Towards systematic planning of small-scale hydrological intervention-based research

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Abstract

Many small-scale water development initiatives are accompanied by hydrological research to study either the form of the intervention or its impacts. Humans influence both, the development of intervention and research, and thus one needs to take human agency into account. This paper focuses on the effects of human actions in the development of the intervention and its associated hydrological research, as hydrological research is often designed without adequate consideration of how to account for human agency and that these effects have not yet been discussed explicitly in a systematic way. In this paper, we propose a systematic planning for hydrological research, based on evaluating three hydrological research efforts targeting small-scale water development initiatives in Vietnam, Kenya, and Indonesia. The main purpose of the three cases was to understand the functioning of interventions in their hydrological contexts. Aiming for better decision-making on hydrological research in small-scale water intervention initiatives, we propose two analysis steps, including (1) consideration of possible surprises and possible actions and (2) cost-benefit analysis. By performing the two analyses continuously throughout a small-scale hydrological intervention-based initiatives, effective hydrological research can be achieved.

1   Introduction

Small-scale water development initiatives play an important role in supporting sustainable water resources management. Such projects are usually initiated and/or supported by local non-governmental groups, but also by larger donors such as USAID and others (Van Koppen,

2009; ECSP, 2006; Warner and Abate, 2005). Typical small-scale intervention projects include water harvesting development, improving small-scale irrigation schemes, and small dams for water use or hydropower (Lasage et al. 2008; Ertsen et al., 2005; Falkenmark et al., 2001; Farrington et al., 1999). A basic understanding of the local hydrology is typically required for design, construction and management of small-scale water interventions.

Many small-scale water intervention initiatives, especially those in the so-called developing countries, are located in data sparse areas. In 2003, the International Association of Hydrological Sciences (IAHS) initiated the Prediction in Ungauged Basins (PUB) initiative to promote the development and use of improved predictive approaches for a coherent understanding of the hydrological response of ungauged and poorly gauged basins (Sivapalan et al., 2003; Hrachowitz et al., 2013). The three hydrological studies that built our experiences and the approach we developed as discussed in this paper were located in remote areas in Vietnam, Kenya and Indonesia; all three study areas were originally in ungauged catchments. Our approach for hydrological research was based on investigating dominant hydrological processes through a multi-method approach, in short field campaigns within strict financial constraints (compare with Mul et al., 2009; Hrachowitz et al., 2011). On-site measurements were highly dependent on the support of the local communities. Thus, building and maintaining (informal) networks and relationships were usually essential and required for successful local data collection in all our cases (compare with Mackenzie, 2012).

Our three case studies performed hydrological research within the context of small-scale intervention initiatives; our hydrology was use-inspired in terms of understanding and interpretation of local hydrology, including scenario development in human-modified situations, in our case explicit interventions to do so (Srinivasan et al., 2015, Sivapalan et al., 2014, Thompson et al. 2013). Any intervention can be understood in terms of cooperation and negotiation between actors, which together create a process of (re)shaping design, implementation and use of that intervention (Ertsen and Hut, 2009). In other words, water planning and management are typically co-organised or 'co-engineered' by several actors of different types (Daniell et al., 2010). Our experiences have shown that such co-engineering also shapes the hydrological research itself – and thus principally the science of hydrology as well. As such, we would perceive stakeholder involvement as seeking partnership in the process of (hydrological) change to affect knowledge, attitudes and behaviour of participants in a project's network – rather than researchers simply communicating things to people –

(Ertsen, 2002; see also Poolman (2011) for a more extensive discussion about stakeholder participation in small-scale water initiatives). Motivations for stakeholders' actions within projects – or participation - including acts that may not necessarily be seen as positive by other stakeholders, are a key component for any hydrological project. These motivations may change over time, as we have seen in our Vietnam case study, but there is little recognition of such changes motivations of individuals over time in the literature (see Cleaver (1999) and Leahy (2008) for some attention to this issue). We return to this issue below.

 Looking on studies of small hydrological research related to interventions – if available at all – another returning issue with stakeholder involvement in hydrological research is its description in terms of theft and vandalism (see Kongo et al., 2010; Mul, 2009; Gomani et al., 2009). When theft and vandalism enter the debate, they seem to be perceived as simple bad luck: they could happen every time and everywhere during a research effort. There is no reason to ignore that people do take away or manipulate equipment in the field – we experienced this ourselves – but this does not necessarily make all human interventions leading to disappearing or damaged equipment similar to theft/vandalism. Perhaps people may interfere with measuring equipment out of curiosity, or because they simply do not know what it is. There might be cases of (re)moving equipment when certain agents are against the measurements being taken in the first place, or are against measurements at a certain location – as will be shown below when we discuss how motivations of stakeholders to interfere in our hydrological campaign changed over time, without theft ever being a motivation for action. Whatever the motivations for such involvement, it may result in lower data availability. With data sets being relatively limited anyway in ungauged basins, studies using such limited data are even more difficult to be accepted in the scientific research community (compare with Winsemius, 2009). It is this issue of data availability in relation to stakeholder involvement in small-scale hydrological studies that we discuss in this paper.

When we performed our own hydrological studies, not everything that was about to happen in the three projects was, or probably could be, foreseen. Based on our experiences, in an attempt to compare our experiences and the events afterwards, we traced the social processes relevant for the development of research and intervention in our three cases, looking for possible contextualisation, explanations, and patterns. As hydrologists who cannot be separated from the socio-hydrological world (Lane, 2014), we searched for a way of conducting small-scale hydrological research in the future that would be informed by our

experiences. Can hydrologists make better decisions – in terms of gathering data – when planning hydrological research, realizing that people related to and/or involved in the research make decisions on a daily basis that will affect the intervention and hydrological research itself?

Our objective with this paper is to propose a systematic process of planning and performing hydrological research in small-scale water intervention initiatives taking into account the predicted unpredictability (or surprises) of human interventions. We argue that more explicit attention to this topic helps to design more appropriate answers to the challenges faced in hydrological field studies. In particular, we propose two related steps: (1) take into account possible surprises and resulting actions, and (2) using cost-benefit analysis to analyse the need for certain measurements and assess effects of human intervention. In order to be able to design responses during hydrological studies, we argue that human agency from stakeholders – both positive and negative – should be an integral aspect for consideration when designing, performing, and evaluating intervention-based hydrological research. To be clear, our focus on the question whether hydrological research can be made more effective through considering human interventions does not in any case suggest that this is the only relevant question on stakeholder participation in general. It simply means we do not discuss these other questions. Notions of (improving) hydrological research within small-scale projects have been discussed, for example by Phalla and Paradis (2011), Gomani et al. (2009), and Das et al. (2000), who discuss the importance of hydrological research and local participation in interventions to improve decision-making for such interventions. Involving local communities in hydrological monitoring throughout the world, e.g. in South Africa, Zimbabwe, and India, have shown to be potentially effective for data collection (Kongo et al., 2010; Vincent, 2003; Das 2003; Das et al, 2000). Merz et al (2015) study that surprise is apparently a crucial element in flood risk management. To improve flood risk management, one should not neglect surprises, but to take them into account. Similarly, theories and practices of adaptive management have been suggested as potentially beneficial approaches in order to implement an intervention properly (Fabricius and Cundill, 2014; Beratan, 2014, Von Korff et al., 2012). However, a combined focus on both hydrological research design/management and effects of local participation in hydrological research, especially related to the meaning of surprises when doing the field research, remains absent from the literature. Currently, a more systematic overview of issues on planning hydrological research within small-scale water intervention projects is lacking. This paper aims to fill this gap.

We continue this paper with a summary of our three small-scale hydrological research projects and the building blocks of our proposed planning approach. Next, we discuss the Vietnam case in more detail, as this will be the case we build and illustrate our arguments with human agency within the hydrological research, including issues of participation in Vietnam is discussed as well in detail. With the Vietnam experience available, we detail how we propose to include these in planning hydrological research in the context of small-scale water interventions, particularly attempting to account for the likelihood that researcher expectations will be overturned in actual practice - i.e. that "surprises" will occur.

2 Three small-scale hydrological studies: learning from surprises

In 2007, contour trenches were dug in a semi-arid area in Vietnam (see Fig. 1). A multi-technical approach was used to assess the recharge from water infiltrated in the trenches, using field measurements, isotope techniques, and modeling. In the field, we measured rainfall, water levels in the trenches after events, infiltration, and groundwater in four observation wells in the trenches area. In 2009 a complete set of these field measurements was made for a single wet season. Hydrus (2D/3D) was used to estimate subsurface parameters of the recharge process. The recharge that was actually created could be beneficial for the short term only, up to a maximum of two months. In this case, our multi-technical approach seemed to have provided an adequate understanding of the mechanism of local recharge. Below, we will describe in more detail the process of the research activities, but first we provide some background on our other two cases.

In 2002, contour trenching was initiated to trigger reforestation in a semi-arid area in Amboseli, Kenya (see Fig. 2 – it was actually the experience in this region that created conditions for the Vietnam project to shape up). To study the effects of the trenches, fieldwork was performed in September 2010, consisting of rainfall measurements, soil moisture measurements, and soil samplings. The aim was to assess the impacts of contour trenching on vegetation growth, soil moisture availability, and sedimentation distribution in the trench area. We could only perform a very minor part of these measurements, as much of our on-site equipment disappeared from the site. To understand erosion and sedimentation in the trench area, we could take soil samples with which cesium analysis was performed. Local and external sediment were found in the trench area. Remote sensing analysis was conducted to investigate the differences between situations with and without contour trenches. Results

showed that the signal of high greenness index in the trench area was most likely due to the wet season, and not specifically because of the trenches per se.

In 2010, the potential of micro-hydro power plants was investigated in Maluku province, Indonesia (see Fig. 3). The study combined a digital elevation model (DEM, from the space shuttle Endeavor), rainfall and discharge measurements. Using DEM analysis, a river map with high elevation differences was determined. Discharge measurement data of one year was used to determine the runoff per unit area. It was concluded that the Maluku islands have small potential for micro-hydro power plants, with estimation ranges from 6 to 40 kW. This research project went very smoothly, with local stakeholders only protesting once our studies suggested that the potential for micro-hydro on the study area was only marginal.

Concerning the hydrological/technical aspects of the three case studies, we conducted different measurement techniques depending on the research objectives. We experienced that the development of intervention and hydrological research changed over time due to actions of local stakeholders. In each of the interventions and research in Vietnam, Kenya and Indonesia, local stakeholders of different kinds were engaged. To better understand human actions in small-scale water intervention based research, we looked into the different actions we could collect and considered those as data for further discussion on the social aspects – see Table 1-3. For our three cases (see for the timeframes Table 4), we drafted the human actions in intervention and hydrological research. We focus on the Vietnam case since it contains more events compared to the Kenya and Indonesia case. In order to gain insight on human actions in hydrological research, a timeframe of the social context was made for all three case studies. In our efforts to conceptualize human agency in intervention and research, we looked at existing theories on community participation (several of which were quoted in the introduction). In an early discussion – which we found very useful for our case studies – Arnstein (1969) introduced the ladder of participation for urban development, with the scale ranging from non-participation to being able to make decision (citizen empowerment). The scale influenced other fields and was further developed, for example by Choguill (1996). Her ladder of participation was based on the scale of willingness of governments in community projects. One recent participatory spectrum is IAP2 (2007), where along the spectrum, the impact of public participation increases. Another participation framework during intervention phases was proposed by Srinivasan (1990), explicitly aiming at training trainers in participatory techniques. We found this last approach useful in analysing our case studies, as

the community participation scale from Srinivasan (1990) allows for differentiating attitudes towards change, by sorting them along a scale showing varying degrees of resistance or openness. We use the scale below to identify attitudes towards hydrological research, and are also able to show these attitudes change over time. In itself, the realization that attitudes can change over the course of a project strongly suggests that stakeholder attitudes and considerations need to be considered in projects. Again, in this paper we use this basic analysis on community participation including what went differently than expected to discuss how in the future such developments could be anticipated upon when planning hydrological research in the narrow meaning of planning equipment and measurements.

After identifying the participation of local people in intervention and research, we developed research budget scenarios for the three cases, where we defined effectiveness in terms of process understanding and important model input. Thinking in scenarios for hydrological fieldwork instead of one single approach allowed for making decisions based on expected implications of events on the hydrological results, with the aim to minimize the costs of improvisation. In the procedure, we first evaluated the technical approaches per case study in terms of performance (Blume et al., 2008), defined as the effectiveness of measurements in understanding hydrological processes. We used cost-benefit analysis (Sassone, 1978) in research scenarios that were developed based on the Delphi method (Linstone and Turoff, 1975). A range of budgets were given to hydrological scholars as examples to illustrate the expenditures, with each scenario specifying a budget, the measurements that can be conducted within that budget, and the dominant hydrological processes studied. We asked those scholars their assessment of the added value of higher budgets for gaining understanding of the local hydrological situation of the case area. In changing the budgets, we could explore changes in and differences between probable field campaigns, especially in gaining better understanding of dominant mechanisms of the intervention. Our approach builds on the budgets of scenarios, as budgets in small-scale projects are usually constrained, but everyone still expects good results. Thinking in terms of costs and benefits also allowed making the issues of planning/considering additional measurement activities as concrete as possible for the hydrological researchers we involved in our study.

Based on the results of considering stakeholder participation and cost-benefit scenarios, we were able to develop suggestions how hydrological researchers can include considerations on human agency when planning and performing hydrological field research.

3 Vietnam case: Contour trenches for artificial recharge in Ninh Thuan Province

Contour trenching is a water harvesting technique implemented to increase water availability in semi-arid and arid region. A study on trenches in Chile by Verbist et al. (2009) suggested that only few cases did quantify the (positive) effect of runoff water harvesting techniques on water retention. One older study, Doty (1972), found that almost no change in soil water between areas with and without trenches. In the Vietnam study, we investigated recharge processes of contour trenching, in a study area located in the Phuoc Nam Commune, in Ninh Phuoc district (latitude 11o 27' 46.06" and longitude 108o 55' 44.39" E). The landscape is a foothill with an average slope of about 3.5%. It is dominated by mountainous granite and downhill valley with mix of loamy sand, weathered granite, residual soils and alluvial deposits. The climate is dominated by tropical monsoons. Generally, the wet season with heavy rainfall events occurs from September to December. From April to May there are occasional light rainfall events. The dry seasons are from January to April and from June to August. The average rainfall is 810 mm year-1. The landscape appeared as bare soil with erosion gullies, with some parts covered by cacti and grasses. Contour trenching using 4 m wide and 1 m deep trenches was planned for an area of 97 ha. Ultimately, however, only 22 ha were trenched with a combination of 4 m wide, 1 m deep and 1 m wide, 0.8 m deep trenches. The hydrological research itself focused on an area of about 8 ha.

As already referred to briefly, we conducted a multi-method approach during a single wet year in 2009. Only during one 6-month period (June to November 2009) data of rainfall, water levels and groundwater levels were simultaneously available. On 11 October 2007, before the construction of contour trenches, we installed two rain gauges (Casella tipping buckets, 0.2 mm, with HOBO data logger). Infiltrated ponding water in the trenches was monitored daily after rainfall events. The surface water was measured using a stick and two measuring scales in the trenches. The subsurface (geology and soil) survey was partially conducted three times, in October 2007, March 2008, and June 2009. In October 2007, we performed inverse auger tests (Porchet and Laferrere, 1935) to obtain hydraulic conductivity values at six locations spanning an uphill to downhill transect through the proposed trench area. In March 2008, we drilled 3 m holes at eight locations for additional lithology investigations. We also took four soil samples at the trench plots and analyzed those using wet and dry methods at the laboratory of UNESCO-IHE Delft. In October 2007, we constructed

three observation wells; Wells 1, 2, and 3, at the upstream and middle part of the planned project area. We measured the groundwater level with divers (Schlumberger Water Services, Delft, The Netherlands). Because of the loss of two divers in two different observation wells, after February 2008 we measured groundwater level manually on a 3 to 4-day basis. Moreover, we performed an isotope study; as such studies on recharge are known to allow improved understanding of catchment dynamics (Rodgers et al., 2005; McGuire and McDonnell, 2007). From September 2009 to November 2009, 72 water samples were collected in 2 ml vials. ^{18}O variation of rainfall, surface water and groundwater were analysed at the Isotope Laboratory of Delft University of Technology. Field measurements and isotope results were then used in Hydrus (2D/3D) modelling (Šimůnek et al., 2008).

The combination of field measurements, the isotope technique, and modelling over a 6-month period enabled us to understand the recharge process in contour trenching plots in Vietnam. We concluded that artificial recharge took place in the trench area. In the long term, we are confident that infiltration in the trenches will increase the groundwater levels at the sites. Rapid groundwater level increase during the wet season is followed by gradual drawdown during the dry season. For the time being, the trenches seem to benefit short-term subsurface storage.

In an attempt to look at human actions towards intervention and hydrological research more systematically, we started by identifying the process of participative actions from local people using the scale from Srinivasan (1990; see Fig. 4.). Table 1b provides the detailed results in terms of timing and type of human actions during our intervention processes. The Vietnamese intervention could only be constructed after many negotiations between the initiator and the end users. Such a decision could change the final location of the intervention, which in turn affected directly the hydrological field research. In Vietnam, intervention design and location were determined by the local people, who had the power to choose their preference of intervention and decided whether it could be implemented on their land or not. At the beginning of the Vietnam project, none of the landowners agreed with the intervention, especially because they had not yet seen a successful example in their particular area. After negotiations, a monk organization was willing to provide their land as an example case [#6A]. Hydrological equipment was installed to study the effect of the trenches. After the large trenches were constructed, the monk organization did not like the design. Their rejection of the large trenches enforced the intervention team to reconsider the trench dimensions. Thus,

the team came up with a smaller design of contour trenches. Despite the smaller design, the monk organization still refused to continue implementing the new design on its remaining land. Consequently, the project introduced the smaller design to other farmers and one farmer accepted it. The smaller trenches were then implemented in one farmers' area, and additional hydrological equipment was installed. The acceptance of the smaller design by other farmers continued. Farmers living nearby requested also the small trenches to be constructed on their land. After the monks' organization saw the results at several farmers' land, the monk organization eventually requested the initiator to construct small trenches on their remaining land. The decision of local people who wanted to have contour trenches occurred after seeing an example of a smaller design.

In terms of the scale of participation of the above community, we can observe several "steps" along the ladder (as depicted in Fig. 4):

- 0 to 6; among many landowners, only a monk organization was willing "to try some actions" on their land.

- 6 to 3; the monk organization was sceptic and "have doubts" if they continue implementing the trenches, even with a smaller design.

- 3 to 6; a farmer was willing "to try some actions" on his land.

- 6 to 7; from one farmer with smaller trench design, he advocated change so that the acceptance of the smaller design continued in this particular area.

The engagement of the local community in the hydrological field research was analysed similarly, since it was part of the intervention itself. We found this potential to "measure" attitude even more interesting because our results suggest that these attitudes of stakeholders change over time in the hydrological research itself as well.

In general, we find different processes of involvement and different human actions related to the three hydrological research projects (see Table 1a, on events labelled with [#]). For example, both in Vietnam and Kenya, access tubes [#3, #9A] were taken away. In Vietnam, the divers were taken away as well [#4]. Next to human agency affecting the hydrological research, other events affected the research activities. In Vietnam, one rain gauge clogged [#1] because of fine sands from strong winds, and the screen of the observation wells [#5] proved to be not suitable for local conditions (in Kenya, one rain gauge was actually damaged by elephants, and afterwards removed by local people [#7]). Obviously, these events could

possibly have been avoided. Rain gauges could have been checked and maintained on a regular basis, especially when realizing that local conditions and climate might affect the measurement. However, there were also problems that probably could not have been avoided, especially technical failures of data loggers [#2, #8, #10, #11] from tipping buckets and divers.

Within the context where intervention was done simultaneously with hydrological research – the Vietnam case [#6] – the actual form of the final intervention was decided upon within several rounds of discussions between project team and local communities. Agreement was obtained through a negotiation process. The actual form of the hydrological research was heavily dependent upon knowing the definitive location of the intervention. While the decision process took place, measurements were conducted in the vicinity of the possible locations of the intervention. On-site measurements had to be re-evaluated from time to time due to changes of intervention locations. The intervention period and financial support for research were both limited and limiting as well. Most likely, in conditions of simultaneous intervention and research, changes required adjustments to a new setup, which often means increasing financial expenditure for measurements. Therefore, any decision to start either intervention or hydrological research needs careful thought.

The Srinivasan scale allows for analysing the changes in attitudes and possible actions concerning an intervention over time. How motivation for action is always directly linked to an attitude towards the intervention, remains an open question. An example is the Vietnam case, where access tubes and divers were taken away. Possible reasons may have been that someone rejected the project, did not want any intervention to be constructed on the land, had negative impressions of the intervention, or was not satisfied with the project's offer. On the other hand, the attractiveness of the device itself and/or curiosity could make people eager to have such devices. Therefore, the resulting human action to remove the device may not have been a rejection of the project at all, but just a desire to own a device with a unique appearance.

4   Human actions as surprises in intervention development and hydrological research

Our own experience showed that human actions influenced both the development of intervention and hydrological research. We claim that such events due to human actions could have been anticipated – or even (partially) avoided, by us as well – but usually are treated as

unforeseen side-effects or surprises when they happen – as we did ourselves. For dealing with such surprises, we have found the frameworks, as developed by the RAND cooperation on how to be prepared when facing "surprises" in planning, extremely useful. Dewar (2002) (see also Dewar et al., 1993) discusses such surprises and provides a tool for improving the adaptability and robustness of existing plans by making assumption-based planning (ABP). With ABP, one would double-check the planners' awareness of uncertainties associated to any plan, including assumptions that might have been overlooked.

Baiocchi and Fox (2013) suggest six key issues to be prepared for and respond to surprises; (1) learn from experience: attract and retain the most experienced people, (2) address the negative effects of surprise, (3) assess the level of chaos in the work environment, (4) prepare for "third-party surprises", (5) focus on building a network of trusted colleagues, and (6) conduct regular future-planning exercises. Their recommendations confirm our ideas: planning for surprise requires proper understanding of small interventions within their hydrological context and incorporating interdisciplinary knowledge, learning, and local participation (see Karjalainen et al., 2013; Rodela et al., 2012; Reed et al. 2010).

Despite this potential of looking at uncertainty in planning of small-scale hydrological research related to human actions, there is still a long way to go. The above-mentioned bias towards not publishing small-scale studies not only may limit understanding of the hydrology of small-scale water systems, but it also prevents understanding the nature and performance of the small-scale studies in relation to the intervention itself. Our attempt to operationalize the concept of surprise-based planning in hydrological research, we focused on cost-benefit analysis.

We all know that research budgets for small-scale interventions are usually constrained (e.g. Phalla and Paradis, 2011). In terms of time constraints, a very useful example of how to optimize short-term data is offered by Hagen and Evju (2013). To understand a certain water intervention, ideally a hydrological researcher would prefer measurements being conducted at many locations, for a long time and with high frequency. However, within that general preference and given financial constraints, much remains to be chosen by the researcher (Hamilton, 2007; Soulsby et al., 2008). This suggests that different researchers would select different actions and measurement techniques, even when performing a similar type of hydrological research. As such, options can be studied in terms of costs and benefits. What to do with limited budgets and the possible gains that can be made with certain (additional)

measurements or activities at a cost encourages ("forces") hydrological researchers to take into account how to deal with possibly costly surprises in preparing and implementing field research. We tested this scenario approach with a group of experts, offering three scenarios. Scenario 1 was approximately at the lowest budget, which was estimated by considering the experiences gained by the author. As we already knew how the research went, we set the lowest cost scenario by eliminating the measurements that failed or were not used in the analysis. This scenario combined at least a desk study with field measurement data. In addition, this scenario was a theoretical baseline for a good understanding of the intervention.

Scenarios 2 and 3 covered a longer research period. Extension of measurement and performing other methods were proposed. There were several options related to parameters that were selected and added, with various spatial and temporal combinations. The options we have to make to confirm certain underlying dominant hydrological processes due to an intervention were:

A. Extension of the measurement period.

B. Additional samplings.

C. Additional measurement devices.

D. Additional analysis.

Option C and D are connected since having another type of measurement might use the same or require a new (commercial) software program or service.

Scenario 2 was set with a budget increase of about 20%. We preferred to use this extra budget for the extension of the measurement period and more samplings.

Scenario 3 was set with a budget increase of approximately 80%. It implies a condition of an expansion of Scenario 2 combined with much more room for additional parameters in the field campaign.

Some assumptions for the budgeting were set as follows:

- Expenditures in our (fictitious) budgets are labour and financial costs, which are chosen in ranges of Euros; (+-) is between 0 to 50 Euro, (+) 50 to 250 Euro, (++) 250to 750 Euro, and (+++) above 750 Euro.

- Related research budget components like field personnel, transportation to the site, meals, and accommodation were not considered.

- A researcher was categorized as non-paid labour in the research area, since s/he receives salary from the researcher's institution. Thus, the researcher's expenses were ignored.

- Shipping cost of devices and samples, taxes of research devices, and research permit costs were excluded.

- There were no subsidies from research institutions for measurements devices or models.

- None of the scenarios took into account decisions made for a particular intervention and its development.

For Scenarios 2 and 3, the end results of possible field campaigns and analysis were discussed with ten experts from different Dutch institutions, who were selected from the working environment of the author. Each scenario had its own specific hydrological objective that fits to an expertise (i.e. hydro-geology, hydrology, remote sensing), but the experts had different hydrological backgrounds. The implemented research with the results and proposed scenarios of several field campaigns were explained to the experts to clarify the content and objective of the research. Subsequently, they had to grade the scenarios based on the level of additional understanding (if any) that would be achieved. The required budget itself was not mentioned to allow experts to objectively value the proposal without any economic consideration. The author picked the Dutch grading scale as follows:

- 1-5,5 = little understanding of the relevant mechanism of intervention

- 6-7,5 = good understanding of the dominant mechanism of intervention

- 8-8,5 = better understanding of the dominant mechanism of intervention

- 9-10 = complete (full process) understanding of the mechanisms relevant for the intervention

In the interview following the assessment of the scenarios, the experts were also given the opportunity to provide their own alternative approaches that could result in better understanding.

Even though this was a theoretical exercise and that it was not easy to provide clear-cut evidence for the scenarios to be realistic enough, results are useful. There may be many other options of optimization, such as cheaper measurement devices and modelling. Different

research institutions prefer different measurement devices, or software developed by certain institutions. Research institutions might already own measurement devices and software, thus do not want to spend money on others. This specific setup is merely an estimation in the context of the three case studies and may well vary from person to person due to people's preference. However, by asking ten experts for their input and analyze further their responses over the entire width of the scenarios, a good degree of objectivity, certainty and reality can be reached, if not in absolute, then at least in comparative terms. Our results are given in Fig. 5. We discuss the Vietnam case in more detail.

5   Vietnam case: research budget scenarios and experts' opinions

To have sufficient understanding of groundwater recharge during the actual research, the expenses of the research budget were reduced to about 60% (see Table A.1). Rainfall measurement is a must since it is used for the input of the model. The hydraulic properties of soil and infiltration tests are important as well. The water level measurement is required to get the ponding in the trench correctly. These costs are not much compared to other measurements. Soil moisture measurement is removed from the field campaign since it is not only expensive, but also the access tubes are prone to be taken away by the local people. Isotope tracers are excluded, because the constructed observation wells were not suitable for groundwater sampling. In addition, the cost for this analysis is considered to be expensive. On the other hand, isotopes are beneficial and will provide signals as long as the observation wells would be better constructed. A minimum of three observation wells are set, since it is the minimum or triangle layout to get an idea on the groundwater flow direction. A short but sufficient period of measurements would be during the wet season, where the trench may be filled with rain water.

Even though the cost reduction is significant, the conditions to apply these methods could remain uncertain. For example, when a researcher made a plan for scheduling the starting point of measurement at the beginning of a wet season, no one would expect at first that negotiating with the local community was difficult, even though this determines whether or not the intervention can be built or continued. There has to be willingness from the community to provide land for the intervention. After several discussions and meetings, a local to local approach was needed to convince stakeholders that the intervention would be beneficial to the local community. However, no one could predict when and where it could be realized. If the decision to be made for construction was delayed, the plan for hydrological

measurements would have to wait until the next wet season, which would have been one year later. And if there is a tension to install the measurement devices for an analysis of "with and without", the location of the intervention might shift in time. Thus, new measurement set ups have to be adjusted. These conditions will result in loss of data and time for the hydrological research. As such, the minimum budget is somewhat artificial. Conversely, the big difference between the minimum budget and the actual budget suggests that in the Vietnam case, negotiations on the intervention brought along high costs.

When more budget would be available, scenario 2 (see Table B.2) could expand the implemented program by constructing one new observation well and its groundwater level measurements. Also the sampling period for isotope tracer is extended. The observation well should be placed in line with the existing wells and its screen should be along the pipe, from near soil surface to the bedrock. It would be expected that the recharge can be more apparent where the signal of infiltrated rainwater can directly infiltrate into the pipe. Thus, the groundwater fluctuation and sampling can confirm the result of the implemented research.

In scenario 3 (see Table B.3), an 80% increased budget gives options for more applications and/or more advanced methods. Besides one new observation well and isotope samplings, three other wells should be constructed. The observation wells should be placed at the small trench area. A possible advanced measurement is by performing an Electrical Resistance Tomography (ERT) survey for subsurface imaging. Several cross sections of the subsurface could be obtained during the dry and wet period. By having these new wells combined with the analyzed ERT data, the hypotheses could be made more pronounced regarding the difference in groundwater behaviour with and without the intervention structure.

The results of the interviews with the experts can be seen from Table B.1-B.3. Of the three cases, the Vietnam case had most options, due to better financial conditions, compared than the other two cases. Considering scenario 2, 70% of the experts believe an additional well and a 1-year continuation of the groundwater level measurements, including isotope samplings and analysis, would result in similar data collection as in the implemented research. One expert considered that extra data might even lead to confusion. Another period of 1-year data could be used for validation, thus might give more confidence. A very long data series, from two to about ten years of groundwater level measurement would be very beneficial for better understanding the mechanism of the recharge.

In Scenario 3, with 80% increase in budget, the value of measurements points to similar results as in Scenario 2, with some additional elements. 80% of the experts say that Electrical Resistivity Tomography (ERT) measurements could increase the understanding of mechanism of the recharge and provide more explanation of the disconnected groundwater system. Thus, it could potentially confirm the groundwater profile and the groundwater level during recharge. Performing ERT either during dry or wet seasons sometimes yields results hard to interpret, since ERT is a static measurement.

In summary, a research plan with 20% increased funding (Scenario 2) appears to obtain similar understanding as the reference result. On the other hand, an 80% increase in funding may be capable of gaining a better understanding. A costly research plan for a small-scale intervention project may not be economically feasible and thus impossible to implement.

6 Towards systematic planning

Despite all the problems we encountered in the three field research projects, we could develop a good understanding of the hydrological impacts of interventions in three different developing countries. In Vietnam, during the wet season, contour trenches contribute to recharge, but only for short-term impact, up to two months. In Kenya, vegetation growth in the trench area as reflected in the signal of greenness index was most likely due to the wet season, without a clear long-term effect from the trenches. In Indonesia, the potential of micro-hydro capacity on Maluku islands ranges from 6 to 40 kW. In the three cases local people participated during the implementation of the projects, both in the intervention and hydrological research. As a result, the field campaigns were not perfect in terms of hydrological standards. Measurement devices were damaged, removed, disappeared or not located at the final intervention. In the end, we ended up with less data or data of lower quality. Local participation and financial constraints forced us to deal with research and intervention as interacting with and affecting each other.

As this setting is not unique to our three small cases, balancing intervention and research is a general challenge. Tracing back the social reality and the way it shapes intervention and research with the associated budget allowed us to gain more insight into trade-offs between hydrological knowledge and hydrological research management. Based on our experiences, we propose that planning ahead is possible. We propose a new systematic perspective on how to prepare hydrological research for a more effective way to implement small-scale water intervention research initiatives. Being prepared for and responsive to surprises due to human

actions can be achieved by developing scenarios that combine hydrological issues with cost-benefit analysis – in a process similar to RAND studies providing guidance for an approach that anticipates on known surprises (Dewar, 2002). In planning for surprises, as outcomes of local negotiations are not known before, considering financial costs and specific research objectives of small-scale interventions, options for field campaigns and analysis that could answer the research questions can then be defined.

Similar to balancing development and conservation (Garnett et al., 2007), when financial constraints – and usually time as well – become important, a researcher should be able to balance what he/she can and cannot do. Since budgets and time for a small-scale intervention are limited, research should be well planned. In order to include the costs of performing hydrological studies and the efficiency (effectiveness) in planning for surprises, we discussed an approach applying cost-benefit analysis. Despite its simplicity, it appears to be a good way to quantify research efforts versus the (probable) outcomes.

The judgments of the outcomes were obtained from interviews with water experts. Sharing options with other experts adds value to the preparation. Each scholar has their own preferences, and thus there is no single solution. This was shown during the interviews with the experts, when they were forced to make a choice by pushing their preference in grading the available field campaign options. Eventually, even when incorporating experts' inputs, we will still have to make decisions and will possibly select our own preferred choices. In the end, dealing with the local constraints is a decision to be made by the researcher. However, by doing the two analyses of scenarios and cost benefits continuously during planning and performing hydrological research, one will be better informed to make decisions.

The notion that the effects of human actions to be expected in hydrological field campaign are basically unspecified does not imply that they could not adequately and fruitfully be translated in specific planning, as we have shown. Taking into account human actions in planning field campaigns for something that is usually seen as a single-scientific activity implies that each field design should be tuned to the situation under consideration. A designer cannot come up with a standard solution and may experience different stages of learning processes that continue to shape both intervention and hydrological research (see Fig. 6). Paradoxically, introducing such a multifaceted approach asks for hydrological researchers with higher qualifications. Planned improvisation needs scientific expertise, as much as it requires a specific attitude.

Appendix A: Research budget scenarios

Appendix B: The experts' opinions

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1   Table 1a. Vietnam case; hydrological research

Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning of the event and/or action to research)	Period
Install two rain gauges	Intermittent rainfall data	-	-	October 2007-March 2011
	Clogged rain gauges [#1]	Need of checks and maintenance	Loss of rainfall data series	October 2008
	Logger failed to record events [#2]	Tried to retrieved data from manufacture company and manual measurement	Loss of rainfall data series	December 2009-March 2011
Install access tubes for soil moisture measurements	Loss of access tubes [#3]	Substituted with new access tubes	Loss of soil moisture data series, extra costs for new tubes	September 2008-March 2011
Check infiltration at the bottom of the trench	-	-	-	September 2009- November 2009
Measure soil porosity and bulk density	-	-	-	October 2007-June 2009
Measure infiltration capacity	-	-	-	October 2007 & April 2009
Measure surface water level in the trenches during wet season	-	-	-	October 2007 - November 2009
Construct observation wells	Loss of divers [#4]	Perform manual measurement	Loss in groundwater level data series	December 2007
	Improper screen instalment for isotope sampling [#5]	Nothing	Possible misinterpretation of isotope signal	October 2007 & April 2009
	Construction before intervention [#6]	Extra costs for constructing new wells	A shift in location of intervention requires more measurements, thus more cost	October 2007-April 2009

1   Table 1b. Vietnam case; intervention

Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Introducing the concept of intervention to local authority and community	Meetings	Presentations and discussions to obtain support	Needed an agreement from local community	May 2006 - September 2007
Constructing contour trenches [#6A]	A monks' organization provided their land in a size of 12 ha for intervention	Larger trenches were constructed on 8 ha area	Needed an agreement on someone's land to be interfered	October 2007
	After large contour trenching, the monks' organization refused to continue construction on their remaining land	Meetings and discussions to convince the intervention would be beneficial for the community	Although the monks gave permission for large contour trenching, they did not like the design	November 2007 - March 2008
	The initiator approached other land owners	The initiator offered a smaller contour trench design	Negotiated on the design	March 2008
	A local farmer excepted the smaller trench design	Construction of smaller contour trenches on 1 ha area	The smaller design was tested	April 2008 - May 2008
	Other local farmers requested smaller contour trenching.	Construction of smaller contour trenches on other farmers' land (10 ha)	The smaller design was preferred	June 2008 - August 2008
	The monks' organization also provided their remaining land for smaller contour trenching	Construction of smaller contour trenches on the remaining 4 ha area.	Overall in this particular local community, a larger design was not accepted.	June 2008 - August 2008

1   Table 2a. Kenya case; hydrological research

Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning or impact of the event to research)	Period
Install two rain gauges	One rain gauge was damaged by elephants and thus removed by local people [#7]	Information came very late, thus arrangement for reset up of the rain gauge could not be performed	Loss of rainfall data series	September 2010-March 2012
	One logger failed to record events [#8]	Tried to retrieve data without success	Loss of rainfall data series	September 2010-March 2012
Soil moisture measurements to be conducted by a local person	A long negotiation to start measurement was not successful [#9]	Established new connection with other local people was not successful too	Loss of soil moisture data series	September 2010-Mach 2013
	Loss of access tubes [#9A]	Installed two remaining tubes	Loss of soil moisture data series	September 2010-March 2012
Used TRMM & NDVI analysis	-	-	-	January 2011-March 2011
Measure soil porosity and bulk density	-	-	-	September 2010
Soil sampling for Cesium analysis	-	-	-	September 2010

3   Table 2b. Kenya case; intervention

Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Introducing the concept of intervention to local authority and community	Meetings	Convincing local people with success	Local people accepted the design	2001-2002
Constructing contour trenches	The majority of Maasai supported contour trenches	Trenches were first constructed in smaller dimension and furthermore in larger ones	Easy to implement different dimension of contour trenching in this particular area	2002-2006
After construction of large contour trenches	-	-	-	2002-present

1   Table 3a. Indonesia case; hydrological research

Procedure (the official way of conducting hydrological research)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning or impact of the event to research)	Period
Install two rain gauges	One logger failed to record events [#10]	Only counted on one logger	Loss of rainfall data series	July 2010-July2011
Install two divers	One logger failed to record events [#11]	Only count on one diver	Loss of water level data series	July 2010-July 2011
Measure discharge using dilution method and velocity area	-	-	-	February 2011-March 2011
Used DEM analysis	-	-	-	April 2011-June 2011

3   Table 3b. Indonesia case; intervention

Procedure (the common way of intervention)	Event or observation (an indisputable happening)	Action (the process before an event)	Interpretation (giving a meaning of the event and/or action to intervention)	Period
Proposed intervention to local authority and community	Meetings, permit issue, estimation of micro hydro budget and research on its potential	-	-	March 2010-June 2011
Design suitable micro hydro installation	Two plans were agreed; first an installation of about 80kW and second small kW was estimated after the research	Search for extra funding to meet the construction cost	A decision had to be made based on the availability of funding	July 2010-January 2012
Pilot result	Research result suggests little potential for micro-hydro installation in a village, but funding was still not enough	Constructed micro-hydro model for a local university	The final intervention shifted from a pilot to a model	September 2012-September 2013

5   Table 4. Time periods of three hydrological intervention-based research projects

Case study	Intervention		Hydrological research	
	Start	End	Start	End
Vietnam	October 2007	September 2008	October 2007	March 2011
Kenya	2002	2003	September 2010	March 2012
Indonesia	September 2012	September 2013	July 2010	October 2011

7

Table A.1. Vietnam Case, Scenario 1: to measure rainfall and groundwater level for a short period

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	40	+++	2.015
Soil physics	Lab analysis	6	+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading	13	+	720	+-	15
Groundwater level	Observation well & diver (reached bedrock)	3	++		+++	5.533
			Total I	**760**	**Total II**	**7.876**

Notes:

(+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

Table A.2. Vietnam Case, Scenario 2: to recheck the signal of recharge

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	40	+++	2.015
Soil moisture	TDR (with access tubes)	8	+++	2.160	+++	4.717
Vertical flow path	Dye tracer	3	+-		+-	10
Soil physics	Lab analysis	6	+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading	13	+-		+-	15
Groundwater level	Observation well & diver (reached bedrock)	7 + 1	++		+++	13.893
Isotope tracer	Lab analysis	116 + 116	+		+++	1.856
			Total I	**2.200**	**Total II**	**22.819**

Notes:

(+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

Table A.3. Vietnam Case, Scenario 3: to map the subsurface

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	40	+++	2.015
Soil moisture	TDR (with access tubes)	8	+++	2.160	+++	4.717
Vertical flow path	Dye tracer	3	+-		+-	10
Soil physics	Lab analysis	6	+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading	13	+-		+-	15
Groundwater level	Observation well & diver (reached bedrock)	7 + 4	+		+++	18.909
Isotope tracer	Lab analysis	116 + 116	+		+++	928
Subsurface mapping	ERT	4		2.000	+++	10.000
			Total I	**4.200**	**Total II**	**36.907**

Notes:
(+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

Table A.4. Kenya Case, Scenario 1: to use remote sensing data

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1.305
	Remote sensing analyis		-		-	
Greenness index	Remote sensing analysis		-		-	
			Total I	**120**	**Total II**	**1.305**

Notes:
(+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

Table A.5. Kenya Case, Scenario 2: to retry one year soil moisture measurement

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1.305
	Remote sensing analysis		-		-	
Soil moisture	TDR (with access tubes)	6	+++	2.880	+++	4.990
Soil physics	Lab analysis	8	+-	40	+-	
Greenness index	Remote sensing analysis		-		-	
Erosion & sedimentation	Cs analysis	128	+	100	+++	1.699
			Total I	**3.140**	**Total II**	**7.994**

Notes:
(+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

1 Table A.6. Kenya Case, Scenario 3: to maximize remote sensing analysis

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1.305
	Remote sensing analysis		-		-	
Soil moisture	TDR (with access tubes)	6	+++	2.880	+++	4.990
Soil physics	Lab analysis	8	+	40	+-	
Greenness index	Remote sensing analysis		-		-	
Erosion & sedimentation	Cs analysis	128	+	100	+++	1.699
High resolution greenness index	Remote sensing analysis		-		+++	8.400
			Total I	**3.140**	**Total II**	**16.394**

3 Notes:
4 (+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro
5
6 Table A.7. Indonesia case, Scenario 1: to measure discharge of one river for one year

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Discharge	Velocity area (diver)	3	+-		+++	1.500
	Dilution gauging		+-		+-	25
Head	Remote sensing analysis		-		-	
			Total I	**50**	**Total II**	**1.525**

8 Notes:
9 (+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro
10
11 Table A.8. Indonesia case, Scenario 2: to investigate discharge of another river

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	50	+++	1.990
Discharge	Velocity area (diver)	3 + 2	+-		+++	2.500
	Dilution gauging		+-		+-	25
Head	Remote sensing analysis		-		-	
			Total I	**50**	**Total II**	**4.515**

12 Notes:
13 (+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro
14

1   Table A.9. Indonesia case, Scenario 3: to investigate discharges of four other rivers

Parameter	Method	Number / Samples	Labour	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	50	+++	1.990
Discharge	Velocity area (diver)	3 + 8	+-		+++	5.500
	Dilution gauging		+-		+-	25
Head	Remote sensing analysis		-		-	
			Total I	**50**	**Total II**	**7.515**

3   Notes:
4   (+-) = 0 - 50 Euro, (+) = 50 - 250 Euro, (++) = 250 - 750 Euro, (+++) above 750 Euro

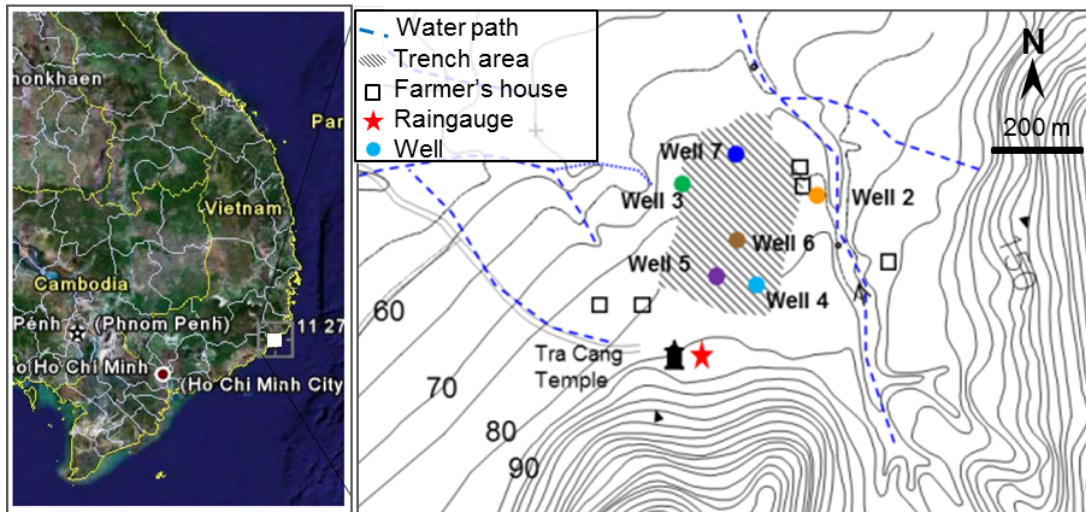
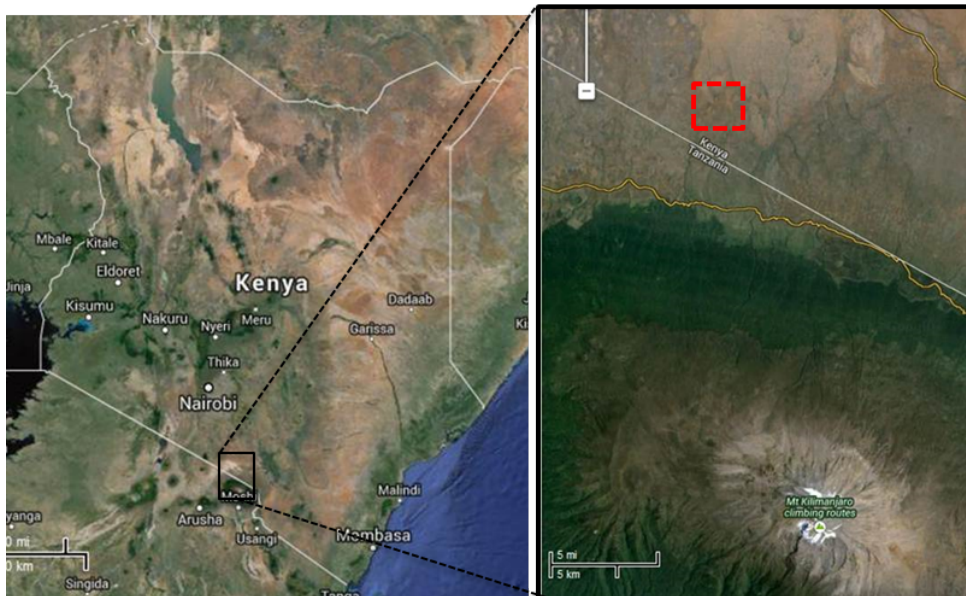
1   Table B.1. Vietnam case; the experts' opinions

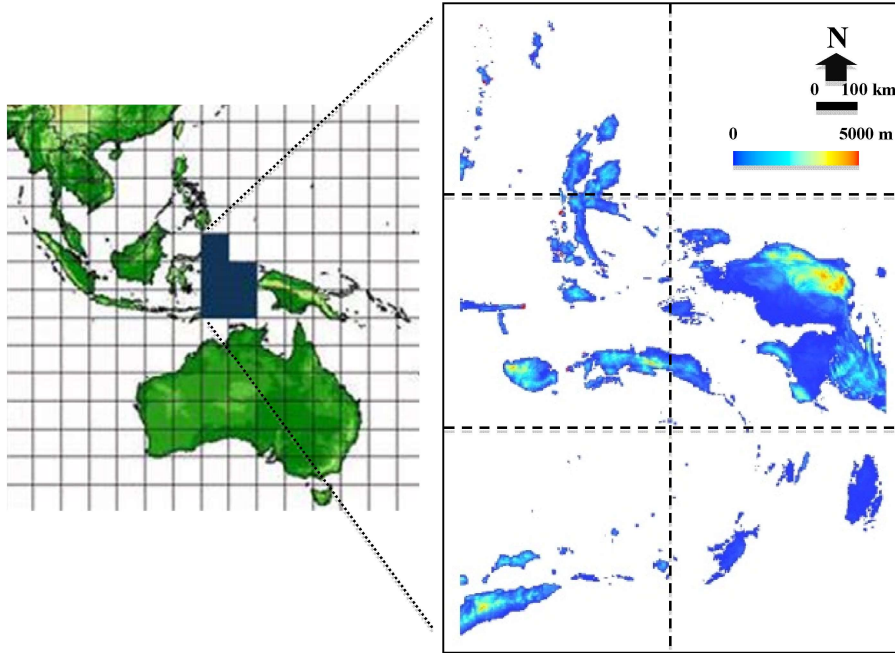
No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	Seasonality is already included	7	Disadvantage: profiles measured only one time	Require 10 year groundwater level data
2	MSc	Delft University	8	Measure for at least 2 years	8.5	Model only tests hypothesis. Measurements already answered the research question	-
3	MSc	Delft University	7	Isotope is an advance method with good result	7	One time measurement equals to nothing	To study the unsaturated zone, to measure rate of recharge using SM sensors etc
4	PhD	Delft University	8	Need validation and try to get more confidence or to decrease uncertainty. But it could even lead to confusing results	8	Hard to interpret	Depending on Ks and soil moisture. Challenging (qualitative result): infiltration test and surface water measurements
5	PhD	Delft University	7	Sceptic	8	-	-
6	Prof	UNESCO-IHE	7.5	-	8	-	-
7	PhD	UNESCO-IHE	7.5	-	8	Increase resistivity of water by injecting sodium chloride	More artificial tracer, (yellow dye), soil moisture measurement below the trench (use cheap sensors like Decagon). A need of timely scale measurements or time laps measurements
8	PhD	Delft University	8	-	8	-	Previous measurements were already sufficient
9	MSc	Eindhoven-Deltares	7	-	8	-	It would be an advantage to have 3-D
10	PhD	Delft University	7.5	-	8	Expensive (cost magnitude about 10.000 to 30.000 Euro for a 5 m interval)	Geophysical approach for spatial information. Soil type analysis, ground radar method, and 1-2 points tracer (pollution)

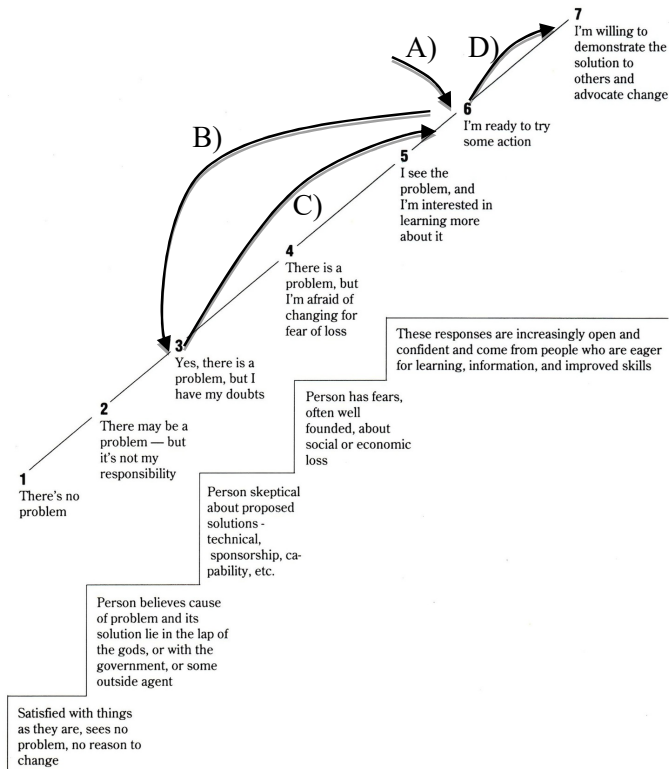
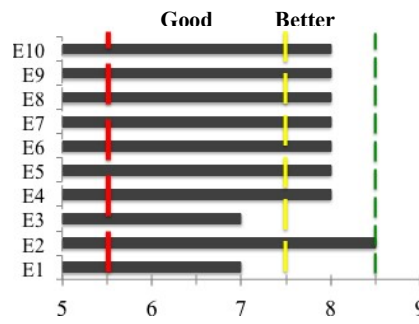
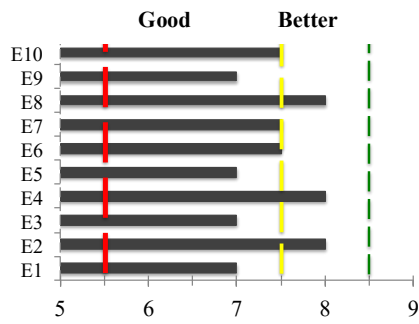
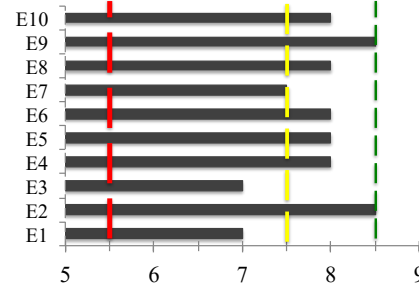
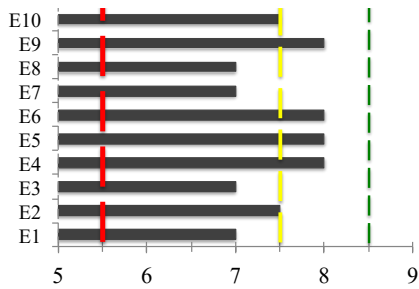
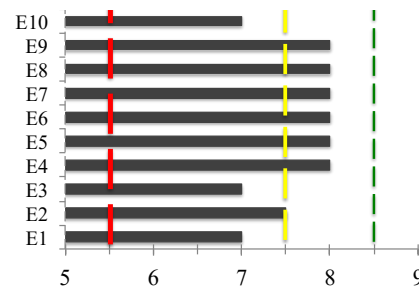
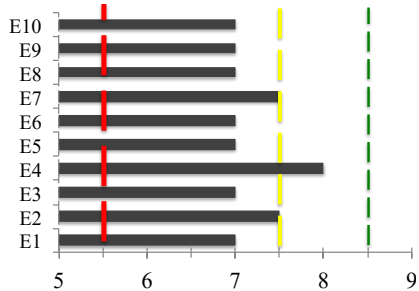
1   Table B.2. Kenyan case; the experts' opinions

No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	NDVI related to temperature, LAI, but does not correlate to soil moisture	7	-	Try FPAR (Fractional Photosynthetically Active Radiation)
2	MSc	Delft University	7.5	-	8.5	-	Soil temperature measurement to estimate evaporation.
3	MSc	Delft University	7	Enough	7	Enough	-
4	PhD	Delft University	8	-	8	-	Aerial photos, LAI (although it is difficult)
5	PhD	Delft University	8	-	8	-	Try to measure discharge, modelling the impact of soil moisture & transpiration
6	Prof	UNESCO-IHE	8	-	8	-	Discharge measurements (notches) to close the detail water balance, micro station especially evaporation
7	PhD	UNESCO-IHE	7	-	7.5	-	Plant's physiological effects like water stress.
8	MSc	Delft University	7	-	8	-	A higher resolution is usually better.
9	MSc	Eindhoven-Deltares	8	-	8.5	-	-
10	PhD	Delft University	7.5	-	8	Try to see sub pixel	Pixel variability (to minimize the interval of images). Sensors for spectrometer through cable trolley/station and aerial photos (for more detail images)

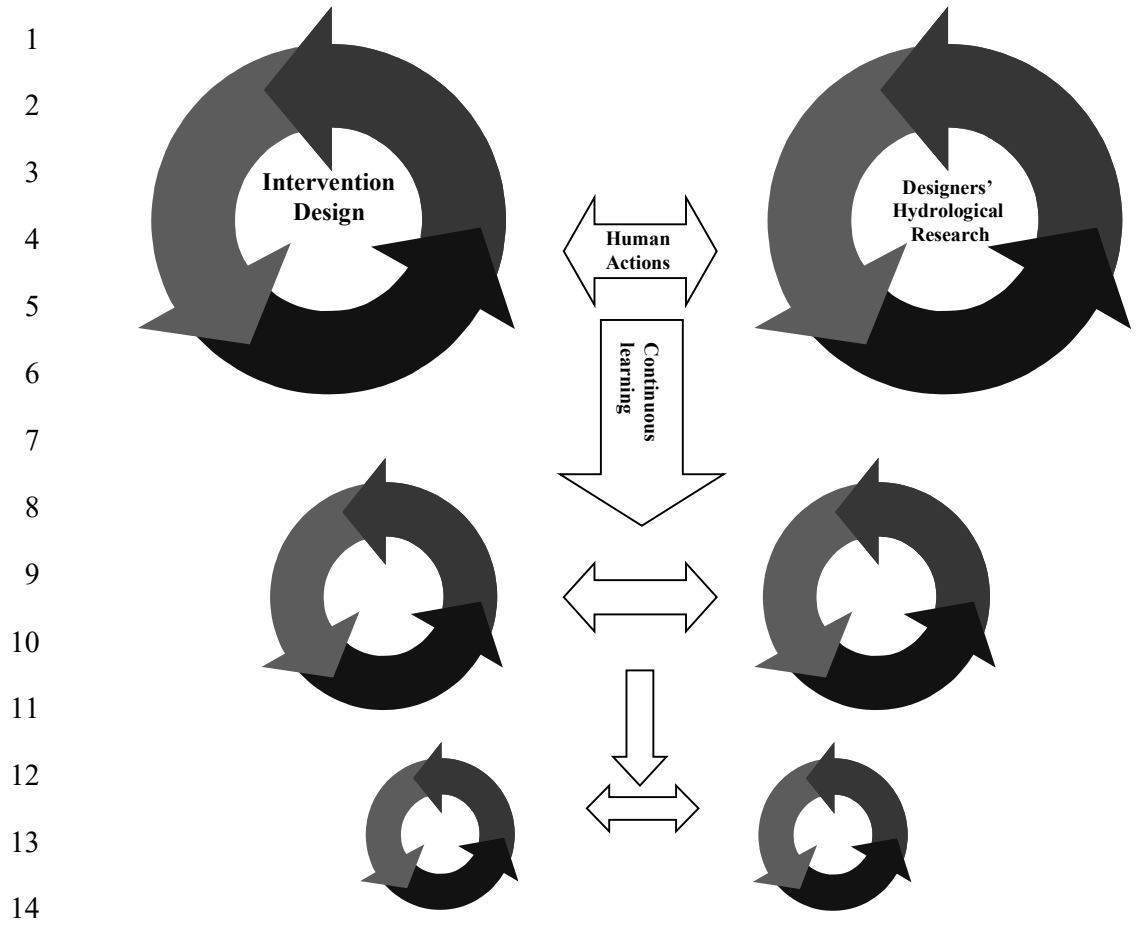
1   Table B.3. Indonesian case; the experts' opinions

No	Title	Institution	Scenario 2		Scenario 3		Other suggestions
			Grade	Remarks	Grade	Remarks	Remarks
1	PhD	Utrecht University	7	Absolut value is enough	7	-	-
2	MSc	Delft University	7.5	Reach a statistical information of regime	7.5	Reach a statistical information of regime	-
3	MSc	Delft University	7	-	7	-	-
4	PhD	Delft University	8	With more data we can get new or not increased understanding	8	Spatial information is important	Integrate geology and other point measurements at other rivers
5	PhD	Delft University	7	Hydrology engineering	8	Measure at more various areas. Start by investigating maps of the different factors; geological, topographical, vegetation, and boundary condition.	More variability means more recommendation to result in a catchment classification with certain discharges, but maybe diverse catchments are depended only on landscape and geology
6	Prof	UNESCO-IHE	7	-	8	-	Higher resolution of DEM.
7	PhD	UNESCO-IHE	7.5	-	8	-	Maps or information on internet: meteorological data (rainfall & temperature) DEM, soil, geology, & land use. Multiple regression (Q)
8	PhD	Delft University	7	-	8	-	Map of the basin. Field survey on all potential places based on the distance from the village etc. Socio-economic studies to answer where to build a MHPP.
9	MSc	Eindhoven-Deltares	7	-	8	-	Geology and land use map.
10	PhD	Delft University	7	-	7	-	Not important in hydrological science, but just as hydrological measurement. If one goes for uncertainty, then a long time series is needed. A flume (which will be costly) is an option to measure the Q.

3   Figure 1. The location of the trenched area, rain gauge, and constructed wells. The study area
4   is the shaded area on the lower map. Source: Local produced map and Google Earth.

6   Figure 2. Location of studied contour trenching in Amboseli, Kenya (red dashed line). Source:
7   Google Maps.

2

5   Figure 3. The result of merged and processed DEM tiles on Maluku islands.

SARAR Resistance To Change Continuum

3   Figure 4. The implemented intervention based on the scale of community participation of
4   Srinivasan (1990).

The Vietnam Case

The Kenya Case

The Indonesian Case

Red dash line = grade 5.5
Yellow dash line = grade 7.5
Green dash line = grade 8.5
E = expert

Figure 5. Summary of three cases; on the left: Scenario 2, right: Scenario 3

15 Figure 6. Designing hydrological field research in small-scale intervention (modified from

16 Ertsen (2002) and Scheer (1996))