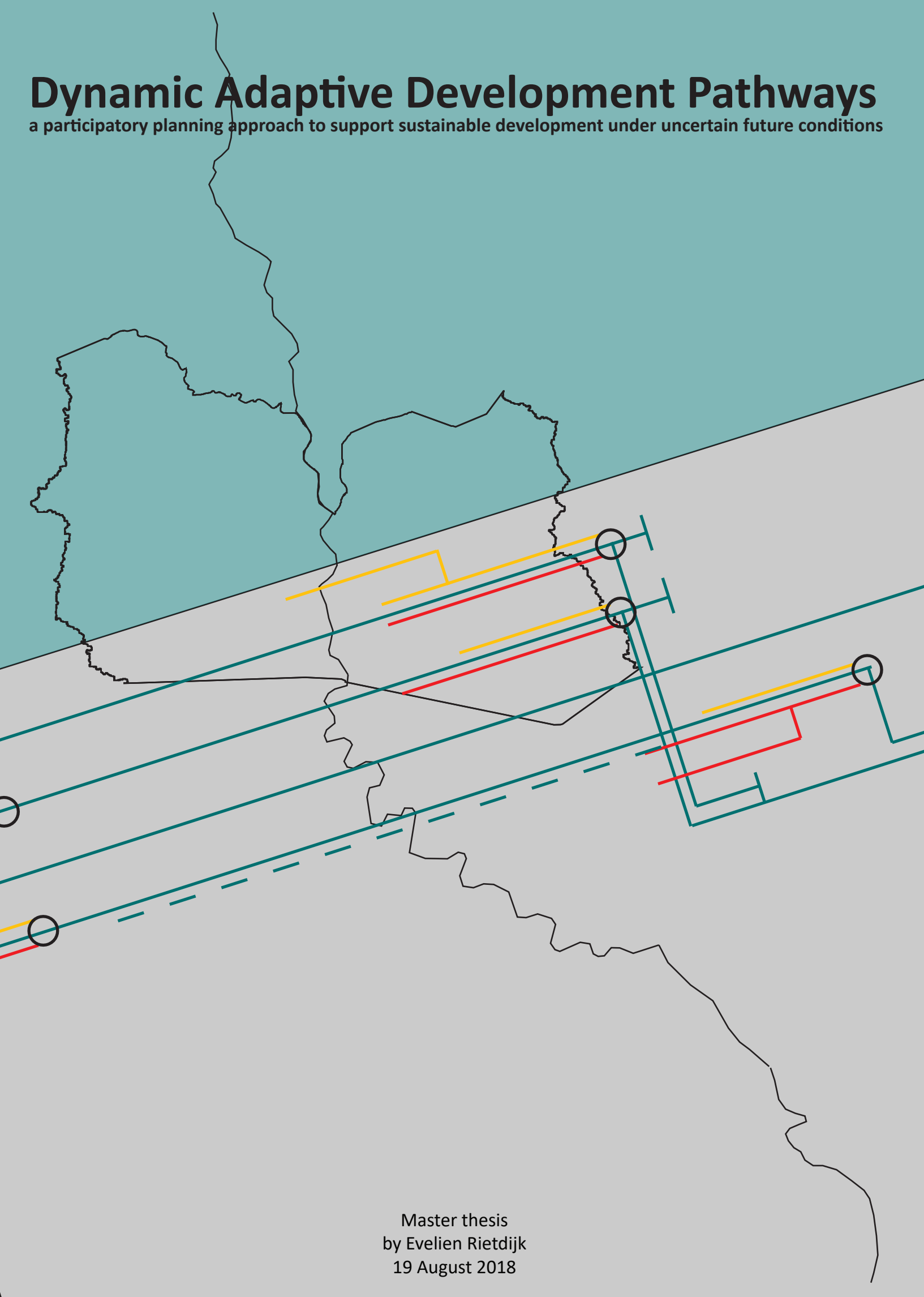


# Dynamic Adaptive Development Pathways

a participatory planning approach to support sustainable development under uncertain future conditions



Master thesis  
by Evelien Rietdijk  
19 August 2018



Master thesis  
By Evelien Rietdijk  
2018

lapho okulamanzi  
khona kulendlela

*where there is water  
there is a way*



# Dynamic Adaptive Development Pathways

A participatory planning approach to support sustainable development under uncertain future conditions

Submitted in partial fulfilment  
of the requirements for the degree of  
Master of Science in Civil Engineering  
at the department of Water Management

Author:

E. (Evelien) Rietdijk

Date of thesis defence:

Graduation committee:

Prof. P. (Pieter) van der Zaag	Delft University of Technology (Water Resources Management) UNESCO-IHE Institute for Water Education, Delft (Integrated Water Resources Management)
Dr. ir. J.S. (Jos) Timmermans	Delft University of Technology (Technical Policy and Management)
Dr.ir. J.H. (Jan) Kwakkel	Delft University of Technology (Technical Policy and Management)
Ir. A. (Annelieke) Duker	UNESCO-IHE Institute for Water Education, Delft

An electronic version of this thesis is available at <http://repository.tudelft.nl/>



# Preface

This report is the final thesis for the master in Water Resources Management of the Delft University of Technology. The thesis work was conducted as part of the A4-labs project in Sub-Saharan Africa. The subject of this research is the development of a planning approach for sustainable development under uncertain future conditions. The research consisted out of fieldwork in Zimbabwe in August and September and a desk study to assess the information and data gathered.

The possibility to think about the integration of social, economic and natural research fields made that I have experienced my graduation period as very interesting and pleasant time. Therewith, the fieldwork made the importance of the research clear and made this, together with the Zimbabwean hospitality, an unforgettable time.

I would like to express my gratitude to Pieter van der Zaag, for giving me this opportunity and guiding me with his positive energy in this research field. I am grateful that Jos Timmermans offered to be my daily supervisor, his strong analytical feedback and friendliness have been of great help. I would like to thank Jan Kwakkel for his knowledge and feedback and Annelieke Duker for her useful feedback and company in the field. Furthermore, I would like to thank Dabane for hosting me, Louise Nkomo and Benard Mpofu for their contribution to the A4-labs project and especially Ever-Joice Mpofu for her help translating during the fieldwork sessions.

I am grateful for my friends and boyfriend for supporting me through both the enjoyable and more difficult moments. At last, I would like to thank my parents for supporting me during my whole study period. Thanks, for giving me the opportunity to find my own pathways and explore life as a student in Delft and abroad.

Evelien Rietdijk

Rotterdam, August 2018





# Abstract

Rural communities in drylands of low-income countries represent highly vulnerable societies that are often strongly affected by the increased climate variability (UNDP, 2007/2008). Additionally to climatic uncertainty, local households have also to cope with strongly fluctuating political and economic conditions, which are difficult to predict and impede regional development. Current planning practices that aim to address these uncertainties are often model based top-down focused approaches that lack an appropriate inclusion of local stakeholders. Crucial next steps are the downscaling of models to increase their local applicability and the incorporation of the knowledge and preferences of practitioners to achieve a sustainable landscape management plan. In this thesis, I developed a participatory planning approach to support sustainable development under uncertain future conditions and applied it to a case study in the southern drylands of Zimbabwe.

The newly developed planning approach is based on a synthesis of current good practices in development aid and recent advancements of research in predictive planning and management. Specifically, the *dynamic adaptive policy pathways* (Haasnoot et al., 2013) are merged with the *landscape approach* (Sayer et al., 2013), which accounts for sustainable development in a participatory manner, and transformed into a new *dynamic adaptive development pathways approach*.

The dynamic adaptive development pathways approach was applied to plan the upscaling of irrigation practices using an alluvial aquifer in Zimbabwe. A critical step was the use of visualisation sessions and focus group discussions to define the landscape area and local values, as well as to assemble a set of promising development actions. I then assessed the collected information using value matrixes and a hydrological model, to design different pathways for sustainable development.

The creation of naturally, socially and ecologically sustainable pathways in a participatory manner for this case study proved possible and may function as a seed for sustainable development in the area. While uptake and application of the approach by local stakeholders still needs to be assessed, the adaptive capacity seems a valuable addition for development planning under uncertain future conditions.

# Table of content

Preface .....	5
Abstract.....	7
Table of content .....	8
List of Figures.....	11
List of Tables.....	13
List of abbreviations and acronyms.....	14
List of symbols .....	15
1 Introduction.....	16
1.1 Research context of this study.....	16
1.2 Relevance of research on pathways in development context.....	16
1.3 Study aims .....	17
1.4 Research approach.....	17
1.5 Thesis outline .....	18
2 Conceptual synthesis.....	19
2.1 Sustainable development .....	19
2.1.1 The landscape approach to support sustainable development.....	20
2.2 Planning for uncertain futures.....	23
3 Dynamic Adaptive Development Pathways .....	26
3.1 Merging DAPP and the landscape approach .....	26
3.2 The DADP approach .....	26
Step 1. Area and objective.....	26
Step 2. Opportunities and limitations .....	27
Step 3. Determine actions .....	28
Example visualisation methodology used for the case study in the Shashane basin in Zimbabwe ...	28
Step 4. Evaluate actions .....	30
Step 5. Develop pathways .....	31
Step 6. Select preferred pathway(s).....	32
Step 7. Determine parameters to monitor.....	32
Step 8. Specify planning .....	32
Step 9. Implementation.....	33
Step 10. Monitoring and learning .....	33
4 Case study.....	34

4.1 Step 1: Area and objective.....	34
4.1.1 Natural system .....	35
4.1.2 Social system.....	39
4.1.3 Economic system.....	42
4.1.4 Landscape area.....	43
4.1.5 Objective .....	44
4.2 Step 2: Future opportunities and limitations .....	45
Natural opportunities and limitations.....	46
Social opportunities and limitations .....	50
Economic opportunities and limitations .....	52
4.3 Step 3: Determine actions .....	53
Set of Development Actions .....	54
4.4 Step 4: Evaluate actions .....	55
Naturally bearable .....	56
Socially equitable .....	58
Economically viable.....	59
Evaluation matrix .....	61
4.5 Step 5: Develop pathways .....	61
4.6 Step 6: Select preferred pathway(s).....	65
4.7 Step 7: Monitoring .....	65
4.8 Step 8, 9 & 10: Towards implementation.....	66
5. Findings and discussion.....	67
Findings .....	67
Discussion.....	68
References.....	70
Appendices.....	77
A. Fieldwork.....	77
A.1 Fieldwork plan .....	77
A.2 Logbook.....	79
A.3 Initial semi-structured interviews with farmers .....	80
A.4 Meetings.....	81
A4Labs Partner meeting .....	81
District meeting .....	82

Ward Meetings .....	82
A.5 Expert open-interviews and discussions .....	83
Woosa – Environmentalist Dabane.....	83
Brian Forsters - Irrigation specialist .....	83
Mr B (Ben) Nyikadzino - Hydrologist ZINWA/Umzingwane Catchment Council .....	84
Sheppard Moyo (Dabane) .....	84
A.6 Visualisation sessions.....	84
Guideline visualisation methodology .....	84
1. Madleloulahlaza .....	87
2. Bekhimpilo .....	87
3. Mpumelela.....	88
4. Kathazu .....	89
5. Masinlanganeni .....	90
6. Thembani .....	91
7 Vusanani Tholoki .....	91
8. Siyazama .....	92
9. Shashane 5.....	93
A.7 Focus Group Discussions (FGDs).....	95
Ward 6 Sigangatsha.....	95
Ward 5 Beula .....	95
Ward 7 Malaba .....	96
B. Hydrological data.....	98
C. Social and economic data.....	99
D. Causal model .....	100
E. Technological uncertainties.....	101

# List of Figures

Figure 1: Own image, based upon Arts et al. (2017).....	21
Figure 2: Different planning approaches have been developed to account with static, static robust or dynamic methods for different levels of uncertainty.(Walker et al., 2013).....	24
Figure 3: The Dynamic Adaptive Development Pathway Approach comprises 10 steps that are followed sequentially. At different points in the process stakeholder consultations (blue numbers) and feedback moments (doted arrow) are incorporated.....	26
Figure 4: A. The adaptation tipping point is defined by the limitations of the hydrological (natural) system. B. The adaptation tipping point defined by the economic lead time. C. The adaptation tipping point defined by the social lead time D. The critical implementation period, defined by the tipping points of the three domains, with the economic dimension being the limiting factor. E. The critical implementation period, defined by the tipping points of the three domains, with the social dimension being the limiting factor. Panel A has been adapted after Haasnoot .....	31
Figure 5: The pathway map includes actions of the different domains, as implementation of an action depends on the natural, social and economic possibilities.....	32
Figure 6: Along the Shashane in the landscape area Dabane Trust already established several gardens, those will be taken as a starting point for the project. ....	34
Figure 7: The Shashane Catchment is part of the Shashe Subcatchment. The Shashe is part of the Mzingwane catchment in south western Zimbabwe. ....	35
Figure 8: Annual and monthly precipitation values from measuring stations near the project area.....	36
Figure 9: Pictures from the landscape showing from left to right i) riparian vegetation, ii) Mixed grassland and woodland and iii) Mixed grassland and woodland (degraded) (auteurs images).....	37
Figure 10: The classification map, showing the different land use types in the area. ....	38
Figure 11: The wards that overlap the Shashane sub-catchment, with a focus on ward 2, 6 and 7 where Dabane has established already a number of community gardens. ....	40
Figure 12: The organisational structure; the practitioners centred, from top-down the government structure and around the farmers the other (influencing) stakeholders. ....	42
Figure 13: The boundaries of the environmental, social and economic domain form together the boundaries for the landscape area of the project. ....	44
Figure 14: Community meeting to present the project to the local communities.....	45
Figure 15: The effect of natural, social and economic variability on the parameters of the landscape area .....	45
Figure 16: The ingoing and outgoing fluxes that contribute to the water storage over time .....	46
Figure 17: Water level changes for the different climate uncertainty scenarios without development actions .....	50
Figure 19: GDP Growth rate of the last 12 years and expected trend (IMF : World Economic Outlook (WEO) 2018).....	53
Figure 20: Visualisation sessions; left an impression of a session and right one of the resulting drawings. ....	54
Figure 21: Causal model of the to be evaluated effect of Development Actions on the natural, social and economic parameters.....	56
Figure 22: Water level (h(t)) for different development action under scenario S1 and S2 at landscape scale .....	57
Figure 23: Effect of water level (h(t)) changes with different consecutive development action at landscape scale for scenario S2 .....	57

Figure 24: Garden scale effect; a. Water abstraction changes for different development actions (A. B. and D), b. Water abstraction (Qabs [m3]) for development action E. sDifferent crop types and F. Fodder cropping;.....	58
Figure 25: Effect of Development Actions on social lead time at landscape scale .....	59
Figure 26: Income from garden/farmer including Development Action C. with a 10% increase in area/year .....	60
Figure 27: Estimated effect of development actions on economic lead time .....	60
Figure 28: Development Pathways for A. the landscape scale and B the garden scale .....	62
Figure 29: Estimated Development Pathways for garden scale, showing the effect of development actions on the social and economic lead time respectively; A. social pathways, B. economic pathways .....	63
Figure 30: The combination of social, economic and natural development pathways.....	64
Figure 31: The visualisation of the current landscape and future development actions of garden Madleloulahlaza.....	87
Figure 32: The result of the visualisation is a map of the current landscape that includes possible development actions of garden Bekhimpilo .....	88
Figure 33: Sensitivity analysis of the hydrological model, A at farm scale and B at garden scale. ....	102

## List of Tables

Table 1: Landscape principles (Sayer et al., 2013) .....	23
Table 2: Example of the visualisation methodology .....	28
Table 3 The classification of the area, based on the developed landscape classification map.....	39
Table 4: Parameters of the aquifer and adjacent area that provides runoff for this reach .....	47
Table 5: FAP crop coefficient for crops most produced in this area .....	48
Table 7: Average water use in the gardens, estimated after research in the field .....	49
Table 8: ↔ no change, ▼ descending, ▲ increasing trend .....	49
Table 9: This value matrix shows the qualitative values of relevant social indicators for 4 stakeholder groups.....	50
Table 10: ↔ no change, ▼ descending, ▲ increasing trend .....	52
Table 11: ↔ no change, ▼ descending, ▲ increasing trend .....	53
Table 12: The development actions and the parameters and domain they affect .....	56
Table 13: --- Large negative impact, -- moderate negative impact, - negative impact, 0 no change, + positive impact, ++ moderate positive impact, +++ large positive impact.....	61
Table 14: Prices of produce sold in the area (Mhlope, 2017) .....	99
Table 15: Price ranges for different cattle in the area (Mzingwane Catchment Scoping Study Report 2017) .....	99
Table 16 Population Distribution of Matobo District from Zimbabwe National Statistics Agency 2012 taken from the Mzingwane Catchment Scoping Study Report 2017).....	99

# List of abbreviations and acronyms

A4Labs	Arid African Alluvial Aquifer Labs
EMA	Environmental Management Agency
DADP	Dynamic Adaptive Development Pathways
DAPP	Dynamic Adaptive Policy Pathways
IWRM	Integrated Water Resources Management
ZINWA	Zimbabwe National Water Authority



## List of symbols

$\beta$	Runoff coefficient	-
$\eta_{\text{irr}}$	Efficiency of irrigation system	-
$\pi$	Income	USD/year
$A_{\text{riv}}$	Total area river	Ha
$A_f$	Area per farmer	Ha
$a_m$	Ratio of garden maize	-
$c$	Indication of the crop type	-
$ET_a$	Actual evapotranspiration	mm/month
$ET_0$	Reference evapotranspiration	mm/month
$k_c$	Crop coefficient	-
$k_{R_s}$	adjustment coefficient (0.16.. 0.19)	[°C <sup>-0.5</sup> ].
$K_{\text{sat}}$	Saturated hydraulic conductivity	mm/month
$R_s$	incoming solar radiation	[MJ m <sup>-2</sup> d <sup>-1</sup> ]
$R_a$	extraterrestrial radiation	[MJ m <sup>-2</sup> d <sup>-1</sup> ]
$T_{\text{max}}$	maximum air temperature	[°C]
$T_{\text{min}}$	minimum air temperature	[°C]
$n_f$	Number of farmers	-
$n_g$	Number of gardens	-
$P$	Precipitation	mm/month
$P_c$	Price for a certain crop	USD/kg
$Q_{\text{abs}}$	Water abstraction	mm/month
$S$	Storage in river basin	mm
$Y$	Yield	tonne/year

# 1 Introduction

## 1.1 Research context of this study

Dabane, a local Non-Governmental Organization of Zimbabwe has launched a new project titled Arid African Alluvial Aquifers Labs Securing Water for Development (A4 Labs) in the semi-arid to arid region of Sub-Sahara Africa. This action research program, funded by UNESCO IHE aims to develop experimental living labs where smallholder farmers, practitioners, agricultural extension officers, water engineers and students co-develop new approaches of accessing and using shallow groundwater to enhance agricultural production.

Communities in these regions are prone to climate change and the majority of young adult males leave the countryside or even the country in search of a better future. The project aims to create a reliable and sustainable source of water for agriculture using nature-based solutions by applying a farmer- and practitioner-centred research approach. The aquifer beneath dry river beds, which is in general replenished every year during rainy seasons, is used to reduce the communities' vulnerability to climate change. This includes sustainable small-scale community irrigated gardens that use simple hand pumps and water harvesting systems that could not only sustain local livelihoods, but also contribute to socio-economic development.

As climatic, social and economic conditions are uncertain upscaling these practices needs to be done in a sustainable manner. Critical focus-points are to (i) contribute to recovery of agricultural production in dry areas while the methods ensure to maintain sustainable groundwater abstraction limits and (ii) assess socio-economic possibilities under constantly changing future conditions. A new planning approach is required to support the design and management of upscaling irrigation practices in the area.

## 1.2 Relevance of research on pathways in development context

The increased variability of local climatic conditions is seen as one of the major challenges of the 21st century and evidence is increasing that poor and vulnerable societies will be most affected (UNDP, 2007/2008). Besides uncertain climatic conditions (Pachauri et al., 2014), socio-economic changes cause increasing demands and pressures on the environment and local communities. The Sustainable Development Goals are formulated to improve this situation and overcome these challenges. The goals are formed to meet the needs of the world's poorest on issues like poverty, health and education and achieving them requires a holistic approach with participation of all stakeholders. An analysis of the general well-being in Zimbabwe in 2016 shows that 42% of the households are considered as food insecure, with an average of 37.5% in the Matobo district, the main focus area of this project (ZIMVAC, 2016). To meet the goals and combat upcoming challenges we need clear-cut strategies for sustainable intensification to ensure a positive development in an uncertain future.

In semi-arid Africa communities, farmers and other stakeholders are desperately looking for opportunities to improve their long-term food security and livelihood perspectives (Love, 2013). Most of the challenges in drylands are water related, and household surveys of communities ranked the access to water as one of the highest challenges (ZIMVAC, 2012). Currently 80 per cent of the agricultural production is rainfed (Chitiyo et al., 2016), while the impact of climate change is unknown. The computer-based simulation of possible future climate regimes is a possibility to deal with this uncertainty. Different climate models, however, differ substantially in their predictions, so counting on the modelled precipitation and water availability brings high risks (Cervigni et al., 2015). The World Bank thus recommends a risk coping strategy, especially in the Semi-Arid regions in Africa (Davis & Hirji, 2014). And the IPCC already mentioned

in 2014 the idea of development pathways in their synthesis report\* (Pachauri et al., 2014). Nature-based solutions, like the use of water storages in alluvial aquifers proposed in the A4-labs project, seem to provide an opportunity for sustainable intensification. Upscaling irrigation practices from these aquifers requires to operate within the uncertain limits of environmental sustainability, but also provides an opportunity to contribute to local livelihoods and improve socio-ecological resilience. Besides the necessity to grow food crops for household consumption, it is important to emphasise the opportunities of producing for local and national markets. An important statement of foreign aid policies is that the focus of development aid should be on economic development to enhance the self-sustaining capacity of low-income countries and get them out of the “poverty trap” (Sachs, 2005). A top down approach with expert research and planning used to be common strategy to support communities and government bodies to develop their region. Local problems often have global causes, which makes it necessary to involve the capacity of the state (Pahl-Wostl, 2009). However, Robert Chambers (1983) already argued that ‘ordinary people know best’ and participatory development was the way to supplement the shortcomings of top down development. Current good practice of development work focusses on the inclusion of stakeholders from different levels coordinating top-down and bottom-up approaches to create an integrated development plan. Nevertheless, available planning approaches for uncertain futures are often model based, focussing on large spatial scales with little emphasis on participation of local practitioners (Lawrence & Haasnoot, 2017). These models often evaluate different policies to protect an area against changing future conditions rather than focussing on opportunities for development. It is necessary to downscale these models to account for regional heterogeneity and to enrich them with local knowledge and a participatory development-oriented approach.

### 1.3 Study aims

The overall goal of this research is to *develop, test and evaluate a participatory planning approach to support sustainable development under uncertain future conditions.*

This new participatory planning approach will be applied in a case study in the A4-labs project in Zimbabwe. The resulting pathway map can be used as a guideline for local water managers to upscale irrigation respecting natural, socio-economic and technical boundaries and to capitalise on development opportunities of the landscape. Hence, the main research question of this study will be:

*How can a planning be developed in a participatory manner for sustainable development under uncertain future conditions?*

### 1.4 Research approach

To answer the research question a participatory planning approach is developed, tested and evaluated. For the development of the approach first a conceptual synthesis is done by a desktop study to define current theories and practices. The developed planning approach is then tested with a case study, for which the steps of the newly developed approach are followed. These steps include a desktop study, fieldwork and the creation of a model. At last this research ends with an evaluation of the newly developed approach and recommendations for further research.

---

\* The fact that the IPCC already defined Development Pathways in their research in 2014 only came up at the end of this research. They do not go further in detail about the development of such pathways, which makes this research still a relevant contribution.

## 1.5 Thesis outline

In chapter 2 the main concepts the research is based upon are described in the conceptual synthesis, the methodology developed based on these concepts is described In chapter 3. This newly developed participatory planning approach is tested in the case study of the Shashane catchment in Zimbabwe (Chapter 4). Chapter 5 includes respectively findings and discussion of this research.

## 2 Conceptual synthesis

The objective of this research is to develop, test and evaluate a participatory planning approach to support sustainable development under uncertain future conditions. To develop this approach, it is necessary to understand the concept of sustainable development and combine current good practices of development aid with recent advancements of predictive planning and management. In this chapter, I will discuss recent conceptual advances and synthesise them into a planning approach that will be tested in this research.

### 2.1 Sustainable development

Humanity was long accustomed to see the environment as an external factor; nature was available to be used and exploited and human knowledge and technology could overcome all obstacles (Dryzek, 1997). However environmental problems and publications about environment degradation resulted around 1960-70 in the awareness that natural resources are not endless (Axelsson, 2009). Environmental problems and socio-economic challenges combined with an increased awareness of the linkages between them contributed to a change of perception (Dryzek, 1997) and led to the concept of Sustainable Development (Hopwood et al., 2005). The overarching aim of development is to improve the quality of life, especially in less developed areas, by transforming the socio-political and improving the economic situation (Rabi, 2016). The now worldwide accepted concept of sustainable development was defined in 1987 in the renowned Brundlandt report; “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland & Khalid, 1987). Social development, environmental protection and economic development, also referred to as people, planet, profit, have been established as the three interdependent pillars of sustainability (Adams, 2006). To measure the performance of sustainable development, the changes implemented in society can, thus, be evaluated according to these three pillars.

#### *Environmental dimension*

Opdam et al. (2006) state that for the achievement of ecological sustainability “the landscape structure should support those ecological processes required for the landscape to deliver biodiversity services for present and future generations.”. Key to sustainability is resilience, defined by Holling (1973) as “the ability of a system to absorb change and disturbance without changing its basic structure and function nor shifting into a qualitatively different state.” The consideration of coherent large-scale spatial structure of ecosystems is fundamental in order to implement ecologically sustainable management design (Opdam et al., 2006). Besides this the development of the landscape should be within the limitation of the natural system. Landscapes may change through human actions, but need to be kept on sustainable trajectory for our ecosystems (Haines-Young, 2009). The values of the ecosystem need to be defined with involvement of the stakeholders. Local actors have knowledge about functionally important species shaping and responding to landscape and it is necessary that they accept the proposed changes to come to a bearable design.

#### *Social dimension*

The social sustainability of a design depends on the ambition level of a society. Ambition, thereby represents a social construction expressed as socio-cultural norms of behaviour or formal policies (Clark & Clark, 2002). The ambition level of the stakeholders is an important component of the concept of weak and strong sustainability by (Neumayer, 2003). Weak sustainability thereby refers to a situation when resources may be used as long as the future generations have the same opportunities. Hence, sustainability includes only the protection of nature and species that is of use to humans. On the other

hand there is the concept of strong sustainability, focussing on the prevention of changing the structure and functioning of ecosystems from their natural state (Axelsson et al., 2011). To assess the social sustainability of a design, it is possible to develop stakeholder-derived sustainability indicators (Sheppard & Meitner, 2005). As different stakeholders can have different desires for the development of their landscape area, social sustainability is actor specific. In response to uncertain environmental and socio-economic conditions, planning strategies often lead to unnecessarily robust and therewith economically infeasible or environmentally unsustainable designs (Ceola et al., 2016). An adaptive approach, designed in cooperation with all stakeholders is often substantially more effective to address newly emerging challenges. Involving local stakeholders and, where possible, encouraging them to lead the process, is more likely to produce positive development outcomes (Smith et al., 2009)

### *Economic dimension*

Economic development has been defined as “an improvement in the quality of life without necessarily causing an increase in quantity of resources consumed” (Goodland et al., 1991). This implies that economic development can be sustainable, but it is important to note the clear distinction between economic growth and economic development. Exponential growth, or increase of per capita income of a country over a long period of time on a finite planet is unlikely to be sustainable. Economic sustainability does not imply a static economy, but human activities should be environmentally viable and result in the destruction of the ecological life support system (Goodland et al., 1991). Further, economic development should be socially equitable. Hence, it should not only decrease the number of people living below an “absolute poverty line”, but also aiming for a more of our society (Meier & Rauch, 1995). Thus, increasing household income is not the only factor considered, but rather economic sustainability should be defined in terms of basic needs such as goods and services (Barbier, 1987). It does not only relate to a higher production output, but also refers to diversification of outputs, quality increases and changes within the sector’s technical and institutional arrangements (Goodland et al., 1991). The focus should change from household and central government levels and decision making to achieve short- or immediate-term financial benefits, to long term sustainable development plans.

#### 2.1.1 The landscape approach to support sustainable development

Integration of the pillars on different spatial and temporal scales is necessary when developing an area in a sustainable manner. To prevent deterioration while increasing agricultural production it is required to not only look at the scale of a smallholder farm, but to integrate development in the landscape with respect to both stakeholder interests and environmental conservation. To support this integrative planning, since the 1990’s, after the Rio Earth Summit, the landscape approach is introduced. This landscape approach is, in analogy to Integrated Water Resources Management (IWRM) an holistic approach, often applied and linked to Sustainable Development (DeFries & Rosenzweig, 2010) and intends to “take both a geographical and socio-economic approach to managing the land, water and forest resources that form the foundation – the natural capital – for meeting our goals of food security and inclusive green growth”. Landscape or area-based approaches date back to Alexander Von Humboldt’s (1796-1859) epos *Kosmos* (1834) in which he wrote about an integrated view on landscapes, bringing together diverse branches of scientific knowledge and culture. The approach increased in popularity in the 1980’s (Sayer, 2009) and is now a widely accepted and used way to address mainly environmental and ecological sustainability issues (Patry & Ripley, 2007).

The landscape approach is often applied when the challenge can be called “wicked”, when the problems and final solutions of the development are very diverse and not clearly formulated (Rittel & Webber, 1973). Water resources management used to be characterised by clearly defined problems that society wanted to be solved (Pahl-Wostl, 2002). The different environmental, economic and social dimensions

were separated and addressed individually and an engineering approach with end-of-pipe solutions was the prevailing method. But increased environmental awareness and changing societal and economic systems changed the dimension of the problems. The problems became more complex and even a shared perception of the problem did often not exist. These so called ‘wicked problems’ asked for new approaches of problem solving. Arts et al. (2017) define the landscape approach as a boundary concept; “adaptable enough to satisfy specific disciplinary needs, but also robust enough to maintain a basic level of conceptual coherence across scientific disciplines”. Where in IWRM the catchment forms the boundary of the planning, the boundaries of the landscape approach are defined by different disciplines. Like a T shaped interdisciplinary approach, where different disciplines work together under one project, the landscape can be seen as the interconnecting factor of the pillars. As systems change in space and time the approach is build up around three dimensions; the spatial integration, social interactions and temporal scale. These dimensions will be discussed consecutively to give an overview of the structure of the approach and its application.

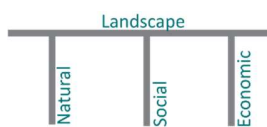


Figure 1: Own image, based upon Arts et al. (2017).

### *Spatial integration*

The first dimension of the landscape scale is the spatial integration of the various socio-economic effects and ecological connectivity. These various disciplines are considered within, but also define the landscape scale. Landscape ecologists, like King (1999) and others, reject the idea that a particular scale can be related to the concept of a landscape. Landscape scale is in ecological terms based on the flexible definition of a scale “at which one considers the pattern and interaction between the various mosaic elements of patch, edge and corridor” (Lavers & Haines-Young, 1993). The landscape approach takes a different definition, but the scale on which the landscape approach is applied is also flexible, varying from small, local areas to the whole earth as one landscape (Holmgren, 2018). Though research of (Pfund, 2010) states that a minimum of 100km<sup>2</sup> is required and 50% of the studies they reviewed fell in the range of 100-10.000 km<sup>2</sup> (Blaschke, 2006). The boundaries of what is a landscape scale are often not clear and this scale can even differ per person, depending on age or interests. Brassler (2012) states that the scale is defined by a shared issue acknowledge by the different stakeholders. The approach takes a specific geographical area as starting point, and besides the geophysical also social and governance factors define the boundaries. Large scale global, national or regional changes can have effect at local scale like household or farm level. Thus, besides the scale of the landscape area considered the local scale should also be assessed during the planning.

The landscape approach has evolved from the sectoral and value chain approach, by taking a more integral way. As the name suggests, the sectoral approach focusses on one specific sector of the economy. The collaboration of stakeholders within this sectors field is accounted for, usually on a national level, but it does not include issues in its wider environment. The value chain approach has already a broader focus and looks at value addition at all components in a chain. It still focusses on one commodity, but aims to add value for the least financially strong smallholders and SME’s. Though It aims for social inclusion the approach has little attention for the environmental and social impacts in the area. The landscape approach takes, instead of the sectoral and value chain, a specific geographical area as a starting point. Within this area it looks at spatial integration of the different sectors and chains and all external drivers influencing them, aiming for an integral development.

### *Social interactions*

Secondly, the approach aims to have a sustainable institutional system, which includes the integration of the different interests within the planning & the incorporation of the priorities of all stakeholders. Costanza and Mageau (1999) define institutional sustainability as: Institutions with a wise government are most likely to be resilient, making good governance and sustainable institutions are mutually enforcing. Institutions need to respond and be able to adapt to changing conditions and environment. But problems are often multiscale and cannot be solved by local leaders alone, therewith changes at one spot have often external effects elsewhere. Policy, governance and management should link the different local to national or regional institutions and make them more aware of spatial consequences. Therewith stakeholder participation is seen as a necessity to come to sustainable plan. Besides the case that people have a fundamental right to be included in considerations including their vision and knowledge can also improve the outcome. The bottom-up approach identifies adaptation strategies empirically, making it more likely that stakeholders approve the plan (Girard et al., 2015).

### *Temporal scale*

Therewith, societal change throughout the process, seen as social learning combined with adaptive management, is seen as the most important aspect in the transformation towards sustainability (Pahl-Wostl, 2002). It is inevitable that landscapes change over time due to internal and external processes. Humans change landscapes based on their economic, social and ecological wishes (Linehan & Gross, 1998) but also natural processes have their influence on the evolvement over time. Landscapes are not static, thus adaptive management is crucial to react to these changes (Brown et al., 2005). Monitoring and evaluation should assess the change in resilience over time, including a change in “drivers of risk, capacities and assets of communities and the enabling environment” (International, 2017). The effect of both development actions and other drivers on the different elements should be assessed to be able to adapt in an appropriate manner to the uncertain future conditions.

### *Principles*

The aspects considered in these three dimensions are summarised in a set of principles (Table 1). Incorporating these in a planning should create a design flexible enough to adapt to change, and that integrates multiple objectives for the best possible benefits of all stakeholders (Sayer et al., 2013).



Table 1: Landscape principles (Sayer et al., 2013)(Sayer et al., 2013)(Sayer et al., 2013)(Sayer et al., 2013)

1. The dynamic nature of landscapes forms the basis for continual learning and **adaptive management**.
2. Intervention strategies are built on **common concerns** and shared negotiation.
3. Landscape processes are shaped by influences from **multiple scales**.
4. Landscapes are **multifunctional** by nature, which requires choices and trade-offs.
5. **Multiple stakeholders** frame objectives differently, hence all stakeholders need to be engaged.
6. Trust among stakeholders is crucial to build up a **negotiated and transparent change logic**.
7. **Clarification of rights and responsibilities**, especially regarding land and resource use, is a necessity.
8. **Monitoring** of progress has to be done in a **participatory and user-friendly** manner.
9. System-wide **resilience** is to be achieved through recognizing threats and vulnerabilities, and the capacity to resist and respond.
10. The complexity of landscape processes requires **strong capabilities of all stakeholders** involved.

The principles can be seen as a toolbox to guide implementation for allocating and managing land (Sayer et al., 2013) to achieve social, economic, and environmental objectives in areas where productive land uses compete with environmental and biodiversity goals. The design should be flexible enough to adapt to change, and integrate multiple objectives for the best possible benefits of all stakeholders (Sayer et al., 2013). While these principles should be taken into account and applied in an iterative manner, they do not provide a directly applicable framework that can be used for planning under uncertainty (Reed et al., 2016). Sayer et al. (2013) provide a selection of methods and tools that might be used to address each principle, but also mentions associated constraints. The landscape approach thus provides a framework to integrate policy and practice for multiple competing land uses (Reed et al., 2015), but lacks a general methodology for implementation (Lindenmayer et al., 2008).

## 2.2 Planning for uncertain futures

To create a planning that supports sustainable development one has to accept, understand, and manage deep uncertainty (Hopwood et al., 2005). Hallegatte et al. (2012) defines deep uncertainty as “a situation in which analysts do not know or cannot agree on (1) models that relate key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes.” For a deeply uncertain future it is possible to come up with multiple different alternative scenarios, but impossible to specify their likelihood (Kwakkel et al., 2010). Deep uncertainties are prevalent in environmental conditions, like climate variability, but are also established in economic changes or developments and societal perspectives and preferences, such as stakeholders’ interests as cited in (Haasnoot et al., 2013). Besides those transient uncertainties of (i) natural and (ii) social uncertainty (Haasnoot et al., 2011) incorporated (iii) technological uncertainties in their categorisation, herewith including the uncertainties that come with modelling complex systems. Technological uncertainty locations include model uncertainty, inputs to the model, parameter uncertainty and model outcome uncertainty (Walker et al., 2013), but also a lack of understanding of processes, model incompleteness or over-simplification of processes (Haasnoot et al., 2011). In developing countries uncertainty lies in the natural and socio-economic uncertainties, but also in the lack of data and thus large technological uncertainty.

Literature distinguishes four approaches to deal with these deep uncertainties in making sustainable plans; resistance, resilience, static robust and dynamic robust planning (Walker et al., 2013). A resistant approach plans for the worst possible case or future, this turns out to be often very costly (Van Drunen et al., 2009). The resilient approach focusses on quick recovery of the system. Since the Brundtland report scientists and policymakers have agreed that it is necessary to develop sustainable plans, meeting the social, economic and natural requirements. These plans used to be static 'optimal', developed for the most likely future, or static 'robust', anticipatory with an acceptable outcome for most plausible futures (Hallegatte et al., 2012). But the extrapolation of trends, on which those futures often are based, are not always correct and plans based on these expectations are thus likely to fail. Recent awareness of changing conditions and the effects of globalisation make that a plan is considered sustainable not only if it coincides with the three pillars, but also if it is robust and adaptive. Meaning respectively it performs effective for or independent of an uncertain future and can adapt to changing conditions. When there is a lack of resources, it is favourable to plan in a dynamic adaptive manner, adjusting the plan based on changing situations or new knowledge. The overview of approaches for adaptive policies (Figure 2 ) shows that the Dynamic Adaptive Policy Pathways approach seems most suitable for this situation.

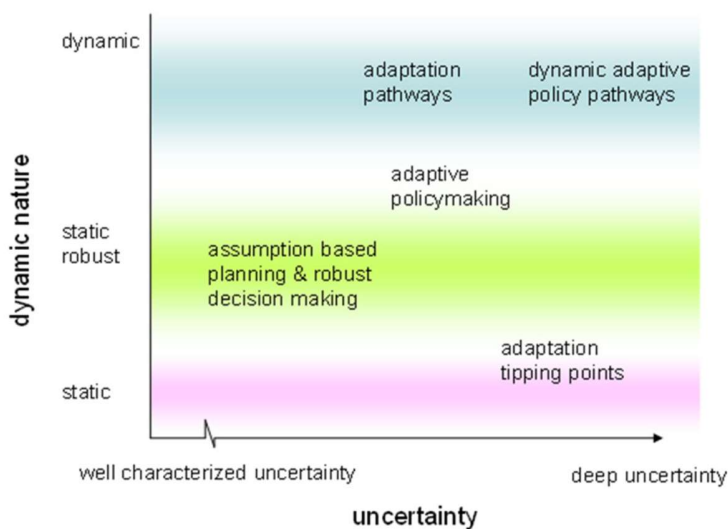


Figure 2: Different planning approaches have been developed to account with static, static robust or dynamic methods for different levels of uncertainty (Walker et al., 2013).

The DAPP approach focusses on adaptive planning to develop a planning for an uncertain future. Instead of a static robust system, a development strategy should be made flexible i.e. able to adapt to changing conditions (Hallegatte et al., 2012). Haasnoot et al. (2013) developed this method to create sustainable water management strategies for an uncertain future. Multiple pathways are developed by the DAPP process, using a computational model. By the use of transient scenarios, representing a variety of relevant uncertainties and their development over time, the impacts of drivers on the water system are explored, and policy actions at trigger points are implemented if necessary. This leads to an adaptation pathways map and, with the relative costs and side effects of each pathway identified qualitatively, into a roadmap for decisionmakers (Haasnoot et al., 2013; Haasnoot et al., 2012; Lawrence & Haasnoot, 2017). Adaptive approaches depend on active learning by all relevant stakeholders (Pahl-Wostl and Hare 2004), this implies targeted monitoring to foresee relevant changes and reassessing the plans continuously (Sayers et al 2012). Research of Maru et al. (2014) has tested this adaptive pathways approach in a developing context and has found it useful in “uniting vulnerability and resilience narratives, and broadening the scope for adaptation policy and action.” The costs in this context need to be kept low and there is an interest to postpone larger investments as long as possible, hence the use of transient scenarios for the

creation of pathways is found useful to determine trigger points. However, the approach is computationally expensive and requires detailed information on design specifications and rules (Kwakkel, 2017). The approach can be used as a basis, but should be adjusted to the development context with most emphasis on the preferences of the stakeholders.

# 3 Dynamic Adaptive Development Pathways

## 3.1 Merging DAPP and the landscape approach

The DAPP approach is a theoretical framework designed by experts and tested mainly with conceptual models of test cases. The planning approach is designed conservatively with the aim to ‘enhance a plan by keeping it from failing’ (Walker et al., 2013). Stable systems are maintained by assessing the limitations of a system and defining when policies are needed to maintain its sustainability. In developing contexts, the focus should not only be on conservation of the area but also on possibilities for development. It is recommended to not concentrate only on the vulnerabilities and limitation of the system and conserving its function, but mainly on opportunities to improve an area in a sustainable way.

The landscape approach is designed to develop an area in a sustainable manner by integrating multiple objectives for the best possible benefits of all stakeholders at different spatial and temporal scales. The incorporation of the landscape approach in the steps of the Dynamic Adaptive Policy Pathways could provide a suitable framework for sustainable development (in Sub-Saharan Africa). By using these two methods in a complementary manner, the DAPP approach is transformed into the Dynamic Adaptive Development Pathways (DADP) approach.

The here presented DADP approach focusses on participatory planning for uncertain future conditions, scaling between local and landscape level whilst incorporating natural and socio-economic values. The DAPP approach provides a structured planning approach that incorporates the landscape approach to account for the aspects of sustainable development. To develop a plan that will be embraced by all stakeholders it is important to consult them in several steps of the planning and implantation process. Qualitative scenarios are explicitly included as, especially in developing countries, data is scarce and qualitative approaches can provide valuable input for predictive models.

## 3.2 The DADP approach

The below described steps of the DADP approach should be sequentially implemented under participation of the different stakeholder groups (Figure 3). During the process, the different principles of the landscape approach are accounted for as explained in the description of the respective steps. The result of the approach is a pathway map that shows the time the development actions are within the sustainable limits of the natural system. It also incorporates the social and economic lead time for the different actions to secure an integrated planning of development actions.

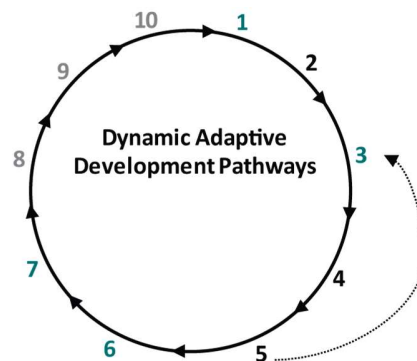


Figure 3: The Dynamic Adaptive Development Pathway Approach comprises 10 steps that are followed sequentially. At different points in the process stakeholder consultations (blue numbers) and feedback moments (dotted arrow) are incorporated.

### Step 1. Area and objective

First, the area and spatial scale of the project are chosen and combined the planning objective will be defined. The scale of the area is defined by natural, social and/or economic heterogeneity, specified by expert and local knowledge. In general, the extend of a landscape area varies between 100-10 000 km<sup>2</sup>. It is necessary to evaluate the natural, social and economic characteristics of the current situation and the major uncertainties that may influence the future. While a complete alignment of objectives among

stakeholders is unlikely, as stakeholder groups have different values, beliefs and objectives, the overall goal of this new approach is to support a sustainable development in the target region.

The description of the landscape is formulated by relevant literature and data studies in preparation of the fieldwork. A field visit is necessary to verify and adjust the data used for the description of the current situation and will allow to define the opportunities and limitations of the natural system. Data about the most important sectors and factors in the area and the scale of the natural environment needs to be assessed in participation of different stakeholders, as interpretations of the baseline situation can vary between them. Field observations, including transection walks and photographs, can be necessary for the ecological data gathering.

The second purpose of the fieldwork is to create a common concern and vision with all different stakeholders as entry point for the project. Ubels & Horst (1993) found that better project outcomes were achieved with a participatory approach. The building of appropriate capacity at all scales at which interventions are implemented is important for a sustainable design (Ncube, 2010). Meetings at local, regional and/or national level need to be conducted, where the plan is presented, to gain the approval of diverse government bodies and administrative units and include their aims. Further, community meetings with communities and local leaders need to be facilitated to determine whether community members are willing to participate.

## Step 2. Opportunities and limitations

In step 1 the different components of the area are described, creating a formalized description of reality. The available knowledge is divided between the domains of the three pillars of sustainability and components relevant for this research are described. The different domains of the landscape area are incorporated in this step using a causal model to identify the relationships between key variables. Models are always simplifications of the real world, but a distinction are frequently made between scientific and, engineering models on the one hand and policy models on the other hand. The first are primarily trying to explain the present situation and match the real world as closely as possible, while policy models are often created to provide insight in the future and help with the decision making process (Walker & van Daalen, 2013). They are, like the model used in this study, created to test and compare the reaction of the system to different policies or, in this case, development actions. Often policy models are relatively simple. To calculate the change in water storage over time, for example, a basic water balance model can be used (Love et al., 2011).

The observations of natural, social and economic systems provide parameters for a hydrological policy model and qualification of social and economic parameters. The values of these parameters are used in step 4 to evaluate development actions and their sustainability. The values and even variables that indicate threshold levels differ between landscapes and it can be hard to define critical indicators for transitions. For this approach they are defined under the involvement of the stakeholders and local experts. Uncertainties are translated into scenarios which are used to identify the potential future system dynamics and help to achieve the ecological, social and economic objectives of development. Further, uncertainties are then taken into account in the form of scenarios for different climate, social and economic projections. The application of such policy models allows to explore the opportunities and limitations of the target area in an uncertain future and investigate the consequences if no development actions are taken.

Sustainable development is related to the social, natural and economic properties of a system. When the focus is put on arid regions of Sub-Saharan Africa, water availability is a crucial component. The hydrological part of the model will thus be translated from a qualitative to a quantitative model to

evaluate the changes in water storage. The capacity of an alluvial aquifer and its current status are measurable, making it possible to quantify changes over time. A model of the changes in aquifer storage and water fluxes at a larger time and spatial scales make it possible to analyse agriculture-focused development opportunities (Cobbing et al., 2008). This model should represent robust values for the aquifer storage under different development scenarios, defining the sustainability of the actions. It is not the aim of such a model to provide an optimal solution, but to provide information about positive and negative aspects of different scenarios and to support sustainable development in the region (Walker et al., 2013).

### Step 3. Determine actions

The third step is primarily based on stakeholder participation and constitutes the establishment of a rich set of possible development actions. Stakeholders will be thereby involved to formulate their ideas about development for multiple scales and functionalities. The desired future will be defined by the stakeholders: NGO's, experts, ministry bodies and, representing a key group, farmers and community members. Therefore, the development of DADPs in a participatory manner requires repeated field visits. In community meetings, focus groups discussions and visualisation sessions, visions of the planning capacity and the adaptability of communities to climatic, technological and socio-economic changes are formulated, which are necessary for the development of the DADP's. Development actions are opportunities to get 'more out of the system' while accounting for its limitations. This means they define possibilities for sustainable development in the area. Visualisation sessions and focus group discussions with stakeholders and experts should result in multiple actions that can be potentially combined to support development of the area in the near and distant future.

Visualisation sessions with stakeholders are used to indicate which potential future scenarios are considered as positive and what is required to reach these aspired development trajectories. The input can be used to develop different pathways, which again will be discussed with the different stakeholders. Poolman (2011) developed and tested a visualisation methodology which can be used to support participatory planning. This technique has the same benefit as narrative interviews; the interviewee guides the interview and will tell information that could not be predicted. The methodology is closely related to other participatory approaches and builds upon the steps of seeing, reflecting and planning an action. The methodology is based upon three questions that facilitate the exchange of ideas and stimulate dialogue. They are addressing (1) the present: what does the water system look like now? (2) the future: what should the water system look like in the future? (3) and the implementation: what has to be done to get from the present to an aspired future? Providing participants the opportunity to create their own drawings of their desired future represents a form of empowerment and creates trust among the interview partners. Table 2 shows an example of this visualisation session, used for the case study in Zimbabwe.

*Table 2: Example of the visualisation methodology*

<p>Example visualisation methodology used for the case study in the Shashane basin in Zimbabwe</p> <p><i>Purpose:</i> Creating a rich set of Development Actions in a participatory manner</p> <p><i>Participants:</i> People that are in some way involved with irrigated farming from an alluvial aquifer (affecting/affected)</p> <p><i>Tasks and questions:</i></p> <ul style="list-style-type: none"> <li>• What is the present situation (natural, social and economic) of the area?</li> <li>• What are the current trends and uncertainties for the future? (agricultural practices / (im)migration /</li> </ul>
--

- Which development actions are possible to support development of the area in the near and further (next generation) future at local (farm) and landscape scale?
  - What are the natural opportunities and limitations?
  - Which ecosystem services are valued and how can the living environment be improved by changes in the ecosystem?
  - What are the social opportunities and limitations?
  - What are the economic and technological opportunities and limitations?
  - What is necessary for upscaling/starting a farm and who can supply this (in which timespan / quantities)?
  - What are the natural opportunities (and limitations)?
    - Different types of agriculture
      - Perishable
      - Fodder crops
      - Maize
      - Combinations
    - Valued ecosystem services
- What are the socio-economic opportunities (and limitations)?
  - Market access
  - Youth involvement / gender equality
  -
- What are the technological opportunities (and limitations)?
  - Different pumps
  - Different irrigation systems

*Tools and resources:*

- Paper (~A1)
- Colored markers/pencils
- Tape
- Notebook & pencil to take notes

*Session:*

1. Present situation
  - Draw outlines to give starting point and ask participants to draw their living area
    - Water (body)
    - Agricultural fields (dry and wet) / irrigation
    - Livestock
    - Housing
    - Market
    - Trees
    -
  - Discuss current situation
    - Responses to changing climate
    - Garden for yourself to make profit?
    - Irrigation dry/wet season
    - Spread risks?
    - Pump breaks?
    - Is environment important commercial, or because it strikes back?
    - What do you do if there's no recharge
    - Would you do things differently if you had a garden for yourself?
    - Different types of agriculture
  - Ask to draw their sources of income
    - What do they use from nature? (ecosystem services)
2. Drawing future situation
  - Circle areas for opportunities (and limitations)
  - Draw changes
  - Number them
  - Discuss the opportunities

3. What is needed? / What can you provide? / How to get the rest?
- Discussion
    - o After a good year, how much of the profit would you invest in the garden?
    - o Willing to pay/ invest?

The future opportunities need to be defined at local and landscape scales. Studying the opportunities and potential stressors at the farm level can create insight into the key factors and processes that may determine opportunities at a larger scale. However, farmers may not have the capacity to make changes at a landscape scale. Hence, information and involvement of diverse stakeholder groups is required. Visualisation sessions can be used to indicate which future is considered positive and what is needed to get there. The result of the visualisation sessions is a set of maps with story lines, those are analysed to establish a rich set of development actions. These development actions are used as levers in the model representing human induced modifications of the system.

#### Step 4. Evaluate actions

The actions are evaluated based upon the criteria of sustainable development defined in step 2. To determine whether a system does not degrade ecological communities and their environment, it is necessary to define the natural limitations of the system, i.e. natural threshold levels. The incorporation of the set of development actions in the hydrological model allows to assess their effect on the water system (e.g. the water storage) and the natural vegetation. The moment the natural threshold level is reached, the system is approaching a tipping point, a moment where a system is expected to change to an alternative state. In most cases, this this state change is not desired and it is necessary to prevent reaching this tipping point.

The evaluation of social system properties is based upon the characteristics of the people who live in the area and are directly or indirectly affected by the development actions. Further, social lead times are actor-specific and defined here by the willingness of stakeholders to cooperate in or take up development actions. Social sustainability was assessed by identifying social indicators in stakeholder meeting and interviews in step 2. Actions need to be evaluated according to these criteria, the threshold levels. When the criteria are not met, a time necessary to create social willingness to participate needs to be estimated, which is referred to as social lead time. When the threshold level is reached a positive development tipping point is met, so i.e. a desired point in time when the state of the social system is positive towards implementation. In the same way the economic viability is defined by economic indicators such as financial means and materials required to implement an action. The economic lead-in time is defined by the time necessary to reach the economic development tipping point for implementation.

The evaluation of social, economic and natural sustainability culminates in the definition of a critical implementation period (Figure 4D). Critical implementation periods are defined as time windows where there is social and economic sustention, while the natural threshold level is not yet reached. The used characteristics of the different domains are defined in step 2 and are scale and space specific. By putting these characteristics on a temporal scale, it is possible to define the lead-in time to reach an objective and the time an action will be sustainable. This is thus a critical time to implement development actions to develop an area in a sustainable way.



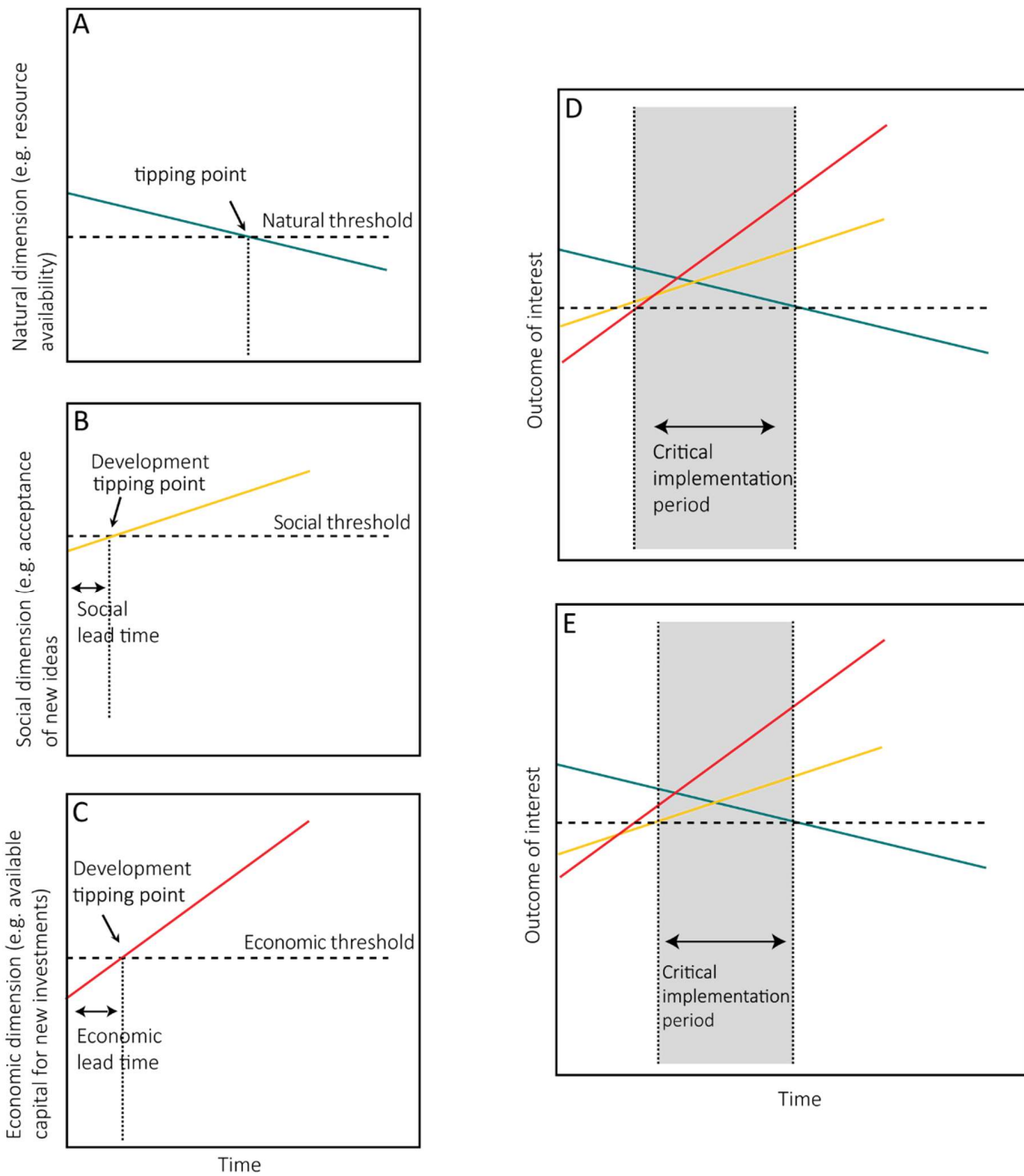


Figure 4: A. The adaptation tipping point is defined by the limitations of the hydrological (natural) system. B. The adaptation tipping point defined by the social lead time. C. The adaptation tipping point defined by the economic lead time. D. The critical implementation period, defined by the tipping points of the three domains, with the economic dimension being the limiting factor. E. The critical implementation period, defined by the tipping points of the three domains, with the social dimension being the limiting factor. Panel A has been adapted after Haasnoot

### Step 5. Develop pathways

In a next step, scale specific development pathways can be assembled based on the information gather for individual actions in step 5. The DADP approach incorporates additionally to the strategy of the DAPP approach of implementing policy actions at critical moments in order to avoid tipping points and prevent the (water) system from undergoing critical transition, actions to develop the landscape area. The

development tipping points define the time periods when a development action can be implemented successfully. Only when the objectives of all domains are met, a development action can be implemented. For the development of a pathway map thus three things are important; the time till the natural limitation is reached, the social lead time and the economic lead time.

The lead-in times, the time it takes to reach the social and economic threshold levels is per development action set out over a time line and on this time line multiple actions are combined. On this time line also the time in which the action is within the natural limits is shown (Figure 5). Together these lines form one path that can be taken to develop an area. When different development actions are put together a pathway map is created.

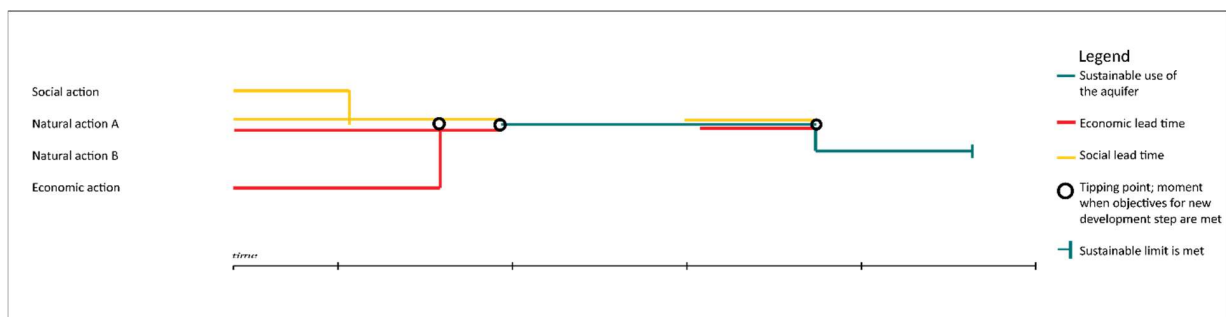


Figure 5: The pathway map includes actions of the different domains, as implementation of an action depends on the natural, social and economic possibilities

The exact time window of the critical implementation time is uncertain due to changing external (e.g. international markets) and internal (e.g. climate) conditions. Further, it can also be changed by the interaction between development actions. Based on fundamental criteria such as urgency and costs a set of promising pathways can be developed, that together form a development pathways map. However, it should be taken into account that changing conditions change the length of the pathways.

#### Step 6. Select preferred pathway(s)

In step six, the stakeholders will choose their preferred pathways. To create the highest chance for success, this decision making should be community-centred. Pathways can be scale and space specific and it is well possible that local and landscape scale pathways are created that interact with each other. Such potential interactions need to be taken into account. Current social and economic values can be used to define the first actions to implement and by monitoring ongoing changes in the landscape, the chosen pathways can iteratively be adjusted over time.

#### Step 7. Determine parameters to monitor

The changes of the social, economic and natural parameters that identify the opportunities of implementation and limitations of development actions should be monitored. In the seventh step the uncertainties in the parameters that influence the implementation and sustainability of actions are identified and monitoring recommendations are given. Therewith the rights and responsibilities of the stakeholders have to be clarified in the project area to ensure that actions are taken before tipping points are reached.

#### Step 8. Specify planning

In the eighth step the Dynamic Adaptive Development planning is specified and the necessary measures to start implementation of the first development actions are chosen. This should be done in cooperation with all stakeholders to verify the uptake of the plan by the community.

#### Step 9. Implementation

The ninth step represents the implementation of the development actions following the selected development pathways.

#### Step 10. Monitoring and learning

And the important tenth step defines the monitoring, necessary to determine when the next trigger point is reached. Participatory and user-friendly monitoring is required to bolster the uptake of the plan.

*(For step 6 till 10 only recommendations will be given in this research.)*

## 4 Case study

In this chapter an overview will be given on how the developed Dynamic Adaptive Development Pathways approach is used in practice. This case study is used to test how *Dynamic Adaptive Development Pathways can be developed in a participatory manner for upscaling irrigation practices from an alluvial aquifer for an uncertain future in the Shashane basin in Zimbabwe*. By the use of the DADP approach a pathway map is designed in a participatory manner for upscaling irrigation practices from an alluvial aquifer for an uncertain future in the Shashane basin in Zimbabwe.

The steps of the DADP approach, as described in paragraph 3.2, will be followed in consecutive order. In step 1 an extensive description of the case study area is given (pg. 32 – 42), the modelling, visualisation sessions and developed pathways are described in step 2 - 5 (pg. 42 – 61) and steps 6-10 consider the implementation (pg. 62 – 63).

### 4.1 Step 1: Area and objective

To further develop, test and evaluate the DADP approach in practice an area is needed where there is an aim for development. The landscape around the Shashane river in south-western Zimbabwe is appointed as test site for the A4Labs project and will be used as case study area for this research. This area is selected since the descriptions about geohydrology and the climatic conditions are representable for a larger part of the area. Therewith Dabane Trust and other organizations have been working in the area for a longer period, thus providing a base for further research (Figure 6). To define the boundaries of the landscape area it is necessary to look at both the natural, social and economic system. Thereafter the objective for development is specified for the area, which coincides with the aim of the A4labs project.

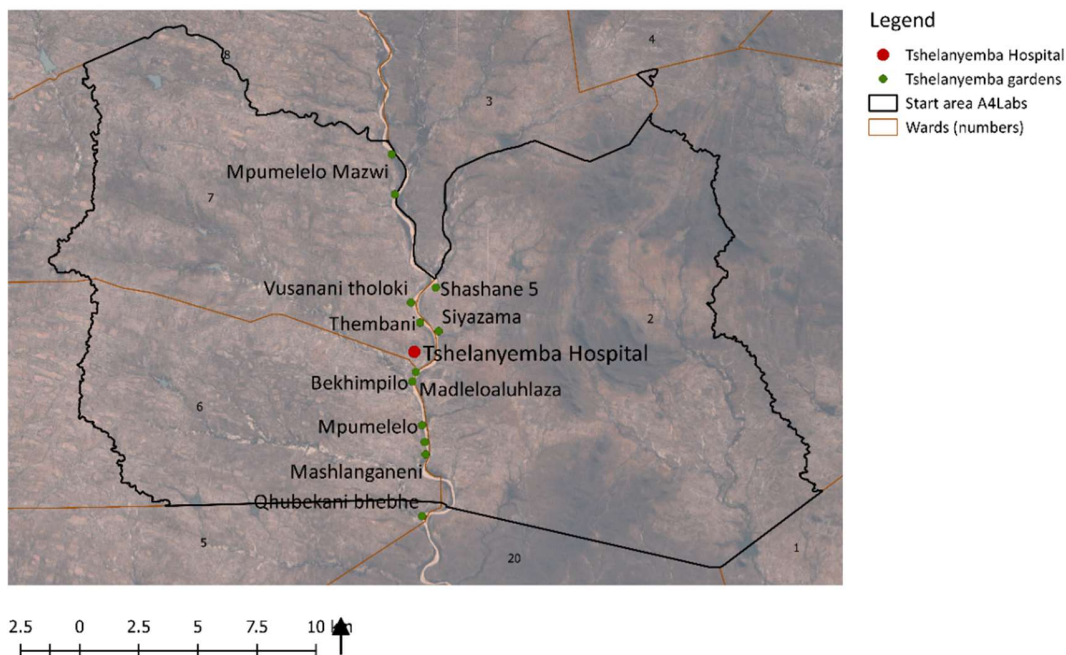


Figure 6: Along the Shashane in the landscape area Dabane Trust already established several gardens, those will be taken as a starting point for the project.

#### 4.1.1 Natural system

A specific geographical area is taken as a starting point to define the landscape area. The test site of the A4Labs project will have a small scale from which upscaling possibilities will be assessed. The Zimbabwe National Water Authority (ZINWA) has divided Zimbabwe into seven catchments, this research focusses on the Mzingwane catchment, and the Shashe sub catchment. The test site is situated in part of the Shashane river catchment, which is part of the Shashe sub-basin in south western Zimbabwe ending up in the Limpopo. The river has a total length of 206 km and has two dams (Shashane dam and Antelope (or Gulameta) dam) in the upper half of the catchment (Mpala et al., 2016). The Shashane catchment has a surface area of approximately 2600km<sup>2</sup> (Blok, 2017). The project location is within the Zimbabwean Lowveld, with an altitude of approximately 1250 m.

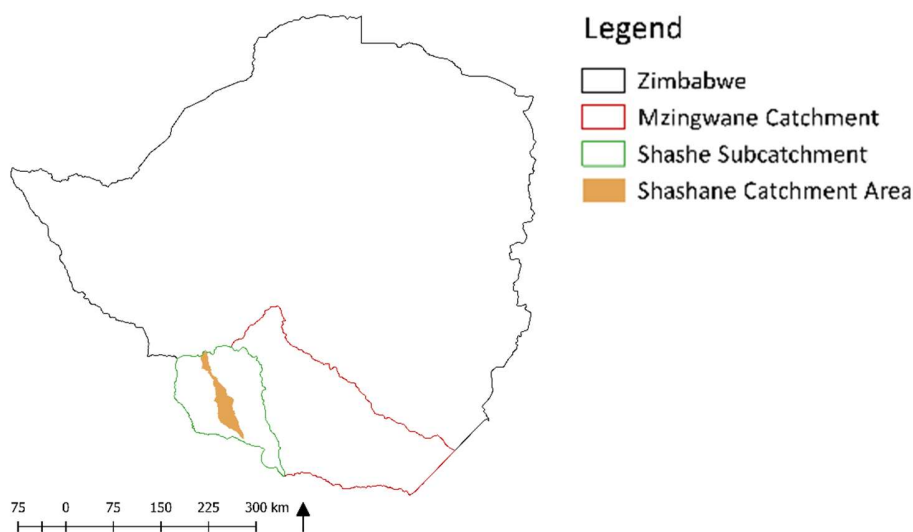


Figure 7: The Shashane Catchment is part of the Shashe Subcatchment. The Shashe is part of the Mzingwane catchment in south western Zimbabwe.

#### Geology, soil characteristics

The upper reach of the Shashane River is more mountainous with large changes in altitude, while the lower reach, the project area, of the Shashane River has more gradual slopes. The bedrock in the Shashane catchment consists of gneissic granite formations and locally a greenstone belt (Rhodesia Geological Map, 1971). Gneissic granite means that the granite formation has been exposed to high pressure and temperatures, but has not fully transformed to gneiss yet. Gneissic granite is an impermeable hard rock which prevents leakage from the aquifer. While seepage can be a substantial flux in more deeply-weathered terrains (De Hamer et al., 2008) the lateral boundaries and the bottom of the aquifer seem to be impermeable (Blok, 2017; Love, 2013). The soil in this stretch of the Shashane catchment is mostly between 100-150 cm deep, with some areas of only 30 cm (Van Engelen et al., 2004). The lower reach consists mainly of luvisols, with a small area of lixisols (Jones et al., 2013). Luvisols generally consist of a mixed mineralogy and have a high nutrient content, good drainage of these soils could make them suitable for a wide range of agriculture. Lixisols develop on old landscapes in a tropical climate with a pronounced dry season, their age and mineralogy have led to low levels of plant nutrients and a high erodibility, making agriculture difficult and only possible with frequent fertilizer applications, minimum tillage, and careful erosion control (Manyanga, 2006). The upper reach of the soils has renosols and leptosols, consecutively sandy, rapid draining and shallow sandy, free draining. The upper soil is thus not able to hold much water, which results in rapid runoff to lower areas. It is known that the area is located on a schist belt (Hussey, 2003), though the exact location is unclear. If the schist would cross the

alluvial aquifer the bedrock would possibly not be impermeable at all places, leading to quick seepage. During recent measurements by (Blok, 2017) in the area this did not occur, therefore the assumption of impermeable bedrock is made, but care should be taken with expansion.

#### *Climate and hydrological parameters*

As said the Shashane catchment lies in the south western part of Zimbabwe, known as one of the driest areas of the country. In this semi-arid region, the rainfall is controlled by the Inter Tropical Convergence Zone (ITCZ). The ITCZ moves with the sun, going south with the start of the rainy season in summer (October/November) and back north in late summer (March/April) (Love et al., 2006). As rainfall is decreasing from north to south, the study area is one of the driest in Zimbabwe. Mean annual precipitation is 450 to 475 mm (in the Shashane catchment) (Mansell & Hussey, 2005) while mean annual potential evapotranspiration is around 1800mm (measured just outside the catchment area). Therewith the wet season is marked by brief convective storms with high spatial and temporal variability (Love et al., 2011)& (Van Engelen et al., 2004). More than 50% of the precipitation has an intensity over 13 mm h<sup>-1</sup>, resulting in high risks of erosion. Figure 8 shows precipitation rates at 4 weather stations close to the research area. It is clear that precipitation varies both on annual and interannual scale, but a clear trend is not visible.

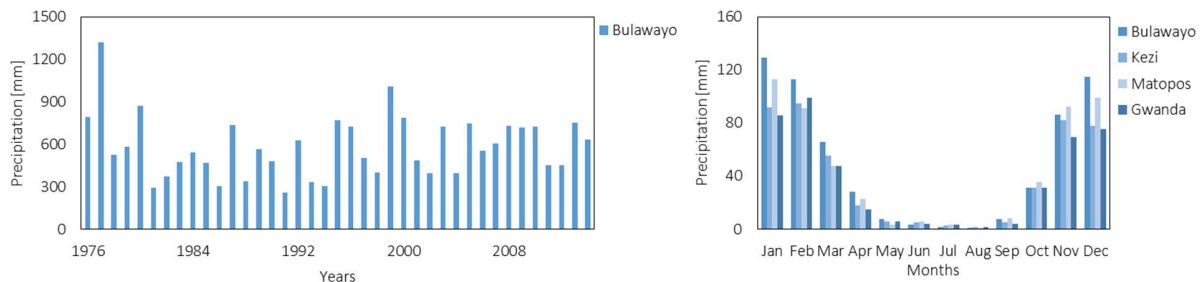


Figure 8: Annual and monthly precipitation values from measuring stations near the project area.

#### *Geohydrology*

The catchment of the Shashane river is descending from north to south, starting with a height of around 1150m at the source and ending at around 670m at the confluence with the Limpopo river. The first part of the river is straight and steeper, followed by a meandering flatter reach with an average slope of 0.26%. The gneissic granite bedrock forms an impermeable base in the lower stretch, covered with alluvial deposits of medium size sand grains, weathered and eroded rock from the upper reach (Mansell & Hussey, 2005). (Blok, 2017) conducted fieldwork in the study area and reports an average porosity of 0.34%, an average hydraulic conductivity of 42m/h (m/d) in the river bed and a groundwater flow of 0.33m/d in the sand alluvium (Appendix B).

Due to the seasonal rainfall the river is ephemeral, but the aquifer is replenished (in general) every year during the rainy season. The sand layer forms a natural storage of water that can be used for household or irrigational purposes in the dry season. The bedrock is irregular, resulting in a riverbed thickness of 0.5-3m (Blok, 2017; Hussey, 2003), as can be seen in appendix B. The subsurface barriers prevent drainage and natural pockets of water remain, forming an alluvial aquifer (Nissen-Petersen, 2006). In Sub-Saharan Africa potential evaporation rates are very high, and soil evaporation in sand rivers occurs up to a depth of 0.6-0.9m. Below this point evaporation becomes negligible (Love et al., 2011), making underground storage favourable. Recent study of (Blok, 2017) and (Mpala et al., 2016) shows an estimated net storage of  $291 \times 10^6 \text{ m}^3$  in the aquifer stretch of 5km, which results in an abstraction potential of  $0.26 \times 10^6 \text{ m}^3$  (15% of the saturated aquifer volume). According to (Blok, 2017) "there is potential that the Shashane river can support large scale irrigation."

### *Land use and vegetation*

Vegetation in southern Zimbabwe is generally patterned at various spatial scales, from local to landscape and regional level cited from (Scoones, 1995). At regional level the woody cover map of Zimbabwe (FAO, 2004) shows a cultivation of 27,5 percent of the land, while 53.2 percent is classified as woodland and 12.7 percent as bushland and only 4.8 percent wooded grassland/grassland. However, there is a strong variation in rainfall regime and number of growing days throughout the country. Based on these characteristic five agro-ecological (natural) zones can be distinguished (Bird et al., 1998) with the research location in region V – extensive farming (Moyo et al., 2017). The area is characterised as dry savannah, with high potential evaporation values of 1800mm. The loose sandy soil or bare rock does not hold much water and the water table is too deep for soil evaporation. Vegetation can reach this deeper groundwater and with transpiration contributes largely to the total evaporation.

At landscape area scale the area has a moderate normalized difference vegetation index (NDVI) of approximately 0.2 to 0.5, which coincides with a sparse vegetation cover. At regional scale two dominant vegetation types can be distinguished; Mopane woodlands and acacia-combretum-terminalia. Mopane woodlands are quite abundant in Zimbabwe, especially in these low-altitude, hot areas with sodic or alluvial soils. Besides the open mopane woodland and bare fields, more dense woodlands called the acacia-combretum-terminalia woodland type, with Acacia often being the most dominant species, can be distinguished along the river channel and in the east (Figure 9). Love (2013) classified three landcover types for his research in the Mzingwane catchment, with crop coefficients varying by season. 'Woodland (highveld)', 'Mixed grassland and woodland' and 'Mixed grassland and woodland (degraded)' where defined. In this research four different vegetation zones are defined, based on Manyanga (2006) and Love (2013). Figure 10 shows the classification map made for this area with; i) Riparian vegetation (Acacia/Faidherbia) ii) Mixed grassland and woodland (Colophospermum mopane/Terminalia) iii) Mixed grassland and woodland(degraded) and cleared fields and iv) Woodland (highveld).



*Figure 9: Pictures from the landscape showing from left to right i) riparian vegetation, ii) Mixed grassland and woodland and iii) Mixed grassland and woodland (degraded) (auteurs images).*



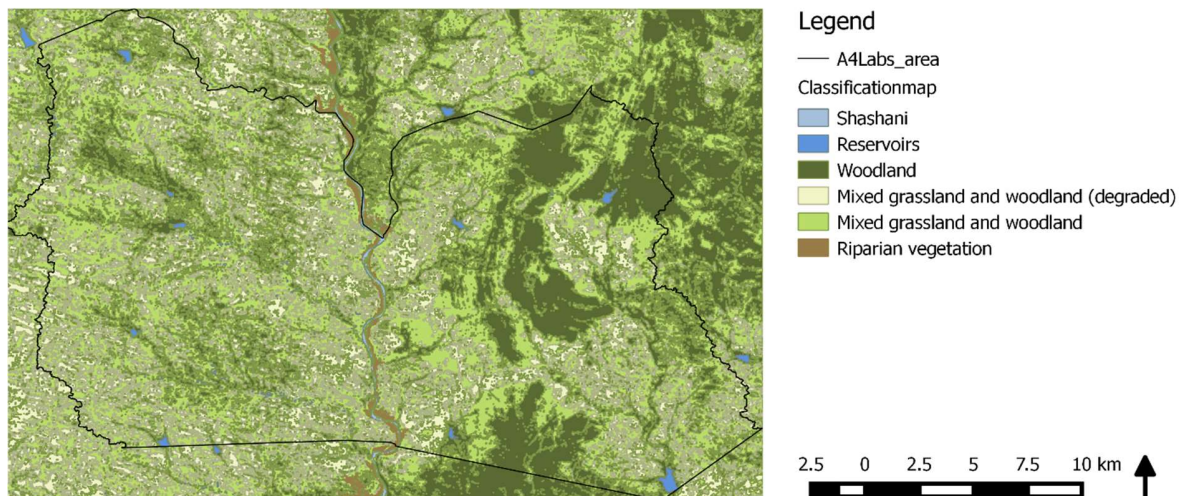


Figure 10: The classification map, showing the different land use types in the area.

The classification map (Figure 10) shows a more abundant groundcover along the Shashani and its tributaries, compared to the arid hinterlands. These alluvial forests often consist of phreatophytes, plants that have roots that connect with the aquifer for water uptake (Busch et al., 1992). This woody cover mainly consists of *Acacia Albida Faidherbia*, a special tree that keeps its leaves during the dry season, supplying fodder for livestock and wildlife (Dunham, 1989). The *Acacia* has a root system with both a tap root, leading to deeper groundwater sources like the aquifer, and lateral roots. (Schachtschneider, 2010) demonstrated with isotopic tests in Botswana in a comparable landscape, that during the dry season a large fraction of the water uptake came from the deep-water table, but also a large fraction from soil layers between 2 to 4 meters below ground surface. While the first rains were directly absorbed by superficial lateral roots. Besides the *Acacias*, Mopane trees in the hinterlands are an important food source for domestic and wildlife. New leaves start to grow about a month before the end of the dry season, making it a food source for the most difficult time of the year. During the hottest part of the day the tree is able to fold its leaves to reduce the leaf surface which leads to a reduction of transpiration (Manyanga, 2006).

The sparse distribution of the mopane trees gives space to palatable grass species. Besides plants, grass species in the semi-arid zone have also adapted to the long dry spells and fluctuating water availability. They grow rapidly and spread many seeds in favourable conditions, while becoming semi-dormant during intra-seasonal dry spells (Manyanga, 2006). Despite this adaptation to the unpredictable climatic conditions several grass species have disappeared over the last decades (Interview Woosa, A.5). And the area has become prone to erosion. While the livestock carrying capacity of the land is estimated by the agricultural Advisory Service to be between 7 and 10 ha per livestock unit (LSU), (17-25 acres per LSU) cited in (Hussey, 2003) these numbers are not respected. The landscape falls under communal land, where there is no ownership, and the land has been overgrazed for half a century. Though farmers try to regulate the grazing by using strategies of herd mobility and local ecological knowledge (Scoones, 1995) they do not seem to be able to avoid irreversible damage. The livestock numbers are regulated biologically cited after Hussey (2003), meaning numbers reduce after (consecutive) dry years and increase during years with more abundant rainfall. But while the area can sustain this growth for some time it now



seems that going beyond its carrying capacity results in degradation of the landscape. While cattle rates decreased, goats and donkeys were able to survive, while they are the only domestic ruminants that crop grass so closely to the ground that they even eat the roots and reduce therewith the vegetation (Hussey, 2003). The growth of livestock, with namely goats and donkeys, combined with extensive deforestation, has resulted in severe sheet erosion and gully formation. The landcover consists of 52 percent bare land (auteurs calculation), and gullies of up to 3 to 4 meters deep, 2 to 3 meters wide. The width of the gullies increases every rainy season destroying roads and coming closer to gardens, water points and buildings.

*Table 3 The classification of the area, based on the developed landscape classification map*

<b>Classification</b>	<b>Percentage</b>
Water bodies	0.7
Woodland	28.0
Mixed grassland and woodland (degraded)	51.9
Mixed grassland and woodland	18.7
Riparian vegetation	0.7

The fields for human use are characterised by fenced and cleared fields that are used for dryland farming. According to recent studies the area is seen as marginally suitable for agriculture due to a lack of nutrients. A major part of the soils of Zimbabwe has moderate to severe limitations in nutrient availability. The poor fertility is generally caused due to very low organic carbon content, the moderately acid nature of the soils, and the often-sandy texture of the topsoil. The soils in the project area are mostly between 100 and 150 cm deep, with areas around the greenstone belt shallower than 30cm (Van Engelen et al., 2004), resulting in a moderate to severe moisture deficit. But the paucity of crop nutrients is the major limitation in subsistence agriculture. Nutrient-limited yield potentials are all low for maize grown under rain-fed conditions and with low inputs. Maize is the major crop in Zimbabwe, at Communal Land as much as 90% of the area is used for this culture. Cultivation practices include the use of hybrid maize, though there is a clear relation between rainfall and productivity leading to less production in drought years. In the Shashane catchment this has led to Climate Smart agricultural practices and a shift to more drought resistant crops such as millet (Bird et al., 1998). As a mitigating measure against droughts and mid-season dry spells irrigation is needed to grow vegetables. Pumping water from the alluvial aquifer enables irrigators to grow crops throughout the year and intensify production. This is practiced for household consumption at household scale and in small community gardens.

#### 4.1.2 Social system

The test site is situated in wards 2 (Dzembe), 6 (Sigangatsha) and 7 (Malaba) in Matobo district, within Matabeleland South Province. It is large enough to include landscape aspects and includes the living area of the people that make use of the water body. The administrative boundaries of the wards contribute to a defined focus group for participatory planning.

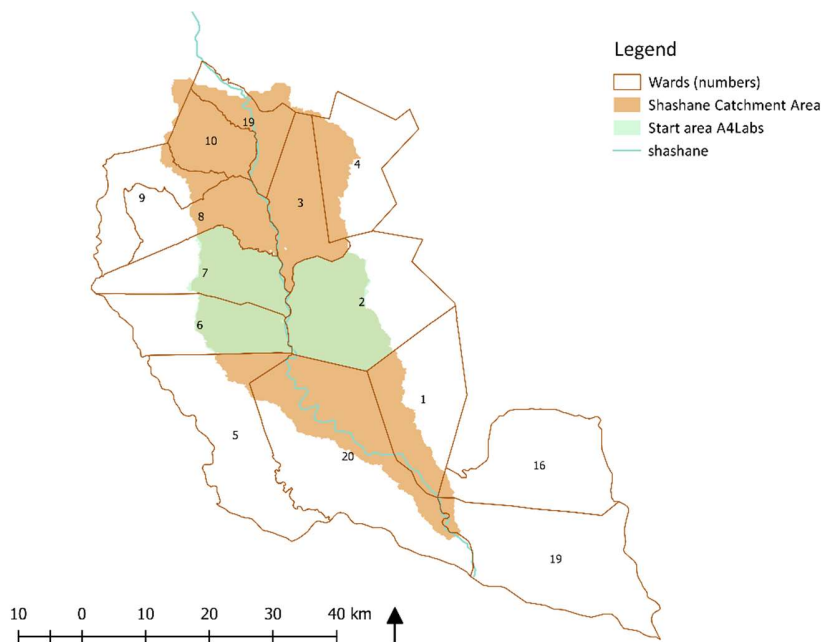


Figure 11: The wards that overlap the Shashane sub-catchment, with a focus on ward 2, 6 and 7 where Dabane has established already a number of community gardens.

#### *Institutional arrangements and stakeholders*

Relevant decision making for the community gardens can be conceptualised in different ways; according to the government structure of Zimbabwe, the project structure of the A4labs project and the constitutions within the gardens. At first the government structure, starting with the water management bodies, will be explained. Other relevant project partners will be discussed afterwards. Last, the constitutions within the current community gardens is explained as an example for the gardens that could be realised.

Since reformations in 1990 the water authority in Zimbabwe consists of two parallel working bodies, namely the Zimbabwean National Water Authority (ZIMWA) and seven Catchment Councils (Jaspers, 2003). ZIMWA is responsible for water resources management, administration and the control of water utilities. The Catchment council is responsible for the provision of information, resources and governance in the Catchment and Sub Catchments and training of users on the Water Act. Their control focusses on and comprises of mainly large, powerful users of blue water, like cities, mines and large-scale commercial farmers (Nare et al., 2006). According to the Water act (2013) the Catchment Council is, via the Sub-Catchment Council, responsible for the Water Allocation permits. These are obligatory when field for water abstraction are larger than 0.5ha and for commercial purposes (ZINWA, interview).

The project area lies in Matobo district, within Matabeleland South Province and is run by District Administrators (DAs) and Matobo Rural District Council (MRDC). Most governmental functions in Zimbabwe are carried out by national government departments, even at the local level in rural areas. The MRDC has elected councillors for the different wards that cooperate with the traditional leaders. The relevant local officials for this research are the Department of Irrigation, Department of Woman Affairs, Gender and Community Development, Ministry of Small, Medium Enterprises and Cooperative Development (MOSMECD) and the Agricultural Extension offices (AGRITEX).

The Department of Irrigation is responsible for water assessments and studies and the development and design of abstraction methods and irrigation schemes with farmers, but also for the provision of irrigation equipment based on irrigation scheme size (>3ha). The Department of Woman Affairs, Gender and Community Development encourages the active participation of youth and women by promoting equitable distribution and utilization of resources and is responsible for community mobilisation and sensitisation. MOSMECD is involved with mobilisation of Youth and Small & Medium Enterprise (SME) through the SME and Cooperative Development Clientele and important for Farming as a Business in terms of marketing and ownership constitutions. AGRITEX advises and trains farmers on crop production, conservation and Climate Smart Agricultural practices. In practice, the activities in rural areas tend to operate by consultation between the RDC, DAs and local officials of national government departments (Love, 2013). All these stakeholders, including the Msingwane Catchment Council and Dabane Trust were thus present during the District Meeting (22/08/2017), except from the traditional leaders who joined the Community Ward Based Meeting of their ward (23-25/08/2017).

The NGO Dabane Trust is the project coordinator and budget holder of the Msingwane project component and as such part of the project management unit. Therewith Dabane is also involved in project implementation, training of farmers and water users, project site identification and selection and infrastructure development. As the project is set up as a learning lab, where both farmers, students and researchers can learn, several universities are involved. IHE Delft is part of the steering committee and initiator of the A4labs project, the National University of Science and Technology (NUST) is involved with (Phd) students from the Department of Civil & Water Engineering and the department of Environmental Science and Health.

All these stakeholders agreed that the project should be farmer centred; development actions should be created and implemented in a participatory manner. In the constituted gardens two different management committees are prevalent; a committee of seven members and a committee consisting of all garden members. The garden committee composed of seven members includes a chairperson, secretary, treasurer and committee members. The garden committees ask monthly subscription fees for maintenance and repairs, from which they pay maintenance costs. The membership in all the gardens is dominated by women who constitute 88% whilst men constitute 12% of the garden membership. Besides this the gardens are characterised by the elderly population, with an absence of youth participants. (Mhlope, 2017).

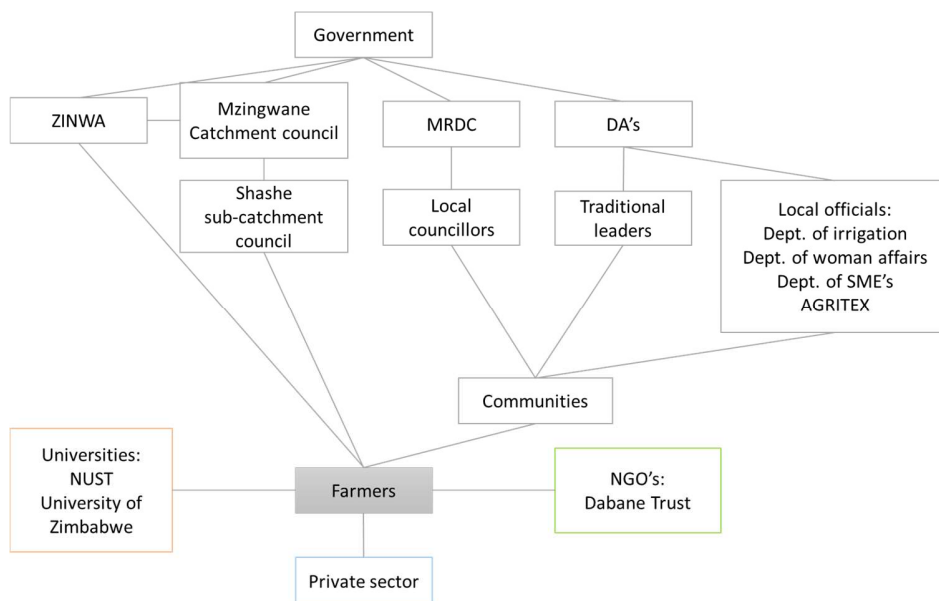


Figure 12: The organisational structure; the practitioners centred, from top-down the government structure and around the farmers the other (influencing) stakeholders.

#### 4.1.3 Economic system

To account for sustainable development, it is necessary to look at the different economic systems in the area and its relations with the social and natural system.

##### Socio-economic

Emigration from Zimbabwe has since 2000 experienced a progressive rise, with mainly young people leaving the country to find a better life abroad. A vast majority of about 1.5 million regular and irregular migrants left for South Africa, including many young and skilled Zimbabweans (*Migration in Zimbabwe, a country profile 2009*, 2010). According to surveys in Zimbabwe from the Southern African Migration Programme (SAMP) the reasons why so many professionals are leaving showed extraordinary dissatisfaction with social and economic conditions in Zimbabwe. Zimbabwe's skilled population proved to be not only highly discontented with domestic economic, social and political conditions, but also extremely pessimistic about the possibility of positive change which makes many of them leave without the expectation of coming back (Crush & Tevera, 2010). This ends up in developed countries profiting from taking up the more skilled workers while the developing countries lose their professionals. To turn this tendency to migrate we should not end the right to move, but focus on improving the environment at home (Harris, 2001).

The Zimbabwean economy can be defined as agro-economy, with commercial agriculture contributing to approximately 12 per cent of the country's GDP, more than 60 percent of the raw materials for manufacturing sectors and 40 per cent of total export (Unganai & Murwira, 2010). Employment, income and foreign exchange are thus heavily dependent on natural resources. The household subsistence in the area is mainly linked to livestock keeping, with some rainfed farming of small grains such as maize and recently sorghum. Dabane has, since 1993, established 12 sustainable small-scale irrigated community gardens to give people from the area the possibility to not only sustain their livelihood, but also provide incentives for socio-economic development. Upscaling these development practices could contribute to improving agricultural production in these dry areas while the methods ensure to maintain sustainable abstraction limits and minimise negative socio-economic and ecological consequences under constantly

changing conditions. The 'impact of organisational, markets and technical aspects of alluvial water abstraction on successful community gardening' is analysed by (Mhlope, 2017). Community gardens face marketing challenges. They are usually confined to the local market which they are saturating with similar vegetables from the different gardens. The farmers sell their products to local households, schools, eating places and very few vendors at Tshelanyemba Business Centre. There is no nearby farmers' market and farmers engage in mobile vending, farm gate selling and to a little extent roadside vending. Farmers at times resort to reducing the price of vegetables by half to attract customers. The prices for vegetable produce mainly range from \$0.50-1.00/bundle for leafy vegetables, \$0.20/bulb king onion and \$15/bucket tomatoes, \$0.50-\$1.00/ head butternut.

Therewith money is scarce in the country, making barter trade, trading goods for goods instead of money, the only option. As a result, low incomes are realised from the sales with which farmers are buying kitchen utensils, groceries and pay primary school fees for farmers' children with little or no investment made. While farmers mention that the main part of their income is raised by farming, there are several other income sources all related to the natural environment. Gathering, brick making, woodcarving and basketwork all provide extra incoming sources. Also, children who left the country to work in South-Africa send a package with food supplies to sustain their families at least once a year.

#### *Water use gardens*

The production of vegetables for both household and commercial purposes influences the water balance by the abstraction rates for irrigation. The several community gardens that are already established in this area can be used to determine initial abstraction quantities at farm scale. (Mhlope, 2017) recently conducted a study at the gardens in the project area where farmers were interviewed about their water use and this information was verified during the garden visits and initial interviews of this research. Water is abstracted from the alluvial aquifer by a submerged pump head, connected to either a manual pumping system with a rower or joma pump or a pump powered by solar panels. The water is pumped from the aquifer into a reservoir and from there into a storage tank with an average capacity of 5000 – 7000 litres. Farmers use buckets of 20 litres to divert the water from the tanks over their fields. The amount of water used and the number of flooding days depend on the season, crop stage and crop type, but also depend on the habits of the gardeners. The average water use is calculated to be 2.2 l/d/m<sup>2</sup> for the first stage and 5.5 l/d/m<sup>2</sup> for the flowering stage (Mhlope, 2017).

#### 4.1.4 Landscape area

After assessing the natural, social and economic system, the boundaries of the landscape area are defined. As the objective of the development is the improvement of the living conditions by upscaling irrigation practices, the alluvial aquifer is the most important factor. Two levels of management are highly important for the water conditions for the farmers. The first level is the level of the farmers and how water management measures influence their income, the environment and the water resources downstream. The second level is the (sub) catchment level, which is the level of the water manager. Water use by one community garden influences the water balance in the sub catchment, and thus has an effect on the water availability for other gardens and the ecosystem. To improve the livelihood in the whole area the irrigation practices should be assessed on (sub)catchment scale. The aquifer is supplied by runoff from the adjacent land, dependent on the elevation. With the use of a Digital Elevation Model (DEM) map the catchment area is defined, providing the boundaries of the natural system.

The whole catchment is however too large, as shared negotiation about a common objective is difficult within this whole area. The traditional community groups have their own village and village heads where they settle disputes and decide about common concerns. These villages are part of the modern administrative boundaries, the wards, in which the different village heads work together with the ward

leaders. The communities of ward 2, 6 and 7 have been working with Dabane for about 25 years, resulting in people from these different wards working together in the processing centre in Tshelanyemba. They sell their produce mainly in this area, but sell and buy also at regional scale in Maphisa or even Bulawayo. While there are multiple scales important for the economic system, the farmers mainly used the processing centre and shops in Thelanyemba as their market place. Figure 13 shows the eventual landscape area, bordered in the north and south by the administrative boundaries and in the east and west by the catchment.

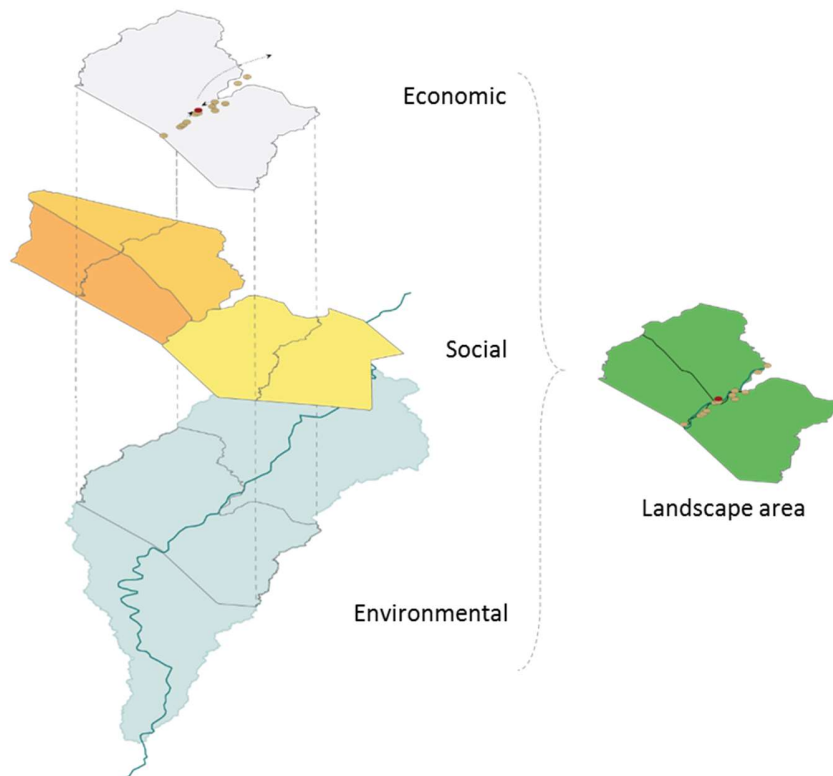


Figure 13: The boundaries of the environmental, social and economic domain form together the boundaries for the landscape area of the project.

#### 4.1.5 Objective

The objective of creating the pathway map is to improve the living conditions in this area and give people incentives to stay. Earlier research has shown potential in the use of alluvial aquifers for irrigated agriculture (Love, 2013), (Blok, 2017; Hussey, 2003) i.e. Dynamic Adaptive Development Pathways should be developed in a participatory manner for upscaling irrigation practices from the alluvial aquifer for an uncertain future in the Shashane basin in Zimbabwe. Upscaling irrigation should be done within the natural, socio-economic and technical opportunities and limitations of the landscape. The sub-surface reservoirs are recharged through flash floods originated from rainfall events (Quilis et al., 2009) and supply water for use at the scale of households and small gardens (Love et al., 2007). Technological and economical possibilities, including construction materials, irrigation practices, energy and storage, of upscaling in this area are limited and will influence the decision making. In addition, previous unsuccessful projects have influenced the peoples' willingness to contribute, making it important to have a

practitioners centred approach to come to a plan that is accepted by the community (stakeholder meeting, Figure 14 and appendix A.4).



Figure 14: Community meeting to present the project to the local communities

#### 4.2 Step 2: Future opportunities and limitations

In step 1, the natural, social and economic domain were described and the system components mentioned in this description are now used to define the characteristics of the landscape area. A causal model is created to identify the relationships between different domains. Both quantitative and qualitative analyses are used to assess the opportunities and limitations for development in the landscape in case no supporting development actions are taken.

There are different types of uncertainties in socio-environmental conditions that influence the future opportunities of water abstraction and development of the area. Uncertainties in natural variability and social change influence directly the agricultural practices and water storage. Drivers of change in the economic and social system, such as political (in)stability and economic growth need to be explored as well, as they indirectly influence the success of implementation. These factors can increase or decrease the lead time, the time until an action can be implemented before a tipping point is reached. Hence, the causal model was extended to assess the influence of the uncertainties on the water balance in the landscape area.

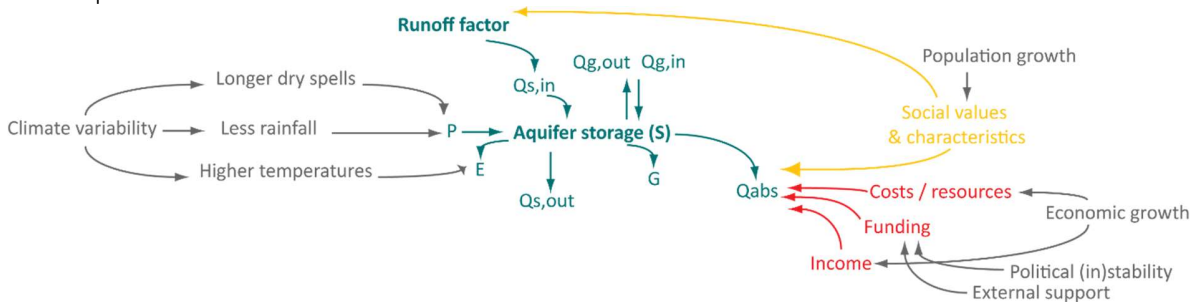


Figure 15: The effect of natural, social and economic variability on the parameters of the landscape area

Different scenarios were evaluated based on the hydrological model to account for the climatic and social variability. The scenarios for the social and economic domains are not taken into account in the hydrological model, but are discussed separately in a qualitative manner. The different domains will then come together by the formation of the development pathways in step 5.

## Natural opportunities and limitations

### *Natural characteristics*

At a landscape scale, the response of the alluvial aquifers' current and future hydrological patterns can be illustrated through a water balance model, illustrating interactions between the system components. The presented hydrological model is kept simple and self-intuitive to allow for participatory adaptive management in further steps. Its main purpose is to give an indication of the water availability under different future scenarios. By generating scenarios with different climatic conditions and incorporating those in the model, the future climate variability will be assessed.

There is scarce data available, so to create a model of the stretch based on the available data, certain assumptions are necessary. To prevent over-simulation of available water in the model more conservative assumptions were chosen. The geohydrological background of the landscape area is studied by Blok (Blok, 2017), who developed a ModFlow model of the sub catchment. Data from this research was used to evaluate the hydrological model.

The graphical overview of the hydrological model displays ingoing and outgoing water fluxes, which contribute to changes in water storage over time.

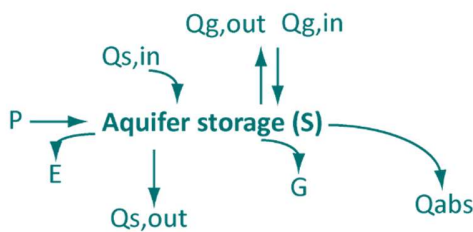


Figure 16: The ingoing and outgoing fluxes that contribute to the water storage over time

where P stands for precipitation, E is the sum of net evaporation from the saturated sand in the aquifer together and evapotranspiration from the adjacent riparian vegetation.  $Q_{s,in}$  and  $Q_{s,out}$  for surface in and outflow and  $Q_{g,in}$  and  $Q_{g,out}$  for groundwater in and outflow G is seepage from the base, where  $Q_{abs}$  accounts for abstraction values.

After the identification of the causal interactions, the qualitative cause-effect relations are translated into a quantitative model. A spreadsheet-based reservoir model was used to simulate the storage in the aquifer, with the storage per timestep calculated with equation 1 and 2.

$$S_t = S_0 + \frac{\Delta S}{\Delta t} \quad (1)$$

$$\frac{\Delta S}{\Delta t} = Q_{in,s} - Q_{out,s} + P - E - Q_{abs} - G + Q_{in,g} - Q_{out,g} \quad (2)$$

S is the total storage in the alluvial aquifer at a moment in time,  $S_0$  is the storage at the start of simulations, here the beginning of the rainy season in the first year of simulations, and  $\Delta S/\Delta t$  is the storage change per time step ( $t$ ).  $S_0$  is calculated based multiplication of the river parameters, which can be found in Table 4. Changes in water storage are calculated in monthly steps, a time interval which allows to evaluate whether water storage is sufficient throughout the growing season.



Table 4: Parameters of the aquifer and adjacent area that provides runoff for this reach

Parameters	Value	
Average specific yield	0.15	[-]
Length reach	15000	[m]
Width reach	100	[m]
Depth reach	3	[m]
Aarea	4.5E+07	[m2]
Runoff factor	0.13	[-]

#### Groundwater flow

Area analysis in step 1 showed an impermeable bedrock, therefore the assumption is made that seepage from the base (G) and lateral groundwater in- and outflow are zero. It is likely that there is lateral groundwater flow, as water is used for transpiration of the riparian vegetation. However, this outflow is considered in the evaporation component of the model. The horizontal groundwater in the steam direction ( $Q_{in,g} - Q_{out,g}$ ) is based on earlier calculations based on measurements in the study area (Blok, 2017).

#### Evaporation

Previous research by Love et al. Love et al. (2011) has demonstrated that evaporation of aquifer water may occur up to a soil depth of 0.9m under the riverbed. In this soil layer the soil evaporation and transpiration are based on values from Blok (2017).

The transpiration rate of the different crop types in the gardens indirectly influences the storage by a change in water abstraction. Evaporations rates were calculated by first establishing the evaporation from the bare soil (reference evaporation) and then adding transpiration of the diverse crops. First the reference evaporation is usually calculated after Penman-Monteith using wind speed, solar radiation and humidity data. However, for areas with limited data available, Hargreaves equations may be used as an alternative (Hussey, 2003). In the model, first equation (3) is used to derive extra-terrestrial solar radiation ( $R_s$ ) data from air temperature differences and incoming solar radiation, using the difference between maximum ( $T_{max}$ ) and minimum ( $T_{min}$ ) temperatures to define the cloud cover. The adjustment coefficient ( $k_{R_s}$ ) was empirical established, for landlocked locations comparable to the project area as  $k_{R_s} = 0.16$  (Allen et al., 1998b). This leads to equations (3) and (4):

$$R_s = k_{R_s} \sqrt{T_{max} - T_{min}} R_a \quad (3)$$

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})0.5 R_a \quad (4)$$

With  $R_s$  and  $R_a$  being the incoming solar radiation and extraterrestrial radiation [ $\text{MJ m}^{-2} \text{d}^{-1}$ ],  $T_{max}$  and  $T_{min}$  the maximum and minimum air temperature [ $^{\circ}\text{C}$ ] and  $k_{R_s}$  an adjustment coefficient (0.16) [ $^{\circ}\text{C}^{-0.5}$ ].

After calculating the reference evaporation ( $ET_o$ ) the evaporation of different land and vegetation types can be calculated applying a crop-specific coefficient ( $kc$ ):

$$ET = kc * ET_o \quad (5)$$

These coefficients are defined per crop by the FAO and relate to their growing stage. Combined with an estimated growing period a crop coefficient per crop type per month is defined (table ..).

Table 5: FAP crop coefficient for crops most produced in this area

Month	Choumollier (leafy vegetables)	Tomatoes	Maize	Fodder (alfalfa)
okt	0	1.15	0.7	0.95
nov	0	1.15	1.2	0.95
dec	0	0.9	0.5	0.95
jan	0	0.9	0	0.95
feb	0	0	0	0.95
mrt	0.4	0	0	0.95
apr	0.7	0	0	0.95
mei	1.05	0	0	0.95
jun	0.95	0	0	0.95
jul	0.95	0	0	0.95
aug	0.95	0	0	0.95
sep	0.95	0.6	0.3	0.95

### Surface flow

Hortonian overland flow, the surface water flow that is generated when rainfall exceeds the infiltration capacity is difficult to predict due to its spatial variability and dependence on the intensity and temporal variability of precipitation [Experimental study of Horton overland flow on tropical hillslopes: 1) soil conditions, infiltration and frequency of runoff.]. There is no recent data available on the discharge of the river and although the runoff from the adjacent land is the largest component of the water balance, it is a highly uncertain factor. Where Dake (1981) mentions that a runoff coefficient of 10% is most common in dryland areas because most of the annual rainfall is lost through evaporation, Blok (2017) assumes that 20% of the runoff ( $P-ET$ ) from the contributing area reaches the river in her water balance. Love (2013) reports a mean annual unit runoff (MAR) of 33mm/year (17.8M m<sup>3</sup>/year), Ncube (Ncube, 2010) has assumed a MAR of 12-20mm/year in this part of the Shashani catchment and the surface water assessment by ZINWA mentions a 28 mm MAR (Mazvimavi, 2006).

Calibration of the model with (Blok, 2017) ModFlow output values resulted in an assumption of MAR of 28 mm in this study, which coincides with the assumption that 13% of P-ET reaches the river. Multiplied by the area flowing to the river this accounts for the surface water flow ( $Q_{s,m}$ ). There is only surface water visible in the Shashani River after the heavy storms of the rainy season (Phaup 1933) and surface water outflow ( $Q_{s,out}$ ) occurs only when the aquifer is fully saturated.

### Water abstraction

The water abstraction ( $Q_{abs}$ ) is defined by the number of gardens and farmers ( $n_g$  and  $n_f$ ), and the area per farmer ( $A_f$ ). Additionally, irrigation efficiency ( $\eta_{irr}$ ) and the transpiration at the garden scape, defined by the reference evaporation ( $ET_0$ ) and crop coefficient ( $kc$ ), affect  $Q_{abs}$ :

$$Q_{abs} = n_g * \eta_{irr} * kc * ET_0 * A_f * n_f \quad (6)$$

Parameter	Value	
n farmers/garden	12	[-]
Area/farmer	0.04	[ha]
Number of gardens	9	[-]
<b>Irrigation eff</b>	<b>0.6</b>	<b>[-]</b>

Current water use in the gardens is estimated after research in the area and summarised in Table 6.

Table 6: Average water use in the gardens, estimated after research in the field

Gardens	dry season	wet season	
Avg water use / farmer / month	13934	22829	[l]
flood irr m3 / month / farmer	14	23	[m3]
Flood irr m3 / ha / month	348	571	[m3]
total water use / year	1505	2466	[m3]

### Storage

The meteorological and hydrological parameters necessary for the calculations of the water storage on landscape scale were based on data presented in the preceding area descriptions and are summarised in appendix B. For aquifer subtraction Gleeson and Richter (2018) mention a minimum of 10% monthly baseflow for environmental protection. However, because of the large technological uncertainties a minimum aquifer water level of 1 meter together with full replenishment in the dry season is considered environmentally sustainable, which is 1/3 of the total aquifer volume.

To assess the opportunities and limitation on local scale only the relations around the water abstraction are assessed. The 'natural' limitation have a more technical background and are based on the pump and storage capacity. These factors are, instead of the water available in the aquifer, currently defining the limiting threshold level. Therefore, at garden-scale level the water balance can be closed around the tank capacity. Farmers are currently equipped with tanks that have a 5m<sup>3</sup> capacity. Current pump systems have an average pump rate of 2.2m<sup>3</sup>/h, which implies a refill of the tank three times a day should be possible. The monthly maximum threshold level for garden scale abstraction is thus 450m<sup>3</sup>.

### Natural uncertainties

IPCC predictions for climate phenomena in Southern Africa were used as input for the changes in meteorological conditions. The most plausible is an increase in temperature of 0.004 degrees per month and a decrease in precipitation of 0.008 % month<sup>-1</sup> (S1) The most severe scenario predicts a 0.048 percent decrease in monthly precipitation, together with an monthly temperature increase of 0.006 degrees (S2). Beside a decrease in mean annual precipitation, the erratic start and end times of rainy season are highly important. Changes in the seasonal migration of the Inter Tropical Convergence Zone increase the likelihood of years without a sufficient recharge. Therefore, also a year without a rainy season is considered in the hydrological model, to account for a year without replenishment of the aquifer (S2).

Table 7: ↔ no change, ↓ descending, ↑ increasing trend

Domain	Uncertainty		S1 (plausible)		S2 (severe)
Natural	Precipitation (mm/y)	↓	-0.008 % month <sup>-1</sup>	↓	-0.048 % month <sup>-1</sup>
	Length of dry spells	↔		↑	Consecutive dry years
	Temperature	↑	0.004 degree month <sup>-1</sup>	↑	0.006 degree month <sup>-1</sup>

### Natural opportunities and limitations

The amount of runoff generated during the rainy season is so large that even in relatively dry years the aquifer is fully replenished. However, longer dry spells or even consecutive dry years have a large effect on the available storage.

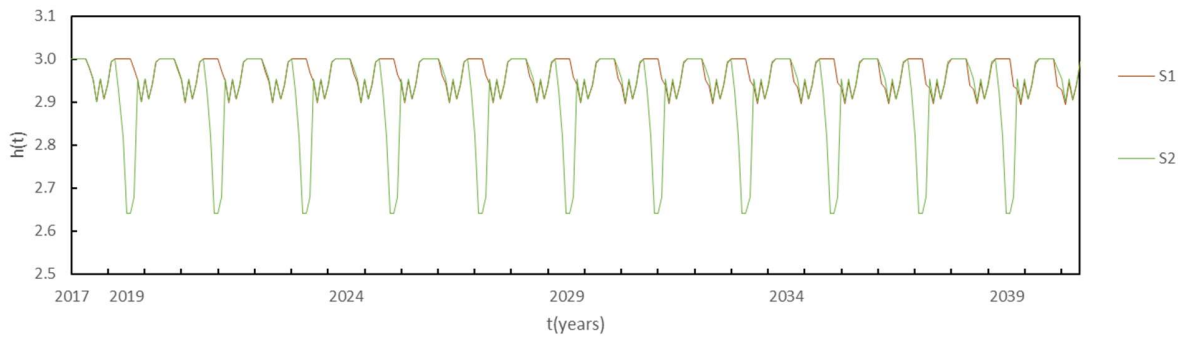


Figure 17: Water level changes for the different climate uncertainty scenarios without development actions

The riparian vegetation along the river is important for the biodiversity and natural resources in the area. Besides water abstraction threats the vegetation is obviously also affected by land clearing for farm land. Due to the increase in pumping head and construction costs with distance from the river all current irrigated gardens that are supplied by the aquifer are located near the Shashane. The only current regulation of the EMA requires a 30-meter distance from the river for environmental protection. Further, locations can be chosen on preference and with agreement of the community leaders. Only 0.68 percent of the landscape area is classified as riparian vegetation, which corresponds to about 500 hectares. Currently the gardens take up only 6 hectares in total, but with a large increase in area per farmer and/or the number of gardens space could become a limiting factor. When this becomes a limitations it is therewith always possible to place gardens further away from the river. This is more expensive, due to longer pipes and higher pump head, but at that time the area is expected to be further developed which makes the costs more bearable.

### Social opportunities and limitations

#### Social indicators

Sustainable water management does not only require information on water availability and the evaluation of environmental and climatic conditions, but also critically hinges on stakeholder engagement. During the introduction of the plan to establish a new community garden in the area only a few farmers showed sustained interest, and those who applied where mostly more than 50 years old. To make use of the available water to foster development in the area, it is necessary to increase the willingness of people to adapt current agricultural practices. Whether stakeholders are willing to contribute is determined by social values and characteristics. Most social values are highly heterogeneous and multi-dimensional and perceptions can change over time and with contexts (Fischer, 2014). Based on the FGD's and visualisation sessions, a value matrix with key factors that influence the decision making of local stakeholders was created.

Table 8: This value matrix shows the qualitative values of relevant social indicators for 4 stakeholder groups

		Money	Health	Little effort/labour	Natural resources	Tradition	Employment
Women	<35	+-	-	++	+-	+-	+
	>35	+-	++	+-	++	+	+
Men	<35	++	-	+	--	-	++
	>35	+-	+-	-	++	++	++
Source		Visualisation sessions	Visualisation + FGD	Community meeting	Visualisation sessions	FGD	Visualisation sessions

**Money** - Money, and especially quick money, money that come quickly after a made investment and does not require long feedback time, is important for young men. However, the decoupling of social structures in villages and access to drugs often causes problems: “Children migrate to other countries and youth drinks and uses drugs” (FGD, Ward 7). Young men often leave their country and wife to make money in other countries to sustain their families. But they state that if work would be available in the area, they would prefer to stay.

**Health** - At the moment, mainly older people, and especially older woman apply for farming opportunities in a new garden. This coincides with the expectations, as currently gardens are used for subsistence farming, increasing the health of the households. This is an important first step, though the aim is to improve peoples’ capacity to reach a state of economic independency and create opportunities for development.

**Little effort/labour** - A main outcome of visualisation sessions was that intensive labour is required for farming activities. Additionally, community meetings addressing the establishment of new gardens revealed the problem of large distance between homesteads and farms, which is linked to a large effort to commute per foot in hot weather conditions. Besides household chores this becomes too heavy for especially young women, which makes it not attractive for them to cooperate.

**Natural resources** - Natural resources such as grasses and trees are highly exploited, but especially older men and women seemed to care for their environment. During FGD’s they mentioned the problem of land degradation, due to extensive tree cutting for fire wood and housing (A.7). They also use a large range of different ecosystem services (A.6) and e.g. let their cattle graze in the area, which creates a willingness to change habits to improve ecosystem integrity.

**Tradition** - Especially older women and men highlighted the importance of traditional practices (A7). In the whole district conflicts are still solved by traditional leadership and local hierarchy is of fundamental importance. While young migrating men introduce new technologies to the area, traditional habits and practices still persist.

**Employment** - The off-farm employment rate in the area is very low and the aim of the project is to improve this situation. Employment is important for all community members. Men especially value the money generated by employment, while women also appreciate the accompanying independence and the increased security in sustaining themselves and their children.

#### *Social uncertainty*

An uncertain social variable influencing the water abstraction is population growth. The average household size in the Matobo District is 4.6 whilst the average in the project area is 4.8 (ZIMSTAT, 2012). In 2012, 15 453 people were living in the three wards, so the estimated population in the project area is 7500 people. shows very different trends in the area, based on national data (ZIMSTAT, 2012) and data from the world population prospects for Zimbabwe. Besides growth due to birth rates, large migration movements are prevalent in the area and especially young men are frequently leaving the country. This local trend is interlinked with the success of development as it influences and is affected by the outcomes of development.

Table 9: ↔ no change, ↓ descending, ↑ increasing trend

Domain	Uncertainty	S1 (plausible)	S2 (severe)
Social	Population	↑ 1.87 % year-1	↓ - 0.58 % year-1

Scenario S1 takes an expected increase by 1.87 percent per year into account. Current local trends measured by ZIMSTAT however show a decreasing trend of 0.58 per cent year<sup>-1</sup> in the area, due to emigration. Scenario S2 is based on this observation, and assumes small annual drops in total population density.

#### *Social opportunities and limitations*

There is a two-way coupling between population growth and the social indicators with migration being the connecting factor. To counter the current trend of out migration of young adults the social indicators that limit the participation in development actions should be reached. The threshold level varies per person and per action, but the indicators show the requirements of development actions. The employment opportunities that bring in money and cost not extreme amounts of effort could make local community members willing to accept the new ideas and support the change.

#### Economic opportunities and limitations

##### *Economic values*

Average household income for Matabeleland South Province, where the project is located, amounts to \$81/month. This is, mainly generated with cattle sales and ranges a bit above the national average of \$62/month (ZIMVAC 2016, Rural Livelihoods Assessment). As described in step 1, crop plantation is an important income source, but certain crops will make more on the market than others. Research from Mhlope (Mhlope, 2017) states an average income from the gardens of only \$88.8 year<sup>-1</sup>, which coincides with an average of \$1.48 m<sup>-2</sup>, and a maximum of \$171.5 year<sup>-1</sup>. Mhlope also found a correlation between crop diversity and income, which highlights a possibility to improve income from the farms. Income per farmer ( $\pi$ ) \$ year<sup>-1</sup> can be calculated with the following formula:

$$\pi = A_f * Y * P_c \quad (7)$$

where  $A_f$  represents the area per farmer,  $Y$  the yield [tonne year<sup>-1</sup>],  $c$  is the indication of the crop type and  $P_c$  the price for a certain crop [\$ kg<sup>-1</sup>]

Besides the income from selling the garden products, also costs and resources necessary for development are factors influencing development. Development often needs investments and if the money that comes in is just - or not even - enough to survive it is impossible to save money to break the cycle. This poverty trap of limited access to credit and capital markets causes poverty to persist. It is unlikely that stakeholders are able to cover all costs for the implementation of expensive development actions at larger scales. Some farm scale interventions, however, might be potentially covered exclusively by local households. The costs of actions and the necessary resources that are available in the area thus define whether an action can be implemented without external support or not.

Besides own capital there are many NGO's working in the area to provide support to communities. If national and international donors are willing to invest in development actions or can provide loans, the uptake of new irrigation practices might increase. However, it is important to state that donor-funded and externally managed projects can also have negative influences (Fischer, 2014).

### Economic uncertainty

While national economic growth has considerable influence on development in the landscape area, it is difficult to predict and was strongly fluctuating over past years (Figure 18).

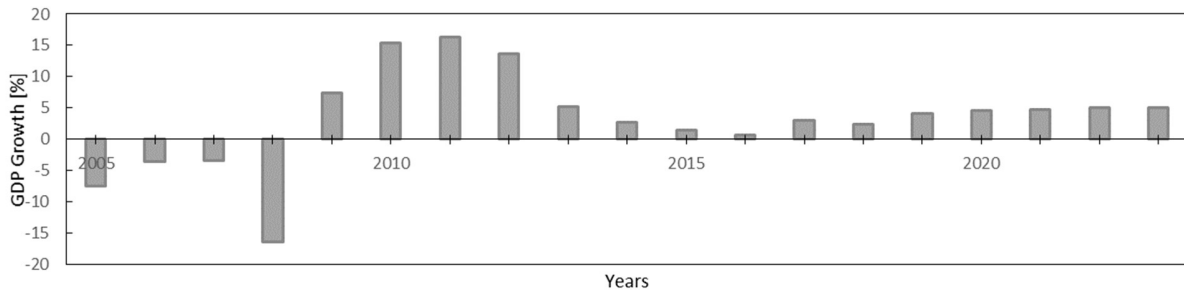


Figure 18: GDP Growth rate of the last 12 years and expected trend (IMF : World Economic Outlook (WEO) 2018).

Political stability and implementation of long-term reforms are necessary to (re)build the economy of a country. Confidence in the governments' economic plan could unlock the potential of the private sector and create an incentive for investment (Chitiyo et al., 2016). However, political instability has shown the opposite effect resulting in a decrease of the GDP, demonstrating negative growth as a consequence of political tensions in 2008.

Consequently, the availability of external financial support is highly uncertain and there have been several peaks and drops in development aid, historically. Global political or economic events can lead to a simultaneous in- or decrease of external aid within short time periods. Support is currently available for the area, but is not consistently guaranteed in future decades. However, the project is currently reaching out for funds to provide loans, which makes it plausible that external support increases for this area.

Table 10: ↔ no change, ↓ descending, ↑ increasing trend

Domain	Uncertainty	S1 (plausible)	S2 (severe)
Economic	Economic growth	↔	↓
	Political (in)stability	↔	↓
	External support	↑	↓

### Economic opportunities and limitations

The capital available for new investments is thus dependent on economic growth, political (in)stability and external support. Whether the threshold level is reached depends therewith on the costs of the development action. It is expected that small interventions at garden scale can be collected by local farmers within a few years. The investments at landscape scale need external support, which is linked to funding opportunities and political stability.

### 4.3 Step 3: Determine actions

Stakeholder participation with focus group discussions and interviews (Figure 19) resulted in a set of possible development actions. The actions that follow from these interviews are substituted with expert knowledge, derived from literature research and interviews.

Farmers were asked to draw the current situation around their garden and possible opportunities for development in the near future (5 years). They all separately stated that the watering system had to be improved. The submerged pump breaks during heavy rainy seasons and the manual pumps and flood irrigation require too much power. Besides these technical issues there were several ideas to increase the garden profit and improve their gardens. Thereafter the farmers were asked how they would like to see their living area for the next generation (25 years), which made them think of developments in the landscape area. All development actions mentioned are summarised in the 'Set of Development Actions'. The numbers behind each action leads to the relevant visualisation session (and farmer group) in appendix A.6.



Figure 19: Visualisation sessions; left an impression of a session and right one of the resulting drawings

#### Set of Development Actions

**A. Number of gardens:** An opportunity is to increase the number of gardens in the landscape. Dabane has since 1993 established 12 community gardens in the area and is currently exploring the options for another one.

**B. Farmers per garden:** Many people involve their children and daughters in law in the farming practices, but young male adults are barely seen on the fields. The reason for this, mentioned by the community, is that the fields are mainly used for subsistence farming and don't bring much profit. To involve youth and keep them involved in the long run the farms should become more profitable, but also create space for them at an early age. Younger children are content with gardening under their parents, and say they are 'scared' of problems that might arise with a new garden. An increase in garden area to create space for youth or young adults that are currently working on the beds of their parents is suggested. The money gained with these extra beds for themselves should encourage them to keep farming, while still learning in these gardens from the older farmers. (4,8)

**C. Area per farmer:** To increase the income per farmer an expansion of garden area per farmer is opted. Currently farmers have an average area of 0.04m<sup>2</sup> per person, while 0.5 ha is considered to be enough to make farming profitable. By starting to increase the size with 10% per year farmers are able to cover the costs for extension and slowly adjust to the extra workload. (1,4,5,6)

**D. Irrigation efficiency:** In scenario 0 the water abstraction is based on data from current practices, acquired during the field visit. Farmers uses flood irrigation, with 20l buckets, to flood their fields. Though the ground is covered with mulch to prevent soil evaporation the efficiency is still low. Flood irrigation, the current irrigation practice is assumed to be 60 per cent, and one of the discussed development actions is a



different irrigation system. Drip irrigation has an efficiency of 85 – 90 %, which results in a substantial increase in efficiency. (1,2,3,4,6,7,8)

E. Cropping for market: Another change in current practices is a more diverse cropping pattern, related to the market (3,5,6,8,9). (Mhlope, 2017) found a relation between a variability in crops and an increase in income and the cropping calendar shows opportunities for two cropping cycles. Farmers state therewith that “it is possible to say on forehand how much will be produced and make arrangements with buyers for a season”, which could also increase the income.

F. Fodder cropping: Cropping fodder for livestock could improve the self-empowerment of the area. Both experts from Zimbabwe (S. Moyo and Forster) and farmers mention the option of livestock keeping as the demand for animal produce is expected to increase. This global trend is not favourable for increasing food availability, though the sale of 7 goats (Foster) or one beast (Love, 2012) would be enough to provide a family with their staple food for a year. Further, the area used to be inhabited by pastoralists and is considered only suitable for in extensive agriculture, making cattle raising an option to evaluate.

G. Workshops: Besides practical actions directly influencing the landscape, the farmers and other stakeholders mentioned the importance of workshops. Workshops in Farming As A Business (FAAB) can be valued as development actions, affecting social characteristics and economic output.

H. Location: The indirect development action of “Location of gardens” influences the willingness of people to participate and can thus be important to catalyse change. The main transport of the community members is by foot, so a distance of maximum 5 kilometres from there home is acceptable. This is not always possible, but gardens closers to homes are more likely to be used.

I. Market accessibility: A lack of a place to sell the produce makes gardening unsustainable. As market flooding is a challenge it is important that, besides looking at different crop types, market accessibility is taken into account.

#### 4.4 Step 4: Evaluate actions

The implementation and effect of these development actions is related to natural, social and economic characteristics of the area. To define how these actions influence the gardens and landscape the causal model is extended with these actions (Figure 20). The actions that directly influence the water balance are then implemented in the model to assess the hydrological opportunities. Based upon expert knowledge, previous studies on possible actions and modelling results the efficacy, sell- by date and vulnerabilities and opportunities will be assessed.

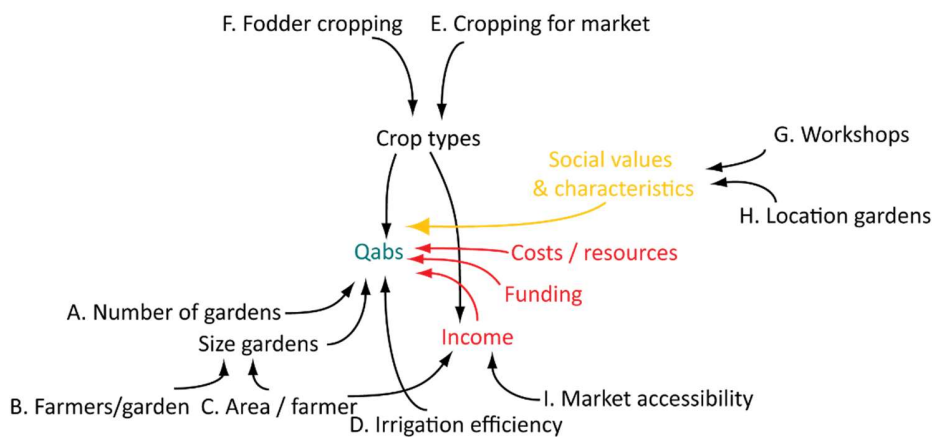


Figure 20: Causal model of the to be evaluated effect of Development Actions on the natural, social and economic parameters

Hydrological opportunities and limitations, that will determine the adaptation tipping point of a policy, will be evaluated by looking at the impact of development actions A - F related to irrigation water abstraction on the water balance. Development actions C, E, F and I will (also) be evaluated for their effect on the economic lead time. Further, the actions G and H are expected to have impact on the social characteristics and will be evaluated qualitatively (Table 11).

Table 11: The development actions and the parameters and domain they affect

Action	Parameters	Landscape scale (long term, 25 y)	Garden scale (short term, 5y)	Domain
A. Number of gardens	$n_g$	+100/y		Natural
B. Farmers/garden	$n_f$	+15/y	+2/y	Natural
C. Area/farmer	$A_g$	+50%/y	+10%/y	Natural / Economic
D. Irrigation efficiency	$\eta_{irr}$	0.6 to 0.85	0.6 to 0.85	Natural
E. Cropping for market	$k_c$			Natural / Economic
F. Fodder cropping	$k_c$			Natural / Economic
G. Workshops				Social
H. Location gardens				Social
I. Market accessibility				Economic

## Naturally bearable

### Water storage at landscape scale

The water balance is affected by water abstraction practices and Development Actions can influence the storage available.

Development actions A, B and C are evaluated for natural sustainability, considering the three different climate scenarios. For action A an increase of 15 farmer per year is considered, for action B an increase in area/farmer of 50%/y and for action C an increase in the number of gardens at the landscape scale of 100 per year. It is important to mention that local water abstractions are considered, which account for current garden practices.

The threshold levels are for all scenarios and actions reached only after 2028, which coincides with + 1000 gardens in the landscape area.

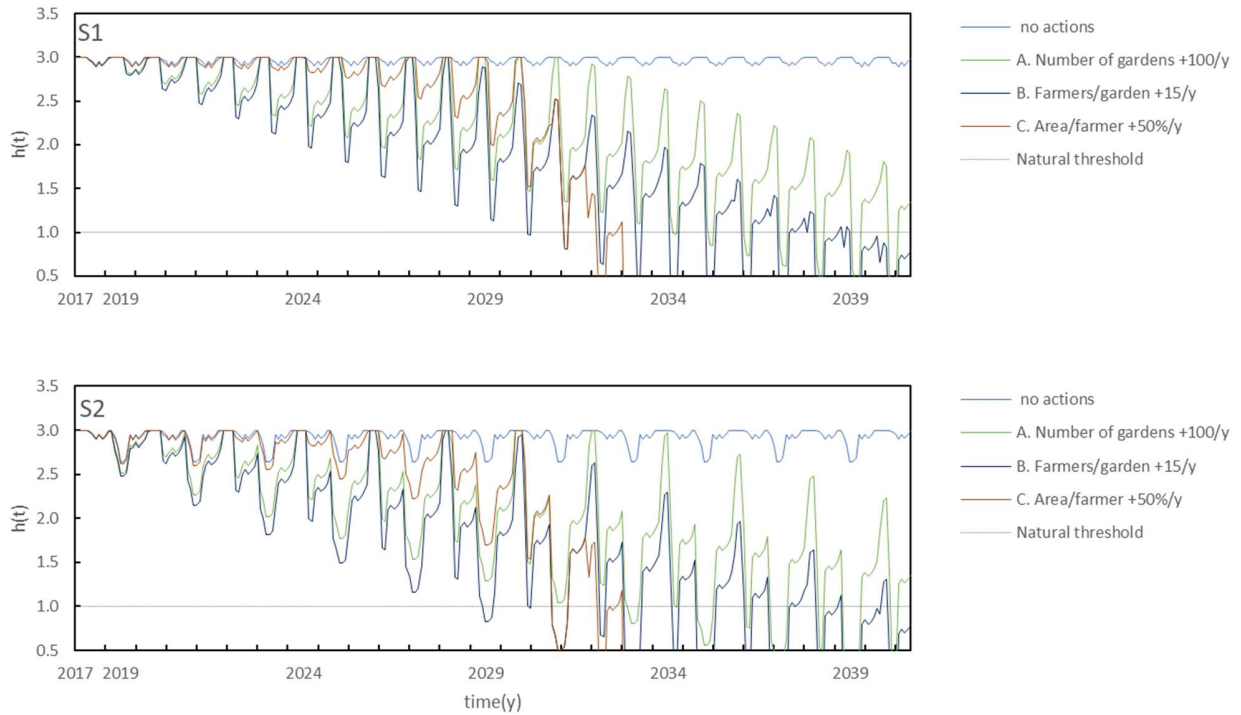


Figure 21: Water level ( $h(t)$ ) for different development action under scenario S1 and S2 at landscape scale

The effect of development action D. irrigation practices at the moment that the threshold level of other actions (Figure 22) is reached increases the sustainability. This action has most effect on development action A, where sustainable abstraction seems possible till at least 2040.

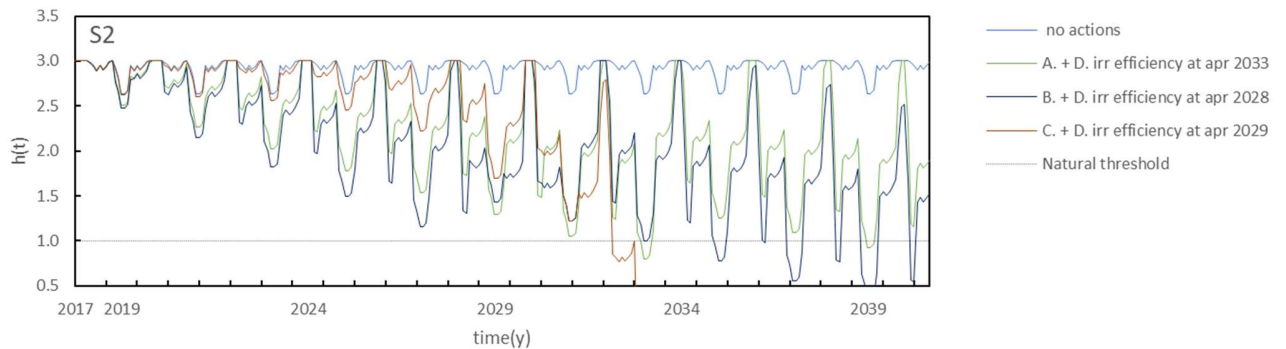


Figure 22: Effect of water level ( $h(t)$ ) changes with different consecutive development action at landscape scale for scenario S2

### Water storage at garden scale

To account for the differences in spatial scale separate calculations were made for landscape scale as well as individual garden scale. As long as enough water is available in the aquifer water abstraction rates at garden scale are limited by the available abstraction equipment (e.g. pumps etc.) and storage facilities.

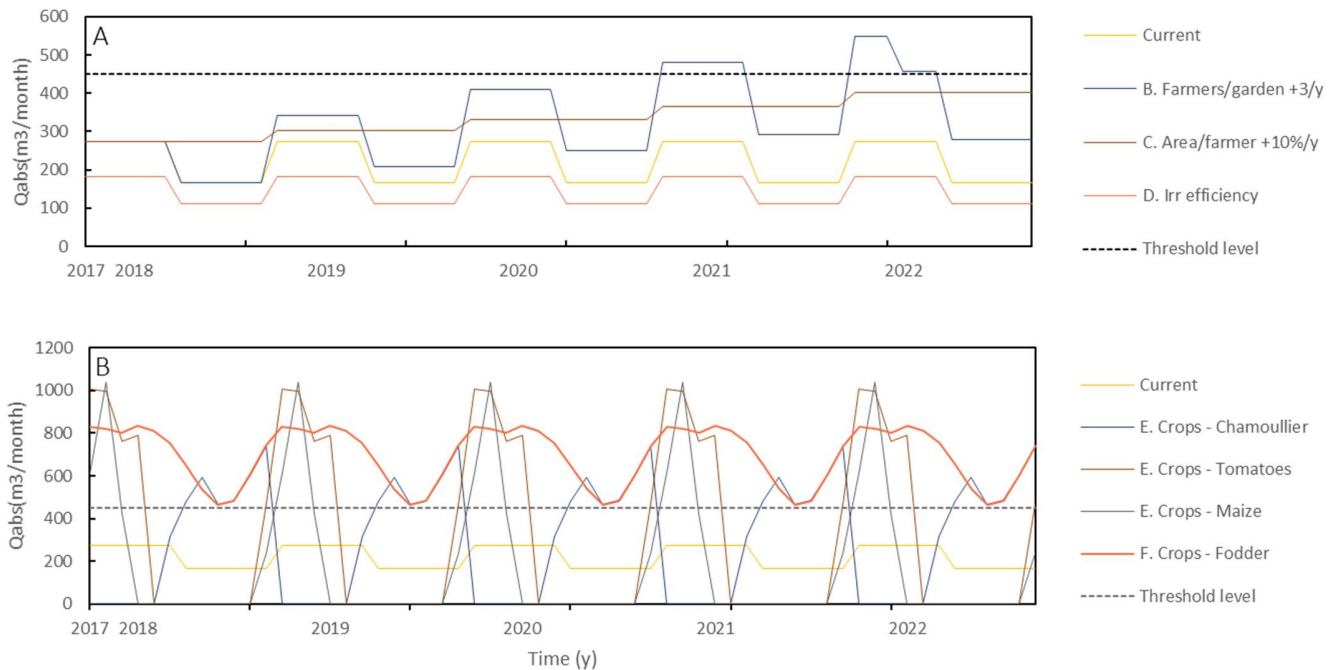


Figure 23: Garden scale effect; a. Water abstraction changes for different development actions (A, B, and D), b. Water abstraction (Qabs [m³]) for development action E. sDifferent crop types and F. Fodder cropping;

### Socially equitable

When Development Actions coincide with social preferences the threshold level for participation is met. However, currently not many stakeholders are willing to participate in a new garden project. The social lead is the time necessary to change stakeholders' social values and characteristics and improve their willingness to participate. Workshops (Development Action G), the location of gardens (Development Action H), but also the success of already established gardens and other unknown parameters can influence peoples' decision making. As social indicators are relative and subjective it is difficult to quantify the change over time, but a qualified guess of the expected effect of the development actions is made.

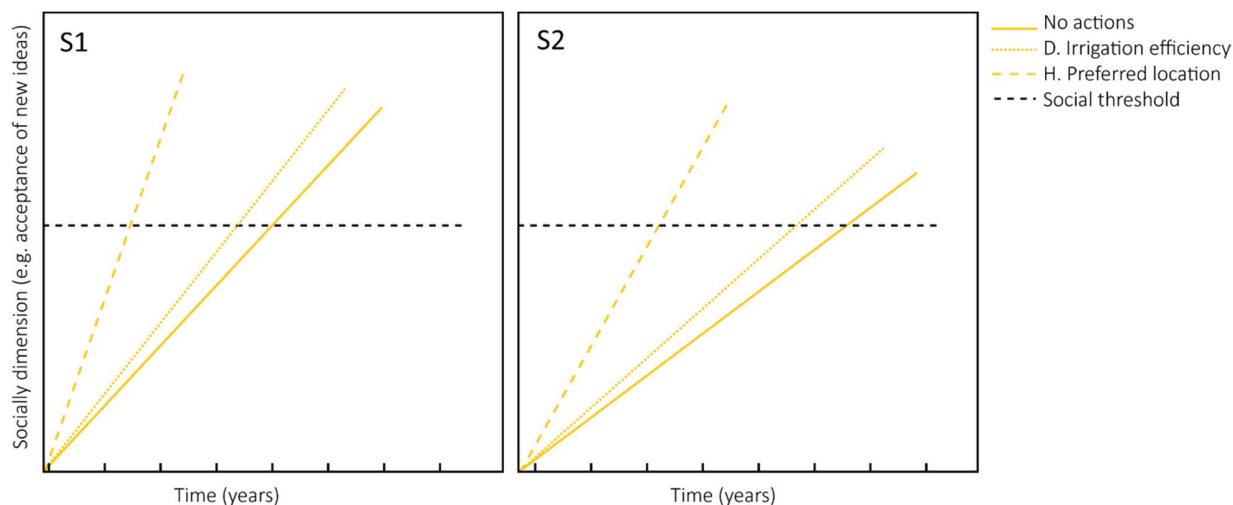


Figure 24: Effect of Development Actions on social lead time at landscape scale

**Women <35** - Younger women hesitant to participate because of the distance to the farms and the hard labour and effort seemed relatively more important than the income generated. The placement of a garden was a critical value mentioned during community meetings and influences the social lead time substantially. Development actions as D. (irrigation efficiency) and H. (distance to the gardens) are likely to change their mindset.

**Women >35** - Older women are the group of practitioners that are currently farming in most of the gardens and also subscribed for the new farm. This means their threshold level for participation is met and no action or changes are needed to make them engage in the activities. As women do not own cattle they are more reliant on farm income then their husbands.

**Men <35** - Young men are the most difficult group to reach, while success of development is related to engagement of the younger population. Their social indicators need to be taken into account to change the trend of migration. However, they are far from the threshold level and it is expected that only shown result can bring about a transformation in their mindset.

**Men >35** - Some older men send in an application letter to apply for participation in the new garden. They value employment and tradition and can have a valuable contribution with their knowledge and force to the gardens.

Economically viable

*Income per farmer*

The objective is to improve the livelihoods in the area and income is one of the main parameters to estimate this. If farmers earn more money with their farming activities they might be able to get out of the poverty-trap and develop their area. Their higher income can lead to investments in both the farms and the area. Development Action C, E, F and I. can influence the income per farmers and thus their ability to invest. Fodder cropping can be seen in line with traditions and livestock accounts for an important savings mechanism. Farmers try to keep as many livestock as possible, and sell them at moments they need money. This results in the fact that people need to sell their livestock at periods of drought. However, in these periods the livestock is not healthy and fat and many people want to sell their livestock at the same time. When they are able to keep their livestock alive through this period and sell it a few months later they can earn much more money. To feed the livestock year round an option is to grow

fodder instead of crops, and earn money by selling healthy livestock. Fodder can grow year rounds, however this upgrade of capital does not give as much profit/area as expected (Figure 25).

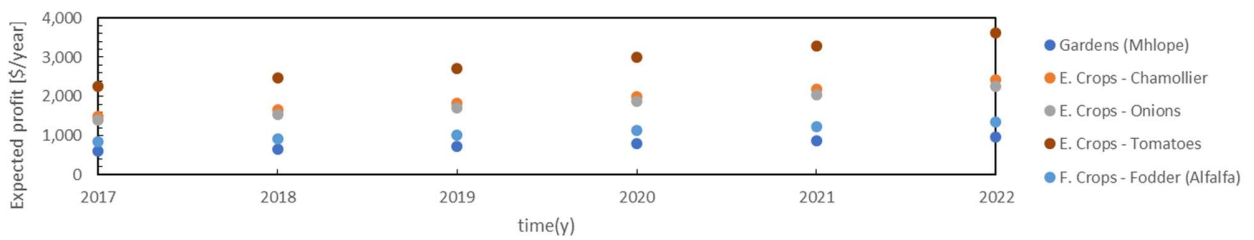


Figure 25: Income from garden/farmer including Development Action C. with a 10% increase in area/year

### Economic threshold level

The costs of the different actions vary highly and coincide with the scale of the development. Small scale interventions can possibly be covered by savings in the garden. Costs range from a few dollars for wire to extend the garden to land clearing, pump and watering system installation costs. Current gardens collect monthly maintenance fees, which are used to fund gardening activities. Those include besides repairs and maintenance often procuring inputs. Landscape interventions could be covered by resource mobilisation within the community and possibly funds. It is however important to cover most costs by the people using the garden, increasing their affection with the plan.

When the threshold level is reached is influenced Development Actions. An indication on the effect of the actions on the lead time is given in Figure 26. S1 shows a plausible economic climate, where S2 shows a less favourable economic situation which increases the lead times.

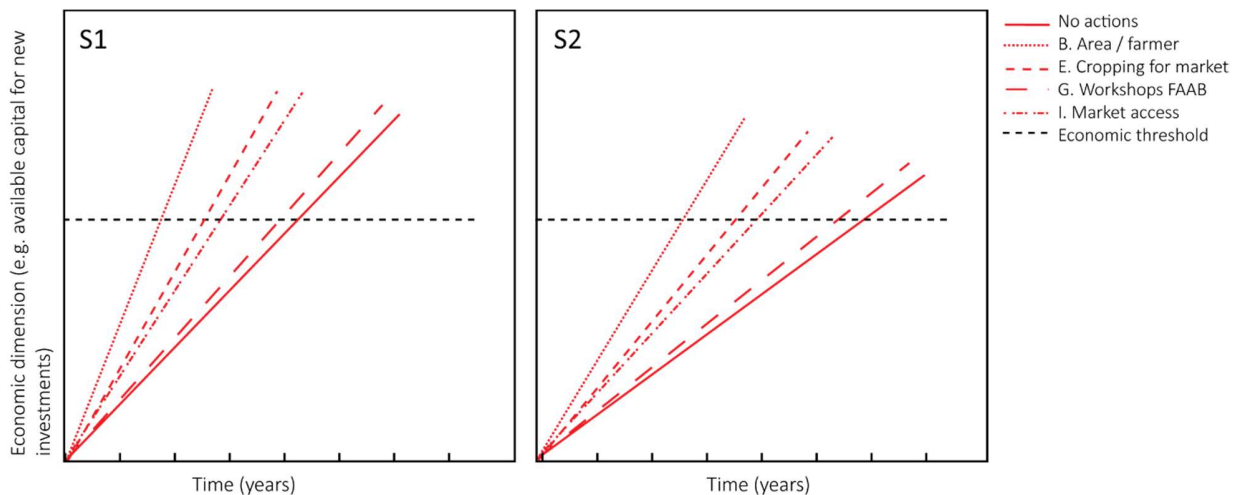


Figure 26: Estimated effect of development actions on economic lead time

## Evaluation matrix

The effect of the actions on total sustainability in the landscape area is summarised in the following value matrix ( The plus and min signs (+ and -) indicate whether a development action has a positive or negative effect on the different domains of sustainability.

Table 12). The plus and min signs (+ and -) indicate whether a development action has a positive or negative effect on the different domains of sustainability.

Table 12: --- Large negative impact, -- moderate negative impact, - negative impact, 0 no change, + positive impact, ++ moderate positive impact, +++ large positive impact

Development actions	Sustainability								
	Social lead time				Natural system			Economic lead time	
	Women		Men		Water storage	Runoff factor	Natural resources	Income/farmer	Costs
<35	>35	<35	>35						
O. No actions	0	0	0	0	0	0	0	0	0
A. Number of gardens	0	0	0	+	--	-	---	+	\$\$\$
B. Farmers / garden	0	0	0	0	--	0	-	0	\$
C. Area / farmer	0	0	+	0	--	0	--	++	\$
D. Irrigation efficiency	+	0	+	0	++	0	++	0	\$\$
E. Cropping for market	0	0	+	0	-	0	0	++	\$
F. Fodder cropping	0	0	+	0	+	++	+++	+	\$\$
G. Workshops FAAB	0	+	0	+	0	0	+	++	\$
H. Preferred location	++	+	0	0	0	0	+	0	\$\$\$
I. Market access	0	0	+	0	0	0	0	+	\$

## 4.5 Step 5: Develop pathways

With the information per action several pathways are assembled. When all objectives are met a tipping point is reached and a development action can be implemented. With the inputs from the evaluation the DADP's can be created for garden and landscape scale. Because the aim is to develop a plan that is accepted by all stakeholders the social lead time is not considered for separate groups, but for the community as a whole.

Figure 27a shows the pathway map assembled for the landscape area. The blue lines show that the period for which the different actions are within the natural limitations of the system. The tipping points are the moment when all objectives for a new development action are met. Panel B (Figure 27b) uses the same format, but then for the garden scale, for which also a smaller time scale is used.

Figure 28 shows then the effect of development actions on the social and economic lead time respectively. Development actions, based on social or economic characteristics can shorten the lead time, moving the tipping point for development forward. The pathways for the different domains are combined in Figure 29, where the effect of social and economic development actions on the implementation of the natural action 'A. Number of gardens' is shown.

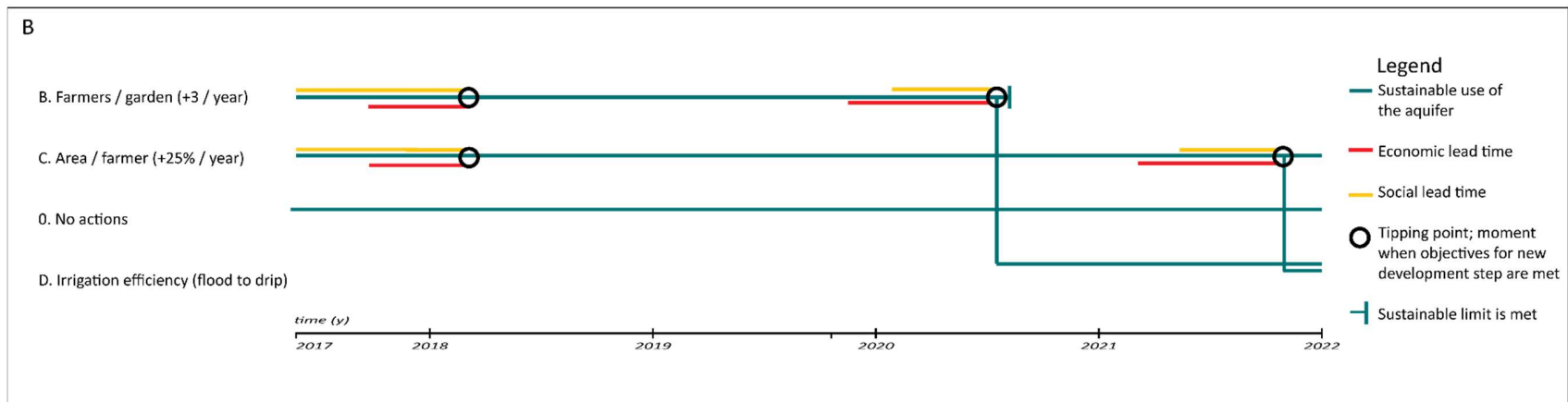
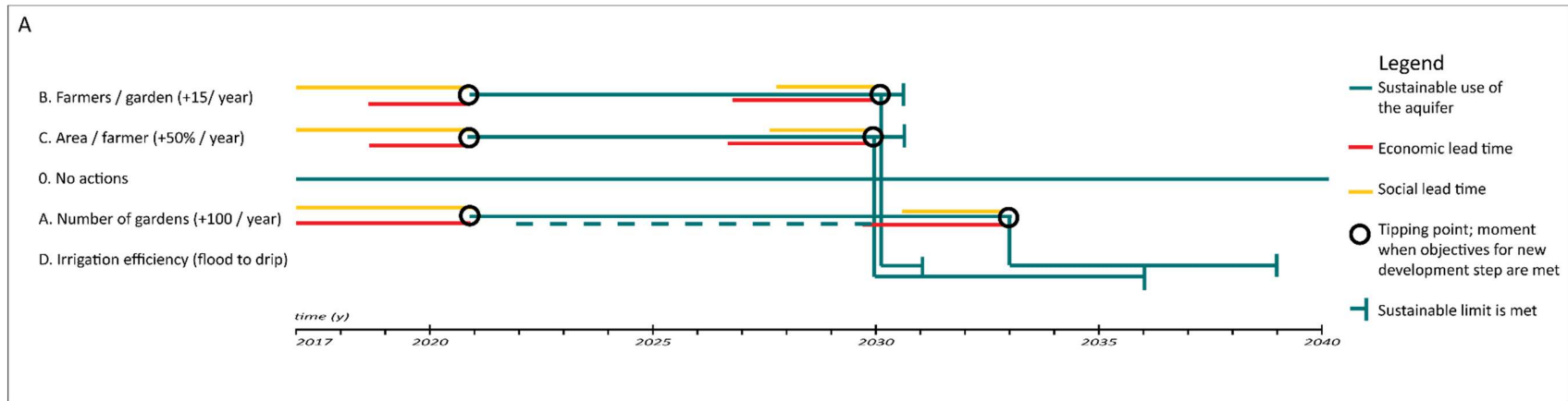


Figure 27: Development Pathways for A. the landscape scale and B the garden scale



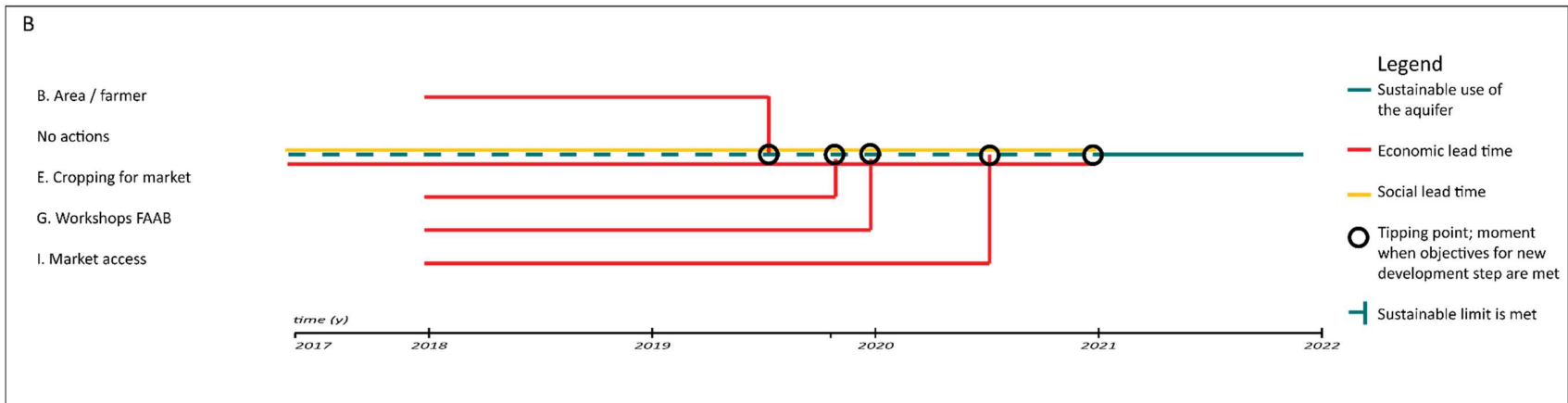
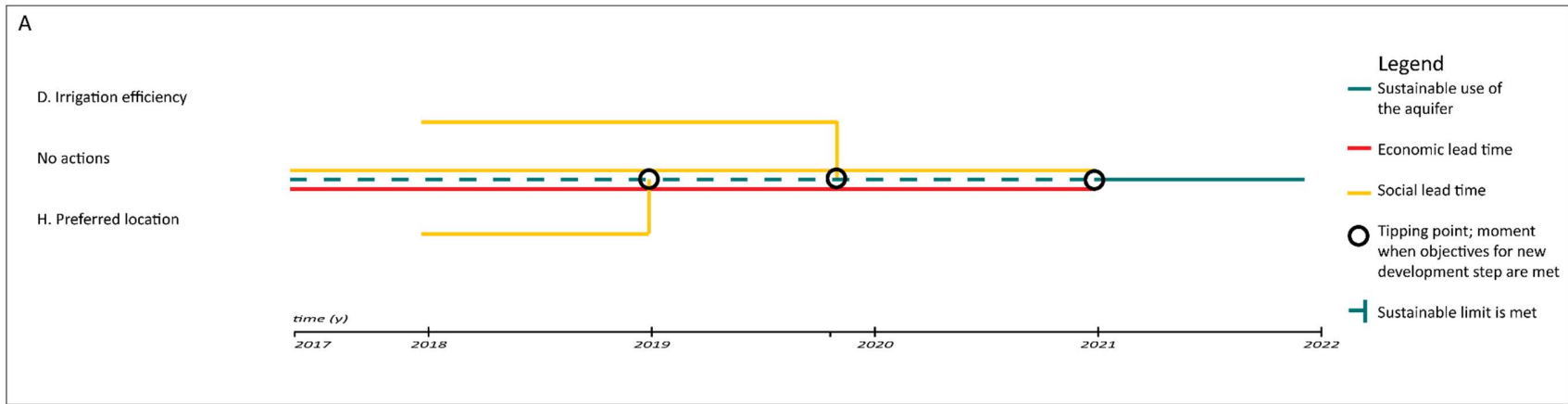


Figure 28: Estimated Development Pathways for garden scale, showing the effect of development actions on the social and economic lead time respectively; A. social pathways, B. economic pathways

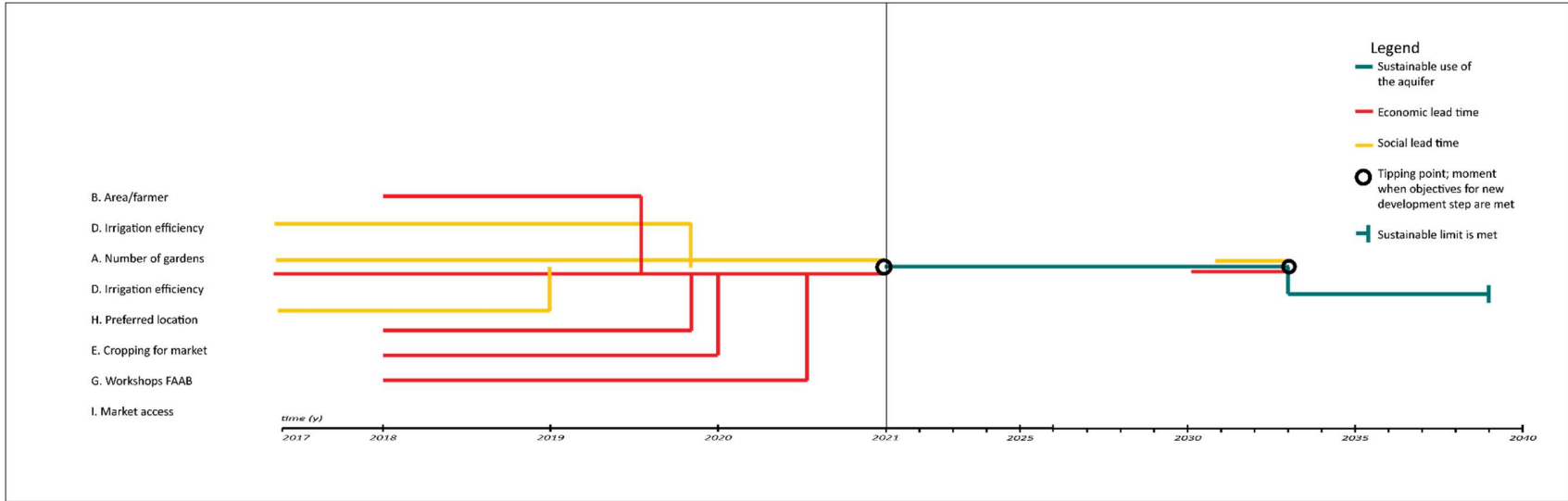


Figure 29: The combination of social, economic and natural development pathways

#### 4.6 Step 6: Select preferred pathway(s)

The strength of the pathway approach is that it is not necessary to decide now for the whole future. The lead time for social actions on the landscape scale is a couple of years, in which social participation level needs to be met. Farmers per garden have mentioned interventions that could easily be implemented at garden scale (Appendix). By supporting participants in taking these small steps it can be assured that only no regret actions are taken, while the base can be set for longer term development.

The pathway map should be seen as a first overview of the development opportunities for the area, which defines which actions can be taken now and how the area can be developed. Feedback from all stakeholders (NGO's, ministry bodies, farmers and communities) is necessary. With this feedback the pathway map can be adjusted throughout the years, and in this way stipulate an iterative path for development. At every decision moment, pathway selection should be done in consultation with the stakeholders. A stakeholder meeting for the partners in the A4labs project, who support the implementation, and a community meeting to consult the community members and potential participants.

#### 4.7 Step 7: Monitoring

To define further research and monitoring actions in the project area the technological uncertainty of the modelling process is assessed.

##### Technological uncertainties

The nature and level of uncertainty at different locations of the planning process are assessed and described consecutively. An uncertainty matrix, based on Kwakkel et al. (2010) is used to define systematically the uncertainties in this study (Appendix E).

The uncertainty in system boundaries is relevant for step 1 of this model, social and economic, since boundaries are vague and stakeholders have all a different view on their landscape area. Therewith the boundaries for the water system are normally defined by a watershed, while for the landscape area the boundaries are an integration of the different domains.

The uncertainty in the model structure of step 2 is small as the model is built up in a spreadsheet and this calculation method does not have errors in its outcomes. However, the model is simplified and does not account for all influences on the water balance.

Large uncertainties are prevalent in the input parameters of the models. However, expanding the water storage calculations of Blok (2017) to this 15 km stretch of the aquifer gives an estimated abstraction potential of  $7.5 \times 10^4 \text{ m}^3/\text{year}$ . These values are based on a ModFlow model of the area and coincide with the model outputs of this research.

Natural input parameters about geohydrological, climate and agricultural data and economic values are epistemic in nature and can be reduced by more research and empirical efforts. There is however ambiguity in the definition of social indicators, which makes them more difficult to improve.

The natural, social and economic future uncertainties made this research to adaptive pathways necessary. These external driving forces produce changes within the system, but are inherently variable and have a deep level of uncertainty.

The creation of Development Actions in step 3 is uncertain in both the size of the research group and the ambiguity in interpreting the data. Effort is taken to create a set of data that includes the views of the different stakeholders, but it was difficult to reach all groups of the population.

#### Monitoring

Since the pathway approach is adaptable over time, new research and monitoring over time can adapt the pathways to take. The model provides an insight in the possible Development Pathways, and this framework provides an insight in the parameters to monitor. Monitoring practices are necessary at different spatial scales of the 3 pillars of sustainability since those provide the input to define tipping points for development actions.

At landscape scale this research and previous studies by Blok (2017) show that there is still enough water available in the aquifer. While it is necessary to monitor this water level, it is now necessary to account for social uptake and economic possibilities. By monitoring these values and indicators, whilst applying development actions that influence their lead times, it is known when the next development steps can be taken.

At garden scale it is shown that the water budget is most sensitive to an increase of farmers in the garden (Appendix E). This should be taken into account when development actions are taken. If water budget gets low it is advisable to use water meters at garden scale to measure the water use to account for changes in the water budget. Therewith, it could be possible to reduce the water use by monitoring soil moisture status to define the adequacy of irrigation.

#### 4.8 Step 8, 9 & 10: Towards implementation

Together with the stakeholders a plan for implementation should be made. It is important that this plan only is executed if it is certain that the community approves the plan and want to contribute to its implementation. It should become their plan and not a plan of NGO's or government bodies. Therefore it is also important to define their rights and responsibilities.

## 5. Findings and discussion

The in this research developed participatory planning for sustainable development under uncertain future conditions is explained in chapter 3 and used for a case study in the Shashane basin in Zimbabwe (chapter 4). In this chapter the findings of the research are described in short, where after the research is evaluated in the discussion.

### Findings

To answer the research question *“How can a planning be developed in a participatory manner for sustainable development under uncertain future conditions?”* first a desktop study is conducted to develop a planning approach for this situation. By combining the landscape approach with the dynamic adaptive policy pathways approach a participatory planning approach is developed to support sustainable development under uncertain future conditions. The newly developed planning approach is based on a synthesis of current good practices in development aid and recent advancements of research in predictive planning and management. The combination of those two approaches provides a planning approach that focusses on opportunities for development under uncertain future conditions in a participatory manner. The approach is then applied in the A4-labs project in Zimbabwe. By following the steps of the new approach Dynamic Adaptive Development Pathways are developed to support upscaling irrigation practices.

In the first step the boundaries of the project are defined by accounting for the different domains of sustainability. The natural, social and economic characteristics are described and combining these results in the landscape area. In this step also the objective of the plan is specified; improving the living conditions in this area and give people incentives to stay.

The second step is the transition of a description of the natural area to a hydrological model that assesses the current condition and future uncertainties. Besides this, social indicators and economic values that account for the landscape and garden scale are defined, based on visualisation sessions and FGD's. After delineating the current situation, the possibilities for development need to be defined in step 3. By the use of a visualisation methodology the aspiration of the stakeholders is integrated in the planning. In step 4 the resulting set of Development Actions is evaluated with the use of the hydrological model and social and economic characteristics.

In step 5 different pathways are assembled for both landscape and garden scale. The lead time till social and economic values are met define, together with the natural limitations, the uptake of a development action.

Step 6 falls out of this research, as it requires the decision making of the pathway map for the region, which should be done by the stakeholders. The map can be used as a guideline for local water managers to upscale irrigation respecting natural, socio-economic and technical boundaries and to capitalise on development opportunities of the landscape.

To guide implementation of the plan, in step 7 the technological uncertainties are presented and recommendations for monitoring are given.

The last three steps 8, 9 and 10 define the last steps towards implementation. Together with the stakeholders a plan for implementation should be made since it is important that this plan is only executed when it is certain that the community approves and want to participate.

After completing these steps, the creation of naturally, socially and economically sustainable pathways in a participatory manner for this case study proved possible and may function as a seed for sustainable development in the area. While uptake and application of the approach by local stakeholders still needs to

be assessed, the adaptive capacity seems a valuable addition for development planning under uncertain future conditions.

## Discussion

To overcome the challenges of planning for sustainable development under uncertain future conditions a combination of two different conceptual frameworks is made. By adapting the DAPP approach based on the principles of the landscape approach the focus changed from conservation of the present situation to a focus on future possibilities. Instead of only looking at the possible negative tipping points the new DADP approach focusses on the existence of opportunities for development in a participatory manner. Development actions can be implemented when the social and economic threshold levels are met, and before the natural (negative) tipping point is reached. The 'critical implementation time', the time in which all conditions for implementation of a development action are met, is thus based on the social, economic and natural characteristics of the area.

The advantage of using the pathway approach for a development context is the adaptability of the plan to changing conditions. Especially in situations where resources are scarce and data is limited, as is the case in development contexts, it can be favourable to generate change with small steps. Instead of implementing large scale expensive projects, development actions are used to explore momentum for further development. For the development of the pathways in the case study conservative values are used, though the pathways should be seen as an indication of what is possible at the moment. By taking small steps and continuously monitoring, it is possible to change direction based on changing situations and prevent lock-in.

The landscape approach was used to define how the different domains of sustainable development can be integrated in the planning. The approach accounts for an integrated plan by including the values of the different sustainability domains over temporal and spatial scales. This resulted in a first step to include social and economic lead times in the development of pathways. While it is important to look at the system in a holistic way, all domains have different boundaries and the compromises that have to be made can increase the technological uncertainty. A hydrological model requires a closed balance, which is difficult when only part of a catchment lies in the model area. Therewith social and economic boundaries are highly subjective, since the spatial scale of those domains differs per stakeholder. While it is important to take these limitations into account when looking at the outcome of the approach, modelling will always have its limitations. The inclusion of these domains requires further research, but could be a valuable contribution for sustainable planning under uncertain future conditions.

Beside setting the boundaries for the project area, the landscape approach also accounted for the participatory part of the concept. Instead of a focus on modelling different possible futures, opportunities for development were defined by local communities. By the use of visualisation sessions the local stakeholders formulated actions to develop their garden and landscape area. The involvement of the stakeholders in the planning process gives a planning that is based on local knowledge, instead of model outcomes. Further, the development actions created by local participants and the resulting pathways thus express their desires for the future, which makes uptake of the plan more likely.

While the inclusion of participants contributed to a more holistic plan, it is important to mention the difficulty of including all stakeholders' interests while being only shortly in the field. This was covered as well as possible by working together with a local NGO, but this also had its disadvantages. It was noticed that the group of stakeholders living in the area mostly consisted out of people already participating in the work of the NGO. There might be other knowledge available with people in the area that are not reached by Dabane. However, by being only for a short time in the area it is difficult to find the right people to talk

to. Dabane has a very good relation with the farmers in the area, but was not able to reach the younger generation, and especially the young men.

They are said to be not interested in farming and only go for 'quick money'. The success of the project is not guaranteed and the income that one can generate with farming is especially at the start substantially lower than the potential wage income of migrating adolescent men. Migration is of course not only related to money, but also to social and security disadvantages, but a shown result of the development actions could have a positive change to migration. For a successful development of the area it is however necessary not to have only applicants of +65 years old, but also younger people. The commitment of the youth is necessary to make such projects viable and effective on the long term. Others ways should be discovered to reach this younger population and define their social values and characteristics to take appropriate actions to increase their willingness to participate.

While the case study undertaken for this research suggests that it is possible to create pathways for a development context in a participatory way, the uptake of these pathways in the area falls beyond the scope of this research. Feedback moments with stakeholders in the field and local government should be organised to discuss the outcome of this research and plan implementation. Therewith, further research should be carried out to explore the full potential of applying adaptive pathway approaches to a development context.

# References

- Adams, W. M. (2006). *The future of sustainability: Re-thinking environment and development in the twenty-first century*. Paper presented at the Report of the IUCN renowned thinkers meeting.
- Allen, R., Pereira, L., Raes, D., & Smith, M. (1998a). Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO-Food and Agriculture Organisation of the United Nations, Rome (<http://www.fao.org/docrep>) ARPAV (2000), La caratterizzazione climatica della Regione Veneto, Quaderni per. *Geophysics*, 156, 178.
- Allen, R., Pereira, L., Raes, D., & Smith, M. (1998b). Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO-Food and Agriculture Organisation of the United Nations, Rome (<http://www.fao.org/docrep>) ARPAV (2000), La caratterizzazione climatica della Regione Veneto, Quaderni per. *Geophysics*, 156, 178.
- Arts, B., Buizer, M., Horlings, L., Ingram, V., Van Oosten, C., & Opdam, P. (2017). Landscape Approaches: A State-of-the-Art Review. *Annual Review of Environment and Resources*, 42, 439-463.
- Axelsson, R. (2009). *Landscape approach for sustainable development* (Vol. 2009): Doctoral dissertation, School for Forest Management, SLU. Acta Universitatis agriculturae Sueciae.
- Axelsson, R., Angelstam, P., Elbakidze, M., Stryamets, N., & Johansson, K.-E. (2011). Sustainable development and sustainability: Landscape approach as a practical interpretation of principles and implementation concepts. *Journal of Landscape Ecology*, 4(3), 5-30.
- Barbier, E. B. (1987). The concept of sustainable economic development. *Environmental conservation*, 14(2), 101-110.
- Bird, K., Shepherd, A., Scott, A., & Butaumocho, B. (1998). Coping strategies of poor households in semi-arid Zimbabwe. *Analysis*, 97.
- Blaschke, T. (2006). The role of the spatial dimension within the framework of sustainable landscapes and natural capital. *Landscape and urban planning*, 75(3-4), 198-226.
- Blok, T. (2017). *Groundwater storage in sand rivers A case study of Shashani, Zimbabwe*. Retrieved from
- Brasser, A. (2012). *From sustainable supply chains to sustainable landscapes*. Retrieved from
- Brown, J., Mitchell, N. J., & Beresford, M. (2005). *The protected landscape approach: linking nature, culture and community*: IUCN.
- Brundtland, G. H., & Khalid, M. (1987). Our common future. *New York*.



Busch, D. E., Ingraham, N. L., & Smith, S. D. (1992). Water uptake in woody riparian phreatophytes of the southwestern United States: a stable isotope study. *Ecological Applications*, 2(4), 450-459.

Ceola, S., Montanari, A., Krueger, T., Dyer, F., Kreibich, H., Westerberg, I., . . . Savenije, H. (2016). Adaptation of water resources systems to changing society and environment: a statement by the International Association of Hydrological Sciences. *Hydrological Sciences Journal*, 61(16), 2803-2817.

Cervigni, R., Liden, R., Neumann, J. E., & Strzepek, K. M. (2015). *Enhancing the climate resilience of Africa's infrastructure: the power and water sectors*: World Bank Publications.

Chitiyo, K., Vines, A., & Vandome, C. (2016). The Domestic and External Implications of Zimbabwe's Economic Reform and Re-engagement Agenda: The Royal Institute of International Affairs London.

Clark, T. W., & Clark, S. G. (2002). *The policy process: a practical guide for natural resources professionals*: Yale University Press.

Cobbing, J., Hobbs, P., Meyer, R., & Davies, J. (2008). A critical overview of transboundary aquifers shared by South Africa. *Hydrogeology Journal*, 16(6), 1207-1214.

Costanza, R., & Mageau, M. (1999). What is a healthy ecosystem? *Aquatic ecology*, 33(1), 105-115.

Crush, J. S., & Tevera, D. S. (2010). Zimbabwe's exodus : crisis, migration, survival.

Davis, R., & Hirji, R. (2014). Climate change and water resources planning, development and management in Zimbabwe. *An Issues Paper. World Bank*.

De Hamer, W., Love, D., Owen, R., Booij, M. J., & Hoekstra, A. Y. (2008). Potential water supply of a small reservoir and alluvial aquifer system in southern Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, 33(8-13), 633-639.

DeFries, R., & Rosenzweig, C. (2010). Toward a whole-landscape approach for sustainable land use in the tropics. *Proceedings of the national academy of sciences*, 107(46), 19627-19632.

Dryzek, J. S. (1997). *The politics of the earth : environmental discourses*. Oxford ;: Oxford University Press.

Dunham, K. M. (1989). Litterfall, nutrient-fall and production in an *Acacia albida* woodland in Zimbabwe. *Journal of Tropical Ecology*, 5(2), 227-238.

FAO, U. (2004). Drought Impact Mitigation and Prevention in the Limpopo River Basin: A Situation Analysis.

Fischer, A. M. (2014, 20 May 2014). Social Values, Employment and Human Development: beyond economic utilitarianism. Retrieved from <http://hdr.undp.org/en/content/social-values-employment-and-human-development-beyond-economic-utilitarianism>

Girard, C., Pulido-Velazquez, M., Rinaudo, J.-D., Pagé, C., & Caballero, Y. (2015). Integrating top–down and bottom–up approaches to design global change adaptation at the river basin scale. *Global environmental change*, *34*, 132-146.

Gleeson, T., & Richter, B. (2018). How much groundwater can we pump and protect environmental flows through time? Presumptive standards for conjunctive management of aquifers and rivers. *River research and applications*, *34*(1), 83-92. doi:doi:10.1002/rra.3185

Goodland, R., Daly, H. E., El Serafy, S., & Droste, B. v. (1991). *Environmentally sustainable economic development: building on Brundtland*. Retrieved from

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *JGEC Global Environmental Change*, *23*(2), 485-498.

Haasnoot, M., Middelkoop, H., Van Beek, E., & Van Deursen, W. (2011). A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development*, *19*(6), 369-381.

Haasnoot, M., Van Deursen, W., Middelkoop, H., Beek, E. v., & Wijermans, N. (2012). An integrated assessment metamodel for developing adaptation pathways for sustainable water management in the Lower Rhine Delta.

Haines-Young, R. (2009). Land use and biodiversity relationships. *Land Use Policy*, *26*, S178-S186.

Hallegatte, S., Shah, A., Brown, C., Lempert, R., & Gill, S. (2012). Investment decision making under deep uncertainty--application to climate change.

Harris, N. (2001). Thinking the unthinkable : the immigration myth exposed.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, *4*(1), 1-23.

Holmgren, P. (2018). On landscapes - Part 2: what are landscapes? . Retrieved from [http://blog.cifor.org/19791/on-landscapes-part-2-what-are-landscapes#.U\\_RiAqPCTcs](http://blog.cifor.org/19791/on-landscapes-part-2-what-are-landscapes#.U_RiAqPCTcs)

Hopwood, B., Mellor, M., & O'Brien, G. (2005). Sustainable development: mapping different approaches. *Sustainable Development*, *13*(1), 38.

Horst, L., & Ubels, J. (1993). Designing sustainable farmer-managed irrigation in Africa. Implications for projects, research and professional training.

Hussey, S. W. (2003). *The feasibility of sand-abstraction as a viable method of ground water abstraction*. © Stephen W. Hussey.

*IMF : World Economic Outlook (WEO)* (2018).

International, C. N. a. W. (2017). *A landscape approach for disaster risk reduction in 7 steps*. Retrieved from

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., . . . Kilasara, M. (2013). *Soil atlas of Africa*.

Kwakkel, J. H. (2017). The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. *Environmental Modelling & Software*, *96*, 239-250.

Kwakkel, J. H., Walker, W. E., & Marchau, V. A. (2010). Classifying and communicating uncertainties in model-based policy analysis. *International journal of technology, policy and management*, *10*(4), 299-315.

Lavers, C., & Haines-Young, R. (1993). The use of landscape models for the prediction of the environmental impact of forestry.

Lawrence, J., & Haasnoot, M. (2017). What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty. *Environmental Science & Policy*, *68*, 47-57.

Lindenmayer, D., Hobbs, R. J., Montague - Drake, R., Alexandra, J., Bennett, A., Burgman, M., . . . Cullen, P. (2008). A checklist for ecological management of landscapes for conservation. *Ecology letters*, *11*(1), 78-91.

Linehan, J. R., & Gross, M. (1998). Back to the future, back to basics: the social ecology of landscapes and the future of landscape planning. *Landscape and urban planning*, *42*(2-4), 207-223.

Love, D. (2013). *Water Resources Strategies to increase Food Production in the Semi-Arid Tropics: With particular emphases on the potential of alluvial groundwater*: IHE Delft Institute for Water Education.

Love, D., Hamer, W., Owen, R. J. S., Booij, M., Uhlenbrook, S., Hoekstra, A. Y., & van der Zaag, P. (2007). Limitations on the utility of small sand rivers: case studies of groundwater–surface water interactions and scale in small alluvial aquifers.

Love, D., Uhlenbrook, S., Madamombe, E., Twomlow, S., & Zaag, P. (2006). An evaluation of climate and runoff variability and associated livelihood risks in the Mzingwane Catchment Limpopo Basin Zimbabwe.

Love, D., van der Zaag, P., Uhlenbrook, S., & Owen, R. (2011). A water balance modelling approach to optimising the use of water resources in ephemeral sand rivers. *River research and applications*, 27(7), 908-925.

Mansell, M., & Hussey, S. (2005). An investigation of flows and losses within the alluvial sands of ephemeral rivers in Zimbabwe. *Journal of Hydrology*, 314(1-4), 192-203.

Manyanga, M. (2006). *Resilient Landscapes: socio-environmental dynamics in the Shashi-Limpopo Basin, southern Zimbabwe c. AD 800 to the present*. Arkeologi.

Maru, Y. T., Smith, M. S., Sparrow, A., Pinho, P. F., & Dube, O. P. (2014). A linked vulnerability and resilience framework for adaptation pathways in remote disadvantaged communities. *Global environmental change*, 28, 337-350.

Mazvimavi, D. (2006). *Assesment of surface water resources of Zinbabwe and guidelines for planning*. Retrieved from

Meier, G. M., & Rauch, J. E. (1995). *Leading issues in economic development* (Vol. 6): Oxford University Press New York.

Mhlope, G. (2017). Impact of organisational, markets and technical aspects of alluvial water abstraction on successful community gardening along Shashane River, Mzingwane catchment, Zimbabwe. . *Unpublished*.

*Migration in Zimbabwe, a country profile 2009*. (2010). Harare, Zimbabwe: International Organization for Migration, Zimbabwe National Statistical Agency (ZIMSTAT).

Moyo, M., Van Rooyen, A., Moyo, M., Chivenge, P., & Bjornlund, H. (2017). Irrigation development in Zimbabwe: Understanding productivity barriers and opportunities at Mkoba and Silalatshani irrigation schemes. *International Journal of Water Resources Development*, 33(5), 740-754.

Mpala, S., Gagnon, A., Mansell, M., & Hussey, S. (2016). The hydrology of sand rivers in Zimbabwe and the use of remote sensing to assess their level of saturation. *Physics and Chemistry of the Earth, Parts A/B/C*, 93, 24-36.

*Mzingwane Catchment Scoping Study Report* (2017). Retrieved from Unpublished:

Ncube, B., Manzungu, E., Love, D., Magombeyi, M., Gumbo, B. and K. Lupankwa. (2010). *The challenge of integrated water resource management for improved rural livelihoods in the Limpopo Basin: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin*. Retrieved from Harare, Zimbabwe:

Neumayer, E. (2003). *Weak versus strong sustainability: exploring the limits of two opposing paradigms*: Edward Elgar Publishing.

- Nissen-Petersen, E. (2006). *Water from dry riverbeds*: ASAL Consultants Limited for the Danish International Development Assistance.
- Opdam, P., Steingröver, E., & Van Rooij, S. (2006). Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. *Landscape and urban planning*, 75(3-4), 322-332.
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (9291691437)*. Retrieved from
- Pahl-Wostl, C. (2002). Towards sustainability in the water sector—The importance of human actors and processes of social learning. *Aquatic sciences*, 64(4), 394-411.
- Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global environmental change*, 19(3), 354-365.
- Patry, M., & Ripley, S. (2007). World heritage forests: leveraging conservation at the landscape level. *World Heritage Reports (UNESCO)*.
- Pfund, J.-L. (2010). Landscape-scale research for conservation and development in the tropics: fighting persisting challenges. *Current Opinion in Environmental Sustainability*, 2(1-2), 117-126.
- Poolman, M. I. (2011). *Present & Future: Visualising ideas of water infrastructure design*. TU Delft, Delft University of Technology.
- Quilis, R. O., Hoogmoed, M., Ertsen, M., Foppen, J. W., Hut, R., & de Vries, A. (2009). Measuring and modeling hydrological processes of sand-storage dams on different spatial scales. *Physics and Chemistry of the Earth, Parts A/B/C*, 34(4), 289-298.
- Rabī, M. (2016). *A theory of sustainable sociocultural and economic development*: Springer.
- Reed, J., Deakin, L., & Sunderland, T. (2015). What are 'Integrated Landscape Approaches' and how effectively have they been implemented in the tropics: a systematic map protocol. *Environmental Evidence*, 4(1), 2.
- Reed, J., Van Vianen, J., Deakin, E. L., Barlow, J., & Sunderland, T. (2016). Integrated landscape approaches to managing social and environmental issues in the tropics: learning from the past to guide the future. *Global change biology*, 22(7), 2540-2554.
- Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, 4(2), 155-169.
- Sachs, J. (2005). *The End of Poverty*, New York: Penguin Books.

Sayer, J. (2009). Reconciling conservation and development: are landscapes the answer? *Biotropica*, 41(6), 649-652.

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., . . . Garcia, C. (2013). Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the national academy of sciences*, 110(21), 8349-8356.

Schachtschneider, K. (2010). *Water Sourcing by Riparain Trees Along Ephemeral Riverbeds*. University of Cape Town.

Scoones, I. (1995). Exploiting heterogeneity: habitat use by cattle in dryland Zimbabwe. *Journal of Arid Environments*, 29(2), 221-237.

Sheppard, S. R., & Meitner, M. (2005). Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. *Forest ecology and management*, 207(1-2), 171-187.

Smith, R. J., Veríssimo, D., Leader-Williams, N., Cowling, R. M., & Knight, A. T. (2009). Let the locals lead. *Nature*, 462(7271), 280-281.

UNDP. (2007/2008). Fighting Climate Change: Human Solidarity in a Divided World. *Human Development Report*.

Unganai, L. S., & Murwira, A. (2010). *Challenges and opportunities for climate change adaptation among smallholder farmers in southeast Zimbabwe*. Paper presented at the 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions, Ceará Convention Center, Fortaleza.

Van Drunen, M., Leusink, A., & Lasage, R. (2009). Towards a climate-proof Netherlands *Water Management in 2020 and Beyond* (pp. 165-194): Springer.

Van Engelen, V., Mantel, S., Dijkshoorn, J., & Huting, J. (2004). The impact of desertification on food security in Southern Africa: a case study in Zimbabwe: Report.

Walker, W. E., Haasnoot, M., & Kwakkel, J. H. (2013). Adapt or perish: a review of planning approaches for adaptation under deep uncertainty. *Sustainability*, 5(3), 955-979.

Walker, W. E., & van Daalen, C. E. (2013). System models for policy analysis *Public Policy Analysis* (pp. 157-184): Springer.

# Appendices

## A. Fieldwork

### A.1 Fieldwork plan

Objective	Research Questions	Methodology	Source
Step 1: Area & objective	<p>What is the present situation (natural, social and economic) of the area?</p> <ul style="list-style-type: none"> <li>- Who are the stakeholders and how is there relation?</li> <li>- What is the objective for development and how is the willingness to contribute?</li> </ul>	<p>Initial semi-structured interviews</p> <p>Partner and stakeholder (district and ward) meetings</p> <p>Visualisation methodology</p> <p>Focus Group Discussions</p>	<ul style="list-style-type: none"> <li>• Dabane Trust</li> <li>• Mzingwane Catchment Council</li> <li>• Zimbabwe National Water Authority ZINWA</li> <li>• Dept. of Irrigation Development Zimbabwe</li> <li>• Farmers</li> <li>• Villagers</li> </ul>
Step 2: Opportunities & limitations	<p>What are the current trends and uncertainties for the future?</p> <ul style="list-style-type: none"> <li>- Agricultural practices</li> <li>- (im)migration</li> </ul>	<p>Visualisation methodology</p> <p>Focus Group Discussions</p> <p>Expert interviews</p>	<ul style="list-style-type: none"> <li>• Farmers</li> <li>• Villagers</li> <li>• Fosters irrigation</li> </ul>
Step 3: Determine actions	<p>Which development actions are possible to support development of the area in the near and further (next generation) future at local (farm) and landscape scale?</p> <ul style="list-style-type: none"> <li>- What are the natural opportunities and limitations?</li> <li>- Which ecosystem services are valued and how can the living environment be improved by changes in the ecosystem?</li> <li>- What are the social opportunities and limitations?</li> </ul>	<p>Visualisation methodology</p>	<ul style="list-style-type: none"> <li>• Farmers</li> <li>• Villagers</li> <li>•</li> </ul>

- 
- What are the economic and technological opportunities and limitations?
  - What is necessary for upscaling/starting a farm and who can supply this (in which timespan / quantities)?
-



## A.2 Logbook

Day	Date	Subject	Location	Report summary
1	03/08	Introduction	Dabane Trust	
2	04/08	Introduction	Dabane Trust	
3	07/08	Meeting RDC Matobo	Maphisa	<ul style="list-style-type: none"> <li>• Handing over scoping study report to get feedback next time.</li> <li>• Planning: <ul style="list-style-type: none"> <li>- 22 Aug: Presentation A4Labs DADP and feedback on scoping study stakeholders</li> <li>- 23-25 Aug: Wards 6,7,2</li> </ul> </li> </ul>
4	08/08	Visit sand dam Nyoka tributary	Tshelanyemba	
5	09/08	Visit 6 gardens	Tshelanyemba	<ul style="list-style-type: none"> <li>- Present A4labs project</li> <li>- Initial questionnaire</li> </ul>
6	10/08	Visit 4 gardens Meet secretary DA	Tshelanyemba	<ul style="list-style-type: none"> <li>- Present A4labs project</li> <li>- Initial questionnaire</li> </ul>
7	11/08	Write-up fieldtrip Planning meeting Louise and Ever-joyce	Dabane Trust	
8	16/08	Write-up fieldtrip	Dabane Trust	
9	17/08	Preparation presentation	Dabane Trust	
10	18/08	Interview hydrologist	ZINWA	Interview Ben Nyikadzino – Umzingwane Catchment Council
11	21/08	Partner meeting A4-labs	Dabane Trust	<ul style="list-style-type: none"> <li>• Partner update reports (Field technical scoping assessment, Business and access to markets scoping assessment)</li> <li>• Presentation DADP's</li> <li>• Preparation for workplan till Sept 30<sup>th</sup></li> <li>• Preparation for Feedback meetings (22-25 Aug)</li> </ul> <p>Present:</p> <ul style="list-style-type: none"> <li>- Ben Nyikadzino – Umzingwane Catchment Council</li> <li>- Shipo – Department of irrigation</li> <li>- Vusumuzi Mlilo – Dabane</li> <li>- Louise Nkomo – Dabane</li> <li>- Everjoice Mpofu – Dabane</li> <li>- Benard Mpofu – Dabane</li> <li>- Evelien Rietdijk – IHE Delft</li> </ul>

12	22/08	District meeting	Maphisa	Present: - MRDC (Matobo Regional District Council) - 4 Ward councilors - DAs - Department of Youth - Department of Woman Affairs - Department of irrigation - AGRITEX - Ministry of SME's - Dabane
13	23/08	Community Ward Based Meeting	Ward 6	Community and local authority meeting (Councilor joins to his ward)
14	24/08	Community Ward Based Meeting	Ward 7	Community and local authority meeting (Councilor joins to his ward)
15	25/08	Community Ward Based Meeting	Ward 2	Community and local authority meeting (Councilor joins to his ward)
16	28/08	Planning FGD's	Dabane Trust	
17	29/08	Administration	Dabane Trust	VISA extension
18	30/08	Writing	Dabane Trust	
19	31/08	Writing	Dabane Trust	
20	01/09	Forster	Dabane Trust	Interview Bryan Forster
21	04/09	Writing	Dabane Trust	
22	05/09	Visualisation sessions	Tshelanyemba	
23	06/09	Visualisation sessions	Tshelanyemba	
24	07/09	Visualisation sessions	Tshelanyemba	
25	08/09	Visualisation sessions	Tshelanyemba	
26	11/09	Writing	Dabane Trust	
27	12/09	Writing	Tshelanyemba	
28	13/09	Writing	Tshelanyemba	
29	14/09	Writing	Tshelanyemba	
30	15/09	Writing	Tshelanyemba	
31	18/09	Interview	NUST Cancelled	NUST (Oliver Dube - mail) → Cancelled, sick.
32	19/09	FGD's	Tshelanyemba	
33	20/09	FGD's	Tshelanyemba	
34	21/09	FGD's	Tshelanyemba	Cancelled due to police interruption
35	22/09		Dabane Trust	Review of the work with L. Nkomo (Project leader)

### A.3 Initial semi-structured interviews with farmers

Summary of semi-structured interviews, which were held to obtain an idea of the area and lay ground for later visualisation sessions.

#### *Setting:*

Attendees: farmers from 9 gardens near Tshelanyemba

Location: Their gardens.

*Main observations:*

- 80% elderly
- Varied productions, some have large crop diversity with more cash crops.
- Mostly subsistence gardening, lack of commercial (SME's)
- Youth only at some garden involved, these are often the better gardens.
- Mindset of youth
- Functionality around 75%
- Farmers seem to be just back from the dryland gardening
- Lot of vibrancy around processing center.
- Cooperation between gardens (2 top servants that meet with other gardens + workshops)
- Different how gardens evolved after getting the same workshops from Dabane and others.

*Suggestions A4labs (test) site*

- Near Shashane or tributary (30m distance)
- Not too rocky field of 3ha.
- Accessible for farmers, distance < 5km

*Questions/ideas:*

- Agritex extension officer (Mlalubu village) gives information about cropping patterns and farming practices
- Upscaling; connect drips in the garden. We can open the drips and go home, water in tank can water whole garden during the day (own experience).
- 3 ways, tank like here, dig trenches (1x pw flooding) + engine (petrol) and pipes.
- Some youth should start a garden among themselves.
- 12 members from Malundu opened garden in Malundu with water source the Malundu Dam.

## A.4 Meetings

At different levels stakeholder meetings were held to discuss the objective of development in the area and assess the willingness of communities to contribute.

### A4Labs Partner meeting

*Setting:*

Date: 21/08/2017

Location: Dabane office

*Attendees:*

- Ben Nyikadzino – Umzingwane Catchment Council
- Shipo – Department of irrigation
- Vusumuzi Mlilo – Dabane
- Louise Nkomo – Dabane
- Everjoice Mpofu – Dabane
- Benard Mpofu – Dabane
- Evelien Rietdijk – IHE Delft

#### Agenda:

- Partner update reports (Field technical scoping assessment, Business and access to markets scoping assessment)
- Presentation DADP's
- Preparation for workplan till Sept 30th
- Preparation for Feedback meetings (22-25 Aug)

#### *Summary project plan:*

- Let communities decide which kind of pump and irrigation practices
- Training For Transformation workshops (TFT) → mindset towards market
- Design, test and utilize gardens
- Mindset youth is not set towards farming
- Monitoring; Water, soil-nutrients, energy, crop productivity (crops/grass/fodder), markets, inclusion, ecosystem
- 5 study areas

#### *Summary field technical scoping study*

- Shashane is chosen as project location because there are already some community gardens to start with. Therewith earlier research has been done in the area, so there is some data available.
- The Shashane has a sand dam 10 km after the Antelope dam, north of the project area, after that the slope of the channel alters. Movement of sediment due to flooding during the rainy season goes till the lowest layer of the aquifer in the Shashane, the movement of sediment makes that pumps break. The river has some major (15-30m width) and minor (5-10m width) tributaries that bring water from the adjacent land to the river.

#### District meeting

Date: 22/08/2017

Location: Maphisa

#### Attendees:

- MRDC (Matobo Regional District Council)
- 4 Ward councilors
- District Administrators
- Department of Youth
- Department of Woman Affairs
- Department of irrigation
- AGRITEX
- Ministry of SME's
- Dabane

#### Summary:

- Refreshed the regional stakeholder on the A4Labs project plan
- Confirmed their agreement of the findings in the scoping study
- Presented the DADP plan, which was received positively; they approve with planning in a practitioners centred way.

#### Ward Meetings

Date: 23-25/08/2017

Location: Ward centres

#### Attendees:

- Community members
- Traditional leaders
- Ward councillors
- Dabane

#### Summary:

- Refreshed the community on the A4Labs project
- Confirmed their agreement of the findings in the scoping study
- The community members seem to be used to development projects where the community get things (stated what they get), the A4Labs research project is a new concept for communities and it's difficult to grasp for them.
- General understanding, but don't see the bigger picture.
- Told what we want to do in the upcoming weeks

### A.5 Expert open-interviews and discussions

During the stay in Zimbabwe some interviews and discussions with experts from the field were held. The interviews were conducted in order to find some background information about the area and are therefore non-structured interviews. The text below gives a short wrap-up of the conversations and highlights the most important information that can be used for this research.

#### Woosa – Environmentalist Dabane

Date: 4/8/2017

Location: Dabane office

#### Summary:

Main species in the land are Mopane and acacia tree species and sparsely some yellow wood.

The riparian vegetation gets its water from the river, but how is uncertain. The first 50m next to the river stay green during the dry season. Transpiration data of the vegetation are not available.

Land clearing is necessary when a new garden is established, though dependent on the place not many trees need to be taken away. The mayor problem in the area s overgrazing, and many grass species got lost.

#### Brian Forsters - Irrigation specialist

Date: 01/09/2017

Location: Forster Irrigation workplace

#### Summary:

Technical information about pumping systems

- The main advantage their pumps have is that they convert from AC to DC, which makes that all parts are available in the country and no import is needed for repairs. This makes the product easy to repair and cheaper.
- They work with a variable speed drive, that depends on the solar radiation. This requires some programming at the start, dependent on head differences and water requirements, but afterwards works good. The problem is that when a pump breaks people should not touch this, cause that would make it worse.
- They assume a specific yield of 20% in the alluvial aquifer, and then take another factor 2-3 to be safe.

#### Project opportunities

- Lower part of the Shashane, towards the confluence with the Shashe, there is even better potential for the alluvial aquifer and better soil quality. The problem here is though that it has a lower population density.
- Wealth is in the cattle
  - o Studies show that with keeping 7 goats alive and selling them a family can buy maize meal for a year.
  - o A bush pump can be used to fill a 5000l tank for household use, with an overflow to a cattle tank.
  - o Bunner grass can be grown all year round, with an extra production of velvet beans in the rainy season. (Ecrocit?)
- Drip irrigation never works, probably because people don't see the water. This causes problems, like creating more holes in the tubes. While they could be used for a double as large area.
- Another example of a failed project are the drip kits distributed by US AID (Pete), while people didn't want this. After one year only 8% of all kits were still used.
- The main problem now is the cashflow, which will also be a point when people want to sell their cattle.

Mr B (Ben) Nyikadzino - Hydrologist ZINWA/Umzingwane Catchment Council

Date: 17-08-2017

Location: ZINWA office

Summary:

Sheppard Moyo (Dabane)

Location: Processing center

Summary:

- The problem with cattle market is the cheating of the buyers. They have a market mind, while the farmers don't. Prices in this area for cows went as low as 150-175\$ in the dry season, while they're normally sold for \$500 or more, going up to \$1000-1200 in Mashonaland.
- Cattle is often kept in paddocks, but goats and donkeys wonder around, this makes that grass does not get time to grow, causing erosion in the rainy season.

#### A.6 Visualisation sessions

Date: 05-08/09/2017

Attendance: Total 63 farmers (women, men and youth), spread over 9 gardens

Summary:

Drawing sessions with farmers at 9 different gardens to assess the opportunities for the future of alluvial aquifers in the area. They were well able to draw maps of the area or their garden, some even with wind directions and a legend. It was though difficult for them to look into a further future, especially for the wider area. So we first focused on opportunities within their garden and then let them think about the future of their youth. With this approach we got to know what opportunities the farmers see for their gardens and their living area (the landscape area).

#### Guideline visualisation methodology

*Purpose:*

Creating a rich set of Development Actions in a participatory manner

*Participants:*

People that are in some way involved with irrigated farming from an alluvial aquifer (affecting/affected)

*Tasks and questions:*

- What is the present situation (natural, social and economic) of the area?
- What are the current trends and uncertainties for the future? (agricultural practices / (im)migration /
- Which development actions are possible to support development of the area in the near and further (next generation) future at local (farm) and landscape scale?
  - What are the natural opportunities and limitations?
  - Which ecosystem services are valued and how can the living environment be improved by changes in the ecosystem?
  - What are the social opportunities and limitations?
  - What are the economic and technological opportunities and limitations?
  - What is necessary for upscaling/starting a farm and who can supply this (in which timespan / quantities)?
  - What are the natural opportunities (and limitations)?
    - Different types of agriculture
      - Perishable
      - Fodder crops
      - Maize
      - Combinations
    - Valued ecosystem services
- What are the socio-economic opportunities (and limitations)?
  - Market access
  - Youth involvement / gender equality
  -
- What are the technological opportunities (and limitations)?
  - Different pumps
  - Different irrigation systems

*Tools and resources:*

- Paper (~A1)
- Colored markers/pencils
- Tape
- Pre-made pieces
- Notebook & pencil to take notes

*Session:*

4. Present situation
- Draw outlines to give starting point and ask participants to draw their living area
    - Water (body)
    - Agricultural fields (dry and wet) / irrigation
    - Livestock
    - Housing
    - Market
    - Trees

- 
- Discuss current situation
  - Responses to changing climate
    - Prepared for drought (1991/2015/16)?
    - Prepared for drought now?
  - Garden for yourself to make profit?
  - Irrigation dry/wet season
  - Spread risks?
  - Pump breaks?
  - Is environment important commercial, or because it strikes back?
  - What do you do if there's no recharge
  - Would you do things differently if you had a garden for yourself?
  - Different types of agriculture
    - Perishable
    - Fodder crops
    - Maize
    - Combinations
- Ask to draw their sources of income
  - What do they use from nature? (ecosystem services)
- 5. Drawing future situation
  - Circle areas for opportunities (and limitations)
  - Draw changes
  - Number them
  - Discuss the opportunities
- 6. What is needed? / What can you provide? / How to get the rest?
- Discussion
  - After a good year, how much of the profit would you invest in the garden?
  - Willing to pay/ invest?



## 1. Madleloulahlaza

Attendance: 4 (2 women, 2 men)

Trees are used for: timber, fruits, poles, protection of wind

Which types? Mainly Mopane and Guwe

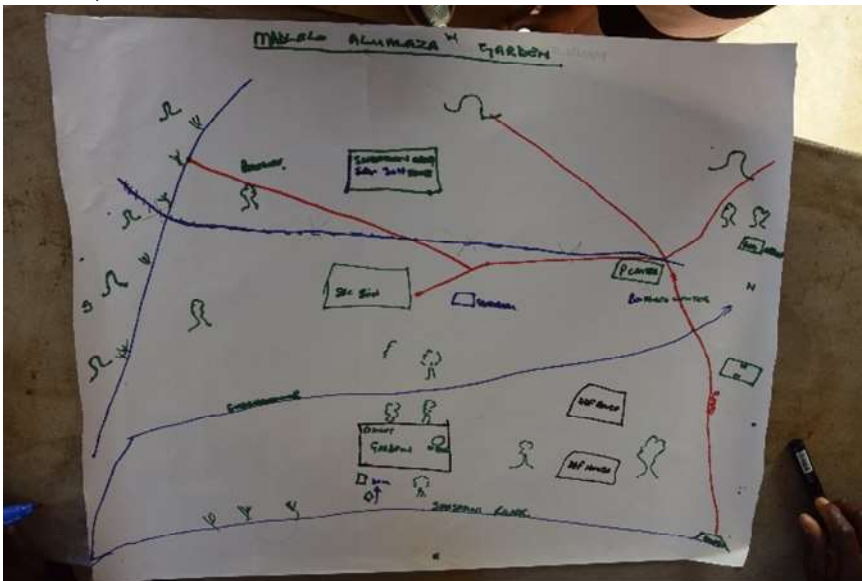
Opportunities (5y):

- Small dams in gully, the gully grows every year and flows near the garden.
- Extend the garden with about 20 meters to make space for an orchard with fruit trees.
- An extra water tank in the garden; we can pump up more water during a day, but have no space to store it.
- The pipes of the watering system break every year during the rainy season.
- Sprinklers could help reduce the labour.

They can provide a wire, so extension should not be a problem.

Notes:

- People were eager to draw and knew the idea of a map (wind directions and legends). They were well able to point on the problematic areas and came with solutions.
- It is difficult to point on things they can provide, as they often get things. It is known that they, for bigger structures, always provide the labour and small materials available in the area. Dabane, or others, provide more expensive structures and materials. Money for initial expenditures is thus required for upscaling or establishing gardens.
- First step: Extend + orchard



- Figure 30: The visualisation of the current landscape and future development actions of garden Madleloulahlaza

## 2. Bekhimpilo

Attendance: 5 (5 women, of whom one woman (Ms. Ndebele) was mainly talking)

Opportunities (5y):

- Drilling a well (boreholes) near the river, because drilled wells on the riverbank don't break easily.

- Powerful solar panels, not the ones that are not able to fill a tank.
- Sprinklers, no drip. But last time, with the initial interviews, a man from this garden mentioned drip irrigation as a good option.

Notes:

Due to our set-up the focus was mainly on the watering system. For the next sessions we can better start with focusing on the garden and then expand the area towards the opportunities within the wards, including socio-economic options. To focus more on income generation we should let them draw the services that generate income for them.



Figure 31: The result of the visualisation is a map of the current landscape that includes possible development actions of garden Bhekimpilo

### 3. Mpumelela

Attendance: 7 (5 women, 2 men)

Income sources:

- Garden (fresh vegetables)
- field (ground nuts/maize)
- Selling livestock: chicken and eggs, cows, donkeys
- indigenous trees (African chewing gum for eating (*Hesperia Garckeana* (Author)), Mopane trees for caterpillar collection and fire wood. They are though not allowed to cut trees by the EMA)
- baskets from grass
- goats

Opportunities (5y):

- Many gardens causes more competition on the market

- Other crops that could be grown:
  - o Potatoes
  - o Sweet potatoes
  - o Sugar beans
  - o Butternuts
  - o Pumpkins
- Cattle eats grass, leaves and maize shells, so growing for cattle is not an option.
  - o Other woman: growing food for cattle is a good idea as they can be kept alive during a drought period, but a larger area is needed to grow enough.
- A better watering system (canals or pipes) and pumps that don't break down so often. People run away from the garden and don't want to work as the watering is very heavy and difficult.
- Not an opportunity but a limitation; Money is a problem, trade is done instead of getting money for crops as there is not much money available.
- The processing centre is just established, thus it is not yet determined how the market will be.
- We can determine how much we can produce for the market, an example is 100kg/member of butternut, potatoes and pumpkins.

Notes:

- This session was mainly useful for valuing ecosystem services and income sources

#### 4. Kathazu

Attendance: 9 (2 men, 5 women, 2 youth (boys))

Current situation:

The vegetable gardens generate most income in the garden, but there is also a conservation farming plot for household consumption.

Mainly butter trade with the vegetables they grow, instead of selling them for money.

Opportunities (5y):

- We would like to extent our garden, but there is a gully that prevents this.
- The wooden poles of the garden easily erode and need to be replaced every two years, it would be good to make them from metal.
- "We had a meeting before as a group of garden to find an easy way of watering. We thought of windmills. We have never seen this in a garden, but it could be a good option. They are easy and not so expensive to maintain and repair. Solar panels have always problems with breaking down and are expensive to repair. And an engine is expensive throughout the year. Then we were thinking of canals for the watering of the beds. Canals are easier than pipes as they bring more water, as pipes are very small. The canals can be about 30 cm wide and can be connected to the tanks"

Sources of income:

- Crops (most income from their garden)
- Curving wood (Carpentry)
- Selling livestock: chicken, eggs, goats
- Baskets and mats
- Wild fruits and caterpillars
- 

In the dry season there is a shortage of food for the cattle, they grow grass in another field (dryland). The garden needs the most water.

#### Opportunities next generation:

- It is difficult to create more gardens – there are no people who want to work in the gardens.
- An option is to extend the current gardens and involve the youth in these. They now are working in the gardens and gain experience, but don't earn anything. An extension to the sides could be an option to give them their own beds. The constitution of the garden approves this.
  - o Youth replies: they rather have a small piece of land in this garden than work in the to be established irrigation scheme. This new scheme is too far and they don't see the profit of it.
- Paddocks for cattle are necessary to improve the environment, for this the whole community needs to be involved.
- The watering system of the garden needs to be improved

#### Notes:

- Enthusiastic group, but old. They are willing to extend and empower the youth. They want to give youth a space in their garden.
- First step: extend + space for youth

#### 5. Masinlanganeni

Attendance: 11 (11 women)

#### Current situation:

- During drought pumping for the garden is very heavy
- They dig holes in the aquifer to get access to the water for livestock

#### Opportunities (5y):

- Create an opportunity to buy seeds nearby
- Solar panels instead of rower, or a windmill, to decrease the labour.
- An extra jona pump/ rower outside of the garden. Pumping in two steps decreases the labour.
- More variety of crops: potatoes (difficult to get seeds), sugar beans, lettuce, sweet potatoes
- New money structure, as now they mainly do butter trade (is trade between goods)
- Using the processing centre as a market place
- Metal fencing instead of the wooden poles, they erode easily

#### Income sources:

- Garden, most income as they are just poor farmers [note: indeed one of the poorest groups]
- Livestock sale: goats (imbuzi) and chicken
- Mats and baskets
- Caterpillars (amacimbi)
- Indigenous fruits

#### Opportunities next generation:

- Not more gardens, this would decrease the market accessibility
- They could increase the size of the gardens
- Sell there produce in Maphisa or at other places
- The focus should not only be on gardens, but one should think of dairy and meat cattle
- Find other ways; maybe the use of poultry

- Other woman: there is a competition on the market for poultry
- Broiler chicken need bought food, they cannot eat what is grown in Zimbabwe.
- Youth doesn't want to work with the bad watering system, they find it too heavy.

Notes:

- Not so much input; maybe the group was too big or the people felt not empowered enough to talk.

## 6. Thembani

Attendance: 9 (7 women, 2 youth (boys))

Opportunities (5y):

- Metal poles for surrounding fence
- Extension with 3 beds → but fencing is expensive to pay from the savings of the garden
- More crop diversity: potatoes, sugar cane, butternut, lettuce, different type of cabbage
- Processing center is the new market, this should make it easier to sell there produce.
- Sprinkling would be easier, but watering with the buckets works okay.
- 

Sources of income:

- Butter trade from the garden is limited, if the garden is extended that could be more.
- Field (together with the garden this provides most of the income)
- Selling of livestock: chicken, goat
- Selling of mats and baskets
- Brick moulding
- African chewing gum

Opportunities next generation:

- New projects for youths are needed
  - Ideas: a new poultry project
  - Goats and chickens to sell
- It is needed to find seeds for fodder crops, these are not on the market as far as they know.
- Boy:
  - Wants to become the next famous football player
  - Content with gardening under parents, 'scared' of problems that might arise with the new garden

Notes:

- Very content women
- First step: larger garden for crops

## 7 Vusanani Tholoki

Attendance: 3 (3 women)

Present situation:

23 years ago the garden was established, they produce many different vegetables and have a lot of experience with farming.

Opportunities (5y):

- The size of the garden is good, nobody showed interest to join their garden. 'We are only old woman and we are very content with what we have'.
- Sprinklers could reduce the labour

Sources of income:

- The garden
- Fields – maize

Opportunities next generation:

- It is difficult to plan for us, because this changes should benefit the youth. They will benefit, but will then always migrate. We should thus think of ways to capture the youth, maybe via schools, before they want to migrate. They need a better understanding of why it is not good to migrate. We don't know what they learn at school, but it should be the same as the parents tell them.
  - o Most of them want to mine and gain quick money.
  - o They even steal cattle from their parents to sell it, but they don't want to be engaged in keeping them.
- The other problem is water for domestic purposes, the water availability at homes should be improved.
  - o It is not allowed to build houses closer to the river, this place is for the livestock.
- What we need most as a country is maize and sugarcane, maybe they could farm that to make it less expensive.
  - o But along the Shashe is an irrigation scheme that is abandoned. It is difficult to estimate if people will also abandon new schemes. This scheme was abandoned not because the market was a problem, but because of political issues. They took the maize without paying for it.
  - o The new scheme might be better, as it comes after 'liberations'.
- The problem is the people.
  - o If you fail to handle a small scheme, you'll fail to handle an irrigation scheme. 'We're shameful for our community'.
- We also work at a big feed lock, besides the hard work in the garden.

Notes:

- Winner of crop competition

8. Siyazama

Attendance: 11 (3 men, 8 women)

Opportunities (5y):

- Watering system should be improved; there are now problems with the solar panels and with the pipes.
  - o Sprinklers could be better
- Fencing should be from a different material than wood, as they last only 2 years.
- There is an inconsistency with farming because of the seeds.
  - o It is only possible to get them in Bulawayo
  - o The seeds in this area are more expensive than in Bulawayo.

- There should be more diversity between the crops of the different gardens. Now everyone grows the same crops, which makes it difficult to sell them.
- There are too many gardens for the market.
  - o The processing center will be too small
  - o A different market is needed, even in Tshelanyemba.
  - o Another option is transport to Bulawayo or Maphisa, but transport is difficult/expensive.
- Focus should be on other projects, not on farming.

Opportunities next generation:

- Youth is used as labour by their parents, they might be interested in having their own garden.
- Everything comes from the wish you have, a new irrigation scheme is a good idea.
  - o Maybe a new scheme could focus on poultry and sell this to the population/market.
  - o Maybe a bigger irrigation scheme can be divided in 2, 1 part crops and 1 part cattle fodder.
  - o Other woman: No! not supposed to do two things at the same time
  - o It depends on the need what should be farmed.

Income sources:

- Garden (most income from the garden)
- Sell livestock: chicken, goats, donkey, some of them cows
- Maize and millet from the field
- Mats and baskets

Tips for new garden:

- Water availability is most important
- Using manure improves the yield
- Planting the crops in the right season

Notes:

- Difficult start of the talk, but good ending with good input.

9. Shashane 5

Attendance: 4 (4 women)

Opportunities (5y):

- Potatoes could be an option to increase crop variety
- Growing for the market
- Extending the garden would be good, but there is no space.
- The watering system should be more stable as the garden is far from the river, thus walking with buckets is very heavy (in case the system is broken).

Income sources:

- Garden (provides whole year round income, so most income)
- Mining
- Sell caterpillars (in season)
- Field cultivation

Opportunities next generation:

- 'With the youth we failed, they don't want to work'.
  - o It is difficult; they don't want to work, but want quick cash. This results in an increase in the crime rate.
- A new garden should grow crops; as everyone needs food this is a good starting point.
- Poultry is difficult, because there is an exact day of selling the chickens.
  - o Also the slaughtering process should not be near the river as it affects the water quality (EMA).

Tips for new garden:

- Compost to improve the soil quality. This doesn't cause diseases in the human body, compared to fertilisers.

Notes:

- The pump was broken and repaired the day we visited.
- Garden was not completely used.
- Mostly chamoulia (chomoiller), small bit of different species (seeds they got).



## A.7 Focus Group Discussions (FGDs)

Date: 12-15/09/2017

Attendees: Community members of the specific wards

Theme: 'Community perspectives of resilience and opportunities for improvement'

- Water management
- Food security and agriculture
- Forest harvest and management
- Disaster Rids Reduction Plans
- Gender equality and women's participation

### Ward 6 Sigangatsha

- o Water management

Water is fetched from Shashane, dams, boreholes, well points

The dams dry up during the dry season, but household water wells are not affected. For some the distance to the Shashane river is quite far.

There are water governing communities

- o Food security and agriculture

Most people have sufficient stock till next season, access to 3 nutritious meals per day and are in good health. This was different last year, after 3 very dry years food aid was necessary.

- o Forest harvest and management

Used as income source and for use at households.

There are fines for cutting down trees (50\$ or a goat), so they cut branches instead of trees.

Water point committees arrange for gully reclamation.

Large distance from pastures to settlement.

- o Disaster Rids Reduction Plans

Wires are now used for roofing

Trees and vegetation is kept around homes to function as windbreakers.

Well prepared for floods, houses in higher areas.

- o Gender equality and women's participation

There are no woman in leadership positions, but they do attend community meetings and contribute to decision-making.

### Ward 5 Beula

Ward 5 is not part of the project area, but thoughts and practices in this area are representable for the project area.

19 (10 men, 9 women)

- o Water management

The Buela dam (reservoir) dries up and is silted, they use it for livestock and domestic purposes.

Ntabansinbi has one dam, they had a fight due to the gear from Mungezi.

There are 2 boreholes in Beula and 5 in Ntabansimbi for more than 400 households. Both villages don't have enough water sources to support the communities, more boreholes would be a possibility to increase water availability.

- o Food security and agriculture

There is one irrigation scheme in the Shashe and a nutrition garden (small irrigation plot) with 56 members. Each member has 10 beds, but the dam cannot supply enough water for this scheme. Therewith not everyone in the community is a member of the scheme and for some the distance to the scheme is far. The beds can supply enough food for family consumption, but not enough for the whole community. An opportunity would be to construct new dams to increase the number of irrigation schemes.

Livestock sales are very low, there is not enough water and food available for them.

- o Forest harvest and management

Deforestation (Mopane trees are used for fencing and roofing) is against the law, though people don't always follow this law as they are not punished.

An important improvement could be the reclamation near households and fields

- o Disaster Rids Reduction Plans

Choosing land for new houses on higher areas and not near rivers and dams.

Planting more (Mopane = strong) trees around houses.

- o Gender equality and women's participation

Situation has much improved recent years; in the past they were beaten by their husbands, but now they are content.

## Ward 7 Malaba

Tuli - 20 participant (17 women, 3 men)

- o Water management

Mtowane (sand) dam needs attention; it dries up and becomes silted up.

Khukumenza (garden) needs a watering system.

Lubhungne garden needs refencing

There are no water restrictions, even during droughts, this should be implemented.

There are not many pumps, which makes it hard to get water and the number of people accessing them is too high.

- o Food security and agriculture

The harvest is affected by the different types of soil.

There is no irrigation scheme in the ward, this could be installed.

- o Forest harvest and management

There are laws to control the trees cutting, but they are not enforced. Trees are sold to other wards and there is also a problem with illegal mining.

- o Disaster Risk Reduction Plans

People build near rivers and dams.

- Gender equality and women's participation

Woman attend meetings and are included in decision-making.

- Other

Children migrate to other countries and youth drinks and uses drugs. And now children need to bring a phone to school. The children should be included in all project, people should bring them to workshops and meetings.

## B. Hydrological data

Parameters	Symbol	Source
Storage	S	
Waterlevel	h	
Runoff	$Q_{s,in}$	Runoff coefficient based on different sources, explained in text
Groundwater flow	$Q_g$	Direct measurements (Blok, 2017)
Evaporation	E	Obtained through MOD16 for river evaporation from (Blok, 2017)
Temperature	T	West Nicholson service station
Radiation	$R_s$	NASA's MERRA-2 Modern-Era Retrospective Analysis
Crop coefficients	$k_c$	Crop values from (Allen et al.)
Precipitation	P	Arc2 precipitation (Blok, 2017)
Abstractions	$Q_{abs}$	Interview with farmers together with data from (Mhlope, 2017)
Length, width and depth reach	l, w, d	Averaged after measurements (Blok, 2017)

Paper	Sand river	Hydraulic conductivity	Porosity	Specific yield	Aquifer depth
Hussey, 2003	Shashane	96-100 m/d	0.32	-	0.5-3 m
Mansell and Hussey, 2005	Shashane	98 m/d	0.42	-	2.9 m
Moyce et al., 2006	Msingwane	40-200 m/d	-	0.15	1-5 m
Masvopo, 2008	Lower Msingwane	60 m/d	0.39	0.05	13 m
de Hamer et al., 2008	Mnyabezi	69 m/d	-	-	0-1.4 m
Love et al., 2011	Lower Msingwane	32-46 m/d	-	0.04-0.11	4-20 m
Ronayne et al., 2017	South Platte	18-70 m/d	-	0.20	0.5-50 m
Blok, 2017	Shashane				

## C. Social and economic data

Table 13: Prices of produce sold in the area (Mhlope, 2017)

Produce	Farmers selling Price
Tomatoes	\$15/bucket
Onions	\$0.20/bulb
Mopane worms	\$30/bucket or \$1/cup or \$7(5l tin)
Butternut	\$1/ head
Spinach	\$1 /bunch
Choumolia	\$1 /bundle

Table 14: Price ranges for different cattle in the area (Mzingwane Catchment Scoping Study Report 2017)

Produce	Farmers selling Price
Chicken road runners	\$8-10
Chicken Broilers	\$6-8
Cattle (Beast)	\$300 to \$850
Goats	\$30 to \$60

Table 15 Population Distribution of Matobo District from Zimbabwe National Statistics Agency 2012 taken from the Mzingwane Catchment Scoping Study Report 2017)

Name	Status	Population Census 18-08-02	Population Census 17-08-12	Population Census 17-08-12 Ward 2	Population Census 17-08-12 Ward 6	Population Census 17-08-12 Ward 7
Matobo	District	99,723	93,940	Female	3099	2935
				Males	2965	2392
				Total	5064	5327
						5062



## E. Technological uncertainties

Location		Nature			Level of uncertainty			Relative influence
		Ambiguity	Epistemology	Ontology	Shallow	Medium	Deep	
System boundaries		Step 1. Landscape area	x					X System boundaries are different per domain, but integrated in this planning.
Conceptual model		Step 2 Landscape scale			x			X Especially social connection are not yet well understood
Step 2 Computer model		Model structure			X			Spreadsheet model
		Water balance			X			
		Evaporation			X			
		Economic			X			
		Input parameters						
		Natural data		X				
		Social indicators	X				X	
		Economic		X				
		Future uncertainties		X	X		X	
								X More research could improve IPCC scenarios
Input data		Development Actions	X					X
Parameters		Evaluation of outcomes	X					X Many uncertainties, but the model gives a good indication of the possible pathways for development

The sensitivity of model based uncertainties can be identified by assessing the relative influence of the various uncertain factors. Sensitivity is approximated using the relative sensitivity ( $S_r$ ), where input values are changed to assess the sensitivity of the parameter.

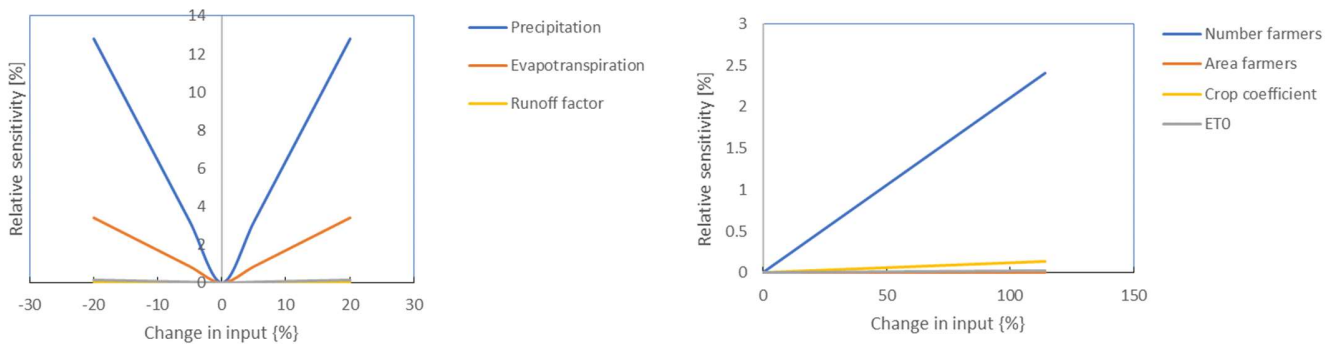


Figure 32: Sensitivity analysis of the hydrological model, A at farm scale and B at garden scale.