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BACHELORARBEIT

Impact of Rainwater Harvesting on the Water Balance in the Area of Monte do Cerro, Portugal

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ABSTRACT

A comprehensive application of rainwater harvesting in South-West Portugal is described and analysed. With simple means, runoff gauges were installed, and a real measurement campaign was conducted over a period of three months. A basic simulation of the connected lake structures was carried out to estimate the system's behaviour during a torrential rain event.

Outcomes: A significant impact of the rainwater harvesting measures to the local water balance could be documented. Buffering or storing effects could be determined. The analysis of measurement series shows that the soil parameters of the Monte do Cerro area are better than expected.

KURZZUSAMMENFASSUNG

Im Südwesten von Portugal wurde ein umfassendes Anwendungsbeispiel für Rainwaterharvesting beschrieben und analysiert. Mit einfachen Mitteln wurden Abflusspegelanlagen installiert und über 3 Monate hinweg Regen-Abfluss-Messungen durchgeführt. Eine einfache Simulation der verbundenen Seenstrukturen in diesem Gebiet berechnete das Verhalten während eines Starkregenereignisses.

Ergebnisse: Ein eindeutiger Effekt der Regenwasserrückhaltemaßnahmen auf den lokalen Wasserhaushalt konnte nachgewiesen werden. Puffer- und Speichereffekte wurden festgestellt. Die Analyse der Messreihen zeigen, dass sich die Bodenparameter des Bereichs Monte do Cerro besser als ursprünglich erwartet darstellen.

CONTENT

ABBREVIATIONS AND ACRONYMS

CAP	Common Agricultural Policy
DLDD	Desertification, Land Degradation and Drought
DEM	Digital Elevation Model
EEA	European Environmental Agency
FAO	Food and Agriculture Organization
GIS	Geographic Information System
HEC-HMS	Hydrologic Modeling System of the Hydrologic Engineering Center
ICNF	Instituto da Conservação da Natureza e das Florestas
IFPRI	International Food Policy Research Institute
MP	Measurement point
SCS	Soil Conservation Service
SCS-CN	SCS-Curve-Number method
SOM	Soil organic matter
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
WMO	Meteorological Organization
WOCAT	World Overview of Conservation Approaches and Technologies

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1 INTRODUCTION

In Portugal, in the sub-humid to semi-arid area of Alentejo, an exciting initiative took shape, challenging the prevailing tendencies of Desertification, Land Degradation and Drought. Redesigning their land with the means of Rainwater harvesting, they established a green oasis within a vastly marginalized region.

This caught the interest of the author. Is it really possible for a small community to halt desertification? Can Water Retention Landscapes really persist against the global threats of an increasingly changing climate in the long run? What are the key triggers leading to a reversion of downward spirals?

The scale of the implemented rainwater harvesting measures is impressive and attracts one to conduct field studies. Until now only a few consistent data is collected about the effects taking place in this surrounding.

This study takes up this inspiration to dive into the domains of applied restoration, hydrometry and computer simulation. Both sections of hydrology were explored, “the wet and the dry”, as insiders joke.

From March till May 2016 an on-side field study was carried out.

The aim of the study was to find answers to the following two guiding questions:

> ***What characterizes the hydrologic system of Monte do Cerro?***
>
> ***What impacts do the applied rainwater harvesting structures have to the water balance?***

A sequence of three research steps was conducted.

> *Creating a detailed description of the hydrologic system of the area of concern*
>
> *Installation of measurement stations and capture significant rain-runoff data*
>
> *Building up a computer model and simulate a torrential rain event*

This document is structured as follows.

In Chapter 2 the backgrounds of the study are laid out. The functions of the hydrological balance, the threat of desertification and the possibilities of ecosystem restoration are described. Furthermore, concepts of rainwater harvesting and the regional and local context will be examined. Chapter 3 continues with the methods of Landscape analysis, Discharge measurement and runoff modelling, as they were applied in this study. Chapter 4 leads to the practical part of the study. After gathering the hydrological peculiarities of the study site and collecting measured data, the scenarios will be reconstructed with simulation models. The final conclusions and future outlooks will be derived in Chapter 5.

2 BACKGROUNDS

In this chapter, the backgrounds of this study will be laid out starting with the functions of the water cycle to continue with an illustration of the complex theme of desertification, land degradation and drought and its implications for the water balance to then present a possible action to land restoration, especially rainwater harvesting. At the end, the geographical context of the study will be portrayed.

2.1 THE HYDROLOGICAL BALANCE

The circulation of water on planet Earth continuously refills the finite water resources on the continents. As a dynamic system it sustains all life and plays an essential role in the evolution of complex ecosystems (Postel & Richter, 2003, p. 5f.). The terrestrial pathway of water can be described as seen in Figure 1. The hydrological cycle is a sequence of transport and storage processes. From its gaseous state in the atmosphere, water comes to the surface in various forms of precipitation. The first layer hit by the water mostly is vegetation where it gets absorbed by the plants (interception) until it is re-vaporized or drained further down (throughfall, stemflow and dripping). The ground is the next layer to be crossed. Here it infiltrates the soil unless it stays on the

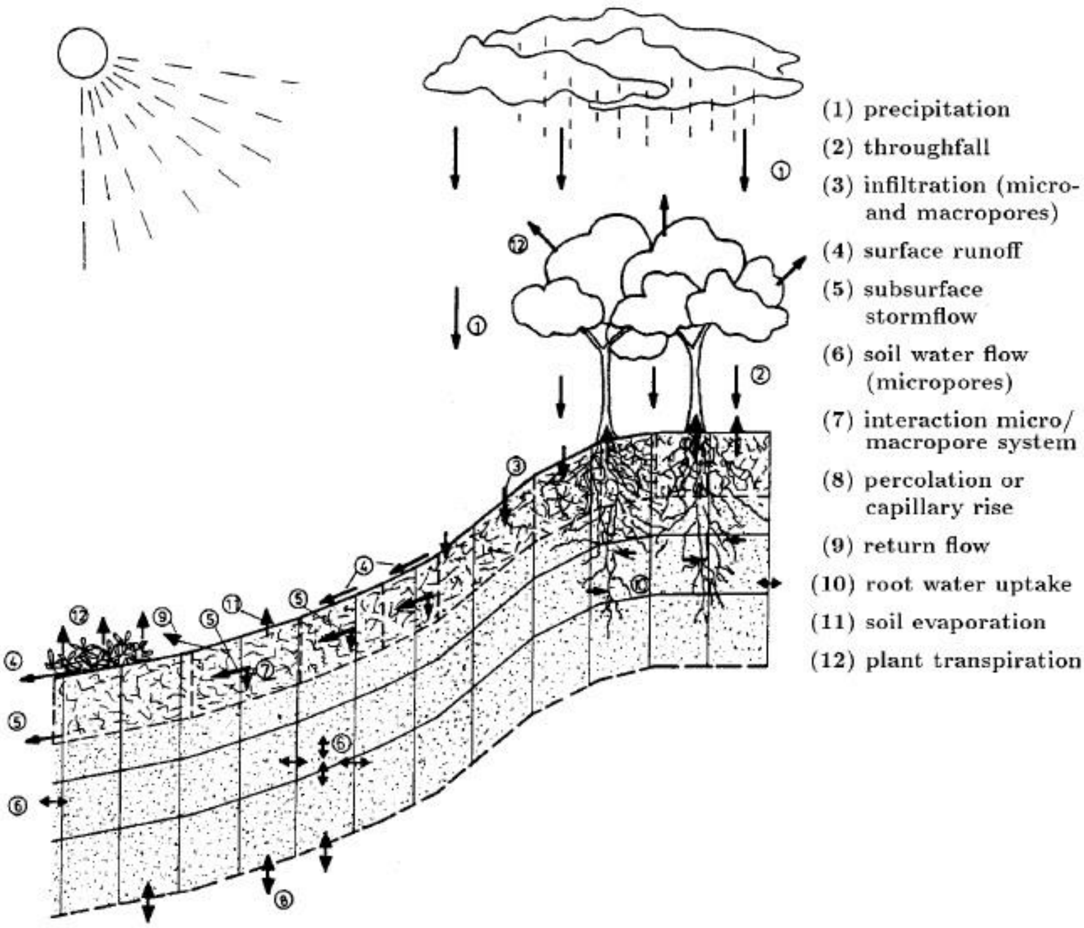


Figure 1: Water on a slope (Bronstert, 1999, p. 26)

surface as overland flow. In the ground it fills the pores and seeps down to recharge the groundwater (percolation). Water in the soils is gradually accessed by the plant's roots (transpiration) or is brought back to the atmosphere through direct evaporation. Discharge is created once an excess of water is accumulated on different possible levels: on the surface as surface runoff, in the soil as sub surface storm flow (interflow) and from the groundwater as base flow. In the end, it is gathered in streams and flows further down the lowest line of the catchment (Baumgartner & Liebscher, 1996, p. 72ff.).

The distribution to the different possible pathways is influenced by following groups of factors:
surface factors, atmospheric factors, vegetation factors, soil factors.

Surface factors are slope inclination, slope aspect, terrain design, soil treatment, soil compaction, etc. Precipitation, radiation, wind, temperature, air humidity are some of many atmospheric factors. Vegetative factors are vegetation cover and density, plant selection, stem, leaf and root ratio, the amount of plant residues and others. Soil factors include soil moisture, soil temperature, grain size, pore volume, soil organisms, soil organic matter (SOM) content and more (Baumgartner & Liebscher, 1996, p. 75f.). Changes in these factors lead to a “hydrological change” and influence the amount and quality of water resources (Bronstert, et al., 2009, p. 289).

Human actions interfere with the water cycle. Direct measures in the streams have as much impact as land use changes. Urban development, restructuring of agricultural land, changes in cultivation type and crop selection, as well as changes in forested areas, have an impact on the different components of the water cycle (Baumgartner & Liebscher, 1996, p. 76ff). Impacts of hydrological change are of high social, economic and ecologic relevance (Bronstert, et al., 2009, p. 310). Desertification is a special case of hydrological change.

The hydrological balance equation encompasses the different elements of water input and output of a particular area as well as changes in storages. Discharge is a main indicator of hydrological balances.

$$R = Q_{in} + P - ET - \Delta S$$

R	Runoff
Q_{in}	external water input
P	Precipitation
ET	Evapotranspiration
ΔS	Storage Change (Baumgartner & Liebscher, 1996)

2.1.1 *DISCHARGE GENERATION*

Discharge is created when a storage element is full or a throughput capacity is reached. This can happen on various levels. In the classical case, the groundwater is refilled and flows following the steepest gradient of its level to an outlet point (e.g. a spring). The field capacity of the soil is the crucial factor to enable groundwater recharge (deep percolation) as well as the interflow. When it is reached, all pores are full of water. On the surface the infiltration capacity is relevant. If in the event of rain the soil is not able to take in the water fast enough, it runs off on the surface. The infiltration capacity is often reduced by crusting and compaction (Baumgartner & Liebscher, 1996, p. 72 ff.).

The amount of precipitation that leads to runoff is described as effective precipitation. A common method to calculate the effective precipitation is the SCS-Curve-number model (Gupta, 2011, p. 46).

2.1.2 *DISCHARGE CONCENTRATION*

The process of discharge concentration describes the flow of the effective precipitation to the receiving stream. On the surface of the ground water flows as surface-runoff, in the unsaturated soil partition as interflow and in the saturated partition as base flow.

2.1.2.1 Surface runoff

Surface runoff occurs due to a surpassing of the infiltration capacity, saturation excess or as return flow. High intensity rainfall leads to a surpassing of the infiltration of capacity. Especially fine-grained soils which contain interrupted, clogged or no macropores are prone to this kind of runoff. Siltation, compaction and incrustation strengthen this process. Surface runoff can also emerge when the saturation point of the soil is reached (e.g. after long rains). In the hills already infiltrated waters can reach the surface again when changes in permeability or slope gradient occur (return flow).

2.1.2.2 Interflow

Interflow is defined as lateral flow within the unsaturated soil zone. Mostly this occurs in the upper layers of the soil. Water first intrudes the macropores and later also seeps through the micropores. A coarse soil structure enhances this kind of runoff.

2.1.2.3 Baseflow

Once water reaches the saturated zone it follows the steepest gradient of the groundwater table. As flow velocity in the ground is quite low, the rise of baseflow after a rain event reaches the receiving stream much later than interflow. Therefore it lasts much longer. Water courses in dry seasons are fed by groundwater. (Baumgartner & Liebscher, 1996, p. 490ff.)

The discharge is plotted graphically versus the time in a discharge-hydrograph. Analyzing this diagram, special phases of the runoff pattern can be indicated (e.g rising limb, peak and falling limb of a flood event.) (Baumgartner & Liebscher, 1996, p. 475)

Characteristics of a catchment can be summarized in a *unit-hydrograph-function* that transforms precipitation input into a runoff pattern (Gupta, 2011, p. 45 f.).

2.2 Desertification, land degradation and drought (DLDD)

The topics of desertification, land degradation and drought are intimately interlinked. In scientific literature as in public discussions the terms are often used for the same processes. Even the United Nations Convention to Combat Desertification (UNCCD) as a core institution in this field has used different definitions throughout its development since 1994. The main differentiations between desertification and land degradation are about the applied boundaries (dryland or not dryland) or the conceptual hierarchy (is desertification a certain stage of land degradation or not) (Safriel, 2009, p. 36f). Another associated term is soil degradation, which according to STEINER and LEVKE is to be seen as a subtopic (Steiner & Levke, 2011, p. 8). In this study the focus lies rather on the overall issues than on distinct concepts. Thus the terms desertification and land degradation will be used as synonyms or the subject will be referred to with the abbreviation DLDD, essentially enforcing the approach of the IFPRI Discussion Paper 01086 (Nkoya, et al., 2011).

2.2.1 Definitions

In the following the single terms will be defined.

2.2.1.1 Land degradation

Land degradation is described by the FAO as "the reduction in the capacity of the land to perform ecosystem functions and services that support society and development" (FAO, 2007, p. 9). The decrease or loss of both economic and ecological vital functions can be triggered by human activities or natural events (Mainguet & da Silva, 1998). In agricultural areas it is observed as declining productivity and utility. Degradation commonly is taking place where land use and land attributes are mismatched (Katyal & Vlek, 2000, p. 11f.).

2.2.1.2 Desertification

Desertification is defined by the UNCCD as “land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities” (UNEP, 1994, p. 71). RUBIO and BOCHET characterize desertification as a gradual process with serious environmental and socio-economic impacts (Rubio & Bochet, 1998, p. 114).

2.2.1.3 Drought

According to PALMER drought is to be seen as a “prolonged and abnormal moisture deficiency”. As a “strictly meteorological phenomenon” the severity can be derived from a climatic analysis of the magnitude of abnormal moisture deficiency and the duration, regardless of biological factors (Palmer, 1965, p. 1). The World Meteorological Organization (WMO) defines drought as “a deficit of rainfall in respect to the long term mean, affecting a large area for one or several seasons or years that drastically reduces primary production in natural ecosystems and rainfed agriculture” (WMO, 1975, p. 127).

2.2.1.4 Soil degradation

According to OLDEMAN et al. soil degradation is "a process that describes human induced phenomena which lower the current and/or future capacity of the soil to support human life" (Oldeman, et al., 1991). The FAO declares soil degradation as “a process which lowers the current and/or the potential capability of the soil to produce goods or services” (FAO, 1979, p. 4).

2.2.2 Indicators

DLDD has many faces. MENSCHING names four physical indicators of DLDD and adds that there are vast socio-economic implications. They occur in various constellations and can lead from one to another during the process of degradation (Mensching, 1990, p. 15):

2.2.2.1 Vegetative Indicators

The state of vegetation is very important to asset the spread of DLDD. Qualitative and quantitative changes can be observed in desertifying landscapes. Soil cover reduces more and more - namely in the disappearing of trees and the emergence of a jaggier layer of grass up to the total loss of vegetation. Also the composition of species becomes less abundant and develops to more resistant plant selections (e.g. to dryness, soil compaction and grazing stress). Perennial species are gradually replaced by annual ones. If grazing is applied a trend to not eatable species can be observed (Mensching, 1990, p. 16).

2.2.2.2 Pedologic Indicators

DLDD has many ramifications to the soil. Through the loss of vegetation the soil gets more and more unprotected and vulnerable. It gets more exposed to direct sunlight. Thereby the evaporation rate raises a lot and the soil dries up quicker and deeper (Mensching, 1990, p. 18). In these drier conditions soil bioactivity decreases and it is more difficult for the microorganisms to sustain an open soil structure. Often a hardening and compaction of the soil occurs including the formation of crusts. The porosity decreases and the amount of soil organic matter declines. Soil water content remains low even when it rains as degraded soils feature a high wetting resistance making it hard to infiltrate. Especially during heavy rain events overland flow is emerging (Mensching, 1990, p. 24f.).

The soil also gets more exposed to the impact of raindrops and runoff. Water erosion is an indicator of advanced degradation. The loss of soil weakens the ability of land to rehabilitate itself quickly (Montanarella & Tóth, 2008, p. 2). According to QUANSAH water erosion encompasses four stages: First, soil particles are detached by raindrops. Next, particles are washed out by runoff. Then, soil is moved by splashes and finally is transported by runoff (Quansah, 1981, p. 215). The implications of erosion to land forms will be described in chapter 2.2.2.4 “Morphodynamic Indicators”. Important factors of the intensity of water erosion are slope inclination and the size of the slopes catchment as well as the type of soil and the degree of root penetration (Mensching, 1990, p. 25). Fine soil particles get relocated more easily than coarse fractions. Stony compartments remain on the hillside while fertile parts are washed away. In depressions holocene colluvium is accumulating (Mensching, 1990, p. 26).

Not only water is threatening the soils. Especially in flat, open landscapes wind erosion is a common process. Fine soil fractions get deflated (Mensching, 1990, p. 20).

Another indicator of DLDD is the increased salt content of the soils. Salinization often occurs on irrigated lands where there is not enough drainage. High evaporation rates in arid to sub humid regions lead to an ascending soil water movement bringing dissolved salts to the upper soil layers and to its surface (Mensching, 1990, pp. 19,24-27).

2.2.2.3 Hydrological Indicators

In areas of DLDD a change in hydrological patterns is to be observed regularly. The discharge of rivers is getting less balanced. The amount of continuously flowing water is diminishing and periods of total dry up occur more often. Especially the lower reaches can suffer from that aridification. In contrast to that flood events get more intense and appear as high-floods with a lot of sediment load (Mensching, 1990, p. 19).

The drawdown of the groundwater table is an indicator of DLDD as well. Intensive groundwater use and decreased groundwater recharge can be assumed in this case (Mensching, 1990, p. 18f.).

2.2.2.4 Morphodynamic Indicators

The changes in vegetation cover, soil conditions and hydrological patterns have an impact to the landscape shaping processes. Fluvial activities can be observed more often. The formative powers increases as runoff events get more accentuated. Rivers carry a large sediment load leaving floodplains filled with deposited material. Infrastructure damage can be seen frequently. Due to the decreased infiltration rate surface runoff is occurring more often, bringing erosion further up the drainage system. Laminar erosion gradually takes away soil on the entire surface. Within a few years the surface can be lowered by several decimeters. As the runoff concentrates it cuts deeper and starts to be abrasive even to the stony sub material. Linear structures like rills can develop within a single heavy rain event and grow further to meter deep gullies.

The impact of wind can be observed in a higher dust loading of the atmosphere as well as in a reactivation of sand and the formation of dunes (Mensching, 1990, p. 20ff.).

2.2.2.5 Socio-economic Indicators

According to IBRAHIM, socio-economic indicators are not to be brought into a linear cause and effect correlation as easy as the physical ones; rather, it is a complex interplay. The following factors can be taken into account: An economic weakening can be observed as crop yields decrease and also the natural supply of fodder, firewood and construction materials decline. In the long run numbers of livestock are also reduced. This threatens the basic needs of the population leading to malnutrition and health issues. Trying to escape, many people, especially young men, migrate to cities where there is better access to water, education and work. The rural settlements become abandoned. The risk of conflicts rises in areas of DLDD (Ibrahim, 1992).

2.2.3 CAUSES

As BAARTMAN et al. conclude in their study, the causes of DLDD are as broad as the indicators. It is the rarest case that only one factor causes the disastrous consequences of DLDD. A complex composition of both socio-economic and biophysical factors can be accounted to cause DLDD. They interfere with each other and build feedback loops. Often a combination of factors triggers a transition to a less resilient system (Baartman, et al., 2007, p. 22 ff.) GEIST & LAMBIN show besides the immediate causes as well the underlying drivers (Figure 2).

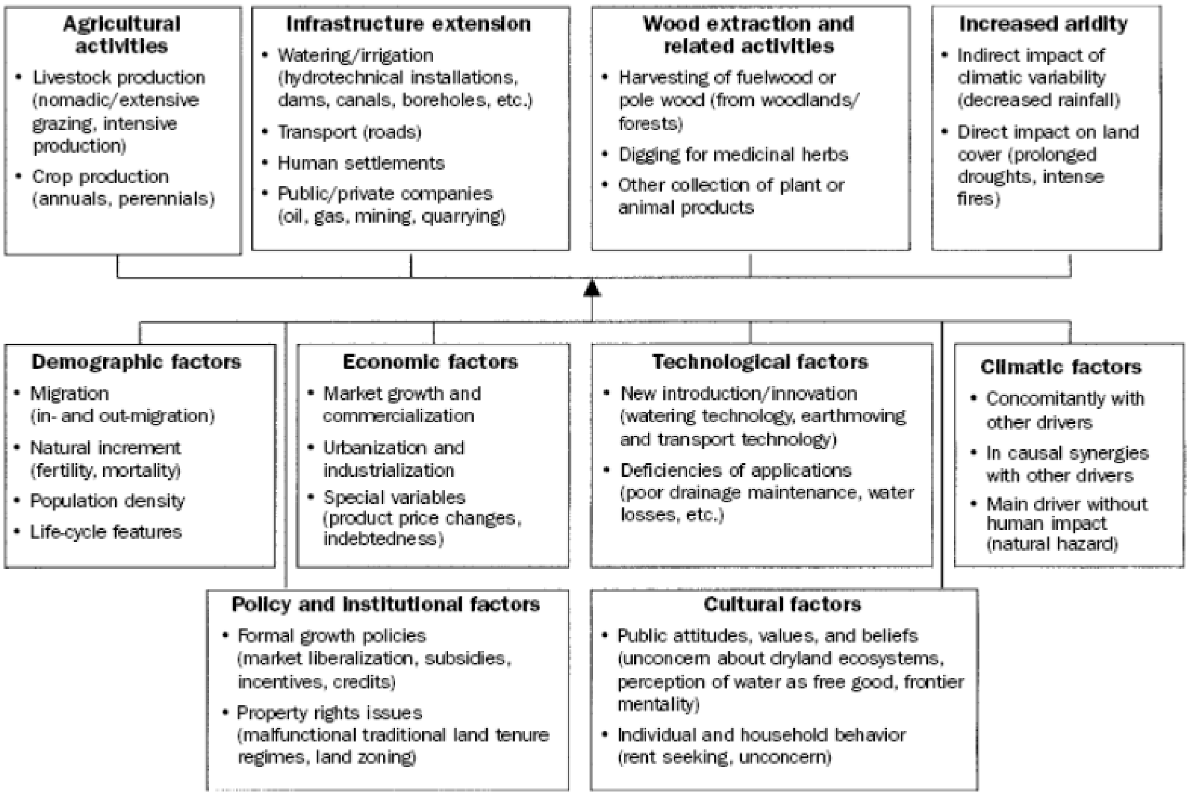


Figure 2: Causes of DLDD: direct influences with underlying drivers (Geist & Lambin, 2004, p. 819)

GRAINGER also names four main immediate causes of desertification: overcultivation, overgrazing, deforestation and mismanagement of irrigated cropland. They are pushed by underlying factors like population growth, economic development and political decisions (Grainger, 1990, p. 105f.).

2.2.3.1 Deforestation

The FAO defines deforestation as the "conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold" (FAO, 2001).

According to AMACHER et al., "deforestation takes place when native forest land is cleared either due to agricultural land clearing or illegal logging" (Amacher, et al., 2007, p. 15). This definition puts an emphasis on the first disruption of a natural ecosystem and points out that inappropriate plantations may not reinstall all lost and non-timber related ecosystem services (e.g. retention capacity) (Amacher, et al., 2007, p. 15). GEIST & LAMBIN name the need for fuel wood (including charcoal production) as well as pole wood (for building) and the extension of agricultural land as causes of deforestation (Geist & Lambin, 2002).

Wildfires present great disturbances to forest ecosystems. The fire itself leads to a sudden loss of biomass. This remobilizes a lot of nutrients but also drastically reduces the soil cover and makes it more vulnerable to climatic factors, especially rain. Physical and chemical properties of soil can deteriorate in the post-fire timespan for several years, as nutrients wash out with loose and unprotected ashes and soils (Baartman, et al., 2007, p. 34). In the Mediterranean, natural ecosystems adapted to this threat and wildfires are common every 20-30 years (Margaris & Koutsidou, 2002, p. 91). Introduced fast-growing tree species like poplar, eucalyptus and pine are highly flammable and thus prone to wildfires (Baartman, et al., 2007, p. 34).

2.2.3.2 Overcultivation

Overcultivation is the use of agricultural land exceeding its carrying capacity. When new agro-technology and techniques are introduced in an imprudent manner, intensified agriculture on prone land can lead to a degradation of the soil. Often fallow periods are shortened or left out leaving the land with less recovery time. Without that a decrease in soil nutrients and fertility can be observed (Hartmann, 1991). An estimate of 1 240 000km² of land is degraded due to agricultural activities (Bot, et al., 2000).

2.2.3.3 Overgrazing - Mismanaged cattle

In general, overgrazing can be described as “an excess of grazing animals that leads to degradation of plant and soil resources” (Mysterud, 2006). SCHWENNESEN points out that not only the stock rate is an important indicator of unsustainable use, but also management practises have an impact to land degradation. Rotational grazing systems, for example, decrease stress on the vegetation. He defines overgrazing as “the removal of tissue from a living plant to the extent that the tissue removed exceeds the ability of the plant to replace it within a growing season” (Schwennesen, 2005, p. 6)

2.2.3.4 Mismanagement of irrigated cropland

Irrigation systems need to be planned and managed in a good manner. Wrong irrigation practises can lead to a fast salinization or alkalization of the soil. It is important to avoid ascendant water movements. Through evaporation, the water brings up dissolved minerals that accumulate in the upper layers or on the surface of the irrigated land. A high salinity poses a similar pressure to plants, as soil water is less available. Building crusts, the salt can make the surface impermeable and decreases the capability to absorb water when it naturally is available. If a proper draining or flushing is not secured, irrigated fields can be irreversibly damaged (Grainger, 1990).

2.2.3.5 Abandonment

Not only the intensification of agricultural practices endangers the lands properties but also the abandonment of land can lead to severe signs of degradation. According to LESSCHEN et al. the appearance of gully erosion increases on abandoned fields in comparison to cultivated fields. Due to crust formation and reduced surface storage capacity, abandoned fields tend to show a quicker concentration of runoff. In the Mediterranean abandonment of agricultural land is a leading part in land use change (Lesschen, et al., 2007). REY BENAYAS et al. conclude that land abandonment is mainly driven by socio-economic factors. Areas that are not taken care of anymore show an increase of fire frequency and intensity and soil erosion (Rey Benayas, et al., 2007).

2.2.4 OCCURRENCE

In this subchapter the geographical dimensions of Desertification will be shown.

2.2.4.1 Global Occurrence

According to ESWARAN et al. about 34% of global land surfaces are affected by DLDD. As seen in Figure 3 the desertification tension zones stretch throughout all continents. Around 44% of the world population is directly affected by DLDD (Eswaran, et al., 1998, p. 3).

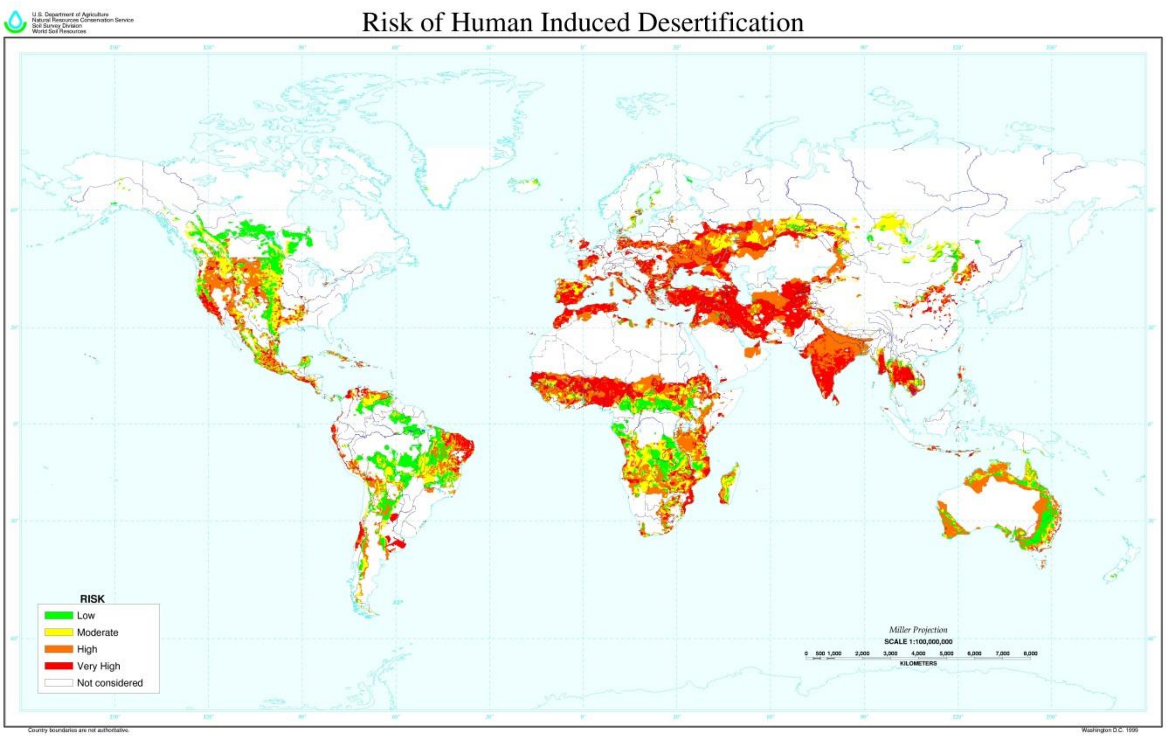


Figure 3: World map Risk of Human Induced Desertification (Eswaran, et al., 1998)

2.2.4.2 Occurrence in Europe

In Europe, the sub arid to sub humid areas mostly stretch along the Mediterranean Sea, including Portugal, Spain, Italy, Greece and Turkey. In these areas the history of cultivation is several thousand years old and characterized by large scale deforestation, overgrazing and overcultivation. The vegetation is severely degraded and soils of hilly and mountainous regions already eroded to a great extent. About a fifth of the total drylands area is to be classified desertified (Grainger, 1990, p. 130f.). Also the Pannonian basin and some east European countries are under risk of degradation processes (Eswaran, et al., 1998).

Within the Annex IV of the UNCCD the ecological state of the northern Mediterranean countries was described by following statements:

"(a) semi-arid climatic conditions affecting large areas, seasonal droughts, very high rainfall variability and sudden and high-intensity rainfall;

(b) poor and highly erodible soils, prone to develop surface crusts;

(c) uneven relief with steep slopes and very diversified landscapes;

(d) extensive forest coverage losses due to frequent wildfires;

(e) crisis conditions in traditional agriculture with associated land abandonment and deterioration of soil and water conservation structures;

(f) unsustainable exploitation of water resources leading to serious environmental damage, including chemical pollution, salinization and exhaustion of aquifers; and

(g) concentration of economic activity in coastal areas as a result of urban growth, industrial activities, tourism and irrigated agriculture" (UNEP, 1994, p. 55)

According to the UNCCD Action Program Portugal 60% of the territory of Portugal is in moderate risk of desertification (DGdF, 1999)

2.2.5 Combat on Desertification

DLDD is a broad range of topics threatening human livelihood on different levels and scales. The world, represented by the United Nations, took the amelioration of this issue to its agenda. Already in 1977 there was the first conference on Desertification and a Plan of Action was developed. Even though 194 countries and the EU signed the UN Convention on Combating Desertification (UNCCD) from 1994 (UNCCD, 2016), in many regions a failure is to be observed and the situation often got worse. In 2012, 16 years after the UNCCD entered into force, the Rio+20 conference still recognized a "need for urgent action to reverse land degradation [… and] stress[es] that desertification, land degradation and drought are challenges of a global dimension" (United Nations, 2012, p. 40).

On the technical side it can be asserted that a lot of experiences were made with different techniques. The World Overview of Conservation Approaches and Technologies (WOCAT) describes many success stories of land conservation and the combat of desertification (WOCAT, 2007).

It can be deduced that the technical know-how is available, but it was not applied sufficiently to bigger areas until today.

REYNOLDS et al. summarize "[…] the complexity of sustainable development in the drylands with five lessons learned (1) Integrated approaches are needed; (2) Short term measures cannot solve slowly evolving conditions; (3) Dryland systems have nonlinear processes; (4) Cross-scale interactions must be anticipated; and (5) Greater value must be placed on local environmental knowledge" (Reynolds, et al., 2007)

According to BAUTISTA et al., "ecological restoration combined with adaptive management can be effective tools in response to this environmental and socioeconomic problem" (Bautista, et al., 2009, p. 7).

2.3 Ecosystem Restoration

Combat on desertification encompasses more than the amelioration of the water systems.

The Society for Ecological Restoration defines ecological restoration as an "intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" (SER, 2004, p. 2).

Restoration refers to longer-term measures aimed at improving the resilience and maturity of the ecosystem (Vallejo & Alloza, 1998, p. 93).

Up to now that is still a big vision which needs to become reality.

2.3.1 *Strategic aspects*

It is important to consider complete eco systems rather than concentrating on one small area only. The inclusion of the bigger context is necessary to define appropriate and sustainable local actions.

In the Mediterranean climate regions a wide range of restoration objectives is present, but the overall common features can be stated as following:

Soil and water conservation is the highest priority to reduce and prevent degradation and desertification. Regulating water and nutrient fluxes is the key.

It is necessary to ensure the sustainability of restored lands by promoting the re-emergence of communities of plants, animals and microbial structures.

The prosperity of key native species should be fostered by their reintroduction to promote biodiversity. Alien invasive species should be eradicated, including battling their reestablishment.

Only if the measures are accepted by the local inhabitants, they can be successfully implemented. They must be culturally adopted and should create an improved livelihood on the base of better landscape quality and stable provision of ecosystem services.

That way it is possible to establish connected eco-regions which are resilient to human and nonhuman disturbances (Vallejo, et al., 2012, p. 133)

2.3.2 *Biophysical Solutions*

According to BAARTMAN et al. there are different categories of biophysical solutions to DLDD.

2.3.2.1 Agronomic measures

A conserving agriculture which relies on manuring/composting and mixed cropping systems belongs to this category. Important features of these annually or seasonally applied activities are for instance the horizontal cultivation of crop field structures and soil building by appropriate techniques like mulching and conservation tillage.

2.3.2.2 Vegetative measures

Reinforcement of the vegetation carpet can be achieved by introducing special structures such as grass stripes, hedge barriers, windbreaks or agro-forestry. They should be applied considering the specifics of slopes or windy areas to foster protective micro climates for obstruction of erosion processes. Also Afforestation is a key measure here.

2.3.2.3 Structural measures

Often substantial labour or money is required to install solid structures. With major earth movements terraces, banks, bunds, palisades or even more complex constructions are built. The profile of slopes is changed to support soil conservation and water retention on landscape scale. Those measures focus on long term and permanent installations.

2.3.2.4 Management measures

These are conscious land use changes, area closures, rotational grazing and other administrative means. It may lead to a less intensive land use. The aim is to secure fewer disturbances to affected areas to achieve the recovery of vegetative covers through natural succession. Another focus is for instance to manage wild fires.

Concluding BAARTMAN et al. write that an integrative and sustainable land management must be combination of all those measures (Baartman, et al., 2007, p. 59).

According COUTINHO and ANTUNES "it is clear that the canopy cover is quite relevant to mitigate erosion and desertification." (Coutinho & Atunes, 2003, p. 522)

As "… droughts and dry spells constitute a more common cause for low biomass production and crop failure than absolute water scarcity in terms of low cumulative annual rainfall" (Falkenmark, et al., 2001, p. 7), "water management is a crucial point in that combat. Rainwater harvesting is a part of ecosystem restoration techniques" (Katyal & Vlek, 2000, p. 51).

2.4 Rainwater harvesting

Water harvesting in its broadest sense is defined by SIEGERT as "the collection of water for its productive use" (Siegert, 1994). GLENDENNING and VERVOORT see rainwater harvesting (RWH) as "the small-scale collection and storage of runoff to augment groundwater stores" (Glendenning & Vervoort, 2010).

2.4.1 Rainwater harvesting in general

Rainwater harvesting is used to mitigate the consequences of longer periods without rain and to create a more balanced supply of water resources. Rain from the rainy season is stored for drier months. The applied methods split into two categories of water harvesting: Within-field (in situ) water harvesting and external water harvesting (runoff farming).

Within-field water harvesting is collecting the rainwater directly in the field where it will be used. This can be done through surface treatments like conservation tillage or mulching, helping to increase infiltration without decreasing the area planted. Several techniques are also available where a part of the field is used to build a small structure that catches surface runoff, sinks it or leads it to a preferred plant e.g. strip cultivation, micro catchments, pitting, demi-lunes or infiltration trenches.

External water harvesting can be applied in different dimensions. Excess water from a neighbouring ground that is not used for plantation (like streets and compacted or stony surfaces) is concentrated on a treated crop field. Upscaling, the runoff of rivulets or larger gullies is collected and distributed to agricultural land or stored in bunds. The complexity of the systems increases from runoff farming over flood water harvesting to storage systems for supplemental irrigation. As the quantities of water that are dealt with rise, more severe damage could be the result of mismanagement. An increasing size of the drainage area implies more and more stakeholders to be involved (Falkenmark, et al., 2001, p. 38 ff.).

The significance of rainwater harvesting in small reservoirs in semi-arid zones has been underlined by (Smith, 2002) and (Liebe, et al., 2005).

Rainwater harvesting generally results in increased crop production and greater crop yield, because resulting rises in the water table mean better accessibility and yields of groundwater" (Keller, et al., 2000)

Concluding it needs to be noted that a comprehensive system of rainwater harvesting measures always needs to be adjusted to local conditions. It needs to work technically and should be carefully integrated to the users' production system. This includes socio-economic constraints (Falkenmark, et al., 2001, p. 29).

2.4.2 *Concept "Water Retention Landscape"*

The Tamera Research Centre developed a Water Retention Landscape design. It is a result of their more general investigation to come to a concept of "healing the nature in all its aspects" (Dregger, 2015). Initiatives and ideas from many sources were collected and integrated to a comprehensive approach.

A water retention landscape is a redesign of a whole landscape with the methods of rainwater harvesting. The intention is a landscape without surface runoff. All precipitated water is infiltrated in the ground or stored directly in the terrain. The permanent presence of water within a landscape is the base for sustaining rich ecosystem services throughout all seasons. The design starts at the valley bottom to capture as much of the flood waters to ensure further ecosystem restoration efforts. It aims on rebuilding the soil to buffer the incoming rainwater by increasing SOM.

Those technical installations should only act as a kick-starting help triggering the reestablishment of natural cycles in the long run again. This refers particularly to increased air humidity, fog building and finally targets to influencing the overall local climate so that the amount of rain will increase again

The demand is a significant difference to small scale harvesting, which focus to local benefits only, but to boost real atmosphere feedback loops. According to KRAVCIK et al. a large proportion of occurring precipitation originates from continental evapotranspiration. Thus an increased evaporation in larger areas contributes to the regional amount of rain (Kravcík, et al., 2007, p. 17).

In a case study in India, this large-scale application of RWH led to a significant leverage of regional water balance and water availability (Glendenning & Vervoort, 2010, p. 331).

2.5 Study area Alentejo region

The Alentejo is a region in the south of Portugal that stretches from the Tejo River to the Algarve between the Atlantic Ocean to the Spanish border. Only 5,3% of Portugal's population live in the biggest region of the country (approx. 27000km²). A population density of 19,1 inhabitant/km² ranks as one of the lowest in Europe. Mean altitude is 200m above Sea level (Vieira & Eden, 2005).

Figure 4: Map of the Alentejo region
http://robertbroadtravel.blogspot.de/2011/05/alentejo-portugal-europes-hidden-gem.html

2.5.1 CLIMATE

According to Köppen and Geiger classification, the southern part of Portugal falls under the category Csa (warm moderate climate with hot summers) (Kottek, et al., 2006). As seen in the climate graph for Colos (Figure 5), the climate is shaped by strong precipitation in the winter months and five arid summer months. The strong seasonalization of the precipitation corresponds to the Mediterranean climate type. The annual rainfall comes to an average of 561mm. Albeit VENTURA writes on strong irregularities and interannual variability in the amount of rain (Ventura, 1994, p. 14). BRANDAO and FRAGOSO also write that the rain regime is featured by frequently occurring heavy rain events (Brandao & Fragoso, 1999, p. 113).

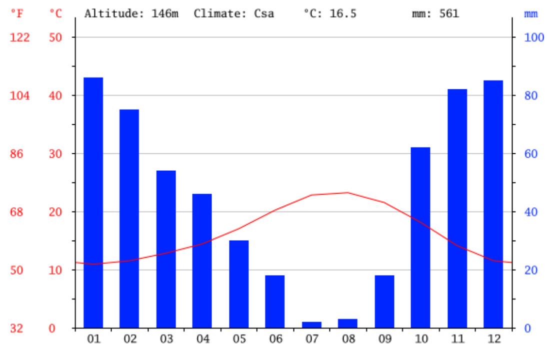


Figure 5 Climate graph Colos
http://de.climate-data.org/location/828905/

2.5.2 GEOLOGY, HYDROGEOLOGY AND SOILS

The Alentejo region geologically is situated in the South Portuguese Zone, which is a main geostructural domain of the Precambrian and Paleozoic Shield of the Iberian Peninsula. Rocks are derived from sedimentary and volcanic material that was compressed during the Hercynian Orogeny. Most recent sediments of the South Portuguese Zone are found in the Baixo Alentejo Flysch Group. Metamorphic rocks such as shales, schists, phyllites, greywackes, quartzite and metavolcanic (acid and basic) represent the majority of the rocks. These are characterized by a low hydraulic permeability. A thin alternation of layers often causes very low aquifer yields. Only in highly fractured quartzite and greywacke structures a higher yield is common (Chambel, 2006).

According to DAUM the soil of the study site “Monte do Cerro” is characterized by heavy Luvisols in the valleys and Leptosols on the hills with pH around 6 (Daum, 2014, p. 15).

2.5.3 LAND USE HISTORY AND THREATS TO THE LANDSCAPE

The Alentejo region was and still is characterized by a traditional form of cultivation called *montado*. This human-made agro-silvo-pastoral ecosystem is adjusted to local climate conditions and consists of a scattered tree cover dominated by cork-oak (*quercus suber*) or holm-oak (*quercus Ilex spp rotundifoliae)* with pastures and agricultural fields below. These are cultivated in a rotation scheme that often includes fallows. The development of a shrub layer is controlled through the integrated animal husbandry (Pereira & Fonseca, 2003). More intense cultures like olive groves, vineyards and citrus orchards, as well as vegetable production are situated close to settlements (Rodrigo & da Veiga, 2009). The European Environmental Agency (EEA) classifies this type of cultivation as a high nature value farmland (EEA, 2004).

This type of land use has continually decreased since the national wheat campaign tried to intensify the cultivation since the 1930s by means of industrialized agriculture; Mechanical work, chemical fertilizers and monoculture were introduced. The density of trees was drastically reduced. Under the prevailing climate, this disturbed the fine balance of the developed ecosystem and resulted in a decrease in fertility and accelerated erosion. After few years yields dropped and left a degraded landscape behind, only used for extensive grazing or the plantation of fast growing trees like *eucalyptus* (Pinto Correia, 1993). While the intensification focused on the more favorable zones like flat areas, marginal lands were used less and less (Caraveli, 2000, p. 231). An extensivation or direct abandonment leads to another pathway of degradation. The absence of grazing animals lowers the available nutrients and lets a shrub layer of *Arbutus unedo, Cistus, Erica, Lavandula, Ulex ssp* take more and more space. This raises competitive stress for the remaining trees and the increases danger of wildfires (also see chapter 2.2.3.1) in this more monotonous form of vegetation cover (Pinto Correia, 1993). See a typical state of a former montado land in Figure 6.

Figure 6: Culvert catchment, a typical montado relict

The Common Agricultural Policy (CAP) (starting with the integration of Portugal to the European Economic Community in 1986) had major influences on land use as well. The spread of more intense types of agriculture like irrigated olive groves and vineyards could be observed on former grain fields (Rodrigo & da Veiga, 2009). According to ROXO et al. subsidies led to the maintenance of unfeasible wheat production and raised livestock numbers - especially bovines and sheep (Roxo, et al., 1998).

Another part of EU-Policies was the extension of woodlands by plantations. The EU- Regulation 2080/92 fostered the plantation of trees on former agricultural land. Mostly pine and eucalyptus trees were planted in monocultures that are harvested through clear-cut-management (Rodrigo & da Veiga, 2009, p. 214). Brought from the Australian continent *Eucalyptus* first was introduced to Portugal in 1829. An excessive increase of area planted with e*ucalyptus* (mainly *eucalyptus globulus*) is going on since the 1950ies. They are replacing former oak or pine locations or abandoned agricultural lands (Araujo, 1995, p. 6) According to the Instituto da Conservação da Natureza e das Florestas (ICNF), *eucalyptus* plantations now account for about 26% of Portugal's woodlands (ICNF, 2013). Constituting a major part in forest product export (48%), eucalyptus helps to maintain economic survival of rural areas (Araujo, 1995, p. 6). However, harsh effects on the ecosystem need to be considered in contrast: Changes in local micro-climate, wildlife habitats and a reduction of soil moisture (Pereira de Almeida & Riekerk, 1990, p. 56).

2.5.4 Signs of desertification in the Alentejo region

As outlined in chapter 2.2.2, signs of desertification and land degradation can be observed on different levels. In the Alentejo both social and bio-physical indicators of DLDD can be witnessed.

2.5.4.1 **Social signs:**

According to VIERA and EDEN, in the last 50 years strong changes in the demographic structure have occurred. A rural exodus mainly of young people to the economically advanced regions and cities combined with a negative birth/death ratio have led to a reduction in population. The proportion of elderly people has also increased. The exodus was pushed by a crisis in the primary sector which can be related to an increased vulnerability of agriculture to droughts by degradation processes (Vieira & Eden, 2005, p. 136).

2.5.4.2 Bio-physical signs:

Changes in land use as described in chapter 2.5.3 in total led to a degradation of vegetative cover. The area continuously covered by trees is reduced and shrub patches increase on former agro-silvo-pastoral sites. Transformed into land cultivated with grain soil protection is even poorer (Pinto Correia & Mascarenhas, 1999, p. 128) Soil degradation can be claimed by combining low content of soil organic matter (below 1%) (Vieira & Eden, 2005, p. 136) and compaction due to the use of heavy machinery and stocking heavy cattle breeds (Rodrigo & da Veiga, 2009).

A reduction in infiltration rates and an increase in overland flow result in a high sediment yield caused by erosive processes (Ramos & Reis, 2002, p. 275). According to VANDAELE et al. erosion occurs in the forms of sheet, rill-interill and ephemeral gully erosion. Soil loss rates are ranked between 4.5 and 13 t/ha/year (Vandaele K., et al., 1996).

According to RAMOS and REIS, rivers in the south of Portugal show great irregularity. The interannual differences in flow can be factor 100-240 between wet years and dry years. Also during the year rivers have a high variability. Drought periods ranging from less than 25% of average river flow to a complete dry fall occurring for about 6 months contrast with very high peak floods that are 200-300 times higher than the average annual discharge. This is traced back by the authors to the geological situation with low permeability of the underlying schists and clayey formations and enhanced by a type of land use that reduces infiltration rates and increases overland flow (Ramos & Reis, 2002).

Facing both, drought and floods, the Alentejo region is vulnerable to the prevailing climate. To sustain vital ecosystem functions and human livelihood in that area, the implementation of rainwater harvesting could be promising.

2.6 Study site

The study area Monte do Cerro is situated in the parish of Reliquias in the municipality of Odemira, Alentejo, Portugal. WGS84 coordinates are 37°42´54” North, 8°30´57” West. Here a group of people settled down in 1995 to set up a holistic research station. As a community they transformed the formerly abandoned farm into a real life laboratory, implementing technical innovations into vivid social surrounding. The aim and self-conception of the approx. 180 people permanently living there is to establish a complex show-case model of a sustainable society (Dregger, 2015). This encompasses a wide range of ecologically (and hydrologically) relevant measures. Living with a growing population in a fragile ecosystem they represent a common global reality asking for adequate sustainable answers. In 2007 the first large scale rainwater harvesting measure was build, being the start of the establishment of a "Water retention landscape" (see 2.4.2).

Figure 7: Lake 1 before and after (TameraArchive)

At a narrow point of the valley, an earth dam was built out of locally available materials. A clay core as a sealing ensures water impermeability. The flanks are stabilised with stony material.

A water body is impounding behind that dam (see Figure 7). Further along the line more of those dams were constructed which led into an impressive water landscape. A detailed inventory of the valley is presented in chapter 4.1 as part of the study results.

3 METHODS

This chapter presents the applied methods.

3.1 LANDSCAPE ANALYSIS

To get a proper understanding of the study site and its hydrologic functions information was gathered through different methods. An inventory of the hydrologic elements will be developed.

3.1.1 SITE VISIT

A field visit was conducted to gather the geographical background data. Possible measurement points were indicated and documented. The technical details of the retention structures were explained by a local expert.

During the measurement campaign the performance of the landscape was observed. Especially changes in hydraulic connectivity between the sub-basins were registered. As well the occurrence of overland flow was monitored.

3.1.2 *GIS-ANALYSIS*

The author was provided with some basic map data and aerial pictures by the Tamera research centre. They were analysed using the Geographical Information System (GIS) Software ArcMap 10.3.1. Additionally, a digital elevation model of southwest Europe was downloaded from the website of the European Environmental Agency with a resolution of 25x25 meter (European Environment Agency (EEA), 2016)It was cropped to an appropriate size. To derive the catchments of the single retention structures and measurement points, the following work steps are taken. Potential spots with no hydraulic outlet are eliminated through the *Fill*-function. After that, each raster point gets a *flow-direction* to show the direction draining water takes. With the function *flow-accumulation,* these directions are combined to pathways showing the dendritic system. With defining a pour-point a specific catchment can be defined with the *watershed*-tool. This is done for every potential measurement point. The calculated catchments are laid over georeferenced aerial pictures from 2012 and approved to be approximate enough to calculate catchment sizes. Due to research economics a further specification did not take place..

3.1.3 *ASSIGNING THE OBSERVATION POINTS*

To analyse the impact of rainwater harvesting structures on the water balance of Monte do Cerro a catchment within the treated area is compared to a neighbouring piece of land with traditional land use. The determination of the measurement points is done on the base of following criteria:

- Significant runoff is to be expected during the measurement campaign.
- The single locations should be easily reachable during a rain event and should not lie far apart from each other to allow a fast measurement and a short measuring interval
- The location suits to install the measurement device. This includes:
- The backwater is not buffering runoff
- The installation will not divert the flow to the side
- The installation and maintenance costs are low

3.2 WEATHER DATA

The department of research operates a “Davis Vintage Pro” weather station in Monte do Cerro. It logs climate data every 5 minutes. Following sensors (producer) are installed additionally: Solar irradiance (EKO); Temperature and Humidity (Vaisala); wind speed (GILL); precipitation (EML).

The rain gauge EML ARG100 registers rain from quantities of 0,2 mm using the principle of the "tipping bucket" mechanism.

3.3 DISCHARGE MEASUREMENT

The base of the calculation of superficial water resources are data of the runoff regime. With the help of discharge measurements hydrographs can be developed. To measure the runoff of streams and rivers there are various methods available. There are direct and indirect ways of measurement (Maniak, 2005, p. 57ff).

Direct methods

Direct measurements use a known correlation between runoff and water level to derivate the runoff by a simple measurement of the water level. For this, regular designed structures like overflow weirs and measuring channels are installed. In case of very little amounts of water the discharge can be measured by taking the time needed to fill up a vessel with a defined volume (Maniak, 2005, p. 58ff.).

Indirect methods

To count the discharge indirectly one needs the mean velocity v and the corresponding flow area A. The mean velocity is calculated from several individual measurements within the cross section. The most commonly used method is speed measuring with measuring blades at different depth and several measuring verticals (Dyck & Peschke, 1995, p. 93). Other methods to measure the velocity work on electromagnetic or ultrasonic principles (Pertl, 2004).

Another method is based on the dilution of injected marker substances such as salt, fluorescent or even radioactive substances. The coefficient of concentration between a starting solution and in stream measured tracers is directly linked to the runoff (Dyck & Peschke, 1995, p. 97).

3.3.1 *Choice of device*

The decision of the measuring device was taken on the base of various constraints:

- The applied system should be capable of measuring in a frequent interval
- High range of possible discharge amounts detected. High sensitivity also to low runoff.
- Avoid retention behind the weir that could influence the runoff patterns especially after a dry fall.
- Low cost: Low installation costs, low maintenance needed

Anticipating chapter 4.1.3, it can be stated that trapezoid shaped weirs were installed at two locations.

3.3.2 *Discharge Measurement with Weirs*

A common way to measure the amount of runoff is the installation of weirs.

Overflow weirs are distinguished by several parameters. Most important are the geometry of the cross section and the design of the weir crest. Other factors are upstream flow angle, jet characteristics and influence from the downstream.

The design of a weirs cross section determines the functional correlation between discharge and overflow highs: Q = f(h^x). The other parameters are integrated into the flow coefficient µ (Aigner, 2008).

The discharge Q of a trapezoid weir (Figure 8) can be described by the adjusted formula of POLENI

$$Q = \frac{2}{3} * \mu * \sqrt{2g} * b * h^{\frac{3}{2}} * (1 + \frac{4}{5}\frac{h}{b'})$$

where $b' = \frac{b}{m}$ and $m = \frac{m_1 + m_2}{2}$

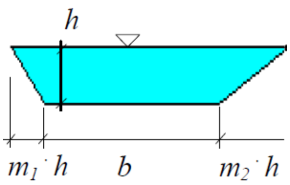


Figure 8: Geometry of a trapezoid

Q: Discharge [m³/s]

µ: flow coefficient

g: force of gravity 9,81 [m/s²]

b: width [m]

h: height [m] (Aigner, 2008, p. 166)

A table with the heights-runoff-correlation of the applied design can be found in Appendix I.

3.4 Runoff Modelling

To calculate hydrological key values computer models became a common tool. Their application helps to display (parts of) the circulation of water on different scales and scopes. A variety of hydrologic models is available for different task formulations. Corresponding to the available data resources the appropriate application can be chosen.

Hydrological modelling is based on the water balance equation and encompasses components and processes of a catchment model like evapotranspiration, precipitation, vegetative cover, root zone, unsaturated soil zone, saturated soil zone as well as surface runoff and flow processes in the riverbed (Hörmann, 2016, p. 231 ff.).

In this study HEC HMS 4.1 was chosen as an application.

3.4.1 HEC HMS

The Hydrologic Modelling System of the Hydrologic Engineering Center (HEC-HMS) is a complex hydrological model surrounding.

In HEC-HMS a watershed is represented by a basin module. Here all its physical properties are entered. A number of elements are set to design a hydrologic network: subbasin, reach, junction, reservoir, diversion, source, and sink. Here also methods are defined to represent the components infiltration respectively loss processes, transformation of excess precipitation into surface runoff, base flow, channel routing, impoundments and diversion.

The meteorological model constitutes the climatic input to the system. This can be data of historic rain events or standardized simulations.

In a control file the duration and the time interval of a simulation is set.

In the simulation manager basin model, meteorological model and the control file are chosen and can be given a ratio to calculated (Scharffenberg, 2015, p. 3 ff.)

3.4.2 Application of the Model

In this study two models will be created to extrapolate the outcomes of the measured runoff data. Model one represents the hydrologic system of Monte do Cerro and model two represents the neighbouring untreated area.

Parameter for infiltration, flow concentration and storage function will be calibrated on the base of collected rain and runoff data from the own measurement campaign (Rain-Runoff-Event 1). After finding adequate values other rain-runoff-events will be used to verify the model settings. The Split-Sample test was applied, where the validation is done on the base of data that were not used for the calibration, cf. (Klemes, 1986, p. 18).

In the end a flood simulation will be carried out to test the performance during a 150mm SCS Storm Type 1.

As such the model use can be described as deterministic, single event, lumped-parameter modelling.

4 RESULTS

4.1 INVENTORY OF THE HYDROLOGIC SYSTEM

The first aim of the study is a detailed description of the hydrologic system of the Monte do Cerro property. As described in chapter 3.1 different data sources were combined to analyse the conditions at the site.

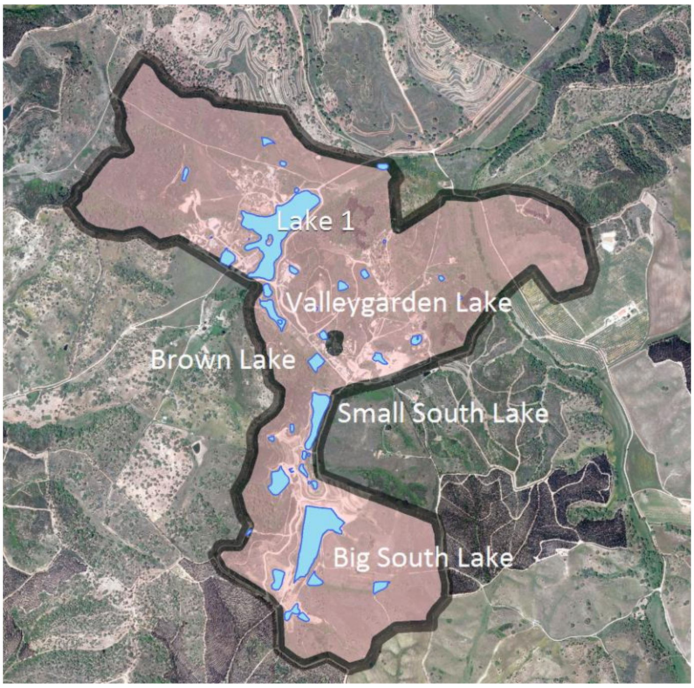


Figure 9: Monte do Cerro property

In general the land of the Monte do Cerro property (Figure 9) is hilly. The elevation ranges from 140 to 200m above sea level. Its land use consists mostly of former montado land, shrubland and meadows. In some parts afforestation measures were taken. The settlement area takes on a small proportion and shows a low building density. In the following a description of the existing rainwater harvesting measures is given.

4.1.1 RETENTION SPACES

In the bottom of the valley water bodies are to be found. These are the predominant structures which are built for the purpose of rainwater harvesting. Though the appearance of the structures has much in common with a lake, by legal definition they represent seasonally flooded retention spaces. Creating a succession of water bodies along the drainage line, dams were built at narrow point of the valley. Each structure drains into the next, when it overflows. Each structure has new contributing areas. As the structures are relatively new, this system must be considered in a development.

With the available map data it was possible to create a more precise depiction of the hydrologic conditions. Especially for determining the extent of catchment areas and lake surfaces it was expedient to match calculated results with areal pictures and on-site observations (see Figure 10).

Through this approach the following characteristics were attributed to each lake individually: surface area, catchment area, land use type, depth of lake, and common change of water level.

The catchment is described from above as the lakes are positioned along the valley.

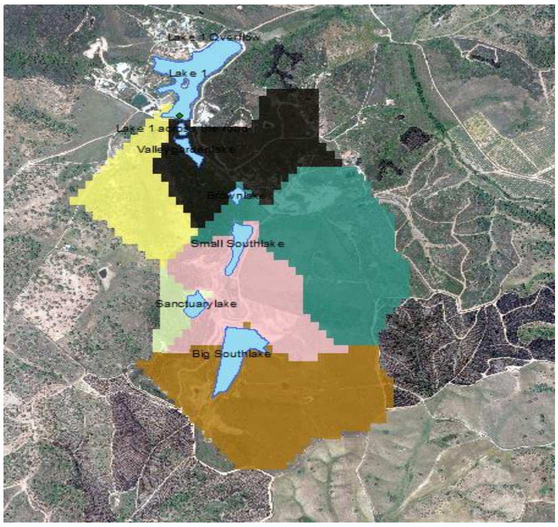


Figure 10: Drainage basins of the retentions spaces

Big South Lake

The latest retention space was built in 2011. A 13 meter high dam of natural material retains the runoff of approximately 23ha. Its water is used for irrigation purposes. The surface area of the lake is approximately 4 ha once it will be full. As it never reached over flow yet, the maximum extension was about 2ha until now. Land use in the catchment consists of shrubland, pasture and young afforestation of mixed forest.

Sanctuary Lake

The sanctuary lake has quite a small catchment of only 4ha, mainly consisting of forest land. Since the Big Southlake was built in 2011 it never reached its maximum level as parts of the formerly bigger catchment were cut off.

Small South Lake

Built in 2010, this lake has a surface area of about 0,75ha. Being positioned below the Big Southlake, the side slopes constitute a large proportion of the catchment area of about 12 ha. They consist mainly of grassland. Directly around this lake terraced garden land that is used to grow vegetables prevails. The dam is approximately 7m high. Water table is varying about 2-3 meter.

Brown Lake

The brown Lake is an old pond structure of 0,2 ha size. It has an additional catchment area of 20ha. Here forestland, loose settlement structures and meadows prevail. It is approximately 5m deep and can drop down for 2 meters.

Pig Pond

The Pig Pond with its 0,07ha size and a depth of 2 meters is rather a flow-through structure, as it only adds the drainage of 2 ha of forestland to what overflows from the Brown Lake.

Valleygarden Lake

The Valleygarden Lake has a surface area of 0,3 ha and is approximately 6m deep. Around the lake small scale gardening terraces are implemented. A bigger contribution to the runoff is contributed by a side valley with settlement structures on about 1,5ha. The other 11,5 ha consist of shrubland, pastures and reforestation measures. Its level is quite stable throughout the year.

Lake 1

The first retention structure of about 3,5 ha size was built in 2007. Situated in the main valley, it has additional 80ha land with a mixed pattern of settlement structures, shrubland, forest and meadows. Directly around the lake gardening areas are situated. Its water is used for irrigation purposes as well. As it was below both measurement points it was not considered in the examination.

4.1.2 Other Structures

In some parts of the study site in-situ harvesting is practised. Most of the gardening land is terraced and managed by organic farming using mulching techniques. In areas with afforestation the trees are planted in trenches. Also swales are built in the upper catchments. Due to research economics these diverse small scale structures were not included into this study.

4.1.3 *Measurement Points*

The runoff was monitored visually at every lake's overflow. At the start of the measurement campaign in April 2016, only one retention structure already reached its full capacity, due to a quite dry winter season. So within the treated area only at the overflow of the Valleygarden Lake a measuring device was considered to be reasonable. There an installation should have a good chance that rainfall will be visible in the discharge pattern.

The second measurement station was built at a culvert channelling the runoff of 9ha untreated land under a road. This catchment belongs to another property than Monte do Cerro, representing a typical Alentejo landscape situation without any RWH measures. The land use of this plot consists of pasture, open forestland and some small parts with eucalyptus plantations (See Figure 6: Culvert catchment, a typical montado relict on page 15)

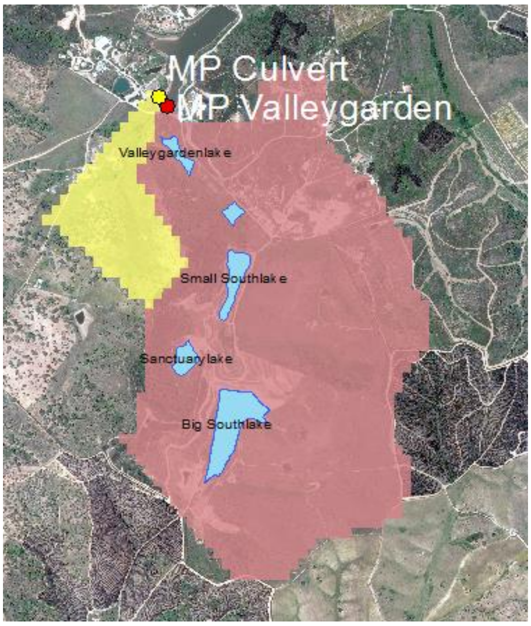


Figure 11: The two study areas: Culvert (yellow) and Valleygarden (red)

In Figure 11 the measurement points (MP) and their respective catchment are shown; the "Culvert"-system in yellow, the "Valleygarden"-Catchment in red. Due to the inbuilt retention structures, the catchment of the latter is divided into several subbasins. The active surface reduces from 75 ha to 13 ha (also see Figure 10).

After a test installation of a triangular weir it became obvious that a higher discharge could not be let through the structure without creating a large buffering zone or risking uncontrolled side flow. Thus the design was altered and a trapezoid weir was carried out.

The Valleygarden Lake has an uncontrolled overflow situation leading to a small creek like channel. Here the gauge was installed so that the backwater does not influence the lake level. It is build out of cement-bonded particleboard (see Figure 12).

Figure 12: Weir in the overflow of the Valleygarden Lake

The weir at “Culvert” station was directly fit into the entrance of the culvert. It is made out of corrosion free rolled-sheet metal. Also here the base was set as low as possible to avoid high levels of backwater.

Figure 13: Weir at Culvert

The weirs at both MPs share the same geometry to be able to compare the runoff immediately. They are designed in a trapezoid shape with the base of 15cm and flanks going up in a 45° angle. The wide base and low positioning were chosen to minimize the buffering effect in the backwater. During the application an aired jet could be observed on both weirs.

The flow coefficient μ is set to 0,572 resulting of from the basic geometry factor μ_0 =0,52 and a factor for the design of the crest that leads to an aired jet μ_1= 1,1. All other influencing factors were considered to be insignificant. In Appendix I the heights-runoff correlation is shown in a table.

The actual measurement was done manually by registering the water table. It was beneficial to have both measurement points not too far away from each other, so that all value reading could be done in parallel by only one person. The time schedule was determined using weather forecast as well as Rain Radar monitoring from IPMA.pt web side. Whenever a rain shower was indicated, measurement was started early enough to determine a base value for each checkpoint. The intensity of rain was varying, which made its prediction and adoption of the logging schedule a little bit difficult. Most rain events took place during the night, which as well was constriction to some extent. But nevertheless several quite reasonable documentations could be achieved.

4.2 Discharge measurement

4.2.1 Measured events

There have been 8 rain-runoff events during the measurement campaign. At the measurement locations in the upper catchment there was absolutely no basin-discharge to be observed. That can be traced back to the low total amount of rainfall in that season and a quite low intensity of most rains that fostered infiltration rather than surface runoff. So the measured runoff of MP Valleygarden only represents the area of the lowest catchment Valleygarden, as seen in black in Figure 10. This enables to compare the curves of MP Valleygarden and MP Culvert directly, as sizes match.

Event 1

At event 1 within 20 hours a total precipitation of 26,6 mm accumulated. The maximum intensity is 1,6 mm/15minutes. A reflection of that is to be observed at MP Culvert within one hour. After the rain stops the graph drops fast. MP Valleygarden's responses are softer. It shows a slightly increased continuous runoff. The culvert's peak of 2,2 l/s is three times higher than the peak of "Valleygarden".

Both curves did not react a lot to the first 15mm. Unfortunately some intermediate values are missing between 6 and 12 o'clock. Since it was the first measurement run, there was a lack of measurement experience. Important is the direct response to the rain at 11:45. Although there was already an initial higher discharge from the previous rain fall in the morning, the values went further up again immediately after the peak of precipitation came. The negative peak around 16:00 should be considered as measuring mistake, since there is no other evident event remembered at that time. (See Figure 14)

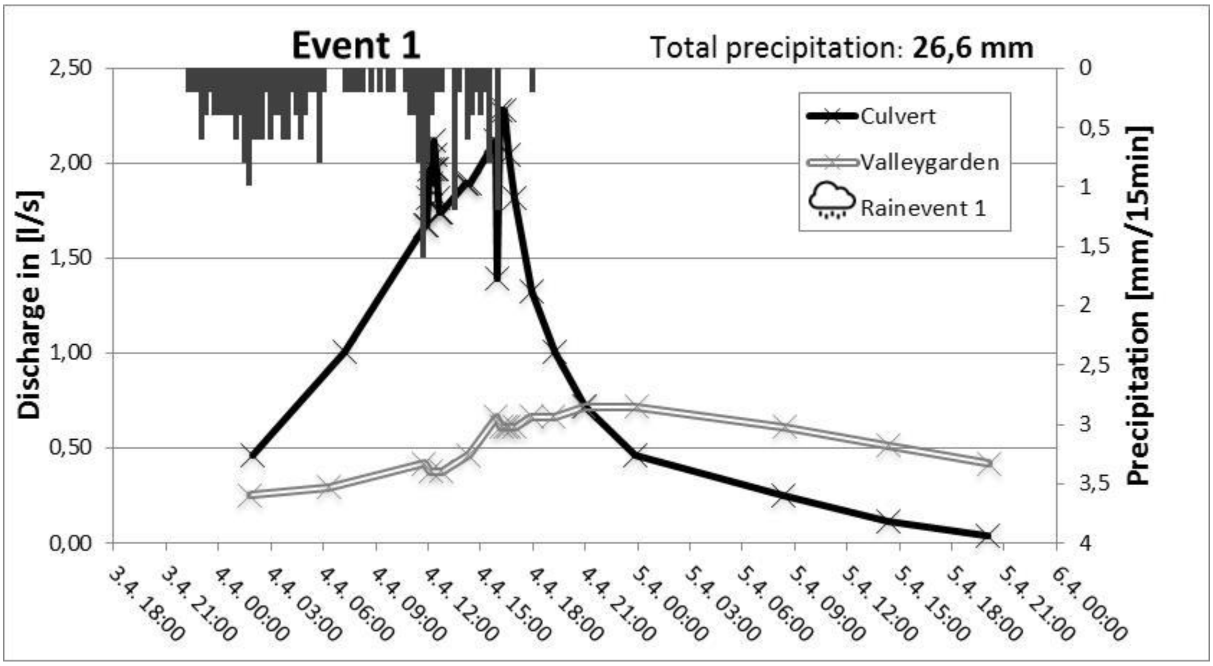


Figure 14: Rain-Runoff-Diagram Event 1

Event 2

The total precipitation is 15,4mm and fell with a maximum intensity of 2mm/15min. Before the rain event came the Culvert was almost dry. The Valleygarden showed a constant flow of roughly 0,3 l/s. The response of MP Culvert comes almost immediately and sharp, while the peaks of MP Valleygarden show up only 2-3 hours later and are of a gentle type. After the curve for Culvert went down constantly after 3:00 in the night, there was no further measurement done until 9:00. It was a surprise that the first value at this time was that high, although the automatic weather station only showed some smaller rain showers during that period. But this high value could be confirmed with some more value dumps after 30 and 60 minutes. This seems to be another indication of the immediate response of the Culvert (See Figure 15).

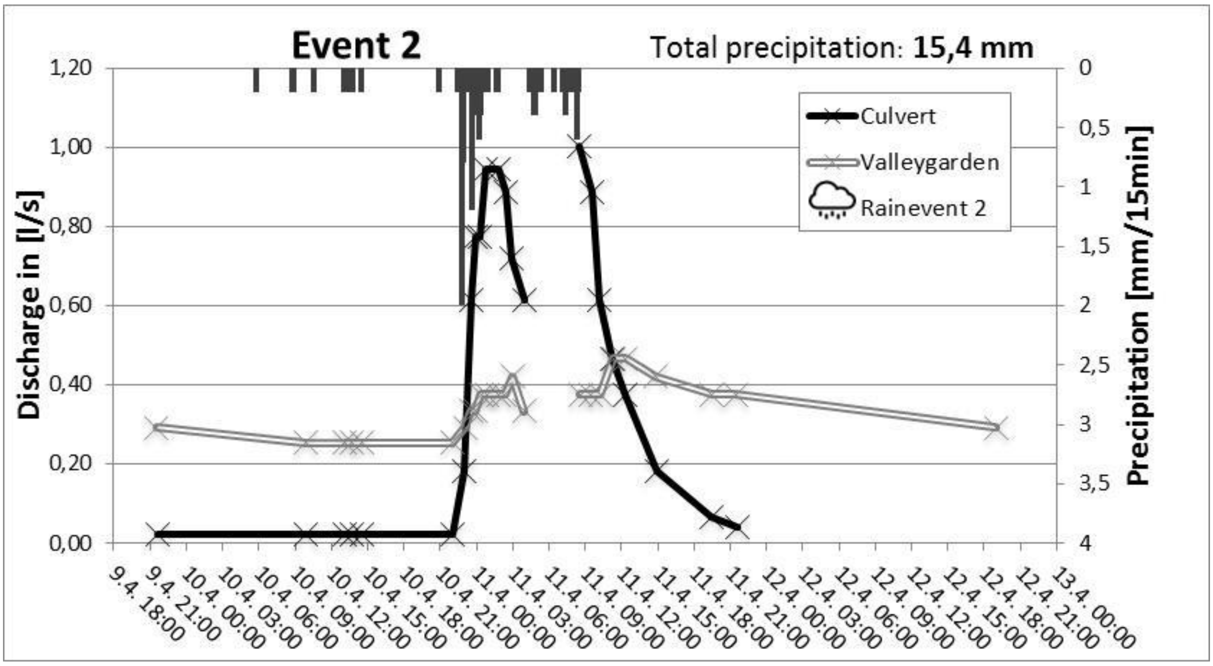


Figure 15: Rain-Runoff-Diagram Event 2

Event 3

Event 3 is a short rain of only 20 minutes but with the highest intensity of all measured events. The total amount of rain is 4mm. MP Culvert shows a significant response. After a fast peak the curve drops down as quickly as it rose. The discharge at MP Valleygarden on the other side reacts very moderately. It has a slight increase only and comes back to its base value with a very flat curve (See Figure 16).

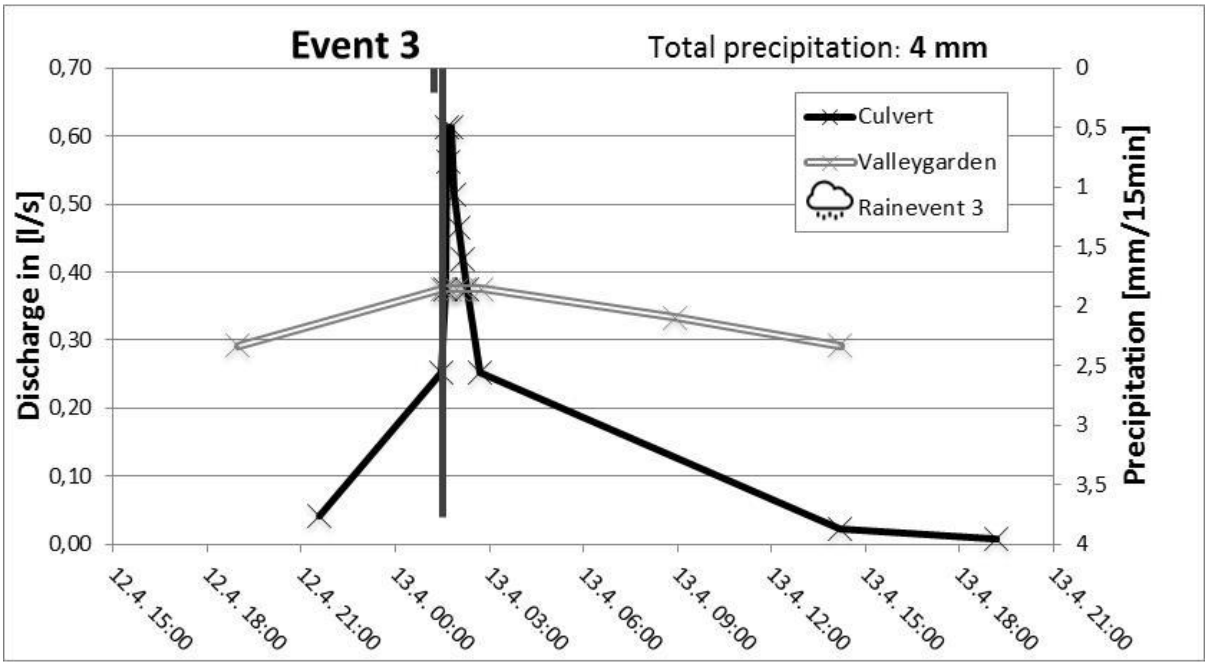


Figure 16: Rain-Runoff-Diagram Event 3

Event 4

A similar amount of rain like in Event 3 in the beginning of Event 4 did not have the same impact to the runoff; the intensity is much lower. A peak event in the night was not captured directly but two hours later still a strong response to 12 more mm is visible (see Figure 17).

Until the observation was finished at 4:00 there was no significant rain. On the rain radar the later event was not predictable. That's why the concrete peak was missed.

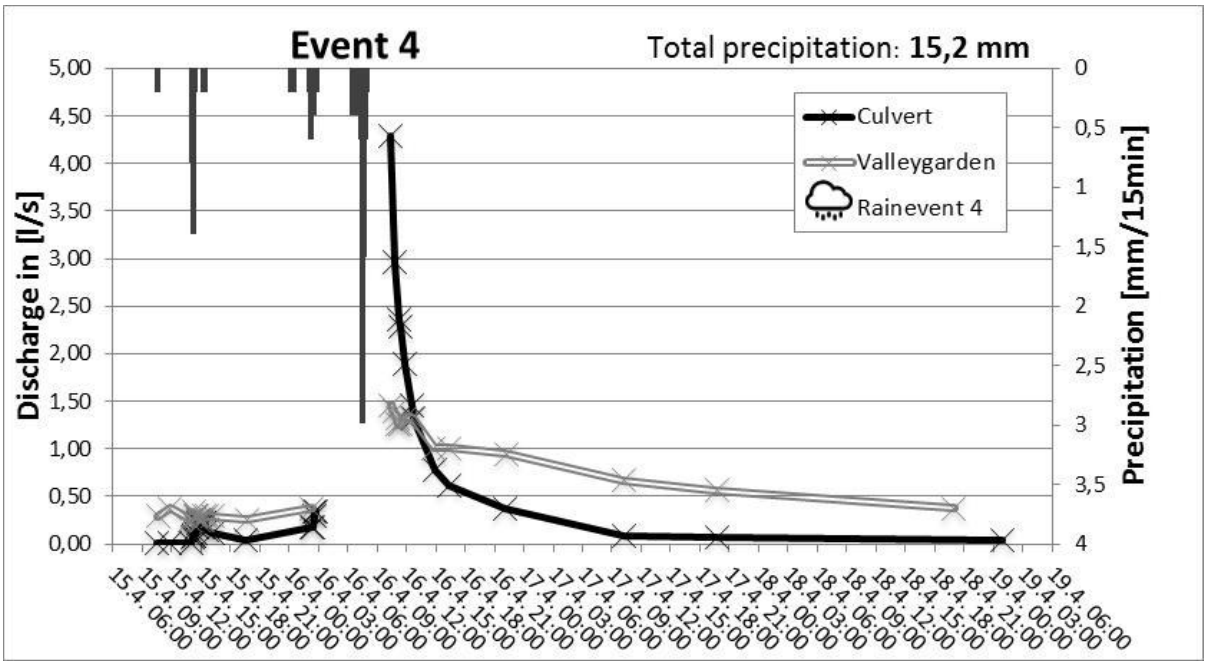


Figure 17: Rain-Runoff-Diagram Event 4

Event 5

After the experience of rain events missed before, the measurement schedule for this event was adopted, so that this curve is based on a sufficient amount of sampling points.

Event 5 has a focused rain of 10mm and the Culvert's curve runs high again immediately. Interesting to observe is the delay time of the reaction in wet conditions. Impinged with increased pre-values, a second rain peak of 2mm at 3:00 pushes up the curve after about one hour to a new maximum.

A small additional rain of 1,6 mm at 15:00 the next day leads to a small increase of the discharge again. The discharge at the Valleygarden is balanced all the time (see Figure 18).

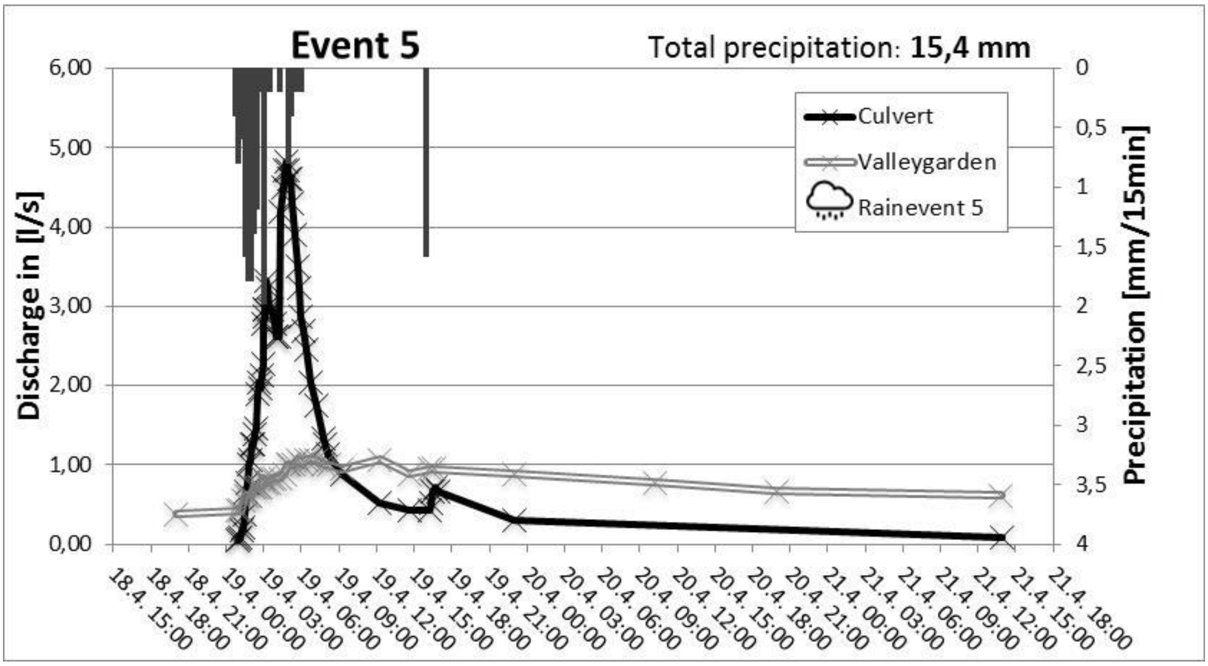


Figure 18: Rain-Runoff-Diagram Event 5

Event 6

Bear in mind the differing scale of that graphics. A small amount of rain with an intensity of 2,4mm/15 min leads to immediate runoff at Culvert, while the Valleygarden does not show any response to this event.

Worth to mention is the fact that Valleygarden has still a permanent (however of cause decreasing) discharge during several days of not raining after the last bigger event; although most of the catchment is similar to the not treated neighbour valley (see Figure 19).

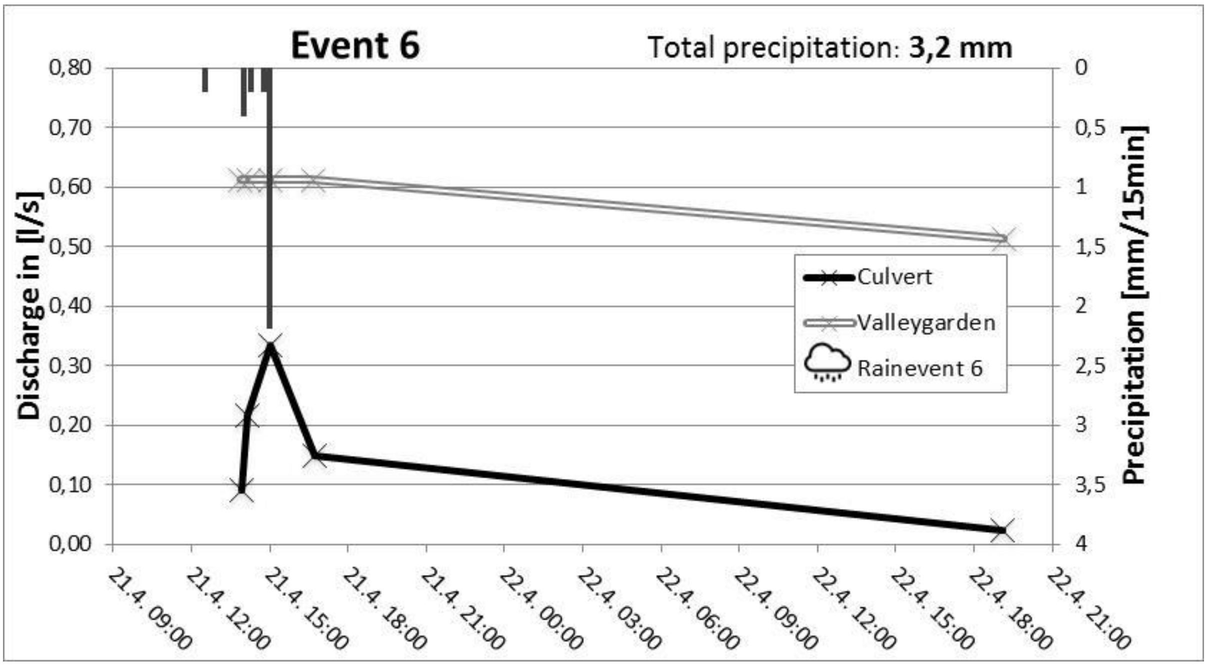


Figure 19: Rain-Runoff-Diagram Event 6

Event 7

Maximum intensity is rather low at 1mm/15min. Nevertheless the runoff curve of Culvert shows a quick response to both of the two rain peaks. A superposing of two runoff waves can be observed in both stations. The offset time for the Valleygarden curve is much longer and the peak only appears after the rain already stopped. The Total precipitation is 14,4mm (See **Fehler! Verweisquelle konnte**

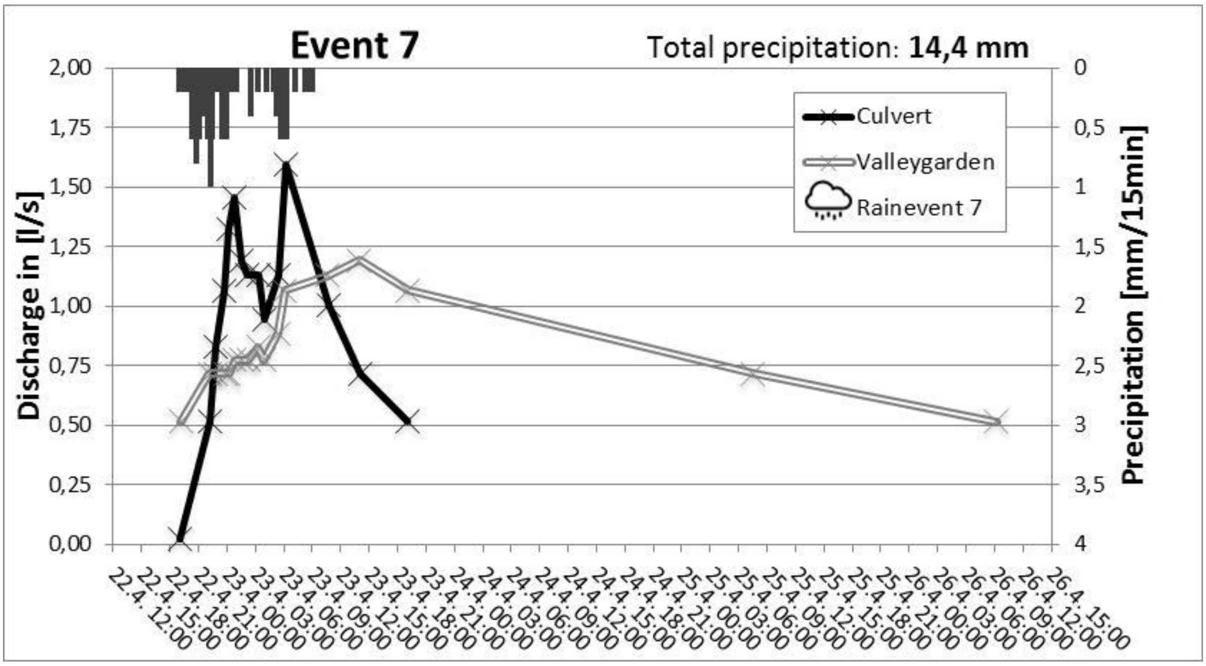


Figure 20: Rain-Runoff-Diagram Event 7

icht gefunden werden.).

Event 8

The total precipitation is 25,8 mm. The first part, accounting 8 mm, does not have a lot of influence to the curves though a response is seen. It looks not much because of the scale of the diagram, but in fact it is similar to other events before, which had the same rain intensity until here. The second part of the rain falling on pre-soaked soil leads to much more runoff through the Culvert. Values from the Valleygarden did not change a lot and kept a steady and low flow. Temporary drop downs in the Culvert's curve could be identified as measuring insecurities (see Figure 21).

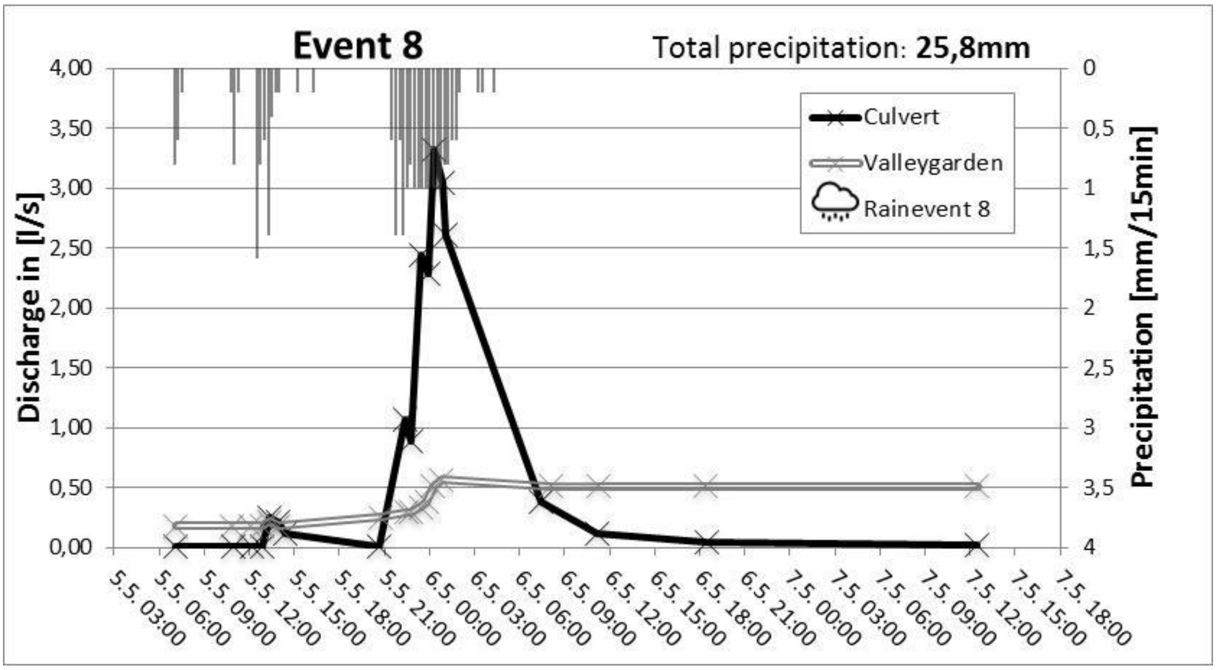


Figure 21: Rain-Runoff-Diagram Event 8

4.2.2 DISCUSSION OF MEASURED RESULTS

At first the general campaign setup will be considered. After that, as a conclusion of the measured results, commonalities of all data sets will be identified.

It was tried to collect as many sampling data as possible during the measurement campaign. However for a fundamental interpretation of the discharge behavior it may not be sufficient enough. As residents told, it was an average April, even a little bit more than average after a real dry winter.

The on-site situation was suitable to install the measuring equipment. It could be mounted in a way to keep in place and not being destroyed by changing water levels and other impacts during the whole measuring campaign.

It was really beneficial to have two similar valleys with differing water management practises in direct neighbourhood. That enabled comparing measurements of both areas having the same precipitation at the same timestamps. Even with only one person, values could be collected in an evident time period. This same-person approach eliminates also different individual manners of how to gain value logs. Even if there were deviations in total measurement they can be considered as compensating.

In general it can be asserted that the measuring concept created results at all. That means it is applicable so far, even in areas with such low total amount of rain.

Looking to the continuity of measured values over time it can be stated that value-reading at the weirs took place in a consistent way; even though values were measured in millimeters, most times during the night with artificial illumination and level difference being very small sometimes. There is only a low "noise" in the values. That displays the fault safety of that method.

Considering the measured curves themselves, the following conclusions can be yielded:

The runoff-patterns of the two catchments differ significantly in all observed events. In all cases the "Culvert"-Catchment delivered an impressive stronger response to the rain. The peak discharge was reached earlier and peaked higher. The decrease down to total stop of flow happened quickly as well.

The Valleygarden area shows a very smooth response to short but high peaks on one hand as well as to longer continuous rain events on the other hand. Taking into account that the lake as a single structure is full already, there seems to be still a high potential for infiltration of water into the soil due to the positive human interaction with the nature in this area.

A limit of infiltration is connected to the rain intensity. A similar amount of rain in Event 3 and 4 had significantly different responses. At an intensity of 4mm/15 minutes (16mm/h) there might be a threshold value of the infiltration capacity, leading to immediate overland flow.

4.3 RUNOFF MODELLING

In the coming chapter the outcomes of the runoff modelling will be presented.

4.3.1 THE MODEL CONFIGURATION

In the following chapter the building of the simulation model will be shown. A hydrologic model is structured in different components:

Basin model, Meteorologic model, control Specifications, Time-Series Data and Paired Data (see Figure 22)

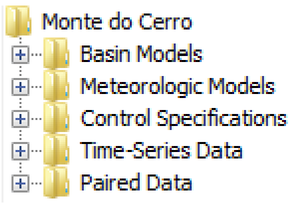


Figure 22: Model components

4.3.1.1 Basin model

A complex basin model of the Valleygarden catchment was created, incorporating all retention spaces, as they are described in chapter 4.1.1 (see Figure 23).They are displayed as *reservoir elements*. Their associated catchments are added as *subbasin* elements. All elements were connected by definition of the respective *downstream element*.

The Culvert's catchment is calculated as a single subbasin element.

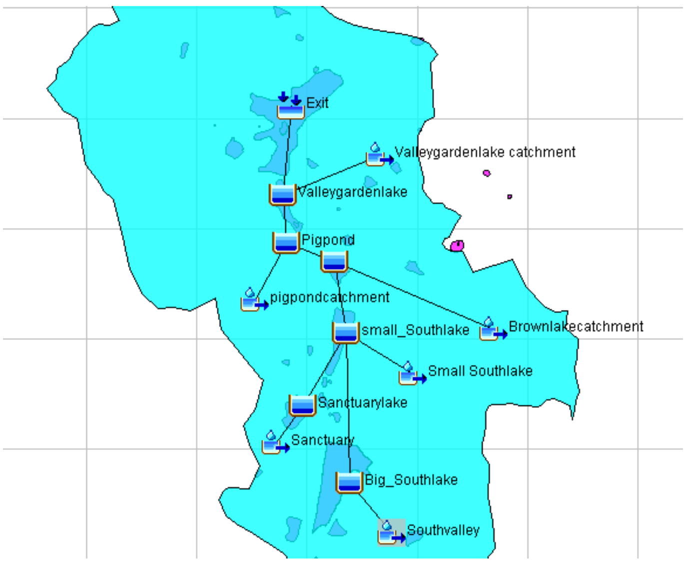


Figure 23: Basin-model of the Valleygarden catchment

Subbasin elements are characterized by the catchment size and the methods representing hydrologic processes. To avoid over-parametrisation not all possible options need to be taken, especially in single event modelling. As a **Loss method,** representing discharge generation, the *SCS-Curve-Number* processing was chosen. **Transform** processes, calculating discharge concentration, were modelled through *Clark Unit Hydrographs*. **Baseflow** is entered as a *constant* value. Special considerations of vegetation cover (canopy) and surface functions are not implemented (see Figure 24).

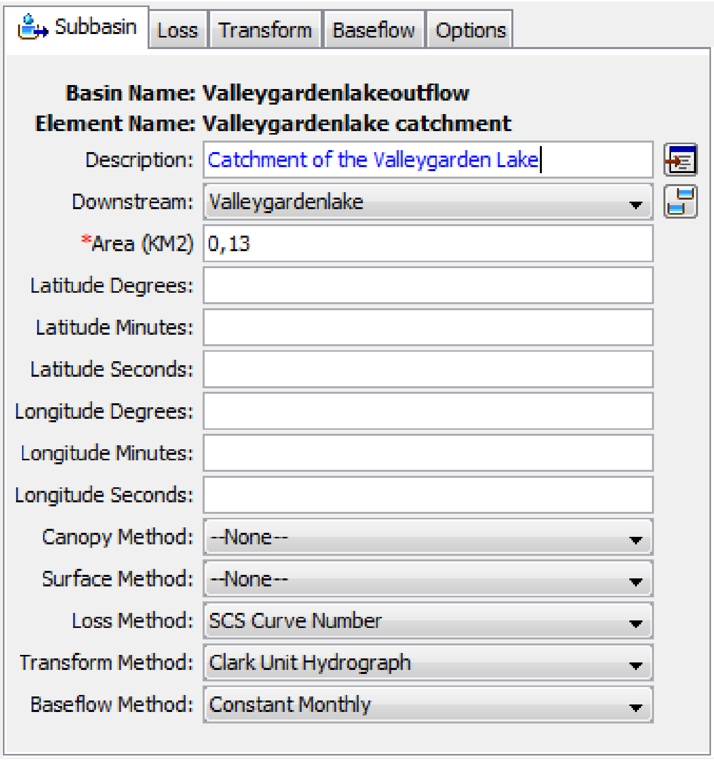


Figure 24: Subbasin properties

Reservoir elements are characterized by a volume and a function how to process input water. To calculate the outflow of Reservoir elements the **Method** *outflow structures is* selected. The volume is derived of the surface area in correlation with the filling height (**Storage Method**: *Elevation-area*).

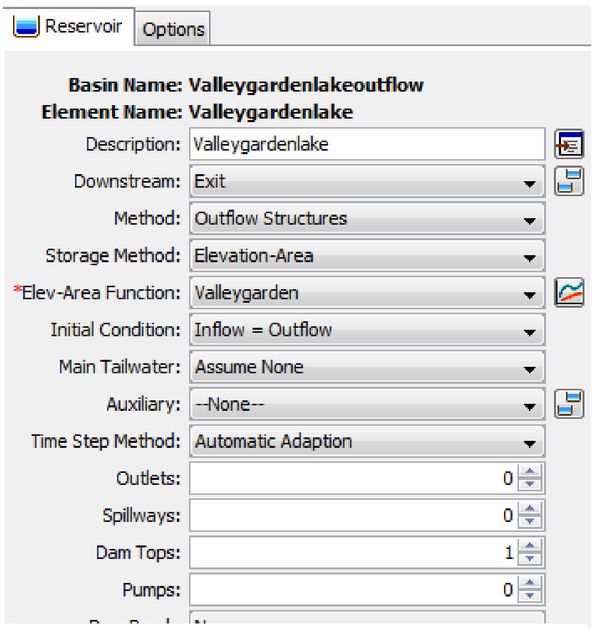


Figure 25: Reservoir properties full structures

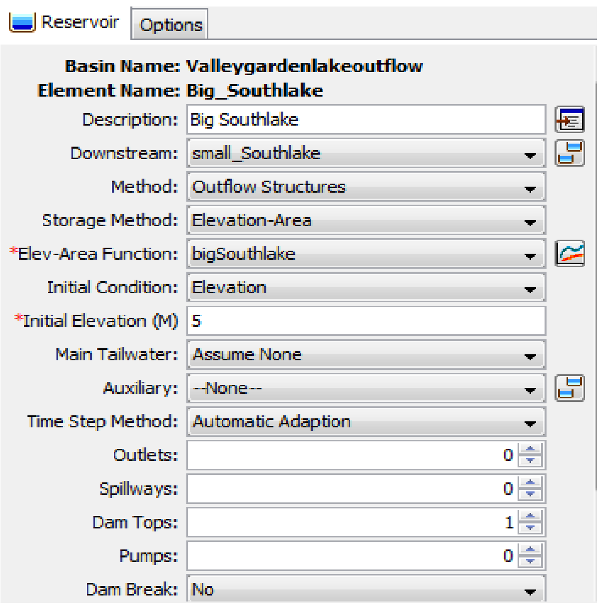


Figure 26: Reservoir properties buffering structures

For each reservoir an **Initial Condition** was defined. The Valleygarden Lake is the only lake that was overflowing during the measurement campaign, so *Inflow equals Outflow* was set. For the other lakes an *Initial Elevation* was set suitably since they were not yet overflowing (see Figure 25 and Figure 26).

Detailed data backgrounds required by several methods are entered as *Paired Data (see* Figure 28*). Cross sections* and *Elevation-Area Functions* are entered as tables (see Figure 27).

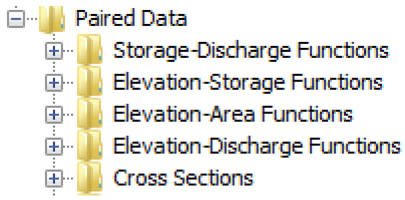
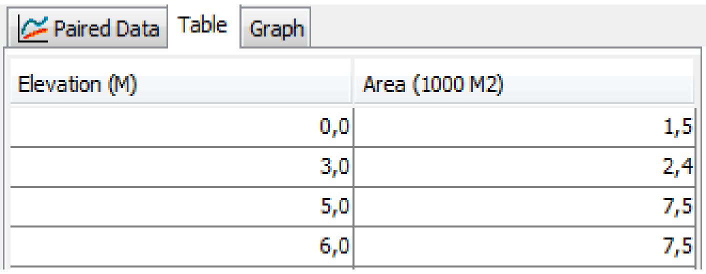


Figure 28: Paired data



Elevation (M)	Area (1000 M2)
0,0	1,5
3,0	2,4
5,0	7,5
6,0	7,5

Figure 27: Data entry Elevation-Area Function

As runoff structures **Dam tops** were designed with a *cross-section* of the runoff situation.

4.3.1.2 Meteorological model

In the Meteorology model climatic inputs like solar radiation, precipitation, Evapotranspiration, snowmelt can be selected (see Figure 29). For a single event modelling precipitation data is sufficient.

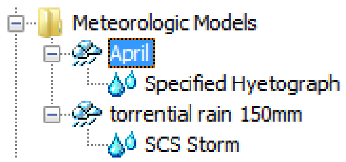


Figure 30: Meteorological models

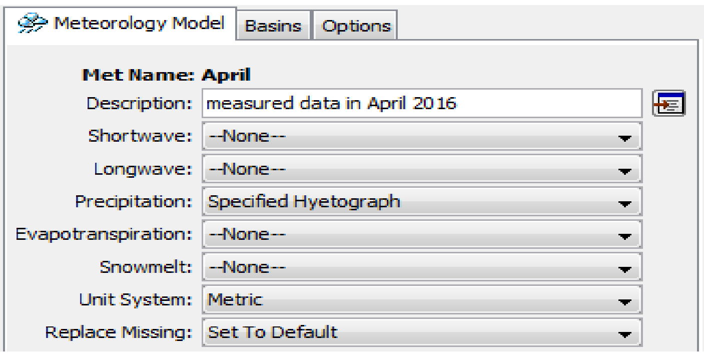


Figure 29: Meteorology model

In this study, two meteorological model cases were defined: At first, the real rain events that took place during the measurement campaign were set as *specified Hyetograph.* The measured rain data were entered as *time-series* records. Furthermore a simulated rain event was created, which represents a torrential rain of 150 mm within a day. (See Figure 30, Figure 31 and Figure 32)

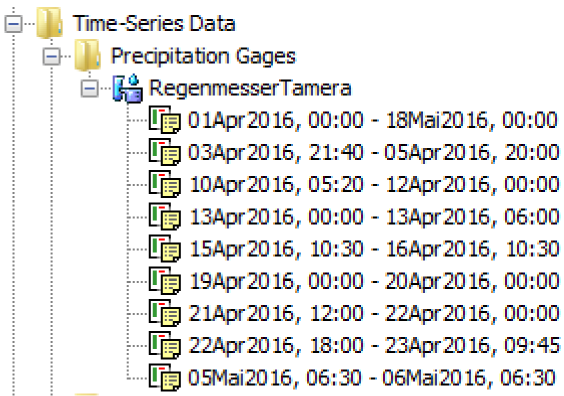
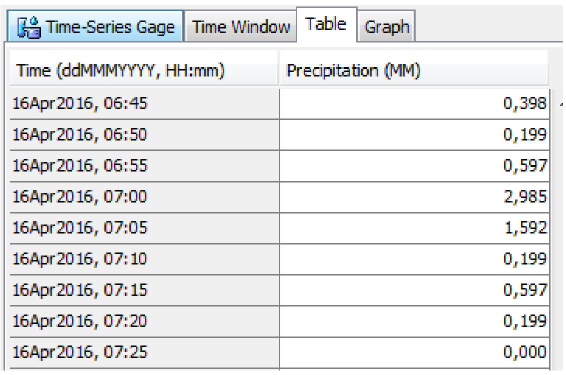


Figure 31: Entering rain data



Time (ddMMMYYYY, HH:mm)	Precipitation (MM)
16Apr2016, 06:45	0,398
16Apr2016, 06:50	0,199
16Apr2016, 06:55	0,597
16Apr2016, 07:00	2,985
16Apr2016, 07:05	1,592
16Apr2016, 07:10	0,199
16Apr2016, 07:15	0,597
16Apr2016, 07:20	0,199
16Apr2016, 07:25	0,000

Figure 32: Entering rain data

4.3.1.3 Control specification

For each rain event a correspondent control file was created. The time frame of the simulation runs was set as large as to cover all relevant responses comparing to the real runoff reactions.

4.3.2 Model Calibration with measured data

A Calibration of the model was carried with the gauged rain data and the runoff of Event 1. The following triggers were adjusted to calibrate the model:

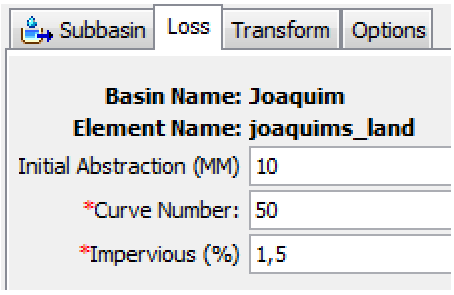


Figure 33: Loss calibration

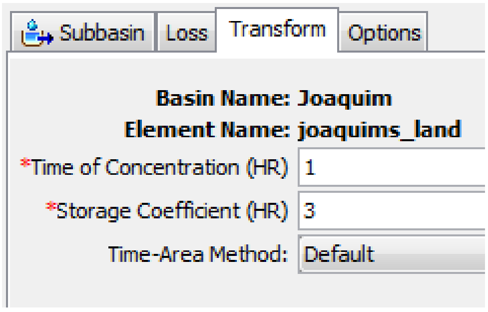


Figure 34: Transform parameter calibration

Loss factors: *Initial Abstraction, SCS-Curve-Number, Partition of impervious surfaces.* (Figure 33)
Transform factors: *Time of Concentration, Storage coefficient (*Figure 34*)*

The different modelling runs and their settings were documented in an Excel-file (see Figure 35). A diagram of the modelled and measured data was set up to compare the curves visually. The results are shown within the text as small diagrams. The full size graphics can be found in Appendix II.

E	F	L	M	N	O	P	Q	R	S	T	U	V
initial abstraction		2,00	2,00	3,00	4,00	7,00	10,00	10,00	10,00	10,00	7,00	15,00
CN		86,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00
concentration factor		1,00	1	1	1	1	1	1	1	1	1	1
storagefactor		3,00	3	3	3	3	3	3,5	4	5	5	5
impervious												
	1000											
active in m³/ activ in l/s												
Mod 17		5	6	7	8	9	10	11	12	13	14	15
0,0008	0,8	0,0112	0,0023	0,0019	0,0019	0,0008	0,0002	0,0002	0,0002	0,0001	0,0006	0

Figure 35: Documentation of the calibration stages in Excel

At first, the soil properties were classified quite low with a CN-Value of 86. This value was suggested in the SCS table TR 55 2.2c for woods–grassland combination for soil group D which characterizes a loamy soil; see (Scharffenberg, 2015). The setting showed a vast overestimation of runoff (Figure 36). To compensate this, a reduction to 10% of the values was necessary which resulted in an almost perfect match of the curves (Figure 37). But reconsidering this again, it could not be an appropriate representation of the system, as described later. There is no simple way to reduce the calculated runoff proportionally on the base of physics. So a trial and error approach was taken including more

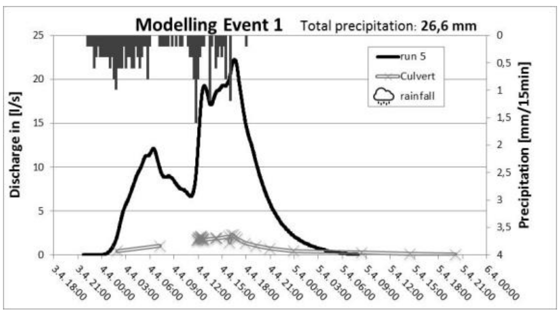


Figure 36: Model Culvert Run 5

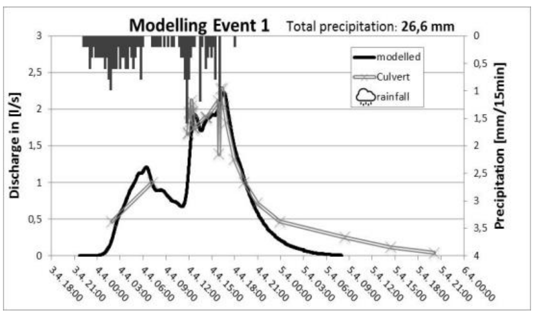


Figure 37: Model Culvert Run 5 with factor 0,1

trigger components than only the CN-value. In total 35 simulation runs were executed.

The transformation values were considered fitting, as the timing of the peaks was good. So in the further calibration there was a focus to the runoff generation.

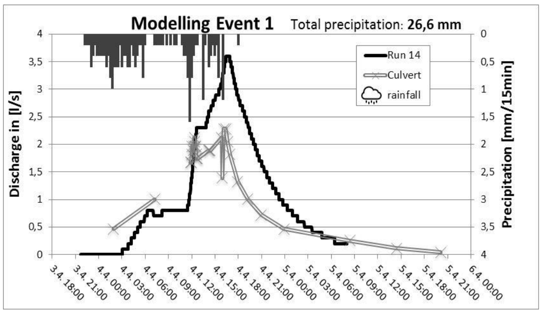


Figure 39: Model Culvert Run 14

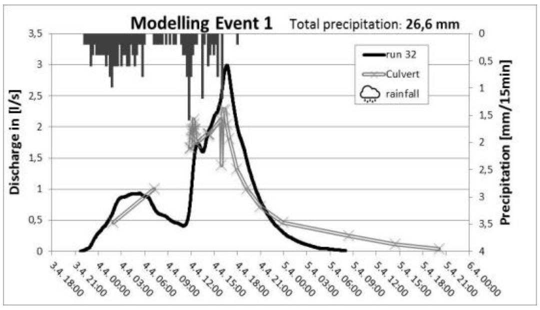


Figure 38: Model Culvert Run 32

The initial abstraction, CN-value and the percentage of impervious area were adjusted until a satisfactory result was found. Run 32 produced the best match (Figure 38). The final values are: CN 50, impervious area 2%, storage factor 3h and concentration factor 1h. The initial abstraction for Event 1 was set 15mm.

The same methodology was applied to the Valleygarden. Here similar soil properties were set right from the beginning. The main calibration focussed on the differing transform behaviour. The criteria for selecting run 18 (see Figure 40) were the best fit of the peak and the following decrease of the curve. Unfortunately it was not possible to display a closer approximation within the rising flank without introducing more parameters. But this was considered a lower priority. The final values for Valleygarden are: CN 50, impervious area 0%, storage factor 4h, concentration factor 1h.

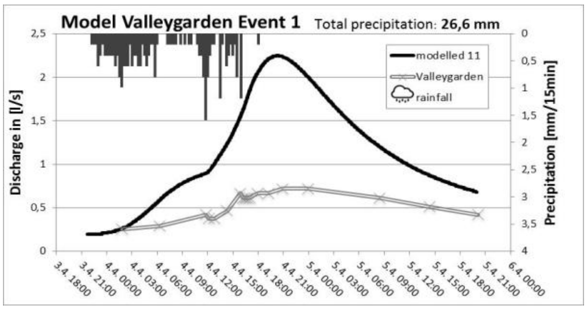


Figure 41: Model Valleygarden Run 11

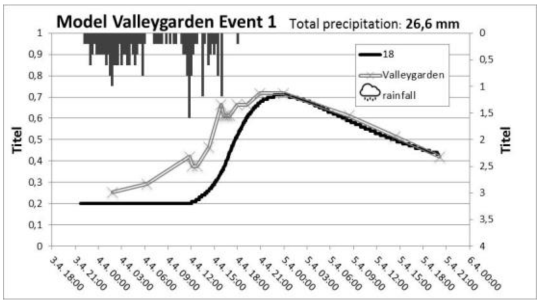


Figure 40: Model Valleygarden Run 18

As a next step the determined values were validated with a split-sample test. The only value changed during the validation was the initial abstraction as the preconditions of the two events were different. Event 1, used for the calibration, had 15 mm of initial abstraction; Event 2, used for the validation, only 6. As Figure 42 shows, the Culvert simulation reproduces the existing peaks reasonable. The validation run for the Valleygarden (Figure 43) matches the peak heights again and the gradient of the decreasing curve is fitting as good as possible within the given set of parameters.

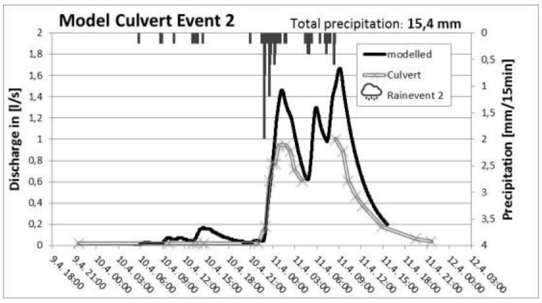


Figure 42: Model Validation Culvert Event 2

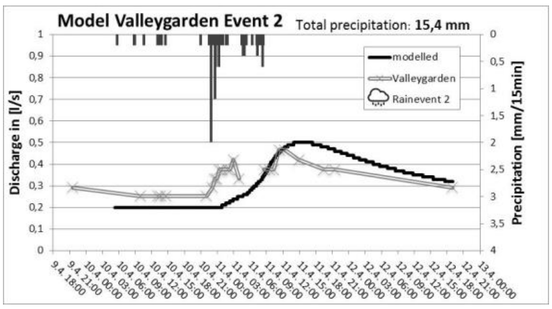


Figure 43: Model Validation Valleygarden event 2

4.3.3 *Discussion of model setup*

To recall the overall aim of this study: it is to find out the mechanics of rainwater harvesting in Monte do Cerro. In addition to running the onside measurement activities, a simulation model was developed which represents this real landscape in a simplified manner. This enables an analysis of situations that were not possible to experience in real life during the campaign.

The important task was to select all crucial hydrological parameters and to define reasonable model boundaries. Therefore several restrictions were accepted:

Evapotranspiration and groundwater features were not considered for this single event setup.

For basin elements, the Detail level of catchment information was summarized to a lumped parameter set: The individual shape of catchments was discarded, DEM information were not integrated. Elevation data were only indirectly included through *transform* parameters. Modelling does not represent small scale RWH structures like in-situ harvesting.

For reservoir elements, a detailed calibration of the upper lakes was not possible due to the lack of reference, since there was no overflow. Interesting parameters like roughness of the runoff could not be examined.

With the existing number of parameters in some cases it was not possible to reach a real perfect match of simulated curves to the measured data. Therefore store was set by the following calibration features: First, a timely adequate representation of the impulses is visible; second, the overall volume is fitting; third, the level of the peak is matched.

Special consideration of the CN value

A major inconsistency occurred during the calibration. The simulation curves exceeded the measured data highly.

An intense error analysis was conducted. Conversion and transcription errors were considered but could not be identified. A measuring mistake or a misperception of the catchment (e.g. a hidden outlet or depression) can be eliminated, because that phenomenon occurs for both scenarios.

The defined parameters were challenged again. In the beginning the properties of the soil, regarding infiltration and storage capacity, were classified rather bad according literature, see page 35. The concern was indicated that this may not be appropriate.

Another cross-calculation was done analysing the total amount of water fluxes: In Event 1 the total amount of rain that fell in the Culvert catchment summed up to 2400m³. By integration of the measured runoff curve it came out that only 100m³ ran through the gauge. The difference must have been absorbed.

The simulation run #5 for this event with a CN-Value of 86 calculated the too high value of 800m³.

The conclusion of this mismatch is that the infiltration must be much underestimated, which means better soil properties than expected even for this degraded land.

Another verification path was executed. Considering the increase in the water table of the Valleygarden Lake, an intense runoff creation, as it was projected, would raise the water table for about 45cm. This does not correspond to observations made during the measurement campaign. Therefore lower CN-values must be considered realistic. For further simulation runs, the value was reduced to 50.

This concern was also discussed with local experts. They remembered an unpublished infiltration test series some years ago, which came to a similar conclusion, but was discarded because of poor execution of this study. But now here is another indicator for this hypothesis. Further studies should be conducted.

Summarizing the overall model setup discussion, it can be stated that model is applicable for general behaviour calculations and trend analysis. Said that, it leads to the next chapter where this model is used for an up-scaled calculation.

4.3.4 Simulation of torrential rain event

To simulate the performance of the system in a stress scenario, a SCS-Storm type 1 of 150 mm was chosen. Storm type 1 is prevailing in climatically comparable areas of the USA (California). Three states of the Monte do Cerro valley were calculated.

The first run represents a state of the Valley before the retention spaces were built. The basin only consists of one single subbasin.

The second run represents the Valley after the implementation in a worst case scenario where all the retentions structures already reached their capacity before the rain starts as it could be the case in the spring of a wet year.

The third run represents the Valley in an autumn scenario where the water level in the retention spaces dropped to a minimum after a drought season.

In Figure 44 the results of all three simulations are overlaid in one diagram.

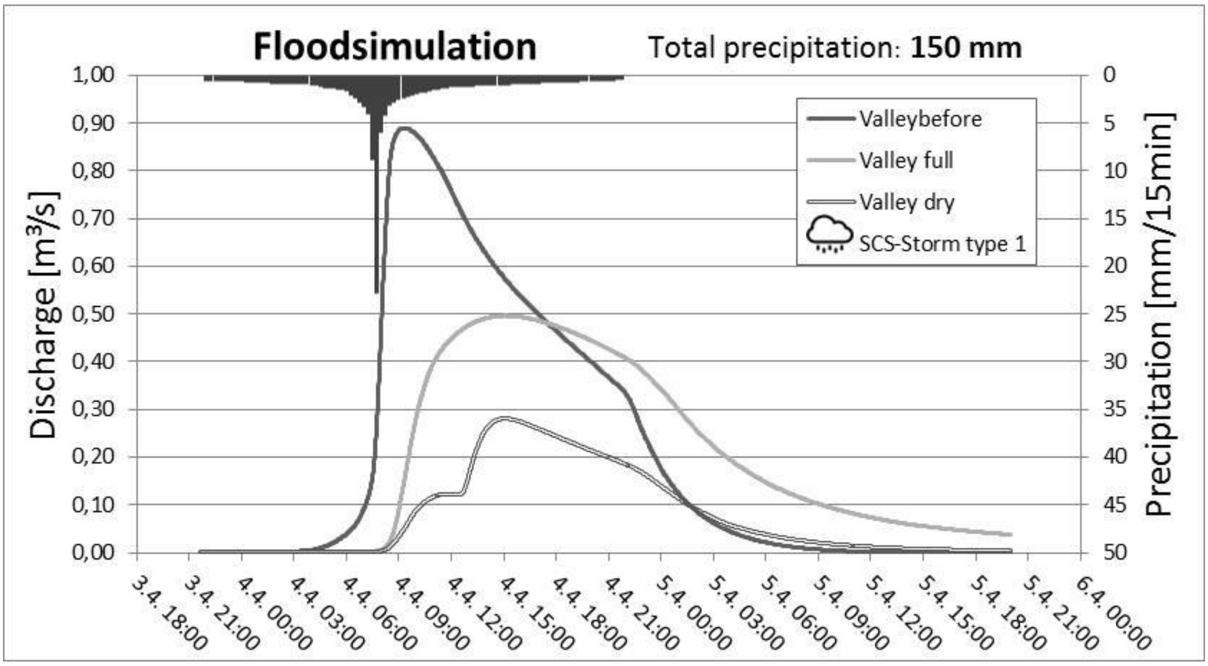


Figure 44: Flood simulation

A big difference in the runoff pattern for each run can be observed.

At first the growth of the curves to the peak will be considered. The curve of *Valleybefore* shows a sharp peak immediately after the strongest rain hits the system. It boosts up to almost 0,9 m^3/s within one hour. At this moment the two other curves don't show any strong reaction yet. Even the full lake system did not cross the 0,1m^3/s line. They show a strong incline in the next hours as well, but the gradient is much lower. The *valley full* curve reaches the peak after 8 hours with 500l/s (55 % of *Valleybefore*). The simulation run for a dry situation (*Valley dry*) reached its peak flow at the same time. However in this configuration a lot more water was held back. Only a third of the comparable peak of *Valleybefore* (280 l/s) left the site.

In the simulation results of *Valley dry* it is also visible that both South Lakes and the Sanctuary Lake did not overflow at all; even though a significant increase in their water level was calculated. A sudden jump is to be observed when the capacity of the Brown Lake is reached at 11:15 a.m.

Now the decline after the peak is described. Simulation run *Valleybefore* shows an exponential decline for about one day. A faster reduction can be noticed after the rain finally stops. Run *Valley dry* does not exceed run *Valleybefore* a lot in the late phase. That means that the full volume that is represented in the area between the curves is really stored in the harvesting structures. It is not only buffered and still released later. In run *Valley full* this is what happens. It shows high runoff values much longer with a soft decline, the typical curve for buffering.

To summarize this simulation the following can be detected: The implementation of water retention spaces definitely has a big effect to the runoff pattern. It at least buffers the water and stores it as long as there is still capacity available.

5 Conclusion

5.1 Summary

The wide range of backgrounds was studied including the topics of hydrological balance, the complex interplay of factors leading to Desertification, Land Degradation and Drought, possible amelioration approaches of ecosystem restoration and Rainwater harvesting, on the base of a literature review. The existence of ideas, initiatives and approaches, like for instance the WOCAT initiative, gives hope that it is still possible to overcome challenging bottlenecks of current developments. The reader got familiarized with the Alentejo region in South-West Portugal in general and the comprehensive application of rainwater harvesting in Monte do Cerro in particular.

To dive one level deeper into the interrelations of this area from a scientific point of view, a set of methods was provided. Concrete landscape analysis can be achieved of cause by a site visit, but also analysing from a distance with Geographical Information Systems. Using those methods an inventory of the hydrological properties of the Monte do Cerro area was assembled. After that, the reader was taken along on a measurement campaign of discharge from rain events during a three month period. Braking down those results, the transformation into a computer model was performed, including calibration and validation of model parameters. Finally a torrential rain event was simulated on the base of the previous outcomes.

The following findings were gathered. There is a significant impact of the rainwater harvesting measures to the local water balance. Especially buffering and storing effects could be determined. Conducting parallel measurement series on two different scenarios, one with and one without rainwater harvesting structures, significant discrepancies in runoff results were observed. The treated area could store almost the full amount of fallen rain, being available for later use during the dry summer season. A discussion was held on the quality of hydraulic properties of the soil. The analysis of measurement series shows that the soil parameters of the Monte do Cerro area are better than expected. The outcomes of the simulation of a torrential rain event with 150mm falling within one day showed, that an application of rainwater harvesting structures on a large scale (multiple retention spaces) can mitigate even such a heavy incident.

5.2 Outlook

The possible research areas are not for a long time yet exhausted. The need for further investigations is stressed in following topics:

An appropriate assessment of soil properties

Effects of rain water harvesting to the groundwater storage and potential increase of baseflow

Implications of the applied design to the downstream areas

Based on methodological critique, the following improvements could be done to foster future outcomes: Development of a comprehensive measuring concept, including automatized data logging of lake levels and discharges. Increase the stock of GIS-data, especially making high resolution Digital Elevation Models available. Improve the number of integrated model parameter to capture evapotranspiration and groundwater features.

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7 APPENDICES

Appendix I: Correlation of heights and runoff

Appendix II: Modelling data

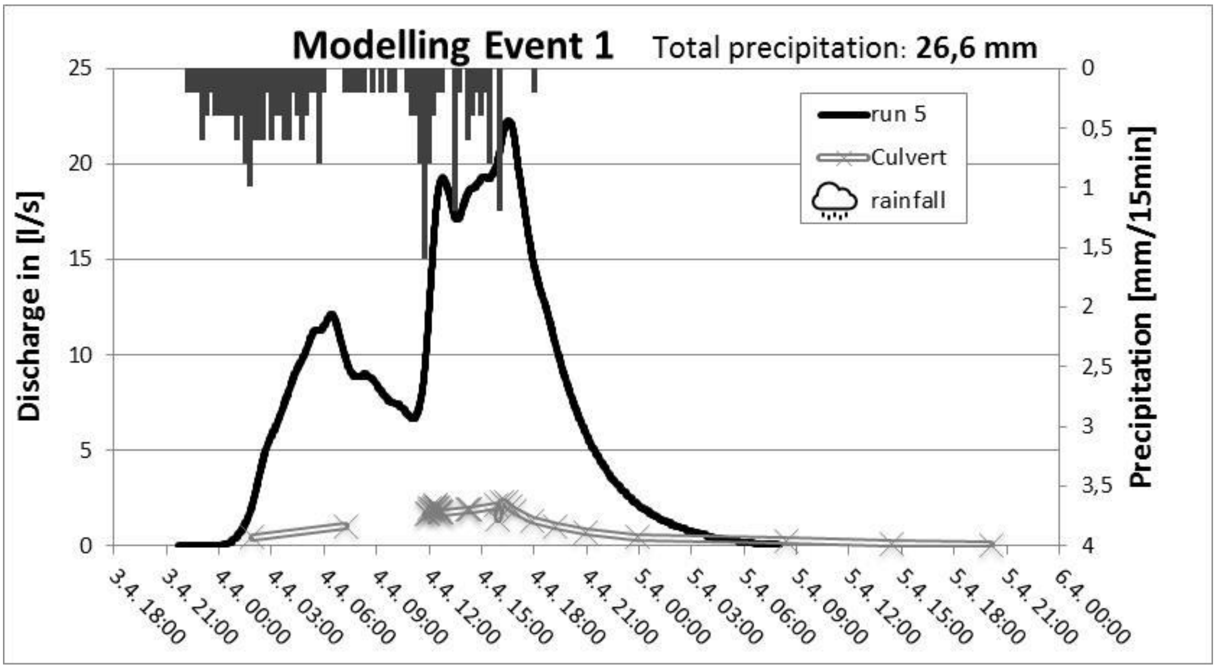
Appendix I: Correlation of heights and runoff

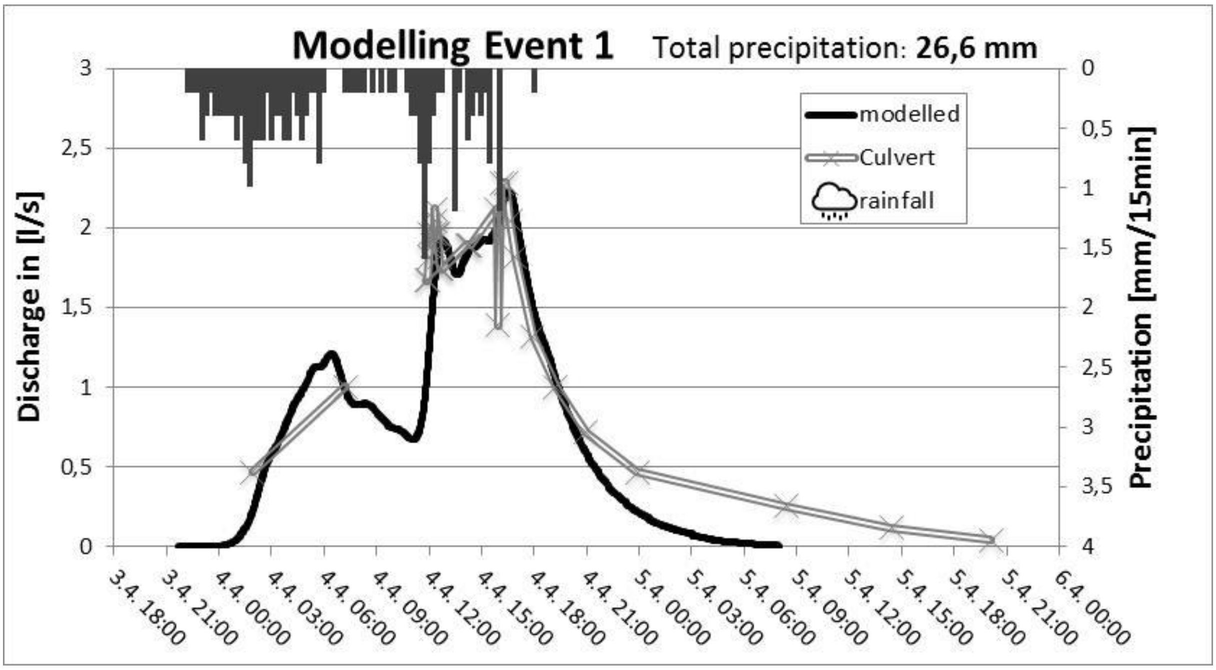
h - Q - table		$Q = \frac{2}{3} * \mu * \sqrt{2g} * b * h^{\frac{3}{2}} * (1 + \frac{4}{5}\frac{h}{b'})$			$b' = \frac{b}{m}$	$m = \frac{m_1 + m_2}{2}$
μ = 0,57	μ 0 = 0,52	μ edge = 1,10	4,43	b = 0,15	0,67	

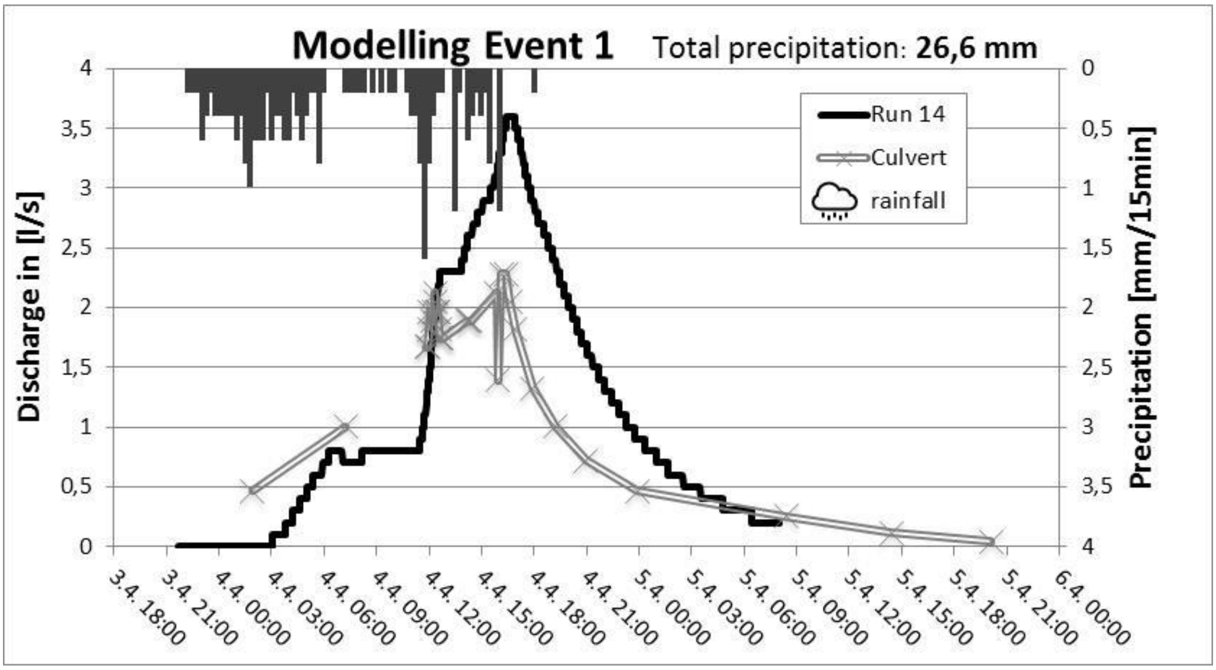
h in mm	Q([l/s]	h in mm	Q([l/s]	h in mm	Q([l/s]	h in mm	Q([l/s]	h in mm	Q([l/s]
1	0,01	21	0,77	41	2,12	61	3,89	81	6,05
2	0,02	22	0,83	42	2,20	62	3,99	82	6,16
3	0,04	23	0,89	43	2,28	63	4,09	83	6,28
4	0,06	24	0,94	44	2,36	64	4,19	84	6,40
5	0,09	25	1,00	45	2,44	65	4,29	85	6,52
6	0,12	26	1,07	46	2,53	66	4,40	86	6,64
7	0,15	27	1,13	47	2,61	67	4,50	87	6,76
8	0,18	28	1,19	48	2,70	68	4,60	88	6,89
9	0,22	29	1,26	49	2,78	69	4,71	89	7,01
10	0,25	30	1,32	50	2,87	70	4,82	90	7,14
11	0,29	31	1,39	51	2,96	71	4,92	91	7,26
12	0,33	32	1,46	52	3,05	72	5,03	92	7,39
13	0,38	33	1,53	53	3,14	73	5,14	93	7,52
14	0,42	34	1,60	54	3,23	74	5,25	94	7,65
15	0,47	35	1,67	55	3,32	75	5,36	95	7,78
16	0,51	36	1,74	56	3,41	76	5,47	96	7,91
17	0,56	37	1,82	57	3,51	77	5,58	97	8,04
18	0,61	38	1,89	58	3,60	78	5,70	98	8,17
19	0,66	39	1,97	59	3,70	79	5,81	99	8,30
20	0,72	40	2,04	60	3,80	80	5,93	100	8,44

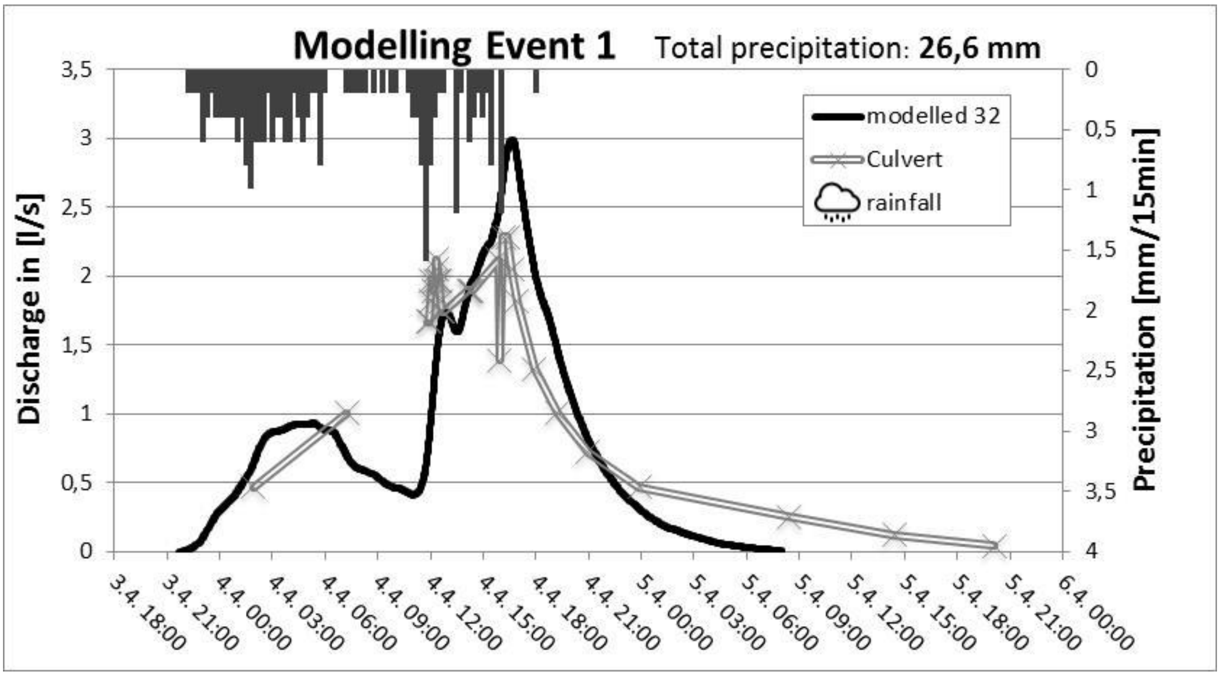
APPENDIX II: MODELLING DATA DIAGRAMS

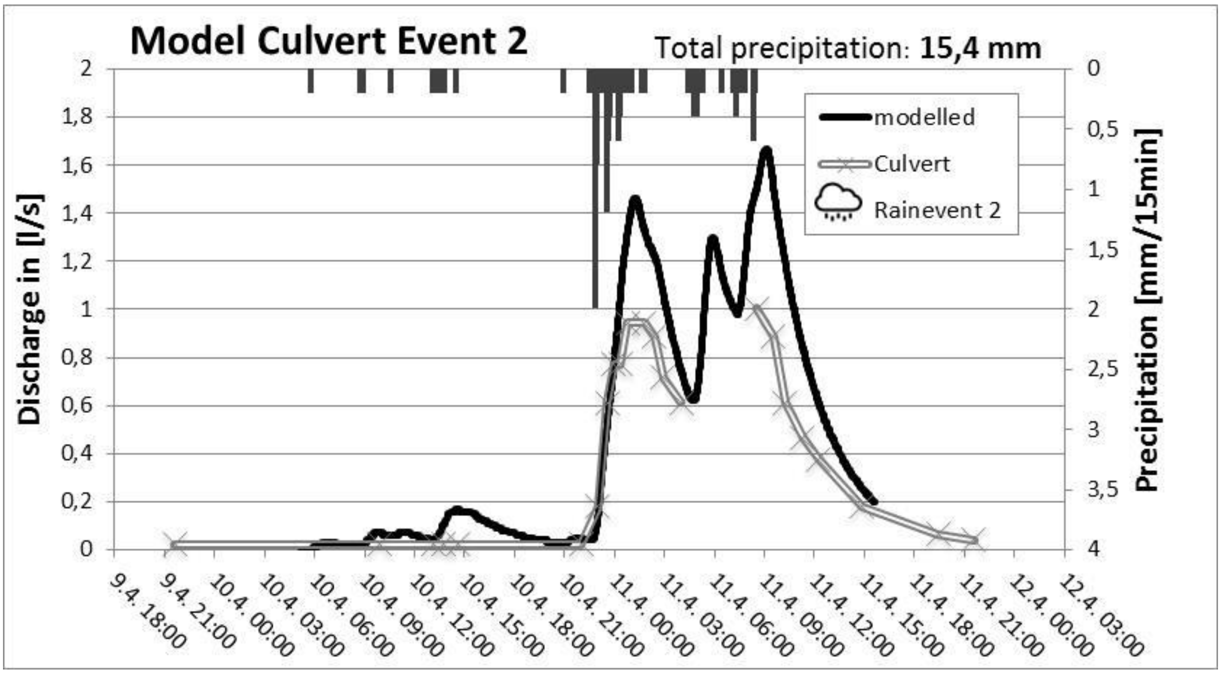
All diagrams in big as the appear in the text



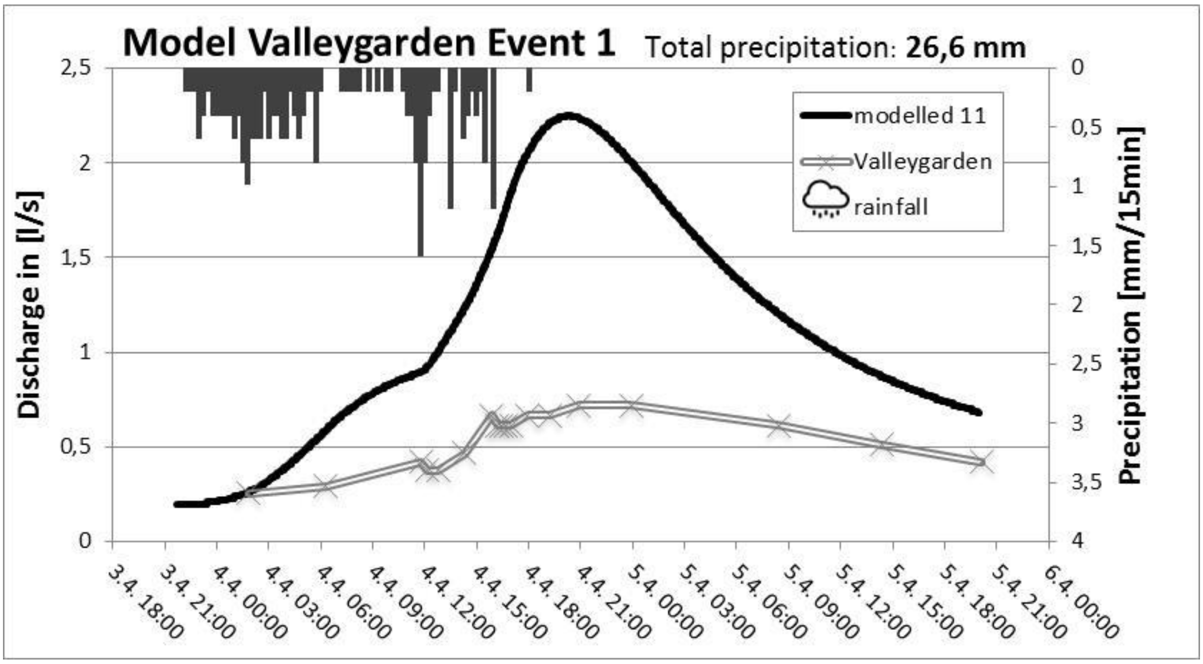



Modelling Event 1
Total precipitation: 26,6 mm
Run 14
Culvert
rainfall
Discharge in [l/s]
Precipitation [mm/15min]
4
3,5
3
2,5
2
1,5
1
0,5
0
3.4. 18:00
3.4. 21:00
4.4. 00:00
4.4. 03:00
4.4. 06:00
4.4. 09:00
4.4. 12:00
4.4. 15:00
4.4. 18:00
4.4. 21:00
5.4. 00:00
5.4. 03:00
5.4. 06:00
5.4. 09:00
5.4. 12:00
5.4. 15:00
5.4. 18:00
5.4. 21:00
6.4. 00:00

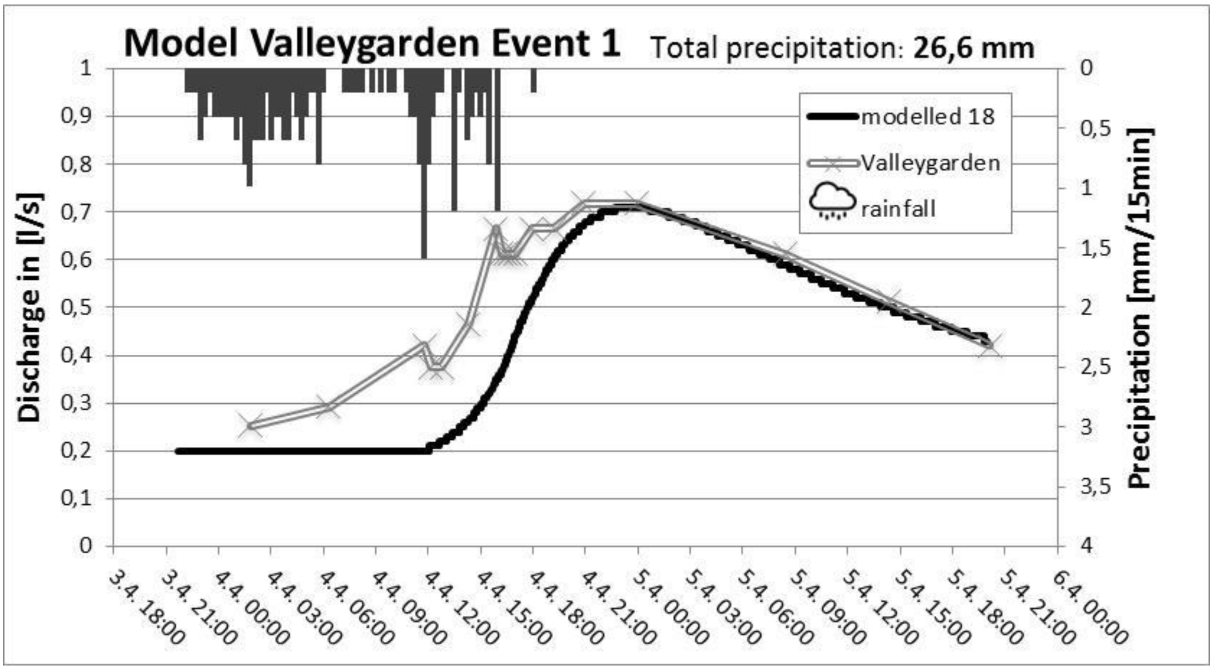

Modelling Event 1
Total precipitation: 26,6 mm
modelled 32
Culvert
rainfall
Discharge in [l/s]
Precipitation [mm/15min]
3,5
3
2,5
2
1,5
1
0,5
0
3.4. 18:00
3.4. 21:00
4.4. 00:00
4.4. 03:00
4.4. 06:00
4.4. 09:00
4.4. 12:00
4.4. 15:00
4.4. 18:00
4.4. 21:00
5.4. 00:00
5.4. 03:00
5.4. 06:00
5.4. 09:00
5.4. 12:00
5.4. 15:00
5.4. 18:00
5.4. 21:00
6.4. 00:00



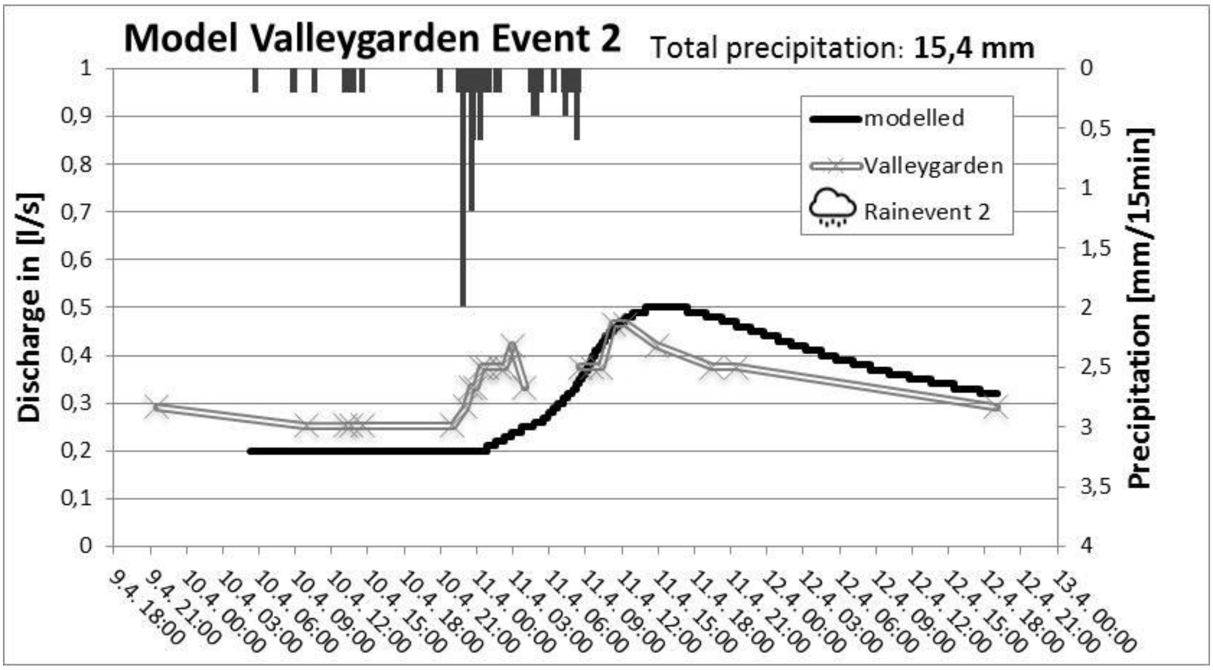
Model Culvert Event 2
Total precipitation: 15,4 mm
Discharge in [l/s]
Precipitation [mm/15min]
modelled
Culvert
Rainevent 2
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
0,5
1,5
2,5
3
3,5
4
9.4. 18:00
9.4. 21:00
10.4. 00:00
10.4. 03:00
10.4. 06:00
10.4. 09:00
10.4. 12:00
10.4. 15:00
10.4. 18:00
10.4. 21:00
11.4. 00:00
11.4. 03:00
11.4. 06:00
11.4. 09:00
11.4. 12:00
11.4. 15:00
11.4. 18:00
11.4. 21:00
12.4. 00:00
12.4. 03:00



Model Valleygarden Event 1
Total precipitation: 26,6 mm
Discharge in [l/s]
Precipitation [mm/15min]
modelled 11
Valleygarden
rainfall
2,5
2
1,5
1
0,5
0
3
3,5
4
3.4. 18:00
3.4. 21:00
4.4. 00:00
4.4. 03:00
4.4. 06:00
4.4. 09:00
4.4. 12:00
4.4. 15:00
4.4. 18:00
4.4. 21:00
5.4. 00:00
5.4. 03:00
5.4. 06:00
5.4. 09:00
5.4. 12:00
5.4. 15:00
5.4. 18:00
5.4. 21:00
6.4. 00:00



Model Valleygarden Event 1
Total precipitation: 26,6 mm
Discharge in [l/s]
Precipitation [mm/15min]
modelled 18
Valleygarden
rainfall



Model Valleygarden Event 2
Total precipitation: 15,4 mm
Discharge in [l/s]
Precipitation [mm/15min]
modelled
Valleygarden
Rainevent 2

EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, dass ich die vorliegende Bachelorarbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

Jakob Kadura

Burgstraße 40

72108 Rottenburg am Neckar

Rottenburg, den 05.Oktober 2016

....

(Jakob Kadura)