Small-scale hydrological intervention-based research: on systematic planning and perspectives

Pramana, K.E.R.

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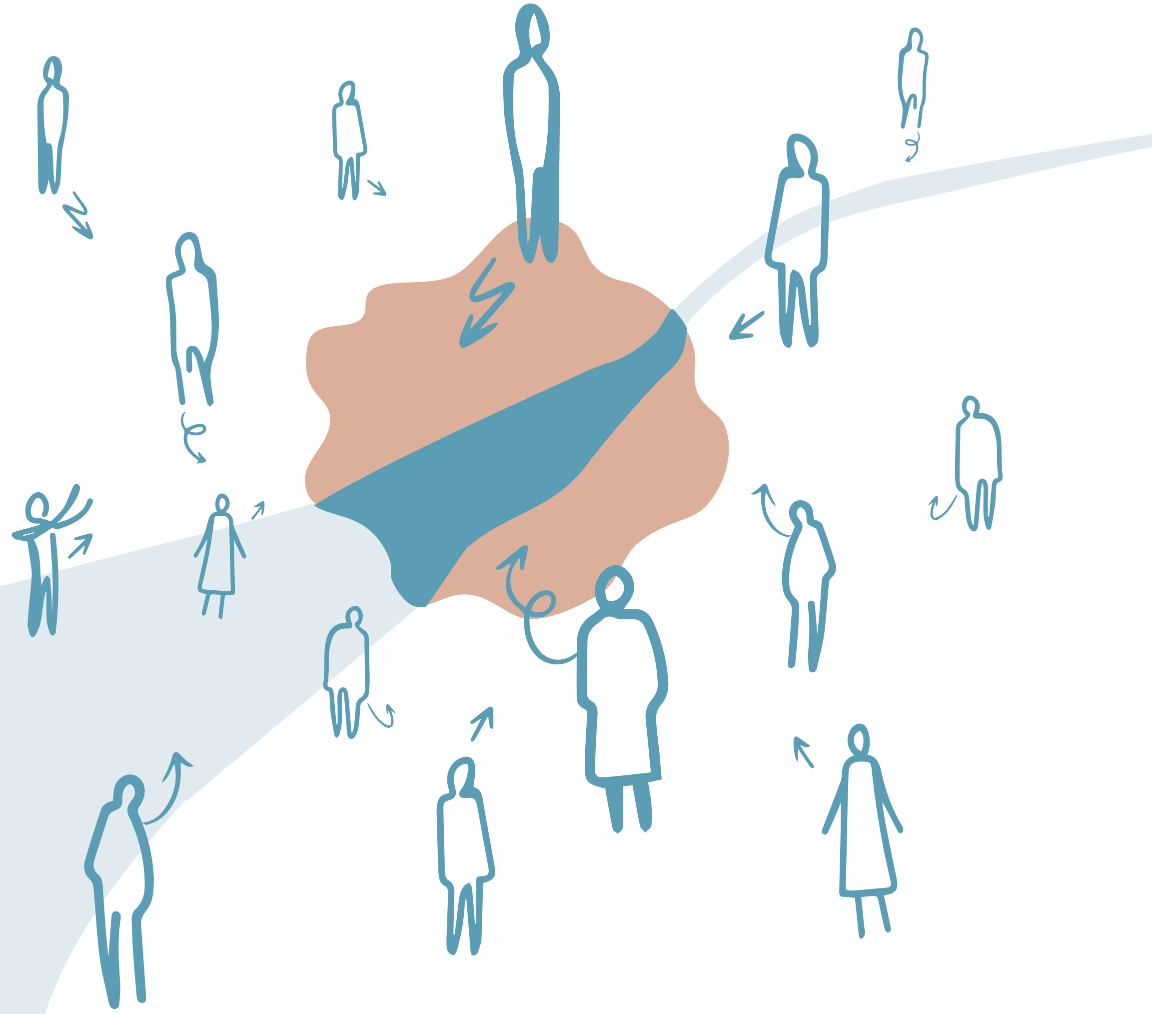

Kharis Erasta Reza Pramana

Small-scale hydrological intervention-based research: on systematic planning and perspectives

Kharis Erasta Reza Pramana

Small-scale hydrological intervention-based research: on systematic planning and perspectives

Small-scale hydrological intervention-based research: on systematic planning and perspectives

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Summary

The world as we know it today has largely been shaped by human intervention. Given the importance of water in particular many small-scale interventions in the hydrological system have been applied. In order to predict and monitor how these interventions affect the hydrological cycle, hydrological research has to be performed. In this thesis, three cases from three different countries (Vietnam, Kenya and Indonesia) are explored to investigate how such small-scale hydrological studies can be arranged in the most optimal way.

In 2007, contour trenches were dug in a semi-arid area in Vietnam to improve infiltration. A multi-method approach was used to assess the resulting recharge, using field measurements, stable isotope techniques, and modelling. The field measurements consisted of two rain gauges, surface water measurement in the trenches after events, infiltration tests, and four observation wells in the trenched area. In 2009, a complete set of field measurements was made for a single wet season. The results on subsurface and groundwater levels suggests that between two wells, the groundwater system is disconnected. Water stable isotope sampling and analysis showed how one well was recharged through a short cut. Water retained in the trenches evaporated or took days to infiltrate completely. After rainfall events, sedimentation in the trenches increased, which decreased the infiltration capacity. The recharge appears to be beneficial for a brief period only, up to a maximum of two months. Furthermore, Hydrus (2D/3D) was used to estimate subsurface parameters by matching surface and groundwater level data. For this case, the multi-method approach provides an adequate understanding of the mechanism of local recharge.

In 2002, contour trenching was initiated to trigger reforestation in a semi-arid area in Amboseli, Kenya. To study the effects of the trenches, fieldwork was performed in September 2010, consisting of rainfall measurements, soil moisture measurements, and soil sampling. The aim was to assess the impacts of contour trenching on vegetation growth, soil moisture availability, and sediment distribution in the trench area. Remote sensing analysis was conducted with monthly TRMM and NDVI images, with TRMM values being correlated to NDVI differences for situations with and without contour trenches. Results show that TRMM and NDVI do not correspond to each other, both in terms of direct monthly impacts and lags. The signal of a high greenness index in the trench area was most likely triggered by the wet season, not by additional soil moisture storage from the trenches. To understand erosion and sedimentation in the trench area, cesium analysis was performed. Local and external sediment was found in the trench area. The amount of sedimentation in the trenches suggests that the sediment trap structure still allows fine material to enter the trench area. For this Kenya case, the multi-method approach provides an adequate understanding of the effects of trenches.

In 2010, the potential for a micro-hydro power plant was investigated in Maluku province, Indonesia. The study combined a digital elevation model and discharge measurements. A river map with elevation differences was prepared. Discharge measurement data were used to determine the runoff per unit area, which was extrapolated to other islands in the Maluku region. The study suggests that the Maluku Islands have potential for micro-hydro power plants, especially on the two islands of Buru and Seram, with a potential of up to 200 kW.

Specifically, the potential of micro-hydro power plants on Aboru is 5 kW. For this Indonesia case, the multi-method approach provides an adequate understanding of the potential of micro-hydro power plant in Maluku province.

In these three case studies, multi-method approaches have been applied, especially the Vietnam case; all yielded a good understanding on the dominant hydrological mechanisms of the respective small–scale intervention projects. The multi-method approaches were further evaluated, with the importance of adapting to local conditions in mind. Scenarios for each intervention project were developed, applying cost-benefit scenarios to show whether additional investments could lead to a better understanding of the underlying hydrological mechanism(s) in the intervention projects. A first scenario aimed at optimizing the actual project cost-benefit, with failed field measurements removed from the research budget. The second and third scenario allow a researcher to spend 20% and 80% more funding respectively, based on the optimized budget. Ten experts were asked to judge the possible results of these second and third scenarios. It turned out that a research plan with 20% extra funding was more likely to achieve similar understanding as the baseline. Additional 80% funding would result in a better understanding. However, such extra finances are unlikely to be available for small-scale research projects.

In small-scale intervention-based research, typical problems that emerge include technical failures, dislocation or disappearance of measurement devices, and shifts in the location(s) of interventions. Together, these problems lead to a decrease in amount or quality of field data. During the research period, a researcher has to determine or adjust the method for the research as a result of such events, especially where and how to conduct new measurements. In general, intervention projects treat the problems mentioned as unavoidable, if these are treated as relevant for hydrological research at all. Technical failure could just happen without anyone being able to avoid it, but especially the impact of human actions on hydrological research within intervention-based projects is something that should be anticipated upon in planning and performing the hydrological research.

Furthermore, an interesting part of the discussion with ten experts was reviewing their responses. All scenarios were not only provided, but were also suggested by the ten experts. It is shown that they had different suggestions on how the same research should or could be done. These differences created a wide range of possible perspectives: how does one measure in the field, how to translate those measurements into analysis and modelling, etcetera?

This thesis brings up two important aspects when conducting small-scale hydrological intervention-based research. First, problems related to human actions may vary with the level of involvement of stakeholders. However, no matter the level of involvement, a hydrological researcher will have to deal with human actions when planning and executing field research. Human actions, the intervention, and its associated hydrological research affect each other. Using two additional analysis steps on top of a multi-method, any researcher needs to include systematically considerations concerning the hydrological project plan: (1) consideration of possible surprises and possible actions, and (2) cost-benefit analysis. By performing the two analyses before and possibly continuously throughout a small-scale hydrological intervention-based project, effective hydrological research can be achieved. Second, in relation to the hydrological research, it also suggests that a hydrological researcher will have his/her own preference that will create a certain perspective on hydrological issues. Choices made in measurements and modelling by the hydrological researcher during his/her research are specific. This poses the question whose hydrological reality is emphasized – whose knowledge counts. Paying more attention to this continuous ambiguity to encourage a stronger co-evolutionary process of water-related intervention and associated research seems to be a reasonable requirement for the hydrological community.

Samenvatting

De wereld die we kennen vandaag de dag is veelal gevormd door interventies van de mens. Gezien het belang van water zijn er in het bijzonder veel kleinschalige interventies gedaan in het hydrologische systeem. Om te kunnen voorspellen en monitoren hoe deze interventies de hydrologische cyclus beinvloeden, moet er hydrologisch onderzoek worden gedaan. In deze thesis worden drie casussen in drie verschillende landen (in Vietnam, Kenia en Indonesie) verkend om te onderzoeken hoe dergelijke kleinschalige hydrologisch onderzoeken optimaal kunnen worden georganiseerd.

In 2007 werden in een semi-aride gebied in Vietnam contourgeulen gegraven om de infiltratie te verbeteren. Een aanpak bestaande uit meerdere methodieken is toegepast om de resulterende aanvulling te beoordelen, gebruik makend van veldmetingen, stabiele isotoop technieken en modellen. De veldmetingen bestonden uit twee regenmeters, oppervlaktewaterhoogtemetingen in de geulen na regenbuien, infiltratietesten en vier observatieputten in het gebied waar de geulen waren gegraven. In 2009 werd een complete set veldmetingen gedaan tijdens het natte seizoen. De resulterende ondergrondse- en grondwatermetingen suggesteren dat het grondwatersysteem tussen een set putten niet in verbinding staat. Analyse van metingen van stabiele isotopen liet zien in welke mate een put was aangevuld door een korte weg. Water dat werd vastgehouden in de geulen verdampte of infiltreerde volledig in twee dagen. Na regenbuien nam de sedimentatie in de geulen toe, wat de infiltratiecapaciteit verminderde. Het lijkt er dus op dat de infiltratiecapaciteit verhoogd was voor slechts een korte periode, tot aan een periode van twee maanden. Verder is Hydrus (2D/3D) gebruikte om een aanpak te vinden voor ondergrondse parameters door de oppervlakte- en grondwaterhoogtes aan elkaar te koppelen. Voor deze casus in Vietnam leverde de aanpak met meerdere-methodieken een adequaat begrip op van het mechanisme van lokale aanvulling.

In 2002 was het graven van contourgeulen opgezet om herbebossing te initieren in een semi-aride gebied in Amboseli, Kenia. Om de lokale effecten van de geulen te bestuderen is veldwerk gedaan in september 2010, bestaande uit regenmetingen, bodemvochtmetingen en metingen van de samenstelling van de grond. Het doel was om de invloed van contourgeulen te beoordelen op de groei van vegetatie, beschikbaarheid van bodemvocht en sediment samenstelling in het gebied waar de geulen waren gegraven. Satelliet analyse is gedaan met maandelijkse TRMM en NDVI afbeeldingen, waar de TRMM waarden werden gecorreleerd aan NDVI voor situaties met en situaties zonder contourgeulen. De resultaten laten zien dat TRMM en NDVI niet corresponderen, zowel in termen van directe maandelijke invloeden als in responstijd. Het signaal van 'veel groen' in het contourgeulengebied was waarschijnlijk het resultaat van het natte seizen, niet door het extra bodemvocht dat de gegraven contourgeulen opleverden. Om erosie en sedimentatie te begrijpen in het contourgeulengebied is cesium analyse uitgevoerd. Lokale en extern sediment is gevonden in het contourgeulengebied. De hoeveelheid sedimentatie in de geulen suggereert dat de constructie om het sediment vast te houden fijn materiaal doorlaat naar het contourgeulengebied. Voor deze casus in Kenia leverde de aanpak met meerdere-methodieken een adequaat begrip op van de effecten van geulen.

In 2010 is het potentieel onderzocht van een kleinschalige waterkracht centrale in de provincie Maluku in Nederlands-Indie. De studie combineerde een digitaal hoogtemodel en afvoermetingen. Een rivierkaart met hoogteverschillen is gemaakt. Afvoermetingen zijn gebruikt om de afvoer te bepalen per oppervlakte-eenheid, wat was ge-extrapoleerd naar andere eilanden in de regio Maluku. De studie suggereert dat de Maluku eilanden potentieel hebben voor kleinschalige waterkracht centrales, vooral op de eilanden Buru en Seram, met een potentieel oplopend tot 200 kW. Het potentieel van kleinschalige waterkracht centrales op Aboru is 5 kW. Voor deze casus in Nederlands-Indie leverde de aanpak met meerdere-methodieken een adequaat begrip op van het potentieel van kleinschalige waterkracht centrales in de provincie Maluku.

In deze drie casus-studies zijn multi-methode aanpakken gebruikt, vooral in de Vietnam casus; allen leverden een goed begrip op van de dominante hydrologische mechanismen in de respectieve kleinschalige interventie projecten. De multi-methode aanpakken werder verder geevalueerd met de gedachte van het belang van aanpassen aan lokale omstandigheden in het achterhoofd. Scenario's voor elk interventie project zijn ontwikkeld, waarbij gebruik gemaakt werd van kosten-baten analyse om te laten zien of de extra investeringen konden leiden tot een beter begrip van de onderliggende hydrologische mechanismen in de interventie projecten. Met een eerste scenario werd geprobeerd om de kosten-baten verhouding van het project zelf te optimaliseren, waarbij gefaalde veldexperimenten uit het projectbudget werden verwijderd. Het tweede en derde scenario's staan de onderzoeker toe om respectievelijk 20% en 80% meer geld uit te geven. Aan tien experts is gevraagd om de mogelijke resultaten van scenario's twee en drie vast te stellen. De uitkomst was dat een onderzoeksplan met 20% meer financiering waarschijnlijk een vergelijkbaar resultaat zou geven als scenario een. Met 80% extra financiering zou een beter begrip behaald worden. Het is echter onwaarschijnlijk dat dergelijke extra financiering beschikbaar gemaakt zou worden voor kleinschalige onderzoeksprojecten.

Typische problemen die voorkomen in kleinschalig, interventie-gebaseerd onderzoek bevatten onder meer technisch falen, verplaatsing of verdwijning van meetapparatuur en verplaatsingen van de lokaties van interventies. Samen leiden deze problemen tot een vermindering in hoeveelheid of kwaliteit van velddata. Gedurende de onderzoeksperiode moet een onderzoeker beslissen om, ten gevolge van zulke gebeurtenissen, de onderzoeksmethode aan te passen, vooral wat betreft het waar en hoe nieuwe metingen te doen. In het algemeen worden de genoemde problemen in interventie projecten bestempeld als onontkomelijk, als ze uberhaupt benoemd worden als zijnde belangrijk voor hydrologisch onderzoek. Technisch falen kan gewoon gebeuren zonder dat iemand er iets aan kan doen, maar vooral de invloed van menselijke handelen op hydrologisch onderzoek, in het kader van interventie-gebaseerd onderzoek, is iets waarop zou moeten worden geanticipeerd tijdens de planning en de uitvoering van het hydrologische onderzoek.

Verder was een interessant onderdeel van de discussie met de tien experts het beoordelen van hun antwoorden. Alle scenario's waren niet alleen gegeven, maar ook gesuggereerd door de tien experts. Het liet zien dat de experts verschillende suggesties gaven over het hoe onderzoek gedaan moest of kon worden. Deze verschillen creerden een groot aantal verschillende perspectieven: hoe doet men metingen in het veld, hoe vertaalt men zulke metingen naar analyse en modelleren, etcetera?

Dit proefschrift brengt twee belangrijke aspecten van kleinschalig hydrologisch interventie-gebaseerd onderzoek naar voren. Ten eerste, problemen die te maken hebben met menselijk handelen varieert wellicht met de hoeveelheid betrokkenheid van belanghebbenden. Een hydrologisch onderzoeken zal echter, ongeacht de hoeveelheid betrokkenheid, om moeten gaan met menselijke handelingen tijdens de planning en de uitvoering van het veldonderzoek. Menselijk handelen, de interventie, en het bijbehorende hydrologische onderzoek zijn aan elkaar verbonden. Met twee extra analyse stappen dient een onderzoeker systematisch twee overwegingen mee te wegen: (1) overweging van mogeljke verassingen en mogelijke acties, en (2) kosten-bate analyse. Door deze twee analyse stappen te doen tevoren en wellicht ook constant tijdens een kleinschalig hydrologisch interventie-gebaseerd project, kan hydrologisch onderzoek effectief worden uitgevoerd. Ten tweede, met betrekking tot het hydrologische onderzoek, suggereert het dat een hydrologisch onderzoeker zijn of haar eigen voorkeuren zal hebben, wat als gevolg een bepaald perspectief op hydrologische zaken zal geven. Keuzes die gemaakt worden door de onderzoeker met betrekking tot het meten en modelleren tijdens zijn of haar onderzoek zijn specifiek. Dit roept de vraag op wiens hydrologische realiteit wordt benadrukt - wiens kennis telt. Het lijkt een behoorlijke vereiste voor de hydrologische gemeenschap om meer aandacht te besteden aan deze continue ambiguiteit met als doel om een sterker co-evolutionair proces aan te moedigen van water-gerelateerde interventie en gerelateerd onderzoek.

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1 Introduction

1.1 Background

Small-scale water development initiatives play an important role in supporting sustainable water resources management worldwide. Such small projects are usually initiated and/or supported by local non-governmental groups, but larger donors such as USAID and others support them as well (Van Koppen, 2009; ECSP, 2006; Warner and Abate, 2005). Typical small-scale intervention projects include water harvesting development, (improvement of) 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.

The initiative "Predictions in Ungauged Basins" (PUB), within the International Association of Hydrological Sciences (IAHS) in the decade of 2003-2012, aimed 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). A basic idea of PUB was that understanding the natural system could be gained by studying responses of systems, making prediction on changes more appropriate (Gupta et al., 1998, Boyle et al., 2000). Exhaustive modelling development frameworks have been proposed for water management purposes (Refsgaard and Henriksen 2004, Refsgaard et al., 2005). Additionally, in terms of modelling the concept to enhance better observational methods (Beven, 2018), and the challenge in hypothesis testing or modelling to consider the required data and how to relate them to the hypotheses for prediction (Pfister and Kirchner, 2017) are prominent. Many small-scale water intervention projects, especially those in the so-called developing countries, are located in data-sparse areas. These include three hydrological studies that built experiences and the approach developed in this thesis. They were located in remote areas in Vietnam, Kenya and Indonesia; all three study areas were originally in ungauged catchments.

The studies show that PUB ideas and the efforts within small-scale hydrological interventions appear to be closely connected. However, despite being perceived as a 'grass-roots' movement amongst hydrologists, PUB did not specifically engage with the type of small-scale hydrological field research discussed within this thesis. PUB studies are dominated by prediction of runoff in all kinds of climatic regions, with some studies focusing on other topics, such as the transfer of parameters from donor catchments (Samaniego et al., 2010; Pokhrel and Gupta, 2010), the use of remote sensing data (Winsemius et al., 2008), water level (Alsdorf et al., 2000), and understanding from comparing data rich and data poor areas (Sivapalan, 2003; Sameniego et al., 2010). Subsurface processes were heavily investigated and were determined as one of the crucial hydrological processes that needed to be considered, even when understanding such processes is challenging due to heterogeneity (Mcdonnell et al., 2007, Nieber and Sidle, 2010).

Building on PUB notions, the approach for hydrological research as discussed in this thesis was based on investigating dominant hydrological processes through a multi-method approach within short field campaigns within strict financial constraints (compare with Mul, 2009; Hrachowitz et al., 2013). On-site measurements were highly dependent on the support of the local communities. Thus, building and maintaining (informal) networks and relationships were essential for successful local data collection (compare with Mackenzie, 2012). Notions of (improving) hydrological research within small-scale projects (Phalla and Paradis, 2011; Gomani et al., 2009; Das et al., 2000) stress 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, has shown to be potentially effective for data collection (Kongo et al., 2010; Vincent, 2003; Das, 2003; Das and Rao, 2000).

When the projects started, not everything that was about to happen was, or probably could have been, foreseen. Based on the collective experiences from the projects, in an attempt to compare the experiences and the events afterwards, the social processes relevant for the development of research and intervention in the three cases was traced. Possible contextualization, explanations, and patterns in each of the case studies were examined. How do hydrologists decide his/her research in small-scale interventions, when he/she needs to deal with social interactions (aside from organizing stakeholders) and limited options for research? Could hydrologists make better decisions – in terms of gathering data – when planning hydrological research using the realization 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?

Planning for these daily possibilities and associated changes has been more prevalent in other disciplines. 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). Similarly, to improve flood risk management, one should not neglect surprises, but to take them into account. Merz et al. (2015) study that surprise is apparently a crucial element in flood risk management. However, a focus on hydrological research design/management using our knowledge on (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.

Furthermore, Rangecroft et al. (2020) show why interdisciplinary water research should be conducted during fieldwork, and provide several examples of good practices. These examples offer insights on why stakeholders make choices, and how building connections between different stakeholders and specialist can be arranged, including working with social scientists and how a hydrologist could incorporate such cooperation in the research. The notion of different positions of stakeholders is introduced to acknowledge the different development process and perceptions. It is also clear that scholars from different fields – and often within the same fields too – use different representations on a similar phenomenon (compare with the different practices within the same hospital found by Mol (2002)). The three case studies in this thesis show how the author dealt in practice with issues that are discussed in Rangecroft et al. (2020). In contrast to Rangecroft et al. (2020), this thesis does specify in detail how different perspectives (representations) on hydrological aspects of interventions have immediate impact on the hydrological field work itself. As such, this thesis provides examples of interdisciplinary water research that dealt with the structure of different settings of field research. In terms of policy settings, where large scale interventions are more frequently discussed and multiple perspectives are more easily recognized, the small-scale interventions that are central in this thesis are rarely covered, and thus need more emphasis – both in terms of relevant hydrological processes for these interventions and in terms of perspective of hydrological processes in disciplinary scholarship.

1.2 Building the argument

Building the argument of this thesis started with the hydrology of three case studies. The performance of hydrological research to study hydrological issues was examined. Then the author explored the social-economic aspects of the hydrological research to highlight social-economic issues as a substantial influence on the technical arrangements in field campaigns. The findings of each case were related to the performance of the stakeholders during intervention construction and development, and will be connected to the (adapted) hydrological research. To review the results, the author attempted to understand how these three studies could help to improve future research practices. At the end the author's claims stress the importance of surprise, cost-benefit and recognition that different researchers prefer doing the research of similar problems differently as perspectives. This claim can be linked to the theme on Prediction in Ungauged Basin (PUB) and Socio-hydrology as guiding principles.

1.3 Hydrological research in small-scale intervention

There are several ways how an actual intervention activity (a dam, a water system, etc.) relates to the hydrological research. First, there is the hydrological knowledge about the (natural) system to be modified. Any change in a (pristine) system has to be followed by updating our hydrological knowledge for improved management. Usually one encounters a situation where a previous intervention is already present in an area and a subsequent intervention will be located on top of a changed landscape. Different stages may occur in intervention and hydrological research. However, a general process of performing intervention and hydrological research (see **Figure 1.1**) is summarized as follows:

1. Usually the process starts with a funding agency or a self-funded group being interested in a certain intervention. Initial plans of design and siting are based on agreements between individuals or parties from outside and local people who are affected by the intervention. A general research question would be to understand the mechanism of an intervention in a hydrological context.
2. Checking resources and local conditions, including their boundary and political conditions (i.e. government priorities) and taking limited available funding in consideration.
3. Proposing measurements (type, siting and timing) and negotiating the intervention and research in more detail, where research should be in accordance to temporal and spatial conditions of the intervention.
4. Deciding for a certain approach towards intervention and/or research, as a result of agreements among stakeholders. This phase describes where intervention and research have been agreed upon among stakeholders. Afterwards, if the intervention and research evolve, the cycle repeats from number 1.

Number 2 and 3 are the main actions to perform actual hydrological research. However, in practice these actions may move back and forth in time, depending on the implementation of the intervention. Therefore, instead of a smooth move through time from phase to phase, there could be much improvisation on which step to take next. Meanwhile, room for negotiation could always emerge before, during, and after the implementation of interventions.

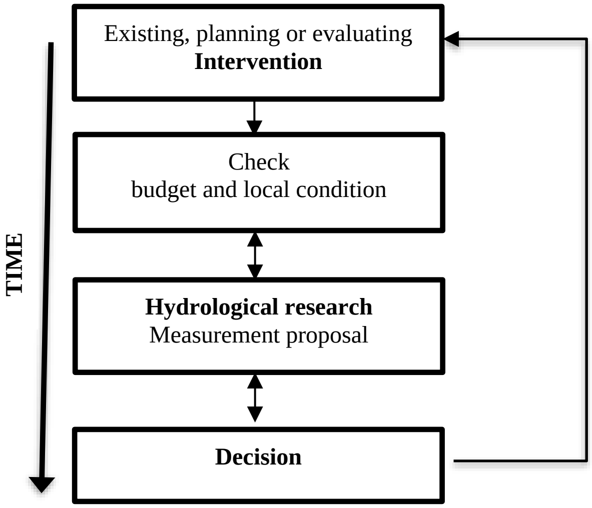


Figure 1.1 Schematization of the general process of performing intervention and hydrological research.

From a hydrological research perspective, an important question to answer is how to accommodate the selection of hydrological measurements related to the intervention. It is usually expected that intervention and research proceed as planned and that research results can and do determine the siting and design of an intervention. Although a hydrological researcher usually prefers this outcome, this thesis shows that not all research is in line with the intervention and vice versa. The intervention could take priority over hydrological research, such as in our Kenya case. The intervention could even be a negotiation process throughout the project lifetime, with useful hydrological research, but without any actual construction (see the Indonesia case). In the end, the intervention project is rather an agreement between stakeholders than a mere physical object.

1.4 Planning and designing hydrological research

Performing hydrological research in small-scale intervention projects is challenging because the budgets for such research are usually limited. Thus, the type of research has to be planned and designed accordingly. Some issues when planning hydrological research need careful thought, especially for field measurements, when (expensive) devices have to suit a particular study area (e.g. modern electronic gadgets, prone to vanish and break down, or vulnerable to climatic conditions, etc.). Budgets for measurement devices in research should be spent wisely. Eventually, the question is how to conduct a proper hydrological research in a small-scale intervention project.

In practice, different interventions will have different research questions and goals. Research questions may range from how to plan, design, or manage an intervention. Commonly, an intervention is proposed, tested, or up-scaled in the study area, or even transferred to different locations and countries. This suggests that it is necessary to first understand how an intervention functions and how it affects certain environments, and second, whether the intervention ultimately benefits the end user(s).

Hydrological research may vary for different types of small-scale intervention projects. There are four main known approaches to conduct hydrological research: 1) field measurements, including tracer studies 2) modelling, and 3) remote sensing. In general, the combination of these approaches in a multi-method setup is preferred (Mul, 2009) (e.g. field measurement, and modelling). In the selection of approaches, one needs to (and can, as will be shown in this thesis) pay attention to the costs of the proposed research activity in relation to anticipated benefits.

1.4.1 Field measurements

To understand the hydrological impacts of small-scale intervention projects, ground data are of importance. This means that a network of measurement devices has to be installed at certain costs. Basic measurement techniques and devices (see for more options WMO (2008)) without considering specific requirements for local conditions in the field include:

- ✓ Rainfall – rain gauges
- ✓ Evaporation – estimated indirectly by measuring solar radiation, heat flux, temperature, humidity and wind, and for small-scale measurement using lysimeter, class A-pan
- ✓ Infiltration – ring infiltrometer, inversed auger hole method (Porchet)
- ✓ Groundwater - observation wells
- ✓ Discharge – velocity area method, float, slope area method, dilution gauging, weirs (or structures)

A hydrological researcher often requires local people to assist during monitoring campaigns. Most of the time, local people are willing to help. They even can show researchers additional options to place measurement devices. Sometimes, for security reasons, local people offer their yards to be the location for devices. On the other hand, for those who might not know anything about the monitoring campaign and do not live near the monitoring area, measurement devices could be interesting as well. People are often curious if they find something different or unique that is rarely seen in the field. In order to avoid losses due to people interference, good preparation and planning are essential. As research funding for small-scale intervention projects is limited, a hydrological researcher has to include possible effects of interference through human actions. One would have to ensure in advance that field measurements can be performed effectively, and thus minimize the loss of data. Moreover, planning requires careful thoughts on location, environment and local people who assist the hydrological researcher.

Tracer studies

Tracer studies is a technique to monitor the flow path of surface water, water in the unsaturated zone, and the groundwater system. Hydrological studies using tracers are for example stable isotopes in the unsaturated zone (Gaj et al., 2016) and dyes (Flury and Wai, 2003). Tracers potentially provide integrated information and can be very efficient in characterizing complex systems in remote areas (Leibundgut et al., 2011). With low concentration, one can detect sources, processes and residence times of water. Based on their substance, there are three types of tracers: artificial tracers, pollution tracers, and natural tracers. Tracers have their own measurement devices to measure in the field (e.g. salts, fluorescence) or in the laboratory (e.g. oxygen-18, deuterium, tritium).

In its modelling, tracers can provide results from analytical solutions, breakthrough curves and transport equations. In the context of small-scale intervention projects, the cost of tracer experiments can vary from low cost of local available dyes to measuring stable isotope components at considerable cost.

Again, this method needs to be combined with others. In tracer techniques and remote sensing, measured data accompanied by modelling are used to analyze the dominant process. In both techniques, quantitative and qualitative results may also be a direct answer to the research question and/or can provide supplement to the main modelling and field measurements (e.g. stable isotope signals of rainwater found in the groundwater system).

1.4.2 Modelling

According to Gharari (2016), the use of modelling can be summarized in four groups: 1) extrapolation of existing knowledge in space, 2) extrapolation of existing knowledge in time, 3) hypothesis testing, and 4) prediction of system response to change in system characteristics. When humans interfere in hydrological system, modelling is likely to fall in the last two categories. The modelling will mainly be essential to distinguish between situations with and without interventions on the long term. On the other hand, in hydrological engineering such as planning dams or micro-hydro power plant, modelling is used to design a certain intervention.

The selection of modelling depends on the type of intervention, but the affected dominant process will be the one to focus on. Relevant field measurements are of importance, as data are required for the modelling. When field measurements are not available, one could use secondary data and assumptions, but the credibility of the modelling will be influenced as well. Thus, modelling in case of intervention is as important as data from field measurements.

1.4.3 Remote sensing

Valuable hydrological data can be extracted from remote sensing. Many hydrological studies demonstrate the use of such data, for example on precipitation (Duan and Bastiaanssen, 2013), soil moisture (Parajka et al., 2009, Ahmad et al., 2010), evaporation (Bastiaanssen et al. 2005; Mohamed et al., 2006; Senay et al., 2007), and river discharge (Alsdorf et al., 2007).

Remote sensing can be a source of hydrological data to represent global or relatively large areas. In cases of small-scale interventions, low-resolution remote sensing data need to be downscaled to better represent a study area. Such resolution can be found in some web data sets ranging from low cost to being free of charge. For more high-resolution data, the cost of remote sensing data increases. As costs increase based on resolution, the use of remote sensing data in small-scale intervention studies needs careful consideration, as the budget for those research efforts is typically constrained.

To be more reliable, especially in a small-scale area studies, remote sensing data require ground data for calibration. Again, field measurements are of importance. A combination of the two approaches will result in a better understanding of hydrological data and their correlation and is useful for possible extrapolation in time.

1.5 Contextualization: The triangle of small-scale intervention, hydrological research, and human agency

Humans change landscapes through interventions for many purposes due to human demands (Ehret et al., 2014). Hence, human agency is continuously changing future hydrology, which means we need to build deeper understanding of human-water dynamics (Sivapalan et al., 2014; Ertsen et al., 2014). It turns out to be highly relevant to look at the interactions between humans (as initiator and/or stakeholder of intervention and/or research itself) and the complex hydrological system.

Many studies of small hydrological research related to interventions – if available at all – include human agency in the research through the lens 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, which could happen every time and everywhere during a research effort. This may be true, but one should be aware that human interventions that move hydrological equipment are not always acts of theft/vandalism. Perhaps people interfere with measuring equipment out of curiosity, or because they simply do not know what it is. There might be cases 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 discussing how motivations of stakeholders to interfere in one hydrological campaign changed over time, with theft never being a motivation for action. Whatever the case, human intervention usually results in lower data availability. Especially as data sets would have been relatively limited anyway, studies using such limited data are even more difficult to be accepted in the scientific research community (compare with Winsemius, 2009).

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). Experience shows that such co-engineering also shapes the hydrological research itself – and thus principally the science of hydrology as well. As such, it is perceived that stakeholder involvement as seeking partnership in the process of (hydrological) change to affect knowledge, attitudes and behavior 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).

1.6 Three case studies: Vietnam, Kenya, and Indonesia

In this thesis, solutions were scanned, research management in the three cases were analyzed, and how it can be improved in practice (see Sutherland, 2014) was defined. Daily realities of performing small hydrological studies are the focus. Based on evidence of the effectiveness of certain actions and practices collected in the three case studies, experiences were contextualized to extrapolate towards general principles how to improve knowledge development for researchers and practitioners (Beratan, 2014).

This thesis shares and discusses experiences of three different hydrological situations in three different countries (see **Figure 1.2**).

Figure 1.2 Map of the study areas; Vietnam (red), Kenya (yellow), and Indonesia (green).

In 2002, contour trenches – ditches to catch runoff – were dug in an area of about 40 hectare (ha) in Amboseli, a semi-arid area in Kenya. Due to claimed success of enhancing the greenness of a previously dry landscape, there was an opportunity to transfer this intervention technology to different countries. A semi-arid area with about 22 ha available for a test case in Ninh Phuoc district, Vietnam, was selected in 2007. The objective of the intervention in Vietnam focused on the assessment of groundwater recharge. The Vietnam research offered opportunities to go back to the original site in Kenya to study hydrological impacts. To investigate these impacts, a multi-method approach was conducted at both study areas. The Vietnam case offered close observation how intervention and hydrological research went on simultaneously when in the making. In the Kenya case, the study area had already been developed. Thus, the Kenya case was a post-evaluation of already constructed contour trenches. In 2010, an Indonesia case study started in a small village on Haruku Island, Maluku Province. The region has a humid tropical climate. The island is about 150 km^2. The objective of this study was to assess the potential of micro-hydro power plants on small islands as source for electricity generation.

In each case study, the research period varied; the Vietnam case had the longest time frame of about three years, the Kenya and Indonesia cases were about one year. In each case study, intervention processes were determined to a large extent by political and cooperation developments. Only in the Kenya case, the intervention had been constructed in 2002; as such, it was relatively free from political discourse, but not from human intervention, as will be seen later.

Finally, in the three case studies, the researcher (the author of this thesis) took different positions. In the Vietnam case, the author was a researcher in a consortium within an intervention project that started in 2007. The consortium relied much on local connections and local data collection. The author dealt directly with local people during the fieldwork. In the Kenya case, the author was a researcher conducting fieldwork in 2010. This project initially started from establishing connections with local people for research cooperation. The position held in the Indonesia case in 2010 was on both sides, as a researcher and initiator. Furthermore, the background culture of the author is Indonesian. Therefore, a more promising, smooth cooperation was foreseen in the Indonesia case.

1.7 Thesis outline

This thesis discusses additional aspects that a hydrological researcher must have in small-scale water intervention-based projects: hydrological and/or technical expertise (**Chapters 2** to **4**) and socio-economic expertise (**Chapters 5** and **6**). At the end, shaping the perspective of hydrology by the author or any hydrological researcher (**Chapter 7**) are elaborated.

Chapters 2 to **4** describe three case studies from different areas from a hydrological point of view. Each study represents specific research questions to be answered for different types of interventions. Each of the three cases was performed to develop a basic understanding of the dominant mechanism(s) of intervention in its hydrological context. Direct measurements in the field were vital, thus in every case study, a field campaign was implemented. **Chapters 2** and **3** are linked because of the transfer of the intervention technology from Kenya to Vietnam. **Chapter 4** is regarded as an independent case.

Chapter 5 traces back the social realities of **Chapters 2** to **4**. It provides a detailed description of the development of the implementation of interventions and hydrological studies. The focus is on how stakeholders influenced both topics. Some important issues concerning human actions in intervention-based hydrological research are explained.

Chapter 6 emphasizes the cost-benefit analysis of the hydrological research. Scenarios are developed to provide options for water experts to evaluate (possible) research outcome(s). Additionally, a practice to address a better hydrological measurement setup is through questioning oneself.

Chapter 7 reviews the measurements and modelling of the Vietnam case. This chapter uses parts of **Chapter 5** and **6** as the underlying data. Thus, overlap between chapters is expected, as a deliberate choice by the author. The discussion relates to the negotiations of a researcher during a hydrological field campaign and the resulting perspective(s) of experts on the (proposed) hydrological research and results.

Chapter 8 summarizes the proposed systematic way to deal with surprises in field work – anticipating such surprises and possible actions in hydrological research and intervention, and performing cost-benefit analysis of hydrological research. This chapter also highlights the importance of recognizing different perspectives specifically in hydrological research, and presents some final thoughts on the author's claim as additional guiding principles for the hydrological community.

2 Contour trenches for artificial recharge in Ninh Thuan Province, Vietnam

2.1 Introduction

Contour trenching is a water harvesting technique implemented to increase water availability in semi-arid and arid regions. A study on trenches in Chile by Verbist et al. (2009) suggested that only in a few cases, one could quantify the positive effect of runoff water harvesting techniques on water retention. In an older study, Doty (1972) shows that there is almost no change in soil water between situations with and without trenches. In other words, further understanding of the technology seems to be needed.

The contour trenches discussed in this chapter are located in an area that has not been studied before, located in Vietnam. Constructing these trenches started from a previous "successful implementation" in Kenya (**Chapter 3**). This chapter focuses on the recharge, mainly the retained water in the trench that infiltrates into the subsurface. The construction of contour trenches was divided in two stages. In October 2007, 7 trenches of 4 m wide and 1 m deep, with different lengths along the contour, were constructed. Then, in March 2008, 5 smaller trenches, 2,5 m wide (bottom width 1 m, side slopes of 1:1) and 0,75 m deep were constructed.

Recharge processes of contour trenching after rainfall events were investigated by conducting a multi-method approach (Blume et al., 2008). This research was designed as a field study into contour trenches for a single year of 2009. The field measurements were used for explorative modelling in Hydrus (2D/3D) (Šimůnek et al., 2008). Moreover, a stable isotope study was performed, as such studies often allow improved understanding of catchment dynamics (Rodgers et al., 2005; McGuire and McDonnell, 2007; Soulsby et al., 2008). Our investigations focused on analysis of runoff entering the contour trenching area to possible recharge the groundwater system and its effect on groundwater level fluctuations.

2.2 Site description

The study area is located in the Phuoc Nam commune, in the Ninh Phuoc district (latitude 11° 27' 46,06" and longitude 108° 55' 44,39" E, see **Figure 2.1**). The study area is a foothill with an average slope of about 3,5% with an elevation ranging from about 65 to 82 m above sea level and lies about 10 km from the coastline. The study area has a tropical savanna climate (Köppen). Generally, the wet season with heavy rainfall events occurs from September to December. From April to May, there are sometimes light rainfall events. The dry seasons are from January to April and from June to August. The average rainfall and temperature are 810 mm/y and 27°C, respectively. The study area used to be cultivated land. In the past few years, local farmers faced prolonged droughts that resulted in lack of water, and thus reduced crop yields. In the current situation, local people mainly let livestock graze and grew Neem trees. The landscape is covered with bare soils with erosion gullies, with some parts covered by cactuses and grasses. Initially, contour trenching was planned for an area of 97 ha. Ultimately, however, only 22 ha were trenched. The research focused on an area of about 8 ha.

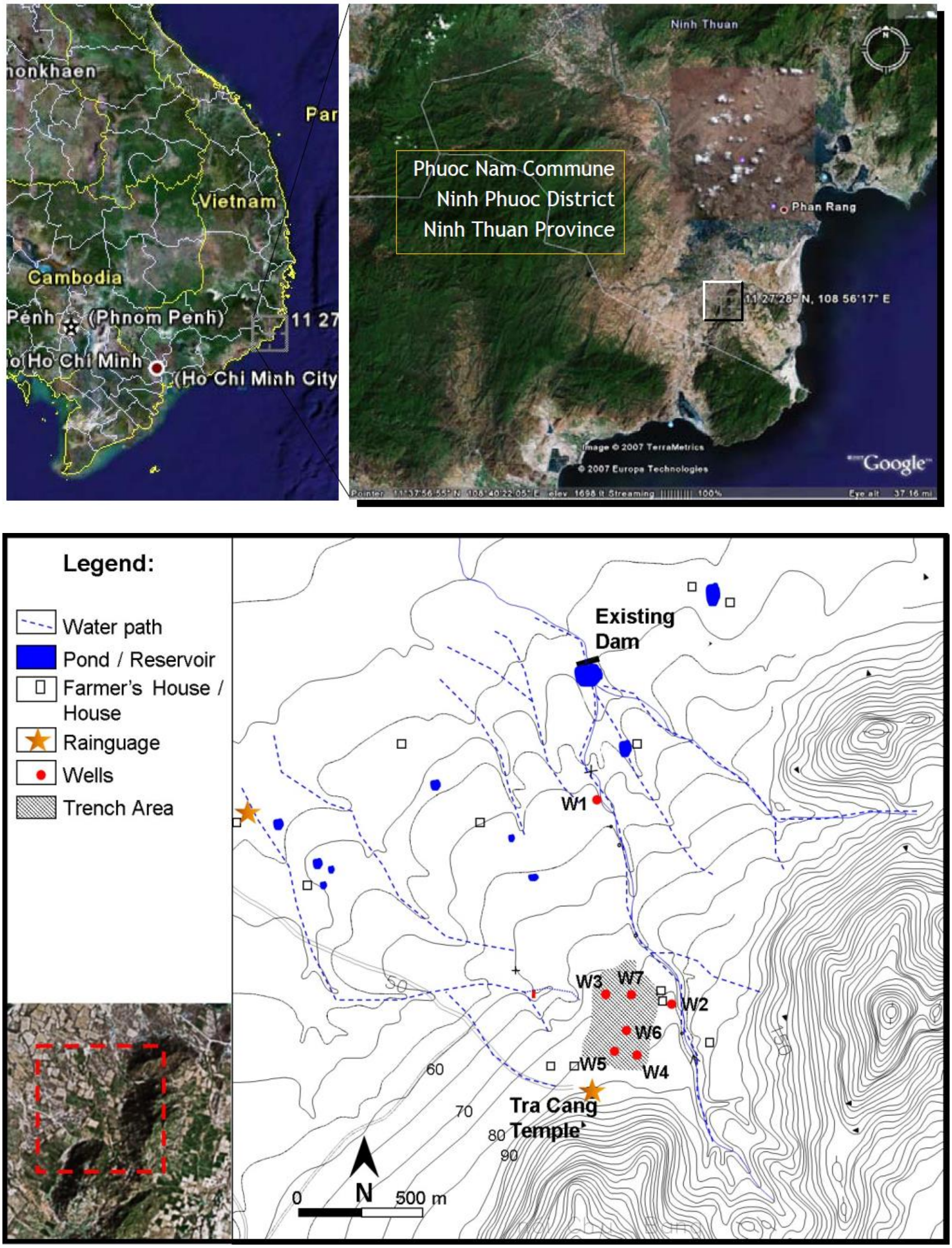


Figure 2.1 The location of the trenched area, rain gauges, and constructed wells. The study area is the shaded area on the lower map. Source: Google Earth and locally produced map.

2.3 Material and methods

2.3.1 Field measurements; rainfall, surface water, and groundwater level

The field measurements differed in time and space for two reasons. First, there was a decrease in area from planned to implemented contour trenching. The construction of trenches needed to be agreed upon by the landowners, while infiltration tests and construction of three observation wells had already started. Second, there were problems with the measurements. Three Divers (Schlumberger Water Services Delft, The Netherlands, measurements at 30-minute intervals) were lost and rainfall measurement loggers could not be read out. Field measurements results are summarized in **Table 2.1**; only for one 6-month period (June to November 2009, the bold lined box), data of rainfall, water levels and groundwater levels were simultaneously available.

Table 2.1 Collected Field Measurements, from June to November 2009

Parameter	2007			2008												2009												2010												2011		
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	N
Rainfall	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																
Surface water level in the trenches												■	■	■	■									■	■	■																
Water table																																										
Well 1, 2, & 3 (outside trench area)			■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				■	■	■	■	■	■	■	■	■	■	■	■	■
Well 4, 5, 6, & 7 (inside trench area)																					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

On 11 October 2007, before the construction of contour trenches, two rain gauges (Casella tipping bucket, resolution 0,2 mm, Bedford, UK) were installed. One rain gauge was installed on the roof of a building at a temple located uphill about 150 m from the study area (see **Figure 2.1**); the other one was installed on the roof of a farmhouse located downhill about 2 km from the study area. Recorded data were downloaded by the end of each season.

Between September and November 2009, rainfall was measured using a plastic bucket as manual rain gauge (see **Figure 2.2**). Measurements were conducted directly after an event. In addition, potential evaporation was measured with a local plastic pan with a diameter of 65 cm, placed on the same roof of the building at the temple. The evaporation pan was put about 5 m from the manual rain gauge.

Figure 2.2 A Casella tipping bucket, next to it a manual rain gauge and a locally made evaporation pan at the roof of the temple (upper) and ponded Trench 1 with a scale of the depth in circle (bottom).

Infiltration of ponding water in the trenches was monitored daily after rainfall events. Measurements were done until ponded water had infiltrated completely. The surface water was measured using a stick and two measuring scales in the trenches. The location of measurements in the trenches was fixed at a certain spot. Despite the fixed spot, measurement results could slightly deviate since the depth of trenches along the contour was uneven and the thickness of sedimentation at the bottom differed.

The subsurface (geology and soil) survey was conducted during the site visits and construction of the observation wells. In October 2007, an inverse auger-hole method tests (Porchet method) was performed to obtain hydraulic conductivity values at six locations spanning an uphill to downhill transect through the proposed trench area. Three observation wells around the proposed trench area were drilled up to bedrock, resulting in depths of 4,8, 24, and 25,5 m respectively. In each observation well, a 2 -m screen was set 3 m above the bedrock. In March 2008, 3-m deep holes at eight locations at the study area were drilled for additional lithology investigations. Furthermore, four soil samples at the trench plots were taken and analyzed at the laboratory of UNESCO-IHE, Delft, The Netherlands. After oven drying a bulk density between 1,46 and 1,65 gr/cm^3 was determined and the porosity ranges between 0,33 and 0,39.

The three observation wells, Wells 1, 2, and 3 (see **Figure 2.1**), were constructed at the upstream and middle part of the planned project area. The groundwater levels were measured with Divers (Schlumberger Water Services). Because of the loss of two Divers in two different observation wells, after February 2008 groundwater level measurements were done manually on a 3 to 4-day basis. A local person (see Figure 2.3) assisted with the measurements. In June 2009, four other observation wells inside the implemented contour trenching area were drilled. Below in **Figure 2.3** a typical set up of an observation well is provided.

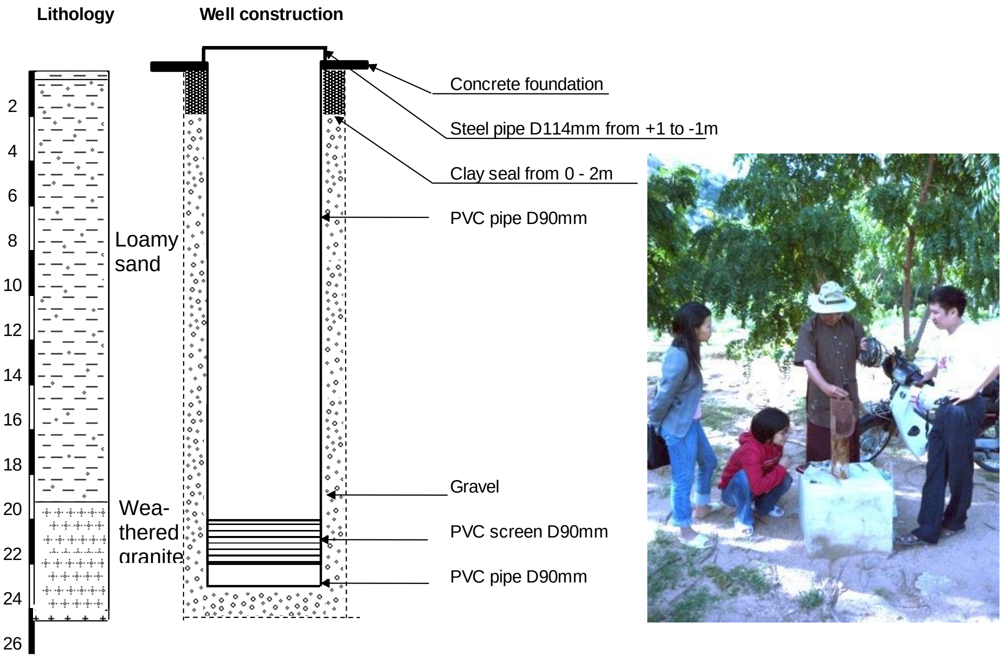


Figure 2.3 A typical set up of observation well.

2.3.2 Stable isotope Oxygen-18 and dye tracer

From September 2009 to November 2009, 72 water samples were collected in 2 ml vials, to analyze ^{18}O variation of rainfall, surface water and groundwater. Samples were collected on site at an interval depending on rainfall events. The filled vials were then sealed and subsequently packaged to the Netherlands. A spectrometer at the Isotope Laboratory of Delft University of Technology was utilized. The ^{18}O analysis results are expressed in mil units relative to Vienna Standard Mean Ocean Water (VSMOW) with an average standard deviation of 0,15 ‰.

There were 13 samples from the manual rain gauge. Directly after an event, rainfall was sampled from a measuring cup. A syringe was used to transfer water from the measuring cup to the vial. To minimize the effect of evaporation, the collected water was transferred to the vial shortly after rainfall events.

Ponded water samples were taken from the first uphill trench, as that received most of the runoff. 22 samples were taken where each of them was located at two different depths, at the water surface and lower depth (about 2/3 of the trench depth), resulting in composite samples. The samples were taken using a syringe that was tied to a small hose and further injected into the vials.

Groundwater was sampled from two observation wells inside the trench area (Well 4, 5, 6, and 7). 19 samples were collected. Groundwater was pumped using a hand-operated foot valve pump. It took about half to one-and-half hours to extract the groundwater. The difference in time was due to groundwater levels. After the groundwater level returned to its initial static level, groundwater was pumped and poured to a bucket. A syringe was used to transfer the samples into the vials.

The vertical flow paths at the bottom of the trench were checked using dye tracer. Dye tracer in forms of powder and low cost was available at the nearby market. Initially, about 40 cm x 40 cm area and 3 cm deep of the sediment surface in the middle of the trench was dug and poured evenly the dye powder. Afterwards, the dug sediment was filled back.

2.3.3 Modelling Hydrus (2D/3D)

Hydrus (2D/3D) (Šimůnek et al., 2008) was chosen to simulate the process of infiltration and recharge. It is a physically-based model using finite-elements that solves numerically the Richards' equation for unsaturated and saturated flows in porous media. The model used Genuchten (1980) and Mualem (1976) soil-hydraulic equation:

$$K(\theta) = K_S {S_e}^{0.5} \left[1 - \left(1 - {S_e}^{\frac{1}{m}}\right)^m\right]^2$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

$$\theta\ (h) = (1 + |\alpha h|^n)^{-m}$$

where *K* is the hydraulic conductivity function (m s^{-1}), h is the matric head (kPa), S_e is the effective water content (–), and *m* is empirically assumed 1-1/*n*, *n* is the pore size distribution index, *n*>1 (van Genuchten, 1980; n=1,23, 1,89, and 2,68). Θ is the water content (m^3 m^{-3}), *s* represents saturated and *r* residual, and α is a fitting parameter.

Hydrus (2D/3D) was used for two reasons. First, the focus was on a combination of infiltration in the unsaturated and recharge in the saturated zone. Measurements in the unsaturated zone were limited, and modelling was selected to see how surface and groundwater could be connected. Second, fine sediment was trapped in the trenches, especially the first uphill one. After several events, a few cm of clay accumulated. This layer was included in the model domain to see its effect on flow directions, as growing influence of sedimentation is to be expected over the years.

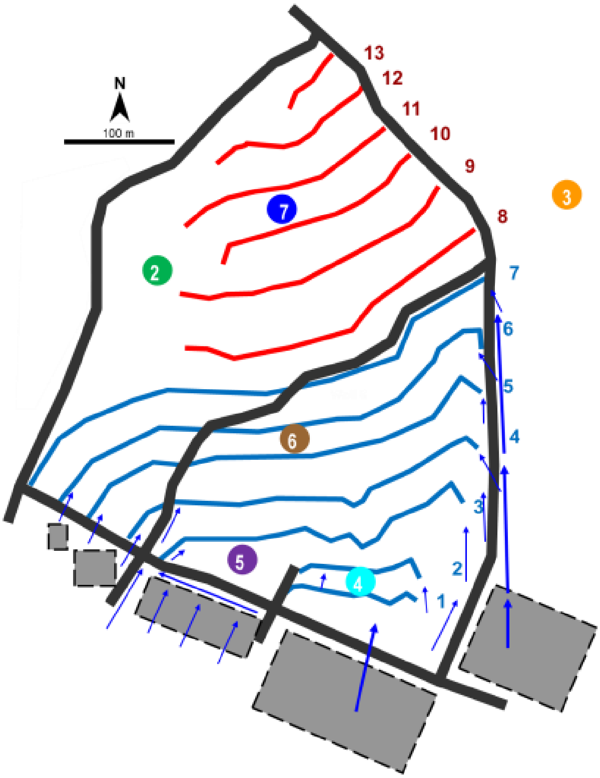
Four main limitations in this modelling could be identified. First, rainfall-runoff from the uphill area was excluded in the simulation. The runoff process into the trenches could not be modeled; visual observations showed that runoff entered the trenching area through small erosion gullies (see also 2.4). As a result, measured maximum water level in the trench was set as an input for the initial condition of ponding. Second, the modelling domain was narrowed to one trench and excluded the investigation of the entire trenching area. Third, since groundwater level measurements showed different fluctuations compared to trench water levels, it was suggested that the groundwater system between observation wells was disconnected. Only one trench was simulated, located at the most uphill trench area. Fourth, a 6-month simulation period was used, as all successful measurements were available for this period.

2.4 Results and discussion

Rainfall-runoff processes to the trench area and potential evaporation

According to four nearby meteorological stations, the long-term average of annual rainfall in the area is 810 mm/y. In 2008 and 2009, rainfall measurements at the study area reached annually 1134 mm and 1303 mm respectively, suggesting two very wet years in a row – assuming that the nearby rainfall station could be used for comparison. Ponding in the trenches were observed due to significant rainfall events of about 60 mm per day and above. For events below 60 mm, the trenches remained almost empty. Therefore, it is assumed that runoff resulting in ponding occurs during rainfall events with minimum size of 60 mm per day.

Observations showed that runoff entered the trench area through specific paths; it became concentrated in space (**Figure 2.4**). These flow paths occurred due to the nature of the local topography and the soil road path surrounding the trench area. Trench 1 to trench 7 received water fluxes from the area uphill of the trenches, which were dominated by granite hills. These fluxes produced the main ponding in the trenches. As the first trench originally obstructed an erosion gully, it received the maximum runoff. Every event resulted in specific runoff generation. The contribution of runoff towards the trenches from a bigger catchment area uphill the trench area is much larger than the surface created by the spacing between trenches.



Notes:

- “Large trenches” in blue (1-7) were constructed in October 2007.
- “Smaller trenches” in red color (8-13) were constructed in June 2008.
- The slope is to the North direction, with trenches parallel to the contours.
- Arrows represent flow paths from upstream to downstream.
- Grey boxes illustrate the estimated area for runoff generation.
- Colored circles with different numbers represent the observation wells.

Figure 2.4 Schematization of the runoff entering the trench area.

The amount of runoff that entered the trench area remains unknown, since fluxes from the uphill area came from random flow paths into the trench area. In addition, the overflow from an uphill trench to the downhill ones was also hard to distinguish during heavy rainfall events. In practice, the flux was assumed to be retained in the trenches, which was measured shortly after significant rainfall events.

Compared to other trenches (**Figure 2.5**), ponding water in the first uphill trench took a longer time to infiltrate because of sedimentation. Fine material was brought by runoff into the trench. During storms, sand from uphill was also brought to the first trench, which filled up the trench about half full. The smaller trenches showed lower water levels. The ponded water infiltrated quicker, because there was little fine sediment and the main soil type was grey sand. Thus, a high infiltration capacity was predicted. Additionally, the smaller trenches were not affected by external runoff such as in trench 1 to 7.

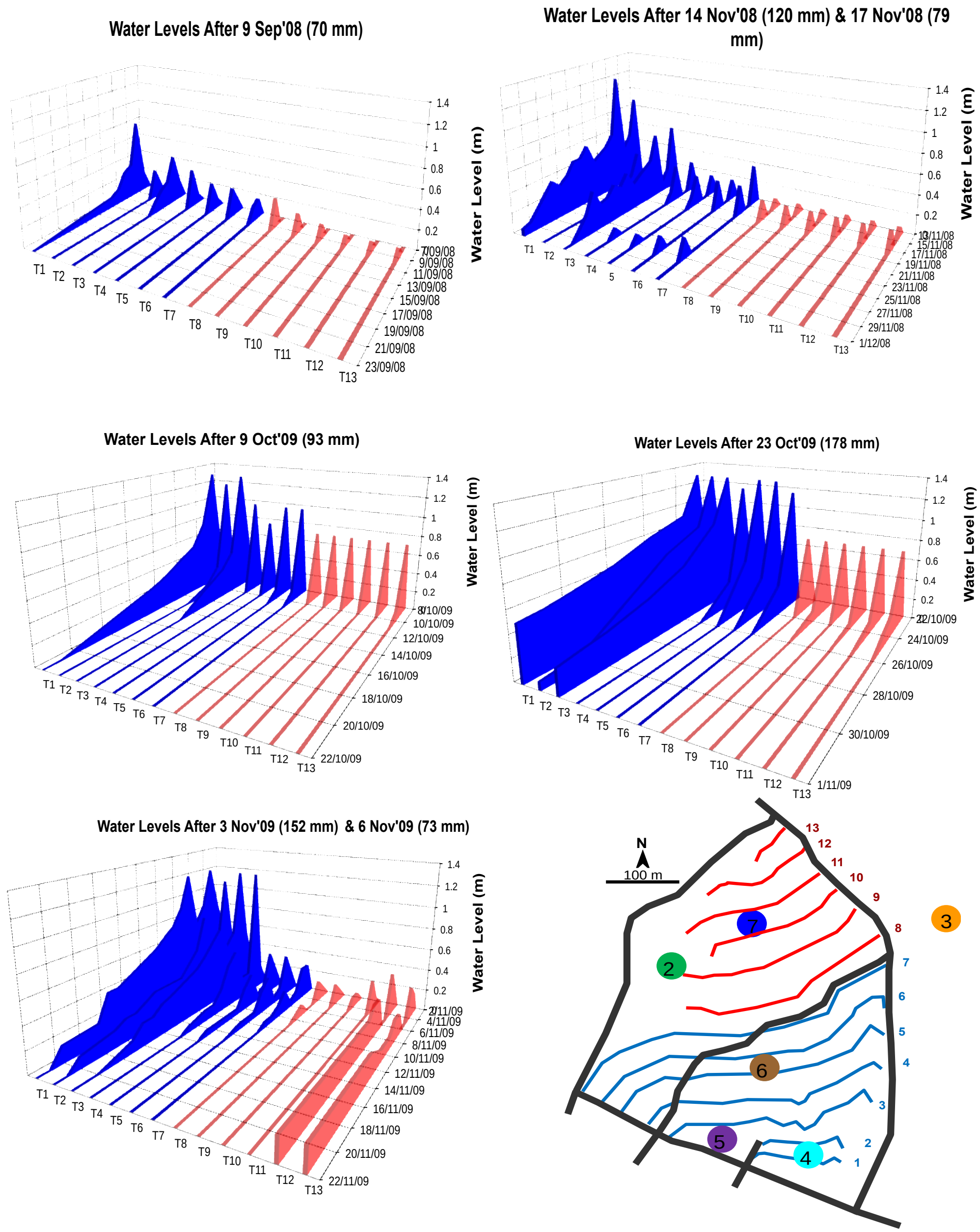


Figure 2.5 Ponding water level measurements during the wet season in year 2008 and 2009. Blue colour represents large trenches (T1-T7) and red colour represents small trenches (T8-T13). Numbers represent uphill to downhill.

A long-term data series of 15 years from a nearby meteorological station, Phan Rang town, showed an average pan evaporation of 4,7 mm/d during wet seasons. During the dry season, pan evaporation was about 6 mm/d. Our measurement showed an average of 4,2 mm/d of the daily pan evaporation (see **Figure 2.6**). In conditions when trenches were filled with ponding water, it was likely that water evaporated close to the same rate. This value was further used for modelling purposes. Using evaporation of 4,2 mm/d with observed infiltration of ponding water taking up to a maximum of three weeks, the total evaporation results in 88 mm or 8,8 cm. For a trench fully filled with water and infiltration at a maximum of three weeks, it was estimated that about 9% of the retained water contributed to evaporation.

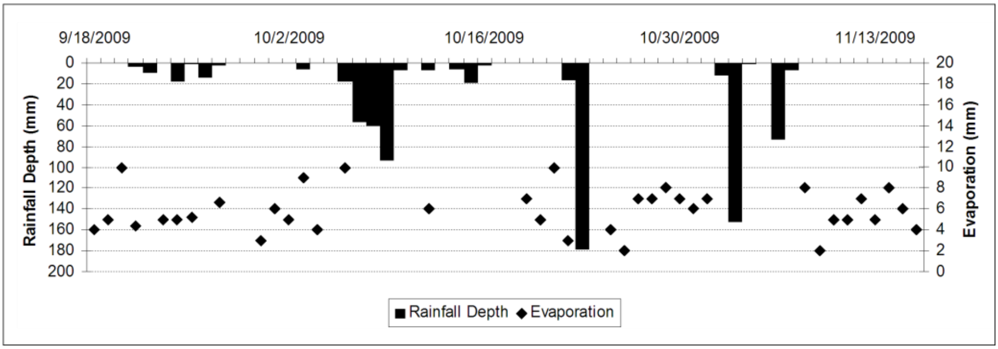


Figure 2.6 Manual rainfall and evaporation measurements during the wet season in 2009.

The influence of spacing to ponding

There could be three reasons to explain why spacing did not affect ponding much in the trenches. First, the rainfall intensity and the type of soil affect the ponding height. Second, infiltration occurred quickly because of the sandy soil material of the landscape. Third, concentrated runoffs such as gullies and road runoff from outside the trench area dominated the fluxes into the trenches, and thus runoff accumulated from different small catchment areas uphill from the trenches. Therefore, spacing did not explain variations in ponding in the trenches. Instead, ponding was mainly influenced by the catchment outside the trench areas.

Geo-hydrological conditions and groundwater level response

The subsurface conditions seem to control the recharge processes and groundwater flows. The landscape is dominated by mountainous granite and downhill valleys with mixes of loamy sand, weathered granite, residual soils and alluvial deposits. Interpolating lithological logs resulted in **Figure 2.7**, showing loamy sand, weathered granite, and possibly fractured granite forming the subsurface.

The hydraulic conductivities from the inverse auger test at six locations at the trench area ranged from 25 cm/d to 3 m/d. Some references of the range of hydraulic conductivities of loamy sand and granite in semi-arid areas were used to compare our infiltration tests. On a granite terrain in Hyderabad, India, the hydraulic conductivities were estimated by Chandra, S. et al (2008), at a maximum of 7,9 m/d and minimum of 7,9 cm/d. Katsura, S. et al (2009) characterizes the hydraulic properties in weathered granite as matrix flow with a moderate core-scale hydraulic conductivities of 8,6 m/d to 86 cm/d. This indicates that our measurements are in the range of the two researchers.

The geology of the observation wells shows similar stratifications, from a top surface layer of loamy sand, through weathered granite to bedrock. Moreover, data indicate granite bedrock, with assumed very low permeability, at 15 m to 32 m below the soil surface. Despite the similar stratification among the wells, groundwater levels responded differently. On an annual basis, groundwater levels (see **Figure 2.7**) at wells 3 and 5 increased slowly in time. Well 5 did react once; a rapid increase and drop in December 2010. Well 4, 6, and 7 show rising groundwater level trends after significant events and a drop during the dry season. Both conditions revealed various local hydraulic conductivities.

A possible explanation for the different groundwater fluctuations is the heterogeneity of geology. Even from two nearby locations of observation wells (100 to 200 m), groundwater level fluctuation was different. As shown in **Figure 2.7**, the groundwater level responded in two ways: a slow annual increase and an increase after events. From uphill to downhill of the observation wells, the gradient between Well 4 and Well 6 (100 m distance) is much lower than between Well 6 and Well 7 (200 m distance). This suggests that extrapolating subsurface layers may result in failure to identify the correct subsurface profile.

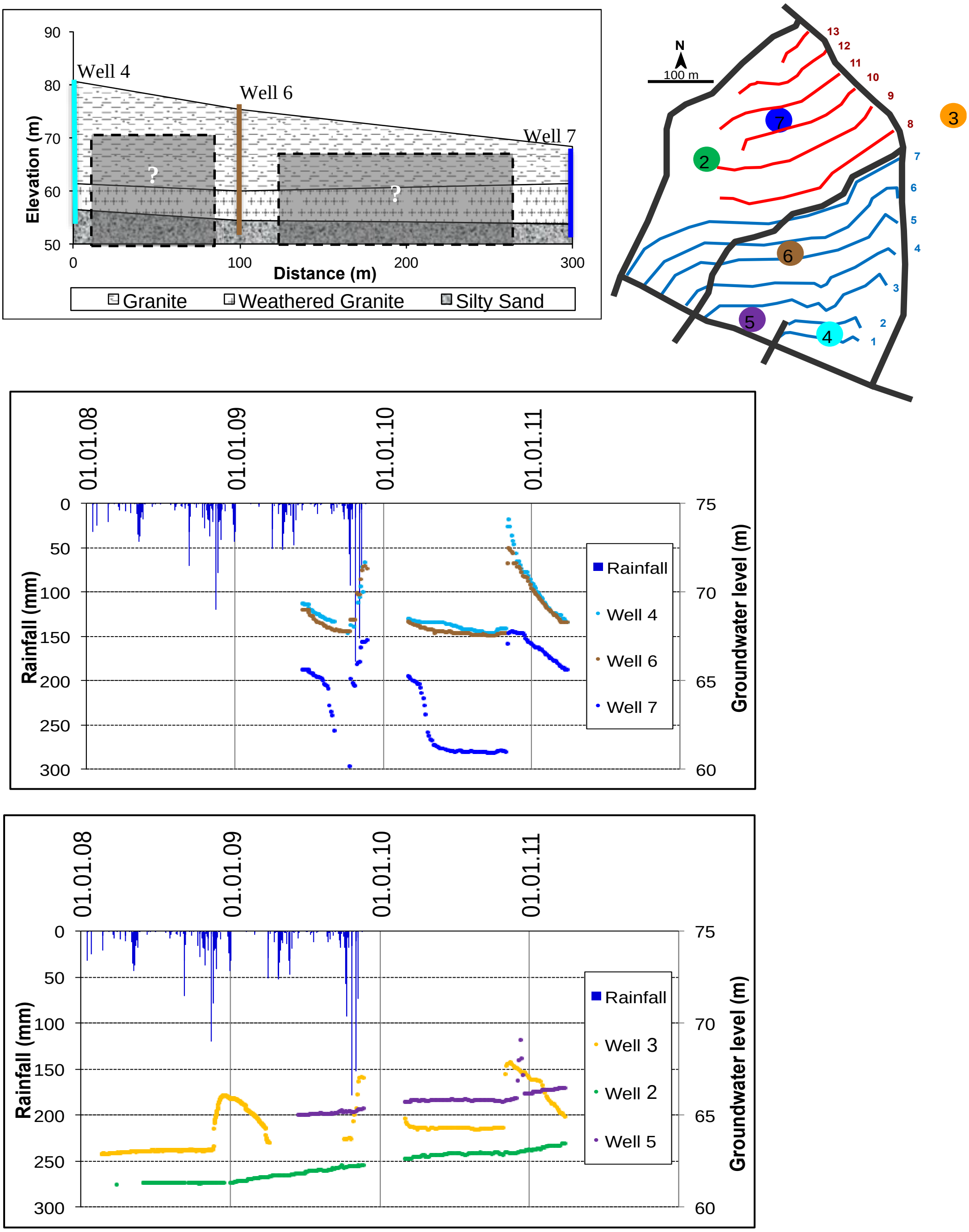


Figure 2.7 The ground surface, interpolated subsurface layer, and groundwater levels.

Stable Isotope Technique

The rainfall analysis produced a local meteoric water line. For a short period of observations MLWL is $\delta^2H = 7{,}97 \times \delta^{18}O + 11{,}41$, corresponding to measurements by IAEA at Kings Park, Hong Kong. Average composition of $\delta^{18}O$ and δ^2H are -7,8 $^0/_{00}$ and – 50,6 $^0/_{00}$ for rainfall and -8,1 $^0/_{00}$ and -56,1 $^0/_{00}$ for groundwater.

Retained water in the trench originated from rainfall events. The mixing of previous ponding water with the following rainfall events resulted in mixed isotopic content of the ponding water. If one considers groundwater level increases due to recharge, then the mixing process of rainfall should also influence the groundwater system. The groundwater level measurements at three wells (Well 2, 6, and 7) showed an increase, but they did not respond to the rainfall signals. Their average stable isotope composition remained the same. The explanation to this unchanged isotope composition seems due to the depth of the water sampling. The depth of the groundwater well screen was placed 3 m above the bedrock, whereas the bedrock was between 15 m to 32 m deep. Therefore, the rainfall signal should have been difficult to reach the depth of the screen.

Figure 2.8 shows the influence of rainfall on the groundwater system at the most uphill trench (Well 4). The composition of $\delta^{18}O$ and δ^2H in rainfall varies in from -4,5 $^0/_{00}$ to –12,9 $^0/_{00}$ and -23,3 $^0/_{00}$ to -95,4 $^0/_{00}$, respectively. During 3 to 8 October 2009, light events with heavy composition started and continued on 9 October by heavy rainfall (93 mm/d). The following significant events were on 23 October (178 mm/d), 3 November (152 mm/d) and 6 November (73 mm/d). Among the events, the 9 October 2009 composition of $\delta^{18}O$ and δ^2H is the lightest.

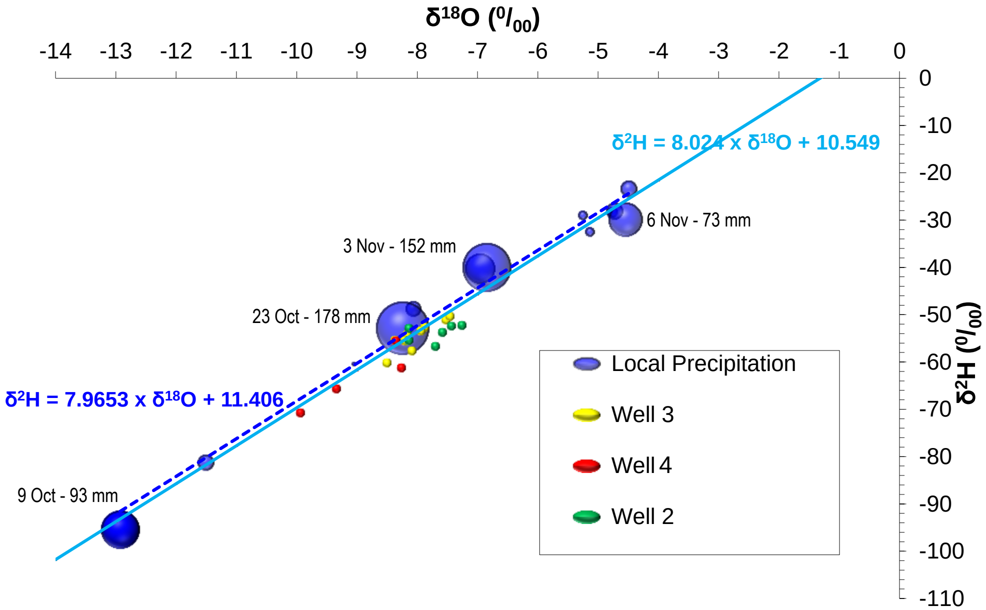


Figure 2.8 Stable isotope compositions ($\delta^{18}O$ and $\delta^{2}H$) of both rainfall and groundwater.

Initial groundwater composition at Well 4 before the events was -8,3 $^{0}/_{00}$ in $\delta^{18}O$ and – 61.1 $^{0}/_{00}$ in $\delta^{2}H$ (see **Figure 2.9**). After about two weeks, the signal of mixed small rainfall events with the one on 9 October could be found. Recharge is first indicated as the composition turns to -9,9 $^{0}/_{00}$ in $\delta^{18}O$ and – 70,7 $^{0}/_{00}$ in $\delta^{2}H$, decreased by 1,6 $^{0}/_{00}$ in $\delta^{18}O$ and 9,6 $^{0}/_{00}$ from the initial values. Subsequently, its stable isotope composition increased due to the following events that had heavier composition. In the end, the stable isotope composition returned close to the average value with little increase due to the last rainfall event, a mixture of heavy composition.

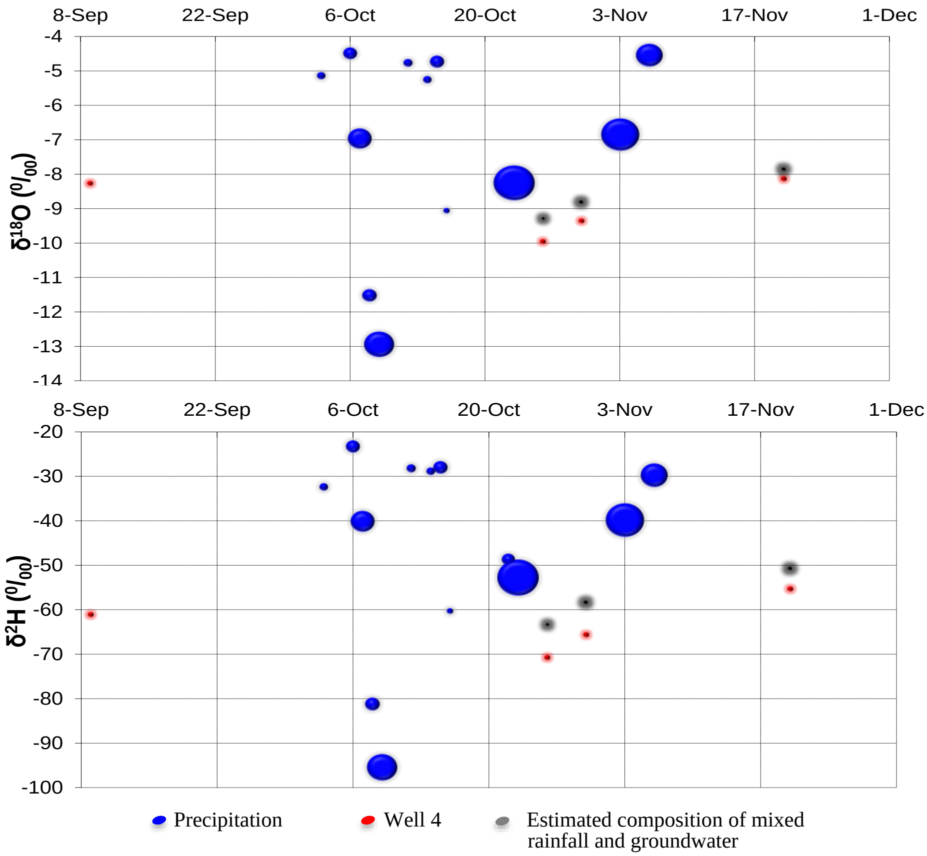


Figure 2.9 The $\delta^{18}O$ (upper) and $\delta^{2}H$ (bottom) composition in groundwater at Well 4 from September to November 2009.

The evaporation in the trench is divided into three lines (see **Figure 2.10**). The lines correspond to heavy rainfall events, which were 93 mm/d, 178 mm/d, 152 mm/d, and 73 mm/d, respectively. Mixing of different rainfall compositions occurred between the second and third rainfall events and between the third and fourth rainfall events. Retained water during 178 mm/d was mixed with 152 mm/d rain results in a heavier isotope composition.

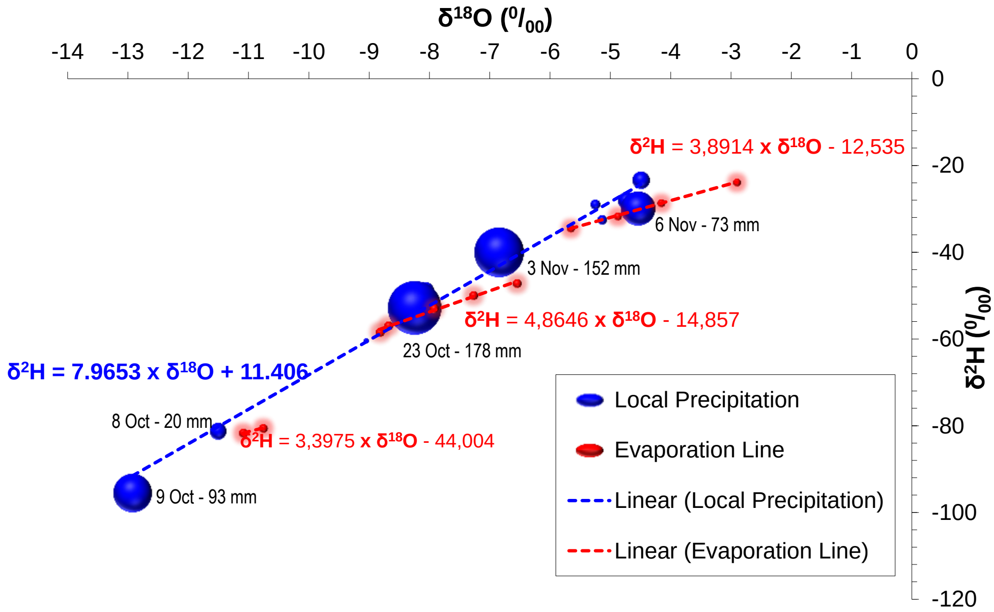


Figure 2.10 Measured evaporation composition after three significant events.

The dye was found by digging into the sediment about 50 cm (see **Figure 2.11**). It was found to be about 30 cm from the sediment surface. Initially, dye was poured about 3 cm from the previous sediment surface. Then, a ten-centimeter sedimentation was estimated during the current wet season (with four times of ponding). Thus, dye "moved" about 17 cm downward. This suggests a very slow infiltration process through the bottom of the trench.

Figure 2.11 Dye was found about 30 cm from the sediment surface.

Modelling – Hydrus (2D/3D)

Hydrus (2D/3D) was used to analyze the recharge processes in the unsaturated and saturated zones for one large trench at the most uphill part of the trench area. This trench was chosen for the simulation as it received the biggest water fluxes compared to other trenches. The initial condition of the measured surface water level was set as input. Drawdown of the surface water level in the trenches and increase of the groundwater level were set as two variables with which the model was calibrated. Runoff entering the trenching area through erosion gullies and flow paths was excluded in the modelling.

Furthermore, the retained water in the trench was set based on the maximum measured water level per event. The modelling also included the fine sediment trapped in the trenches. The purpose was to observe how ponded water recharged the subsurface – or not. After a few significant events during one wet season, the sediment accumulated to about 5 to 10 cm. Since the time scale was for one wet season, a 10 cm thick fine material was assigned in the model domain.

The modelling started with a random search of one parameter on infiltration of retained water in the trench. The drawdown of ponding based on the time of measured infiltration was checked in order to get an order of magnitude for soil hydraulic properties. Then, the groundwater drawdown in the dry period was adjusted to search for the correct magnitude of decrease in groundwater level. This allowed the model to run without rainfall inputs. The groundwater level increase was calibrated by combining several scenarios of selected parameters. Possible groundwater flows from the sides of the simulation domain, macro pores (preferential flow) and possible fractured areas were excluded in the modelling.

The model set up can be seen in **Figure 2.12**, where the subsurface domain is 15 m wide and 15 m deep. Subsurface properties were assumed to be homogenous. A sensitivity test was conducted by changing its hydraulic conductivity (Ks) and porosity of the domain. The boundary condition (BC) was set with three types of water flow, with the upper part receiving atmospheric inputs, whereas the bottom mainly as no flux, free drainage, and variable head following the measured groundwater level fluctuation of the assumed area without trenches. On the left and right side, the domain receives no flux. As initial condition, the soil water content was assigned as dry condition before the events with its measured groundwater level. The observation node is set at the well downhill the trench.

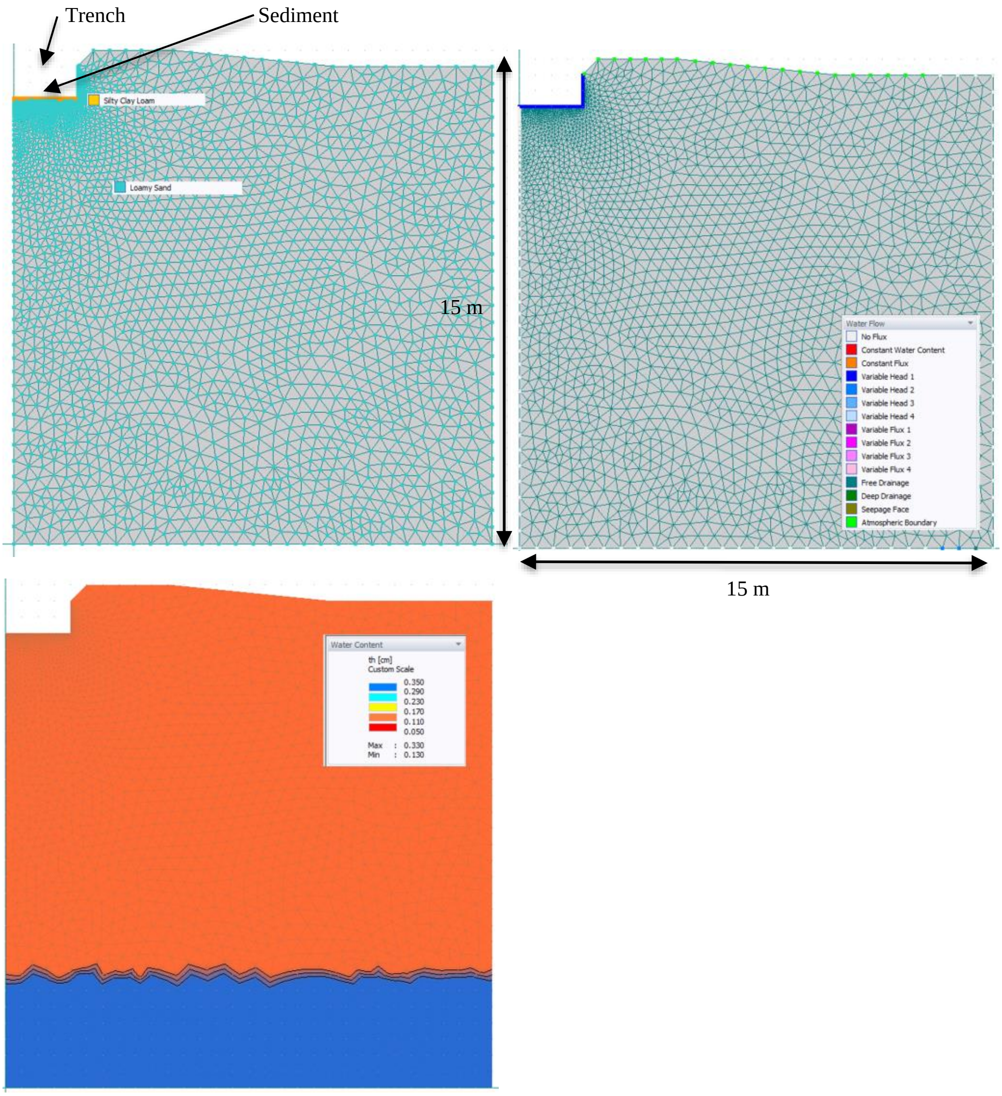


Figure 2.12 The model set up; subsurface properties (upper left), boundary condition (upper right), and initial condition (bottom).

Parameter Estimation

The parameter estimation started with trial and error of two parameters that were sensitive to fit the measurements of surface water drawdown and groundwater level fluctuation. The two parameters were the subsurface hydraulic conductivity (Ks) and the porosity. First, the Ks values were set according to the measurement of our inverse auger tests. In reality, it would be hard to obtain all Ks of the subsurface where in this case the measured Ks was only up to 2 m below the soil surface. Also, the value of the porosity was set as a variable although it was measured 33% for a soil depth of 1 m. These parameters were adjusted through different scenarios of values. The effects of changing selected parameters are summarized as follow (see **Figure 2.13**).

First, the Ks of a homogenous subsurface was simulated in three scenarios where the values were set 25 cm/d, 50 cm/d and 75 cm/d. Additionally, the sediment at the bottom of the trench was assumed to be very low in accordance to the properties of silty clay loam. The porosity was set at 33% as measured from the sample the field. The results show different responses and magnitudes of groundwater level during dry period and increase during the events. A higher Ks suggests a quick drawdown and increase of the groundwater level. Second, the Ks of 50 cm/d and porosity differences of 27%, 30%, and 33% were simulated. The results show the lower porosity would accelerate the groundwater level increase after events.

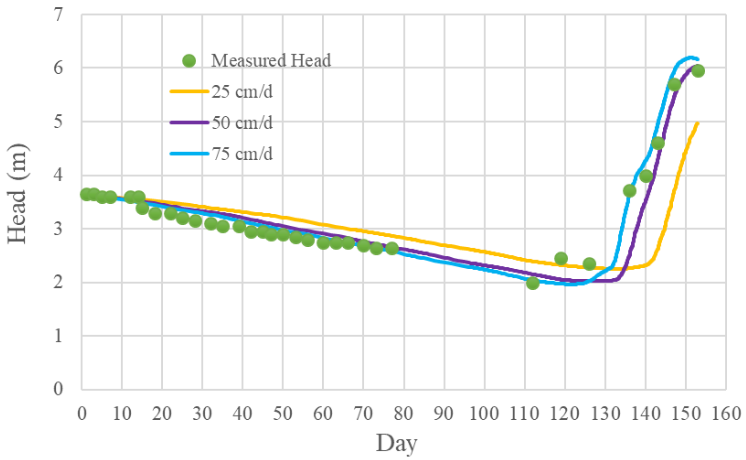


Figure 2.13 Example of sensitivity analysis using different Ks: 25 cm/d (orange), 50 cm/d (purple), and 75 cm/d (blue).

As a result, a combination of Ks and porosity was found to mimic the water level and groundwater level measurements. The most probable hypothesis of subsurface properties is presented in **Figure 2.14**. The simulation results provide visualization of the infiltration mechanism to the subsurface. Sedimentation at the bottom of the trench retains water for longer periods, but water infiltrated dominantly to the side of the trench walls and then downward direction to the groundwater system.

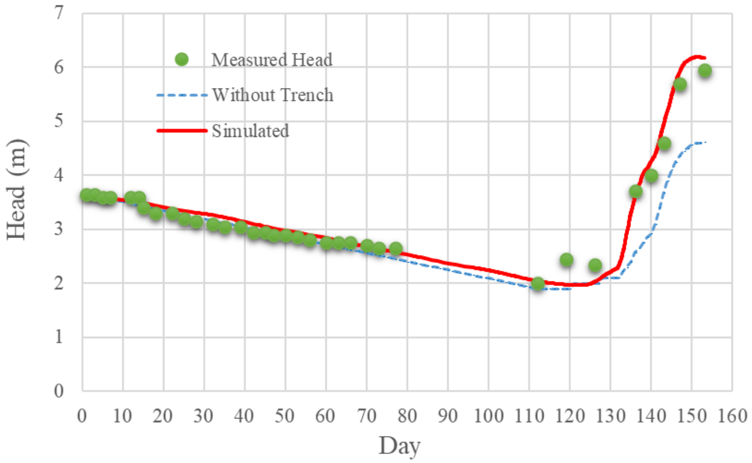


Figure 2.14 Simulation result with main Ks 50 cm/d and porosity 30%.

The simulation describes the conditions without a trench, where it is assumed that Well 2 was not affected by the trench area. Thus, groundwater level decrease during the dry period used the average drawdown of the measured groundwater level and after the first significant event extrapolated data from Well 2 was set as the input of the model. This was performed through variable head. The recharge from the trench would need some time to reach the groundwater system but the magnitude of this flux was more pronounced compared to infiltration from the atmospheric condition.

When comparing the simulations and measurements, it appears that the selected subsurface properties in the modelling fit to the groundwater level fluctuation was set to 50 cm/d, for simplification, the model was set to be homogeneous in depth. This is still in the range of the infiltration measurement where it was found between 25 cm/d and 3 m/d. The porosity measured was about 33%, whereas in the simulation it was better set to 30%. The phenomenon of this parameter decreasing with depth is observed by several researchers; Neuzil (1986), Manning and Ingebritsen (1999), Saar and Manga (2004), Wang et al. (2009a), Jiang et al. (2010).

2.5 Conclusion

The combination of field measurements, stable isotope techniques, and modelling over a 6-month period, enabled us to understand the recharge process at contour trenching plots in Vietnam. Infiltration in the trenches from uphill to downhill responded differently during a particular wet year in 2009. Based on the groundwater level measurements, it is concluded that artificial recharge took place in the trench area. It seems reasonable to explain this recharge, although it is hard to simulate the measured groundwater level based on the obtained isotope signal. For the time being, hypothetically groundwater level increase and its fluctuation is a combination of the groundwater flux and the recharge occurred due to the infiltration of ponded water in the trenches.

Stable isotope analysis suggests that one (Well 4) out of four wells shows a signal of mixed rainfall with groundwater. However, the recharge isotope signal would actually be difficult to find if it was infiltration-based, because the flow path from the trench to the observation well screen (close to bedrock) would need more time. Thus, if the rainfall signal could be found in the groundwater, this suggests that the recharge process went through a short cut (macro pore) from the trench to the screen of the observation well. Moreover, stable isotope data show evaporation processes during three different ponding conditions.

From the modelling in Hydrus (2D/3D), the values of parameters were in accordance to the range of the field measurements. The parameter estimation focused on matching scenarios of possible hydraulic conductivities and porosities, whereas the latter one was better set at 30% in the model. Even though the geology of observation wells was available, those data cannot be simply interpolated. The groundwater level measurements indicate a very steep slope between two wells; the distance between well 6 and 7 is 200 m and about 4 m head difference. This suggests that between the two wells, the groundwater system is disconnected. Additionally, the modelling shows that water in the trench infiltrates downward and through the side of the trench wall. The time of infiltration requires a few days to two weeks.

Sedimentation occurs after events and reduces the infiltration capacity. During the dry season the artificial recharge that yields subsurface water storage can be maintained up to 2 months. In the long term, 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.

2.6 Outlook

To confirm the subsurface and groundwater level fluctuation, the existing research should be extended. There are some options for research expansion in terms of measurement tools. Despite of the current understanding on local recharge and to provide more confident answers of its long-term impact on recharge, an extension for a minimum of two following years of current measurements would be preferred. Moreover, to gain understanding of the recharge process itself, a more advanced and costly geophysical survey with its analysis could be performed; for example, by using electrical resistance tomography (ERT). Mapping some transects of the subsurface at the trench plot from time to time during dry and wet season could provide more information.

3 The impacts of contour trenches in Amboseli, Kenya

3.1 Introduction

In Amboseli, a semi-arid area in Kenya, contour trenching started in the year 2002. Until recently, the hydrological long-term impacts of this construction were not well documented. Previous studies showed impacts of similar water harvesting techniques of different dimensions in semi-arid areas. For example, Makurira et al. (2010) concluded that *fanya juus* (infiltration trenches with bunds) increased soil moisture in the root zone, and thus supplementary food crops could be grown even in dry seasons. Singh (2012) stated that rainwater-harvesting structures enhanced vegetation growth and biomass production. Mhizha and Ndiritu (2013) showed that, depending on the soil type conditions, modified contour ridges resulted in crop yield benefits. The three studies above also indicated that those techniques reduce soil erosion.

One of the main purposes of contour trenching in the Kenya case was to have perennial vegetation growth. Given the lack of data on results, an attempt was made to assess the impacts of contour trenching eight years after construction. The research questions were threefold: 1) What is the impact of trenching on vegetation growth? 2) What is the impact of trenching on soil moisture in the unsaturated zone? 3) What is the impact of trenching on soil redistribution in the trench area?

To analyze long-term impacts of interventions, long-term rainfall and vegetation growth data are required. Given the absence of ground data from the past, an effort by using satellite imagery analysis for the nine years period (2002-2010) was conducted. For example, with the absence of rain gauges, satellite images can be a source of data (Nesbitt et al., 2004; Su et al., 2008). The Tropical Rainfall Measuring Mission (TRMM) quantified rainfall “best” between 50^0 N and 50^0 S (Huffman et al., 2007). The Normalized Difference of Vegetation Index (NDVI) is used to investigate the greenness of an area. In this study, NDVI values were compared from areas with and without trenches. Whether the trenches increased vegetation growth or not should become apparent from these comparisons. Furthermore, the relation between NDVI values and TRMM data were investigated to check possible correlations.

Also, a short field visit was able to be arranged. As will be discussed below and in **Chapter 5** in more detail, the original idea was to conduct field measurements on soil moisture as well, but at the end this turned out to be impossible. Furthermore, visual observation showed that eight years after construction sediments had been deposited in the trenches. The soil redistribution itself differs from one trench to the next due to different fluxes that are retained in the trenches. The uphill trench would receive most of the runoff. This hypothetically means that over time, this type of contour trench could be fully filled by sediment. Whether sediments (and as such the water as well) originated from the trench area or its upstream area was still unclear. Therefore, erosion and sedimentation investigation using cesium-137 analysis (Ritchie and McHenry, 1990; Zapata, 2003) was performed to qualitatively understand the sources of sediment, both in the trench and its surrounding area.

3.2 Site description

The contour trenching area is located in Kitenden, about 30 km downstream of Kilimanjaro Mountain (altitude 5.895 m). The study area lies at altitude 1245 m, with latitude 2° 46' 57,46'' S and longitude 37° 16' 45,93''E (see **Figure 3.1**). The study area was eroded and has an average slope of about 2% and was situated next to an erosion gully originating from Kilimanjaro Mountain.

From the dimensions, there were two types of trenches. The first are small trenches (1-m wide, 0,8-m deep), which were constructed in 2002. The larger ones (4-m wide, 1-m deep) were constructed in 2003. From 2002 until 2010, a temporary diversion structure from stones was made to divert upstream rainwater to the whole trenched area. The location of the diversion structure changed in time because of the development of larger trenches in the uphill direction. The last diversion structure from gabions was rebuilt in 2010. Inside the trenches, there were grass and shrubs. Surrounding the trench area, bare soil and sparse big trees could be seen.

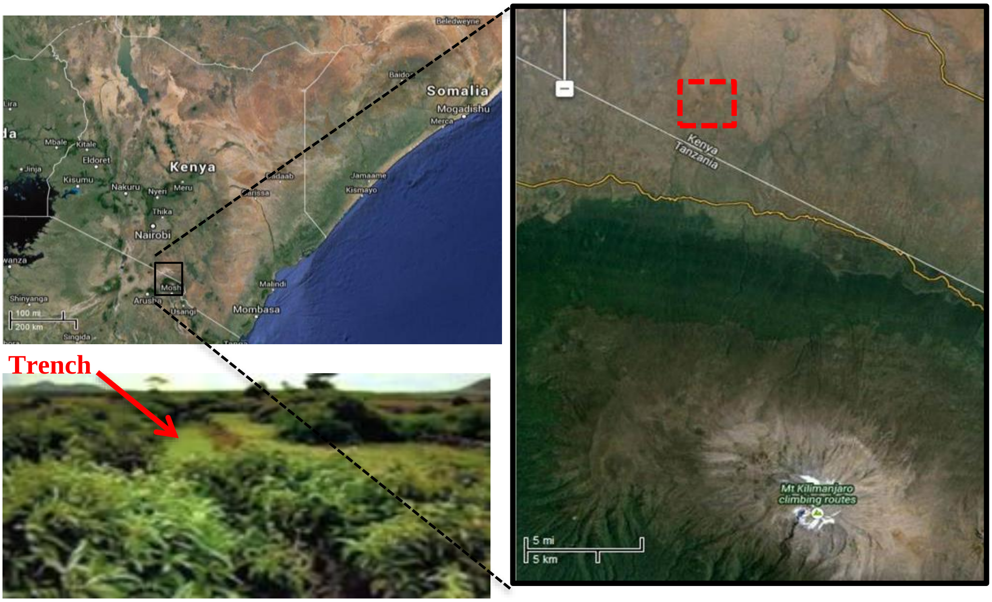


Figure 3.1 Location of contour trenching area in Amboseli, Kenya (red dashed line). Source: Google Maps. Left bottom picture: an impression of greenness in the trench area during wet season.

3.3 Material and methods

Three different methods were conducted to analyze the impacts of contour trenches, related to:

- vegetation growth,
- soil moisture in the unsaturated zone, and
- erosion-sedimentation.

3.3.1 Vegetation growth

Two types of satellite images were used. The Tropical Rainfall Measuring Mission (TRMM) and Moderate Resolution Imaging Spectroradiometer (MODIS) time series were downloaded from https://wist.echo.nasa.gov/api/ in January 2011. Those satellite images were processed using ERDAS Imagine 9.1, within which they were sequentially stacked, resulting in time series data.

TRMM is a joint project by NASA and the Japanese Space Agency (JAXA), launched in November 1997. It is a satellite mission to study tropical and sub-tropical rain systems

(Kummerow et al., 2000). The products are satellite images with spatial resolution of 25-km and temporal resolutions of 3-hourly, daily, and monthly. **Figure 3.2** provides an illustration of the coverage of one pixel (in blue). In this study, monthly temporal resolution data were used. Data were available from the beginning of 1998 onward, but images from January 2002 to December 2010 were used. TRMM images were corrected using WGS84. Additionally, downscaling was excluded from this study. TRMM images were compared with average rainfall measurements by the Kenya Wildlife Service (KWS), one of the stations located close and downstream of the study area with a distance of ten kilometers. The TRMM data were taken from a pixel that encompasses the study area including its upstream part. Monthly TRMM data were then compared to monthly NDVI data of the same time frame.

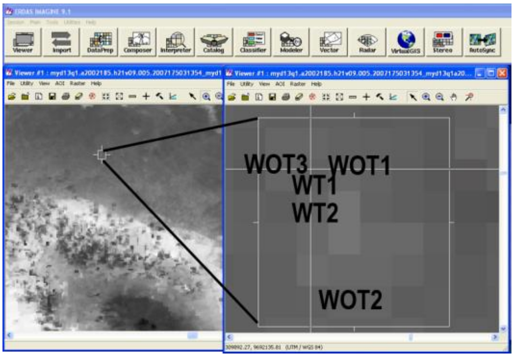


Figure 3.2 Left: The coverage of monthly rainfall by TRMM (blue square), with one pixel of about 25 x 25 km^2. The red dot represents the study area. Right: MODIS-NDVI, with one pixel of 250 x 250 m^2.

MODIS-NDVI is a readily available satellite image of cloud-free vegetation activity. It is available in three spatial resolutions 250-m, 500-m, and 1000-m and temporal resolution of 8-day, 16-day, monthly, quarterly and yearly composite. In this study, MODIS in 250-m and monthly resolution were used.

MODIS data are assumed to be sufficient to identify vegetation growth despite its coarse resolution compared to the width of the trenches (1-m and 4-m wide). In total, 102 MODIS images, from 2002 to 2010, were used for this analysis. The coordinates of MODIS images use WGS84, which was also in accordance with TRMM data. The analysis was based on NDVI values by investigating actual NDVI increase after the construction of the trenches. In case of success, vegetation growth should not only increase NDVI values, but also keep NDVI values high throughout the year.

Two fields with trenches, small and larger ones, were mapped (as “With Trench 1” or WT1 and WT2). Three areas without trenches were selected for comparison. The selected areas represent the condition before trenches were dug (as “Without Trench 1” or WOT1, WOT2 and WOT3). The downstream condition was observed to be similar to the upstream. From field observations, downstream area WOT3 was found to be bare soil, an extreme condition (having the least green area) to compare with.

Hypothesis testing of two samples on two means (Walpole et al., 2012) was used to evaluate the impact of contour trenching to vegetation growth. Specifically, the two-tailed z test was applied with a confidence interval of 95% or $\alpha = 0{,}05$. NDVI values of areas with trenches were compared with NDVI values without trenches. The null hypothesis (H_0) is that there is no significant difference between NDVI values with and without trenches. The alternative hypothesis (H_1) is that there is a significant difference between NDVI values for areas with and without trenches.

3.3.2 Soil moisture in the unsaturated zone

Six access tubes were installed for TDR (Time Domain, with series IMKO's PDA, PICO-BT and Trime PICO-IPH) soil moisture measurements at five locations in and one outside the trench area. At the end of this research, due to lack of labor, disappearance of access tubes, and difficulties in finding home electricity to charge the soil moisture devices, it turned out to be impossible to conduct this measurement. An attempt to install two rain gauges (tipping bucket model, with HOBO Pendant Event Data Logger) was successful. Both were placed in the *manyatta* (kraals). However, due to technical failure data on the two loggers could not be retrieved. Due to lack of soil moisture and rainfall data, the research on soil moisture could not be pursued.

3.3.3 Erosion-sedimentation; Cesium-137

Fallout Cesium-137 (^{137}Cs) is a tracer used for erosion and sedimentation studies (Zapata, 2003) in different environments around the world. ^{137}Cs originated from the nuclear tests in the 1960s, was absorbed in soil particles, and has a half-life of about 30,2 years. The ^{137}Cs concentration is assumed to be evenly distributed throughout the study area. By measuring the concentration of ^{137}Cs in its vertical distribution, sources of sediment can be identified (Walling and Quine, 1991; Wallbrink et al., 1999).

For the impact of contour trenching to erosion-sedimentation, soil samples (using split tube sampler, Eijkelkamp Agrisearch Equipment) with a depth of 40-cm from the soil surface were collected. **Figure 3.3** shows the sample locations, which are divided into four parts; two undisturbed samples for references, six samples in areas not influenced by trenching, four samples in areas influenced by trenching, and four samples inside the trenches. Each point was sampled three times in a radius of 1 m; the sample were made together into one composite sample (Sutherland, 1994).

In total, 16 soil samples at 40 cm deep from the top surface were collected. One sample location was cut into eight smaller samples of 5 cm. The samples were oven-dried at a temperature of 105^0C for 24 hours, sieved in 2 mm, and weighed at Moi University, Eldoret, Kenya. For cesium concentration measurement, 100 gr samples were packed into small polyethylene bags, sealed, and sent to ISOLAB, Georg-August-Universitaet Goettingen, Germany. The concentration was measured in Bq kg^{-1} using a HP Germanium detector. Due to low activity concentration, the measurement time per sample took a maximum time of 250.000 s.

To roughly indicate the thickness of sedimentation in the trenches, a measuring tape was used. The measurement in one trench took place at two different points, about one third from both end-sides of the trenches. The sedimentation was calculated from the original soil surface to the trench bottom. The initial depth of the small trenches was designed about 80 cm below the soil surface.

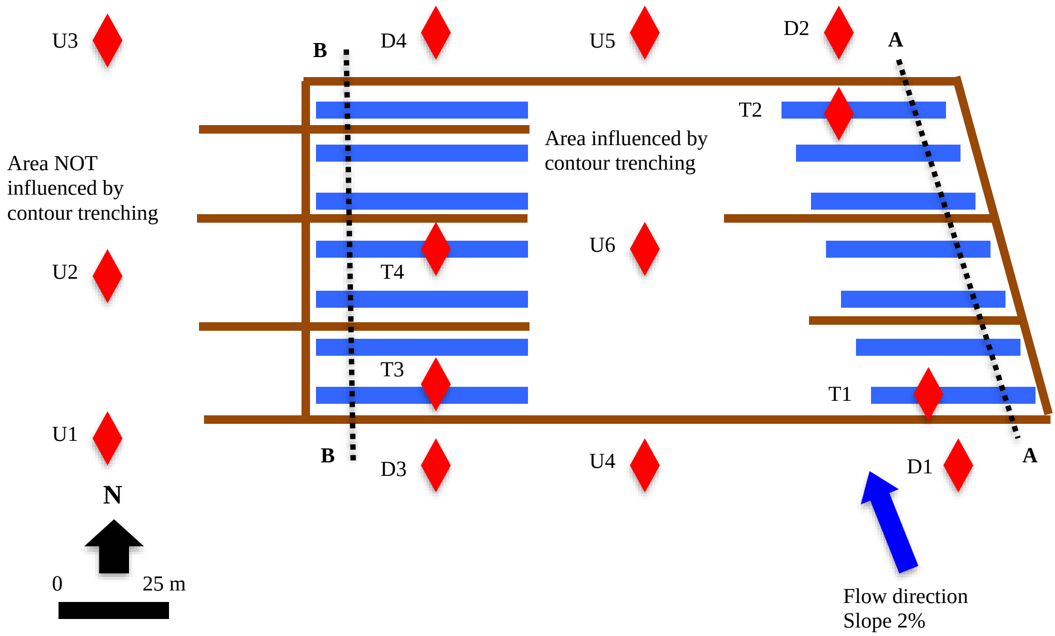


Figure 3.3 The "small" contour trenches (about 2 ha) in Amboseli. Blue squares are the trenches, brown lines are the stone walls, and red diamonds are the soil sample locations. The thickness of sedimentation in the trenches are measured from cross sections A-A and B-B.

3.4 Results and discussion

3.4.1 TRMM versus KWS data and between two TRMMs

Figure 3.4 shows the comparison between average monthly data of TRMM and rainfall measured by KWS. The pattern for both data sources is similar: the wet season from November to May and the dry season from June to October. The difference is seen in the magnitude of the wet season, where average monthly rainfall of KWS is higher than TRMM. Only rainfall in April of KWS shows lower values than TRMM. The correlation coefficient between TRMM and data from KWS is considered low (R = 0,37). Possible reasons include the different years (KWS average data from 1993 to 2002 and TRMM from 2002 to 2010) and the location of the measurements. Nevertheless, data from KWS are considered as a check to the satellite images and confirm the possible use of these images. Since monthly data are available in TRMM, rainfall can be related to NDVI data.

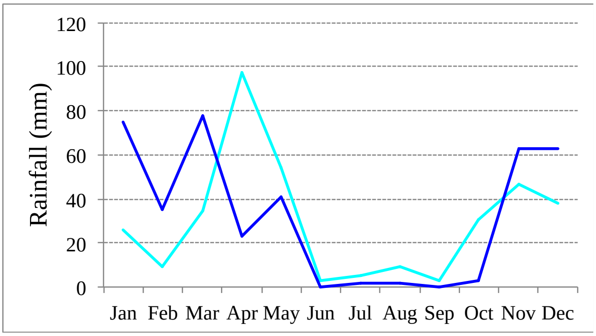


Figure 3.4 Average monthly rainfall in Amboseli, from 1993 to 2002 by KWS (dark blue) and TRMM measurements from 2002 to 2010 (light blue).

TRMM data for locations between the trench area and Kilimanjaro mountain are compared (**Figure 3.5**). The accumulation of the two rainfall data series shows a pattern where rainfall in Kilimanjaro is less than in the trench area. However, the trend throughout the year is similar. This suggests that comparing monthly data between TRMM and NDVI, one pixel of TRMM is sufficient against NDVI data.

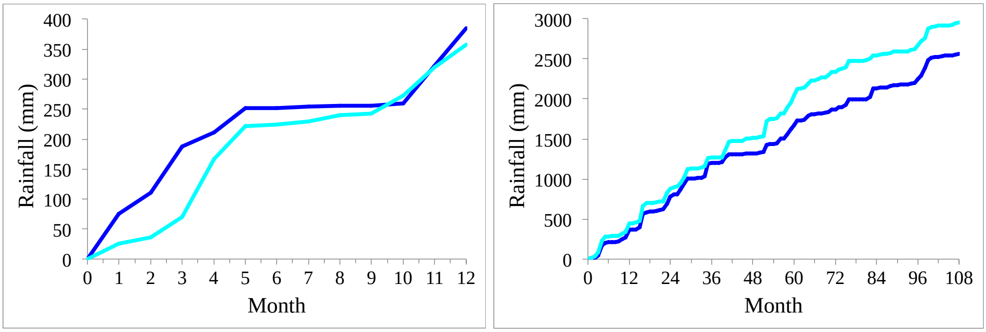


Figure 3.5 Left side: comparison between data of KWS (dark blue) and TRMM (light blue) (R=0,37). Right side: TRMM comparision; at trench area (dark blue) and at Kilimanjaro mountain (light blue) (R=0,76).

3.4.2 NDVI with and without trench, TRMM versus NDVI

The NDVI values in areas with and without trenches are compared. NDVI values of areas with trenches (WT1 refers to small trenches and WT2 refers to large trenches) were compared to areas without trenches (WOT1, WOT2, and WOT3) using a fixed area size (for the small trenches 2 ha and for the large trenches 4 ha).

The results are summarized in **Figure 3.6.** The figure shows that the differences in NDVI values for areas with and without trenches have similar patterns. There are a few periods where the NDVI values of the trench area are much higher than the area without trenches. For example, in February and May 2007, April 2008, and January 2010, the differences are significant compared to the other months. This specific condition is only visible for a short term. Most of the times, the trend shows a peak followed by a drop. In other words, when comparing the period after the trenches were built, NDVI values show high greenness indexes during the wet season.

Is there a significant difference in NDVI values in areas with and without trenches? The average of NDVI with trenches in 2002 to 2010 is 0,3; the NDVI without trenches is 0,27. To reject H_0 (no significant difference in NDVI values), the mean must differ significantly. The result showed z value equals to 1,76 and was compared to the critical region, $z_{0,025}$ equals to 1,96. Since the z value is smaller than $z_{0,025}$, it suggests that there is a no significant difference between situations with and without trenches.

Furthermore, an attempt to correlate TRMM with NDVI values of the trench area was performed. Martiny et al. (2006) showed a lag of 1 month in western Africa and 1.5 month in southern Africa between rainfall and NDVI peaks. In addition, the relation between soil moisture and the greenness index may lie in the order of a few weeks (Cheema et al., 2011). Thus, by shifting TRMM values up to 2 months earlier to its actual month, it is expected that a lag correlation could be obtained. Results show, however, low values of correlation (1-month lag R = 0,44, and 2 months lag R = 0,16).

Overall, it has been possible to study monthly NDVI values between 2002 and 2010. A comparison of NDVI for areas with and without contour trenches was made. The results of MODIS images indicate that NDVI values fluctuate in time because of alternating dry and wet seasons. Thus, there is no clear signal that contour trenching increases the NDVI (or “greenness”) throughout the year, but it does show a short-term effect in the rainy season.

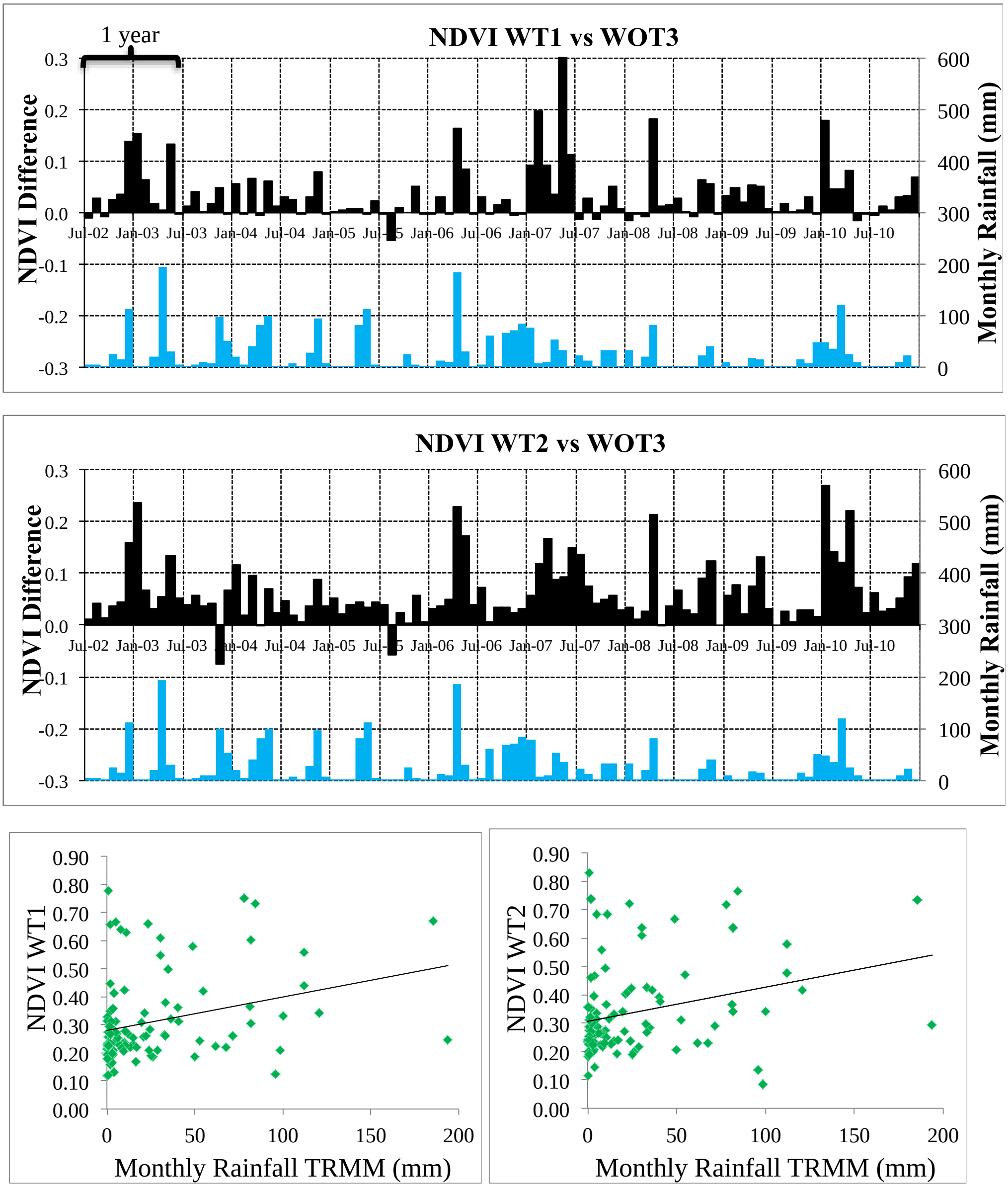


Figure 3.6 The difference of NDVI values of with (WT) and without trenches (WOT) compared to monthly rainfall. The correlation between TRMM and NDVI of WT1 and WT2 are given in the lower image.

3.4.3 Cesium-137 analysis

In this study, 128 ^{137}Cs sample concentrations at the small trench area are analyzed:

- Between the reference (R1 and R2) and the area that is not affected by trenches (U1 to U3)
- Between the reference (R1 and R2) and the area assumed to be affected by trenches (D1 to D4, and U4 to U6)
- Amongst the samples in the trenches (T1 to T4).

From **Table 3.1**, the trench area appears as an eroded area with a low concentration of ^{137}Cs at the top 20-cm soil surface. Based on the two reference samples, ^{137}Cs concentrations are lower than 2 Bq kg^{-1}. Below 15-cm, there is almost no ^{137}Cs concentration found. In the trench area to the West, erosion and sedimentation were much more pronounced. For the vertical soil profiles, low ^{137}Cs concentrations are found unevenly distributed up to a depth of 20 cm.

Inside the trench area that is surrounded by a stone wall, sediments show a layering of high and low ^{137}Cs concentrations. It is presumed that early deposition originates from local sediment within the trench area. The first sediment (about 30 cm in the trenches (T1 to T4)) shows ^{137}Cs concentration values below 2 Bq kg^{-1}. In the upper part, ^{137}Cs concentrations are above 2 Bq kg^{-1}. This difference can possibly be explained in two ways: ponding and/or grazing activities. The upper sediment is enriched ^{137}Cs concentration, which most likely originates from outside the trench area. The sediment is brought to the trench area through runoff that passes the erosion gully and settles in the trench area. This suggests mixed sources of sediment, either from the trench area or external source upstream, during different (period of) rainfall events.

This ^{137}Cs analysis could be considered vulnerable, due to the possibility that two reference samples might be eroded samples. The external sources with higher ^{137}Cs concentration seem to be high at the first few centimeters below soil surface, where the values lie between 2 Bq kg^{-1} and 9 Bq kg^{-1}. The United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR (1972, 1977), estimated the ^{137}Cs concentration at latitude 0 to 10^0 S of 5.2 Bq kg^{-1} in the first 5 cm below soil surface. In addition, deGraffenried (2009) detected ^{137}Cs concentration in non-eroded topsoils in Western Kenya up to 9,49 Bq kg^{-1}. In practice, it is difficult to find a reference point (Poreba, 2006; deGraffenried, 2009).

Table 3.1 Cesium-137 Analysis at the Small (1-m wide) Trench Area.

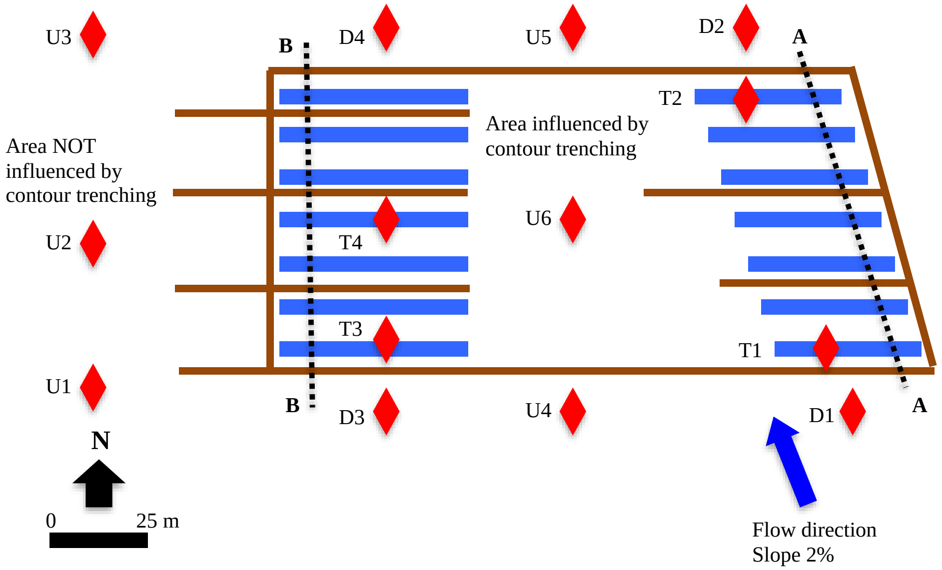
Depth (cm)	Cs (Bq kg-1) R1	R2
5	1.98	1.87
10	1.70	1.05
15	0.34	<
20	<	<
25	<	<
30	<	<
35	<	<
40	<	<
45		
50		
55		
60		
65		
70		
75		
80		

Depth (cm)	Cs (Bq kg-1) U1	U2	U3
5	<	<	<
10	<	<	0.74
15	<	<	<
20	<	0.61	0.56
25	<	<	<
30	<	<	<
35	<	<	<
40	<	<	<
45			
50			
55			
60			
65			
70			
75			
80			

Depth (cm)	Cs (Bq kg^{-1}) D3	T3	T4	D4
5	<			0.73
10	<			<
15	<			<
20	<			<
25	<		3.89	<
30	<	7.69	6.48	<
35	<	8.89	6.48	0.64
40	<	5.84	8.31	0.64
45		2.37	5.60	
50		<	3.00	
55		0.37	1.07	
60		0.52	<	
65		<		
70				
75				
80				

Depth (cm)	Cs (Bq kg-1) U4	U6	U5
5	4.70	6.65	9.37
10	6.33	4.11	5.73
15	2.82	2.38	<
20	2.03	1.10	<
25	0.75	<	<
30	<	<	<
35	<	<	<
40	<	<	<
45			
50			
55			
60			
65			
70			
75			
80			

Depth (cm)	Cs (Bq kg^{-1}) D1	T1	T2	D2
5	1.78			1.58
10	0.77	2.94		3.60
15	0.37	3.40		<
20	<	3.44		<
25	<	4.66		<
30	0.38	4.89		<
35	<	3.43	2.17	<
40	<	3.26	1.50	0.79
45		4.74	0.48	
50			1.00	
55			1.05	
60			<	
65			<	
70			1.30	
75				
80				



Notes: Samples are up to 40 cm from the soil surface. The soil surface is being marked as bold lines. Red values represent local sediment and green values as external sediment.

Regarding the effectiveness of the stonewall as a sediment control strategy, external sediment still enters the trench area – as can be seen in the high ^{137}Cs concentrations inside the trench area (at U4, U5, and U6) and even in the trenches. Concerning points U4, U5, and U6, the gradual decrease of ^{137}Cs concentration in the vertical soil profile indicates that external sediments are trapped and accumulated uphill of the stonewall. ^{137}Cs concentration depletes further downhill at a distance of 100 m, suggesting that external sediment passes the stonewall. This process suggests that the wall is less effective in reducing sedimentation in the trenches.

During the fieldwork, the thickness of sediment was observed to be different among the trenches (see **Figure 3.7**). At cross section A-A, the first and second uphill trenches have more sediment than the downhill trenches. At cross section B-B, sedimentation is more or less evenly distributed. This suggests that the erosion gully directed to the trench area, the land conversion uphill the trench area, and the additional diversion structure all play an important role in water accumulation in the trenches.

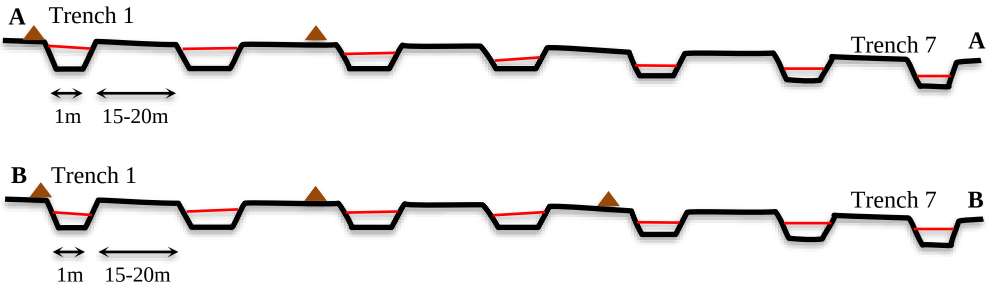


Figure 3.7 Sedimentation height (in red) accumulated in the trenches in 2010. The slope is from Trench 1 (uphill) to Trench 7 (downhill). The brown triangle illustrates the stone walls.

In the long term, sedimentation tends to cover the trenches and as such creates a return to the initial soil surface. The first uphill small trenches were almost fully filled when the fieldwork was done. The time needed to fully fill-in the trenches depends on the conversion of the upstream landscape, rainfall events, grazing activities, and the diversion structure of the uphill runoff. During the development of construction, larger trenches were constructed uphill of the smaller trenches. During a dry year, rainfall in the wet season might be little. If there is no grazing, animals do not interfere the trenches. If the diversion structure is damaged, little runoff enters the trench area. Therefore, due to these conditions, little sediment would be retained in the smaller trenches.

3.5 Conclusion

To analyze the impacts of contour trenching in Amboseli, Kenya, fieldwork was conducted in September 2010. The contour trenching impacts on vegetation growth, soil moisture availability, and sedimentation distribution was investigated. On-site rainfall and soil moisture measurements were unsuccessful, and therefore, the research question on soil moisture availability could not be answered.

To understand the impact of contour trenching on vegetation growth, a monthly TRMM and NDVI analysis was performed. TRMM values estimated rainfall upstream and in the trench area from 2002 to 2010. NDVI values indicated the greenness with and without trenches after the construction of small and large trenches. The signal of greenness that was found appeared to be dominated by alternating dry and wet seasons but did show a short-term effect of contour trenching. The relation between TRMM and NDVI was analyzed, in terms of both direct impact and lag times up to two months. Results show a low correlation between TRMM and NDVI.

The results of the erosion and sedimentation analysis show the study area is an eroded area. Sediments found in the trench area are a combination of local and external sources; early deposition originates from local sources (up to about 30 cm thickness of sediments), after which sediments from external sources enter the trench. As sedimentation still occurs in the trench area, the stonewall apparently still allows sediment to enter the trench area.

3.6 Outlook

There are several approaches to gain better understanding of the impacts of contour trenching in the future. Below are some options for further studies considering the expenses. Research budget issues and effectiveness will be described in more detail in **Sub-chapter 6.4**.

Since this study mainly used remote sensing data, with limited ground data, verification through ground measurements is still essential. Rainfall measurement should be calibrated against TRMM images. Moreover, soil moisture data is of importance, since it could be related to the response of vegetation growth. Those data can either be taken from the satellite images that have information on 5 cm below the soil surface or/and direct measurements using sensors up to 2 m below the soil surface. As experienced before, the latter one seems to be costly and difficult to be conducted. Considering a different type of soil moisture measurement is required. Furthermore, an extension of remote sensing studies would be easier to conduct, especially due to its free availability on the Internet. However, there is also an option to purchase higher resolution NDVI images (10 m to 5 m pixel), as with the free products 1 m or 4 m wide trenches may not be covered by a 250 m data pixel.

The amount of water entering the trench area during rainfall events has never been recorded. Runoff that came from the upstream varied in time and space, which limited the understanding on origin of runoff. Therefore, discharge measurements can be proposed. A flume or notch could be built at the study area before runoff is diverted, using a gabion structure. Additionally, data on water levels in trenches during and after an event would provide more information on the frequency of ponding in the trenches.

Moreover, aerial photos of the land cover over time can be used to compare the trench area with its vicinity. Current pictures are available, but are limited to one time during a season. A series of “present to future” pictures can help to confirm whether the intervention over time result in continuous vegetation growth. Photos to mark the starting point and its continuity of one point is valuable. For example, **Figure 3.8** shows the condition of vegetation growth after the wet season in July 2012. It appears that vegetation in the trenches is green, but one would need a longer time series to be able to monitor conditions throughout a year. Finally, a complete picture of temporal development of contour trenching is essential to estimate its long-term impacts to the vegetation growth.

Figure 3.8 Condition of vegetation growth in July 2012. Source: Naga Foundation, the Netherlands

4 The potential of micro-hydro power plants on Maluku Islands, Indonesia

4.1 Introduction

The Maluku province is located in East Indonesia and consists of about 1000 small to big islands. Due to the large distances between the islands, the province typically demands high investments to build up and sustain its energy infrastructure. Sustainable growth for developing economics and habitat requires increased energy input (Dudhani et al., 2006), in Maluku as well as anywhere else. Without a reliable energy input, it is difficult to accelerate the economic growth in this province.

One of the important elements to support economic growth is providing local communities with a reliable electricity supply. This supply is expected to encourage small industries and economic activities in general, so that eventually the whole rural area benefits. In the current situation, the state electricity company of Indonesia (*Perusahaan Listrik Negara or PLN*) mainly provides electricity through diesel generators. Thus, fossil fuel is the main source for electricity. Rural electrification in Indonesia seeks a reduction in the dependency of fossil fuels by promoting renewable energy, something the local government in Maluku promotes as well. This program requires follow up actions by PLN. Indonesia is an archipelago with an abundance of water resources that can be used to create hydropower as a valuable source of energy. Many micro-hydro power plants (MHPP) have been installed in regions on big islands like North Sumatra, Central Java, West Java and Bengkulu (Suroso, 2002; Hasan et al. 2012).

For MHPP to be useful and effective, potential locations have to meet technical and economic demands. In this first evaluation of MHPP in Maluku, the technical point of view can provide potential locations that might be of interest to start an economic evaluation. An example of an economic feasibility study of potential hydropower using a GIS approach has been conducted for the La Plata basin (Popescu et al., 2012). In addition, Kosnik (2010) carried out research on construction cost-effectiveness of MHPP in the US. Economic feasibility is explicitly excluded from the study discussed in this chapter although some economic are considered specifically for the Aboru case study.

Meanwhile, there is limited information on suitable locations to build MHPP in the Maluku province. Therefore, this study aims to estimate the technical potential of MHPP in this region. In 2011, two research efforts were conducted. A desk study of a Digital Elevation Model (DEM) processed with ArcGIS, was combined with a fieldwork and on-site discharge and rainfall measurements focusing on Aboru village on Haruku Island (including using secondary data of rainfall). The project on Aboru village intended to build a MHPP as a pilot that could improve the socio-economic situation of the local community (compare Balakrishnan 2006;

Anyi et al. 2010). Through the two research efforts, the potential of MHPP in the whole Maluku province could be estimated. Further details, like the suitable turbine, local regulation related to MHPP development and its environmental impact assessment, were excluded in this analysis presented in this chapter.

4.2 Site description

The Maluku province (see **Figure 4.1**) is in the east of the Indonesian archipelago. In total, there are 1027 islands with a total surface area of 85,728 km^2. Most Maluku Islands are mountainous (about 57%); on some islands, active volcanoes can be found. The climate is humid, affected by monsoons, with an average annual temperature of 26 degrees Celsius. High annual rainfall, ranging from 1.000 mm to 5.000 mm, occurs from May to August, with the remaining months shaping the dry season. In the northern part of Maluku, the wet season is from December to March, with a similar seasonal trend as most other regions in Indonesia. The Maluku Islands are mainly covered by rainforests, in which the people cultivate sago and rice. In 2009, the population of the Maluku province was estimated at about two million, which is about 1% of the total population in Indonesia. More specific for this research, the study area is in Aboru, a small village on Haruku Island (latitude 3°35'33"S and longitude 128°31'0,7"E). The catchment area is roughly 3 km^2. Aboru has about 1000 inhabitants.

Figure 4.1 The area of the Maluku province (white dashed line), Indonesia and A is the study area. Source: Google Earth.

4.3 Material and methods

The general equation to estimate the potential of micro-hydro is

$$P = \rho \times g \times H \times Q \times \eta$$

where P is the potential capacity (W), ρ is density (kg/m^3), g is the gravitational acceleration (m/s^2), H is the head (m), Q is the river discharge (m^3/s), and η is the efficiency (%, typically in the range of 60% to 80%) (Paish, 2002; Purohit, 2008). The potential of run-of-river micro-hydro power (P) depends on two main parameters: energy head and river discharge.

To find options for available high heads, a Digital Elevation Model (DEM) analysis was conducted in combination with fieldwork, measuring the topography along one river from downstream to upstream to search for the most feasible location for a MHPP. (See Mosier et al, (2012), for DEM-based research). Data were downloaded from http://srtm.csi.cgiar.org, provided by the Consortium for Spatial Information (CGIAR-CSI) of the Consultative Group for International Agricultural Research (CGIAR). The DEM data have a pixel resolution of 3 arc-second ≈ 90 m and are available in 5 x 5 degrees tiles in GeoTiff format. To analyze the DEM data, ArcGIS was used. In the field, the stream of potential MHPP locations was tracked using a theodolite (Wild T0, Wild Heerbrugg, Switzerland).

Uphill of the planned MHPP, the water level of the river was measured using two divers (Schlumberger Water Services Delft, The Netherlands, measurements at 20-minute intervals). After measuring the surface water levels, the Strickler-Manning equation was used to calculate the theoretical discharges. To compare these results, a test using the dilution gauging method (Calkins and Dunne, 1970) was also performed eight times – four at the upstream and four at the downstream – at the planned location for MHPP. One diver was put inside one of the tipping buckets for barometric correction. For the MHPP design discharge, a Flow Duration Curve (FDC) was drafted. The discharge with exceedance probability of 80% was selected. For extrapolating discharges to other islands in the whole Maluku region, the discharge data of Aboru were used in combination with the area ratio. In this case, by assuming the region is homogeneous this method was seen as the only way to estimate the discharges from a very limited ground data.

Two rain gauges (Onset Data Logging Rain Gauge RG3-M, tipping bucket, resolution 0,2 mm, Bourne, US) were installed at the planned location for MHPP and downstream in the yard of one inhabitant in Aboru village. The measurements were conducted for one year, from July 2010 to June 2011. Also, rainfall data from three different stations (Ambon about 35 km, Buru about 200 km, and Amahai on Seram Island about 56 km) were collected and compared to see the correlation of rainfall data between stations.

4.4 Results and discussion

4.4.1 DEM analysis

Most of the potential locations for MHPP are found on Buru and Seram Island (see **Figure 4.4**). The two islands are mountainous and the two largest islands in the Maluku region. On Buru Island, high heads are located on the western part, close to the western coast. On Seram Island, high heads are found along the northern and southern coasts, at the middle of the island. Halmahera Island also has some hills, however, the available heads in the river on this island are considered low, and thus no potential was identified. Specifically, looking at the point where the MHPP is planned in Aboru, the head was found to be 23 m. This is not satisfactory, considering the head found with ground measurements was 35 m. Other heads on the island were not possible to be measured due to limited time, and the efforts to track the rivers on different islands would require lots of logistics. Therefore, in order to assess potential applications for MHPP, a DEM based analysis may provide only very indicative estimates.

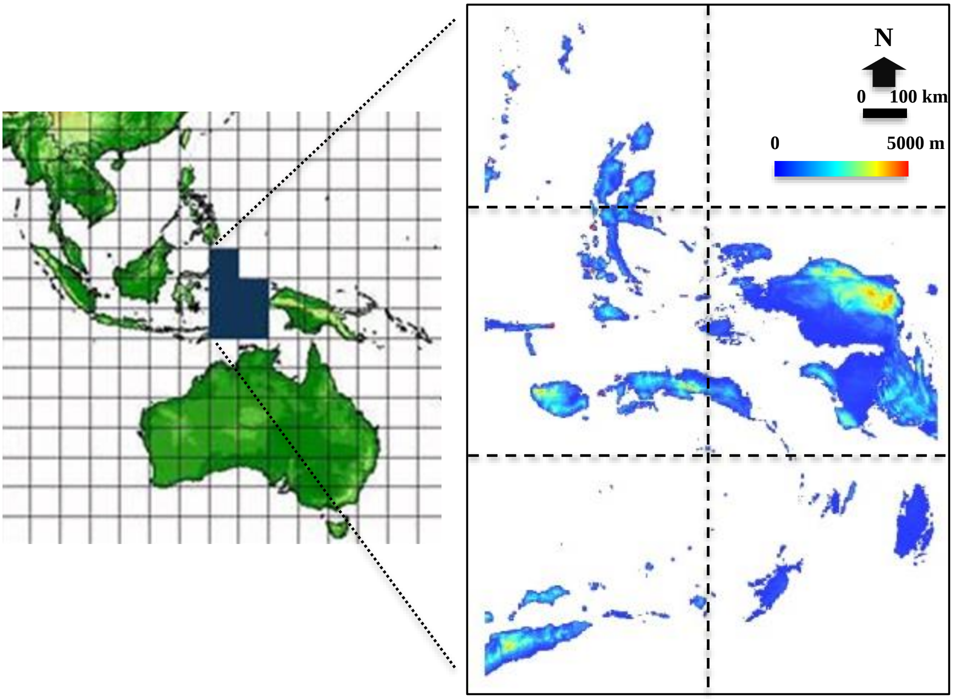


Figure 4.2 The result of merged and processed DEM tiles on Maluku Islands.

4.4.2 Field measurements; water level and rainfall

Two Divers were installed close to the proposed MHPP intake. The distance along the river between the two divers was about 10 m, and it was expected that the distance could be used to indicate the surface water slope for velocity calculation. Unfortunately, recorded data from one diver provided incorrect values, and thus were excluded in the analysis. Measured water levels were used as inputs alongside with cross section inputs in the Strickler-Manning equation to get theoretical discharges. With a Strickler coefficient or k equal to 23 $m^{1/3}/s$, estimates ranged between 0,012 to 0,016 m^3/s of stream flow. This result confirmed the dilution gauging measurement of 0,015 to 0,017 m^3/s. Furthermore, a relationship of water level or stage and discharge was estimated (see **Figure 4.3**).

From 1-year discharge data of Aboru, an FDC was plotted. The Aboru data were used later to extrapolate the discharges to other islands in the Maluku region. Even though this is not very accurate, an estimation of the local discharge could be obtained. Indeed, discharge measurement in the local condition where the MHPP would be built is preferred. However, discharge measurement in Maluku region is scarce. Future work should determine the correlation of rainfall data between stations.

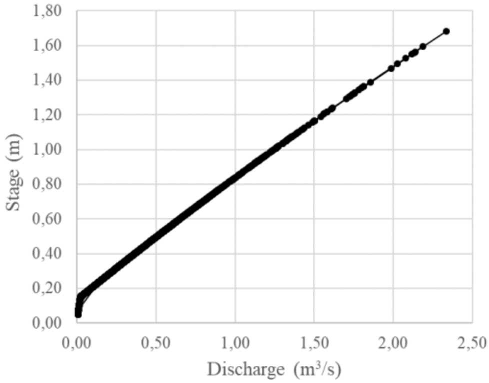


Figure 4.3 The stage-discharge relationship.

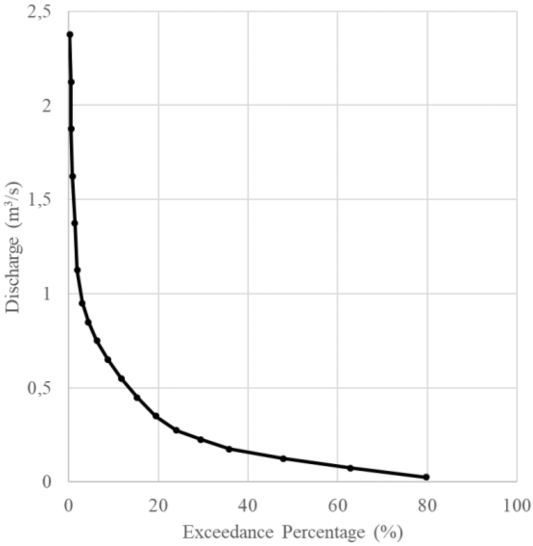


Figure 4.4 Flow duration curve of Aboru

Two rain gauges were set up, but only the data from the upstream rain gauge were used. The data from the one downstream could not be retrieved due to a technical problem. Compared to the closest station in Ambon (located about 35 km from Aboru), the measurements with the rain gauges suggest 2010 was a wet year. The correlation coefficient of monthly rainfall between Ambon station Aboru is 0,98. Differences in rainfall between wet and dry seasons are shown in **Figure 4.5**.

During the 2010 wet year, the 4-month high rainfall resulted in a 5-month consecutive period of estimated monthly discharge of 0,2 m^3/s. During the dry season, low water levels were recorded, corresponding with ranges from 0,015 m^3/s to 0,06 m^3/s. This observation was included in the final decision on the capacity of a proposed MHPP. For example, facilitating only five months of hydropower (during the wet season) and a shutdown of seven months might yield a higher MHPP capacity for a limited period. Another option was using a low MHPP capacity for the entire year. From these two possible scenarios, the latter one was preferred, as is discussed further in **4.4.3**.

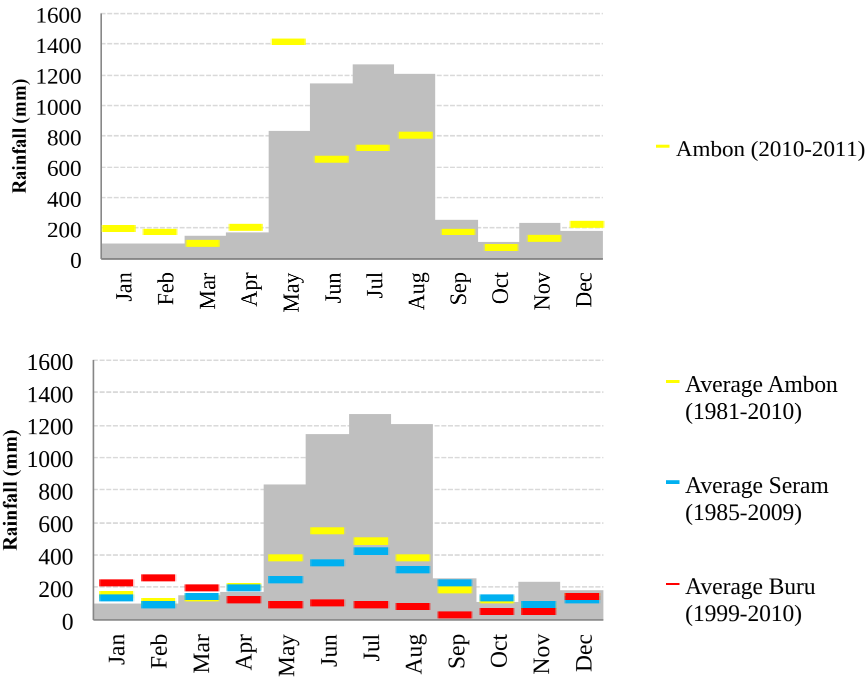


Figure 4.5 Upper picture: one-year (2010-2011) onsite measurement with Ambon meteorological station. Comparison of lower picture: Comparison of one-year (2010-2011) onsite measurement in grey with long-term average rainfall from three local meteorological stations.

4.4.3 Potential capacity of MHPP

Both discharge and head influence the potential capacity of a MHPP. A trade-off may occur, as more head and less discharge can generate the same power as vice versa. In this study, DEM for the head estimation and the measured water levels result in discharge in Aboru are used.

Extrapolated discharges by taking the exceedance probability of 80% range from 0,16 m^3/s to 0,92 m^3/s. Available streams with combined head between 20 to 33 m can produce up to 200 kW. As a result, Buru and Seram Island have some potential for MHPP. The overall result of the potential capacity is listed in **Table 4.1** that can be installed at ten locations in the Maluku region as shown in **Figure 4.6**.

Table 4.1 The 10 Potential Capacity in Maluku Islands

No	Discharge (m^3/s)	Head (m)	Potential capacity (kW)
1	0,920	27,4	148 - 198
2	0,595	22,4	78 - 105
3	0,395	24,9	58 - 77
4	0,475	20,3	57 - 76
5	0,250	31,3	46 - 61
6	0,255	27,7	42 - 55
7	0,320	21,1	40 - 53
8	0,180	35	37 - 49
9	0,300	20	35 - 47
10	0,160	32,9	31 - 41

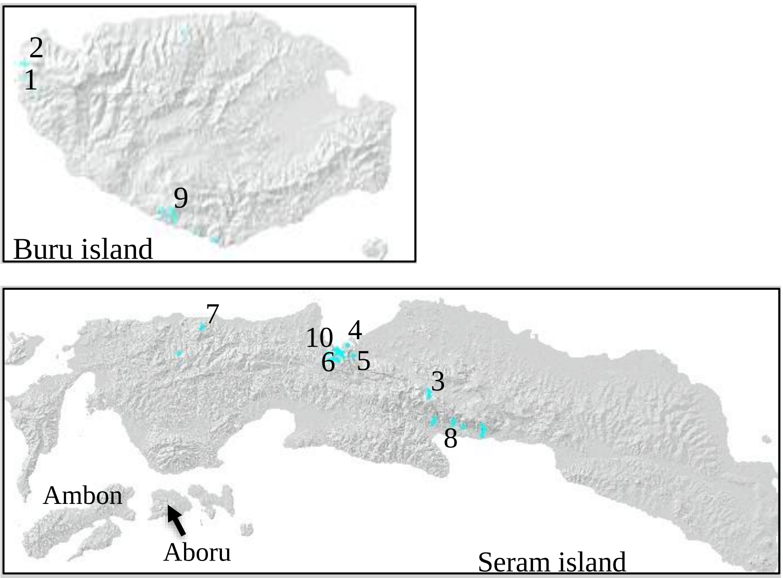


Figure 4.6 The locations of potential MHPP in Buru and Seram Island.

One often designs a MHPP with average monthly discharge. However, it would not always represent the daily discharge. Specifically, at the proposed location in Aboru village, the rainfall-runoff process is determined by a quick response. The discharge is reduced within days after a rainfall event. For a continuous annual operation of MHPP, it is suggested to take the minimum discharge during the dry season. For Aboru, a capacity of about 5 kW, in accordance to the local head (35 m) and discharge (0,02 m^3/s) would be the result. This means that Aboru village would be suited for a very small hydropower (pico-hydro) scheme.

To increase the capacity of the MHPP at Aboru village, two scenarios are possible. First, one could rely on the higher discharges during the wet season, which would offer the gain of a bigger capacity, but would also result in a shutdown of the MHPP for seven months during the dry period. It has been calculated roughly that the costs of building a bigger capacity of MHPP, for example a 50 kW MHPP, would cost about four times the cost of a 5 kW MHPP. Moreover, the gain in kWh per year of 50 kW MHPP is about three times the 5 kW MHPP in terms of economic there are trade-offs between the initial high investment, further costly maintenance, energy production and a potentially longer period of return rate. The second scenario is building a reservoir to assure water availability during the dry season. In this study area, those options were calculated, indicating a required reservoir volume of 10.000 cubic meter. Consequently, the total budget for constructing the overall MHPP would increase significantly, since the civil works usually contributes about 40% of the total construction cost.

4.5 Conclusion

It was shown that by combining remote sensing techniques and short-term field measurements, one could roughly estimate the potential for MHPP development in the Maluku Islands. By assuming homogeneous topography, drainage, soil properties, and geology, the discharges were extrapolated using the area ratio found in Aboru to other islands in the Maluku region. For one location in Aboru, the application of a DEM provided a low accuracy of the head. Thus, this DEM approach might not be ideal, but it gives first estimation on the potential head in the province, that needs follow-up in terms of a fieldwork per specific location. Ten locations in the Maluku region have been identified to have a potential of 30 to 200 kW, and specifically, Aboru itself has a potential of 5 kW. Other related factors were not considered, such as socio-economic ones. However, this approach provides a step forward towards follow-up surveys on related factors, to ensure that MHPP could be built to benefit local communities.

4.6 Outlook

To better estimate the potential of MHPP in Maluku Islands in the future, from the hydrological point of view, further study on discharge measurements is preferred. An option of extra discharge measurements in other basins on different islands could increase the confidence of spatial discharge responses. Different catchments with different types of geology, soil, and land use will result in different discharge responses. This would especially be valuable in areas with different rainfall patterns. In practice, to provide more accurate discharge data, the use of divers and constructing a flume at a small stream could be considered. Secondary data of maps of geology, soil, and land use would be beneficial for further analysis. Those data can be used for multiple regressions, where the discharge is set as the target. Moreover, a survey to integrate secondary data at other locations could result in a discharge classification of the Maluku region.

In terms of available head, details need to be investigated further by matching the DEM with actual conditions in the field. A rough topographical survey along other possible rivers can be conducted. Additionally, some issues regarding socio-economics matters would still be necessary to be investigated to check whether a MHPP can be implemented. These include issues like determining which village has priority, the possible high costs due to the remote location, where the infrastructure to the planned site is limited, etcetera. For our study area in Aboru, since the potential was found to be about 5 kW, a low-cost modular turbine could be used, as suggested by Alexander and Giddens (2008).

5 Human actions towards intervention and hydrological research

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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 small-scale hydrological intervention-based initiatives, effective hydrological research can be achieved.

5.1 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 nongovernmental 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 (compared 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-organized 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 behavior 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 it below.

Looking at 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 have even more difficulty gaining acceptance 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 contextualization, explanations, and patterns. As hydrologists who cannot be separated from the sociohydrological 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 analyze 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 Govardhan Das and Rao (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; Govardhan Das, 2003; Govardhan Das and Rao, 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. 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.

5.2 Three small-scale hydrological studies: learning from surprises

In 2007, contour trenches were dug in a semiarid area in Vietnam (see **Figure 2.1**). 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 trench area. In 2009, a complete set of these field measurements was made for a single wet season. Hydrus (2-D/3-D) 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 2 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 semiarid area in Amboseli, Kenya (see **Figure 3.1**); it was actually the experience in this region that created conditions for the Vietnam project). 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 the Maluku province, Indonesia (see **Figure 4.1**). 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 1 year were 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 40kW. 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 **Tables 5.1**–**5.3**. For our three cases (see **Table 5.4** for the timeframes), 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 cases. 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 nonparticipation 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 analyzing 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.

Table 5.1 Vietnam case (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 [no. 1]	Need of checks and maintenance	Loss of rainfall data series	October 2008
	Logger failed to record events [no. 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 [no. 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 [no. 4]	Perform manual measurement	Loss in groundwater level data series	December 2007
	Improper screen instalment for stable isotope sampling [no. 5]	Nothing	Possible misinterpretation of isotope signal	October 2007 & April 2009
	Construction before intervention [no. 6]	Extra costs for constructing new wells	A shift in location of intervention requires more measurements, thus more cost	October 2007-April 2009

(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 [no. 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

Table 5.2 Kenya case (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 [no. 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 [no. 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 [no. 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 [no. 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

(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

Table 5.3 Indonesia case (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 [no. 10]	Only counted on one logger	Loss of rainfall data series	July 2010-July2011
Install two divers	One logger failed to record events [no. 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

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

Table 5.4 The Duration of Hydrological Intervention-based Research Project

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

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 (see **Chapter 6** for results). 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.

Furthermore, 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 **Figure 5.1**. **Table 5.1** 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 (no. 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 **Figure 5.1**):

- 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 skeptical 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 analyzed 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 5.1**, on events labeled with "no."). For example, both in Vietnam and Kenya, access tubes (no. 3, no. 9A) were taken away. In Vietnam, the divers were taken away as well (no. 4). Next to human agency affecting the hydrological research, other events affected the research activities. In Vietnam, one rain gauge clogged (no. 1) because of fine sands from strong winds, and the screen of the observation wells (no. 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 (no. 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 (no. 2, no. 8, no. 10, no. 11) from tipping buckets and divers.

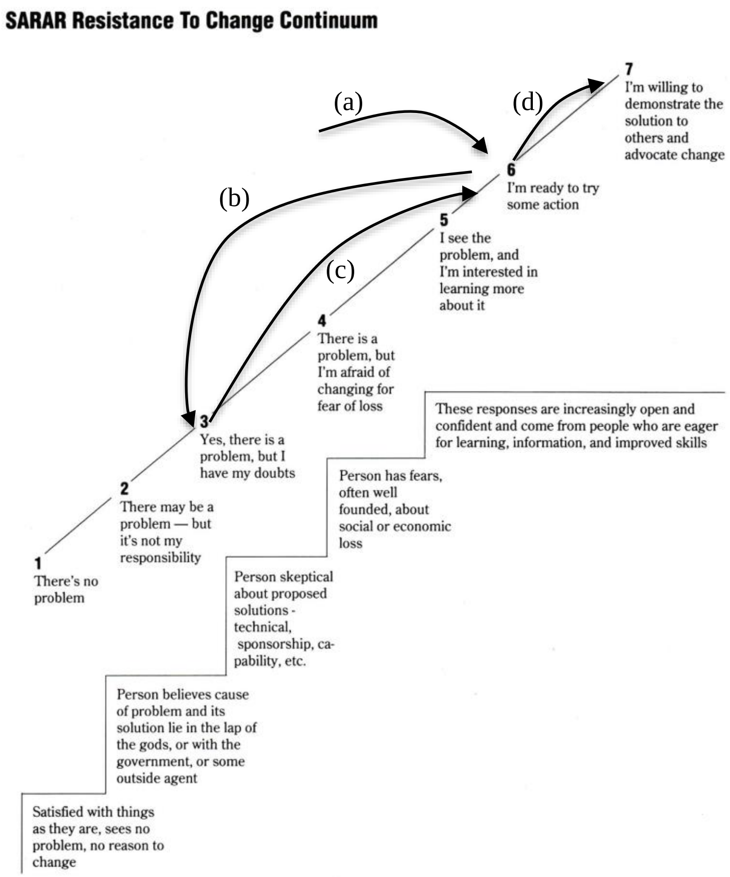


Figure 5.1 The implemented intervention based on the scale of community participation of Srinivasan (1990).

Within the context where intervention was done simultaneously with hydrological research – the Vietnam case (no. 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 analyzing 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.

5.3 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 the following:

A: extension of the measurement period;

B: additional samplings;

C: additional measurement devices;

D: additional analysis.

Options 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:

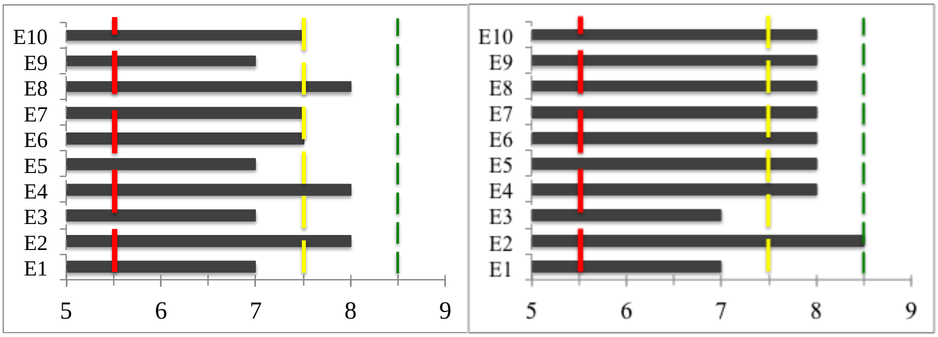
- Expenditures in our (fictitious) budgets are labor and financial costs, which are chosen in ranges of euros; (+-) is between EUR 0 and 50, (+) EUR 50–250, (++) EUR 250–750, and (+++) above EUR 750.
- Related research budget components like field personnel, transportation to the site, meals, and accommodation were not considered.
- A researcher was categorized as unpaid labor 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., hydrogeology, 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:

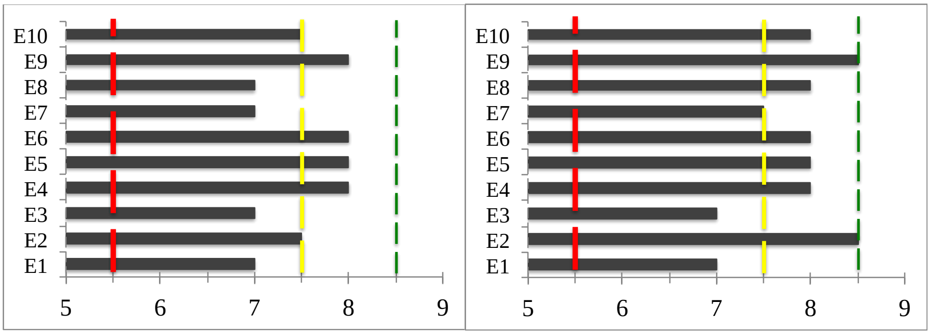
- 1–5.5 = little understanding of the relevant mechanism of intervention
- 6–7.5 = good understanding of the dominant mechanism of intervention
- 8–8.5 = better understanding of the dominant mechanism of intervention
- 9–10 = complete (full process) understanding of the mechanisms relevant for the intervention

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.

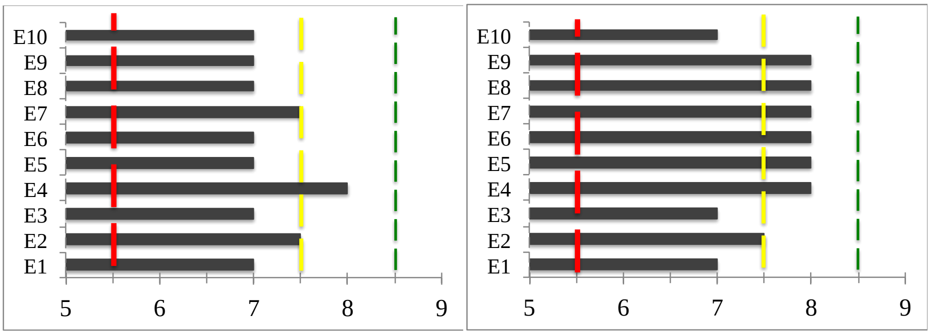
Even though this was a theoretical exercise and that it was not easy to provide clear-cut evidence for the scenarios to be realistic enough, results are useful. There may be many other options of optimization, such as cheaper measurement devices and modelling. Different research institutions prefer different measurement devices, or software developed by certain institutions. Research institutions might already own measurement devices and software, and 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 10 experts for their input and further analyzing 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 **Figure 5.2**. We discuss the Vietnam case in more detail.



The Vietnam Case



The Kenya Case



The Indonesia Case

Red dash line = grade 5,5
Yellow dash line = grade 7,5
Green dash line = grade 8,5
E = expert

Figure 5.2 Summary of three cases; on the left: Scenario 2, right: Scenario 3.

5.4 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 6.2**). 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 being 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 1 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 setups 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 6.3**) 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 6.4**), 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 behavior with and without the intervention structure.

The results of the interviews with the experts can be seen in **Tables A1-A.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, and thus might give more confidence. A very long data series, from 2 to about 10 years of groundwater level measurement would be very beneficial for better understanding the mechanism of the recharge.

In scenario 3, with an 80% increase in budget, the value of measurements points to similar results as in scenario 2, with some additional elements. A total of 80% of the experts say that 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.

5.5 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 2 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 the Maluku Islands ranges from 6 to 40kW. 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 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 vs. 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 **Figure 5.2**). 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.

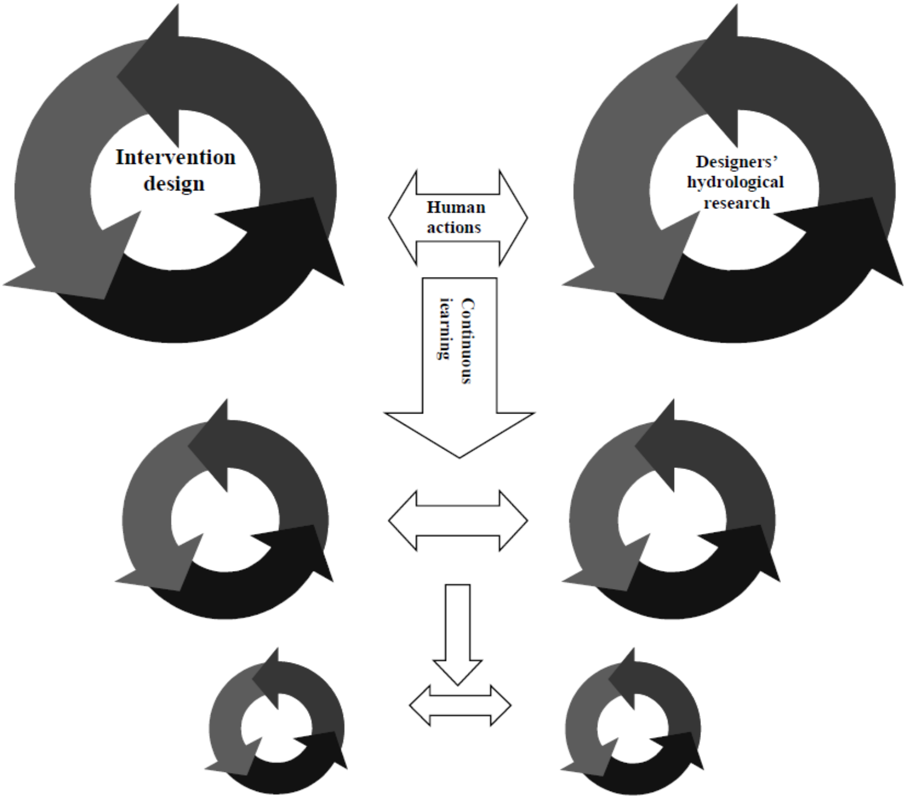


Figure 5.3 Designing hydrological field research in small-scale intervention (modified from Ertsen, 2002, and Scheer, 1996).

6 Evaluation and development of research scenarios

6.1 Introduction

The multi-method approach resulted in quite a good understanding of the interventions as explained in **Chapters 2** to **4**. During the process of combined hydrological research and intervention, the method had to be decided. Every shift in intervention planning influenced the positioning of the measurements. **Chapter 5** discussed development of the studies over time, in relation to the social context of the three projects (see more detail in **Annex B**). Also referring to **Chapter 5**, the uncertainties in terms of human actions towards interventions and hydrological field research influence the decision of a researcher on where and how to place measurement devices. As mentioned earlier, frameworks as developed by the RAND cooperation on how to be prepared when facing uncertainties in planning, can be useful for deciding how to deal with these issues in future research. This was discussed by Dewar (2002) through the Assumption-Based Planning (ABP, **Figure 6.1**).[1]

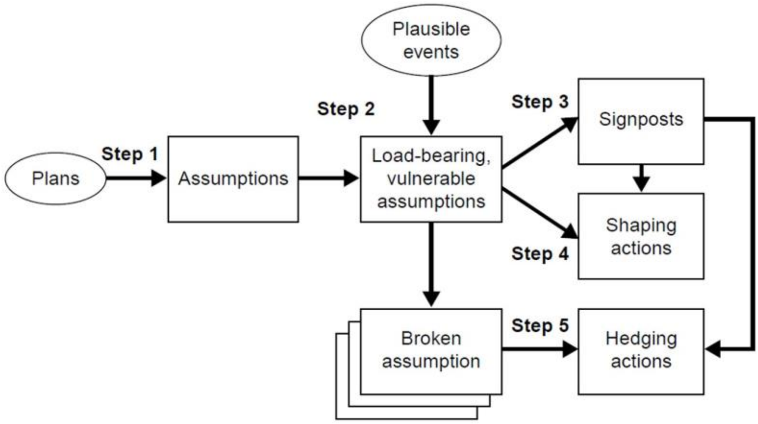


Figure 6.1 The basic steps of Assumption-Based Planning (Dewar, 2002, page 2).

[1] Parts of this chapter are included in Pramana and Ertsen (2016)

Box 1. A hydrological measurement campaign example of ABP

Someone plans for a measurement campaign on a small-scale intervention:
Step 1: Identify assumptions, e.g. availability of funding for the intervention and measurement campaign, local people activities, measurement devices, animals, etc.
Step 2: Identify assumptions of a plan that could potentially fail and "the most vulnerable" one e.g. the support of local people to the intervention or/and the measurement campaign, availability of the researcher to be present in the study area
Step 3 to 5 are dealing with potential surprises:
Step 3: Warning sign, e.g. a "no" response of the local people to intervention or/and measurement campaign, or if the local people (activities) can interfere, then more security for the measurement devices needs to be considered, or by negotiation
Step 4: To control as much as possible, e.g. meeting the local people and negotiate on the intervention and measurement campaign, checking and following up now and then the status of the intervention and measurement campaign.
Step 5: To prepare for the possibility that an assumption will fail, e.g. when the measurement device disappears, then a backup measurement device should be prepared, when the intervention plan is shifted then the timing of the installation of the measurement devices should be adjusted, etc.

When evaluating a hydrological research, in theory, the more parameters are analyzed, the more understanding one could achieve (see Silberstein, 2006). However, it is not easy to assess whether any amount of data collection is sufficient for a better understanding of the intervention. Long-term research is definitely worthwhile from a hydrological research point of view. New data, spatially and temporally, can always provide more information on how an intervention functions in the long run. However, looking at the situation when more time and budget would be available to continue the hydrological research does yield insights into one's measurement plan. In this chapter, the evaluation of hydrological research within a small-scale intervention context with its potential scenarios is discussed.

6.2 Material and methods

First, multi-method approaches per case study were evaluated, similar to "performance" in Blume et al. (2008), who analyzed the effectiveness of their measurements in understanding hydrological processes. This method is to search for maximum data from field measurements with minimum expenditures. Similarly, the attention here is to check the gain in understanding versus expenditure.

Second, cost-benefit analysis (Sassone, 1978) was used in research scenarios that were developed based on the Delphi method (Linstone and Turoff, 1975). A range of budgets was estimated 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. The judgments on the benefits were obtained from the interviews with water experts.

> **Box 2**. Delphi Method
>
> Delphi method is a method for structuring a group communication process so that the process is effective in allowing a group of individuals to deal with a complex problem. It originally came from RAND corporation in the 50s that tried to build a consensus of experts' feedbacks on how the Soviet military would attack the United States. Afterwards, Delphi method was widely used on many other topics with the same goal, to reach a consensus on a problem where inputs or data are difficult to obtain. It is a structured decision-making for complex problems and its application may consist of different models and variations. A typical model of Delphi method is an expert panel. At first, the panelists provide their inputs, which are further analyzed for the basis of the subsequent rounds. Then, panelists are given the second chance to revise or keep their judgements. More rounds can be performed to get closer to the consensus.

Third, an example in practice of including possible surprises is by frequently questioning oneself (see Bolt and Fonseca, 2001 - checklist examples of simple questions to better assess water availability and quality). Example of questions that might be raised during three different case studies of intervention and research are provided in **Sub-chapter 6.6**. More questions will emerge when a researcher conducts different interventions and researches in different areas. The local setting – community participation and financial constraints - will enforce a researcher to think about intervention and research as interacting and affecting each other.

6.3 Evaluation of the hydrological research

Table 6.1 summarizes the evaluation of the multi-method approaches in all three cases. First, in the Vietnam case, to understand the recharge process, eight parameters are analyzed. Rainfall is considered to be the source input for the catchment to calculate runoff. Given the irregular landscape, rainfall converted to runoff also yields irregular patterns of flow paths. Several flow paths directed to several trenches are the inputs for accumulated water in the trenches. The recharge quantity is determined roughly by estimating the volume of water retained in the trenches. Retained rainwater in the trenches is much more compared to natural recharge or areas without trenches.

Table 6.1 Evaluation of multi-method approach: gain versus expenditure

Vietnam case

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labor	Cost	
Rainfall	Tipping bucket	++	+	+-	+++	Clogging due to fine sand & logger
Soil moisture	TDR (with 8 access tubes)	+-	+-	++	+++	Prone to vandalism
Vertical flow path	Dye tracer	++	++	+-	+-	Destructive sampling
Soil physics	Lab analysis	++	++	+-	+	Point data, lack of deeper samples
Infiltration capacity	Inverse auger test	++	++	+-	+	Point data
Water level	Meter height reading	+++	+++	+-	+-	Point data
Groundwater level	Observation well (reached bedrock depth)	+++	+++	+	+++	Point data & divers prone to vandalism
Isotope tracer	Lab analysis	+++	++	+	+++	Short period of sampling

Notes:
(+) positive rating = greater gain

Kenyan case

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labor	Cost	
Rainfall	Tipping bucket	++	+	+	+++	Logger & removal
	TRMM (remote sensing)	++	++	-	-	Low resolution
Soil moisture	TDR (with 6 access tubes)	+-	+-	+++	+++	Point data & prone to vandalism
Soil physics	Lab analysis	++	++	+	+-	Sample composition
Greenness index	NDVI (remote sensing)	++	++	-	-	Low resolution
Erosion & sedimentation	Cs analysis	++	++	+	+++	Reference point

Notes:
(+) positive rating = greater gain

Indonesian case

Parameter	Method	Gain		Expenditure		Problems
		Process	Model	Labor	Cost	
Rainfall	Tipping bucket	++	++	+-	+++	Logger
Discharge	Velocity area	++	++	+-	+++	Logger
	Dilution gauging	++	++	+-	+-	Short measurement
Head	DEM (remote sensing)	++	++	-	-	Low resolution

Notes:
(+) positive rating = greater gain

The vertical flow paths at the bottom of the trench were checked using dye tracer. The dye signal was found to be close to the soil surface, suggesting a very slow infiltration process. To get initial soil moisture and porosity, soil samples were collected and analyzed. Inverse auger tests were conducted at several locations, from uphill to downhill in the study area, to estimate the hydraulic conductivity. These are essential to determine the range of hydraulic properties in the modelling part. The water levels in the trenches were measured after rainfall events. This parameter is of importance for initial fill in of the trench, although a small amount of ponded water might have infiltrated at first. Infiltration in trenches was slower due to sedimentation. In significant rainfall events, all trenches were fully filled with rainwater.

The bedrock depth provided the bottom boundary condition and groundwater level fluctuation was the most important parameter in the recharge assessment. It provided the understanding that water retained in the trenches recharged the groundwater system. The annual data implied quick recharge during the wet season. The stable isotope experiment aimed to confirm whether the rainfall signal could be found in the groundwater system. The signal was found with the hypothesis that recharge processes were through preferential flow, as generally water particles were slow in reaching the deep screen of the observation wells.

Second, in the Kenya case, to understand the impacts of trenches, four parameters were analyzed. Two rain gauges were installed close to the study area. One rain gauge in front of the *manyatta* was destroyed by elephants, and afterward removed by local people. The other one had a data logger that could not be retrieved. Thus, rainfall measurements were substituted with TRMM data. However, for a better clarification on rainfall, on site measurements need to be compared with TRMM data. Then, the uncertainty was found in the appropriate events that resulted in runoff, and thus ponding in the trenches. Runoff was estimated as generated on a bigger catchment in an unknown upstream part of the trenches. An empirical correlation between trenching and vegetation growth was determined by comparing the greenness index (NDVI) of the area with and without trenches. Furthermore, TRMM with NDVI were correlated to analyze possible effects of rainfall on vegetation growth. These two remote sensing analysis tasks required little cost due to the fact that the available remote sensing data were in low resolution and free of charge, but could provide an indication of long-term impacts. Soil moisture analysis would have indicated correlations with rainfall events and the impact of trenching. However, it could not be performed due to disappearance of tubes and difficulties getting labor. Local people seemed to prefer other work (easier to be conducted without the need for a long trip to the study area). Soil physics and cesium analysis were conducted to understand the sedimentation. The layering of sedimentation in the trenches could be explained in a qualitative way.

Third, in the Indonesia case, to understand the potential of micro-hydro, three parameters were analyzed. On small islands, high discharges were considered to be generated by high rainfall events. Rainfall measurements were used to check with data from a nearby meteorological station for long time series analysis. Subsequently, for measuring the discharge, two methods were conducted; velocity-area and dilution gauging. Both confirmed similar results for specific locations and time during the dry season. For the design of the micro-hydro installation, the required discharge varied around the minimum values. Information on the heads was needed to search for locations with high potential where DEM data were used.

Overall, in the three cases, not all measurements were successful. Thus, in situations where measurements were not successful, a complementary question is how to ensure the field campaign for continuous collection of long-term measurements. How to select locations for measurements and samplings? How to set up the measurement devices? How to ensure devices stay in place? How to ensure measurements are continuous? Those examples of questions would trigger a researcher to think how to adapt to the local conditions, as explained already partially in **Chapter 5**.

The above questions discuss implicitly the combined technical and social aspects in performing field campaign. Adding cost-benefit analysis would better inform a researcher to choose the “best” option. In the next paragraph, the results of developing scenarios for planning field research steps are presented.

6.4 Developing scenarios

6.4.1 The Vietnam case

To have sufficient understanding of groundwater recharge during the actual research, the expenses of the research budget could have been reduced to almost 60% (see **Table 6.2**). Rainfall measurement is necessary since it is used for the input of the model. The hydraulic properties of soil and infiltration test are also important. 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 being removed. Stable isotope tracers are excluded, because the constructed observation wells were not suitable for groundwater sampling. In addition, the cost for this analysis is considered expensive. On the other hand, stable isotope tracer is beneficial and will provide signals as long as the observation wells would be better constructed. A minimum of three observation wells is 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 rainwater.

Table 6.2 Scenario 1: to measure rainfall and groundwater level for a short period

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	40	+++	2,015
Soil physics	Lab analysis		+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading		+-		+-	15
Groundwater level	Observation well & diver (reached bedrock)	3	+	720	+++	5,533
			Total I	**760**	**Total II**	**7,876**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is less compared to the implemented one.
- Extra security cost for observation wells.

Even though the cost reduction is high, the conditions to apply these methods could remain uncertain. For example, when a researcher planned for scheduling the starting point of measurement at the beginning of a wet season, no one expected at first that negotiating with the local community was difficult. As it turned out, the local community was the one to decide whether the intervention could be built or continued. There had 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 is after one year. And if there is a tension to install the measurement devices for an analysis of a "with and without intervention", the location of the intervention might shift in time. Thus, new measurement setups have to be adjusted. These conditions will result in lost 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 could expand the implemented program by constructing one new observation well and its groundwater level measurements. In addition, the sampling period for stable 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 could 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.

Table 6.3 Scenario 2: to recheck the signal of recharge

Parameter	Method	Amount / Samples	Labor	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		+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading		+-		+-	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**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is estimated doubled to the implemented one.

In scenario 3, an 80% increased budget gives options for more applications and/or more advanced methods. Besides one new observation well and stable 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 ERT data, the hypotheses could be made more pronounced regarding the difference in groundwater behavior with and without the intervention structure.

Table 6.4 Scenario 3: to map the subsurface

Parameter	Method	Amount / Samples	Labor	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		+-		+	238
Infiltration capacity	Inversed auger test	8	+-		+	75
Water level	Meter height reading		+-		+-	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**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is estimated fourfold to the implemented one.
- The expenses for the labor to conduct ERT test is estimated to be 2.000 Euro

6.4.2 The Kenya case

The optimum budget for understanding vegetation growth and sedimentation distribution in the trench area can be reduced to 66% of the expenses during implementation. This reduction relates to the soil moisture measurement that had not worked. NDVI with rainfall data from satellite images would suffice for the analysis. On the other hand, ground data has to be collected to confirm the satellite images. The differences between the optimum budget with the implemented one is the fact that soil moisture measurement failed to be conducted due to low security and cooperation with the local community. More solid cooperation with local inhabitants at closer distance to the research area and having connection to electricity would have been beneficial, but could have been possible only with a much longer period of stay at the research area, resulting in increased costs. Thus, for the time being it is still difficult to estimate the cost of a sustainable soil moisture measurement since it was not realized yet.

Table 6.5 Scenario 1: to use remote sensing and soil data

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1,305
	Remote sensing		-		-	
Soil moisture	TDR (with access tubes)		+++		+++	
Soil physics	Lab analysis		+	40	+-	
Greenness index	Remote sensing analysis	128	+	100	+++	1,699
			Total I	**260**	**Total II**	**3,004**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is comparable to the implemented one.

In scenario 2, assuming that it would work in the past, one could extend the soil moisture measurements for another year, yielding more data, to include the impact of the dry and wet season. The total cost is dominantly in the soil moisture measurements since conducting it one time is expensive. Per measurement, first the caretaker needs to charge the device, which means the person has to have access to electricity. Furthermore, the study area is far from an electricity connection. Second, the caretaker needs to have skills in operating the device. Third, the transportation to travel to the research area is difficult to be arranged. Using a motorcycle would be the best option. However, local inhabitants who have a motorcycle in combination with skill and an electricity connection are rare.

Table 6.6 Scenario 2: to retry one year soil moisture measurement

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1,305
	Remote sensing		-		-	
Soil moisture	TDR (with access tubes)	6	+++	2,880	+++	4,990
Soil physics	Lab analysis		+	40	+-	
Greenness index	Remote sensing analysis		-		-	
Erosion & sedimentation	Cs analysis	128	+	100	+++	1,699
			Total I	**3,140**	**Total II**	**7,994**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is comparable to the implemented one. Only the labor cost of a year is required and monitoring runs smoothly.

In scenario 3, one could search for more and higher resolution NDVI images. For example, with a higher resolution pixel of 10 m (that would cost to about 700 Euro each), it is expected to gain more insight of the greenness at the 4 m wide trenches. To be selected are four images per year during three wet years. Thus, the total cost would be determined solely by higher resolution images.

Table 6.7 Scenario 3: to maximize retry one year soil moisture measurement

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+	120	+++	1,305
	Remote sensing		-		-	
Soil moisture	TDR (with access tubes)	6	+++	2,880	+++	4,990
Soil physics	Lab analysis		+	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**

Assumptions:
- Scenario 2 with additional higher spatial resolution imagery of particular wet years.

6.4.3 The Indonesia case

The optimum budget for understanding the discharge for potential micro-hydro installation can be reduced to about 57% of the expenses during implementation. This 57% cost is mainly the rainfall measurement. It is eliminated since the discharge is one of the significant parameters to come up with the potential of a micro-hydro installation, besides head or difference in elevation. A correlation of rainfall-discharge in this case goes more into the response of a catchment due to rainfall, which is less related to getting the potential of micro-hydro installation.

Table 6.8 Scenario 1: to extend one year discharge measurement

Scenario 1: to minimum measure discharge 1 year

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket		+-		+++	
Discharge	Velocity area (diver)	3	+-		+++	1,500
	Dilution gauging		+-		+-	25
Head	Remote sensing		-		-	
			Total I	**-**	**Total II**	**1,525**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is comparable to the implemented one.

In scenario 2, investigating discharge in another river is proposed. It would require two divers to be installed on a different island with different landscape and geology. The whole measurement would be similar to the implemented one. However, the location should first be investigated to check available locations. Not only should the location be very close to an area with big differences in elevation, but it should also be close to a village for a micro-hydro installation.

Table 6.9 Scenario 2: to investigate discharge of another river

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	50	+++	1,990
Discharge	Velocity area (diver)	5	+-		+++	2,500
	Dilution gauging		+-		+-	25
Head	Remote sensing analysis		-		-	
			Total I	**50**	**Total II**	**4,515**

Assumptions:
- The expenses (transportation and accomodation) for the researcher and labor to perform the research is comparable to the implemented one.

In scenario 3, 3 more discharge measurements on different islands are proposed. It is an extension of scenario 2. Transportation cost from island to island is considered to be low, thus not included in the proposed budget.

Table 6.10 Scenario 3: to investigate discharges of other rivers

Parameter	Method	Amount / Samples	Labor	In Euro	Cost	In Euro
Rainfall	Tipping bucket	2	+-	50	+++	1,990
Discharge	Velocity area (diver)	11	+-		+++	5,500
	Dilution gauging		+-		+-	25
Head	Remote sensing analysis		-		-	
			Total I	**50**	**Total II**	**7,515**

Assumptions:
- Scenario 2 with 3 discharge measurements at 3 other rivers.

6.5 Results and discussion

6.5.1 Comparing the three cases for Scenario 1

In estimating cost-efficient research, a simple reduction of costs was used in combination with the question of how much one could actually perform to get the same results. The magnitude of reduction cost among the three projects is different. This is due to the different starting points of the projects. In an existing intervention like in Kenya, the setup of the field campaign would be much easier than with interventions constructed during the project. On the other hand, in a simultaneous intervention and research, the research cost tends to increase, as extra investment is needed to ensure the actual performance of measurements. For future work in more or less similar cases, the planning should be critical to what could happen. Especially in the Vietnam case, besides the disappearing access tubes and divers, one needed to ask oneself whether a measurement location would be suitable or could be adjusted easily, because this was the problem. Shifting locations of the intervention resulted to adding new observation wells that were costly. For a moderate budget such as in Kenya, the problems were in the security of the access tubes and negotiations to conduct the soil moisture measurement. It happened to be difficult to get a local person with skills living close to the research area. In the end, only one short time series was achieved but the soil samplings and analysis were successful. For a low budget such as in Indonesia, the important thing is to measure the dominant parameter, which was the discharge. As a strategy, the cost would be used only for discharge measurement devices.

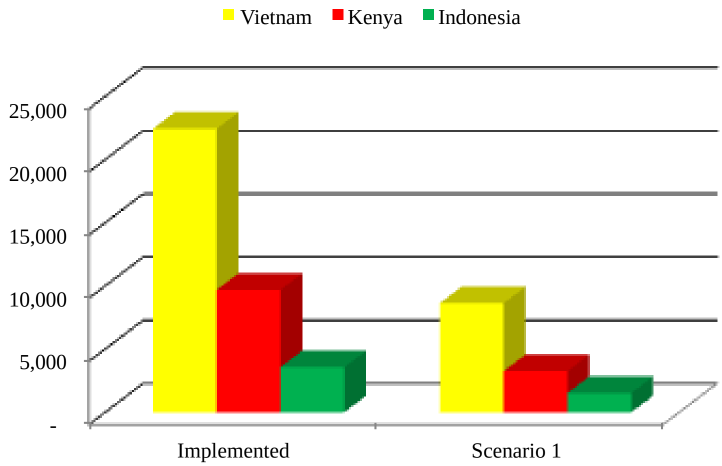


Figure 6.2 Result of research scenario budget for 3 case studies. (Y-axis is in Euro)

6.5.2 Comparing the three cases for Scenarios 2 and 3: the expert opinions

In **Scenario 2** or in a budget increase of 20%, the value of the planned measurements may direct to two results. One is that the understanding will be the same as gained by the author of this thesis and the other one would provide better understanding of the dominant mechanism of the intervention (see **Figure 5.2**).

The Vietnam case:

- 70% of the experts believe an additional well and a 1-year continuation of the groundwater level measurement, including stable isotope samplings and analysis, would result in similar understanding based on data collection compared to the implemented research. One expert also considered that extra data might even lead to confusion.
- On the other hand, another period of 1-year data can 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.

The Kenya case:

- 60% of the experts value the outcomes of additional soil moisture measurement, extension of rainfall and NDVI images as similar to the implemented research.
- The remaining 40% value the new soil moisture measurement could lead to additional understanding.

The Indonesia case:

- 90% of the experts think that the result of extending discharge measurement will not increase the understanding.
- However, one expert says new data matter, as measurements could be during very dry or very wet years.

Scenario 3 or in an 80% increase budget:

The Vietnam case:

- 80% of the experts say that ERT measurements could increase the understanding of the mechanism(s) of the recharge and provide more explanation on the disconnected groundwater system. Thus, it could confirm the groundwater profile and the groundwater level during recharge.
- In the performance of several times during dry and wet seasons, ERT performance is static, as it is a one-time measurement, and sometimes hard to be interpreted.

The Kenya case:

- 70% of the experts say adding higher resolution of 10-m might be sufficient to capture the 4-m wide trenches. The images could be of importance to see probable constant greenness signal.

The Indonesia case:

- A micro-hydro installation usually requires a minimum annual discharge. Therefore, a long-term discharge time series will have to be used for discharge statistics.
- 60% of the experts believe that more discharge measurements at different locations with different soil types, geology, and land uses, could improve our understanding, especially the discharge response of different catchment on different islands.

By comparing Scenario 2 and 3, a research plan with 20% increased funding is more likely to obtain similar understanding as the current research result, which means certain expenses could be saved. An 80% increase in funding may result in a better understanding but realizing the costly research plan for a small-scale intervention project may not be economically feasible, and thus impossible to be implemented.

6.6 Examples of questioning oneself in response to possible actions

Questioning oneself is part of being prepared during planning and implementation of a monitoring campaign. It reminds a researcher to acknowledge losses of measurement devices (thus data) in the field. However, this does not guide a researcher to ensure his/her plan to work accordingly, but more to being able to adjust when required a monitoring campaign in hydrological small-scale intervention research.

Based on the experiences in the three case studies, examples of questions are divided in two perspectives - the hydrological research and intervention. As a researcher, it is crucial to question oneself during the development of intervention in relation to the spatial and temporal aspects of the associated hydrological research.

- *Have we told the local community about our measurement proposal? Will the local community accept it when we perform it in their area? Is the local community aware of the hydrological research and supportive?*

  These questions are commonly raised at the beginning of a hydrological research where the focus is to introduce the research to a local community. The idea is to remember once a researcher enters the study area, he/she needs to be recognized by the local community. A lack of direct communication between the researcher and the local community may lead to unexpected events and even a conflict. Practically, one way to establish a good cooperation with the local community is by having meals and/or drinks together.

  In the Vietnam and Kenya case, the connection between the local community and the researcher relied on a local person. The local person bridged the research by introducing the researcher and the scope of research to the local community, which may vary in different culture. This socialization is part of the researchers' activities to secure the measurement devices.

- *What rain gauge would be suitable to this area? Will this measurement device work properly under the local climate condition?*

  This question can be made broader to any measurement device. Specifically, in the Vietnam case, it refers to the condition when fine sand blocked the funnel of the tipping bucket. Thus, data were lost for one wet season. It could have been avoided if one could maintain the rain gauge by regularly checking and cleaning up the funnel.

  A selection of another type of rain gauge is an option. The rain gauge should be more suitable for certain local climate condition. Thus, a preliminary study on local conditions is crucial.

In the Kenya case, two rain gauges were placed in two *manyatta*. After about two years, both devices did not provide any data; one rain gauge at the location where it was initially set up was removed because the elephants destroyed it and the other one had a technical problem. The latter issue also occurred in the Indonesia case, where at the end only one rainfall measurement series was used.

- *What type of device would suit to measure soil moisture?*

  Both in Vietnam and Kenya case, it was difficult to manage the soil moisture measurements, as the access tubes disappeared. Perhaps the attractive look and the ease of pulling out the tubes from the soil made some people eager to own them. Only one tube was found back nearby the study area. Perhaps building a small concrete structure could hold the tubes, but this would disturb the infiltration mechanism in the area surrounding the tube. Thus, a permanent construction of the tubes would disrupt the infiltration.

  To change the soil moisture devices was also an option, such as burying sensors in the soil. Although it was not implemented, as long as local people find that attractive, sensors would be likely to vanish too.

- *Where and how should we construct an observation well, including the placement of the diver?*

  In the Vietnam case, constructing observation wells before the intervention resulted in additional costs for the entire research. New observation wells had to be constructed at the final contour trenching area. However, this reminds us of a situation where a researcher needed to make a decision based on his/her original research plan and has to update his/her information based on the development of the intervention. Thus, by knowing the exact location of the intervention, one could have constructed the observation wells accordingly.

  The divers were problems as well. At first, a secured observation well was not easy to make. Having it in someone's yard was preferable. However, in location where there were no inhabitants or in an open public space, the observation wells should have been locked properly. First, we used a padlock, which was apparently not secure enough. Local people could still break down the padlock. Then a modified seal on the top of the well was required, which made the padlock covered by an iron plate.

  During the investigation of recharge using isotope tracer methods, the well screen was not properly constructed. The screen should have been set from near the soil surface to close to the bedrock.

- *How can we make a backup of our measurement?*

  Even though we used automatic measurement devices, it was not guaranteed that data could be downloaded easily. We experienced data failure - loggers for rainfall and divers, blocked rain gauge, and divers disappearing. In addition, two rain gauges, uphill and downhill or two divers were not sufficient. Thus, manual measurements were made from local material - for rainfall measurement using plastic buckets and for groundwater level measurement using electric cables with Ammeters. The cost of making a local rain gauge was much cheaper than the cost for performing the measurement itself. In the long run, manual measurements require labor budget, which was very important to ensure the availability and continuation of data.

- *How to deal with (local) labor to conduct the measurements?*

  Negotiating the price for labor to conduct measurements is sometimes easy, but can also be frustrating. We have to weigh the best price for conducting the measurement based on the research budget. An advantage would be when the researcher originates from the country where intervention and research take place. In the Indonesia case, there were hardly difficulties due to labor since communication and cooperation were well established.

  In the Kenya case, the problem lied on the long negotiation on payments to conduct soil moisture measurements, whereas finding labor was already difficult. The manual for conducting measurements and the process of downloading data were demonstrated during the fieldwork. In addition, when to perform the measurements including the required skills of the labor were agreed. Other issues were the availability of electricity to recharge the measurement devices and the means of transportation to the study area. Unfortunately, these issues could not be settled during the negotiation and thus yielded lack of data.

- *How to secure a measurement device in the field?*

  This general question directs us to secure in practice any measurement device. We could think of a few solutions that suit to the local situation, e.g. hiding, modifying, to secure the measurement devices with socio-economic approaches.

Examples of questions to criticize the intervention process are as follow. These questions concern the implementation of interventions and are inputs for the initiator, where a researcher could be of help to ensure successful implementation of intervention.

- *How can we explain the intervention in a way that local people would accept it? How do we convince local people that the intervention benefits them? What type of intervention do local people prefer?*

  In the Vietnam case, contour trenching was new to that particular community. At the beginning, the community responded differently during the presentation of the intervention. Many doubted the success of the intervention and thus at first no one wanted to have this type of intervention. After several discussions, the initiator approached a monk's organization that lead to an agreement to implement the trenches. However, after the first phase of construction, the trenches were not accepted anymore by the monk's organization due to the large dimension of the trenches.

  A following question could be "*do the local people need to see an example of the real intervention?*" It might be a good idea to construct an example of the trench with its actual dimension and show it to the community. As such, early mobilization of heavy equipment would then be required, which could result in extra costs during the construction phase. Since we were informed that the design was not acceptable, we needed to postpone the construction of the trenches and had to approach the community differently. However, in the future showing a real example would actually be better even though the risk of more costs is foreseen. Frequently, local preference on intervention differs from the initiator. Therefore, the intervention should accommodate local peoples' preferences.

- *How can we know the definitive location of the intervention?*

  Expanding the previous question, it directs to the spatial uncertainty of the intervention location. It would still be unknown until an agreement is reached. Sometimes it depends on the willingness of local people. In a society where land is owned individually, it is the decision of the owner to provide land for interventions.

  This question implicitly links to the temporal conditions of data collection related to the research. Delaying the implementation of the intervention may result in loss of seasonal data.

  For the Kenya case, since it was only possible to trace roughly the intervention stages, the question would be to what stage research is essential. Thus, in the analysis, the impact of development needs to be taken into account.

- *What if the intervention could not be constructed?*

  This question emerged in the Indonesia case. It relates to social conditions and how end users might question the initiator. The construction of the intervention may contribute to the economic benefit of the local community. The local community would like to have the intervention, but the initiator could cancel it due to lack of funding. For a researcher, staying for a longer period at the site, there could be questions by the community why the intervention was not yet constructed. This situation could increase tensions between the initiator (including the researcher) and the end users.

In small-scale hydrological intervention-based research, frequently questioning (including answering) can minimize the surprises in research. Not only can budget and time made more effective, but also assistance of local people in research will lead to a success. Local people may benefit and gain knowledge of the intervention and hydrological research. Once a researcher conducts different studies in different areas, the scope of questions in the hydrological research and intervention mentioned above may be broadened. Thus, the intervention to be studied will have its own local challenges. In the end, those conditions will raise other important questions that need to be considered.

6.7 Conclusion

The first element to be essential in small-scale intervention project is the research budget itself. Also, everyone always expects good results in their hydrological research. We know that for small-scale interventions, the research budget is usually limited. Therefore, evaluating the costs of the method to investigate the underlying mechanism of the dominant process of intervention and frequently questioning is key. It suggests further that surprises during intervention and field research may limit the result of on-site measurements. Developing scenarios that include cost-benefit analysis could be a useful approach to ensure the best use of the research budget. Thinking of scenarios for field campaigns and analysis that could answer the research question, based on a specific research objective, offers multiple options for field research. Then, proposing those options to several water experts and let them give their opinions, allows evaluating the research plan and comparing the research expenses with possible outcomes. In the end, being alert of possible loss of measurement devices and shifting intervention location by frequently questioning oneself, including the cost-benefit analysis with expert opinions, are a matter of decision to be made by a researcher. However, there is a choice to be made for effective research by thinking about this issue systematically.

7 Revisit hydrological measurement and modelling in the Vietnam case

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In the first decade of the 21st century, a water harvesting approach based on contour trenches—ditches to catch runoff—from Kenya was proposed as groundwater recharge technology in a semi-arid area in Ninh Phuoc district, Vietnam. In order to modify this solutions to tackle water scarcity, hydrological conditions at the site needed to be known. For such small-scale interventions, finding the most suitable set of (cheap and quick) efforts to study local hydrology is not easy. After our own study, we explored how different experts evaluated the chosen approach. The results from this evaluation suggest that different perspective for appropriate hydrological research can be found within a group of experts. This finding—in line with anthropologically inspired science studies—suggests that integrating different perspectives from stakeholders when working on suitable solutions in real-life water scarcity situations needs to be complemented with attention for different perspectives on the underlying hydrological processes and how they are to be studied. We discuss how this notion on the multiple perspectives intrinsic to hydrological research can be fruitfully included when developing water interventions.

7.1 Introduction

The river Rhine saw its water quality problems increase dramatically in the late 19th century, caused by industrialization and subsequent dumping of wastewater in the Rhine and its tributaries. In the early 1930s, due to high concentrations of phenol and potential high salinity levels, Dutch drinking water companies established contacts with upstream riparian states (Disco 2007). In July 1950, Germany, France, Luxemburg, the Netherlands and Switzerland founded the International Commission for the Protection of the Rhine. Next to recommend water protection measures, an international monitoring network was also a key activity. Soon, it proved to be necessary to improve the comparability of analysis results, as measurement and analysis methods differed in the participating countries. Apparently, the French and German monitoring campaigns, although taking samples from the same location (albeit from different banks), found different values of the same chemical components in the Rhine water. In other words, the German measurements produced another (perspective on) Rhine water quality compared to the French efforts. Once this was recognized, a common basis for shared assessment of the water quality in the Rhine became an important topic for further exchange of measurement techniques and data.

We decided to start with a river – the Rhine – that may not be a river associated with water scarcity, even though it is expected to become an issue in this basin as well more often in the future, for two reasons. The first reason is what matters when considering water scarcity. The notion that water scarcity refers to inadequate availability of water is more often than not associated with water quantity. This in itself is not strange, as indeed the amount of water being available is a key determining factor for many socio-economic activities. Our main case study in this paper does also engage with an intervention to increase the amount of water available in a relatively dry area of Vietnam. However, water availability is also seriously affected by issues related to water quality, as water resources might not be useable due to specific compounds in the water (see Van Vliet et al (2017) and Zheng et al (2013)). Sivapalan and Blöschl (2015) show an example how river water quality is much more valued than before. Especially in more urbanized areas, it can be observed that water quantity and water quality issues go hand in hand – with both water quality and quantity becoming serious issues in drier seasons and years as well, as is also clear in the Rhine basin. Apart from allowing us to start a paper on water availability with an example of river water quality, this expansion of water quality as an aspect of water scarcity would also mean that what we argue in this paper can be expanded to many other situations. We provide one additional example related to water quality and scarcity towards the end of this paper, as this example allows us to build upon our main argument.

This main argument is the second reason why we started with the Rhine narrative – it does offer a very useful example of the argument we aim to develop in this paper. Our main suggestion in this paper is that co-design of water-related interventions and research by different stakeholders from academia and society builds on negotiations on what counts as realistic perspectives of both interventions and hydrology. This means, as we continue building our main argument, that such negotiations create more than the intervention: interventions create the hydrological research itself – and thus principally the science of hydrology – as well. As such, we argue that stakeholder involvement – the seeking of partnerships in the process of (studying) hydrological change in interventions – affects knowledge, attitudes and behavior of all participants in a project's network. Hydrological scientists learn as much as the stakeholders about hydrology. Such an image is an important correction of the standard image that water-related interventions are based on fixed (hydrological and water resources) knowledge systems that researchers simply need to communicate to the other stakeholders (Ertsen, 2002; see Poolman (2011) for more discussion on stakeholder participation in small-scale water initiatives).

Next to developing this argument in detail, using one case study, we propose ways to incorporate our more theoretical notions to practices in which interventions and hydrology – or policy and science in general terms – are linked. This paper discusses in detail one setting in Vietnam to show how different perspectives on hydrological aspects of contour trenching (could) have had immediate impact on the hydrological field work itself. In our own field and model study, we made specific choices – with good reasons, but leading to a certain perspective of the local hydrology. Afterwards, as explained in Pramana and Ertsen (2016), our experts came up with different suggestions for field and model studies – and thus potentially other hydrologies of the same setting. As such, we provide an example of interdisciplinary water research dealing with the structure of and consequences for hydrological knowledge claims. After positioning our argument further, we expand on the hydrological study at stake, to discuss how our own work was influenced and created by our own knowledge claims and by interventions from others. Then, we will specify the knowledge claims from other experts can be understood, which is followed by a more conceptual discussion on knowledge-related perspectives. The general recommendations that result from this discussion are translated in one example – based on our current joint research effort.

7.2 Positioning

Whether discussing water quantity or quality, it is clear that a more complete understanding of such issues requires building relations between different academic disciplines, and between academic and other practices. Given that humans change landscapes through interventions for many purposes due to human demands (Ehret et al., 2014), for example interventions to deal with water scarcity in agriculture (Pachpute et al., 2009) or sand dams for subsurface storage (Lasage et al., 2008), human agency is continuously changing present and future water systems and hydrological processes, which means we need to build deeper understanding of human-water dynamics (Sivapalan et al., 2014; Ertsen et al., 2014). Within this emerging interdisciplinary field (now usually labelled as socio-hydrology), our earlier work suggested a systematic approach how to include explicit recognition of human actions in the development of water interventions and its associated hydrological research, in the planning of such research (Pramana and Ertsen, 2016). Based on our field studies, we suggested the usefulness of considering a range of possible actions by human agents related to the intervention (like moving a monitoring station that is seen as a nuisance) and their effect on hydrological research (like lower amounts of data) – which we labelled as unexpected surprises and possible actions. We proposed a cost–benefit analysis in terms of gains of knowledge versus costs of research, to plan hydrological field work that includes possible surprises in the process of doing this field work.

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). The relevance to look at the interactions between humans (as initiator and/or stakeholder of intervention and/or research itself) and the hydrological system has been recognized more and more within the hydrological community. Apart from the academic interests in socio-hydrology, the recent contribution by Rangecroft et al. (2021) suggests that interdisciplinary water research should be conducted during fieldwork and provides several examples of good practices. These examples offer insights on why stakeholders make choices, and how building connections between different stakeholders and specialist can be arranged – including suggestions how (knowledge and methods of) social scientists can be incorporated by hydrologists in water-related studies (see also Law and Mol (2008)).

Indeed, in order to design more successful interventions, building on a wider knowledge base beyond hydrology, makes sense. Having said that and using one of our three case studies from Pramana and Ertsen (2016), in this paper we expand on both Rangecroft et al. (2021) and on our own original argument. We mobilize the social sciences (and humanities for that matter) in an additional way to clarify an important observation that we already discussed in Pramana and Ertsen (2016). When asked what would be the more suitable measurement techniques to be applied to study certain hydrological processes, our hydrological experts did not fully agree with each other. Without suggesting that this is a strange finding – or even a problem – such different claims on what and how to measure, when used to design a field campaign, could very well result in different data sets from the same setting. Different data create different settings – and as such hydrological reality. We do not aim to make our reasoning more theoretical than necessary – as we want to suggest practical approaches to deal with diversities of opinions in hydrological studies – but it is worth noting that different data would indeed create different versions of that setting, as they did in the Rhine. One researcher would tell another story about a situation than another researcher from the same discipline might tell.

This reasoning is in line with well-known anthropological work on scientific studies like Latour (1987) who shows that the notion of an objective external reality solving issues between scientists is problematic, as the daily activities of those scientists show how they create that same external reality. In Mol (2002), we discover how the different practices within the same hospital create their own version of “the disease” arteriosclerosis. Mol concludes that in the different daily practices in the hospital, different diseases are being created and used to guide those practices. Both Latour and Mol do not suggest at all that these different perspectives of what is typically seen as one “real” setting is a problem. That different perspectives on what counts as “good” or “useful” knowledge can be (seen as) problematic, however, is illustrated by Junier (2017) who shows that the question whose version of specific causal relations is included in hydrological models goes beyond mere practical issues. All three studies we referred to are firmly based in the humanities, but it is important to note that they are as much based on extensive field work as many of the studies that build the field of hydrology. Our three studies simply argue that daily practices by researchers and academically trained practitioners are built on different interpretations of the issues of relevance for those practices. We have recognized this notion in our own work and would like to explore in this paper with the aim of providing suggestions to the discipline how to use this notion as productively as the ones already provided by other recent work on mobilizing insights from other fields in hydrological studies. For this, we move to Vietnam.

7.3 Contour trenches in Vietnam

In **Chapter 5** and **6**, the Vietnam case has been discussed in terms of the more detailed hydrological measurement and modelling approaches and results. Based on these, we discussed how scenarios on the hydrological research can be developed further for a better understanding of the hydrological impact of contour trenches. Even more details can be found in Pramana (forthcoming). In this paper, we will present the actors and on how the project went in terms of the intervention and its associated hydrological research. Having a broader picture on the sequence of the process of intervention and research allows us to consider our options and thus choices we made. This intervention and research project was conducted by a Dutch consortium consisting of a consultancy company (Royal Haskoning/RH), two research institutions (UNESCO-IHE Delft/IHE and TU Delft), one non-governmental organization (Westerveld Conservation Trust/WCT), in close collaboration with a Vietnamese governmental agency, the Department of Natural Resources and Environment (DONRE) and the local community. WCT and RH were the initiator of the idea to apply contour trenches in the area. The local community participated in the decision-making of both intervention and research.

7.3.1 The project

The idea to use contour trenching to harvest runoff water and infiltrate it to feed groundwater in Vietnam originated from Amboseli, Kenya, where the approach was developed and implemented by WCT in 2002. In 2007, the same technique was introduced to a small Vietnamese community in Phuoc Nam, Ninh Phuoc district. Between January and August 2007, the contour trenching concept was presented to the local community. Photos, drawings, and slideshow presentations were used. Two main impacts were foreseen to result from the intervention: subsurface water storage and increased vegetation growth. These impacts were discussed between the initiators, governmental authority, and the local community. In line with the original Kenyan project, the proposed contour trenches were 4 meters wide and 1 meter deep, with almost vertical side walls (see **Figure B.1**, left side). The distance between the trenches was set at about 36 m. At the beginning, 97 hectares of potential area for contour trenching was identified. However, as detailed in Pramana and Ertsen (2016), at the end of the intervention period, due to limited landowner’s will and permission, the trenched area was much less – namely 22 ha.

In October 2007, a first agreement between the local community and the initiators to implement contour trenches was reached. A monks’ organization provided its land to be utilized, providing about 8 ha (Pilot Area 1). The area was uncultivated land, generally covered by small bushes, cactus and erosion gullies. Random cattle, owned by surrounding pastoralists walked freely in this area. As planned, this first stage of construction resulted in (seven) trenches with a width of 4 m (intervention A, see **Figure B.2**) and different lengths being constructed along the contours. The trenches themselves were dug using an excavator. The excavated soil was placed downhill of the trenches; a bulldozer evenly distributed and afterward compacted the soil deposits. About five ha of the total area were covered with this type of trenches, when in March 2008, the initiators and the monks’ organization evaluated the contour trench design. Even though the trench dimension had been discussed several times before the construction, the monks’ organization was unhappy with the trenches being rather wide and deep. A meeting to discuss this issue was set up. All parties in the consortium gathered for lunch at the monks’ temple. It was clear that the monks did not like the trenched area: the trenches were too big. Perhaps surprising, safety (livestock could perhaps fall into the trench) was not an issue. Nevertheless, as a result, the monks refused to continue with any type of intervention on their remaining land. Hence, the construction plan of Pilot Area 1 had to be stopped.

In April 2008, RH approached other landowners with plans for smaller contour trenches, with the expectation that construction of trenches could be continued. The new trenches would have a bed width of 1 m with a top width of 2,5 m and side slopes of 1:1. The depth was 0,75 meter ((intervention B1, see Figure 1 (right)). The distance between the trenches was reduced to 25 m. In May 2008, one of the farmers in the area agreed that the design would be more esthetic. He provided about 1 ha of his land (Pilot Area 2) for the smaller contour trenches. Hence, RH constructed five contour trenches, with different lengths along the contour. In August 2008, after the monks’ organization saw the result of Pilot Area 2, the monks indicated interest in the smaller trenches being implemented on their remaining land as well. As a result, six smaller trenches were constructed at the remaining land of Pilot Area 1 (intervention B2). Progressively, other landowners next to Pilot Area 2 requested the same trench design to be constructed on their land. In October 2008, the implementation of the big and small trenches yielded an area of 22 hectares in total.

7.3.2 The hydrological research

In October 2007, before the construction of the actual trenches had started, a setup for a field campaign was discussed and introduced – including rainfall, soil moisture, surface water, and groundwater level measurements. Two rain gauges were sited at two different locations, uphill and downhill from the planned intervention area. Six access tubes were placed inside the trench area, and two were placed outside the trench area. Surface water measurements, using a diver, started at the location of an existing reservoir, close to the planned intervention area, monitoring inflows into the reservoir. The groundwater level measurements were established by constructing three observation wells, uphill and downhill the planned intervention area, which used divers too. The setup of hydrological research and spatial development of contour trenching can be seen in **Figures B.2** and **B.3**. More detail is provided below.

During the measurement period, however, the installed measurement devices had to be modified and adjusted. Two automatic rain gauges that had been placed at the roofs of local residences were clogged due to accumulated fine sand blown by the strong wind during the dry season. Fine sand was trapped in the rain gauge funnel, blocking rainwater to enter the tipping bucket. Thus, during the second wet season, loss of data occurred. In addition, the data logger fail when downloading data. Soil measurement with access tubes seemed to attract the local people, possibly because of the appearance above the soil surface. In any case, the tubes were taken out from the soil at the measurement locations. The diver at the reservoir and two divers from the three observation wells disappeared as well. These divers (both at the reservoir and observation wells) had been placed in an open area and could easily be reached. In addition, there was no secure installation for the divers, for example by using a strong padlock or installing them at isolated or private areas owned by a farmer. Only one observation well was constructed in a local farmers' yard close to the trench area. After the loss of three divers, observation wells were equipped with stronger padlocks. Furthermore, observation wells without divers were measured using local materials, with an Am-meter connected to a long electric cable, attached to an iron stick at its end. When the iron stick touched the water table, it would transmit an obvious current signal. A monk conducted these manual measurements during almost three years.

Although during the drafting of the research plan, the risk in failing to obtain a signal from infiltrated water was recognized, the observation well screen was installed close to the bedrock, which made it difficult to find the isotope signal of recharge in all wells. Nevertheless, stable isotope samples were still collected and analyzed. Fortunately, one of the upstream groundwater samples did contain the signal of rainwater. Locations to measure groundwater levels were added too during the field period. Since the contour trenching shifted from its original location plan to locations where community members agreed their land to be trenched, the measurement locations needed to be adjusted too. Thus, four new observation wells were constructed to investigate the recharge impacts inside the trench area.

7.3.3 Developing relevant small-scale hydrology

To study the hydrological impact of contour trenching – or, in other words, to construct a useful local hydrology – we selected several devices and approaches.

- Our two rain gauges (Casella tipping bucket, resolution 0,2 mm, Bedford, UK) had been suggested by our partner from IHE. As already mentioned earlier, after negotiation with the local people, one rain gauge was installed on the roof of a building at a temple located uphill about 150 m from the study area, the other one was installed on the roof of a farmhouse located about 2 km downstream from the study area. The experience of clogged automated rain gauges, made us add a manual rain gauge, which was set next to the first automated rain gauge.
- To examine the impact of contour trenching on soil moisture in the unsaturated zone, we used a Time Domain Reflectometry (TDR) probe with access tubes. With the help of a local person, we installed the access tubes at locations in and one outside the trench, as well as in areas with and without the trenches.
- The water level in the trench during water accumulation in the wet season was measured to estimate the flux of the recharge. We then applied the water level and soil moisture measurements as inputs and calibration parameters in the modelling. Furthermore, we investigated the influence of the water level in the trench to the fluctuation of the groundwater.
- The groundwater levels were measured with divers (Schlumberger Water Services), based on the recommendation of our partner from IHE. After the loss of two divers in two different observation wells, groundwater level measurements were done manually on a 3 to 4-day basis. We asked and negotiated with a local person to assist us further with the measurements.
- Given the availability of a spectrometer at the Isotope Laboratory of TU Delft, we initiated and conducted isotope analysis as well. Water samples – rainwater, ponded water in the trench, and groundwater – were taken from the field and analyzed in Delft.
- In the modelling part, we used Hydrus (2D/3D) for two reasons. First, the focus was on a combination of infiltration in the unsaturated and recharge in the saturated zone. Measurements in the unsaturated zone were limited, and modelling was selected to see how surface and groundwater could be connected. Second, fine sediment was trapped in the trenches, especially the first uphill one. After several events, a few cm of clay accumulated. This layer was included in the model domain to see its effect on

flow directions, as growing influence of sedimentation is to be expected over the years.

Pursuing our research with the above setting, measurements and interventions were (co-) shaped on a particular moment. Observing local community members and how they reacted, stimulated different thinking and actions in the project consortium. Meanwhile, being confronted with the actions and ideas of others required an understanding of the processes involved in the intervention-based research itself. We perceived or observed the situation concerning measurements of small-scale intervention and re-interpreted both the measurement devices and the location of the intervention. The measurements demanded an effort from us to produce ideas on the relevant hydrological reality due to the loss of measurement devices and shifting intervention. Measurements remained limited, but modelling required measured data. Our modelling had to be performed with data from the research period. In line with Beven (2018), who suggested that modelling a hydrological system should preferably use both hydrological and tracer response information, we combined Hydrus (2D/3D) with isotope tracer data. However, our result showed a non-agreement on water flow paths to the subsurface between our modelling and the groundwater level data we had. This may have been partially due to having the geological conditions of the study area only available in qualitative format (compare with “soft data”; compare with Epting et al., 2009).

7.4 Experts defining relevant small-scale hydrology

In relation with how experts would deal with the same Vietnam case, **Chapter 5** and **6** provided a step-by-step survey interviewing 10 experts to gain their perspectives. As a theoretical exercise (in the sense that the suggestions would not be applied), the survey asked for experts’ judgements and grading of three scenarios. In the first scenario, experts valued the existing research results. This was followed by the second and third, to receive the experts’ opinions on proposed extensions of the hydrological research and related budgets. At the end, experts were also given the chance to suggest any other methods they would propose to gain better understanding. The initial objective was to study these expert opinions in terms of costs and benefits, given the limited budgets and the possible gains in understanding the intervention. Our focus in this paper – based on the same results – is to discuss similarities or differences in perspectives on hydrological research within a community of experts. When our experts were requested to score the existing measurements (**Table A.1**), they generally agreed that the measurements and results provided a basic understanding of the hydrological processes of the contour trenches. However, several remarks, comments, and ideas emerged when discussing the results of our hydrological research in terms of adding research activities in case additional budget would be available.

In Scenario 2, we included the option to expand the measurements by constructing one new observation well. Additionally, the sampling period for stable isotope tracer was extended. The observation well should be constructed properly – placed in line with the existing wells and its screen should be along the pipe, from near soil surface to the bedrock. Using this idea, recharge could become more apparent where the signal of infiltrated rainwater could infiltrate into the pipe directly. Thus, the groundwater fluctuation and sampling could confirm the existing results. In relation to this scenario, an expert mentioned that the available groundwater data would already allow observing fluctuations in (or seasonality of) groundwater. Another expert, however, claimed the need to measure two more years. Moreover, one expert acknowledged that the advanced method using isotopes would certainly offer good results. On the other hand, two experts were sceptic about this, with one claiming the new measurements could not lead to new insights and the other one suggesting that the data to validate the groundwater model would not become available. Yet, (how) to decrease the uncertainty remained an open question. Even with uncertainty potentially decreased, however, the latter expert doubted the possible outcome anyway – suggesting it would still produce confusing results.

In Scenario 3, we proposed options for more measurement applications and/or more advanced methods. Besides one new observation well and stable isotope samplings, three other wells were to be constructed at the area with the smaller trenches. A possible advanced measurement was introduced by performing an electrical resistance tomography (ERT) survey for subsurface imaging. Several cross sections of the subsurface should be obtained during both dry and wet periods. Together, these new wells combined with ERT data would allow building more pronounced hypotheses regarding the difference in groundwater behavior with and without the intervention structure. Again, experts provided their feedbacks on the measurement proposal. Three expert suspected ERT survey to be useless, since it would measure only one profile at a time, and would thus be hard to interpret. Another expert argued that the measurements had already answered the research question, and thus would not need any addition to allow better understanding of recharge in contour trenching. On the other hand, two experts supported the ERT approach – with one suggesting to inject sodium chloride for better results and one advising to check on the costs since small intervals could require more budget.

Based on the open questions to the experts after they had valued the pre-constructed scenarios, five experts concluded that they were satisfied with the existing and proposed scenarios, while the five others did suggest extra measurements. One expert actually indicated that understanding recharge in the area should build on at least 10 years of groundwater level data. Another expert proposed to study the unsaturated zone, using soil moisture sensors. The preference for the type of sensors was not discussed, but we speculate that this might vary in terms of technology between experts, given different experiences with and availability in the research organization of the respective expert. Another expert argued that putting more effort in the infiltration tests and surface water measurements was key. The specific type of test and devices to measure were (again) not put into detail and might vary as well. Comparable soil moisture measurements with cheap sensors, adding tracers and investigating the time lap measurements, were of importance to another expert. In addition, another colleague would choose 3-D modelling over measurements to better understand the infiltration mechanism. Last but not least, an expert would approach the problem from a geophysical point of view, combining soil type analysis, ground radar and tracers. Our sample is too small for any relevant statistics, but the backgrounds and preferences of the experts concerning the type of selected measurements appear to be related – at least, they do not appear as random combinations.

7.5 Reality in hydrological research: whose knowledge counts?

In our Vietnam work, decision after decision resulted in the specific hydrological-research-and-intervention complexity that we mentioned. Choosing a model that fitted with the collected data appeared as possible - and we will certainly continue to defend our choices – but it still represents a possible realization of the relevant perspective of hydrological setting. Another hydrological researcher would or could particularly see a different approach to measuring and modelling of the same case. The result of the hydrological research presented in this study was not perfect, and could indeed have been conducted differently – as our experts suggest. Follow-up actions on the measurement devices and modelling could probably add understanding, but on what would be preferable, our hydrological researchers showed disagreement.

The possibility of the existence of multiple perspectives on what is proper hydrology might sound like the narrative of the men that see different parts of the elephant, without realizing that they touched a complete elephant. This is already a strong metaphor for the existence of different ideas, but we think that our study brings it one step further. After all, the metaphor assumes that one already knows that what the men examine is indeed an elephant. What happens when we do not know that the observed is an elephant? In other words, once hydrological researchers do not agree exactly on what matters to understand a specific hydrology – once one cannot be certain about what is observed – one needs to come up with a convincing analysis on what is happening, has happened or may happen – in hydrology or other fields. This does not mean that all options for hydrological research are automatically equally valid, or that all participants bring equal knowledge to the negotiations, but it clearly poses the question whose hydrological reality is emphasized – whose knowledge counts.

In a recent comment, Ertsen (2018) explores issues of uncertainty in situations where hydrology and humans interact. He identifies the challenges of using a definition of uncertainty based on a given external reality, that only needs identifying and uncovering. After all, different perspectives of risk and uncertainty should be expected – similar to different ideas on hydrological studies and interventions. Furthermore, he poses the question who decides what the relevant uncertainties are. In line with Latour (2013; see also De Vries 2016, and Junier 2017), he argues that expertise is relative to other actors. Who is a 'scientist' or a 'stakeholder' is not automatically given, and as such the power to define relevance needs to be considered. In line with this reasoning, when discussing the intervention and associated research for the Vietnam case in paragraph 3, we find that hydrological research itself is subject **to** negotiation. However, in paragraph 4, we have shown that hydrological research itself is subject **of** negotiation. Negotiating the meaning of hydrological (reconstructions of) reality touches on "the negotiations between humans and non-humans that co-shaped the hydrology we aim to clarify, but also the negotiations on how we as scholars in the present chose to study that same hydrology and its associated uncertainties" (Ertsen, 2018).

Defining what we know less, or know differently, would quite often not only pose constraints on our certainties, but also allow additional insights in what we wanted to understand in the first place. Confronting different approaches and ideas on what is discussed – either between hydrological researchers, as discussed by Pramana and Ertsen (2016), between government and stakeholders, as discussed by Poolman (2011) or both, as discussed by Junier (2017) – typically should help clarifying where the shared understanding actually would be, what different ideas would be and how these matter.

7.5.1 Relevance of recognizing perspectives on/off hydrological realities

Returning to the main focus of the special issue, most scholars will relate water scarcity to factors beyond the hydrological – indeed, the concept of anthropogenic drought (Van Loon et al, 2013) is widely accepted. Multiple perspectives are clearly recognized as well. Molden (2020) emphasizes the management aspects when dealing with water scarcity. Tzanakakis et al. (2020) emphasize the importance of water management revision. Vallino et al. (2020) provide an economic point of view in the agricultural sector. Cities do experience water scarcity, where pronounced water scarcity is due to water quality problems in Beijing (Zeng et al. 2013), which again is closely related to governance issues (Millington 2018). Water scarcity constraints sectoral uses, also due to water quality (Van Vliet et al. 2017). What does our idea of the importance of perspectives on/within hydrology offer for such complex debates? Let us offer a brief insight on this relevance, using our current research efforts on water quality governance and monitoring in the Brantas River Basin in Indonesia.

The basin of the Brantas is about 11,800 km^2. Compared to the Vietnam case, the larger study area involves more stakeholders. In our effort, six main stakeholders are involved: BBWS Brantas (the governmental agency for the river basin territory), the Provincial Environmental

Agency (DLH), Perum Jasa Tirta I (PJT1, a semi-governmental company on water allocation, operation and maintenance), Ecoton (a local NGO), TAUW (Dutch consultancy), and TU Delft. This Brantas project builds on the need to simultaneously engage with the monitoring of the river water quality in the basin and the strengthening of water governance by (semi-)governmental institutions – including community participation. The academic interest focuses on the participatory planning of these two processes. The project uses notions as discussed by Junier and Mostert (2014), who provide an example of studying and understanding the development process and the perceptions of different stakeholders on the validity and usability of the Water Framework Directive Explorer. Furthermore, factors influencing collaboration in river basin management are clearly related to the (social) process of problem framing and decision making (Silveira et al., 2016). We are working on hydrological research, specifically engaging with citizen science setups in monitoring the water quality (similar to Thatoe Nwe Win, 2019).

In the Brantas, we observe both negotiations we noted above. In terms of different ideas on what is important to do, stakeholders represent both different ideas and different roles; as such, one can expect that the needs of different stakeholders, the beneficiaries of this joint effort, their opinions on the Brantas river will create different representation of that same Brantas. For example, Ecoton could see the river as being filled with too much industrial effluent, too much micro-plastic, and too many killed fish. PJT1 would see a need to regulate river water quantity, in order to distribute the water. BBWS would see the stream as a place to build or use water structures. In our project, we acknowledge that such multiple ideas on what counts as important exist – stakeholders have several agendas (e.g. Carr et al., 2012). These different positions already bring the question how a hydrological researcher should deal with these complexities in relation to his/her research to the front? Starting with the premise of different perspectives of stakeholders allows engaging with and planning for possible tensions in our own hydrological research.

It is the second negotiation, however, that brings new possibilities develop the debate on river water quality in the Brantas basin. Bringing the different procedures of monitoring water quality in the Brantas into contact with each other allows developing a debate on how measurement data do (not) create different water qualities (instead of quality) in the Brantas. We are just beginning this process, but our first efforts (as reported in Willard forthcoming) strongly suggest that the databases of the three measuring agencies (BBWS, DLH and PJT1) do provide different perspectives on the same river in terms of river water quality and the most useful components to reconstruct this quality. We have not even started to include the measurements from Ecoton in the discussion, but it is clear that their point measurements – less structural as they may be – add the important element of sudden changes in quality (for example because of industrial discharges) to the mix. Recognizing that the measurements themselves allow building different claims on Brantas water quality will allow us to bring these different ideas together and discover possible consequences for and impacts to the hydrological research and water quality policy – similar to what we observed for the Rhine basin.

7.6 Embracing hydrological perspectives

Recent studies, such as Baldassarre et al. (2018) and Rangecroft et al. (2021) call for different disciplines to collaborate and develop datasets and analytical tools capturing the long-term dynamics produced by the interactions of physical, social and technical processes. Interestingly enough, the Editorial Nature Sustainability, vol. 4 (2021) claims that hydrological research has become less grounded, and suggests there is a need to push hydrology forward through unique conceptual advances and theoretical innovation. Whatever one thinks of such claims – as they might say more about the journal than the field – it is clear that the issue of water scarcity need to be studied in an interdisciplinary way. In the context of water scarcity, ongoing efforts for solutions are often arranged through interventions that combine with hydrological research. In connection with such research, a wide range of perspectives could be used: how does one measure in the field, how to translate those measurements into analysis and modelling, etcetera?

We have shared our ideas and method when investigating the hydrological impact of contour trenches in Vietnam, including possible changes if that research would have been done and continued by other experts. Similarly, we are currently involved in the implementation of interventions through research in a water quality monitoring campaign in the Brantas basin, Indonesia. Despite of the different scales, we recognize similar challenge when it comes to agreeing which intervention-based research is or should commonly be accepted in the hydrological community involved in the projects. In the Brantas, like in Vietnam, different types of intervention projects would differ in their associated research, and as such in the type of budget discussions one would expect. The local setting influences assumptions for the research approach, ranging from the choice of measurement devices to the preferences of the researcher him/herself. When a hydrological researcher comes from the project area/country, this could mean that he/she knows how to deal with the local conditions – and possibly that the research options can be better defined. On the other hand, differences in socio-economic position within countries (urban-rural, rich-poor, young-old, etcetera) may be larger than a shared nationality may suggest. Furthermore, data from different local institutions in the Brantas suggest that monitoring campaigns, interventions in river basins, and the hydrological research itself are closely linked. These different perspectives on local hydrologies offer new ways to engage with interdisciplinary water studies – both theoretical and practical.

As demonstrated, data produced from research or/and organization arrangement tend to be various and frequently determined by local conditions. Acknowledging that this is likely to produce different perspectives on local hydrology, we propose the notion of embracing those perspectives of different scholars. From one case study, we indicate multiple approaches and methods for the same case study, with larger or smaller overlap –indicating that we as researcher could think of different approaches and methods to conduct the research (light gray circles). These approaches and methods are related to perspectives, indicated as the outer black circle (see **Figure 7.1**).

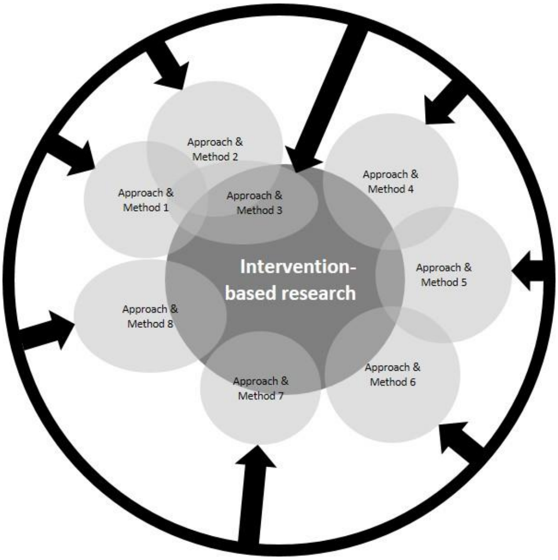

Figure 7.1 Theoretical notion of hydrological perspectives in intervention-based research

This implies that in the hydrological science, both hydrological understanding of interventions and building hydrological science from these interventions are recognized. This paper nurtured the idea how to better think of hydrological research within a simultaneous intervention: we propose to conceptualize such an effort as building a perspective by a specific hydrological researcher. Using ideas and concepts from the humanities and social sciences, we claim that a hydrological researcher is required to think better in terms of deciding on measurements and models; what to measure or model, why certain types of measurements and models, where, and when, etcetera, as these choices shape the hydrological discipline itself. Likewise, necessary questions to be considered include how hydrological researchers create their perspective. How do hydrological researchers argue about different perspectives? Hydrology is created in the process of obtaining data and further analysis performed by a hydrological researcher – within a larger community with members of different backgrounds and in different partnerships. Paying more attention to this continuous ambiguity to encourage a stronger co-evolutionary process of water-related intervention and associated research seems to be a reasonable requirement for the hydrological community.

8 Hydrological research in small-scale intervention: systematic planning, perspectives, and outlook

The three hydrological research projects within three small-scale intervention projects built a basic, but good understanding of water interventions in Vietnam, Kenya, and Indonesia. Over time, cooperation between the initiator, researcher, local people and communities near the study area reshaped both the water-related intervention and the hydrological research. All actors experienced, shared, and developed knowledge to achieve an understanding of the intervention in hydrological terms. The three cases offered different starting points for intervention and research, linked to the cycle of an intervention project.

- The hydrological research starts before the intervention (Indonesia case).
- The hydrological research is conducted simultaneously with the intervention process (Vietnam case).
- The hydrological research starts after the intervention or is an evaluation study of an existing intervention (Kenya case).

Despite all the problems in the three field research projects, a useful understanding of the hydrological impacts of interventions could be developed and the basic processes could be summarized.

- In Vietnam, during the wet season, contour trenches contribute to recharge, but only with 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 capacity of micro-hydro installation on Maluku Islands is up to 200 kW per site.

Based on this experience, it has become clear that, from a natural-sciences point of view, the dominant hydrological process(es) to be studied is (are) the main consideration when designing hydrological research within small-scale intervention projects. A researcher should look well into what would be required to arrange research into such processes, because a smart combination of field measurement, modelling, tracers, and remote sensing analysis in a multi-method approach is key.

Moreover, it is important in small-scale intervention-based research to consider human actions before and during intervention phases, including both hydrological research and the actual intervention itself. In all three cases, local people participated during the implementation of the projects, both in the intervention and hydrological research - and both invited and unexpected. As a result, the field campaigns were not perfect in terms of hydrological standards. Measurement devices were (re)moved, devices disappeared or ended up not being located at the final intervention site. At the end of each case study, there were less data or data of lower quality than the original plan had foreseen. Even though these issues did not prevent reaching useful conclusions on hydrological processes in each of the sites, it is nevertheless clear that anticipating such processes of change of and engagement with hydrological field research could offer gains for similar field studies still to be developed. The three field campaigns and their associated discussions between experts also stressed that different perspectives on hydrology as a field of enquiry – and as such on scientific findings within hydrology – are built through research activities. Personal choices affect (create) the hydrological consensus.

This final chapter suggests how to deal with socio-economic conditions in systematic planning, the perspectives of hydrological experts, and the outlook in the context of issues and theme in the hydrological community.

8.1 Systematic planning

Tracing back the social reality and the way it shaped research and interventions in the case studies in the shape of the associated budgets, allowed us to gain more insight into trade-offs between hydrological knowledge and hydrological research management. In order to be able to design responses during hydrological studies, (possible effects of) human agency - both positive and negative - should be an integral aspect of designing, performing, and evaluating intervention-based hydrological research.

Planning ahead is possible. When one has to perform hydrological research in a small-scale intervention, it is suggested to think more systematically about the hydrological research approach to be applied. Intervention and research plans are vulnerable to change due to human actions. Therefore, the proposal when preparing hydrological research in small-scale intervention research projects is to:

- Include possible surprises and possible actions
- Include cost-benefit analysis with expert feedbacks

8.1.1 Include possible surprises and possible actions

The field measurements performed in the three case studies were certainly not perfect. Measurement devices were prone to vanish. Measurement devices broke down, some disappeared, and the quality of data were occasionally unsatisfactory. As a result, a considerable amount of valuable data was lost. Measurement devices should be secured well, and additional measurement structures should be strengthened. Specific cooperation should be established in a wide range of local levels, from local communities to governmental agencies. A considerable effort spent building and maintaining informal networks and relationships (Mackenzie, 2012) will yield success in local data collection. Having a good connection and cooperation with the local community is essential to keep continuous measurements, but still this is not enough.

To achieve success in performing the field measurements one wants to do, one should include possible surprises and possible actions in both research and intervention development. In a simultaneous intervention and research phase, inclusion of possible surprises and possible actions on both the intervention and research in the planning process is a guidance for being able to adjust a research plan in execution. In terms of planning for surprises, the framework developed by the RAND cooperation on how to be prepared when facing "surprises" in planning including questioning oneself is very useful.

8.1.2 Include cost-benefit analysis with expert feedbacks

In order to translate the concept of surprise planning to the hydrological field, the proposal is to include cost-benefit analysis explicitly in the planning process. To understand a certain water intervention, a researcher would prefer measurements conducted at all locations, on a long term, with high frequency. Scientists with different backgrounds, biases and inevitable budget constraints, invariably carry out hydrological data collection for different reasons, in different regions, in different ways, over varying timescales (Hamilton, 2007). This suggests that among researchers, their actions towards the same type of hydrological research could be various. However, when facing time and financial constraints, a researcher should be able to balance what can and cannot be done. What to do with such limited budget, how human action affects research activities and budget, and how to deal with possibly costly surprises are important questions to prepare oneself for. As such, choices can be studied in terms of costs and benefits. For this, the Delphi method was used, with costs defined as (probable) research expenses and benefits obtained from water experts.

In this study, to illustrate budget scenarios, three scenarios were set, with the reference budget showing an optimum budget that could be set lower than the implemented ones. Economically, this budget would achieve a good understanding of the intervention. The additional expenses were spent mainly to cover costs such as shifting intervention locations, loss of measurement devices, and no performed measurements correlated to the social condition. It was found that with an increase of 20% of the total research budget, the research would not provide a better understanding. Instead, it would require an increase of 80% of the budget. In reality an increase of 80% of the budget would be very difficult or impossible. Obviously, the 80% increase is an arbitrary one. However, by thinking in those cost-benefit terms, a researcher will be able to optimize his/her research proposal by asking the question which budget increase for which activity would actually yield additional understanding.

8.2 Perspectives

The hydrological research of the three case studies shows that different experts have different ideas to conduct the research. Even though those different ideas in themselves do not yet suggest what to do in practice when human actions have a consequence to those ideas, a possible route to scale up the findings of perspectives in small-scale projects to other, larger-scale efforts that build on interrelated interventions and research actions within the field of hydrology, was suggested for a current research effort at the Water Resources group of Delft University of Technology on water quality governance and monitoring in the Brantas River Basin in Indonesia.

It has become clear throughout this thesis that the dominant processes that have been named, measured and modelled in the field in different areas do not necessarily cover all that is hydrologically going on at the field sites - let alone that there is a single possible representation of local hydrology and intervention in a group of experts. What is supposed to be a single entity - a single outside reality - may not be that single in actual (research or other professional) practice, as argued in The Body Multiple by Annemarie Mol (2002) who shows that what is supposed to be a single disease (atherosclerosis) is shaped differently continuously by different (professional) communities in the hospital.

This recognition of the importance of actual research practice in creating scientific knowledge, implies that in the hydrological science, both hydrological understanding of interventions and building hydrological science from these interventions are to be recognized as connected. Building on this notion opens up the idea how to better think of hydrological research within a simultaneous intervention: it proposes to conceptualize such an effort as building a perspective by a specific hydrological researcher. Using ideas and concepts from the humanities and social sciences, the author claims that a hydrological researcher is required to think better in terms of deciding on measurements and models; what to measure or model, why certain types of measurements and models, where, and when, etcetera, as these choices shape the hydrological discipline itself. Likewise, necessary questions to be considered include how hydrological researchers create their perspective and why/how this perspective matters. Hydrology is created in the process of obtaining data and further analysis performed by a hydrological researcher – within a larger community with members of different backgrounds and in different partnerships. How do hydrological researchers argue about different perspectives? Paying more attention to this continuous ambiguity to encourage a stronger co-evolutionary process of water-related intervention and associated research seems to be a reasonable requirement for the hydrological community.

Different types of intervention projects would differ in their associated research, and as such in the type of budget discussions one would expect. The local setting influences assumptions for the research approach, ranging from the choice of measurement devices to the preferences of the researcher him/herself. Whether a researcher comes from the same country as the project area which would mean that he/she knows how to deal with the local conditions (as the author experienced), could mean that the selected research option might be better in control. Furthermore, this thesis shows that different representations of hydrology, the water-related intervention and the hydrological research itself are closely linked. The thesis offers a systematic approach to use this observation when designing hydrological research that claims to benefit society.

8.3 Outlook

In any project, negotiation would influence most of the intervention and hydrological research. Negotiation is a vital researchers' effort that determines the success of hydrological field measurements. The negotiation part is imbedded in a hydrological researcher's work even before a decision is made for intervention and research. Most of the time it is not obvious, but develops from cooperating with local people to agree on a proposed intervention and research. Local communities could support the field campaign. An intervention can be constructed after many negotiations between the initiator and the end user. Interventions may be cancelled due to insufficient funding. Further study will provide more material on the role of negotiation in hydrological research and shed additional light on this analysis and specific cost-benefit approach to plan for surprise.

The suggestion of systematic planning and perspectives can be further developed in other hydrological research projects. Furthermore, to have more related samples of hydrological research in small-scale interventions, projects that have been done in a different research setting would have to be evaluated. A similar evaluation using cost-benefit analysis could be developed to compare the suitability of the proposed analyses. Extrapolating these findings to a larger scale of intervention is a challenge. Nevertheless, the observation remains that measurement devices installed in the field will in any case be affected by human agency. The question is whether the practical performance of the researcher in the field dealing with human actions would determine the results of the hydrological research in other smaller or larger projects as much as it did in the three case studies.

The quantities of field measurements' failure because of technical, animal, climate, or human agency are not yet specified for a larger data set, amongst others because failures hardly reach the scientific literature. More research efforts have to be evaluated from the "failure" perspective – with failure being defined in terms of lower data availability. This would direct the question whether – as the three case studies – failure due to human actions is significant in different small-scale intervention projects as well. A discussion on options for measurements and analysis might start with asking water experts. The more experts are involved, the more options would be available. Eliminating options and screening for the majority of advised measurement and analysis could be feasible. The result would prove whether the proposal still holds.

8.3.1 On Prediction in Ungauged Basins (PUB)

As in the PUB initiative, the three cases in this thesis dealt with hydrological situations that were basically undefined. As such, activities were mainly conducted by fieldwork, within relatively short time periods. Hydrological processes and their results could be clearly observed in the landscape, but their exact magnitudes, rhythms and relations were unclear. To address an ungauged basin, the hydrological science community has managed to think through many of the issues that relate to the thesis (as also already mentioned in the Introduction), and has come up with several ways forward. To name just a few, PUB has explored new observation techniques and modelling approaches, in a range between data- and calibration focused methods to methods that are more strongly based on theoretical insights into physical processes and system understanding (Hrachowitz et al., 2013). The three cases are indeed closely related to ungauged basin problems, which can potentially be approached satisfactorily by using the right measurements (timing).

In terms of data, according to McGlynn et al. (2012), data scarcity is a major issue. Often, lack of data increases with decreasing catchment sizes. Thus, acquiring information (for estimating runoff) from ungauged catchments can follow a hierarchical approach (see **Figure 8.1**), depending on resource availability. Dedicated measurements provide detailed information at high costs over small spatial scales, whereas global data sets provide more generalized information at lower costs over big spatial scales.

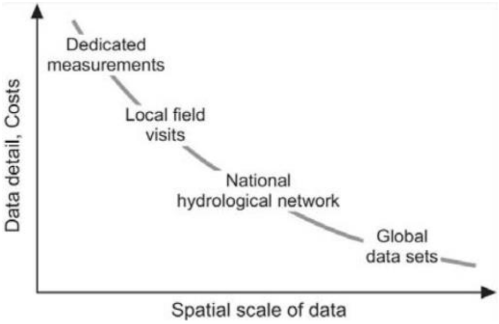

Figure 8.1 Hierarchy of data acquisition by McGlynn et al. (2012)

Working in such basins must be treated as a learning process (Seibert and Beven, 2009). Within PUB, the call to recognize so-called "soft data" (i.e. qualitative knowledge) has been made as crucial for the improvement of model performance (Seibert and McDonnell, 2002). The argument of this thesis builds on these rather general notions, in suggesting that more explicit attention for this topic helps to design more appropriate answers to the challenges faced in the dedicated measurements. In particular, the thesis drafts a proposal of taking into account possible surprises and resulting actions, and using cost-benefit analysis to analyze the need for certain measurements and assess effects of human intervention. When a hydrological researcher allows him/herself to keep these two steps in our minds, then he/she can avoid unnecessary costs and consequences, meaning also he/she can reduce uncertainty in terms of the amount of field measurement data, especially for the modelling attempt.

Uncertainty may vary for different sources from the model parameter set, the model structure, and the measured data. Many studies of PUB have already used short- to long-term measurements at different locations. Some studies were performed in pristine catchments (Jia et al., 2009; Sriwongsitanon and Taesombat, 2011; Winsemius et al., 2006). Others were stimulating the transfer and extrapolation approach when model calibration cannot be performed (Sivapalan et al., 2003; Yadav et al., 2007). Uncertainties especially increase in arid areas, where events are distributed extremely unevenly (McMichael et al., 2006). Therefore, uncertainty analysis needs to be performed as an approach to move forward on this research.

8.3.2 On Socio-hydrology

'Everything flows', the slogan of IAHS for the period 2013 to 2022 (Montanari et al., 2013), expands on PUB to correlate with dynamics including human behavior, society and its interactions, non-steady modelling, integrated process understanding, and improvement of uncertainty analysis. The idea of socio-hydrology to involve humans is because humans continuously change the environment. Most of the current predictions in ungauged basin are based on stationary conditions, but in the long-term human activities will result in changing dynamics.

Socio-hydrology becomes even more relevant by looking at the interactions between human (as an initiator of intervention and/or stakeholder) and the complex hydrological system. In relation to human demand, society is continuously changing future hydrology through its interventions. Likewise, as the interventions influence society – beneficially or not – societal actors (need to) create an awareness and overall understanding of the interventions. Hydrological change usually occurs after a certain intervention has been implemented. On the other hand, societal actors interact before, during, and after the intervention. Therefore, potential interactions with possible feedbacks and changes not only show that humans play an important role in determining much of the behavior of catchments, but also may already influence hydrology – and consequently society – before the original hydrological effects of an intervention would have shown themselves.

The author searched for a better way of conducting small-scale hydrological research. The hydrological research discussed in this thesis was performed to gain and/or improve understanding and interpretation of local hydrology, including scenario development in human-modified situations, within a context of small-scale interventions. Performing proper hydrology that links to socio-hydrology, requires a hydrological researcher to make more explicit attention of the author's claim that can help to design more appropriate answers to the challenges faced in hydrological field studies. If a hydrological researcher forces him/herself to consider how to deal with surprises of human actions in a cost-effective way, he/she can better prepare for the changes that most likely need to be made during the hydrological field campaigns.

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Annex A – Results of scenarios

Scenarios of the research extension per case study have been asked to experts - water managers and hydrologists. Three tables below show the opinion of ten experts with their grades and remarks.

Table A.1 Vietnam case

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)

Table A.2 Kenya case

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)

Table A.3 Indonesia case

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.

Annex B – Actors, intervention, and hydrological research

For each case study, the narrative of the actors, intervention, and hydrological research are described as follow.

Vietnam case

The actors

This intervention and research project was conducted by a Dutch consortium consisting of a consultancy company (Royal Haskoning/RH), two research institutions (UNESCO-IHE Delft and TU Delft), one non-governmental organization (Westerveld Conservation Trust/WCT), in collaboration with a Vietnamese governmental agency, the Department of Natural Resources and Environment (DONRE). WCT and RH were the initiator of the intervention. The local community participated in the decision-making of both intervention and research.

The intervention

Contour trenching by WCT started in Kenya in 2002 (see Kenya case below). This technology was then introduced to a small community in Vietnam in 2007. From January to August 2007, the contour trenching concept was presented to the local community. Photos, drawings, and slideshow presentations were used. Two main impacts were foreseen due to the intervention, subsurface water storage and increased vegetation growth. These were discussed between the initiators, governmental authority, and the local community. The proposed contour trench had a dimension of 4 m wide and 1 m deep (see **Figure B.1**, left side). The distance between the trenches was set at about 36 m. At the beginning, 97 ha of potential area for contour trenching was identified. However, at the end of the intervention, due to the limited landowner's will and permission, the trenched area was much less, namely 22 ha.

Figure B.1 The large (left) and small (right) dimension of trench.

In October 2007, a first agreement between the local community and the initiator to implement contour trenches was reached. A monks' organization provided its land to be utilized, providing about 8 ha (Pilot Area 1). The area was uncultivated land, generally covered by small bushes, cactus and erosion gullies. Random cattle, owned by surrounding pastoralists walked freely in this area.

At the first stage of construction, seven trenches with a width of 4 m (intervention A, see **Figure B.2**) with different lengths along the contour were constructed. These contour trenches were dug using an excavator. The excavated soils were placed downhill of the trenches and a bulldozer evenly distributed and afterward compacted the soil deposit. About 5 ha of the total area were occupied with this type of trenches. In March 2008, the initiator and the monks' organization evaluated the contour trench design. Even though the trench dimension had been discussed several times before the construction, the monks' organization was unhappy. A meeting to discuss this issue was set up. All parties in the consortium gathered for lunch at the monks' temple. The monks did not like the trenched area. The trenches were too big. Safety (livestock could perhaps fall into the trench) was not an issue. Nevertheless, as a result, the monks refused to continue with any type of intervention on their remaining land. Hence, the construction plan of Pilot Area 1 had to be stopped.

In April 2008, RH approached other landowners by introducing a smaller contour trench design with the expectation that construction of contour trenches could be continued. The newly offered trench dimension had a bottom width of 1 m with a top width of 2,5 m and side slopes of 1:1 (intervention B1). The depth was 0,75 meter (see **Figure B.1**, right side). The distance between the trenches was reduced to 25 m. In May 2008, one of the farmers was convinced that the design would be more esthetic. He provided about 1 ha of his land (Pilot Area 2) for the smaller contour trenches. Hence, RH constructed five contour trenches, with different lengths along the contour.

In August 2008, after the monks' organization saw the result of Pilot Area 2, they requested the smaller trenches to be implemented at their remaining land as well. Therefore, six small trenches were constructed at the remaining land of Pilot Area 1 (intervention B2). Progressively, other landowners next to Pilot Area 2 requested the same trench design. In October 2008, the implementation of the big and small trenches in total yielded an area of 22 hectares.

The hydrological research

In October 2007, before the intervention began, a setup for a field campaign, which included rainfall, soil moisture, surface water, and groundwater level measurements, was introduced. Two rain gauges were sited at two different locations, uphill and downhill from the planned intervention. Six access tubes were placed inside the trench area and two were outside the trench area. Surface water measurements, using a diver, started at the location of an existing reservoir, close to the planned intervention area. The groundwater level measurements were established by constructing three observation wells, uphill and downhill the planned intervention, which used divers too. The setup of hydrological research and spatial development of contour trenching in Vietnam can be seen in **Figure B.3** and has been discussed in **Chapter 2**.

During the measurement period, however, the installed measurement devices had to be modified and adjusted. Two automatic rain gauges that had been placed at the roofs of local residences were clogged due to accumulated fine sand blown by the strong wind during the dry season. Fine sand was trapped in the rain gauge funnel, blocking rainwater to enter the tipping bucket. Thus, during the second wet season, loss of data occurred [no. 1]. In addition, the data logger happened to fail during downloading data [no. 2]. Soil measurement with access tubes seemed to attract the local people, possibly because of the appearance above the soil surface. The tubes were taken out from the soil at the measurement locations [no. 3]. The diver at the reservoir and two divers from the three observation wells disappeared as well [no. 4]. These divers (both at the reservoir and observation wells) had been placed in an open area and could easily be reached. In addition, there was no secure installation for the divers, for example by using a strong padlock or installing them at isolated or private areas owned by a farmer. Only one observation well was constructed in a local farmers' yard close to the trench area. After the loss of three divers, observation wells were equipped with stronger padlocks. Furthermore, observation wells without divers were measured using local materials, where an Am-meter was connected to a long electric cable, attached to an iron stick at its end. When the iron stick touched the water table, it would transmit an obvious current signal. A monk conducted these manual measurements during almost three years.

The observation well screen was installed close to the bedrock [no. 5], which made it actually difficult to find the isotope signal of recharge in all wells, as discussed in **Chapter 2**. Although during the drafting of the research plan, the risk in failing to obtain a signal from infiltrated water was recognized. However, stable isotope samples were still collected and analyzed. Fortunately, one of the upstream groundwater samples did contain the signal of rainwater.

Locations to measure groundwater levels were added too. Since the contour trenching shifted from its original location plan [no. 6 and no. 6A] to locations where the local people agreed their land to be trenched, the measurements needed to be adjusted. Thus, four new observation wells were constructed to investigate the recharge impacts inside the trench area.

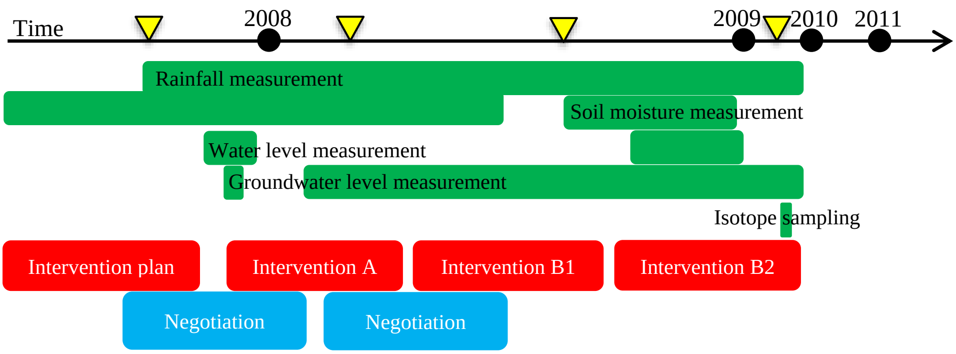

Figure B.2 Schematization of hydrological research, small-scale intervention and conditions for negotiation in Vietnam case. (Yellow triangle = field visit)

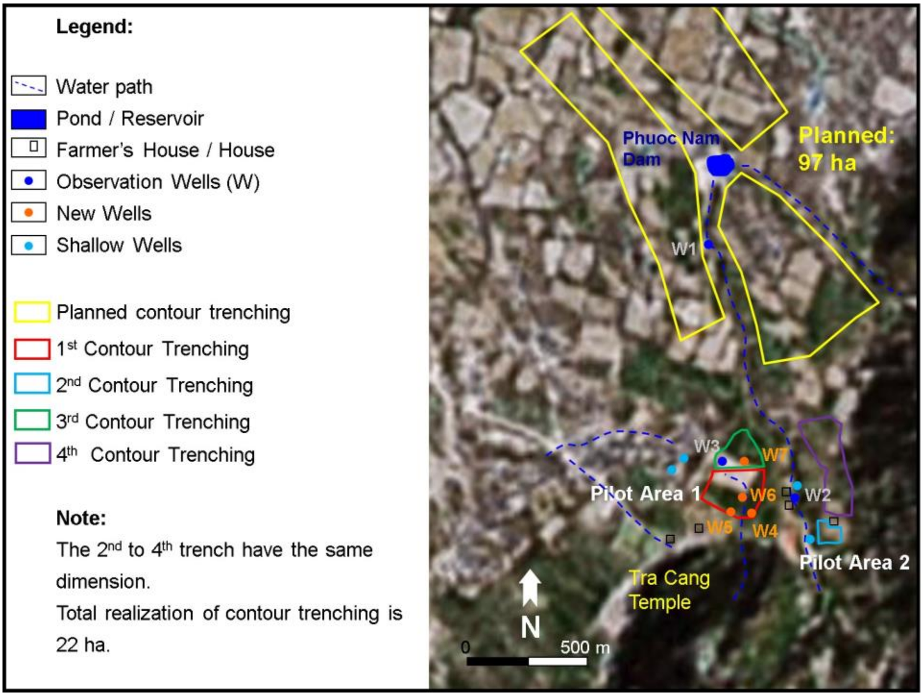

Figure B.3 The spatial development of the small intervention in the Vietnam case.

Summary

The process of negotiation affected decisions for both intervention and hydrological research. The initiator explained the intervention to the local community by many approaches. Final dimensions of the structure and location were a result of local preference. The first location was determined by the willingness of a monk organization, the second one by a single local farmer to provide his land. It was due to their kindness and less to a convincing design that trenches could be constructed in the first place. Later there was new agreement to continue contour trenching by other farmers, including the monk organization, because of "seeing is believing". The smaller trench design was accepted and therefore new locations for constructing contour trenches could be found. The hydrological research focused more on the larger trenches by constructing new observation wells with higher security. Furthermore, the measurement device for groundwater level was modified. It was adjusted by using local materials. As a result, a manual rain gauge and a plastic evaporation pan were created.

Kenya case

The actors

This intervention project was conducted by a Dutch non-governmental organization (Westerveld Conservation Trust or WCT) with assistance from the Kenya Wildlife Service (KWS). TU Delft studied the hydrological impact of the intervention. The local people (the Maasai) participated during the intervention and research.

The intervention

In 2002, WCT introduced contour trenches with a dimension of 1 m bottom wide and 0,75 m deep (intervention X, see **Figure B.4**, left) to the Kenya Wildlife Service (KWS). KWS is a public organization mainly conserving and managing Kenya's wildlife for the Kenya people. One of their main responsibilities in Amboseli is to supply water for local inhabitants, the Maasai. Contour trenching was seen as one technique to provide water to the Maasai. There was trust between the initiator and KWS; KWS agreed with contour trenches to be constructed on its land. The agreement on the location of contour trenches itself was laid fully down in KWS hands. The end users, the Maasai, did not take part in the design and siting process at all. During the construction phase, the Maasai were given the task to construct the stonewall uphill, surrounding the trench area and the diversion structure.

In 2004 and 2005, an extension of the contour trenching was proposed to KWS. A larger trench (intervention Y), with a dimension of 4 m wide and 1 m deep, was introduced. However, there were neither complaints nor inputs by the Maasai on the trench dimension. Most of the intervention phase went smoothly without any local refusal.

Figure B.4 The small (left) and large (right) dimension of trench.

The hydrological research

In October 2010, about eight years after the intervention, a setup for a field campaign was developed by TU Delft (see **Figure B.5**). It included rainfall and soil moisture measurements, and soil sampling. Two rain gauges were sited at two different locations, uphill and downhill from the contour trenching area. Six location for soil moisture measurement, using a TDR probe and access tubes, were installed at the smaller contour trench area. Additionally, 16 soil samples were collected from this area for further cesium analysis in the laboratory. The spatial set up of research and development of contour trenching in Kenya can be seen in **Figure B.6**.

During the installation of the measurement devices and soil sampling, local people from outside the study area provided assistance; this activity took four effective working days. For safety reasons, two rain gauges were placed at two different *manyatta* (kraals); one inside a *manyatta* and the other one in front of the *manyatta*, close to a small school. The latter one was damaged by elephants and was further moved by the Masaai [no 7]. The other one had a data logger that could not be retrieved [no 8]. Soil moisture measurement required installing six 2-m access tubes up to 1,8 m into the soil. After a few weeks of installment, the tubes had disappeared [no 9A]. Tracing the tubes back was difficult, since many local people might walk in the study area. Some local key persons were asked about the tubes, but without success. Two new tubes were planned to be installed. For more than one year, however, an agreement with a local person to reinstall the two tubes and conduct soil measurement could not be reached [no 9]. Consequently, this study continued without soil moisture data. Soil sampling and further basic soil analysis at Moi University in Eldoret was successful.

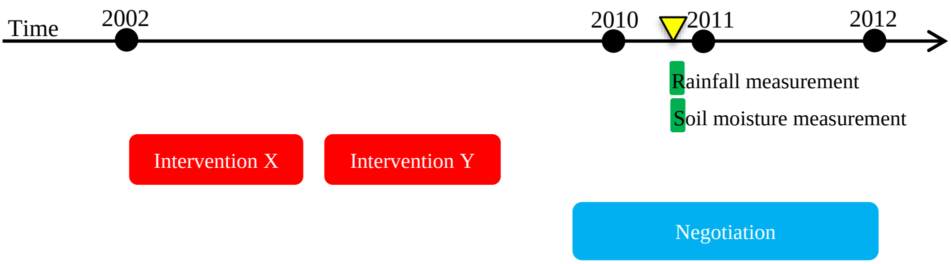

Figure B.5 Schematization of hydrological research, small-scale intervention and conditions for negotiation in Kenya case. (Yellow triangle = field visit)

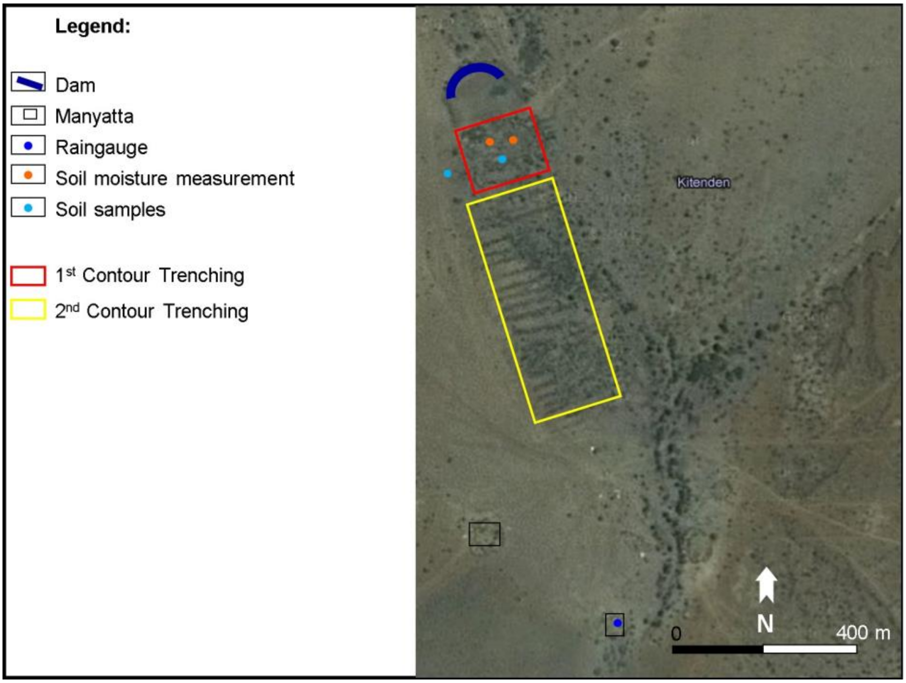

Figure B.6 The spatial development of contour trenching in Kenya case.

Summary

Since the hydrological research took place long after the intervention itself, the hydrological research could be designed according to the layout of the intervention. The location set up was fixed. The soil moisture measurements could be conducted once during the initial installation, but after a week the tubes had disappeared. At the beginning of the installment, different groups of random local people surrounding the study area were already approached. The purpose of the installed tubes was explained. One group who came across the study area even requested for formal research permission by the community –so, the formal letter of permission from the government authority had to be shown. It is believed that a good connection with the local people and recognizing power issues within the Maasai groups were essential. Even with such a condition fulfilled, it was still difficult to achieve good results. The study area was an open public area, which means local people would still be given the opportunity to interfere with the measurement devices installed in this area.

Indonesia case

The actors

This intervention and research project was a collaboration among a Dutch educational institute (Delft University of Technology or TU Delft), a Dutch non-governmental organization (Foundation BIA), an Indonesian education institute (*Universitas Kristen Indonesia Maluku* or UKIM), and an Indonesian non-governmental organization (*Institut Bisnis dan Ekonomi Kerakyatan* or IBEKA). The project concentrated on capacity building among the actors with a pilot of micro-hydro installation. TU Delft and UKIM worked on the education subject by developing a micro-hydro curriculum for the bachelor degree at UKIM. The NGOs focused on the implementation of the pilot for a micro-hydro power plant.

The intervention

The project started in 2010. IBEKA estimated that a micro-hydro installation with a capacity of 80 kW could be built. At the submission of the construction proposal, the local potential had not been investigated yet. However, the cost of installing an 80kW micro-hydro installation was estimated around four times the available budget for its construction. Meanwhile, the initiator worked simultaneously on fundraising to get the remaining three-quarters of the budget.

The field survey tracked the river from downstream to upstream. The purpose was to look for suitable locations close to the village for the power plant and storage if needed. As a result, only one single location with a significant elevation difference of up to 35 m could be obtained. Before the hydrological measurements started, a constant discharge data of 0,2 m^3/s was assumed for the design of the proposed micro-hydro installation.

After the field measurement (with a duration of eight months), consisting of rainfall and water level measurements, an overview of actual annual discharge data at the study area was achieved. Without any additional storage construction, the minimum annual discharge was measured to be about 0,02 m^3/s (or ten times less than the initial design). Thus, with such low discharge, only a small capacity micro-hydro installation could be built. However, a low capacity installation was not economically feasible, since the return rate would be low as well.

Therefore, the planned micro-hydro installation had to be changed. An option to shift from the proposed village to another on the same island was hard, due to the fact that permission for and security of a new location would have to be surveyed and rearranged. Hence, more time and labor were required, which would exceed the project budget.

With the available budget for intervention and the fact that the overall region had low potential, in the order of 5 to 25 kW, the initiator decided for a small-scale model on UKIM territory, to strengthen the training component. As a result, a micro-hydro model was brought to a local university in the region. Thus, this intervention project shifted from a micro-hydro installation at a village scale to a model at a local university level.

The hydrological research

In July 2010, the hydrological research (see **Figure B.7** and **B.8**) started by installing two rain gauges and two divers. One rain gauge and two divers were set up at the upstream end of the planned intervention. The other rain gauge was placed at one of the local inhabitant's yard. One rain gauge and one diver failed to record events [no 10 & no 11]. In February 2011, a collaboration of local people and a Dutch student crosschecked discharge measurement using dilution gauging. Since the research result suggested a low annual discharge at this particular village, it was concluded not to invest in a micro-hydro installation for the moment.

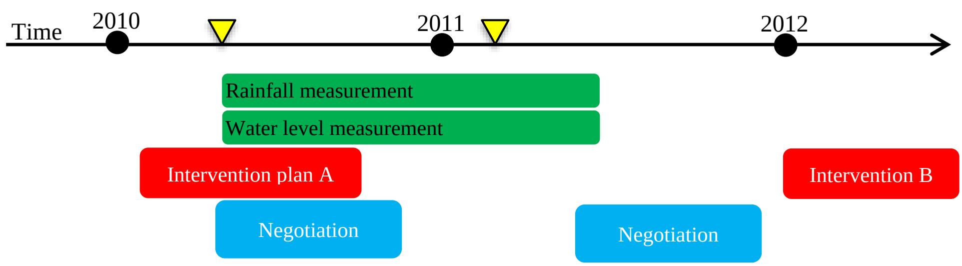

Figure B.7 Schematization of hydrological research, small-scale intervention and conditions for negotiation in Indonesia case. (Yellow triangle = field visit)

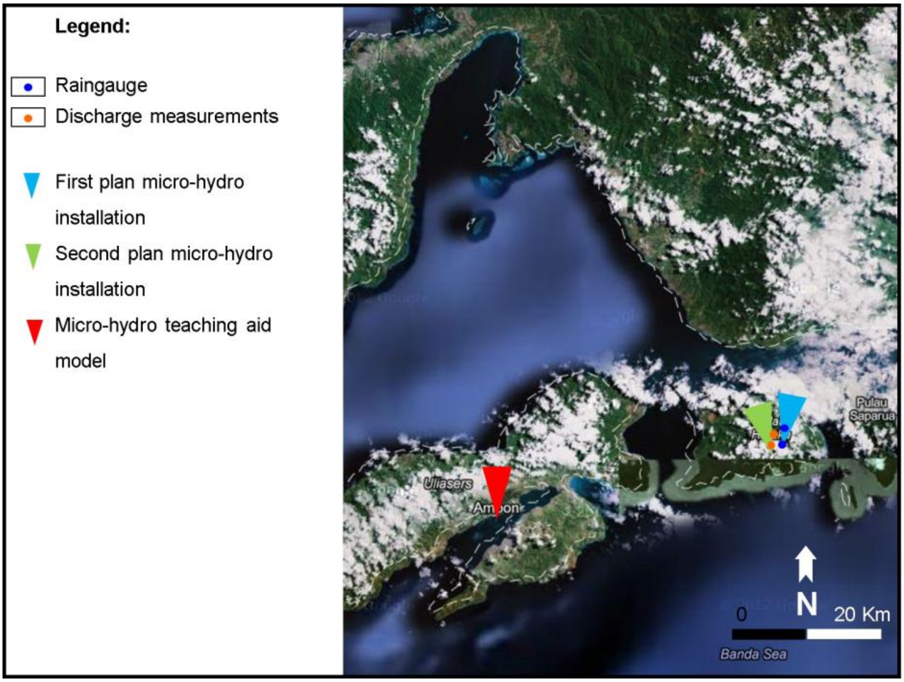

Figure B.8 The spatial development of the small intervention in Indonesia case.

Summary

For hydropower, discharge and economic feasibility determine whether a micro-hydro power plant could be built. The hydrological research suggested that the study area was not a suitable place to set up a micro-hydro installation. However, in terms of research activities, the local people were supportive in providing assistance and security of the measurement devices. All four devices remained at their locations until the end of the research period. Only data from the logger of the rain gauge in the inhabitant's yard could not be retrieved. On the other hand, local people wished some construction development could occur in their village and expected the realization of a micro-hydro installation because the project was well known to help the village. Although the low capacity would technically be suitable, the local people had to realize that the amount of funding could still not support the construction. Therefore, the constraint in the intervention project was not the social setting itself, but external circumstances that eventually caused a shift of the project to another end user.

Acknowledgments

Groundwater, so slow… In some way, the flow of groundwater mirrors the journey of writing this thesis, encompassing all the processes involved in its completion. Despite the challenges faced, I have ultimately achieved this significant milestone, and I am aware of my indebtedness to the multitude of individuals who provided unwavering support and assistance throughout my research and the finalization of this thesis.

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About the Author

Kharis Erasta Reza Pramana (1977) was born in Singaraja, Bali, Indonesia. He obtained his BSc in Ocean Engineering from the Bandung Institute of Technology, Indonesia, and his MSc in Water Resources Management from Delft University of Technology, the Netherlands. During his PhD he conducted three different small-scale water research projects, specifically on small-scale water interventions. These projects were individually tailored, emphasizing field measurements to assess the impacts of the interventions. He attempted to clarify the relation between the intervention and its field measurement, within the context of the hydrological discipline. Currently, he is working on his postdoctoral research on water quality monitoring in the Brantas basin, located in East Java, Indonesia.