide variability in LU. The parameters from Menzel (1997) should be generally  
8 more valid, because of the higher number of observations. Yet the use of IPG235 parameters  
9 resulted in an underestimation of observed variability, compared to the observations for  
10 *Populus tremula* in Tharandt. Differences between IPG235 and Max1 also show the  
11 importance of parameterisations for local site conditions and specific species. Comparing the  
12 parameter sets presented in Tab. 1 these effects become evident.

13 Especially threshold temperatures for chilling and forcing units,  $T_0$  and  $T_I$  vary more widely  
14 between IPG235 and Max1. Due to this wider range the model is able to describe extreme  
15 values and therefore a higher variability of LU, which was observed in our calibration years  
16 2012 and 2013. We evaluated our parameter set on observations of the poplar SRC  
17 Reiffenhausen in 2014 and the poplar SRC Großfahner (2012-2014), which was planted with  
18 the same clone and in the same year like Reiffenhausen. The differences for LU between  
19 observations and the Max1 model setup are low and within the observed variability. The use  
20 of IPG235 parameters for the Max1 clone, which is a common procedure when specific  
21 values are missing, can result in large deviations as shown for ground water recharge (GWR),  
22 especially in the year 2012 with the drought period in spring.

23 The source of temperature data also influences the parameters derived for phenological  
24 models as well as the results obtained by applying these parameter sets. We compared the  
25 estimated DOY of LU derived with local temperature measurements and with temperatures of  
26 the nearest DWD stations. For Reiffenhausen, with the nearest DWD station Göttingen, we  
27 additionally tested an altitude correction using the vertical temperature gradient of  $-0.0065\text{ °C}$   
28  $\text{m}^{-1}$  to account for 158 m altitude difference between Göttingen (167 m a.s.l.) and  
29 Reiffenhausen (325 m a.s.l.). Deviations in DOY of LU are small when using the DWD  
30 temperature instead of the local measurements. Interestingly, the altitude correction of  
31 temperature increases differences in DOY of LU comparing to observations. The reason could  
32 be the often occurring thermal inversion, when the air temperature in Reiffenhausen is higher

1 than in Göttingen, so that implemented altitude reduction of temperature increases the  
2 differences even more, due to that also the differences of the estimated DOY of LU increase.  
3 The effects of the altitude correction are larger for the Max1 than for the IPG235 parameter  
4 set, because our model is more sensitive to extreme values due to higher  $T_0$  and lower  $T_l$   
5 temperatures. This shows the importance of applying the local temperatures, associated to the  
6 phenological observations, to calibrate and use the temperature-dependent phenological  
7 models. The use of local temperatures improves the estimation of LU and better represents  
8 inter annual variability.

9 According to the criteria of Moriasi et al. (2007), the hydrological model results, using  
10 measured values of LAI and Rsc (start and development of LU is implemented), are  
11 satisfactory only for the simulation LI191SA with  $Rsc = 80 \text{ s m}^{-1}$ . The simulation using the  
12 LAI values from the LAI2000 fails to satisfy the recommended criteria (Tab. 4). However the  
13 model produces better agreement with observations when Rsc minima of  $40 \text{ s m}^{-1}$  are used  
14 with any LAI data. The reduction of Rsc is a consistent way to simulate the observed soil  
15 water conditions. An increase of LAI could lead to lower soil water contents as well, but is  
16 also effecting soil evaporation and interception evaporation. Additionally larger values for  
17 LAI, necessary to minimize the model deviations to measurements, have to be unrealistically  
18 high for the poplar SRC investigated here. When using a Rsc minimum of  $40 \text{ s m}^{-1}$  together  
19 with measured LAI the model evaluation is good for the year 2013, reaching NSC values of  
20 0.87 and 0.89 for the LAI2000 and LI191SA simulations.

21 Data of such intense measurement campaigns are not available for all sites where hydrological  
22 modelling should be done. Therefore literature values, often providing maximum or minimum  
23 values for LAI and Rsc only, are used and the annual course has to be modelled. The question  
24 of transferability of these values to different sites, years or even species has to be solved. The  
25 applied step function is the simplest approximation of the annual course for LAI and Rsc.  
26 These simulations also pass the recommended criteria for a satisfactory model performance  
27 (Tab. 4).

28 For the year 2013 the best model fit could be obtained by the adjusted annual courses for LAI  
29 and Rsc. They are based on the observed course and maximum values of LAI measurements.

30 The weather regime and therefore the development of soil water conditions are not suitable in  
31 2013 to show the effects of different estimates for the start of LU in spring. Drought  
32 conditions started not until July 2013. Therefore we performed scenario simulation by

transferring the vegetation parameterisation for 2013 to the weather regime of 2012. This year was characterized by a drought period in spring. In consequence the effects of different estimates of DOY of LU are pronounced. The adjusted simulations using the IPG235 parameters to estimate LU, i.e. later LU by approx. 30 days in 2012 show GWR in this year. Due to the delayed start of the growing season the drought stress in spring is missed in the model mostly, leading to wetter soil conditions which benefits percolation and rewetting and finally enlarges GWR (Fig. 7). The tensiometer measurements available for 2012 suggest that GWR is rather unlikely for this year. The step function simulation using the IPG235 parameters for LU and both adjusted simulations (Max1 and IPG235) result in zero GWR for the year 2012. However, the strongest simplification of the course of LAI and Rsc, i.e. the step function, shows the lowest GWR for 2013 and for the long term simulations (Tab. 5).

In Fig. 7 the effects of the different simulations on GWR are presented for the years 2012 and 2013, which are characterized by rather different weather regimes. Whereas a realistic description of LAI and Rsc seems to be less important in 2013, it is even more essential in 2012, showing the importance of distinct spatial and temporal characteristics for local modelling.

We performed a long term simulation, by keeping the parameterisation for the vegetation constant for the period 1969-2013 to account for the effects of climate variability. This is a more theoretical scenario, because it accounts for changes in climate forcing only. In reality also the vegetation characteristics are changing over the years, as well as soil properties on a longer time scale, especially for SRC, whereas rotation cultivation is applied, e.g. harvesting and resprouting. Particularly the rotation cultivation can reduce extreme drought conditions, when dry years coincide with rotation stages that have a lower water demand. The vegetation parameterised here can be seen as fully developed in hydrological terms, characterized by a large water demand. The simulations here are rather artificial, especially by succeeding dry years when soil water storage is not refilled completely in winter and drought conditions are influencing the following growing season. Nevertheless the effects caused by different descriptions of vegetation parameterisations are quiet large (Tab. 5). Especially on a local scale such differences can be important by evaluating effects of land use change, particularly in dry years.

Taking into account, that the best model evaluation for 2013 is achieved with the adjusted course of LAI and Rsc, the adjusted simulation using the Max1 phenology parameters seems to be the most reasonable parameterisation. It fits best to the evaluation in 2013.

## 5 Conclusions

For hydrological analysis of some area or sites with the focus on land use change or climate change the adequate parameterisation of the vegetation cover is important by determining processes like soil evaporation, interception evaporation and transpiration. Sources of model parameters for the vegetation cover are local measurements or scientific literature. The analysis shows simulation uncertainties evolving from the use of model parameters that are derived from i) non-local measurements or ii) some appropriate literature values.

Answering objective 1 our study shows that LAI, Rsc as well as the beginning and length of growing season are very sensitive parameters when effects of an enhanced cultivation of SRC on local water budget are investigated. Particularly, it reveals that correct information about the beginning of the growing season is highly important to obtain correct and acceptable simulation results of evapotranspiration components and GWR. If the start of growing season is misclassified such as shown for the different species as in the IPG235 and Max1 parameterisation (Tab. 1), the accuracy of other parameters, i.e., LAI and Rsc; plays a minor role. Concerning GWR, LU is the most sensitive parameter. Its parameterisation is particularly important when inter annual variations and hydrological extreme conditions are on focus.

The implementation of locally measured vegetation parameters for hydrological modelling has both advantages and drawbacks. Measurements are expensive, time consuming and also not always feasible. In such cases the use of appropriate literature values and transposition of adjacent observations is necessary and common practice.

The present study displays for the parameter LAI, that the simulations using locally measured plant specific values show the suitability of data. The comparisons between locally measured and adjusted parameter sets reveal that simulation results are less affected by other model parameters, like Rsc or LU, when using adjusted parameters of LAI.

Contrary results appear for Rsc. Simulation results differ significantly when site specific values of Rsc are available. However, for Rsc the benefit of direct use of local measurements is arguable: minimum has to be reduced within WaSim to produce model results comparable



1 with soil water measurements. In consequence the implementation of Rsc values from  
2 literature for hydrological modelling without accompanying measurement data for model  
3 evaluation can produce very uncertain results. The analyses done here illustrate that the  
4 locally adjusted vegetation parameterisation shows the best model fit. Additionally the  
5 adjusted course of LAI and Rsc is less sensitive to different estimates for LU, due to a slower  
6 increase in spring compared to a step functional annual course. But the adjusted courses are  
7 also approximations and not a distinct measure and are therefore more generally valid for  
8 different sites and years, than a direct use of measured parameters.

9 For the land use poplar SRC there are certain years where the modelled GWR is reduced to  
10 zero, like in the year 2012 (Fig. 7). Different parameterisations for vegetation characteristics  
11 are influencing modelled GWR for those years producing a wide range from GWR present or  
12 completely absent.

13 Hydrological models are often used to analyse effects of climate and land use changes on  
14 spatial and temporal scale becoming smaller and smaller. Approximations in the description  
15 of vegetation, a lack of local information (also soil and climate description), the transfer of  
16 inappropriate parameters and lacks in model formulation can cause large differences in  
17 simulation results. To account for small-scale and local effects of land use change more  
18 detailed descriptions of sites and processes are necessary to capture the spatial and temporal  
19 variability of effects. Especially when analysing extremes, they are often underestimated  
20 when the description of site and processes are insufficient.

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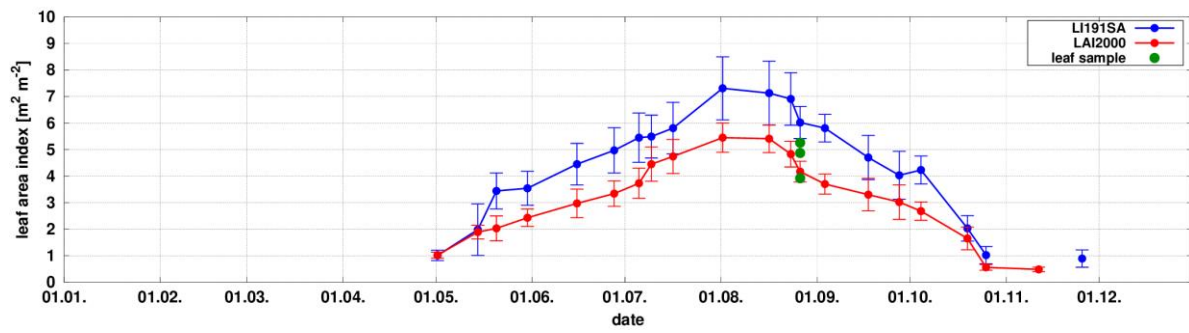
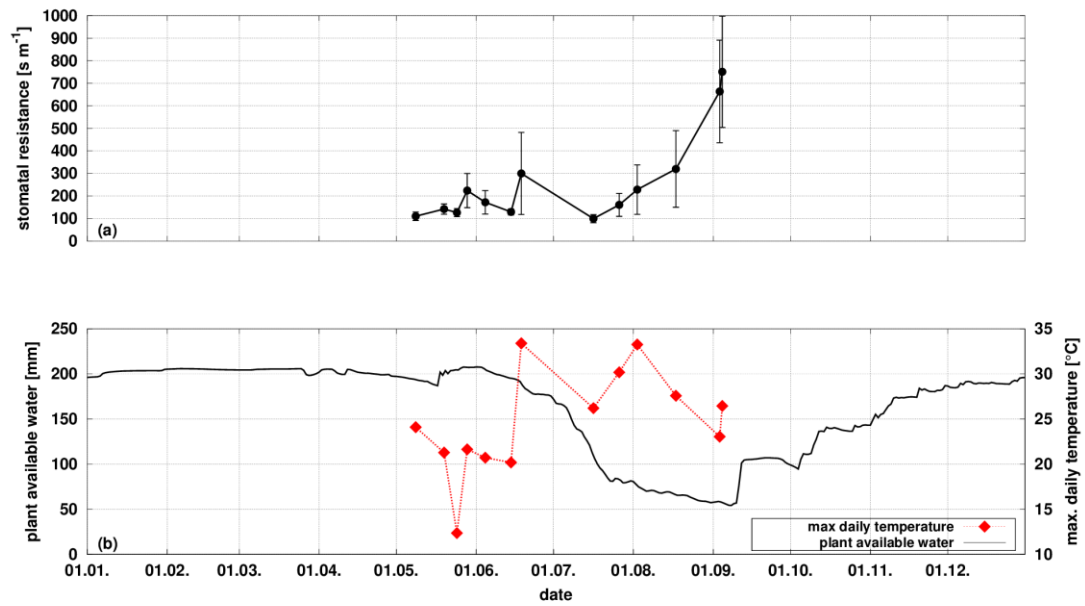




Figure 1. Means and standard deviations of leaf area index of the poplar SRC Reiffenhausen in 2013. Measurements of two optical devices: LI191SA calculated with constant extinction coefficient  $k = 0.5$  and LAI2000 are shown. LAI values obtained by destructive harvesting at the 26 August on three plots are shown as green dots.



1  
2 Figure 2. Means and standard deviations of stomatal resistance of sun leaves derived from 10  
3 to 11 repetitions every day at 10 measurement plots and (a) the plant available water,  
4 calculated from soil water content measurements until 1 m soil depth and (b) daily maximum  
5 temperature at the poplar SRC Reiffenhausen in 2013. High temperatures effecting stomatal  
6 resistance (18 June); starting from August drought stress occurred, increasing the stomatal  
7 resistances.



1 Table 1. Parameters of the modified approach for estimating leaf unfolding (LU) according to  
 2 Cannell and Smith (1983), which is used in WaSim. Estimated day of years (DOY) of LU for  
 3 Reiffenhausen (2012 and 2013) are used to calibrate the Max1 parameters  $T_0$ ,  $T_1$ ,  $a$  and  $b$ , i.e.  
 4 threshold temperature for chilling units and forcing units and two ~~tree specific~~ regression   
 5 parameters, respectively. Additionally the parameter set for IPG235 according to (Menzel,  
 6 1997) (appendix A7) is shown.

Parameter	Max1 	IPG235 (Menzel, 1997)
$T_0$ [°C]	10	8
$T_1$ [°C]	2	5
$a$	2200	1693.4161
$b$	-403	-301.9361

7

1 Table 2. Observed and estimated day of years (DOY) of leaf unfolding (LU) for  
2 Reiffenhausen and Großfahner. The Max1 parameters are calibrated at the observations in  
3 Reiffenhausen using local temperatures (2012 and 2013) and evaluated with Reiffenhausen  
4 (2014) and Großfahner (2012 – 2014). Additionally the DOY of LU is compared to estimates  
5 using the IPG235 parameter set as well as the temperatures of the nearest DWD climate  
6 station (Göttingen for Reiffenhausen, distance approx. 17 km; Dachwig for Großfahner,  
7 distance approx. 3.5 km) are presented.

	observed	Max1	Max1	IPG235	IPG235
temperature data		local	nearest DWD	local	nearest DWD
Reiffenhausen DOY 2012	88	91	89	119	121
Reiffenhausen DOY 2013	115	112	112	125	126
Reiffenhausen DOY 2014	83	82	85	111	113
Großfahner DOY 2012	88	89	88	111	112
Großfahner DOY 2013	114	113	112	121	121
Großfahner DOY 2014	89	-	86	-	103

8

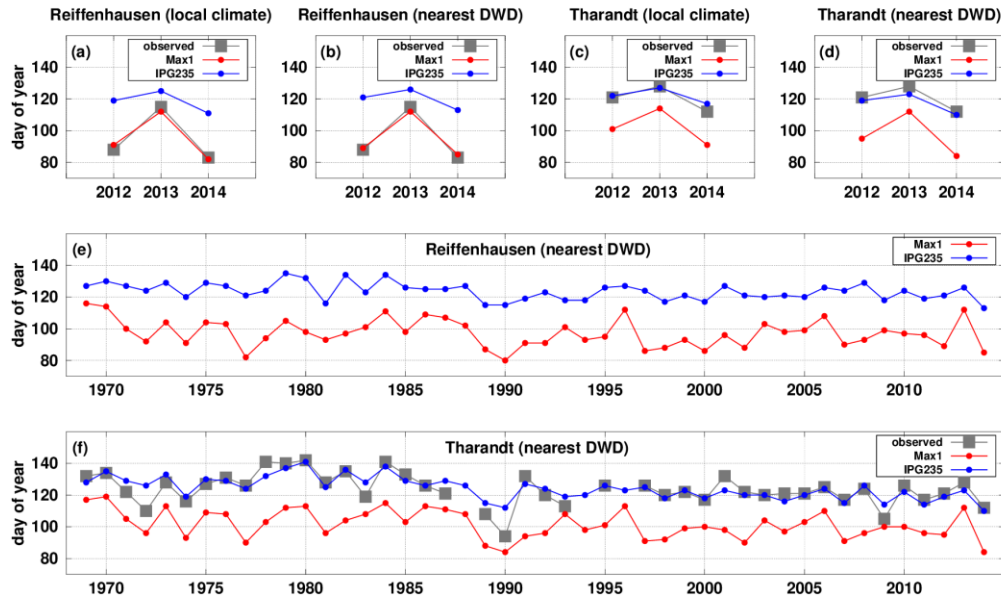


Figure 3. Estimated day of year (DOY) of leaf unfolding (LU) using the Max1 and IPG235 parameters for the site Reiffenhausen with local temperature measurements (a) and temperatures from the nearest DWD station Göttingen (b) for the years 2012 to 2014; same for Tharandt, local temperatures (c) and nearest climate station Wildacker (d); with observations. The lower subplots show long term estimates for DOY of LU using the DWD temperatures for Reiffenhausen (e) and for Tharandt (f), where also long term observations are available.

1 Table 3. Description of the eight performed model simulations. All model parameters are  
2 constant, except leaf area index (LAI), stomatal resistance (Rsc) and the date of leaf unfolding  
3 (LU) for the two parameter sets Max1 and IPG235.

version	LAI	Rsc	LU
LAI2000 Rsc80	LAI-2000 measurements	minimum 80 s m <sup>-1</sup> (LAI > 1)	defined by measured LAI
LAI2000 Rsc40	LAI-2000 measurements	minimum 40 s m <sup>-1</sup> (LAI > 1)	defined by measured LAI
LI191SA Rsc80	LI-191 SA measurements	minimum 80 s m <sup>-1</sup> (LAI > 1)	defined by measured LAI
LI191SA Rsc40	LI-191 SA measurements	minimum 40 s m <sup>-1</sup> (LAI > 1)	defined by measured LAI
LAIstep Rsc40 Max1	step function (6 in growing season; else 1)	minimum 40 s m <sup>-1</sup> (LAI > 1)	Max1 model
LAIstep Rsc40 IPG235	step function (6 in growing season; else 1)	minimum 40 s m <sup>-1</sup> (LAI > 1)	IPG235 model
LAIadjusted Rsc40adjusted Max1	course calibrated to improve model fit (max. = 6)	minimum 40 s m <sup>-1</sup> (LAI > 1)	Max1 model
LAIadjusted Rsc40adjusted IPG235	course calibrated to improve model fit (max. = 6)	minimum 40 s m <sup>-1</sup> (LAI > 1)	IPG235 model

4

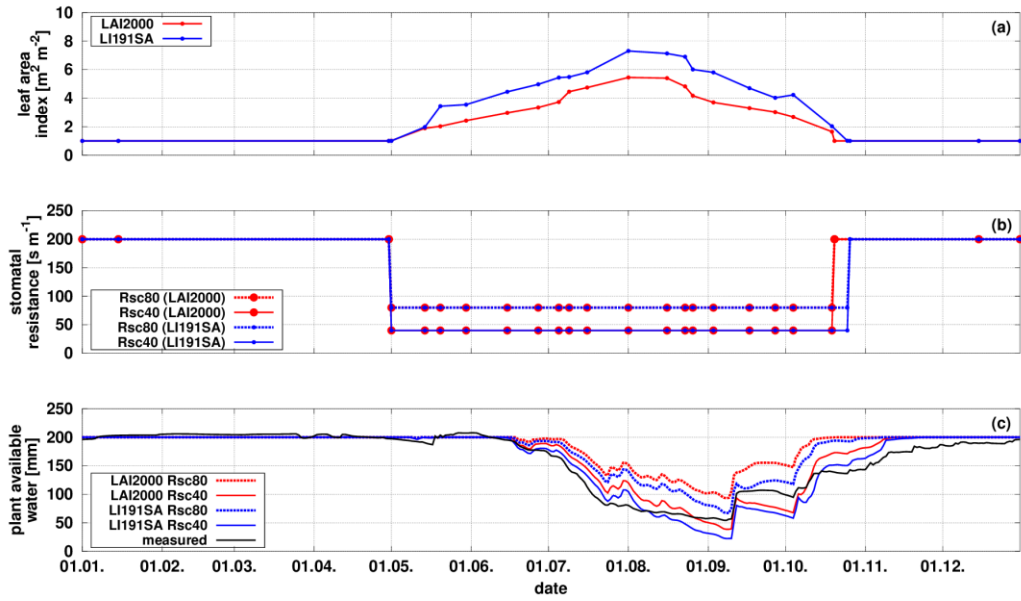
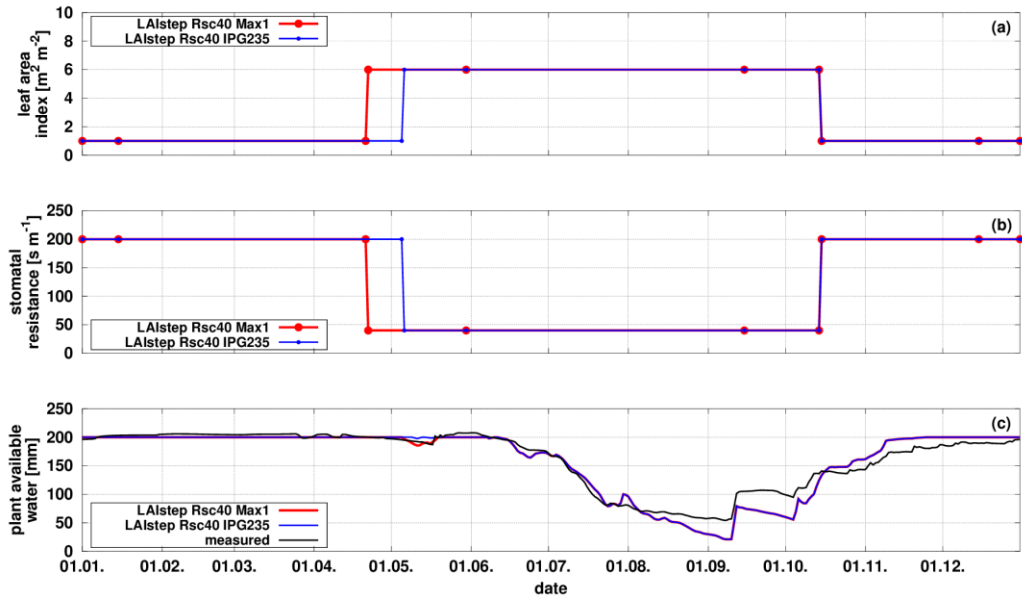


Figure 4. Leaf area index and stomatal resistance as parameterised from measurements. Leaf area index is used as measured, LAI2000 (red) and LI191SA (blue). Stomatal resistance is set to the measured minimum, i.e. 80  $\text{s m}^{-1}$  (dashed line) and to 40  $\text{s m}^{-1}$  (solid line) as leaf area index is larger than 1. Length of growing season is determined by the leaf area observations. Simulation results using the four combinations of leaf area index and stomatal resistance are shown as plant available soil water, calculated until 1 m soil depth and compared to values based on soil water content measurements.

1 Table 4. Statistical parameters for model evaluation in terms of the accuracy of simulated data  
2 compared to measured values. Nash-Sutcliffe efficiency criterion (NSC), percent bias  
3 (PBIAS), and ratio of the root mean square error to the standard deviation of measured data  
4 (RSR) are calculated from plant available soil water till 1 m soil depth as derived from model  
5 simulations and soil water content measurements for the period from April till December  
6 2013, to cover the period of most variability.

	NSC	RSR	PBIAS [%]
Recommended as satisfactory by (Moriassi et al., 2007)	$> 0.5$	$\leq 0.7$	$\pm 25$
LAI2000 Rsc80	0.44	0.75	19.2
LAI2000 Rsc40	0.87	0.37	5.5
LI191SA Rsc80	0.69	0.56	13.9
LI191SA Rsc40	0.89	0.33	0.0
LAIstep Rsc40 Max1	0.89	0.33	-2.0
LAIstep Rsc40 IPG235	0.89	0.33	-1.7
LAIadjusted Rsc40adjusted Max1	0.90	0.31	1.3
LAIadjusted Rsc40adjusted IPG235	0.90	0.31	1.6

7



1

2 Figure 5. Leaf area index and stomatal resistance parameterised as step function, using  
3 maximum and minimum values in the growing season 2013, respectively. LAI is set to 6,  
4 stomatal resistance is set to 40 s m<sup>-1</sup> when LAI is larger than 1. Leaf unfolding (LU) is  
5 determined by the dynamic phenology approach implemented in WaSim, using the Max1  
6 parameterisation and IPG235. Simulations results using the two combinations of LAI and  
7 stomatal resistance are shown as plant available soil water, calculated till 1 m soil depth and  
8 compared to values based on soil water content measurements.

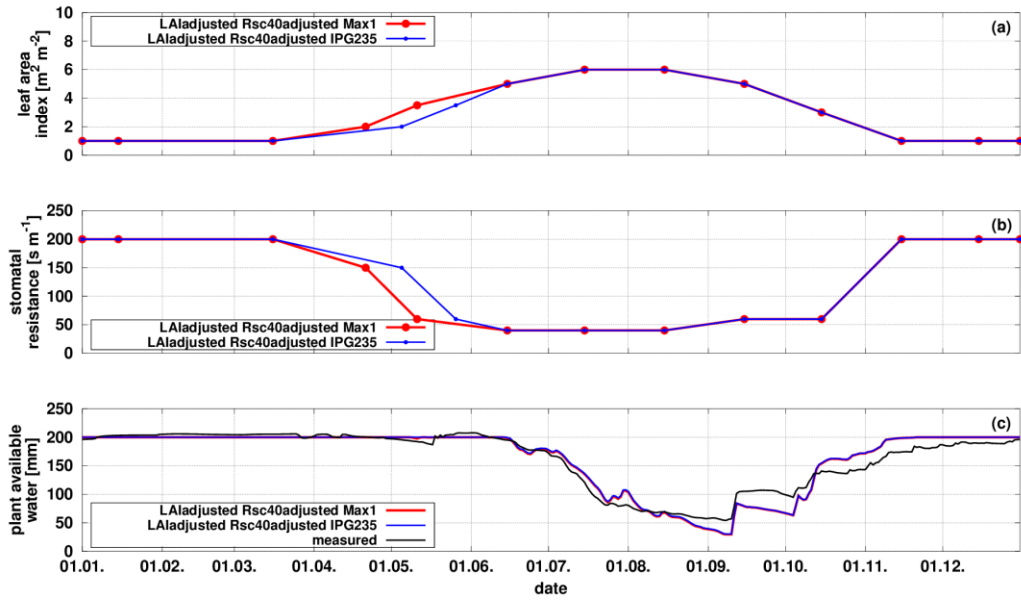


Figure 6. Leaf area index and stomatal resistance as parameterised from adjusted values for 2013. Maximum of leaf area index is set to 6, minimum of stomatal resistance is set to 40 s m<sup>-1</sup>. Leaf unfolding (LU) is determined by the dynamic phenology approach implemented in WaSim, using the Max1 and IPG235 parameterisation. The annual course of leaf area index and stomatal resistance is orientated on measurements for leaf area and used as calibration parameter for stomatal resistance. Simulations results using the two combinations of leaf area index and stomatal resistance are shown as plant available soil water, calculated till 1 m soil depth and compared to values based on soil water content measurements.



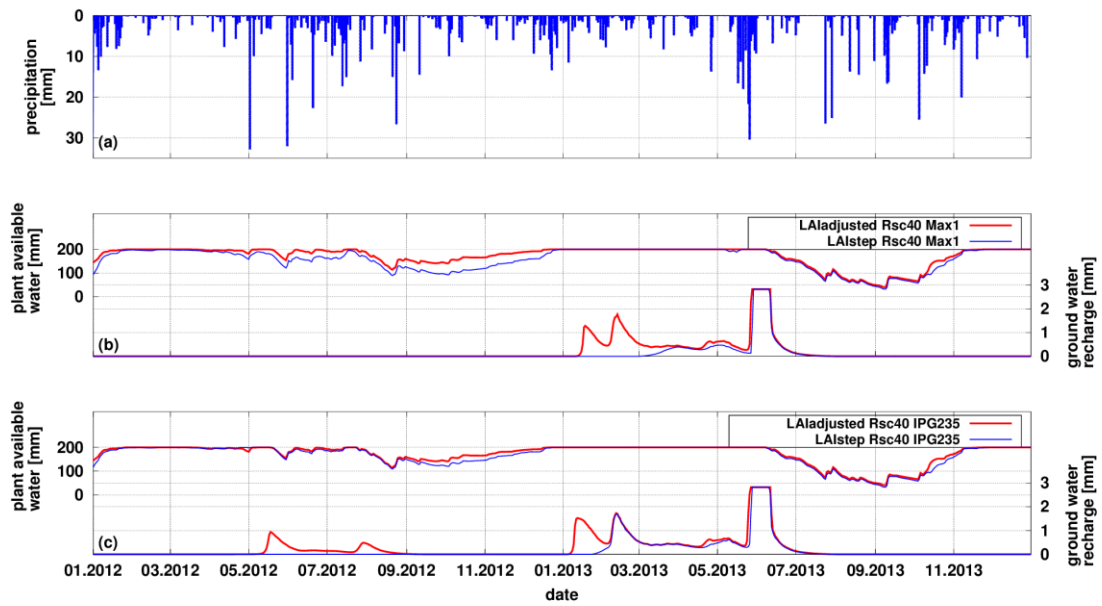


Figure 7. Measured daily precipitation (a). Plant available water and ground water recharge as simulated for the step-function and adjusted course for leaf area index and stomatal resistance, using the leaf unfolding (LU) parameters Max1 (b) and IPG235 (c) for simulating LU. The parameterisation for poplar is equal for 2012 and 2013, i.e. the same vegetation hydrological modelled driven by different weather conditions, i.e. a drier year 2012 with an earlier dry period in May.

1 Table 5. Precipitation ( $\text{mm year}^{-1}$ ), total evapotranspiration (ETR) and ground water recharge  
2 (GWR) for the period 1969-2013. Simulations are shown for the step-function simulation and  
3 the adjusted course for leaf area index and stomatal resistance, using the leaf unfolding (LU)  
4 according to the Max1 and IPG235 parameter set for simulating LU. The parameterisation for  
5 poplar is equal to that derived for 2013 for the whole period, i.e. the same vegetation  
6 hydrological modelled driven by different weather conditions. Values are summed up for all  
7 years (1969-2013) of the period and for the 5 driest and 5 wettest years, respectively.

	ETR	ETR	ETR	GWR	GWR	GWR
	(all years)	(5 driest)	(5 wettest)	(all years)	(5 driest)	(5 wettest)
precipitation	676.7	500.4	896.6	676.7	500.4	896.6
LAIstep						
Rsc40	527.8	487.1	533.6	79.7	23.2	140.2
Max1						
LAIstep						
Rsc40	488.5	463.0	482.6	105.0	37.9	170.4
IPG235						
LAIadjusted						
Rsc40adjusted	484.1	460.8	477.9	107.1	41.3	173.9
Max1						
LAIadjusted						
Rsc40adjusted	425.9	424.4	411.7	144.7	68.1	232.9
IPG235						