Author's point-by-point reply to reviews of: An alternative approach for socio–hydrology: case study research, Erik Mostert

First of all, I would like to thank the two reviewers for the reviews they provided. These have helped me to improve the paper. Before going into detail, it may be useful to outline the main changes:

a. The Dommel case study has been extended and restructured. It now goes into much more detail, uses more sources, and follows the structure proposed in the previous section. Moreover, a case study conclusion has been added and the case is compared more systematically with the Kissimmee model.

b. The discussion and conclusion sections have been combined and now discuss the general issue of coupled models versus (or: and) case studies.

c. The abstract has been rewritten to better reflect the new version of the paper.

The structure of the first three sections has not changed, but some important improvements have been made. These are outlined below. Because of all the changes, including many moved text and minor editorial improvements, I do not recommend to read the marked-up manuscript version, attached to this reply..

Anonymous Referee #1

1. I welcome this paper, it attracts attention to an area that has not been well covered in the literature.

Reaction: Thanks for the appreciation.

2. But I believe the paper is based on a false or ill-informed premise. By calling it "an alternative approach", the author claims he is proposing something that was not previously known to people working in socio-hydrology. This is false (...).

Reaction: In the revised version I have tried to prevent any suggestion that case study research is completely new to socio–hydrology. My main conclusion is that case studies deserve "more" attention, which I also mention in the abstract and the introduction. Moreover, in section 2 I have added references to four previous socio-hydrological case studies, and in section 4.5 I discuss what new insights the Dommel case study brings.

3. (H)e might have got this impression from selective reading of the literature. I see that much of the literature he cites is work on the "levee effect". It is true that this research started from conceptual modeling, which were not necessarily inspired from actual case studies or data arising from them. In reality, there is a branch of socio-hydrology, that on human-environment competition for water in the context of irrigated agriculture. Most/all of these based on real case studies. These include the work of Kandasamy et al. (HESS) and Liu et al. (HESS, China). Early papers were data-based historical narratives, which generated ideas and hypotheses, which were followed by modeling studies (van Emmerik et al, HESS, Liu et al., HESS). There were other studies like Elshafei et al (HESS, WRR) which

were inspired by previous historical studies/narratives. Chen et al. (WRR, Florida) is another work which combined data analysis and modeling in a real case study. The work of Srinivasan (HESS) was a study that indeed a case study focused on a city, combined with modeling. It also included multiple social actors. These studies were followed by the review paper of Sivapalan and Bloeschl (2015) who provided guidance to socio-hydrology studies, one element of which was indeed the generation of narratives based on real case studies and expressing these in terms of unexplained phenomena (either local or universal) which will then generate the hypotheses to be explored through modeling studies.

Reaction: I have tried to make clear that I do not focus specifically on the levee effect. In the new introduction I make clear that my review of the socio-hydrological literature in section 2 focuses on the coupled models that have been made and I have also added "modelling" in the heading of section 2. These models include not only models of the levee effect but also models of human-environment competition for water and the pendulum swing from development and control to protection and restoration. Section 4.1 discusses one model of the pendulum swing in detail (Chen et al.). Moreover, in section 5 I have added a discussion of how coupled models and case studies can be combined, mentioning Kandasamy and Van Emmerik et al. as an example.

4. Having said that, I will welcome it if the author takes the idea of case studies to expand into territory not well covered in previous studies, including modeling studies. I do completely accept the point that in previous studies the social aspect may have been lumped into one abstract concept of a social variable (flood memory in levee effect papers, community sensitivity). It can be disaggregated into different parts of the social system, which might also include governance systems. If this is what he wants to do, then by all means illustrate this through an example case study, and demonstrate either conceptually, through modeling or through data analysis, why any conclusions one makes can be seriously impacted by the lumping.

Reaction: This is indeed what I intend to do by means of the Dommel case study. I have completely rewritten the case study and expanded it a lot. Section 4.5 provides an answer to the question "why any conclusions one makes can be seriously impacted by the lumping." In one sentence: crucial variables and processes may be missed. As discussed in section 2, a good match between model results and data does not necessarily mean that all crucial variables and processes have been included. It could be that crucial variables and processes did not change in the area and period covered, it could be that the model includes many variables for which no data are available and consequently has many degrees of freedom, and it could be a combination of both.

5. Unfortunately, even when the author presents a case study, the paper goes back to theoretical and philosophical issues and does not deliver anything new that I did not know already. I do not like to more criticism, discussion and philosophy - I want real case studies from which I can learn something that I do not know already. I guess that might mean a totally different approach to presenting this paper, more data analyses or building of conceptual models inspired by a real place/case study - this calls for major revision

Reaction: I hope the extended discussion of the Dommel can count as a real case study. Moreover, I have limited criticism, discussion and philosophy to the final discussion section, which discusses the relative pros and cons of case study research and coupled modelling, their fundamental differences, and the possibilities to combine them.

Anonymous Referee #2

6. Mostert argues for an increased focus on detailed case study research in the field of socio-hydrology. He reviews the socio-hydrology literature noting the modeling focus. He then presents case study research as an alternative approach and compares the advantages and disadvantages of the two approaches. As an example of case study research in socio-hydrology, Mostert describes the case of Dommel Basin, located in Belgium and the Netherlands. Mostert details the limitations of modeling and demonstrates that a diversity of approaches is needed to understand complex sociohydrological systems. The manuscript makes an important point and the topic is of interest to Hydrology and Earth Systems Science readers but discussion of existing socio-hydrology case study research and more support of the methods, advantages, and disadvantages of the case study approach is needed. I have a series of specific comments that, if addressed, would strengthen the paper:

Reaction: I appreciate the overall assessment. I agree there were areas for improvement, and I thank the reviewer for pointing these out. Below, I indicate how I have addressed the more specific comments.

7. In the discussion socio-hydrological research approaches, the author focuses on modeling which he characterizes as the dominant approach. However, there are examples of case study research in socio-hydrology and a more nuanced discussion that discussion these examples and their strengths and weaknesses is needed (Gober and Wheater 2014; Kandasamy et al., 2014; Liu et al. 2014; Treuer et al., 2017).

Reaction: In section 2 I now mention four socio-hydrological case studies explicitly, and in section 4.5 I briefly compare the Dommel case study with these studies.

8. Additionally, there are numerous examples of case study work aiming to address questions relevant to socio-hydrology that are not explicitly categorized as socio-hydrological research. Acknowledging these efforts would further illustrate the potential of socio-hydrological case study research and point researchers to related work not yet well integrated in to sociohydrology (for a few examples see: http://sfwsc.fiu.edu/Research_Questions.html, https://www.nsf.gov/awardsearch/showAward?AWD_ID=1204685, https://www.nsf.gov/awardsearch/showAward?AWD_ID=0948914 (missing from the last list: Mini et al. 2014)).

Reaction: I have tried to acknowledge the importance of work not yet well integrated in to socio-hydrology. The new case study conclusion (section 4.5, last paragraph) emphasizes the importance of older literature on specific basins and of water management and social science more generally, and mentions a few examples. Other examples can be found throughout the paper, e.g. in the very first paragraph. In the penultimate sentence of the paper I conclude that case studies are a good vehicle for bringing together literature, experts and insights from many different disciplines.

9. On page 3, the author notes that moving beyond the scale of the river basin to incorporate factors such as trade would necessarily result in more complex models. Model complexity should correspond with the model aims not model scale, a point which both references cited make (Pande and Sivapalan 2016, p13; Srinivasan et al. 2017, p5). Please revisit this point.

Reaction: I have changed the formulation of the sentence: “Unless one simplifies in other respects, this actually results in more complex models.” I agree that model complexity should correspond with model aims, but data availability is a limiting factor, and if one incorporates additional factors, other factors should be excluded if one does not want to increase complexity.

10. In section 3, the author describes the case study approach. This section is central to the author’s message but there are notably few references here. Further examples of case study research that demonstrates the use of alternate data types, the range of questions addressed, theory guided analysis, and case selection. In particular, the discussion of case study selection criteria is an important one that is need of expansion. While the two methodological references provided are useful, examples of each of the case study selection strategies are needed. These examples need not be from water resources if more appropriate examples are found in other fields (energy).

Reaction: Referencing has been improved. I have added references to examples of case selection strategies, as well as some methodological references that I find particularly useful. Concerning the data sources that can be used I refer to the Dommel case study, which in effect uses many. The purpose of the section is not to discuss case study research extensively, but to introduce the approach and specify it for socio-hydrology, e.g. by proposing three central questions. The central section in the paper is the expanded section 4: the Dommel case study.

11. In section 4, the author presents the case of the Dommel Basin. The addition of a case study example is welcome here but the case as currently presented is weak. A stronger example would demonstrate the general points made in section 3 (i.e. range of research questions that case studies can address, integrating different data types, selecting case(s), etc.) rather than again stating these points. Revising this case to illustrate how the case study approach enables a more nuanced understanding of the shift from development to restoration, how different data types can be combined and why this case was selected would strengthen this example. Further, continuing the comparison between the Kissemee model and the Dommel Basin case to the discussion of findings would improve this discussion.

Reaction: The Dommel case study has been completely rewritten. It now contains references to several data sources: old maps, the archives of government bodies, old census data, topographical descriptions, newspaper reports, old consultancy reports and other studies. The structure of the Dommel case study has been brought in line with what is proposed in section 3, with separate sub-sections for each central question (4.2: main activities, 4.3: main actors, and 4.4: main factors). The Dommel basin is first introduced as a “typical example” of the pendulum swing. This is the first option for selecting cases mentioned in sect. 3. Moreover, the comparison between the Kissimmee model and the Dommel case study is continued into section 4.5 with the case study conclusion. Information that was repetitive has been removed.

12. The author makes the important point that many socio-hydrology articles use modeling for inference but that a diversity of approaches is beneficial. However, the author presents modeling and case studies as the only two options for socio-hydrological research. Other approaches, such as large-N statistical studies, are also not widely used in socio-hydrology and have certain advantages and disadvantages (i.e. Hornberger et al. 2015). Other approaches beyond case studies and modeling should be acknowledged and the reason for the focus on case studies clarified.

Reaction: A paragraph has been added in the final section that discusses other approaches and gives some examples, including Hornberger et al. (2015). Moreover, it states that “the reason why this article focused on coupled modelling and qualitative case study research is that coupled modelling is the most popular approach in socio–hydrology and qualitative case study research is a contrasting approach with many potential benefits.”

13. The author rightly notes limited generalization as one drawback of the case study approach but it is worth mentioning here that there are efforts to address this challenge in socio-hydrology through meta-analysis of case studies and by synthesizing quantitative and qualitative data from case studies (Srinivasan et al. 2012; Treuer et al., 2017).

Reaction: Both references have been added in section 3: Srinivasan et al. (2012) as an example of a meta-analysis of published case studies, and Treuer et al (2017)as an example of the use of theory in case studies.

14. On page 2 line 8, and again on page 3 line 1, the term “socio-ecological” should read “socio-hydrological.”

This has been corrected.

An alternative approach for socio–hydrology: case study research

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Abstract. Currently the most popular approach in socio hydrology is to develop coupled human–water models. This paper argues forarticle proposes an alternative approach for socio–hydrology: detailed, qualitative case study research. Currently, the dominant approach in socio–hydrology is developing coupled human–water models. With very few exceptions, these models treat society as one actor or asThis involves a groupsystematic review of individual 1) the human activities affecting the hydrology in the case, 2) the main human actors, and do not include management structures3) the main factors influencing the actors and processes.their activities. Moreover, there is a shortage of data to calibrate and validate the models. Detailedthis article presents a case study of the Dommel basin in Belgium and the Netherlands, and compares this with a coupled model of the Kissimmee basin in Florida. In both basins one can observe a "pendulum swing" from water resources development and control to protection and restoration. The Dommel case study points to the importance of institutional and financial arrangements, community values and broader social, economic and technical developments. These factors are missing from the Kissimmee model. Generally, case studies of individual river basins can be of help in these respects. They can result in a more complete understanding of how society interacts with hydrology and can help to identify new data sources. In addition, they canindividual cases than coupled models, and if the cases are selected carefully and compared with previous studies, it is possible to generalise on the basis of them. Case studies also offer more levers for management and facilitate interdisciplinary cooperation. Two questions should be central: which human activities have had a significant impact on the hydrology of the case study area, and which factors can explain these activities? To give an idea of what a socio–hydrological case study may look like and what its potential benefits are, this paper presents a short case study of the Dommel Basin in the Netherlands and Belgium and compares this with a typical socio–hydrological model. The paperCoupled models, on the other hand, can be used to generate possible explanations of past developments and quantitative scenarios for future developments. The article concludes that there is room for different approaches in socio–hydrology. However, given the limited attention they currently get, and their potential benefits, case studies deserve more attention should be paid to developing detailed case studiesin socio–hydrology.

1 Introduction

Suppose you are interested in how river basins and human society interact and evolve together. And suppose you are interested especially in the Great Ouse Basinbasin in the east of England. How would you study this basin? One option would be to set up a large interdisciplinary research project that studiesto study the topography and geology of the basin, and the formation of peat soils since 6000 BC,; the first human interventions, in the Neolithic, Roman and Mediaeval period; the 17th

Century drainage works~~,~~ and the resulting peat shrinkage and wastage~~,~~; the subsequent ~~water management~~ works~~,~~ to cope with the increasing flooding problems; the changing governance structure to ~~undertake and finance~~make these works~~,~~ possible; the changing economy of the basin~~,~~; and the ~~changing influence~~role of politics and agricultural lobbies (e.g. Godwin, 1978; ~~Darby, 1983;~~ Richardson et al., 1978; Darby, 1983; Hall and Coles, 1994; Sheail, 2002; Purseglove, 2015; Mostert, ~~2017~~2017a). This would involve extensive literature search and a lot of field work and archival research.

Another option would be to model the co–evolution of water and society~~ in the Great Ouse Basin.~~. Using insights from previous research on ~~this~~ the Great Ouse basin and ~~other~~ comparable basins, a coupled human–water model could be developed, which could then be calibrated and validated in order to simulate past and predict future developments. Alternatively, the coupled model could be used as an exploratory toy model to generate possible explanations and ~~identify possible~~develop scenarios for future developments.

~~In socio–hydrology the~~ The most popular option in socio–hydrology currently is ~~to develop~~the second one, developing coupled models. In this paper I argue for more ~~detailed~~attention for the first option, qualitative case study research. ~~To give an idea of what a~~ I will first briefly review the current socio–hydrological models, focusing on how society is included, and propose a specific type of case study ~~may look like and what its benefits can be~~research as an alternative. Next, I will present a ~~short~~ case study of the Dommel ~~Basin~~basin in Belgium and the Netherlands ~~and Belgium~~since 1800 and compare this with a ~~typical socio–~~coupled model of the Kissimmee basin in Florida (Chen et al., 2016). Both basins are examples of the "pendulum swing" (Kandasamy et al., 2014) from water resources development and control to protection and restoration. In the Kissimmee model the pendulum swing is explained in terms of community sensitivity, but I intend to show that important elements are missing from this explanation. In the final section, I will discuss what the best approach for socio–hydrology is. I will discuss the key differences between qualitative case study research and coupled modelling, their comparative advantages and disadvantages, the possibilities to combine them, and whether there are any other approaches that could be used.

2. Socio–hydrological ~~model. In the concluding section I will discuss which of the two options is best and whether they are really different or complement each other. But first I will briefly review the state of the art in socio hydrology, focusing on how society is included in the different socio ecological models.~~modelling

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~~2. Socio–hydrology~~

The term socio–hydrology was coined in 2012 by ~~three well–known hydrologists (~~Sivapalan et al~~.,~~. (2012). ~~They~~It was defined ~~socio–hydrology~~ as "a new science of people and water" that aims at "understanding the dynamics and co–evolution of coupled human–water system" (Sivapalan et al., 2012, 1271). Socio–hydrology treats ~~people~~society as an endogenous part of the water cycle~~. It~~ and studies not only the impact of people on water, but also of water on people (e.g. Pande and Sivapalan, ~~2016~~2017). This would result in better understanding of long–term developments, better long–term predictions, and better support for water management than ~~for instance~~approaches that treat society as exogenous, such as scenario–based approaches~~ that do not consider hydrological constraints~~.

TheWhile there are some qualitative socio–hydrological studies (Wescoat, 2013; Gober and Wheater, 2014; Kandasamy et al., 2014; Liu et al., 2014), the dominant approach in socio–hydrology is developingto develop coupled human–water models. The number of thesesuch models is slowly increasing. The issues modelled include flooding (Di Baldassarre et al., 2013, 2017; Viglione et al., 2014; Grames et al., 20152016; Yu et al., 2017; Girons Lopez et al., 2017; Barendrecht et al., 2017),); water quality management (Chang et al., 2014),); reservoir operation (Garcia, 2016),); water supply (Srinivasan, 2015; Ali et al., 2017),); groundwater abstraction (Noël and Cai, 2017); land degradation (Elshafei et al., 2015), subsistence farming (Pande and Savenije, 2016), the shiftpendulum swing from water resources development and control to protection and restoration (Van Emmerik et al., 2014; Elshafei et al., 2014; Chen et al., 2016),; Roobavannan et al., 2017); and the collapse of civilisations (Kuil et al., 2016).

With very few exceptions, these studies model society as oneSociety is included in these different models in different ways. Most commonly, it is modelled as a homogenous actor (e.g. Elshafei et al., 2014; Van Emmerik et al., 2014; Viglione et al., 2014; Grames et al., 2016)). In a few cases it is modelled as one actor consisting of two segments (Chen, et al., 2016; Roobavannan et al., 2017), or as a group of individual actorshomogenous individuals (e.g. Pande and Savenije, 2016; Noël and Cai, 2017). Management structures and decision–making processes are rarelyseldom modelled. Yet, in practice it makes a big difference whether decisions are taken at the basin level, at the local or at the national level; which interests are involved and which not; who will benefit and who will have to pay; and whether there is strong sense of community or not (see Mostert, 2015, 2017). The importance of these issues is recognised in the socio–hydrological literature recognises the importance of these issues, but this recognition is rarelynot yet reflected in the coupled models that have been made. A very interesting, or only in a rather crude way, for instance in the form a fixed "cooperativity coefficient" (Elshafei et al., 2015, 6449). The only exception to date is the toy model by Yu et al. (2017), which analyses the issue why farmers in the polders in Bangladesh are willing to make voluntary contributions to the upkeep of the flood defences, even though when it seems economically rational for them to free–ride on the efforts of others.

Despite their simplifications, most socio–ecologicalhydrological models can mimic patterns that can be observed in reality. This could be because the models include many variables for which no data are available and consequently have many degrees of freedom (Troy et al., 2015). It could also be because the variables and processes not included did not vary a lot in the area and period modelled and consequently can reasonably be ignored (cf. Garcia et al., 2016).covered. Or it could be a combination of both. In any case,Whatever the explanation, the result is that the validity of the models outside of the area and period modelled is unclear and predictions based on them are highly uncertain.

Socio–hydrological systems cannot be modelled exhaustively, but it is important to include the most influential variables and processes (cf. Garcia et al., 2016). What these are dependsThese depend, first, on the issue of interest, which in turn depends on the disciplinary background of the researchers and the political and policy context (Lane, 2014). Secondly, they depend on the area and period studied. Societal response to hydrological change may be limited when the costs of action are individual but the benefits collective and when costs have to be made upstream but the benefits are downstream and when costs are individual but benefits collective. Response. Societal response will be bigger when there are strong community values (Yu et al., 2017; Mostert, 2017a) and when appropriate institutional arrangements are in place (e.g. Ostrom, 1990; Brondizio et al., 2009~~) and when there are strong collective values (Yu et al., 2017; Mostert, 2017).~~). However, such values and arrangements ~~and values~~ will not be present always and everywhere~~ and always. They~~: they have to be developed and maintained~~. Moreover, as~~ and adapted to changing conditions ~~change, they may no longer function satisfactory~~ and ~~may need to be changed or replaced or else may collapse~~needs (e.g. Mostert, 2012).~~[1]~~ ~~To complicate matters, these changes may be triggered by hydrological factors, such as droughts and floods, but also by factors that are not or only weakly connected with hydrology, such as population growth, increasing levels of education, technological development and political changes.~~

The socio–~~hydrology~~hydrological literature contains several recommendations for future research. A first one is public participation (Lane, 2014; Sivapalan and Blöschl, 2015; Srinivasan et al., 2017). Public participation can be a means to obtain data from the public, to educate them, and to promote buy–in of model results and subsequent decisions. In addition, it can be a means to involve the public in the modelling itself and give them control over what to model exactly and what (policy relevant) assumptions to use.

Another recommendation is to start modelling with clearly defining objectives and to include only the most influential variables and processes given these objectives. This would prevent overly complex models and promote transparency (Garcia et al., 2016). A quite different recommendation is to move beyond the scale of individual river basins and include more variables and processes, such as international trade and climate change (Pande and Sivapalan, ~~2016~~2017; Srinivasan et al., 2017). ~~All else being equal~~Unless one simplifies in other respects, this ~~would result~~actually results in more complex models.

A general recommendation is to collect ~~and use~~ more data (e.g. Troy et al., 2015; Blair and Buytaert, 2016). This is essential for calibration and validation and for preventing overfitting. Calibration and validation may be less important for exploratory toy models that do not aim to simulate specific systems accurately, but to capture essential processes and feedbacks, generate possible explanations and explore possible future developments (e.g. Thompson et al., 2013; Di Baldassarre et al., 2015, 2017; Yu et al., 2017). ~~Still, toy models need data too, at least qualitative data, to check how realistic they are~~Yet, they should be realistic, and to check this (qualitative) data will be needed.

~~[1] I will leave aside the question whether institutional arrangements can be designed (e.g. Ostrom 2005) or develop in practice (e.g. Cleaver 2002). The answer depends on whether one defines institutions as explicit agreements and enactments, or as types of practices. Moreover, it is not an either–or issue. To have any effect, agreements and enactments need be taken up in practice and become part of that practice. They may be used for purposes that differ from what they have been designed for (Cleaver 2002), but they can still have a large impact on practice.~~

3. ~~The~~Case study research

An alternative

~~Before adopting any recommendation for improving~~ approach to developing couples models is case study research. Case study research can be defined as a qualitative research approach in which a researcher studies one or more systems (cases) within their real-life context through in-depth data collection, using multiple sources of information. The aim is to achieve an in-depth understanding of the ~~current~~system or systems concerned (Yin, 1989; Creswell and Poth, 2017).

In socio~~-hydrological models, it is good to look whether there~~ hydrology the relevant systems to study are ~~alternative approaches. One alternative is~~ water and society and their interaction in a specific ~~form of case study research. It involves detailed research of the long-term developments in individual river basins or other hydrologically relevant units~~area, such as a ~~lake~~river basin or an aquifer area~~. It addresses two~~ , and over a long period. The central questions to ask are the following:

1) Which human activities have had a significant impact on the hydrology of the area?~~and~~

2) ~~Which~~Who were the main actors?

3) What were the main factors~~can explain~~, hydrological and other, affecting these actors and their activities?

The human activities ~~can~~ include all activities that significantly change land use, water use or water flows, such as deforestation, ~~surface and groundwater~~ water abstraction, ~~field~~ irrigation and drainage, ~~dredging, river regulation, hydropower generation and flood protection. These activities could be identified by hydrologists in cooperation with historians and social scientists. The latter are familiar with sources not often used by hydrologists, such as historical monographs, archival sources, newspaper articles and old maps (Zlinszky and Timár, 2013). For determining the impact of the different activities modelling can be useful, but the models do not need to be coupled: the activities identified can be included as external forcing factors. Depending on the area and period covered, the involvement of soil scientists, ecologists~~ and ~~river morphologists may be useful as well.~~

~~To explain the different activities, a sound understanding of how a society functions and what role water plays in this is needed. This requires insights from disciplines such as political science, (institutional) economics, law, sociology and anthropology. A first question to address is who are the major actors? In general terms these~~ the construction of reservoirs. The main actors are the main individuals, groups and organizations that~~-~~:

- use the land and water~~,~~;
- construct, operate, maintain or finance the infrastructure necessary to use the land and water; or
- regulate land and water use~~,~~ or ~~construct and maintain~~ the ~~water management~~ infrastructure~~.~~
  ~~Further questions~~

Factors that ~~can be addressed~~affect these actors and their activities may include ~~which interests are represented in water management and how is it financed? Moreover, what are~~ for instance the following:

- the values and ~~perceptions~~interests of the main actors;
- the ~~major actors and how do these evolve? Are there~~ presence of any conflicts ~~of interests~~ between ~~different actors or sub-areas, such as~~ groups, e.g. city versus countryside~~,~~ or upstream versus downstream~~, or flood-prone areas versus higher grounds? How do~~ (e.g. Bavinck et al., 2014);
- the interactions between the different actors ~~interact? Is there~~(e.g. Pahl-Wostl et al., 2007);
- the presence or absence of a sense ~~of~~ community ~~and an open dialogue, or is there a lot of political manoeuvring? How important is~~ (e.g. Mostert, 2017a);
- the importance of water for the economy in the area~~? And how much~~ (e.g. Roobavannan et al., 2017); and
- the control ~~do~~ the actors have over external factors that affect the area's hydrology~~?~~.

~~These are just some questions that may help to explain the different activities: there may be more.~~Other factors may be important as well. The trick~~,~~ or "art" (cf. Savenije, 2009~~),~~) is to zoom in on those factors that have the biggest explanatory power in the specific case. Potential explanations as well as alternative explanations should be checked carefully against the collected data. Moreover, as new explanations suggest themselves or new data sources are discovered, the research design may have to be modified ("emergent design": Creswell, 2014, 186).

Depending on the area and period studied, different data sources can be used, such as:

- archaeological and paleoecological data
- old maps
- old land use surveys and census data
- the archives of (local) government bodies, water management organisations and other relevant organisations
- old laws, byelaws and judicial decisions
- chronicles, topographical descriptions, memoirs and letters
- newspapers
- old consultancy reports and other studies
- field surveys
- social surveys
- interviews

The next section will give many examples.

To achieve sufficient detail, it is advisable to focus on one or two important activities~~.~~, such as the construction of a reservoir. In addition, one could use an existing theory to guide research and help

Formatted: List Paragraph, Indent: Left: 0 cm, Hanging: 0,75 cm, Bulleted + Level: 1 + Aligned at: 0,63 cm + Indent at: 1,27 cm interpretation, such as ~~the theory on~~ common pool resources management (e.g. Ostrom, 1990; Araral, 2014~~). However, this~~) or triple exposure theory (Treuer et al., 2017). The use of theory is quite tricky ~~as many~~since theories tend to ~~be one–sided and~~ focus ~~one or a few~~on specific factors ~~only.~~and leave out many others. Consequently, their explanatory power may differ from case to case, and one should always keep an open eye for ~~explanatory factors that do not fit the theory~~alternative explanations.

~~As in all case study research, the selection of cases is crucial (Yin, 1989;~~ Every case study should finish with some conclusions or “lessons” that are of more general relevance than the specific case itself, unless the case itself is of special relevance (an “intrinsic case”: Creswell and Poth, 2017). When the conclusions are based on one or a few cases only, they are necessarily tentative, but they may also be based on a comparison with earlier research. Moreover, they may be tested in subsequent research. If a significant number of case studies have already been published, it is also possible to conduct a meta–analysis, using techniques such as Qualitative Comparison Analysis (Srinivasan et al., 2012).

Cases to study can be selected in different ways (Eisenhardt, 1989; Yin, 1989; Mollinga and Gondhalekar, 2014). ~~There are several options. If one is interested in the shift from water resources development and control to protection and restoration, one can~~ A first option is to select a case that is a representative or typical example of ~~this~~the phenomenon of interested, such as the pendulum swing, to explore what are the most important variables and processes~~ may play a role.~~. The next section provides an example of this. If there ~~is~~are already quite a ~~lot of information on this phenomenon~~few case studies, one ~~could~~can select a very different case ~~either~~ to ~~replicate~~complement the previous research or a very similar case to ~~complement~~replicate it, ~~e.g.~~and if ~~all previous cases studies were about small watersheds in North America, one could select another small watershed in North America or a large river basin from another continent. If~~ there is a theory that seems ~~applicable~~relevant, one could select a case that is critical for testing ~~the~~that theory~~, e.g. one that prima facie seems to falsify it.~~ (e.g. Aggestam and Sundell, 2016). Practical considerations such as data availability and accessibility should play a role as well. If there is enough time to conduct multiple case studies, one ~~could~~can adopt either a most different or a most similar design. A most different design involves selecting cases that are as different as possible, to cover as much of the diversity in the population of cases~~.~~ (e.g. Huitema and Meijerink, 2010; Benson et al., 2014). In a most similar design, the cases are as similar as possible ~~and differ in one important respect only,~~except for ~~instance they all have a similar size, population and level of economic development, but the type of water governance differs.~~one variable. This ~~is~~ a good ~~design~~approach for ~~isolating~~studying the effect of an individual ~~factor, in this example water governance.~~variable (e.g. Kochskämper et al., 2016).

Case study research as proposed here is ideally interdisciplinary. Hydrologists should play a large role, but so should historians and social scientists. They are more familiar with many of the data sources that can be used than hydrologists and have specific expertise to contribute. Depending on the area and period studied, other experts should be involved as well, such as archaeologists, soil scientists, ecologists, and river morphologists.

4. The Dommel Basinbasin

To give a better idea of this alternative approach and its potential benefitswhat a socio-hydrological case study may look like and the insights such a study can bring, I will present a concretespecific case: the basin of the Dommel River. basin since 1800. The Dommel River has its source in Belgium and, then flows into the Netherlands until the city of Den Bosch, where it joins the Aa River. Here it changes its name into the Dieze, which after five kilometres discharges into the river Meuse River. The Dommel has a basin area isof circa 1,700815 km^2, 200408 km^2 in Belgium and 1,500407 km^2 in the Netherlands. (Bongaerts, 1919). The total drop in elevation is 75 metre only, from 77 metre above mean sea level at source, to 25 metre at the Belgian-Dutch border, and 2 metre at Den Bosch. Still, this drop was enough to drive some 30 water mills in the basin.

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The river valleys in the basin used to flood regularly, but until around 1900 only summer floods were seen as problematic. These resulted in a loss of the hay harvest, whereas winter floods were seen as increasing the fertility of the soil (Bongaerts, 1919; Deckers, 1927; Crijns and Kriellaars, 1987). Dykes could only be found downstream of the last water mill on the river in the town of Boxtel (Fig. 1). Water levels in this part of the river were influenced not only by the upstream discharge, but also by the water level of the Meuse.

Figure 1: Map of the Dutch part of the Dommel basin in 1971 (Website Brabant Historisch Informatie Centrum, www.bhic.nl; geographical names added)

From 1875 onwards river regulation works were undertaken on the Dutch part of the Dommel was regulated to increase the discharge capacity and reduce flooding. From, but from 1990 onwards, however, these works were replaced by river restoration projects were executed (Roeffen, 1963; Didderen et al., 2009).

The This makes the Dommel basin is a typical example of the shiftpendulum swing from water resources development and control to protection and restoration. Using

4.1 Modelling the socio- hydrologicalpendulum swing

It would be possible to model of the Kissemeethe pendulum swing in the Dommel basin in the same way as Chen et al. (2016) have done for the Kissimmee basin in Florida (Chen et al., 2016) as an example, it would be possible to explain this shift in terms of. In their model "community sensitivity". If community" plays a central role. Community sensitivity is reflects people's collective concern about their livelihood concerns versus environmental health. If it is low, people give more weight to economic considerations and prefer to develop or control the environmentbasin, and if it is high, they give more weight to environmental considerations and prefer to protect or restore itthe basin. Community sensitivity depends negatively on the memory of flooding – the bigger and more recent the flood, the lower community sensitivity – and positively on the degree of environmental degradation – the more degradation, the higher community sensitivity. Flooding and environmental degradation in turn depend on the regulation and restoration works, as well as that have already been executed and on external drivers, such as precipitation.

~~As in~~In the ~~Kissemee~~Kissimmee model~~, it would be possible to~~ community sensitivity differs between the urbanised upstream basin and the rural downstream basin, and overall community sensitivity is calculated as the weighted average of the two. In the Dommel basin one could distinguish between ~~different groups of people with different community sensitivities, such as people in~~the flood~~-~~-prone areas and ~~people living on~~the higher grounds~~, and then calculate community sensitivity as a weighted average of the sensitivities of these groups~~. Using a limited number of equations, a coupled human–water model could be constructed that explains the decision to either regulate or restore. Given the number of parameters – six in the ~~Kissemee~~Kissimmee model – and the limited availability of societal data, it should be possible to achieve a reasonable fit.~~ Moreover, it would probably be possible to validate the model to some extent by collecting newspaper articles that discuss either flooding issues – mostly prior to 1990 – or restoration – after 1990 (cf. Elshafei et al., 2015). This could indicate a change in community sensitivity – or it could simply reflect the different types of projects being discussed.~~

~~As~~ Community sensitivity can be measured indirectly using newspapers articles. This involves 1) selecting one or more relevant newspapers; 2) sampling articles from these newspapers; 3) analysing quantitatively the coverage of different water–related themes, such as flooding, agriculture and nature; and 4) assessing qualitatively the economic or environmental "tone" of the newspaper articles (Wei et al., 2017). Another source that could be used are children's books. A few years ago I analysed 89 children's books on flooding published in the Netherlands in the 20th Century (Mostert, 2015). The analysis showed that many books published after 1970 are critical about technology and approach nature not only as something that should be controlled, but also as something that should be protected. This indicates an increase in community sensitivity in the Netherlands around 1970. But if so, why did it take until 1990 before the first river restoration works in the Dommel basin were executed? And why did the river regulation works start only in 1875 and not much earlier? To answer these questions, it is~~, I~~ necessary to have ~~not made a socio–hydrological model. Instead, I~~a close look at the developments in the Dommel basin.

4.2 Human activities

As outlined in sect. 3, the first question to address is which human activities have ~~made~~had a ~~start with a case study on the Dommel Basin: I have read one monograph~~significant impact on the ~~basin (Anonymous, 1963) and combined this information with my background knowledge of Dutch water management and water governance. This explained why flooding had become problematic in the first place.~~hydrology of the basin. If we look at flooding, we can mention four human causes. First, already in 1818 there were complaints that the water ~~mills on the Dommel~~ millers maintained a too high water level~~. Moreover~~, causing flooding upstream. This remained an issue until at least the 1930s (Deckers, 1927; Roeffen, 1963).

Secondly, in the 1840s 4,000 ha of water meadows were constructed upstream in Belgium. These were flooded in winter with water that was rich in Calcium and ~~mineral rich Meuse~~ minerals to improve the fertility of the soil. The water~~,~~ was imported from the Meuse via a newly constructed shipping canal, ~~to improve fertility of the soil. In~~ but in spring~~, however,~~ the surplus water was discharged onto the Dommel~~. Furthermore~~, thus overcharging the river.

Thirdly, in the ~~late~~ 19th and ~~early~~especially the first decades of the 20th Century large tracts of heath and moorland ~~in the basin~~ were ~~turned~~converted into forest and agricultural land (Crijns and Kriellaars 1987, 1992; see Fig.~~1). This was seen as increasing flooding. The change in~~2). This often involved the construction of field ditches, which increased peak runoff from the land ~~use was made possible by the introduction of artificial fertilisers, which removed the need for sheep manure and therefore for the heath to graze the sheep~~. In 1873, the percentage of "wild lands" in the southern parts of the basin still ranged from 25% to 75% (Crijns and Kriellaars 1987, 344), but nowadays there is little left.

~~To facilitate the river regulation works, the Dutch Province of North–Brabant set up a regional water board that could execute the work and tax the landowners in the basin. This took seven years, from 1856 to 1863. Following, it took another 12 years to finalise the plans and agree on financial contributions from the State and the Province.~~

~~By 1990, when the restoration works started, the situation had changed drastically. The population of the basin had increased a lot and they had more free time. Consequently, the recreational and landscape values of the Dommel had increased in importance. Moreover, in 1950 the water board had become responsible for sewage treatment. As a result representation on the board had been broadened to include citizens and industry; before only the land owners were represented (cf. Mostert, 2016). In addition, in 1916–1923 a new shipping canal was cut through the basin, the Wilhelmina Canal. This canal could also be used for draining the upper basin, thus reducing the load on the lower Dommel. And finally, in the mid–1980s a new national policy, called "integrated water management", had been introduced, which emphasised the ecological aspects of water systems (Ministerie van Verkeer en Waterstaat, 1985, 1989). This new policy had been triggered by the controversy on the closure of the Eastern Scheldt estuary more to the west in the 1970s. This controversy in turn can be explained by the growing environmental awareness in the Netherlands since the late 1960s and the limited flexibility of the State Water Management Agency at the time (Disco, 2002; Mostert, 2006).~~

Figure ~~1~~2: Part of the Dommel ~~Basin~~basin in 1837, showing meadows along the river (light green), arable land (white) and large tracts of heath ("heide"). The Zonsche Heide is now mostly arable land, with forests and new residential areas in the south. "WM" indicates a water mill. (National Archives, topographical map of the area around Boxtel and Sint Oedenrode (detail), toegang 4.TOPO, inv. nr 9.169)

Fourthly, the basin became more urban. Eindhoven, which in 1842 was only a small market town with 3,000 inhabitants (Van der Aa, 1842), grew to 46,000 inhabitants in 1920, 113,000 in 1940 and 227,000 presently. Tilburg grew in the same period from 14,000 to 194,000 inhabitants. The result was an increase in hard surfaces and in peak runoff.

To cope with the increasing flooding problems, several river regulation works were executed. Between 1875 and 1893, several small river bends were cut off, the sluices of several water mills were enlarged, and other obstacles were removed (Bongaerts, 1919, 124–128). Between 1907 and 1911, the Drongelens Canal from Den Bosch to the Meuse was dug, which gave the Dommel an extra outlet. Following major flooding in 1917, plans were developed to divert water out of the basin (Bongaerts, 1919; Roeffen, 1963, 95–97), and between 1931 and 1941 the Dommel near Eindhoven was connected to the Wilhelmina Canal (completed in 1923). Moreover, between 1933 and 1936 a large river bend going through Boxtel was cut off.

The last wave of river regulation works started already before the Second World War but peaked in the 1960s and early 1970s (e.g. Lohman, 1963). In this period many land re-allotment projects were undertaken to reduce the number of land plots and increase efficiency in agriculture. As part of these projects, many new drainage ditches were dug and the receiving tributaries of the Dommel were straightened. Together with the ongoing urbanisation, these works further increased peak discharges onto the Dommel, and consequently plans were developed to channelize the Dommel itself.

The change from regulation to restoration was not an abrupt one. Increasingly, landscape and nature aspects were considered in land re-allotment projects (Crijns, 1998). Moreover, the plans to channelize the Dommel were only partially implemented. For the stretch between Eindhoven and Boxtel an alternative plan was developed involving less regulation. This plan was accepted by the water board, on the condition that the 500 to 600 ha that would continue to experience regular flooding would be bought from the farmers by nature organisations. The stretch downstream of Boxtel, however, was channelized in 1971–1972. This led to questions in Parliament (Proceeding of the Second Chamber of Parliament 1970–1971, 2738–2748).

Actual river restoration started around 1990 (Didderen et al., 2009). Nowadays, river restoration works are undertaken as part of the implementation of the European Water Framework Directive (Mostert, 2003; Junier, 2017). Examples include re–meandering, the reconstruction of banks, and the removal of obstacles for fish migration. For the period 2016–2021 Water board Dommel plans to improve 93 km of watercourses (Waterschap De Dommel, 2015).

4.3 Actors

To understand all these activities, we need to identify the major actors and the major factors influencing them. Probably the most important group of actors were the farmers and the owners of the agricultural land. They contributed to the flooding problems by converting “wild lands” into agricultural land, and many of the river regulation works were undertaken primarily in their interest. Moreover, they had close connections with the water board and with regional politics.

The history of agriculture in the area has been described in great detail (Crijns and Kriellaars 1987, 1992; Crijns 1998). Around 1800 most farms were small and the farmers were poor and un-educated. At the time, agricultural development got a lot of attention, but few wild lands were actually converted because of a lack of manure and other fertilizing substances. After 1840 there was a small increase in land conversion as a result of a legal change that decreased the tax burden on new agricultural lands, but from 1885 to about 1900 land conversion was practically zero as a result of a global crisis in agriculture. After 1900 it peaked. Not only had prices for agricultural produce improved, artificial fertilizers had also been introduced, which meant that nutrients were no longer a limiting factor. In addition, improvements in transportation meant better access to markets; agricultural education had been introduced; and farmers had started to organise themselves, locally in cooperatives and regionally in the North Brabant Christian Farmers Association (NBC). The NBC was closely associated with the Roman Catholic Church and with politics. Nowadays, the successor of the NBC (LTO) is no longer associated with the church and the influence on politics has decreased. Nonetheless, the agricultural sector is still very well organised and well represented on the Water board Dommel: three of the thirty seats are reserved for agriculture, two other board members are farmer as well, and one more has worked for an agricultural organisation.

The second group of actors is the non-agrarian population of the basin. As discussed in the previous section, their number increased drastically. On top of that, after the First and especially the Second World War, working hours decreased and paid holidays were introduced. The population of the ever bigger cities got time to visit the basin and enjoy the nature and landscape (cf. Noordbrabantsch dagblad 13 October 1941; Maas, 1963, Thijsen, 1963). Already before the Second World War there were protests against the river regulation works, e.g. by the Dutch Association for the Protection of Natural Monuments, established in 1905, and sometimes plans for re-allotment were modified to accommodate the interests of nature and landscape. Yet, during the economic crisis of the 1930s, the Second World War and the first post-war years, agricultural interests prevailed. As one journalist put it in 1941, “what weighs most should be given most weight” (Noordbrabantsch dagblad, 11 August 1941). In the 1960s, this was still the policy of the water board (e.g. De Tijd De Maasbode, 30 June 1961; Lohman, 1963).

The third group of actors were the water millers. With the introduction of steam power, the economic value of the water mills decreased drastically. The province of North–Brabant and since 1907 the water board could regulate water levels (Deckers, 1927, 205–210), but they were not allowed to make the use of private mill rights impossible (Heemskerk, 1992). This led the water board and some municipalities to buy water mills or the mill rights. Nowadays, nine water mills remain in the Dutch part of the basin: seven in private hands and two owned by the municipality of Eindhoven.

The fourth key actor is Water board Dommel. Water boards have a long history in the Netherlands, but mostly in the polder areas (Van de Ven, 2004; Mostert, 2012, 2017b). In the Dommel basin there were only a few small water boards in the downstream part of the basin that maintained and financed local dykes. In 1856, however, the Province of North–Brabant took the initiative to set up a regional water board that could execute river regulation works and tax the beneficiaries. This took seven years (Roeffen, 1963). Until 1921 the water board included only the flood-prone land in the basin, some 4,300 ha. in total (Bongaerts, 1919, 129). Only the owners of this land were charged for the expenses of the water board and could elect the board members. In 1921, the board was extended to cover the whole basin, but the higher grounds in the basin had to pay a reduced rate only. Moreover, houses and other buildings were rated for the first time, through precepts on the municipalities. Consequently, the municipalities got seats on the water board.

The second major change was in 1950, when the water board got the task to treat wastewater. Representation of the municipalities on the board was increased to one-fifth of the seats and industry also got one-fifth of the seats. This did not immediately lead to more attention for the "urban" interests nature, landscape and recreation. Things really started to change in the 1970s and 1980s. Following a controversy over the closure of the Eastern Scheldt estuary in the 1970s, a new national policy was introduced in the 1980s, called "integrated water management." This policy emphasised the ecological aspects of water systems (Ministerie van Verkeer en Waterstaat, 1985, 1989; Disco, 2002; Mostert, 2006). It became leading for the Dutch water boards.

The fifth group of actors are various other government bodies. First among these is the Province of North–Brabant. According to the Dutch constitution, the provinces can establish, regulate and change water boards, subject to approval by national government. Moreover, they can give subsidies. The Province often consulted the municipalities on water management issues. Around 1800, the municipalities had become the owner of most of the wild lands in the basin (Leenders, 1987). In later years they became responsible for the construction and maintenance of sewers and for spatial planning.

National government can adopt general legislation on for instance the water boards and agriculture. Moreover, they are responsible for works on the main rivers, such as the Meuse, and can offer subsidies for other water management works. In addition, they are responsible for international relations. In 1863, they concluded a treaty with Belgium on water allocation of the Meuse River. This treaty allowed Belgium to continue discharging the surplus water of its water meadows onto the Dommel against payment of 250,000 Belgian Francs (118,000 guilders) as damage compensation.

Finally, after 1970 the European Union became very important. The EU adopted several water directives, such as the Water Framework Directive, which are binding upon the EU Member States. Moreover, the Common Agricultural Policy of the EU indirectly influences water use and quality.

Like the other actors, the different governmental actors changed a lot since 1800. Most were initially like committees from the ruling class, but gradually elections became more important and in 1917 universal suffrage was introduced for men and in 1919 for women. Moreover, their staff has increased drastically. According to some, they have become the "fourth power", in addition to the legislative, executive and judicial branch of government (Crince le Roy, 1969).

4.4 Factors

An important factor explaining the river regulation works is financing. The different river regulation works were only partially paid by those benefitting directly. The total costs for the first regulation works (1875–1893) was 732,312 guilders, to which Belgium contributed 118,000 guilders and the province and the State each 145,000 guilders. This left 324,312 guilders for the water board to cover, which proved a very heavy burden for the small water board. The Drongelens Canal (1907–1911) was financed completely by the State. The costs of the works near Eindhoven (1931–1941), including some improvements for shipping, were 940,000 guilders, of which the now bigger water board covered 280,000 guilders only. Subsidies for the works in the post-war period differed, but they were typically in the order of 75%.

Many regulation works could not have been executed without subsidies, and one can doubt whether they were all economically justified. This is hard to tell as there were also indirect benefits for the broader community, such as stimulation of the regional economy and employment, which are hard to quantify. Most likely, non-economic values played a role as well. These include the "causation principle", according to which those contributing to a problem should contribute to its solution. This principle is embedded in the Dutch civil code, which states that owners of lower grounds have to accept the water coming from the higher grounds, but the owners of higher grounds are not allowed to make matters worse for the lower grounds. Arguably, land conversion did make matters worse for the lower grounds, and hence all lands in the basin had to contribute to the costs the water board made (Mansholt, 1941; Schilthuis, 1960).

The second non–economic value is community and solidarity. The whole basin, the Province of North–Brabant and even the whole of the Netherlands could be seen as a community, and in a community members support each other according to their possibilities (cf. Mostert, 2017a). It is hard to assess how important exactly community values were. Traditionally, water management in the Netherlands is based on the benefit principle and to some extent the causation principle (Schilthuis, 1960; Mostert, 2017b). Yet, mutual support, especially during and after flood disasters, is also a cultural value, as witnessed by the many children's books dealing with flooding (Mostert, 2015). Moreover, community does offer the simplest explanation for the financial contributions from the province and the State.

If we look at the activities that increased flooding, the picture is mixed. Economic factors were very important drivers for land conversion and urbanisation, but political and institutional factors played a role as well. Examples include the international relations between Belgium and the Netherlands and the legal change in 1840 that decreased the tax burden on new agricultural land. Technological change was important too, most notably the introduction of artificial fertilisers.

The restoration works and the preceding protection efforts can be explained very well in terms environmental values, but these values did not depend on the state of the environment in the basin only. In addition, the changing composition of the basin's population and their changing interests played a very important role. Moreover, how well the different interests were represented depended on institutional factors, such as the rules concerning representation on the water board. Additional factors may have been the role of individuals and their networks and the strategies they employed. The research so far has only resulted in some hints in this direction concerning for instance Mr. Vosters, chairman of the water board from 1952 to 1983 and of the Dutch Association of Water boards from 1972 to 1981 (Proceeding of the Second Chamber of Parliament 1970–1971, p. 2742).

4.5 Case study conclusion

The Dommel case study has shown that the pendulum swing from water resources development and control to protection and restoration may not consist of two phases, but of three: 1) development and control (in the Dommel basin until 1970); 2) protection (between 1970 and 1990); and 3) restoration (after 1990). Moreover, the case study has shown that changes in "community sensitivity" do not always offer a full explanation of the pendulum swing. As has also been discussed by Roobavannan et al. (2017), a change in the composition of the community may be more influential than the state of the river basin. On top of this, institutional factors can play a crucial role.

Institutions such as rules on the composition of water boards influence how well the different segments of the community and their interests are represented.

Community sensitivity can be defined either as environmental concern (cf. Elshafei et al, 2014, 2144–2145) or as the balance of environmental concerns and economic concerns (Chen et al., 2016, 1229). A first point to note is that “environmental concern” may mean different things. It may mean either concern for the environment itself (loss of biodiversity, landscape values) or concern for the economic damage that environmental change may bring (e.g. the economic damage of flooding caused by land conversion), in which case it is in fact an economic concern. Secondly, what is missing from the concept are community values. As discussed, many of the river regulation works in the Dommel basin would not have been possible without financial contributions from the province, the State, and inhabitants of the basin that did not benefit directly. The simplest explanation for these contributions is a sense of community at different levels. How strong this sense of community was, whether it was based on a shared identity and emotional attachment or on reciprocity (a tacit understanding that any support will be reciprocated), and what role lobbying activities played, are matters that still await further study. Meanwhile, it is safe to conclude that financial arrangements are very important for understanding how water management works.

The Dommel case study clearly shows that the co-evolution of water and humans cannot be understood completely within the confines of individual river basins. This is not a new insight, yet it is not incorporated in the Kissimmee model.

If we compare the Dommel case study with previous socio–hydrological case studies (Wescoat, 2013; Gober and Wheater, 2014; Kandasamy at al., 2014; Liu et al., 2014), we can note that some of the conclusions drawn above are largely new, especially the ones on financial arrangement and community, while for other conclusions the Dommel case offers additional support and more or different details. Outside of socio–hydrology none of the conclusions are completely new, yet also in this case the Dommel case study offers additional support and more or different details. Most of the conclusions could be drawn only because the issue was mentioned in older literature on the Dommel (e.g. financial arrangements in Decker, 1927) or in other water management and social science literature (e.g. community in Putnam, 2000; Pretty and Ward, 2001; and Mostert, 2017a). This points to the importance of reading widely for socio–hydrology.

Future research on the Dommel basin could model the impact of land conversion, urbanisation and river regulation on the flooding. Moreover, there is a need for more detailed research on one or two specific activities, such as the channelization of the Dommel in 1971–1972 or the first river restoration project. This could help to find out more about the role of individuals, social networks and political strategies. Furthermore, the importance of community values can be studied more. One indicator of this is memberships in social organisations (Elshafei et al., 2014; cf. Putnam, 2000). Alternatively, one could analyse the arguments used in discussions on water management (Mostert, 2012) or conduct a content analysis of newspaper articles or even children’s books (see sect. 4.1). And last–but–not–least, it would be interesting to compare the Dommel basin with other basins, focusing on institutional and financial arrangements, the role of community, and their interrelation with changes in the hydrology. This calls for new case study research, but in addition the existing literature could be mined much more.

5. Discussion

~~All these developments can be studied in much more detail. First, it would be interesting to model the impact of the land use changes and the river regulation works on the extent and frequency of flooding. Moreover, the social and economic changes and the changing governance arrangements in the basin can be described in more detail. And finally, individual decision–making processes, concerning for instance the establishment of the water board and the first restoration project, can be analysed in detail. Sources that can be used include the following:~~

- ~~old land use surveys~~
- ~~census data~~
- ~~old topographical descriptions~~
- ~~monographs on agriculture in the area~~
- ~~project reports (feasibility studies, etc.)~~
- ~~old water level data (e.g. in relation to the water mills)~~
- ~~old laws and byelaws~~
- ~~minutes of the provincial board~~
- ~~minutes of the water board~~
- ~~newspaper articles~~

~~Most of these sources are freely available at Brabants Historisch Informatie Centrum in the City of 's–Hertogenbosch and increasingly also online (older newspapers at www.delpher.nl, old maps at the Website of the National Archives www.gahetna.nl, etc.). Concerning more recent periods, additional data can be collected using the following methods:~~

Considering the previous discussion, what can we say about the best approach for socio–hydrology: case study research or coupled modelling? What are their relative advantages and disadvantages, can they be combined, and do they really differ?

To start with the last question: they do. The difference is the difference between qualitative and quantitative approaches. This is not simply words or "narrative" versus numbers (Creswell, 2014, 4). Rather, the aims and strategy differ. Qualitative research aims to understand the unique characteristics of individual cases and has an inductive character, starting with observations and using theory to make sense of these observations. Quantitative research, on the other hand, aims to identify general relations, even when first individual cases are studied (or modelled), and has a deductive character, starting and ending with theory. Whereas qualitative research tries to understand complexity, quantitative research tries to reduce it. The difference, however, is not absolute, and much research falls somewhere between these two extremes.

Case studies have many strong points when it comes to improving understanding of long–term developments. • field surveys

• social surveys

• interviews

• direct observation

• gaming

5. Modelling versus case studies

How does socio–hydrological modelling and detailed case study research as proposed in this article compare? Which approach will improve our understanding of long–term developments most, which will result in the best predictions most and which can support policy best?

For improving understanding detailed case studies have many strong points. They allow for the use of all types of data, including qualitative data. They are flexible, allowing the researcher to move from hydrological issues to other issues and from the basin level to higher levels without having to develop a global model of everything. Unlike mostMoreover, while models, they do not require that variables and many relations are specified in advance and consequently they (Mount et al., 2016), this is not so for case studies. Consequently, case studies are more likely to reveal completely new mechanisms variables and relations one did not think of before. Moreover, theyCase studies also do not require the assumption of stationarity. In fact, they and are well suited to studyfor studying how systems and system behaviour change, how for instance individuals and societies learn and why new management bodies are set up.. Furthermore, case studiesthey can go into much more detail than models and give detailed information on for instance decision–making structures and processes, political strategies, social relations and the distribution of costs and benefits. In addition, they can result in a better qualitative understanding of the issues at stake and can identify new sources of data, which can then be used for developing more realistic models and calibrating and validating these models.. And last but not least, case studies offer good possibilities for cooperation with – and benefitting from – disciplines that are not used to (numerical) modelling, such as law and anthropology. For hydrologists interdisciplinary cooperation may imply losing some control (Wesselink et al., 2016), but the benefits are huge, provided one selects the right persons to cooperate with: those interested in hydrology and not using overly abstract jargon.

A potential problem of case studies is their generalisability: what can one conclude on the basis of one case study only? The answer is: not much. The solution is to select cases carefully, as discussed supra, and compare the results with previous research. In this waySince qualitative case studies can be used to test and further develop theory. Ideally, these theories should be flexible and adaptable to the specifics of the case, to ensure that they are both widely applicable and not too general.

Detailed case studies as proposed here are not good for making quantitative predictions. But models do not fare much better, at least not if by "prediction" we imply a minimum degree of certainty. For the short term this may be feasible, but in the long term too many factors may change that cannot be modelled properly (cf. Srinivasan et al., 2017). What models can do is to generate possible future developments or "scenarios", based on different assumptions concerning for instance climate change. These scenarios can then be used for developing robust and flexible adaptive strategies to cope with a broad range of possible futures (e.g. Haasnoot et al., 2013; Pahl–Wostl et al., 2008). Models can also be used to explore the possible effects of policy measures, such as an insurance system for flood damage (Grelot and Barreteau, 2012).

What detailed case studies can do is to improve our understanding of how unpredictable long–term developments are and how in the past societies have adapted to them. Moreover, since they can be much more detailed than coupled models, they can offer far more levers for managementpolicy. Obviously, models that do not include management structures and processes cannot offer any guidance on these issues. A potential weakness is generalisation on the basis of case studies, but this weakness can be addressed by selecting cases carefully and comparing between case studies, (sect. 3).

Finally, A more intractable weakness of qualitative case studies may have intangible benefits as well. Arguably, increased mobility and trade have led to a de–localisation and de–materialisation of social life. Case histories of how society and hydrology have interacted and depend on each other may help to reconnect the social and the physical world and stimulate a sense of “watershed community” (Barham, 2001). And a minimum sense of community (or “social capital”) is a precondition for effective river basin management as it mitigates conflicts of interests and facilitates cooperation (Mostert, 2017).

6that they cannot be used for making. Discussion

So, which approach is better for socio–hydrology: developing coupled models or detailed case study research as described in this article? Before we can answer that question, it is necessary to revisit the aims of socio–hydrology and address the issue whether developing coupled models and detailed case studies are really different approaches.

Arguably, the central aim of socio–hydrology is better understanding of the human–water system because the other two aims of socio–hydrology, prediction and policy support, can only be realised if there is a good understanding. But "understanding" can mean different things. For me, understanding how my bicycle works means understanding how to operate it, but for a bicycle repair man it means understanding how to repair it. In socio–hydrology, understanding may mean quantitative understanding to enable precise predictions or scenarios. For this purpose developing coupled models is a good approach, preferably supported by detailed case study research. Understanding may also mean detailed qualitative understanding to support policy. For this purpose detailed case study research is a good approach, possibly supported by models, both coupled toy models and more classical models.

Since modelling and case study research can support each other, one might argue that they are not really different approaches, just different techniques that can be used in different phases of research. That would, however, be underestimating the differences. At the risk of overgeneralisation, we can say that quantitative approaches generally aim to identify commonalities and assume that empirical phenomena can be explained in terms of a limited number of general laws, processes or mechanisms. Case study research, on the other hand, focuses on the specifics of individual cases and

~~tries to explain these in terms of a unique combination of factors.~~, It ~~tends to be very empirical. It starts with detailed description, guided by prior knowledge and interest, and then compares the results with other cases in order to identify differences and similarities and better understand the uniqueness of the individual cases. Modelling is usually more deductive and theoretical. The first step is to construct the model using hypothetic knowledge. Empirical data come in later to calibrate and validate the model, and not all models are calibrated and validated. The only exceptions are data–driven modelling, even~~has to be acknowledged, though ~~these use hypothetic knowledge too for selecting the relevant data, and to a lesser extent flexible conceptual models (Mount et al., 2016).~~

~~Modelling works best for~~ , that coupled models do not fare much better in this respect, at least not for the long term and if “prediction” implies a minimum level of certainty (cf. Srinivasan et al., 2017). Which coupled model could have predicted the introduction of artificial fertilisers? Coupled human–water systems ~~that are relatively simple and stable. In socio–hydrology, however, we are interested in quite~~ are complex ~~systems that evolve in time. This means that there is not one system to model, but a suite of related systems. Obviously, this complicates calibration and validation. A possible solution is to redefine the system to incorporate specific qualitative changes, but this would make the system modelled very complex. To~~and to cope with this complexity compromises are inevitable (Levins, 1966; Troy et al~~.~~., 2015). One option is to sacrifice generality to realism and precision~~.~~, and for instance limit the geographical, temporal and thematic scope of the model. This is effectively the strategy of demand–driven modelling~~.~~ (Garcia et al., 2016). Another option is to sacrifice realism to generality and precision. This is what may happen if one makes models too complex to be calibrated properly or if one leaves out ~~important~~crucial processes in order to limit complexity. A third option is to sacrifice precision to realism and generality. Uncalibrated toy models fit in this strategy~~. But~~, but if one is willing to sacrifice precision, ~~one can also think of detailed,~~ qualitative case ~~studies. As argued in the previous section and shown by the Dommel Basin case~~ study~~, case studies have several advantages and can result in important new insights~~ research is a good option too.

~~To conclude, there is no single best approach to achieve progress in socio–hydrology. All approaches have strong and weak points, and it also depends on what it is one wants to achieve. Yet, given the limited attention they currently get, I argue for more detailed case studies along the lines sketched in this article.~~

But while coupled models cannot predict the (far) future very well, they can be used for generating quantitative scenarios, using different assumptions concerning for instance climate change and economic growth. These scenarios can then be used for developing robust and flexible management strategies (e.g. Pahl–Wostl et al., 2008; Haasnoot et al., 2013). Moreover, coupled models can be used to explore the *possible* effects of policy measures, such as an insurance system for flood damage (Grelot and Barreteau, 2012). And last–but–not–least, coupled toy models can be used to generate *possible* explanations of observed phenomena, provided the model is actually played with, e.g. different parameter values are tried out. A good example is Yu et al. (2017).

Qualitative case studies and modelling can be combined in different ways. One could start with a case study and use the results for developing a realistic coupled model, as was done for instance by Kandasamy et al. (2014) and Van Emmerik et al. (2014). This is a sound approach, but it will generally not be possible to keep all the richness of the case study without making the model too complex. Case study research could also follow on modelling and could then be used to help interpret the results, validate the model, or test specific hypotheses. Finally, modelling can be part of a qualitative case study, to determine the impact of human activities (non-coupled models) or to generate possible explanations (coupled toy models).

There are few research approaches and methods that cannot be used in socio–hydrology. Examples of relevant approaches include large–N statistical studies (e.g. Hornberger et al., 2015), which seem very promising for comparative socio–hydrology, and survey research, for instance on how farmers actually react to hydrological change (Sanderson and Curtis, 2016) or on what actually determines environmental concern: personal characteristics or local environmental problems (Hannibal et al., 2016). The reason why this article focused on coupled modelling and qualitative case study research is that coupled modelling is the most popular approach in socio–hydrology and qualitative case study research is a contrasting approach with many potential benefits.

I could leave the discussion here and conclude that 1) qualitative case study research and coupled modelling both have strong and weak points, 2) they can be combined to some extent, and 3) there are more approaches that can be used in socio–hydrology, but these are not the topic of this article. Yet, I want to add one more conclusion: 4) case study research as proposed here should receive more attention in socio–hydrology. They get relatively little attention, yet they can help to make sense of the real–life complexities of humans and water and it is possible to generalise on the basis of them. Moreover, they are a good vehicle for bringing together literature, experts and insights from many different disciplines. Hence, they should receive more attention.

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