Moving down or not?

PHASE II: Dheye

Water supply related technical support for the
necessary resettlement of Dheye village in Thangchung

February 2014

KAM FOR SUD

The second phase of the project "Moving down or not?" was undertaken by

Kam For Sud (KFS)

Swiss NGO working for a sustainable development in Nepal since 1998, www.kamforsud.org

comprises the report at hand, as well as a second report concerning Yara, was written by Daniel Bernet, Marco Baumer, Fidel Devkota and revised by Silvia Lafranchi Pittet who are briefly introduced hereafter:

Daniel Bernet: Technical advisor at Kam For Sud with a Master's degree in Environmental Engineering from the Swiss Federal Institute of Technology in Zurich, Switzerland (ETHZ); Sound working experience in Nepal and India;

- In-field project coordination, hydrology and hydraulic related aspects, editing the report.

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- Responsible for all geology and hydro-geology related issues.

Fidel Devkota: Visual Anthropologist and postgraduate at the Freie University Berlin, Germany; Scientific advisor of the French association Du Bessin Au Nepal; Many years of first-hand practical field work experience in Dheye;

- Responsible for all social and cultural aspects of the project.

Silvia Lafranchi Pittet: Founder and projects coordinator of Kam For Sud with a Master's degree in Environmental Sciences from the Swiss Institute of Technology in Zurich, Switzerland (ETHZ); Extensive working experience in Nepal;

- Overall coordination of the projects, review and revision of the report.

Imprint:

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Summary

The first phase of the project "Moving down or not?", initiated by Kam For Sud, elaborated the best adaptation strategy for the three heavily water-stressed villages Dheye, Samzong and Yara, all located in Upper Mustang, Nepal. The study highlighted several technical key questions, which had to be left unanswered within the limited scope of the project's first phase, posing major obstacles for the communities to proceed with the implementation of the recommended strategies. For that matter, Kam For Sud undertook the project's second phase, aimed at providing the missing technical expertise, concluding in two self-standing reports: one about Yara and one, the report at hand, concerning Dheye. The initially planned technical investigations regarding Samzong's relocation had to be abandoned, as the reconstruction of the village, locally supported by the Lo Mustang Foundation, was suddenly initiated at a location exposed to hydro-geological risks, unlike the one assessed in the project's first phase. Therefore, the field work had to be focused on raising awareness about the associated hazards. As of January 2014, this effort has proven to be fruitful, as the new village is going to be reconstructed at the initially identified, safe location.

Concerning Dheye, the project's first phase highlighted that above all, water for irrigating the fields, a crucial precondition for the resettlement, cannot be supplied by traditional means, which constitutes the main obstacle for the villagers to initiate the resettlement. For that matter, suitable solutions securing the provision of irrigation and drinking water in Thangchung were investigated by an interdisciplinary team in the fall of 2013.

From all investigated options, a relatively short pressure pipeline operated by gravity flow and fed by the current water abstraction, tapping the Dhey Chang Khola, was found to be the best solution to supply irrigation water to Thangchung. The only disadvantage is that the water merely reaches the lowest levels of the relocation site. However, this is acceptable, as this section is recommended to be used exclusively for agriculture, anyway. On the other hand, this option has the striking advantage not to rely on a dam, which is found not to be a suitable measure in the first place. The proposed High-Density Polyethylene pipeline, intended to convey the design flow of 44 l/s, is proposed to be buried underground and routed along the access path at the northwestern corner of Thangchung. To prevent erosion damage by the irrigation water, a drain along the lowest level of the plain, collecting the surplus water and conveying it securely back to the Kali Gandaki, is recommended. An independent drinking water supply system is proposed. The required water demand of 13 m^3/d including losses, is suggested to be lifted up to the highest levels of Thangchung by a solar pumping system comprised by a single pump powered by a 1'200 W Photovoltaic panel array. Groundwater, spring or if necessary even river water may be tapped for that matter, depending on further necessary yield and quality assessments, yet to be carried out.

In conclusion, the best solution for providing the required amount of water to Thangchung was identified. The report at hand should be the basis, on which the water supply scheme is elaborated on implementation level in the next step.

Spellings

Many different spellings of places, water bodies and names can be found in Upper Mustang. This is mainly due to the fact, that many names were translated from the local languages into Nepali and/or English. In the report at hand the spellings from the documentation of the project's first phase are adopted and are consistently used hereafter. This section lists other common spellings.

Dheye	Dhe, Dhey, Dhye, Dewa
Dhee	Dhi, Dri
Chawale	Tsambale
Charang	Chrang, Tsarang
Samzong	Sam Dzong, Samdzong
Tangge	Tange
Tsusang	Chuksang, Chhusang

Glossary

Aquifer	Part of geological strata below the ground suitable to hold and route water
Arak	Locally distilled alcohol, also called raksi
Bhote Pipal	Himalayan Poplar tree
Chang	Locally brewed beer, mostly using barley or oat; also called Arak
Crop evapotranspiration	Evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al. 1998)
Evapotranspiration	Water loss by evaporation from the soil surface and by transpiration of the crop (Allen et al. 1998)
Hydraulic conductivity	Describes the capability of water to pass through the soil measured in m/s and usually denoted by the letter k
Leh	Simple animal enclosure used to protect the animals during the night when they are let to graze in the area; Leh is also the name of a city in Ladakh, India
Magpa	Common practice in Upper Mustang when the husband moves to his wife's house instead of vice versa, often due to the fact that the wife's parents did not have any sons
Phorang-morang	According to Ramble (2007) usually landless people, earning their income by working for others, or by leasing fields from the village or from estates
Raksi	Locally distilled alcohol, also called arak

Abbreviations and acronyms

ACAP	Annapurna Conservation Area Project
asl	Above sea level
AU$	Australian dollar
CSRS	Canadian Spatial Reference System
CWR	Crop Water Requirement
DDC	District Development Committee
EEPROM	Flash Electrically Erasable Programmable Read-Only Memory
EGM08SEA	Earth Geoid Model 2008 of South Eastern Asia
ET	Evapotranspiration
ETc	Crop Evapotranspiration
FAI	Fondation Assistance Internationale
FAO	Food and Agriculture Organization of the United Nations
GLOF	Glacier Lake Outburst Flood
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDPE	High-Density Polyethylene
ILO	International Labor Office
KFS	Kam For Sud
LMF	Lo Mustang Foundation
LSTB	Long Span Trail Bridge
MFSC	Ministry of Forests and Soil Conservation
MOSTE	Ministry of Science, Technology and Environment
MS	Mild Steel
NGO	Non-Governmental Organization
NPO	Non-Profit Organization
NPR	Nepalese Rupees
OD	Outer Diameter
PPP	Precise Point Positioning
SSTB	Short Span Trail Bridge

SUPSI	University of Applied Science of Southern Switzerland
USB	Universal Serial Bus
US$	US Dollar
VDC	Village Development Committee
VRS	Virtual Reference Station

Acknowledgments

One of Kam For Sud's main principles concerning all undertaken projects is to achieve a sustainable impact. Consequently, it was clear that Kam For Sud would try to continue the support for the three heavily water-stressed villages in Upper Mustang, after the conclusion of the project's first phase. Despite realistic hopes for a further funding, the donor decided to withdraw, not willing to fund the proposed second phase aiming at providing crucial technical support for the villages. Therefore, different other possibilities to fund the project were elaborated.

Kam For Sud is very grateful that after all, the project could be financed with a few very generous donations, namely from Bruno Häfliger, Laura Aboli and the Jacob foundation. Furthermore, Marco Baumer, part of the expert team, offered to contribute his expertise as a volunteer. Moreover, Fidel Devkota, who is concluding his PhD, agreed – on virtually shortest possible notice – to complete the expert team as a volunteer, as well. Kam For Sud would like to express its gratitude for these contributions, without which the project could not have been realized.

Preface

To have a better understanding of the topography, especially height differences, which are crucial for all water supply options, different methods were applied to quantify the desired variables. However, as explained in detail in Appendix A.1 and A.2, the measurements are associated with high uncertainty. Moreover, the conversion of the heights to absolute elevations turned out to be ambiguous. To prevent possible misinterpretations, only relative heights, always in relations to the northern end of the first level in Thangchung (GPS point G3: 29°04'08.5247"N / 83°56'42.8990"E), are used in this report.

In order to lead the reader comprehensibly through the report at hand, it is structured as follows: First, the goals and objectives of the project's second phase are presented (Chapter 1). To embed the project in the given context, background information is provided in Chapter 2. Thereafter, the water demand, crucial for the dimensioning of water supply systems, is elaborated in Chapter 3. Chapter 4 discusses all irrigation and Chapter 5 all drinking water supply options. The best solutions are then presented in more detail in Chapter 6. A short outlook is finally provided in Chapter 7.

1 Introduction

It is hard to believe that "(…) until around the sixteenth century, most of Lo/Mustang had an abundance of water from the surrounding snow-covered mountains, diverse vegetation, and dense forest from which Lo-pa people built monumental structures, (…)" (Dhungel 2002) when trekking through Upper Mustang nowadays. In fact, hydrological conditions have been changing severely (Bernet et al. 2012a). In the course, numerous settlements in Upper Mustang, the northern part of the Mustang District in Nepal, which consists of a north-south oriented valley opening up to the Himalayan plateau in the north (Figure 1.1), have been subjected to heavy water stress in addition to several other issues such as geological risks, overall weakening the livelihoods of the concerned communities.

Figure 1.1: Map of Nepal, bordering China in the north and India in the east, south and west. The red ellipse highlights the location of Mustang District. North direction is ↑, the map was taken from (Zurick et al. 2006).

In order to understand the drivers and consequences of these processes, as well as to come up with an appropriate adaptation strategy for the three particularly affected villages Samzong, Yara and Dheye an applied study financed by the Fondation Assistance Internationale (FAI) was undertaken in 2012 by the NGO Kam For Sud (KFS) jointly with the University of Applied Science of Southern Switzerland (SUPSI) in collaboration with the local NPO Lo Mustang Foundation (LMF). The outcome[1] of the holistic study, hereafter referred to as Phase I,

[1] The study's results are presented in four reports including a synthesis report in addition to one report for each village (Bernet et al. 2012a). Note that the report at hand builds up on this study. Please refer to these reports for background information and for that matter either to the synthesis report (Part I) or the report concerning Dheye (Part IV). They can be downloaded from Kam For Sud's website (www.kamforsud.org).

was the recommendation of a specific adaptation strategy for each village. For two out of the three studied villages a resettlement of the whole village was proposed.

Within the limited scope of Phase I the suggested adaptation strategies could not be elaborated in a way to investigate and resolve all issues in detail. In particular, some technical key questions had to be left open which pose a major obstacle for the communities to proceed with the implementation of the recommended measures. Since the current conditions are pushing the communities to take immediate action, suboptimal decisions could be made.

Therefore, KFS initiated the second phase of the project “Moving down or not?”, hereafter referred to as Phase II, and assembled an interdisciplinary expert team once more to provide missing technical expertise in order to advance the successful adaptation process. The project’s written output includes two self-standing reports: one about Yara and one, the report at hand, concerning Dheye.

The initially planned technical investigations concerning Samzong’s relocation had to be abandoned, as shortly before the field work started, it became apparent that the reconstruction of the village, supported by the Lo Mustang Foundation (LMF), the local partner of the project’s first phase, was initiated at a different location than the one assessed in Phase I. As this location is an unsuitable place for the future village, mainly because it is exposed to hydro-geological risks, KFS’s field work had to be focused on raising awareness about the associated hazards of the changed resettlement plan. This effort has proven to be fruitful, as the new village is going to be rebuilt at the safe location investigated in Phase I, as of January 2014.

1.1 Objectives

The main goal of Phase II concerning Dheye is to elaborate and report the solutions of specific technical problems in order to promote the successful resettlement of the villagers at the relocation site called Thangchung. The key issues investigated within the scope of this project can be summarized as follows:

- Compare different options for supplying irrigation and drinking water to the relocation site, identify the optimal solutions, elaborate and report them in more detail thereafter.

1.2 Resources

The report at hand is based on the following resources:

- Study “Moving down or not?” (Bernet et al. 2012a)
- Field work of Daniel Bernet, Marco Baumer and Fidel Devkota, accompanied by Tsering Gurung in the fall 2013
- Satellite imagery provided by Google Earth Pro
- Literature (cited separately; see Bibliography in Chapter 8)

2 Background

The following sections provide relevant background information concerning different aspects of the resettlement of Dheye in Thangchung.

2.1 Demographic and cultural aspects

According to Devkota (2013) Dheye used to consist of 24 households, whereof ten dislocated within the past two decades to Charang (3), Tsusang (1), Muktinath (1), Jomsom (1), Pokhara (2), Kathmandu (1) and India (1) respectively. The population in 2013, including the displaced families, amounted to 158 (Table 10.4 in Appendix B.1).

All but one family (Tashi Phuntosk Gurung's family living in Charang; Table 10.4 in Appendix B.1) intend to move their families to Thangchung. The displaced families are a vital part of the whole resettlement project as they are engaging themselves both financially and organizationally in the whole process.

In addition, the family of Karchung Gurung[2], who comes from Dheye but lives with her husband and two children in Pokhara, would like to rejoin the community in Thangchung.

Another special case is the family of Karma Gurung (Table 10.4 in Appendix B.1), who did not own any land in the village before 2012. They were living a nomadic life, which can be characterized as phorang-morang denoting people, who are "(…) usually landless, and make their income by working for others, or by leasing fields from the village or from estates (…)" (Ramble 2007, 127). In 2012 Karma acquired some land in Dheye. The new state of a landowner is also associated with certain obligations. Now, his family, like all other landowners, has to provide a worker for helping other landowners during sowing and harvest or for labor in the new orchard for instance. If Karma and his family cannot fulfill their duty, they have to pay a fine of about NPR 500.00 which equals roughly US$ 5.00 and corresponds to an average daily wage for unskilled labor. In this way, some of the families living in the cities are contributing quite a high amount of money to the community.

For the elaboration of the resettlement plan, it is important to know how many houses the new settlement has to accommodate. Counting all families still living in Dheye as well as the displaced households willing to rejoin the community, the total number of households amounts to 24 and 150 people, respectively (Table 10.4 in Appendix B.1).

[2] Karchung Gurung's family is magpa denoting the particular tradition when the husband moves to his wife's house instead of vice versa. In Upper Mustang this is often practiced in case a family has no male children. In Karchung Gurung's case the reason are different though, as she has brothers, whereof one went to Tangge in Upper Mustang as a magpa himself.

2.2 Political and intercommunal aspects

Nepal is going through a process of massive political transformations. Currently, the government and major political parties are focused on the new constitution. The second election of the constitutional assembly was held in November 2013. However, elections for the local bodies, namely the District and Village Development Committees (DDC and VDC), as well as the municipalities, have not been held for more than a decade. The last local election took place in 1997 and the respective term expired in 2001/02. In the absence of elected representatives, civil servants have been running these offices ever since. This state of affairs is the reason for a lack of participation by the locals in planning processes and governance.

2.2.1 Land property issues

To have legal ground for the resettlement of Dheye village in Thangchung, the land at the new location has to be privatized. Although there are no legal papers to prove it, Thangchung is commonly considered to be Dheye's communal land because of the following reasons:

- According to the Convention 169 of the International Labor Office (ILO), of which Nepal is a member since 1966, the plain of Thangchung belongs to the people of Dheye, because it has been used by the community for generations.
- Local Self-governance Act 2055 (corresponding to the year 1999 AD) addressing the rights of locals.

However, several issues, listed below, are complicating the question of land property:

- Dheye lies in Upper Mustang, which is part of the Annapurna Conservation Area Project (ACAP). Hence, the traditional rules settling land property issues are more complicated and are sometimes overruled.
- Normally, land that is not owned by an individual or an institution with official land right papers belongs to the Government. As there are no legal papers stating that Thangchung belongs to the community of Dheye, basically the Nepalese Government is the official landowner and for that matter the Ministry of Science, Technology and Environment (MOSTE), as well as the Ministry of Forests and Soil Conservation (MFSC) are concerned.
- According to Nepalese Law there cannot be an exclusive ruling just for Dheye. There are uncountable issues similar to the case of Dheye concerning public/governmental land property conflicts. A special ruling for Dheye could be precedent-setting. Thus, a general ruling from the Government cannot be expected. However, the cabinet could make an exclusive decision for Dheye, but this requires strong lobbying and a lot of political support.

Currently, there seem to be two different strategies to cope with the unresolved land property issues related to the resettlement of Dheye's people in Thangchung:

- One simple solution is that the villagers keep on doing what they are doing. The local level politicians, civil servants and community leaders exhibit a positive attitude towards the resettlement of Dhey in Thangchung. The support from the local Government in the form of small funds is highlighting this fact. In the meantime, the ongoing endeavor to get the official approval of the Government should be continued.

- The other strategy is to perform a land exchange. The villagers could give up their land ownership papers in Dheye and get the same amount of land in Thangchung in return. However, Thangchung should accommodate the ten families currently living elsewhere with no land ownership in Dheye in addition to the 14 families properly owning land. This would require an accepted procedure to divide the land amongst all the 24 families planning to move to Thangchung.

2.2.2 Intercommunal conflicts with Charang

In Upper Mustang, it is common that neighboring villages have disputes over pasturelands. Charang and Dheye are no exception.

Counting roughly eighty households, Charang is one of the biggest villages of Upper Mustang and has always played an important part in the history of Lo. In contrast, Dheye has always been a small isolated village.

Charang with its many animals has a high demand for extra pastureland. Consequently, Thangchung's valuable pasture land, located close to Charang, was fancied by the latter's inhabitants. Political games evolved, where Charang exploited its power and influence to acquire the rights to use Thangchung as additional pasture land. The conflict culminated in a confrontation in Thangchung, where the heavily outnumbered men from Dheye were about to meet Charang's armed men for a fight to death, as the latter were apparently intending to raid the remote village of Dheye to settle the matter once and for all. Only through a mysterious incident scaring the people of Charang away did the confrontation end without bloodshed.

In a long tug-of-war, a deal was finally made that the people of Charang can collect the animal droppings from the plain adjacent to Thangchung named Nakthi, where Dheye's villagers let their animals graze for several months each year. As traditionally a river or a mountain cuts the border between villages, Charang, being separated from Thangchung by the Kali Gandaki, never had the rights to claim the plain of Thangchung. The fact that even today Charang's people can collect the animal droppings yearly amounting to six to seven tractor loads of manure, exemplifies the power and influence of Charang.

Even though three migrated families from Dheye are living in Charang nowadays (Tashi Phuntsok, Chetup Gurung and Norbu Wangchuk, see Table 10.4 in Appendix B.1), the relationship between Charang and Dheye keeps being difficult. This is highlighted by the fact that the villagers from Dheye are still not very comfortable with visiting Charang.

In the near future this old conflict between Charang and Dheye could escalate again, especially in the light of increasing demand for manure due to Dheye's new plantation in Chawale (Section 2.3).

2.3 Characterization of the relocation site

The people of Dheye decided to move to Thangchung, a vast plain overlooking the confluence of the Dhey Chang Khola and Charang Khola with the Kali Gandaki, due to the worsening living conditions at the present location. The decision is supported by the results of Phase I (Bernet et al. 2012a). In the following sections the already completed steps towards relocation and the relocation site itself are characterized.

2.3.1 Completed steps toward relocation

Since 2009, when the villagers decided to take the initiative against the water crisis, the people of Dheye started to invest a lot of effort, labor and money in the cultivation of a tree plantation. It is located in Chawale, a plain constituting the left riverbank of the Dhey Chang Khola upstream of the junction with the Kali Gandaki. Up to now, roughly six thousand apple trees and hundreds of Himalayan Poplar trees, called Bhote Pipal, were planted (Figure 2.1). The plantation also includes pine, walnut, peach and other local trees.

Figure 2.1: A vast area in Chawale was fenced with a rock wall. Within the delineated area, small pits were excavated with the community-owned dozer. Soil, mostly taken from the elevated plain of Thangchung, was added and the trees were planted and cultivated. In 2013 the first apple matured (photo: 19/09/2013, Daniel Bernet).

The villagers plan to sell the apples or products thereof, such as ciders, juice, vinegar, brandy etc., which will help to finance the resettlement. The Bhote Pipal trees are used in construction and could therefore help to meet the large demand for sparse and expensive resource timber needed for the new houses in Thangchung. Furthermore, the villagers envisage preparing Raksi, a locally distilled alcohol, from the orchard's fruits, which is already successfully practiced in other villages like Marpha and Tukuche, both located in lower Mustang. In Mustangi culture, alcohol is very important, as it is used in almost every ritual. Presently, a local beer called Chang or Arak is brewed from barley and oat. A considerable part of the harvest is thus not processed into food. Substituting grains with apples for the alcohol production would elongate the self-sufficiency period related to staple food.

Currently, the plantation includes three different sections. The first section is finished, in the second and third one most of the pits are excavated. A wall protecting the third section still has to be built (Figure 2.2). The third section will be divided into 24 individual plots later, whereof one will be allocated to each family by lottery.

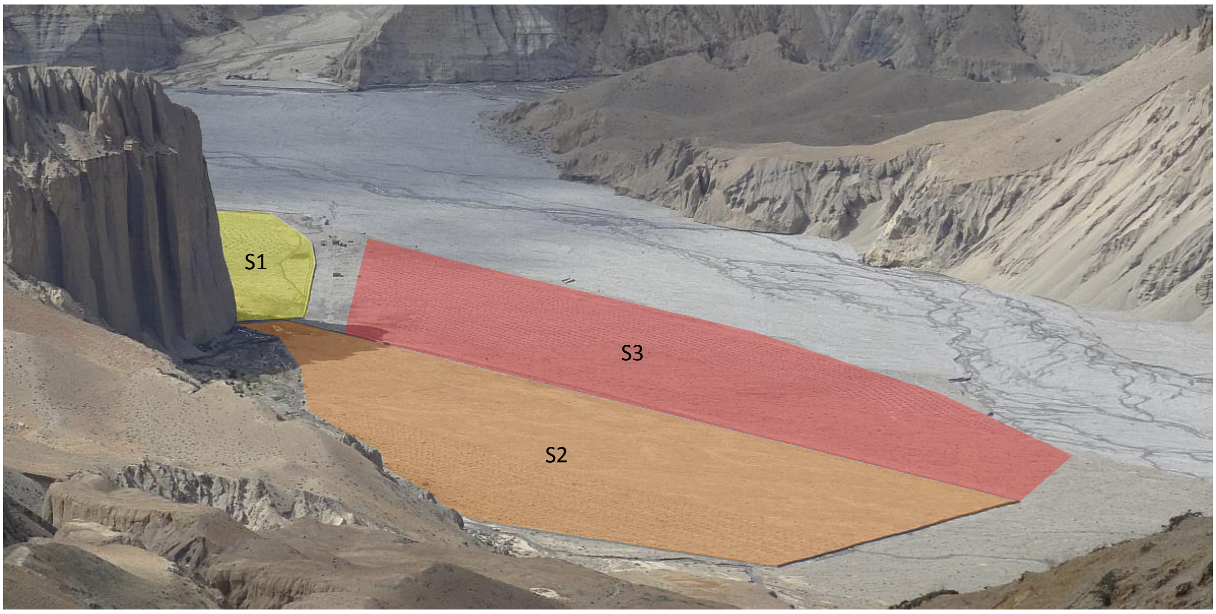

Figure 2.2: The first section of the plantation is finished, of which the northeastern end can be seen (S1, yellow). The wall around the second section (S2, orange area) is completed and most of the pits for the trees are excavated. The wall around the third section (S3, red area) is not built yet, but most of the pits are prepared already. Within the uncolored corridor between S1 and S3 some houses were constructed. In the same corridor, plots for temporary housing of each family during the resettlement process were delineated and marked (photo: 23/09/2013, Daniel Bernet).

There are a couple of small houses in Chawale and a few more under construction (Figure 2.2). A small house was constructed for the caretakers of the orchard. Recently, Topri Gurung and Kunga Angmo were elected by the community to take care of the orchard for the five years. For that matter, Topri's family has moved out of Dheye in 2013. A house with two rooms within the first section of the plantation serves as a sleeping and cooking place, when villagers gather for the work in the plantation. A storeroom harbors communal goods and spare parts for the community-owned dozer. Pema Chewang rented another room, which is planned to be turned into an office later. His own temporary house is almost completed. Other villagers are planning to construct their temporary accommodation in 2014. It is estimated that such a dwelling costs roughly US$ 1'000.00 per house. It will serve as a home until the villagers can move permanently to their new houses at the relocation site. The materials of these temporary dwellings can be reused.

In 2013, a club comprising almost all the young people from Dheye, initiated and financed the construction of a club house located at the eastern end of Chawale, along a popular trekking route connecting Yara and Tangge (e.g. Figure 4.2 in Section 4.1.1). After completion, the house was auctioned. Tsering Largey, who had migrated to Pokhara, could win the auction. He committed himself to pay annually NPR 70’000.00, roughly equaling US$ 700.00, for the next five years. Right next to the club-owned house Dorje Chopten runs a tent hotel.

2.3.2 Topography and area availability

An important characteristic of the relocation site is the area availability, which has to be in accordance with the area requirement of the community of Dheye. In the following paragraphs, the area of Chawale and Thangchung (Figure 2.3) are characterized.

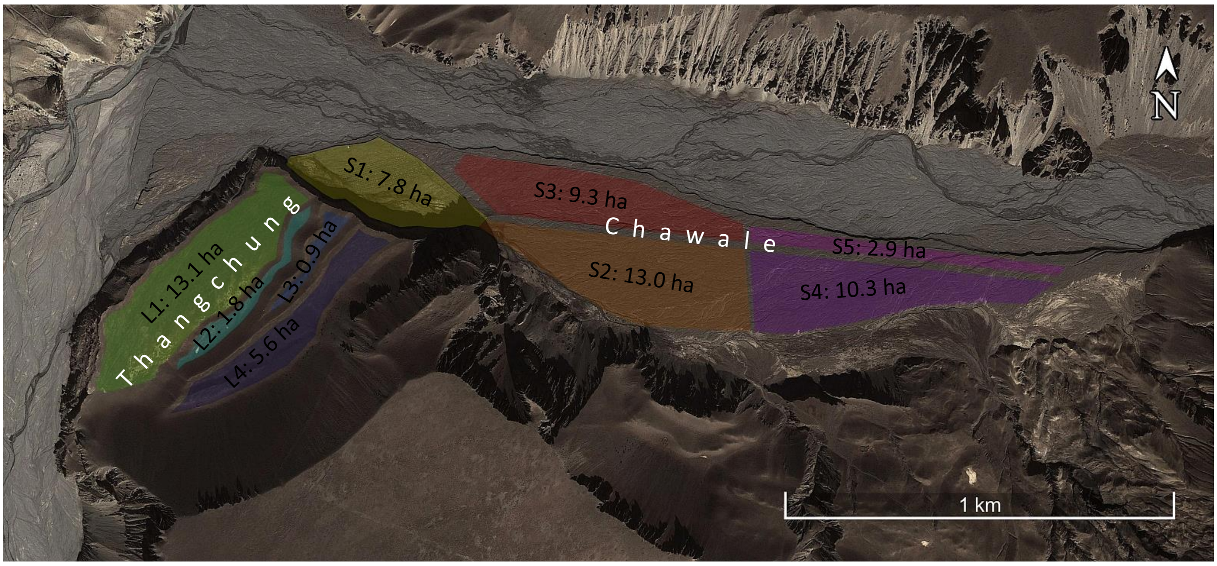

Figure 2.3: Bird’s eye view of the usable area in Chawale and Thangchung. In Chawale, the first section of the plantation is finished (S1, yellow). The second (S2, orange) and the third section (S3, red) are being prepared for cultivation. The fourth (S4, violet) and the fifth section (S5, pink) have not been subjected to any constructional work so far. Thangchung comprises four different levels ranging from the lowest and largest one (L1, green) over two intermediate ones (L2, bright blue and L3, blue) to the highest one (L4, dark blue). Note that effective areas were considered respecting safety distance to scarps and steep slopes (source: Google Earth Pro, accessed 15/01/2014).

Chawale

As described before in Section 2.3.1 and Figure 2.3, different parts of Chawale are already used or at least allocated for the plantation.

Thangchung

In Phase I, Thangchung was analyzed with regards to the area at disposal. In Phase II, the analysis was refined by assessing the usable area. Namely, steep slopes as well as safety distance to the scarp are excluded from the gross area availability.

Simplified, Thangchung is composed by four different levels, while each step is rather flat, but slightly sloped towards southwest. Figure 2.4 indicates the usable area of each level, as well as the approximated relative elevation using the first level (L1) as a reference. The access path leading from the western end of the orchard to L1 covers a height difference of roughly 30 m.

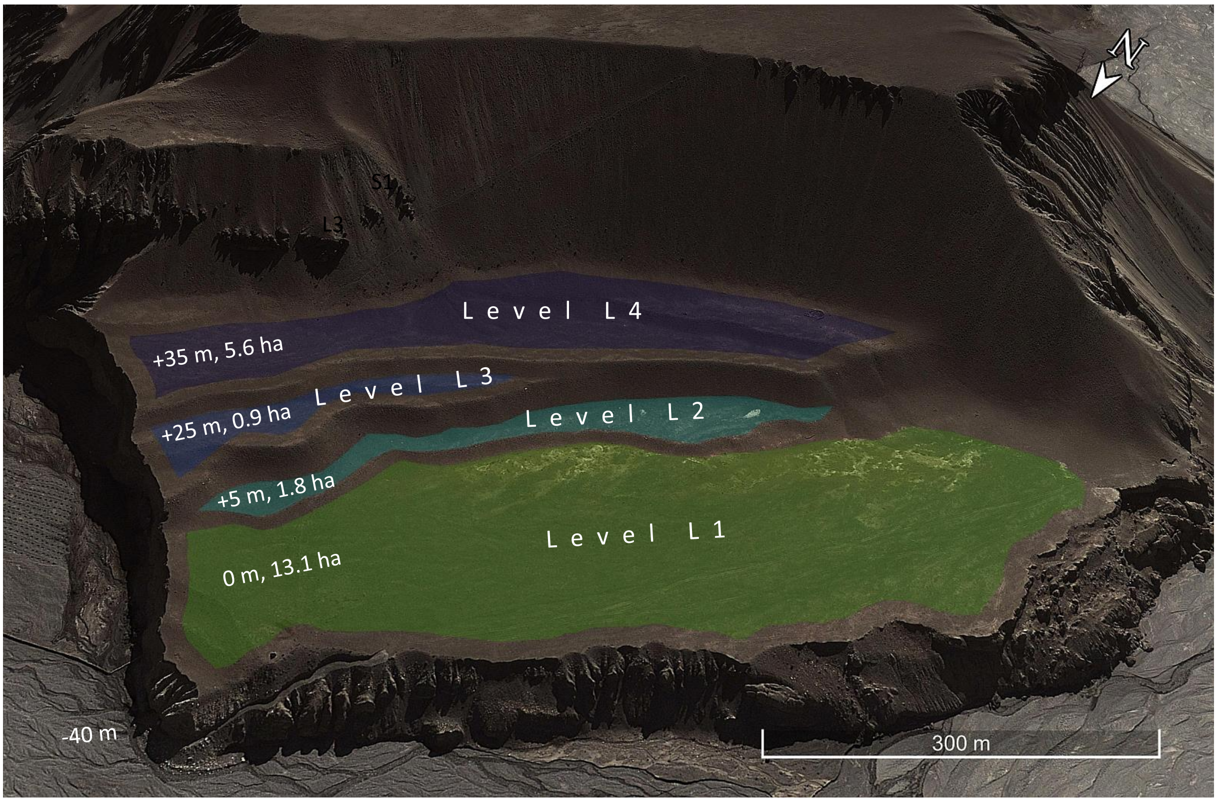

Figure 2.4: Overview of the four-stepped plain of Thangchung. The indicated usable area of each level was estimated in the field and assessed later with Google Earth Pro (accessed 15/01/2014). The relative height was assessed with GPS as explained in detail in Appendix A.2 (source: Google Earth Pro, accessed 19/01/2014).

2.3.3 Partitioning of Thangchung

Doubtless, the first level is predestined to be used as field area. It is the largest level, is very flat, but still slightly sloped towards southwest (approximately 3 %). Readying the land for cultivation does not require a lot of soil works and the fields can be irrigated by routing the water to all the fields by gravity flow.

According to the villagers, supported by the written resettlement proposal elaborated by the villagers (Gurung 2011), the households and the fields are planned to be located on Thangchung's first level. Apparently, this proposal roots in the fact that the sun rises earliest on this level, which was confirmed by simple measurements (Appendix A.8). On average, the sun rises almost one hour later at the second level compared to the first one.

Compared to the cultivated area at the current location (10.39 ha), the area of the first level is 26 % larger (13.1 ha). However, the field area in Dheye is divided amongst 14 families, whereas in Thangchung it will be divided by a total of 24 families. Consequently, the field area per family is decreasing. Constructing the village on the first level is in direct competition with the limited area most suitable for agriculture and will decrease each family's share of field area even more. Thus, it is very important to partition and use the available area in Thangchung as efficiently as possible.

As elaborated in the next chapters, the best solution to supply irrigation water to Thangchung is by a pressure pipeline, which cannot provide water higher than to the second level. Consequently, it makes sense to dedicate the whole first level solely to agriculture, and to build the village on the second level instead. This would also have the desirable side-effect that the houses could be built against the slope uphill, in order to protect the dwellings more naturally against the strong valley winds. Therefore, the houses are suggested to be located on the second level, even if it comes at the expense of a belated sunrise.

2.3.4 Accessibility

In the monsoon season, when the larger rivers in Upper Mustang carry a lot of surface water, they are difficult if not impossible to cross without a bridge (Bernet et al. 2012b). Currently there is no bridge in the vicinity of Thangchung making a crossing of the Kali Gandaki possible throughout the year. Only when the rivers are low enough to be crossed by foot, Charang can be reached easily. In the other case, it is necessary to cross the Dhey Chang Khola by foot (if possible), then to go further up to Dhee, where an all-season pedestrian bridge crossing the Kali Gandaki is in place. Using this detour, going to Charang takes a day's walk. A bridge would therefore make Thangchung more accessible during the year.

Pedestrian bridges have a long tradition in Nepal, where several thousand bridges have been realized until today[3]. Such bridges are categorized into two main types. The Short Span Trail Bridge (SSTB) measuring less than 120 m and the Long Span Trail Bridge (LSTB) with a span exceeding 120 m. The latter is considerably more expensive than the former. The longest bridge built in Nepal is 350 m long (Tuladhar 2007). In Upper Mustang several such bridges can be found (e.g. south of Kagbeni, Tsusang, and Ghyakar). The span of these exemplary bridges ranges between 100 and 150 m.

To possibly make Thangchung accessible throughout the year, a coarse assessment of a suitable place for a bridge has been carried out. However, the examination on site as well as the survey using Google Earth did not reveal an obvious location for a pedestrian bridge. South of Thangchung is a place, where the Kali Gandaki is only 110 m wide. However, the slopes on both sides are very steep and unstable. Moreover, the access to the bridge heads would be very difficult to realize as both sides of the riverbank are constituted of steep, unstable cliffs.

North of Thangchung, the Kali Gandaki is measuring roughly 190 m at its narrowest place. As the bridge head would have to be located further up on solid ground, the bridge would need to be at least 250 m long, considerably longer than the other bridges seen in Upper Mus-

[3] For information see http://www.nepaltrailbridges.org, accessed 11/12/2013

tang. Furthermore, the right riverbank of the Kali Gandaki at this spot is close to vertical making the construction of the bridge head as well as the access path very difficult, if not impossible in the given context. Moreover, to reach the bridge head on the left riverbank of the Kali Gandaki, the Dhey Chang Khola would still have to be crossed by foot.

Most conveniently, the bridge would span from Thangchung to the other side of the valley crossing the Kali Gandaki. Unfortunately, the riverbed below Thangchung is very wide, so that a bridge would have to be at least 500 m long, longer than the longest realized trail bridge in Nepal (Tuladhar 2007). Though technically even this span can likely be crossed by means of a trail bridge, the question is rather whether the financial investment can be justified. Assuming an effective length of 550 m and a rate of 350.00 $/m (Tuladhar 2007), the total cost of the bridge would amount to $ 192’500.00

3 Water demand

Before talking about water supply, it is important to have an idea about the desired water demand. However, the assessment of the actual water demand is not a simple task, mainly because the demand relies on many different factors. For instance, the irrigation water demand depends on the cultivated crops, the way these crops are managed, climatic factors such as temperature, wind and precipitation and last but not least on the characteristics of the soil. There are virtually no data available, so that coarse estimations have to suffice.

3.1 Irrigation water demand

The relevant parameter, which has to be determined, is the necessary irrigation intensity expressed as an irrigation depth per agricultural area (mm/d). Multiplying the intensity with the maximal area used for agricultural activities results in the required water volume per day.

In this context, using the concept of evapotranspiration (ET) is helpful. It is defined as the water loss by evaporation from the soil surface and by transpiration of the crop (Allen et al. 1998). If the water loss from the agricultural field due to ET is compensated by irrigation, the crop should yield its full potential under the prevalent climatic conditions.

For that matter, the crop evapotranspiration (ETc), defined as "(…) evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions" (Allen et al. 1998), was estimated. Since there are no reliable rainfall data in Upper Mustang and the precipitation rates are extremely low (Bernet et al. 2012b), precipitation is not considered. Otherwise, the crop water requirement would be lowered by the effective rainfall, but in this case it corresponds to the ETc.

At least mean monthly minimum and maximum temperatures are needed for the calculation of the ET. As there are no temperature records available in the area, Giovanni Kappenberger, experienced meteorologist and climatologist, made an educated guess based on data from Mustang, Lobuche (Nepal) and Leh (India). These temperature values were then fed into the FAO's CROPWAT 8.0[4]. Furthermore, the wind speeds were set to the maximum value (9.9 m/s) as Upper Mustang is subject to extreme wind conditions (Bernet et al. 2012b; Zängl, Egger, and Wirth 2001). Moreover, the relative humidity was adjusted to reflect the harsh, dry climate of Upper Mustang. Using the standard crop factors for barley and oat, adapting them slightly to match local harvest practices, the monthly crop water requirement could be calculated.

[4] CROPWAT 8.0 can be downloaded from http://www.fao.org/nr/water/infores_databases_cropwat.html, accessed on 13/12/2013.

The irrigation system has to be able to provide sufficient water at all times. Therefore, only the maximal water requirement is relevant for the system design. Based on these considerations, the maximal crop water requirement equals 7.3 mm/d (see Appendix B.2 for details).

This value can be compared to the potential irrigation intensity, which was estimated during Phase I, documented in Bernet et al. (2012b). The amount of water which could potentially be used in the fields was estimated by measuring the water abstracted from the river and dividing it by the cultivated field area. The value amounted to 4.3 mm/d, while the effective irrigation intensity was certainly lower, as the losses associated with the quite permeable open distribution channels were not taken into account in this estimation. Nevertheless, the villagers stated that under such circumstances all the fields under cultivation could just be sufficiently irrigated. Therefore this value can be considered as a lower boundary.

It has to be clear however that the value measured in Dheye is likely not representing the water demand in Thangchung, which is subject to a different climatic setting. For instance the temperatures are higher due to the lower altitude and the area is more exposed to wind. Both factors are increasing ET, thus also increasing the irrigation demand.

In spite of the fact that the estimated crop water requirement in Thangchung is associated with large uncertainty, it can be considered as an upper boundary. In the light of all these uncertainties, a conservative value is certainly appropriate. Thus, the crop water requirement of 7.3 mm/d is taken as a reference[5]. It considers the different climatic setting of Thangchung and offers additional safety related to unforeseen issues.

Considering the maximal available area of the first level in Thangchung measuring 13.1 ha, the daily required water volume is 957 m^3/d. Note that this volume corresponds to the water requirement at the field level. Thus, for each possible water supply system the inherent losses have to be taken into account on top of that.

3.2 Drinking water demand

Clearly, drinking water demand is not a fixed number, but it is strongly linked to culture and local habits. At first sight it is less obvious however that the drinking water demand is linked to the way the water is distributed (Wegelin 1996). If the water has to be brought to the dwelling from a distant well, the consumption is naturally very low. On the other hand, if a household is equipped with multiple tap connections, the water consumption will be very high. Therefore, it is important to have an idea what kind of installations will be put in place at the relocation site of Dheye, as this is also strongly affecting the water demand.

[5] Note that in the reports of Phase I, the preliminary irrigation demand estimation was adopted from Wacker and Fröhlich (1997). Within the scope of Phase II the estimation was refined. The analysis revealed that the considered values in Wacker and Fröhlich (1997) are very low. However, the reasons for that circumstance remain unclear.

In Dheye, there are several fountains distributed within the village. Consequently, the inhabitants fill their water canisters at the taps and carry the water home. The water demand is therefore very low (Bernet et al. 2012b) and is expected to be in the range of public standpipes as defined in Wegelin (1996) and reproduced in Table 3.1.

Table 3.1: Per capita daily drinking water demand depending on the supply system taken from Wegelin (1996).

Supply with…	Demand range (l/p/d)
… public hand pumps	15 – 25
… public standpipes	20 – 30
… yard connections	40 – 80
… multiple taps in each house	80 – 120

Reconstructing the village in a different place also opens up the possibility to improve the infrastructure in general. Related to drinking water supply, this means that instead of a few taps in the whole village, the plots could be equipped with a connection in the yard or even with a tap in each house.

The upper limit of the demand presented in Table 3.1 is almost as high as the consumption in Switzerland or Germany (Gujer 2006). Thus, the upper limit also includes the consumption of flush toilets, showers etc.

Considering the possibility of a more convenient drinking water distribution, as well as potential for further developments, but still taking the local context and standard of living into account, a maximal drinking water demand of roughly 80 l per person per day seems appropriate.

As the new settlement is designed to house 150 inhabitants, the daily drinking water requirement is 12.0 m^3/d. Comparing this number to the water requirement of the crops, it becomes apparent that in terms of volume, the drinking water demand is marginal, namely 1.3 % of the irrigation water demand.

4 Irrigation water supply options

Different technical options for the irrigation water supply at the relocation site of Dheye were investigated, as elaborated in the following sections. Based on this preliminary assessment, the best suitable option was identified.

4.1 Dam feeding long pressure pipeline

Tapping the Dhey Chang Khola is an obvious option. At Thangchung, the river's drainage area measures 366 km^2 whereof roughly 12 % are glaciated. The glaciers, which reach almost 7'000 m asl, are expected to remain at the very least until the end of the current century presenting a reliable water source (Bernet et al. 2012a). However, the fact that the catchment is glaciated also poses inherent difficulties. Related to the flow rate, the dynamics of the river are huge. In winter the river is partly frozen and carries only little water (Figure 4.1, left). During summer the flow rates are heavily increased due to snow and glacier melt accentuated by storm events (Figure 4.1, right). Furthermore, the river might be subjected to Glacier Lake Outburst Flood (GLOF) at present as well as in the future (Bernet et al. 2012b). Overall, these dynamics in terms of water flow, but also related to transported bedload and suspended particles, have to be taken into consideration when tapping the Dhey Chang Khola.

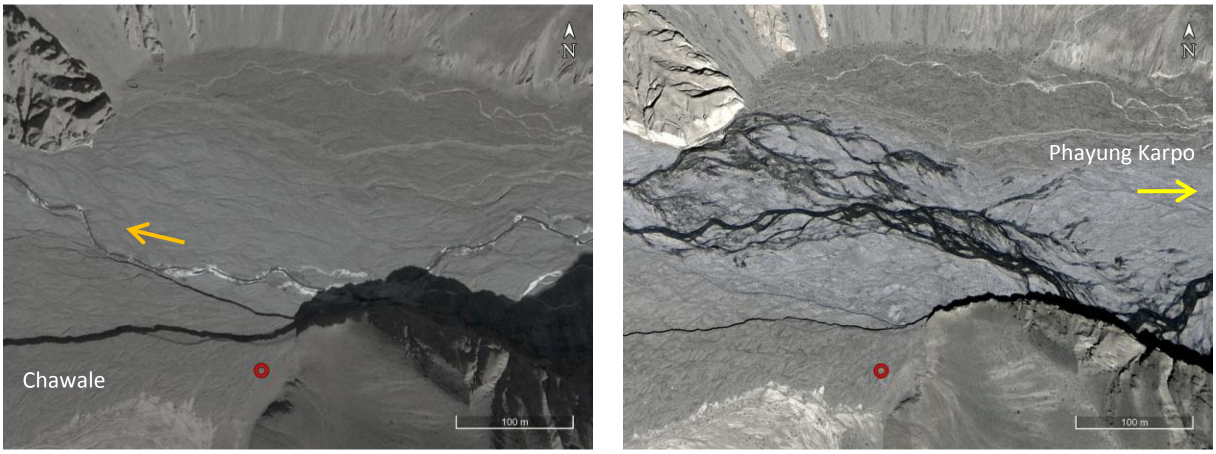

Figure 4.1: Comparison between high and low flow conditions of the Dhey Chang Khola. The red circle indicates the place at the north-eastern end of Chawale, where Dorje Chopten runs a tent hotel. The orange arrow points in the flow direction and the yellow arrow indicates the direction in which Phayung Karpo is situated. ***Left:*** *Low flow conditions in the winter on 13/01/2005 (source: Google Earth Pro, accessed 14/01/2014).* ***Right:*** *High flow conditions in the post-monsoon season on 08/10/2010. Note that there is no information of how much water was actually flowing at that specific date. Likely, the depicted discharge is considerably lower than the highest flows as these are expected to occur in July and August (source: Google Earth Pro, accessed 14/01/2014).*

To abstract the water from the river and to provide the necessary geodetic height difference between the water abstraction and the outlet, the idea to dam the Dhey Chang Khola arose.

The retained water could be transported to the elevated plain of Thangchung through a pressure pipeline by means of gravity flow.

4.1.1 Investigations

Location of the dam at Phayung Karpo

The dam was envisaged in a cut called Phayung Karpo referring to a big white outcropping rock on the right riverbank. At this location the deep gorge conveying the Dhey Chang Khola is only roughly forty meters wide. Rock is exposed on either side of the river. On the right hand side the surface is smooth due to water and possibly glacier erosion. On the left hand side, which corresponds to the inner side of the curve, the surface is rougher. The rock formation is composed by conglomerates with a greyish silty matrix with dark limestone elements. The bedding is dipping steep in south – southeast direction (average 150/80) and is heavily folded. Other discontinuities dipping towards northwest (310/40 and 290/40) and southwest (215/85) were identified. Due to competence contrasts between limestone and silt matrix the hinge of the folds can spread open, possibly causing the rock to be permeable. The bedrock level in the alluvial plain could not be determined during this survey as it is filled with loose material.

Characterization of the alluvial plain

The alluvial plain of the Dhey Chang Khola is mostly composed of gravel, with some boulder and local lenses of very fine sand and silt (Table 4.1).

Table 4.1: List of the most common sediments in the alluvial plain below Thangchung. The numbers in the right columns describe the composition of the sediments in percent.

Lithology	Frequency	Clay	Silt	Sand	Gravel	Stone
Coarse gravel	Most common (60 % of all material)	-	-	20	30	50
Gravel	Quite frequent (30 %)	-	10	30	50	10
Fine sand	Only at isolated locations	0 – 5	20	70	5 – 10	-

There are indications that the riverbed is being eroded during flood events, namely the presence of steep scarps in the loose ground on both sides of the river (Figure 4.2, left) and the observation of a characteristic stone. Reportedly, the rock could be reached from the valley bottom roughly 80 years ago. Nowadays it is hanging freely on the cliff at a height of almost 4 m above the riverbed (Figure 4.2, right).

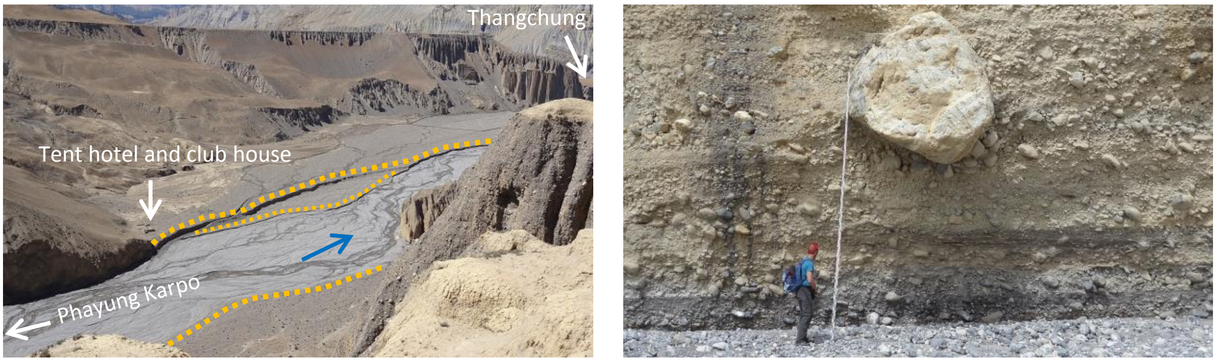

Figure 4.2: There are indications that the Dhey Chang Khola is eroding the riverbed during flood events. ***Left:*** *The alluvial plain between Thangchung and the tent hotel and club house located a little bit downstream of Phayung Karpo is illustrated. The steep scarps on both sides of the active riverbed of the Dhey Chang Khola are highlighted with dotted lines. The flow direction is indicated by the blue arrow (photo: 25/09/2013, Daniel Bernet).* ***Right:*** *Marco Baumer standing below the stone, which reportedly was level with the riverbed some 80 years ago. As a reference, the 5 m long measuring pole was placed next to it (photo: 24/09/2013, Daniel Bernet).*

Suitability of the topography

To find out whether the topography allows operating a pipeline with gravity flow, the elevation of Thangchung and Phayung Karpo had to be assessed. For that matter, using a theodolite a leveling from Phayung Karpo to the orchard just below Thangchung was undertaken (Appendix A.1). The height of the scarp was then approximated by measuring the angle between the horizontal plane and a fixed-point on top of the scarp in Thangchung from different locations. Additionally, the most important points were measured with a Precise Point Positioning (PPP) Global Positioning System (GPS) module from u-blox. The analysis of these different measurement methods revealed that they are not matching well and are associated with unexpectedly high uncertainties (Appendix A.2). Nevertheless, combining all available information, the relative elevation of the necessary points, while respecting reasonable uncertainty ranges, could be assessed. Thus, the measurements show clearly that the height difference between Phayung Karpo and the highest level in Thangchung is large enough that a pipeline operated by gravity flow is feasible.

4.1.2 Assessment

With this option, water from the river could be transported to the highest levels of Thangchung. However, this option cannot be recommended and is discarded. Any structure built in the active riverbed of the Dhey Chang Khola would be fully exposed to the high dynamics of the river including floods, erosion and sediment transport making it difficult to maintain and prone to failure. Moreover, the dam might not be impermeable due to the geological setting of Phayung Karpo. Also from an economic perspective this option is not sensible. The costs of a well-functioning dam are expected to be, relatively speaking, exorbitant. In addition, the pipeline's minimal length of 3.5 km would increase the cost of this option.

4.2 Short pressure pipeline

As envisaged by the villagers (Gurung 2011) and reasoned in Section 2.3.3, all fields are best located on the lowest level in Thangchung (L1, Figure 2.3 in Section 2.3.2). Consequently, it is most important that the water reaches at least to the first level and not necessarily to the higher ones. This realization offers an alternative option: The water could be brought to the first or the second level of Thangchung without the necessity to build a dam, through a relatively short pressure pipeline. Moreover, the pipeline might be fed by alternative water sources, which was investigated in the field, as described in the following sections.

4.2.1 Investigations

Tapping groundwater

Like spring water, using groundwater has several advantages. In case a sustainable management of the groundwater resources is possible, the groundwater table remains fairly constant throughout the year and water can be abstracted even in the winter. Furthermore the water quality, especially in terms of turbidity, is favorable, as the water is cleaned whilst flowing through the aquifer.

The abstraction of groundwater with a gravity flow pipeline might be technically challenging, but likely, solutions could be found. One of the main advantages of tapping groundwater is the possibility to build the abstraction in a place relatively safe from flooding.

However, the properties of the aquifer have to be such that enough water can be abstracted. An important parameter in this context is the hydraulic conductivity (k) of the aquifer. The determination of this number demands for rather elaborate measurements, which were not possible in the given context. Instead, a simple experiment was conducted (Appendix A.4).

Due to the large uncertainty inherent to the measurement method, the k values range from $3 \cdot 10^{-3}$ to $3 \cdot 10^{-4}$ m/s. Thus, the experiment was not accurate enough to obtain valuable results. Nevertheless, it seems that the permeability is too low to satisfy the irrigation demand as defined in Section 3.1.

Tapping the Dhey Chang Khola

The pipeline might be fed by the trench, which is currently diverting abundant water from the Dhey Chang Khola and supplies the orchard with additional water. The abstraction is washed away regularly in the monsoon season, but, reportedly, it takes a day at most to repair the abstraction by hand or with the aid of the community-owned dozer (Figure 4.3).

The abstraction consisting of a simple diversion with piled up rocks, gravel and sludge, has the striking advantage that it is highly adaptive. This is a crucial point related to the abstraction of water from a river as dynamic as the Dhey Chang Khola. For instance, if the riverbed of the main river is eroded or lifted, the abstraction can be adapted very easily, which is not true for rigid structures.

Figure 4.3: The abstraction which is directing water from the Dhey Chang Khola onto the plain of Chawale. ***Left:*** *A flood in June 2012 inactivated the abstraction by disconnecting the channel (green arrows; photo: 05/07/2012, Daniel Bernet).* ***Right:*** *By piling up a dike (blue arrows) with the dozer, the abstraction was reactivated in less than a day. The location of the outcropping rock, which was said to be level with the riverbed some 80 years ago and is displayed in Figure 4.2, is highlighted as well (photo: 24/09/2013, Daniel Bernet).*

Suspension load

As mentioned previously, the Dhey Chang Khola carries a large suspended particle load during high flow conditions. To have a general idea of the constitution of the river water, different experiments were carried out (Appendix A.5-A.7). The experiments indicate that the turbidity is varying greatly even within a short time span. These changes are linked to changes in the flow rate, which are mostly triggered by precipitation events and snow and ice melt. The transported suspension load can be considerably large. In case the water is used untreated, the particles might damage the hydraulic installations, especially valves and accessories. The test revealed that the water quality in terms of turbidity can be greatly increased if the water is set to rest for several hours. A simple settlement pond would therefore be an effective measure to pretreat the water and rid it of the coarsest suspended particles.

Routing of the pipeline

The most direct way to Thangchung leads from Phayung Karpo on the left riverbank to the eastern end of the orchard's first realized section (Figure 2.3 in Section 2.3.2) and from there up through a small valley on the north-eastern corner of Thangchung's cliffs.

The field investigations have shown that the mentioned valley is steep and unstable, overall unsuitable for fixing a pressure pipeline. In addition, the location is exposed to the hazard of rockfall. Besides, routing the pipeline through this valley would only be feasible in case the intake were located higher than the highest point of Thangchung, for instance in combination with a dam in Phayung Karpo.

In any case, direct routing is inappropriate and thus indirect routing has to be foreseen. Reasonably, the pressure pipeline is led along the existing road on the south-western side of the scarp.

4.2.2 Assessment

Realizing that the irrigation water is mostly needed on the first level of Thangchung, a very promising solution becomes available. The water can be taken in from the Dhey Chang Khola with the dynamic abstraction currently in use. Though it needs regular fixing and repair, it is considered to be the best solution in this context. It is low-cost, very adaptive and can be easily maintained by the locals. Building any rigid structures to take in the water is highly discouraged.

On the other hand, the use of groundwater is discarded as well, as the yield does not seem to be sufficient to supply the demanded amount of water.

A settlement pond is a simple and effective measure to reduce the high expected suspension load of the water to prevent the hydraulic installations from damage.

Though direct routing of the pipeline up through the steep valley was foreseen by the people, it is inappropriate in terms of steepness, stability and exposure to rockfall. Moreover, direct routing is not compatible with a short pressure pipeline involving an intake located lower than the highest levels of Thangchung in the first place.

4.3 Pressure pipeline fed by spring from opposing valley

Charang, one of the main villages of Upper Mustang, is located north of Thangchung on a southwards sloping plain. Below the village, a considerable amount of water emerges from a crack in the rock. The idea is to convey this water to Thangchung within a pressure pipeline.

4.3.1 Investigations

Water source

To reach the spring (Figure 4.4), a cave-like structure has to be passed (Figure 4.5, left), from where the water can be seen emerging from a crack in the rock. Little is known about the dynamics of the spring's yield. It is said that the spring does not dry out even during the winter. In the morning, when the spring was visited, the riverbed of the streamlet was wetted above the observed water table suggesting a higher water table during the night. Likely, the flow of the spring is subjected to diurnal variations in addition to probable seasonal fluctuations. Furthermore, the location of the spring suggests that at least part of the water is constituted by infiltrated irrigation water from Charang's fields.

Figure 4.4: Water emerges from a crack (red circle) below Charang. The water could be tapped and conveyed to Thangchung, which is located next to the confluence of the Dhey Chang Khola (orange arrow) and the Charang Khola (green arrow) with the Kali Gandaki (blue arrow; source: Google Earth Pro, accessed 14/01/2014).

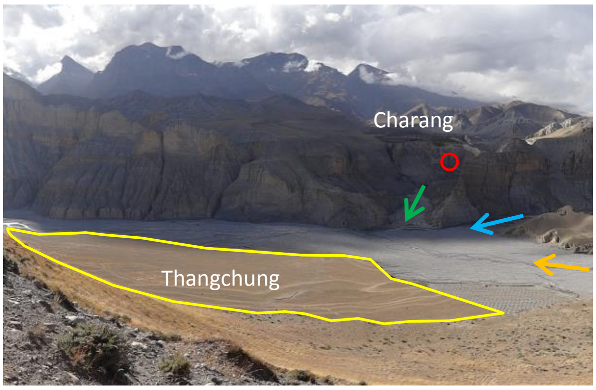

Figure 4.5: The spring below Charang is a possible water source for Thangchung. ***Left:*** *The water emerges from a crack in the rock, passes through a cave-like rock formation, runs down a steep slope and flows into the Charang Khola. The flow direction is indicated by the black arrow (photo: 19/09/2013, Daniel Bernet).* ***Right:*** *The spring (red circle) is located on the opposite side of the Kali Gandaki (blue arrow), which poses a major obstacle for a possible pipeline. Thangchung (yellow polygon) is overlooking the confluence of the Dhey Chang Khola (orange arrow) and the Charang Khola (green arrow) with the Kali Gandaki (photo: 23/09/2013, Daniel Bernet).*

Pipeline routing

The measured maximal height difference between the spring and Thangchung is just enough to transport the water through a pressure pipe to Dheye's relocation site by gravity flow

(Figure 10.4 in Appendix A.2). However, a major obstacle is posed by the main river of the Mustang valley, the Kali Gandaki (Figure 4.5, right). Routing the pipeline along the right riverbank of the Charang Khola, the pipeline has to cross the Kali Gandaki. A different routing would mean that all three rivers shown in Figure 4.5 would have to be crossed.

In case a pedestrian bridge is built (see Section 2.3.2), a pipeline could easily be mounted securing it against floods from the Kali Gandaki. However, this solution is only possible if certain basic conditions are met. For instance, the bridge head has to be lower than the inlet of the pipeline otherwise the water could not be transported by means of gravity flow. Furthermore, such an arrangement would only be sensible, if a rather direct routing of the pipeline was feasible else the pipeline would be unnecessarily long and expensive.

Another possibility is to hang the pipeline on a steel wire suspended over the river. Though cheaper than a bridge, the pipeline would not be accessible for maintenance. Suspending the pipeline on evenly spaced pillars placed into the riverbed of the Kali Gandaki constitutes another option. However, the pillars would be situated within the very dynamic riverbed of the Kali Gandaki directly exposed to high flow conditions and floods. Burying the pipes into the riverbed would be sensible if the trench can be dug deep enough and if the Kali Gandaki can be diverted sufficiently to do the necessary construction work.

Cultural and social aspects

It is very important to note that the option of tapping water from Charang is only thinkable if it is socially and culturally accepted by all stakeholders. As described in Section 2.2.2, the relationship between Dheye and Charang was and is problematic. Thus, in this context, the abstraction of the water would most likely not be accepted by the people of Charang.

4.3.2 Assessment

The advantage of using spring water to meet the irrigation water demand is the superior constitution of the water mainly in terms of turbidity. Generally, floods and high flow conditions, due to snow and ice melt, do not heavily affect the yield and the water quality of springs. Thus, the abstraction of the water is simple and a pretreatment of the water because of turbidity peaks during high flow conditions is often superfluous.

On the other hand, the topographic and geological setting is posing a major constraint for this option. Especially the crossing of the Kali Gandaki is very difficult. The mentioned options are either very expensive (bridge), unpractical (pipe suspended on steel wired), difficult to construct (buried pipeline) or prone to fail (pipeline mounted on pillars).

Above all, the usage of the water would most likely not be accepted by the people of Charang. Therefore, the option of transporting spring water from Charang to Thangchung is discarded.

4.4 Pumping water up to the plain

An obvious way to bring the water to Thangchung is to lift it up with a pump. This option has the advantage that a rather short pipeline can be realized. The water to be pumped is collected or transported to a suitable place as close to the destination as possible. Different water sources could be tapped. However, the most critical issue is how to come up with sufficient power to be able to run the pumps.

4.4.1 Investigations

After the first priority, namely to provide road access to all villages in Upper Mustang, it is planned to connect the villages to the national electricity grid. Due to the central Government's inefficiency in remote places like Upper Mustang, intrigues and local powers of the local centers such as Charang and Lo-Manthang play an important role in such large infrastructure projects to the effect that remote places like Dheye and Samzong are disadvantaged. In this light, it will take years, if not decades, before Dheye will be connected to the electricity grid. However, as Thangchung is not nearly as remote as the current location, connecting the resettled village will be easier and thus quicker than connecting Dheye. Nevertheless, it cannot be expected that a connection to the national electricity grid will be available in the near future. Consequently alternative power sources are necessary for a potential pumping scheme.

The water could be pumped up to the elevated plain of Thangchung using solar power. Photovoltaic (PV) panels in combination with solar pumps are a widely-used and well-tested technology, especially in areas that are not connected to the power grid. For that matter, an exemplary calculation with pumps from NOV Mono[6] was undertaken to assess the suitability of this option. The main input parameters and the results of this simulation are summarized in Table 4.2. All CASS simulation results are presented in Appendix B.3.

[6] Many different companies offering solar pumps exist. NOV Mono (http://www.monopumps.com.au) was chosen for reference as they offer a freeware calculation tool named CASS (Computer Aided Solar Simulation) to assess the best suitable pump. Furthermore, two solar pumps had been installed at KFS's orphanage in Tathali, Bhaktapur, and have proven to be very reliable.

Table 4.2: Chosen input parameters and results of the simulation with CASS (Jeffery 2013), as well as a coarse cost analysis. The water demand of 959 m^3/d, as introduced in Section 3.1, was adjusted to include 10 % of losses of the pumping system itself and 20 % of losses in water distribution from the pump outlets to the plots.

Category	Description	Unit	Value
Input parameter	Water demand	*(m^3/d)*	1'367
	Lift height[a]	*(m)*	36
	Pipe length	*(m)*	600
	Pipe diameter	*(in)*	1½
Output per pump	Wattage	*(W)*	1'600
	Minimal Flow	*(m^3/d)*	33.1
Pumping scheme configuration	Wattage	*(kW)*	67.2
	200 W PV panels	*(-)*	336
	No of pumps	*(-)*	42
Material costs excluding pipes	Pumps[b]	*(US$)*	84'329.28
	Cables[c]	*(US$)*	9'345.00
	Panels[d]	*(US$)*	121'800.00
	Total	***(US$)***	**215'474.28**

[a] In the corresponding configuration the water is pumped to L1 as defined in Section 2.3.2. The solar pumps could also lift the water to the higher levels of Thangchung. This would result in lower yields however.

[b] AU$ 2820.00 per pump, 20 % discount granted by NOV Mono; Conversion rate 18.12.2013: 1.00 AU$ = 0.89 US$.

[c] Average cable length 50 m per pump costing 5.00 AU$/m according to NOV Mono.

[d] Prize per installed power 181.25 NPR/W based on an 80 W EVEREXCEED ESC-36M-80 module purchased from Lasersun (www.lasersunenergy.com) in summer 2012; Conversion rate 18.12.2013: 1.00 NPR = 0.01 US$.

An alternative power source would be wind. However, beside a small-scale wind turbine used for lighting several households in Namdok, the northern most village in Upper Mustang, there are no wind power systems in Upper Mustang. The strong diurnal winds (described in Egger et al. (2000) for instance) and the associated problems with abrasion pose a difficult problem, which has to be investigated further before a pumping scheme may be realized.

A pump powered by a generator is not considered. In the light of climate change such a system cannot be supported, in addition to very high expected operation costs.

4.4.2 Assessment

As exposed in Table 4.2, the costs for a solar pumping scheme to provide the necessary water for irrigation in Thangchung are very high, even more so as only material costs for the pumps, the cables and the PV panels were considered. Beside the cost, the system would be difficult to set up, operate and maintain, since 49 pumps and 392 panels would be necessary. Therefore the option of a solar-powered pumping scheme has to be discarded.

Due to the exceptional diurnal wind patterns in Upper Mustang, the wind potential is generally high. However, to be applicable in a context such as the relocation of a whole village, the system has to be well-studied, practice-approved and readily available. Since these requirements are not met, installation of a wind-powered scheme is no option either.

Summarized, only in case Thangchung were connected to the general power grid, a pumping scheme could be a realistic alternative. As this is neither the case at present nor in the near future, the option of a pumping scheme is discarded.

4.5 Identification of the best option

In general, it is very important that the recommended option is accepted by the community. The discussions with the villagers revealed that they would accept any solution. Their paramount demand is simply that the chosen option serves its purpose.

Table 4.3: Comparison of the studied options to supply irrigation water to Thangchung. The recommended option is marked with a tick.

Irrigation Supply Option	Advantages	Disadvantages	Best option
Dam feeding long pressure pipeline	➢ Water can be transported to the highest levels in Thangchung	➢ Unfavorable geological setting for a dam ➢ Dam very expensive ➢ Abstraction fully exposed to the river's dynamics making it prone to failure ➢ Very long pipeline necessary	
Short pressure pipeline	➢ Dynamic abstraction ➢ Relatively short pipeline ➢ Easy to maintain	➢ Water cannot be brought to the highest levels in Thangchung	✓
Pressure pipeline fed by spring from opposing valley	➢ Abstraction safe from floods etc. ➢ Very good water quality in terms of turbidity and suspended solids ➢ Water can be transported to the highest levels in Thangchung	➢ Difficult routing due to unfavorable topographic setting ➢ Kali Gandaki has to be crossed ➢ Water usage would most likely not be accepted by Charang's people	
Pumping water up to the plain	➢ Short pipeline	➢ Not expected to be connected to the power grid in the near future, thus, autonomous power source necessary ➢ High power consumption ➢ Very technical solution ➢ Expensive equipment necessary ➢ Labor intensive option	

The different options to supply Thangchung with irrigation water have been outlined in the preceding sections. Comparing the four options (Table 4.3), it becomes clear that the best solution is to construct a small pipeline while using the present method of abstracting the water from the Dhey Chang Khola. This option is based on simple, well-known technology, is adaptable to future changes of the riverbed's elevation, is easy to maintain and it is relatively cheap. In Section 6.1 the option is outlined in detail.

5 Drinking water supply options

Different technical options for the drinking water supply at the relocation site of Dheye were investigated, as described in the following sections.

5.1 Pressure pipeline fed by spring currently supplying Dheye

The people of Dheye are currently relying on a spring about 3.25 km south of the existing village to meet their drinking water demand. The spring is located in a catchment, which does not drain into the Dhey Chang Khola, but into a neighboring tributary of the Kali Gandaki (Figure 5.1 and Figure 10.5 in Appendix A.2). The abstracted water is conveyed to the village by a pipeline crossing a height difference of roughly 300 m (Bernet et al. 2012b).

An option for supplying drinking water is to build a pipeline from the currently tapped spring to the relocation site of Dheye.

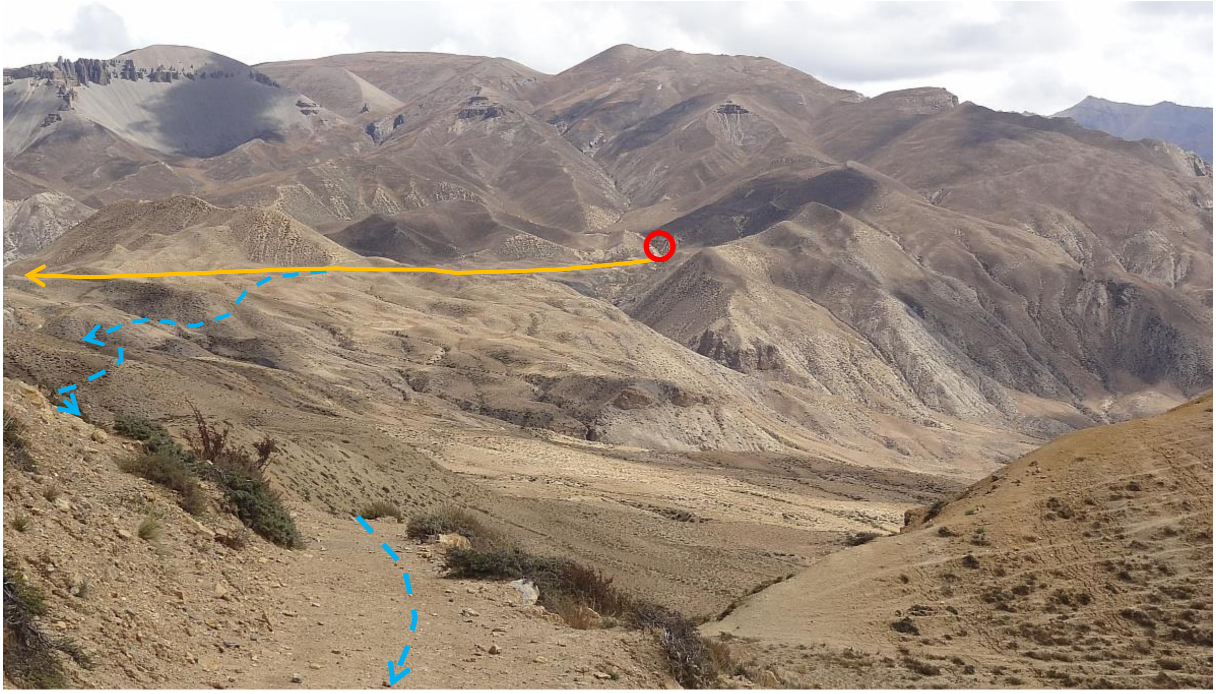

Figure 5.1: Currently, the people of Dheye rely on a spring (red circle) located in a different drainage area than the settlement itself. To transport the water to the village a long pipeline (orange arrow) was built. The drinking water demand at the relocation site of Dheye might be met by building a pipeline from the same spring. The pipeline, indicated by the dashed blue arrows, would have to cross the pictured flat, open area. From the pass seen in the foreground, the pipeline would lead steeply down to Thangchung as illustrated in Figure 5.2 (photo: 23/09/2013, Daniel Bernet).

5.1.1 Investigations

Water source

During the field survey the spring was visited. According to the villagers, the point where the water emerges from the soil had been shifting. Consequently, the cemented abstraction chamber had to be altered several times, so that the water could still be captured and transported to the village. The yield of the spring is very low and is currently just enough to meet the demand of the village. Furthermore, the yield seems to be decreasing generally.

Pipeline routing

To bring the water from the spring to Thangchung, the pipeline has first to be led along a rather flat, open plain crossing several high points until a major pass is reached (Figure 5.1 and Figure 5.2). This pass accommodates the way to the old village, which is used once the Dhey Chang Khola carries too much water inactivating the shorter access through the riverbed. From this pass the pipeline would lead steeply down to a vast plain adjoining Thangchung.

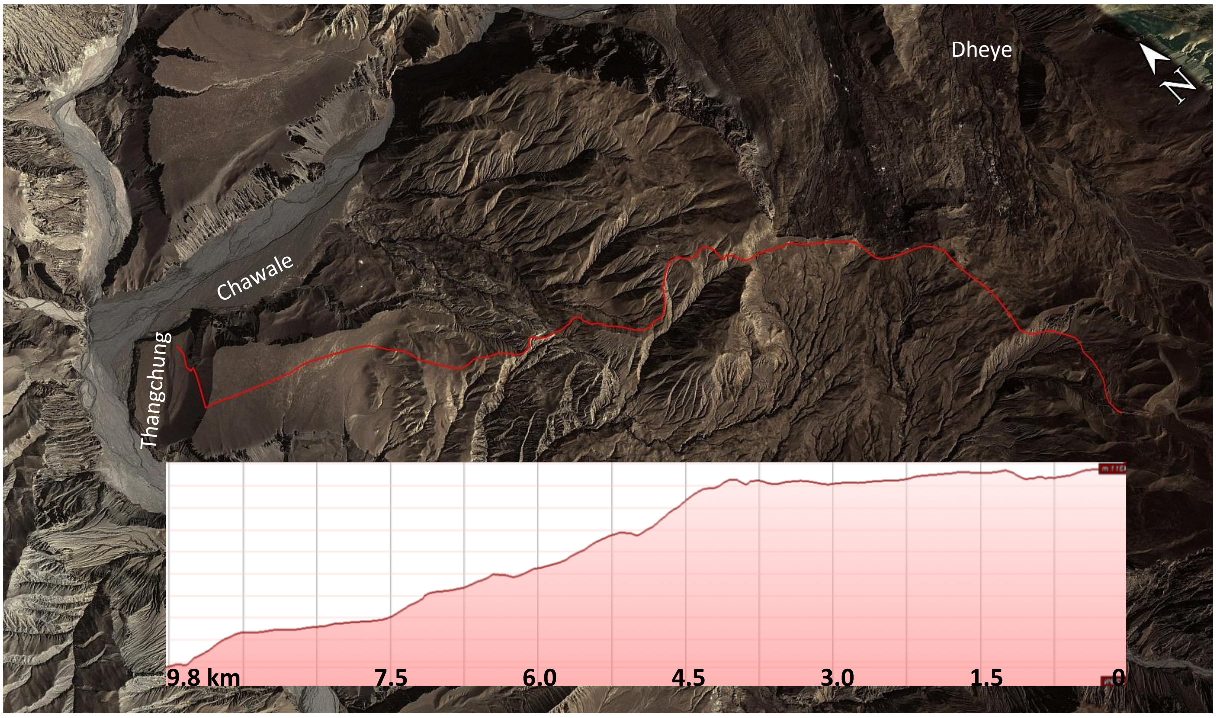

Figure 5.2: Possible routing of the pressure pipe transporting the water from the existing drinking water abstraction to Thangchung. The longitudinal profile of the pressure pipe created with Google Earth is indicated as well. The first roughly 4 km are sloped only slightly, thereafter the pipe is leading steeply down to Thangchung (source: Google Earth Pro, accessed 14/01/2014).

The elevation of the spring, the intermediate high points and the pass are suitable to allow gravity flow (Figure 10.5 in Appendix A.2). However, the topography is such that several ascending slopes have to be surmounted. Consequently, air vents as well as drains at these local depressions would be necessary, so that the pipe can be emptied during winter time to prevent bursting of the pipes.

The length of the pipe would be at least ten kilometers and cover a height difference of almost one kilometer (Figure 5.2). Due to the large height difference and distance, intermediate basins are certainly necessary to break the high static pressure as well as to prevent bursting due to pressure surges.

Flow calculations
Simple, preliminary flow calculations give some indications about the suitability of the option. Using a half inch High-Density Polyethylene (HDPE) pipe (20 mm OD), the resulting flow (assuming one single pipe without basins and any water losses) is approximately 0.2 l/s, 13 l/min or 19’172 l/d. Considering a population of 150 people in Thangchung (Section 2.1), this would amount to 128 l/p/d, which is well above the defined water demand of 80 l/p/d (Section 3.2). However, the question is rather whether the spring’s yield would be sufficient to supply that much water.

The material cost of the pipeline constituted by Panchakanya HDPE pipes (Figure 10.23 in Appendix C.1) would amount to NPR 307’972.20 considering a prize of NPR 31.49 per meter and a pipeline length of almost ten kilometers. The effective cost would be higher of course since air vents, intermediate basins and armatures need to be included in addition to transportation and installation costs.

Operation and maintenance
This option has the big disadvantage that the pipeline is difficult and very laborious to maintain. As a total length of ten kilometers is very long it is difficult to locate any problem, most of all because the pipe should be buried underground to prevent freezing.

5.1.2 Assessment

The advantage of tapping the spring currently supplying drinking water to Dheye is that the water has proven to be suitable for drinking purposes. Furthermore, the spring water is accepted by the villagers, which does not go without saying. The spring water in Chawale for instance is currently rejected by the villagers (Section 5.3.1).

However, it is likely that the yield of the spring will decrease in the future. If the yield is not insufficient already, it might become so in the future. Furthermore, a pipeline with a total length of 10 km is very difficult to operate and maintain, especially in the harsh conditions of Upper Mustang. Therefore, the option of tapping Dheye’s spring to meet the drinking water demand in Thangchung is discarded.

5.2 Pressure pipeline fed by spring from opposing valley

The spring below Charang, described in Section 4.3, might also be suitable to yield water useable for domestic purposes. The idea is to abstract the spring water and convey it in a pressure pipeline to Thangchung.

Note that in case the irrigation water demand were met by abstracting water from the spring below Charang, part of the water could be used for domestic purposes. As the domestic water demand is roughly two orders smaller than the irrigation demand (Chapter 3) the design would remain the same. For this option refer to Section 4.3 and 5.4. In the following, the option of a pure drinking water pipeline is discussed, which has slightly different parameters, as the pipeline can be designed much smaller and more flexible due to much lower flow rates.

5.2.1 Investigations

Water source
Generally, spring water is a suitable source for drinking water: The flow rates are usually quite constant throughout the year, even in the winter months the spring yields running water and the water quality is often good.

Although little is known about the dynamics of the spring, it is probable that the yield is sufficient to meet Thangchung's demand for drinking water. However, there are some concerns about the water quality. As mentioned in Section 4.3.1, the spring seems to be linked to the water use in Charang, at least partly. Thus, water used in agriculture, degenerated by manure for instance, might infiltrate and emerge again from the spring. In such a case the water has to be treated before it can be used. To be sure that the water quality is suitable for domestic use, water quality tests should be carried out.

Pipeline routing
Compared to a larger pipeline conveying irrigation water (Section 4.3.1), the routing of the drinking water pipeline is more flexible, since the pipe diameter can be chosen much smaller. Thus, the crossing of the Kali Gandaki is generally simpler and cheaper, but remains a main obstacle.

Cultural and social aspects
The same cultural and social aspects as discussed in Section 4.3.1 have to be considered for a pipeline conveying drinking water.

5.2.2 Assessment

In the light of the reservations related to the water quality, alongside with the persisting difficulties crossing the Kali Gandaki and above all, the unfavorable cultural and social acceptance, the option of a pressure pipeline abstracting water from the spring below Charang is discarded.

5.3 Pumping water up to the plain

An obvious way to supply Thangchung with drinking water is to lift it up with a pump. For that matter, a suitable power source has to be installed and a suitable water source has to be tapped. The different options are discussed in the following section.

5.3.1 Investigations

Tapping spring water
Generally, using a spring as a water source would be preferable. As already mentioned in Section 4.3.1, the yields of springs are usually quite constant throughout the year, even in the winter. Furthermore, the emerging water is usually very clear, which is an asset in regard to the lifespan of the pumps, for water with a high suspended particle load can heavily damage mechanical parts of a pump.

In Chawale at the base of the cliffs located on the left riverbank of the Dhey Chang Khola, water emerges from several small springs constituting to a considerable amount of water. During the field survey, the water flow from these springs has been measured using a salt tracer and a conductivity meter. The yield of all these springs combined was estimated to be 16 l/s or 1382 m^3/d at the end of September 2013 (Appendix A.3). Thus, the spring yields far more water than the demand of 12 m^3/d as defined in Section 3.1.

However, the people of Dheye explained that the water was not drinkable. Even after boiling, the water would cause stomach ache when consumed. It is imaginable that not the spring water itself, but rather a mixture of spring and river water was consumed, as close to the spring water abstracted from the Dhey Chang Khola flows by and is mixed with the former.

Doubtlessly, the supplied water has to be of impeccable quality, but the social acceptance of the water source is crucial as well and has to be considered before a system is implemented.

Tapping groundwater
The potential of using groundwater as a source has already been discussed in Section 4.2.1. As outlined, groundwater favorable properties has similar to spring water, as the yield is fairly constant over the year and the water quality is generally high.

As reported, a simple experiment was conducted to assess the conductivity of the aquifer (Appendix A.4), which is a crucial variable related to groundwater yields. Due to the large uncertainty of the experiment, the k value ranges from $3 \cdot 10^{-3}$ to $3 \cdot 10^{-4}$ m/s and could not be assessed more precisely. However, the drinking water demand is marginal compared to the irrigation water demand (Section 3.2). The aquifer could therefore be permeable enough to satisfy the drinking water demand of 12 m^3/d, as defined in Section 3.2.

Tapping river water

As the river water is often very turbid (Section 4.2.1 and Appendix A.5-A.7) the water should be rid of the suspended particles prior to pumping. Else, the pump might be damaged heavily, shortening the pump's lifespan. A simple pretreatment should be installed. Such a simple system serving this purpose has recently been installed in Upper Mustang (Figure 5.3).

Figure 5.3: A sequence of pools was installed to rid the water, abstracted from the Kali Gandaki (orange arrow), from suspended particles prior to pumping. Visibly, the water becomes much clearer before it is drawn in by the pump (red arrow). The water is lifted from the Kali Gandaki up to a vast plain near Tangbe, where an orchard is being cultivated. The pumps are connected to the power grid, which is currently not reaching much further up than Tangbe (photo: 21/06/2012, Daniel Bernet).

Power source

As described in Section 4.4.1, a connection to the national electricity grid will not be available anytime soon in Thangchung. Therefore, alternative power sources are necessary for pumping drinking water up to the plain.

Especially related to drinking water supply schemes in Nepal, PV panels in combination with solar pumps are a widely-used and well-tested technology. For that matter, an exemplary calculation with pumps from NOV Mono[7] was undertaken to assess the suitability of this option. The main input parameters and the results of this simulation are summarized in Table 4.2. All results from the CASS simulation are presented in Appendix B.3.

[7] http://www.monopumps.com.au

Table 5.1: Chosen input parameters and results of the simulation with CASS (Jeffery 2013), as well as a coarse cost analysis. The water demand of 12 m^3/d, as introduced in Section 3.2, has been adjusted to include 10 % losses of the pumping system.

Category	Description	Unit	Value
Input parameter	Water demand	*(m^3/d)*	13
	Lift height[a]	*(m)*	65
	Pipe length	*(m)*	1'100
	Pipe diameter	*(in)*	1½
Output per pump	Wattage	*(W)*	1'200
	Minimal Flow	*(m^3/d)*	13.6
Pumping scheme configuration	Wattage	*(kW)*	1.2
	200 W PV panels	*(-)*	6
	No of pumps	*(-)*	1
Material costs excluding pipes	Pump[b]	*(US$)*	2'509.80
	Cables[c]	*(US$)*	89.00
	Panels[d]	*(US$)*	2'175.00
	Total	***(US$)***	**4'773.80**

[a] In the corresponding configuration the water is pumped to the highest level L4 as defined in Section 2.3.2.

[b] AU$ 2820.00 per pump according to a quotation from NOV Mono in summer 2013; Conversion rate 18.12.2013: 1.00 AU$ = 0.89 US$.

[c] Average cable length 20 m per pump costing 5.00 AU$/m according to a quotation from NOV Mono in summer 2013; Conversion 18.12.2013: 1.00 AU$ = 0.89 US$

[d] Prize per installed power 181.25 NPR/W based on an 80 W EVEREXCEED ESC-36M-80 module purchased from Lasersun (www.lasersunenergy.com) in summer 2012; Conversion rate 18.12.2013: 1.00 NPR = 0.01 US$.

A different power source could be wind. As discussed in Section 4.4.1, before a pumping scheme powered by wind could be realized all inherent problems have to be investigated, solved and tested.

A pump powered by a generator is not considered as such a system cannot be supported in the light of climate change. Moreover, the operation costs are expected to be very high.

5.3.2 Assessment

Beside the higher quality requirement for drinking water, the irrigation water is characterized by much higher demand. Using pumps for supplying drinking water to Thangchung is therefore definitely feasible, as the demand can be met by a single solar pump powered by a 1'200 W solar array. The technology is well-tested and widely used in Nepal. Even in remote places like Upper Mustang such a system could easily be installed, operated and maintained.

In general, river, spring and groundwater can be used as a source. River water has the disadvantage of being turbid, which makes a treatment inevitable. Also, it might be difficult to catch the water during wintertime, when the Dhey Chang Khola freezes. In this context, spring and groundwater are preferable. As the villagers have suffered from negative impacts after consuming the spring water, the use of groundwater is probably preferable. In any case, more information about the quality of the different water sources have to be gathered before recommendations can be made.

Thus, on one hand, the use of solar power to supply drinking water to Thangchung can be recommended, but, on the other hand, which water source should be tapped has to be assessed in more detail.

5.4 Conjunctive use of irrigation water supply system

The fact that the drinking water demand amounts to only roughly one percent of the irrigation water demand (Chapter 3) makes the conjunctive use of the irrigation water supply system a lucrative possibility.

In Chapter 4 the different irrigation supply options were discussed. Even though a conjunctive system is not limited to any option, the following elaborations are made in relation to the solution which is regarded the best one, namely a short pressure pipeline fed by the Dhey Chang Khola (Section 4.2 and 4.5).

5.4.1 Investigations

In terms of quantity, the required water volume for domestic uses can easily be abstracted without negatively affecting the irrigation water supply system. Since the two purposes have different quality requirements, the supplied irrigation water simply has to be treated in order to reach drinking quality.

In this context, biosand filters might be a suitable treatment system. These filters are widely used, low-cost, easy to maintain, do not require energy input and above all, the water quality of the treated water is generally very high. Normally, these filters are used in combination with an additional treatment step, such as chlorination for example. Whether such a step is necessary under the given circumstances has to be assessed in more detail. Furthermore, it should be tested how biosand filters used in Nepal would behave in a harsh climatic environment like Upper Mustang. Especially the performance of the filter during wintertime has to be investigated as this has not been tested[8].

Besides, it might be necessary to pretreat the irrigation water brought to Thangchung in case the water is still very turbid. Otherwise, the biosand filter might clog very easily, reducing the treatment efficiency. The system should be designed in a way that a pretreatment step, a

[8] SmartPaani Pvt. Ltd. (http://smartpaani.com/), probably the most experienced private Nepali company providing biosand filters, was asked in summer 2013, whether they ever have installed biosand filters in an environment with seasonal temperatures well below freezing. Apparently, such systems have never been tested, so far.

roughing filter as described in Wegelin (1996) for instance, could be incorporated if necessary.

Another issue to consider is that the irrigation supply system only needs to be operated during the growing season, while drinking water is required during the whole year. Consequently, the irrigation system would need to keep running just to provide the comparatively small amount of drinking water. Although generally nothing speaks against running the system at a reduced capacity, it has to be ensured that the water in the pipes does not freeze as this could lead to bursting pipes.

Furthermore, since the irrigation water, conveyed by a short pipeline as described in Section 4.2, can only be brought to the second level, a pump might be necessary to bring the water up to higher levels in order to supply buildings on higher elevations and to provide the necessary pipe pressure in the drinking water distribution system. For that matter a solar pumping system, as described in Section 5.3, could be used.

5.4.2 Assessment

Conjunctively using the irrigation supply system certainly makes sense, especially in economic terms. However, the drawback is that the systems are not independent anymore. If the system breaks down neither irrigation nor drinking water is available in Thangchung. This issue weights even more in remote places such as Upper Mustang since it may take longer to repair the system especially if spare parts are needed.

Furthermore, in combination with the recommended irrigation supply system (Section 4.5), a pumping system might be necessary in order to provide the necessary pressure in the drinking water distribution system and therefore the installation of a separate drinking water pumping system might be more appropriate.

5.5 Identification of the best option

In the preceding sections different options to cover the drinking water demand were elaborated. Tapping the spring currently supplying Dheye with drinking water as well as the spring below Charang are discarded (Table 5.2). Conjunctively using the short pressure pipeline, regarded as the best solution for supplying irrigation water to Thangchung (Section 4.2), is an option, but it is not considered to be the best one. Mainly the fact that it is not independent from the irrigation system is a drawback. Furthermore, a pump may be needed to lift the water further up to provide the necessary pressure in the drinking water distribution system.

Pumping the water up to Thangchung with a solar system is found to be the best option (Table 5.2). Different water sources can be tapped, only a short pipeline is necessary and the water can be brought to virtually all levels of Thangchung. However, for deciding which water source should be tapped, further investigations are necessary.

Table 5.2: Comparison of the studied options to supply drinking water to Thangchung. The best option is marked with a tick, whereas discarded ones are marked with a cross.

Supply Option	Advantages	Disadvantages	Best option	Dis-carded?
Pressure pipe-line fed by spring currently supplying Dheye	➢ Water has already drinking quality, does not need to be treated ➢ Spring is well accepted by the villagers ➢ Water can be supplied to all levels in Thangchung	➢ Yield is probably insufficient, even more so in the future ➢ Very long pipeline necessary ➢ Intermediate basins necessary to break the resulting high pressure due to the large covered height difference ➢ Difficult operation, maintenance and repair		✗
Pressure pipe-line fed by spring from opposing valley	➢ Spring's yield is sufficient ➢ Low turbidity	➢ Water might have to be treated ➢ Difficult routing, especially the crossing of the Kali Gandaki ➢ By gravity the water is likely not reaching the highest levels of Thangchung ➢ Water abstraction would most likely not be accepted by Charang's inhabitants		✗
Pumping water up to the plain	➢ Short pipeline feasible ➢ Water can be supplied to all levels in Thangchung ➢ Widely-used, well-tested technology ➢ Different water sources can be tapped	➢ Technical solution: Repair task could be costly and could take a long time	✓	
Conjunctive use of irrigation water supply system[a]	➢ Economic solution ➢ Only one system to operate, maintain and repair	➢ Drinking water supply system is not independent ➢ Pump necessary to supply higher levels in Thangchung ➢ Treatment and likely also pre-treatment of the water transported to Thangchung necessary ➢ System needs to be operated even if fields are not being irrigated		

[a] The option is assessed in relation to the short pressure pipeline as described in Section 4.2, which is regarded as the best option for supplying Thangchung with irrigation water.

6 Water supply plan

In the preceding chapters the best suitable option to supply water to Thangchung was elaborated. The indicated best solutions are described in more details in the following sections.

6.1 Irrigation water supply plan

The best option to bring irrigation water to the relocation site of Dheye is by abstracting the water from the Dhey Chang Khola, pretreating it in a pond and transporting it in a buried pipeline to the second level of Thangchung's plain. In the following sections, each unit of the supply system is described in more details.

6.1.1 Abstraction

The abstraction, currently in use, should be kept. Part of the Dhey Chang Khola is directed to the left riverbank by a pile of rock laid into the river course (Figure 6.1). During high flow conditions this temporary diversion is washed away, but can be reestablished easily.

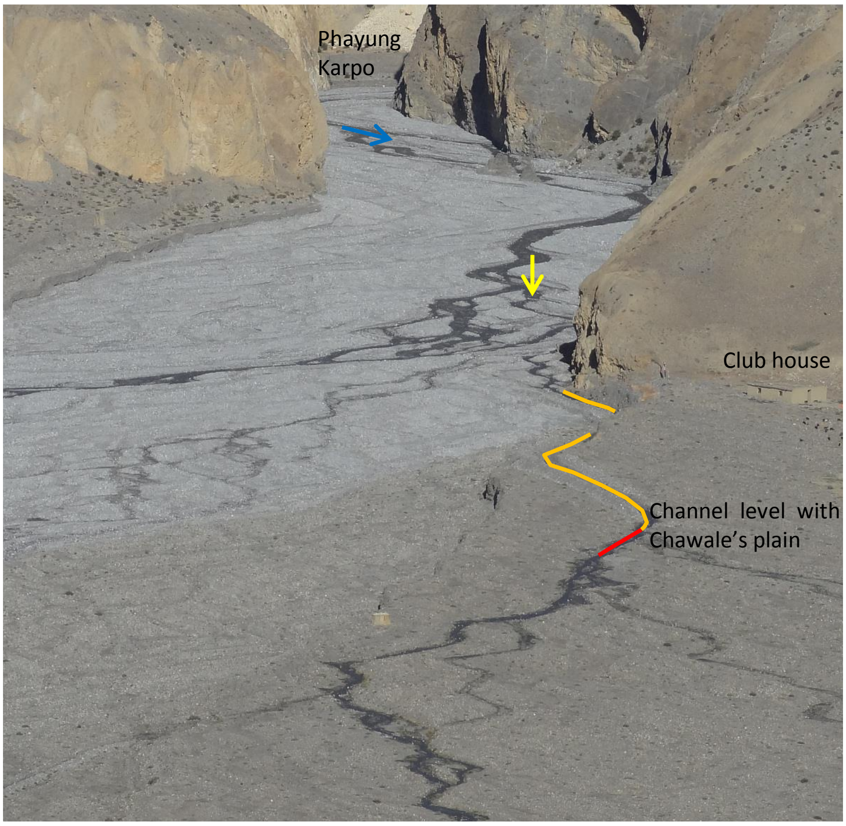

Figure 6.1: The abstraction located next to the recently built club house. Currently, a small amount of Dhey Chang Khola's discharge is diverted by rocks laid into a branch of the river (yellow arrow). The channel dug into the riverbank is highlighted by the orange line. To cope with elevation changes of Dhey Chang Khola's riverbed, which is likely decreasing due to a general erosion tendency, the abstraction channel should be elongated (red line) by lowering the channel bottom accordingly. The flow direction is indicated by the blue arrow. The place named Phayung Karpo, where a dam was envisaged, can also be seen. The option of a dam is discarded as described in Section 4.1.2 (photo: 23/09/2013, Daniel Bernet).

The abstraction channel, highlighted in Figure 6.1, has two different main functions:

- Divert a sufficient amount of water onto the plain of Chawale to supply the agricultural fields in Thangchung as well as the plantation in Chawale
- Limit the flow brought to Chawale to prevent flooding of the plain

The latter point is less obvious than the former one. To achieve a flow regulation, the transport capacity of the channel should not be much larger than the amount of water needed in Chawale and Thangchung. If too much water is brought to Chawale, the orchard might be flooded or the installation of the pipeline could be damaged. Therefore, the dikes at the inlet of the channel should not be higher than 20 to 30 cm in relation to the normal water table within the channel. This mechanism, intended or coincidental, has proven to work, as shown in Figure 4.3 in Section 4.2.1.

Lowering Dhey Chang Khola's active riverbed can be met by two strategies. First, the water can be taken in further up in the valley. In that case the point where the channel bottom is level with Chawale's plain is kept as a fixed point and the channel has to be extended up-stream. Second, the bottom of the channel can be adjusted according to the elevation varia-tions of the riverbed. In that case, the water keeps entering the channel at the same point but extends further downstream, as depicted in Figure 6.1.

The second strategy is strongly recommended. Adjusting the bottom of the channel accord-ing to the elevation changes of the riverbed makes sure the channel bottom as well as the dikes are kept at the same relative height. If more water than the channel can carry is di-rected towards it, the dikes are overflown. Thus, at most the prescribed amount of water is transported onto Chawale. In case the dikes are damaged and the channel disconnected, the bottom of the channel should be lowered carefully until the water flows into the channel naturally again. The dikes should then be reestablished. With the first strategy the channel bottom would be increasingly above the riverbed leading to higher leakage and much more difficult maintenance and repair works. Furthermore, the channel would have to be elongat-ed upstream, where the river is narrower and thus, the channel would be more exposed. With the second strategy, the channel intake stays at the same spot, which is protected by rather solid rock, and only a very small portion of the channel is directly exposed to the Dhey Chang Khola.

An important issue, which has to be kept in mind, is that the point where the channel is level with the plain of Chawale (Figure 6.1) cannot be lower than the inlet of the pressure pipe-line. In order to have sufficient reserve for future adjustments of the bottom of the channel, the pipeline inlet has to be well below the point where the channel currently reaches the plain.

6.1.2 Settlement pond

To prevent the pressure pipeline from damage and to reduce the amount of solids deposited in the fields, the abstracted water should be rid of settleable solids, before it is brought to Thangchung by the pressure pipeline. A very simple structure for that purpose is a settle-ment pond, where water rests for a certain time allowing small suspended particles to sedi-ment. The longer the stopping time, the more suspended particles can be removed. As highlighted by the undertaken experiments presented in Appendix A.5 to A.7, the water quality in terms of suspended solids improved considerably after 24 hours.

As will be elaborated in the following section, the required flow rate which the irrigation system has to be designed for, is 44 l/s (Table 6.2 in Section 6.1.3). In order to guarantee a stopping time of 24 hours, the storage volume of the pond has to be 3829 m^3. Though the pond itself is easy to construct, as it merely needs to be a pit in the ground, the problem is rather the large resulting excavation volume. Considering the size of the community-owned dozer available for such works, it is questionable if such a pond can be constructed within a reasonable budget and amount of time.

Table 6.1: Exemplary design of a rectangular settlement pond providing a stopping time of 24 ridding the abstracted water from the coarsest suspended particles. Using the maximal observed sedimented particle volume of 0.4 ‰ (Appendix A.7) and assuming this rate over the whole year, a maximal annual storage loss is approximated.

Description	**Unit**	**Value**
Required flow rate incl. losses	*(l/s)*	44
Stopping time	*(h)*	24
Required pond storage volume	*(m^3)*	3’829
Considered freeboard	*(m)*	0.3
Slope of pond banks	*(h:l)*	1:3
Length of excavation pit	*(m)*	111
Width of excavation pit	*(m)*	34
Excavation volume	*(m^3)*	6’802
Maximal volume loss due to sediments	*(%)*	15

There are different parameters, which can be changed in order to get a smaller design. First of all, the stopping time can be reduced. Also the freeboard can be chosen even lower. The inclination of the pond bank can also be steeper, which overall reduces the excavation volume. Another possibility is to incorporate filter sections by which the overall size can be heavily reduced. However, designing the pond rather like a roughing filter will also result in more complicated construction and maintenance work. In any case, to decide how the pond should be designed, more information is needed. Especially the costs and the feasibility of constructing such a pond are important factors which have to be assessed before a definite design can be elaborated.

In any case, the settlement pond should incorporate the following features:

- Inlet with a flow control[9]
- Stilling wall to ensure even distribution of untreated water within the pond
- Gentle bank inclinations to ensure pond stability
- Bottom outlet to empty pond for maintenance
- Access path allowing machinery to carry out maintenance tasks within the pond
- Accommodation of the pipeline inlet
- Overflow

6.1.3 Pressure pipeline

Required flow rate

First, the required flow rate, for which the pipeline shall be designed for, needs to be assessed. As described in Section 3.1, the irrigation water demand amounts to 957 m^3/d. Since the area availability in Thangchung (Section 2.3.3), is quite limited, a storage pond in Thangchung is not recommended. Consequently, the desired water volume has to be delivered within the time the villagers can work in the fields. As a lucrative side-effect, the unbuffered irrigation supply offers to use the excess water during the night for hydropower production (Section 6.1.4).

Considering 20 % inherent losses by the pipeline, as well as 20 % losses by the field distribution system, it may be assumed that the water which has to be conveyed by the pipeline equals 1595 m^3 within 10 working hours. Under these circumstances the pipeline has to be designed for 44 l/s (Table 6.2).

Table 6.2: Assessment of the required water flow, for which the pressure pipeline has to be designed for.

Description	Unit	Value
Water demand	*(m^3/d)*	957
Losses of the pipeline	*(%)*	20
Losses of the field distribution system	*(%)*	20
Water demand incl. losses	*(m^3/d)*	1’595
Operation time of the system	*(h)*	10
Design flow rate	*(l/s)*	44

[9] The abstracted river water is used for the orchard as well as for the fields in Thangchung. Therefore, only the water which is going to be transported up to Thangchung needs to be pretreated. The rest of the abstracted river water is flowing down to the orchard without treatment.

Pipe material

HDPE pipes are widely used in Nepal. There are many Nepalese manufacturers producing pipes in a large range of sizes and strengths. Compared to Mild Steel (MS) pipes they are cheaper, lighter and easier to install as shown in the qualitative comparison in Appendix B.5. Furthermore, the expansion of the pipes due to temperature variations are said to be compensated by the flexibility of the pipes, so that no special expansion and contraction joints are necessary. Also, the fact that the technology is well known in Nepal, so that installation, maintenance and repair works can easily be organized, speaks highly in favor of HDPE pipes.

Pipeline specification

The location of the intake is very important. If the intake is too low in comparison to the outlet, the water flow will be inefficient or in the worst case, might not flow at all. On the other hand, the intake should not be located too high, as this requires a longer, and thus more expensive, pipeline. Furthermore, the intake has to be below the place where the abstraction is level with the plain of Chawale as described in Section 6.1.1, because in this way the abstraction channel can be adjusted according to the elevation changes of Dhey Chang Khola's riverbed. Considering these issues, the intake should be located at an estimated relative elevation of + 25 m, while the outlet on the second level of Thangchung is at + 5 m (Figure 6.2). The intake should be located on the plain of Chawale (29°03'57.91"N / 83°57'45.25"E), roughly 600 m downstream of the recently built club house or more specific, 150 m north of the characteristic rock formation in between several Lehs (red cross in Figure 6.2).

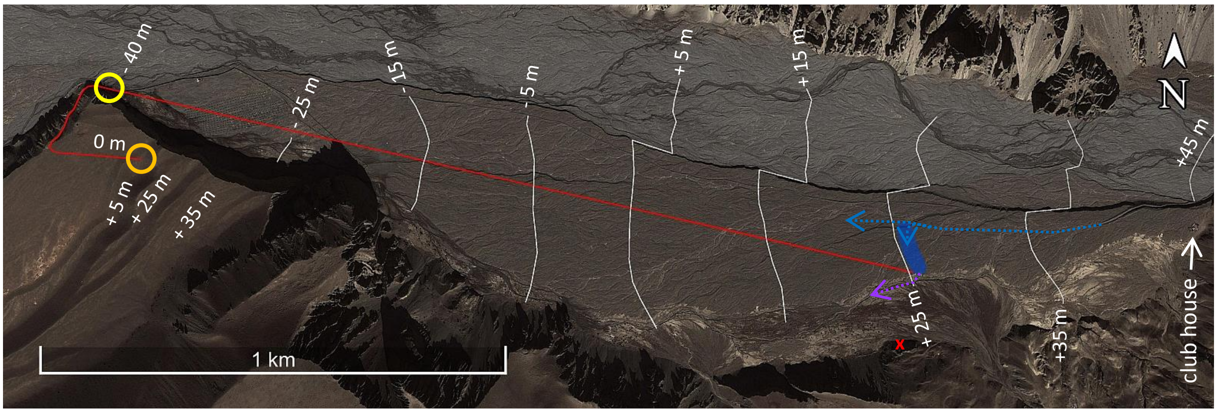

Figure 6.2: From where the abstraction channel is level with the plain (tail of blue arrow) the water is channelized towards the settlement pond (blue area). The water needed in Thangchung is directed into the settlement pond. The rest of the water flows on and is used in the orchard downstream. The water is pretreated in the pond and is flowing into the pipeline (red line). The inlet is equipped with a pipe gate. The excess water flows back into the streamlet along the southern end of Chawale (violet arrow). At the lowest point (yellow circle) the pipeline needs to accommodate a drain, so that the pipe can be emptied (e.g. in winter or during maintenance). The outlet structure (orange circle) is located at the second level (L2). From there the irrigation water can be supplied to every point on the first level (L1) used as agricultural area (source: Google Earth Pro, accessed 18/01/2014).

With the specified height difference between inlet and outlet the required pipe diameter can be determined. The iterative flow calculation is done with an EXCEL sheet using the well-known universal flow formula according to Colebrook and White. The input values and the results are listed in Table 6.3.

Table 6.3: Input variables used in the flow calculations to determine the required pipe diameter. The inner and outer diameter of the class IV pipes (10 kg force/cm^2) are taken from the Panchakanya specification sheet presented in Figure 10.23, Appendix C.1

Description	**Unit**	**Value**
Required flow rate incl. losses	*(l/s)*	44
Gross head	*(m)*	20
Pipe roughness	*(mm)*	0.06
Pipe length	*(m)*	2'250
Cumulated local loss factor	*(-)*	3.8
Pipe diameter (OD)	*(mm)*	250
Flow velocity	*(m/s)*	1.46
Discharge	*(l/s)*	54.84
Pipe costs	*(NPR)*	10'446'525.00
Pipe weight	*(kg)*	44'453
Reflection time	*(s)*	3.13
Maximal head (Joukovski surge + maximal static head)	*(m)*	280
Safety factor: has to be below 1.5 according to Practical Action	*(-)*	1.73

According to the calculation, an HDPE pipe with an outer diameter of 250 mm is required to convey the desired 44 l/s or more. Since the pressure pipeline is very long, pressure surges are posing a serious problem. Closing and opening the pipeline quickly cause water hammers, which are more severe, the longer the pipes are. The maximal possible pressure head, resulting from the maximal static head added to the so-called Joukovski surge, is 280 m, which corresponds to $2.9 \cdot 10^6$ Pa. In order to withstand these pressures, Class-IV HDPE pipes (10 kg force/cm^2), which is basically describing the thickness of the pipe walls, have to be used. That way, the safety factor as defined by Practical Action can be met.

There are different ways to optimize the pipeline. First of all, instead of using a large 250 mm pipe, two 180 mm pipes could be installed at almost the same material cost. More importantly however, the system can be designed to prevent the highest possible pressure surges. The reflection time, denoting the time these surges take to travel through the pipe back and forth, amounts to 3.13 s. Ensuring that the pipe cannot be closed within more than twice the reflection time, 10 s for instance, would heavily reduce the maximal expectable pressure. In that case, also lower class pipes, which are cheaper, could be installed. However, the pipe gates have to be designed in a way that closing and opening the pipes in less than 10 s is not possible. Otherwise, the stronger pipes are necessary. Choosing the next smaller available pipe diameter might also be a possibility. However, by choosing 225 mm pipes the resulting flow (42 l/s) is slightly below the desired flow rate (44 l/s).

Way of installation

As HDPE degenerates when exposed to sunlight, the pipes should be buried in the ground. This has the favorable side-effect that expansion and contraction is heavily reduced, as the pipes are exposed to much smaller temperature differences.

However, damages caused by suddenly breaking pipes leading to water flowing out under pressure, could be observed at several places in Upper Mustang. Such events can trigger deep erosion cuts and lead to the complete interruption of the pipeline. It is believed that such failures were mostly due to improper pipe installation. To prevent such damages, often caused by differential settlements harming the joints, the pipeline should be embedded with sand in a trench that is at least one meter deep, as described in Figure 6.3. Furthermore, sharp 90° bends should not be installed, as they have proven to be very weak. Overall, carefully installing and embedding the pipeline underground is paramount for a long-lasting, reliable system.

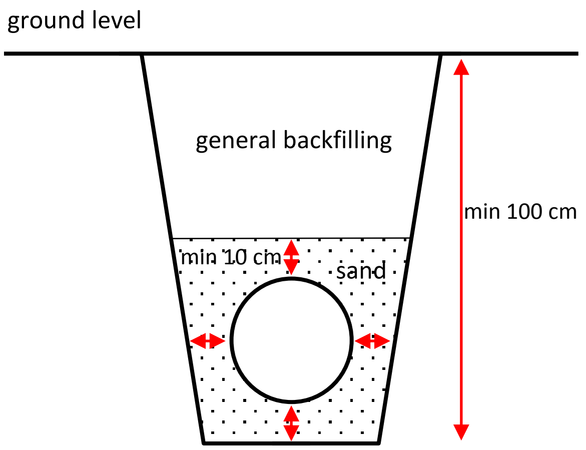

Figure 6.3: The pipeline should be installed with care. The trench should be at least one meter deep. The pipe itself should be embedded by a layer of sand which should be at least ten centimeters thick. As a 22.5 cm wide pipe is recommended, the trench should be at least roughly 45 cm wide at the bottom. The sand embedment shall be covered by general backfilling. The backfilling should be done stepwise. After adding a layer of roughly 20 cm the layer should be compacted well before the next layer is added.

Particular pipeline units

The inlet should be built into the settlement tank. The pipe inlet should be above the pond ground, so that settled particles are not taken in by the pipe. Furthermore, the inlet unit should accommodate a pipe gate. As mentioned before, a gate which mechanically prevents closing and opening times below 10 s are highly recommended. The gate at the inlet is necessary to close the pipe for maintenance or for times when no water is needed in Thangchung.

At the lowest point of the pipeline, which corresponds to the beginning of the access track to Thangchung, a drain has to be accommodated to be able to empty the pipe when needed. For instance, it is recommended to use the pipeline during the growing season only. During the winter, when the Dhey Chang Khola is likely freezing over anyway, the pipe should be emptied. It might be necessary to suspend the pipeline slightly in that section, so as to make sure the pipe can be emptied completely by gravity.

The outlet is planned to be situated at the northern end of the second level (L2) respecting a safe distance to the scarp, as water erosion could have devastating effects. Ideally, the outlet is also equipped with a pipe gate. That way the water flow can be stopped without having to walk all the way to the inlet, which is two kilometers away. However, as mentioned before, it should not be possible to close the pipe quickly, as this leads to heavy pressure surges, possibly damaging the pipe.

6.1.4 Drainage and hydropower

Currently, the ridge of the cliff is quite stable. Nevertheless, bringing a considerable amount of water to the plain of Thangchung could cause erosion, similar to the serious ones, which can be observed on the ridge southeast of Charang. To prevent uncontrolled discharge over the scarp, which will certainly cause erosion damage possibly even beyond repair, a drainage trench all along the scarp of the first level of Thangchung is crucial. At the lowest point, located at the southwestern end of Thangchung, a channel or even better a pipeline should be envisaged to transport the surplus water securely back to the Kali Gandaki without causing any damage to the plain.

As mentioned before, the surplus water could also be turbinated to produce power for the resettled village of Dheye. Ideally, the water would be brought to Thangchung, used for agriculture during the day and producing power during the night. As the water conveyed to Thangchung by a pressure pipeline, would be available in abundance, it would be easy to capture the water, put it to a penstock pipe and turbinate it. Assuming an overall efficiency of 85 %, a flow rate of 44 l/s and a net head of 30 m, a hydropower plant would produce roughly 11 kW. The main problem however is to find a suitable location for the penstock pipe and the power house. The scarp is very steep and unstable and the valley ground is prone to flooding.

6.2 Drinking water supply plan

As discussed in Section 5.5, a solar pumping system is considered as the best solution to provide drinking water to Thangchung. In the following, the recommended system is described in more detail.

6.2.1 Water source

As summarized in Section 5.5, the water source, which is most suitable for drinking water, could either be groundwater or Chawale's spring. Only in case both options are found to be unsuitable, river water should be considered as an alternative source.

In case the permeability of the soil is found to be sufficient to yield the desired water amount, tapping groundwater is recommended. A well should be constructed, in which the submersible solar pump can be fixed directly.

If the groundwater yield is too low, but the spring water is found to be of acceptable drinking quality, for instance by treating it with a biosand filter, the spring water should be captured in a cavern. It is important that only the spring water is abstracted, so that it is not mixed with surface water, which would degenerate the overall water quality. From the cavern, the water should be conveyed in a pipeline to a pumping chamber located next to the PV array, from where the water would be lifted up to Thangchung.

To decide which water source is most suitable, a refined groundwater assessment at the proposed pump location (Section 6.2.2) should be carried out to answer the question whether a well could cover the drinking water demand. Furthermore, both the groundwater's as well as the spring water's quality should be analyzed.

6.2.2 Location

The location of the solar pump and the panels (Figure 6.4) are proposed to be outside of the orchard next to the recently built houses due to the following reasons:

- No shading of the panels by the plantation
- Located far enough from Thangchung's cliffs to have a sufficiently open sky
- Water collected outside of agricultural area preventing direct water intrusion of contaminated water
- Located far enough from the scarp, delineating the active riverbed from the plain, which may be subjected to side erosion

6.2.3 System characteristics

The solar system is described in Section 5.3.1. The input data as well as the results of the simulation can be found in Appendix B.4. The pipeline, with a total length of roughly 1'100 m and a diameter of 1 ½ inch, is proposed to be laid into the same trench as the irrigation pipeline (Section 6.1.3). Furthermore, the pipeline should lead up to the highest level in Thangchung (L4). This ensures that water can be brought to any place in Thangchung with gravity flow. Besides supplying water to each household, this water could be used for small-scale gardening or for a school and other public buildings.

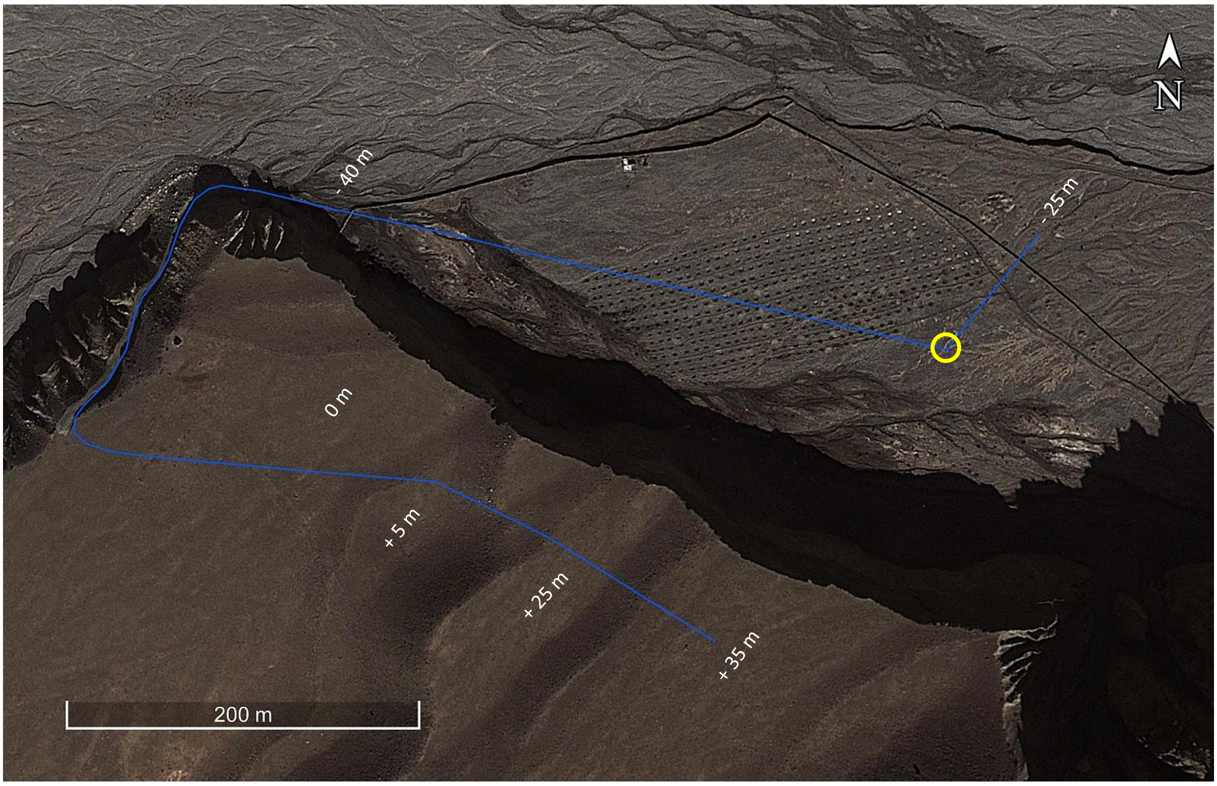

Figure 6.4: The pump and the solar panels are proposes to be located outside of the plantation's first section. After a short stretch, the supply line could be put into the trench used for the irrigation channel. The drinking water pipeline is proposed to lead all the way up to the fourth level (L4) of Thangchung. Like this, the water pumped up can flow to any place in Thangchung by gravity flow. The approximated relative elevations are indicated by the white numbers (source: Google Earth Pro, accessed 19/01/2014).

6.3 Exposure to flooding

Each structure built in Chawale is, without doubt, exposed to possible flooding. This holds likewise for the tree plantation and all buildings, the proposed irrigation supply channel as well as technical installations related to the solar pumping system providing drinking water to Thangchung. The flood plain of the Dhey Chang Khola between Phayung Karpo and the confluence with the Kali Gandaki is very wide. Furthermore the scarp along the northern border of Chawale is very high in the east and successively decreases towards west. Therefore, floods are expected to stay within the corridor limited by the scarp, which delineates the active riverbed from Chawale, especially in the east. To which degree that holds true for a possible GLOF or other flash floods, cannot be assessed within the scope of this report.

In any case, side-erosion of the scarp has to be expected. The most exposed area is the northwestern end of Chawale, on which the first section of the orchard is situated. To prevent area losses and protect all buildings and constructions in Chawale, the scarp has to be protected against side-erosion with gabions, while prioritizing the northwestern section.

Note that generally matured trees are quite a good measure against erosion, however mostly to reduce bank erosion and not to prevent flooding itself.

Overall, the protection of Chawale against side-erosion should receive upmost priority, as the investments could be in vain if a large flood heavily damages the completed structures and the young orchard.

7 Outlook

The report at hand should be considered as the base for any further investigations concerning technical aspects. It is recommended that the proposed irrigation and drinking water supply systems are investigated on implementation level together with the villagers and local contractors and suppliers. Especially the exact costs, including contributions of the villagers in terms of labor, skilled labor costs, transportation etc., should be evaluated in a next step.

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A Experiments and measurements

A.1 Leveling

Using a theodolite, a tripod, a 5 m leveling pole and a 50 m measurement tape two different leveling were made (Figure 10.1).

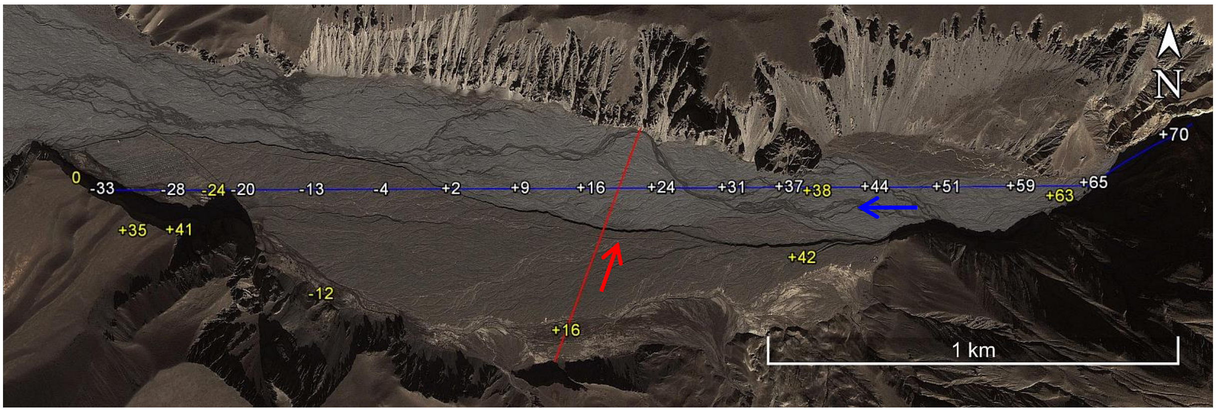


Figure 10.1: The first leveling (blue line, with indicated height in relation to the first level of Thangchung) was done from Phayung Karpo (29° 4'12.62"N / 83°58'36.59"E) downstream up to the scarp overlooking the first section (S1) of the orchard (29° 4'7.31"N / 83°56'46.02"E). The second profile (red line) was made from the left (29° 3'51.57"N / 83°57'33.90"E) across the whole plain to the right valley side (29° 4'12.71"N / 83°57'42.84"E). Due to the limited time, each leveling was measured only once in the indicated direction. The relative heights of the GPS measurements, presented in Appendix A.2 in detail, are indicted with yellow numbers (source: Google Earth Pro, accessed 14/01/2014).

The longitudinal leveling is presented in Figure 10.2, the lateral profile in Figure 10.3 respectively. The corresponding data can be found in Table 10.1 and Table 10.2 respectively.

Note, that the cross-sectional leveling (Figure 10.3) might be misleading. Since the leveling was not carried out along the lateral valley axis, the profile has also a component in the longitudinal direction. Thus, it seems that the valley is sloped towards south, even though this is not the case.

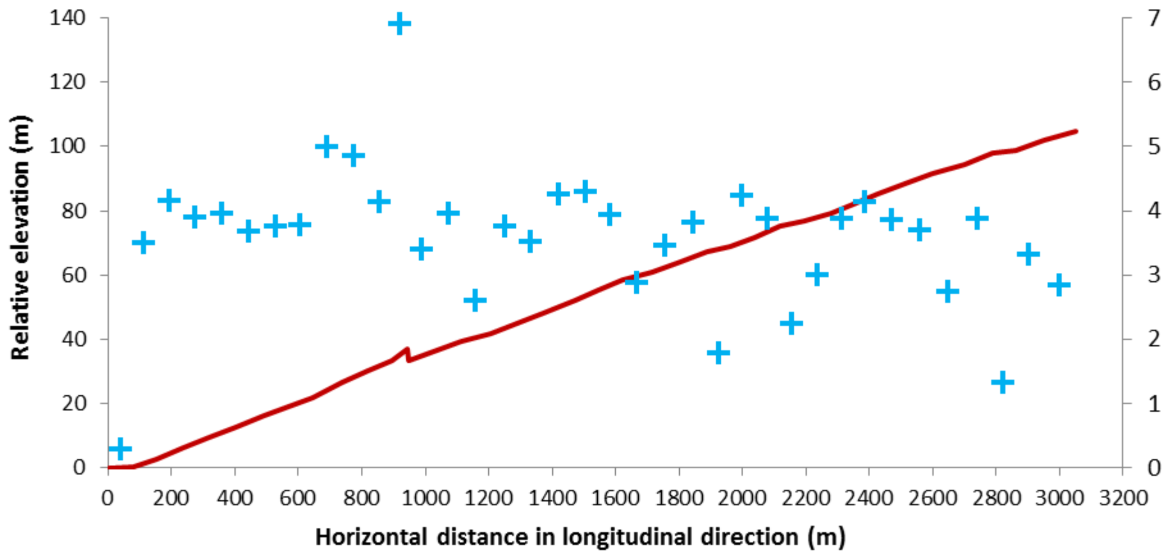


Figure 10.2: Longitudinal profile along the valley bottom from Phayung Karpo to the first section of the orchard. As can be seen from the profile, the valley bottom is quite evenly sloped. The tooth in the profile (red line) corresponds to the place, where the leveling jumped from the active riverbed onto the plain of Chawale. The scarp at this place is almost four meters high. The each section is indicated by the blue crosses.

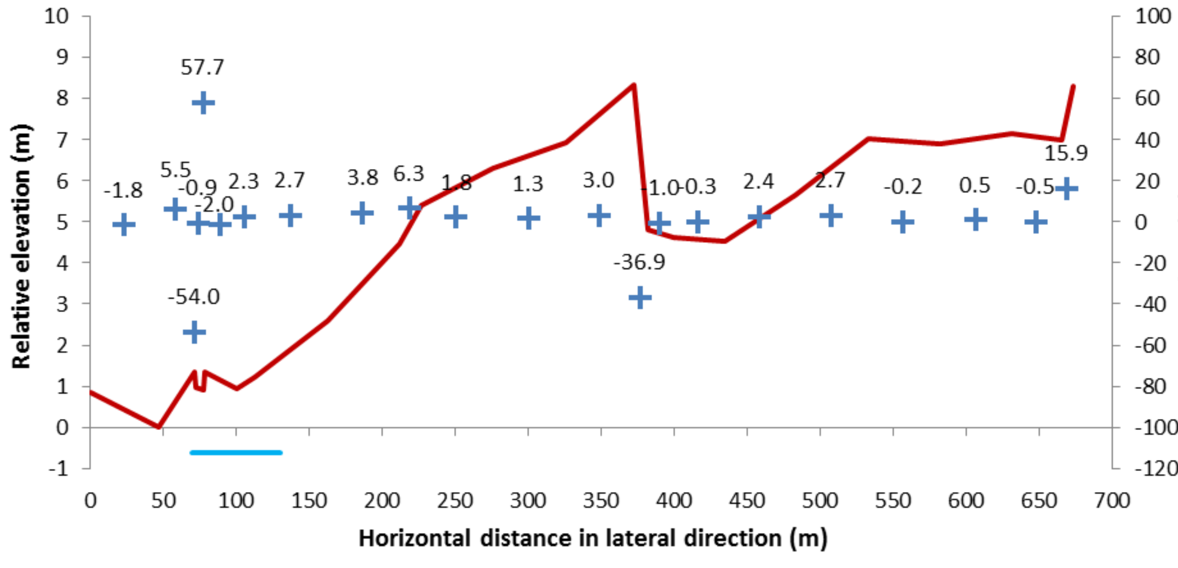


Figure 10.3: Lateral profile (red line) from the left valley side (d=0) to the right valley side. The blue crosses indicate the slope of each section. The blue line indicates the relative depth of the groundwater table, which could be incorporated since the groundwater experiment (Appendix A.4) was done on the leveling track. The riverbed which conveys the water used in the orchard can clearly be seen on the left. The active riverbed of Dhey Chang Khola is located at the distance between 400 and 500 m. Note that according to the profile, it seems as if the valley bottom is overall sloped. However, this is only the case, because the profile was not done along the contour line by mistake. Therefore, the profile is not a pure cross-section but also incorporates a longitudinal component, which causes the apparent inclination.

Table 10.1: Data of the longitudinal leveling from Phayung Karpo to the orchard.

Tachy position ID	Distance upstream	Height difference upstream	Distance down-stream	Height dif-ference downstream	Summed up height differ-ences	Summed up horizontal distance	Slope of each sec-tion
	(m)	*(m)*	*(m)*	*(m)*	*(m)*	*(m)*	*(%)*
01	49.8	0.460	50.0	3.285	104.63	3048.92	2.83
02	39.6	0.375	50.0	3.342	101.81	2949.16	3.31
03	49.7	0.408	21.8	1.345	98.84	2859.61	1.31
04	39.7	-0.100	50.0	3.375	97.91	2788.16	3.88
05	50.0	0.608	50.0	3.349	94.43	2698.53	2.74
06	28.0	0.260	50.0	3.145	91.69	2598.57	3.70
07	47.1	-0.050	49.4	3.660	88.80	2520.62	3.85
08	25.9	0.785	48.3	3.843	85.09	2424.19	4.12
09	22.2	0.501	49.7	3.290	82.04	2350.06	3.88
10	35.2	0.520	50.0	3.070	79.25	2278.21	2.99
11	23.1	1.690	49.8	3.315	76.70	2193.05	2.23
12	34.2	0.290	49.1	3.510	75.07	2120.17	3.87
13	24.9	0.791	50.0	3.955	71.85	2036.93	4.23
14	25.0	1.307	49.3	2.622	68.69	1962.10	1.77
15	36.6	0.347	49.3	3.625	67.37	1887.81	3.82
16	37.1	0.865	50.0	3.874	64.10	1801.97	3.46
17	42.7	0.359	50.0	3.027	61.09	1714.92	2.88
18	29.2	0.553	49.6	3.653	58.42	1622.26	3.94
19	23.2	0.833	49.5	3.948	55.32	1543.52	4.29
20	50.0	0.101	49.5	4.318	52.20	1470.89	4.24
21	24.5	0.401	50.0	3.020	47.99	1371.48	3.52
22	43.0	0.005	49.6	3.470	45.37	1297.02	3.74
23	44.1	0.658	49.4	3.092	41.90	1204.49	2.60
24	24.4	0.258	49.1	3.158	39.47	1111.02	3.95
25	93.9	0.502	-2.0	3.616	36.57	1037.58	3.39
26	29.2	0.130	48.7	3.347	33.53	895.11	4.13
27	30.7	0.162	49.6	4.049	30.32	817.28	4.85
28	42.0	0.369	49.7	4.940	26.43	737.07	4.99
29	34.4	0.372	42.3	3.263	21.86	645.49	3.77
30	29.3	0.486	47.8	3.380	18.97	568.84	3.76
31	41.4	-0.030	49.3	3.296	16.07	491.79	3.67
32	37.2	0.268	47.6	3.620	12.75	401.16	3.96
33	31.6	0.097	50.0	3.265	9.40	316.42	3.89
34	35.0	0.040	48.6	3.510	6.23	234.88	4.15
35	24.2	0.703	48.6	3.245	2.76	151.36	3.49
36	29.4	1.685	49.2	1.900	0.22	78.60	0.27

Table 10.2: Data of the lateral leveling from the left to the right valley bottom.

Position ID	Measured distance *(m)*	Relative height *(m)*	Horizontal distance *(m)*	Slope of each section *(%)*
01	0.00	0.860	0.00	-1.84
02	46.80	0.000	46.79	5.52
03	24.30	1.340	71.06	-53.98
04	0.80	0.960	71.76	-0.91
05	5.50	0.910	77.26	57.74
06	0.90	1.360	78.04	-1.96
07	21.90	0.930	99.93	2.32
08	12.50	1.220	112.43	2.72
09	50.00	2.580	162.41	3.85
10	49.30	4.475	211.68	6.27
11	14.60	5.388	226.25	1.84
12	49.70	6.303	275.94	1.26
13	49.70	6.928	325.63	3.01
14	46.60	8.330	372.21	-36.95
15	10.20	4.795	381.78	-0.99
16	17.50	4.622	399.28	-0.31
17	35.00	4.514	434.28	2.36
18	48.30	5.655	482.57	2.73
19	50.00	7.018	532.55	-0.25
20	49.30	6.895	581.85	0.54
21	49.50	7.160	631.35	-0.46
22	33.50	7.005	664.85	15.87
23	8.20	8.290	672.95	

A.2 GPS measurements

The most important points (Figure 10.4 and Figure 10.5) were measured with the PPP GPS module NEO-6P from u-blox with a Flash-EEPROM for non-volatile memory in a waterproof casing and USB interface together with the Global Navigation Satellite System (GNSS) high precision antenna TW2410 from Tallysman[10]. Although u-blox advertises its device to reach accuracies in the range of decimeters, it turned out not be true for measurements undertaken in Upper Mustang. Different methods (PPP post-processing as well as setting up a Virtual Reference Station (VRS) using Ashtech's GNSS Solutions software) were used to improve the inconsistent data set. Comparing the results using different post-processing methods revealed that not only the u-blox data itself, but also the post-processed data was scattered heavily. No systematic errors could be identified. However, it became clear, that measurements taken under better conditions (clear sky, little obstructions on the horizon, long measurement period, etc.), would also agree better across the different post-processing methods.

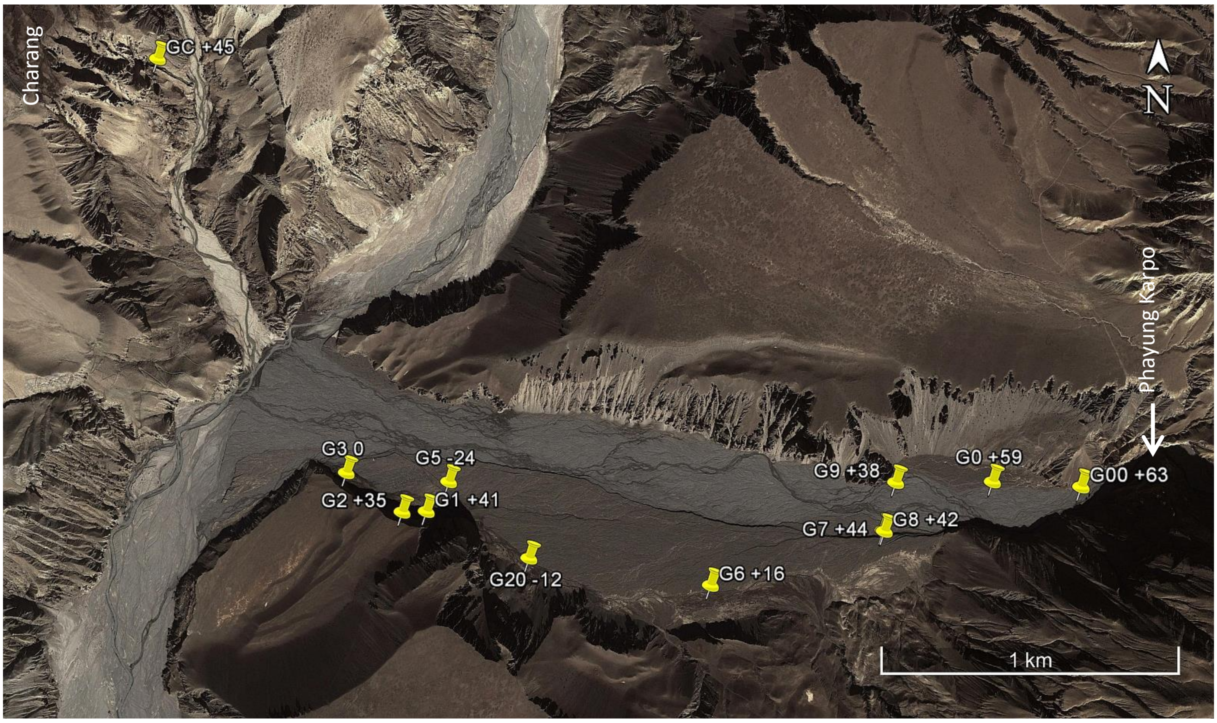


Figure 10.4: Illustration of the GPS measurement points with the indication of the relative elevation in relation to the point G3 located at the northern end of Thangchung given in meters. Note that these relative elevations are subjected to qualitatively assessed uncertainty ranges presented in Table 10.3 (source: Google Earth Pro, accessed 19/01/2014).

The GPS measurements were also compared with the leveling data (Appendix A.1) and were found to agree rather poorly. Since the leveling was only done in one direction, there is no

[10] See http://www.u-blox.com/en.html and http://www.tallysman.com for reference respectively

information about the uncertainty of the leveling's data. As the error of the GPS data cannot be assessed in detail either, one method cannot be used to say something about the other's accuracy.

From all the post-processing methods, the Canadian Spatial Reference System (CSRS) PPP service[11] seemed to yield the most reliable data. However, this service only provided elliptical elevations. To convert it to elevations above sea level, the Earth Geoid Model 2008 of South Eastern Asia (EGM08SEA)[12] was used. Curiously enough, this model exhibits an average difference to the u-blox solution of roughly 8 m, whereas the underlying reasons remain unclear.

Taking all these insights together, combining the GPS data processed with different methods as well as the leveling data, the relative elevations of characteristic points were qualitatively assessed (Table 10.3). Due to the very large uncertainty related to the absolute elevations, in the report at hand the mentioning thereof is forgone and is replaced by relative elevations, always in relation to the elevation of the first level (L1) at 29° 4'8.5247"N / 83°56'42.9090"E.

Table 10.3: Data of the measured GPS points, displayed in Figure 10.4 and Figure 10.5 respectively. Note that the uncertainty of the position (latitude, longitude) is roughly ten times smaller than the uncertainty associated with the elevation.

ID	**Place description**	**Latitude** *(° min s northing)*	**Longitude** *(° min s easting)*	**Rel. elevation** *(m)*	**Uncertainty** *(m)*
GC	Charang's spring	29° 05' 00.2824"	83° 56' 16.3129"	+ 45	± 10
G00	Below Phayung Karpo	29° 04' 06.6984"	83° 58' 25.9830"	+ 63	± 10
G0	Farther below Phayung Karpo	29° 04' 07.2886"	83° 58' 14.5551"	+ 59	± 5
G1	Highest point in Thangchung	29° 04' 03.6971"	83° 56' 54.6899"	+ 41	± 5
G2	Level 4 in Thangchung	29° 04' 03.6170"	83° 56' 51.2347"	+ 35	± 2.5
G3	Level 1 in Thangchung	29° 04' 08.5247"	83° 56' 42.8990"	0	± 2.5
G5	Leveling point, orchard	29° 04' 07.3569"	83° 56' 57.6634"	- 24	± 1
G6	Groundwater experiment	29° 03' 54.4850"	83° 57' 35.1192"	+ 16	± 2.5
G7	End of abstraction channel	29° 04' 01.2516"	83° 57' 59.5710"	+ 44	± 5
G8	End of abstraction channel	29° 04' 01.1677"	83° 57' 59.7306"	+ 42	± 2.5
G9	Leveling point, Chawale east	29° 04' 07.2122"	83° 58' 01.2918"	+ 38	± 2.5
G10	Pass between spring and Dheye	29° 01' 31.0288"	83° 59' 55.5831"	+ 933	± 2.5
G12	Spring supplying Dheye	29° 00' 58.3471"	83° 59' 59.4613"	+ 953	± 2.5
G14	Pass between spring and Thang.	29° 02' 35.1962"	83° 59' 07.8159"	+ 897	± 2.5
G20	Chawale's spring	29° 03' 57.8367"	83° 57' 09.2996"	- 12	± 5

[11] http://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9052

[12] http://resources.ashtech.com/GEOIDS/maps.htm

Figure 10.5: Illustration of the GPS measurement points, which were assessed in the context of the possible pipeline tapping the spring currently supplying drinking water to Dheye. The numbers beside the measurements' ID indicates the relative elevation compared to the point G3 located at the northern end of Thangchung. The associated uncertainty ranges, together with the coordinates, are presented in Table 10.3 (source: Google Earth Pro, accessed 19/01/2014).

A.3 Yield estimation of the spring in Chawale with the tracer method

The cumulative flow of the distributed small springs in Chawale was measured with the tracer method[13]. First, the relation between conductivity and transported salt had to be established. For that matter, the conductivity of the raw water (salt concentration of 0 mg/l) was measured. Following, the concentration was increased to 1000 mg/l and 2000 mg/l and the corresponding conductivities were recorded again. The conductivity was then plotted against the salt concentration (Figure 10.6). The slope of the line of best fit produced the conversion factor required to convert the measured conductivity back to salt concentration for the final flow estimation.

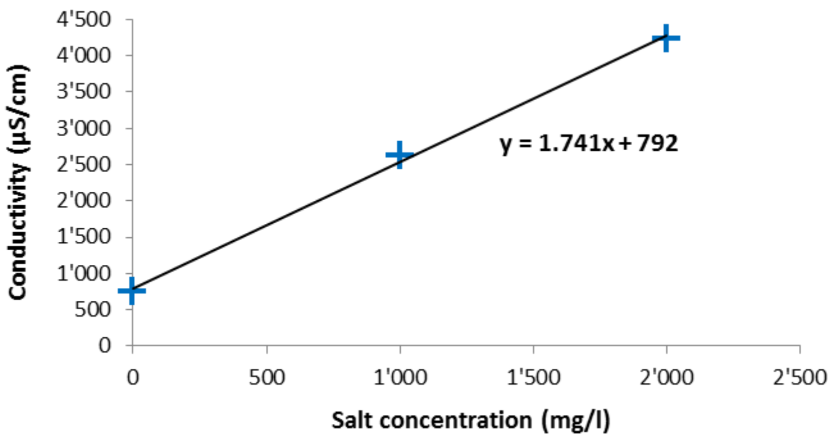


Figure 10.6: The function of the line of best fit gives the conversion factor (1.741) from salt concentration to conductivity. Additionally, the equation indicates the approximated conductivity of the raw water (792 mS/cm).

After the relationship between conductivity and salt concentration had been established, 50 g of salt was dissolved in the raw water. The salt water was added upstream of the point, where the probe head of the conductivity logger had been installed (Figure 10.7). The salt water was added and the conductivity was recorded in short regular intervals. Plotting the measurements against time, a so-called through break curve results. Using the fact, that the product of the mean concentration and the time span of the through break curve remains constant within each streamline of the flow media, the flow rate can be estimated. The conductivity is converted back to salt concentration and the resulting curve (salt concentration versus time) is integrated. Dividing the absolute salt mass added to the river by the integral of the salt concentration through break curve, finally gives the estimated flow rate. Thus, the flow rate on September 24th 2013 was estimated to be 16 l/s.

[13] For background information on tracer methods refer to Wernli (2011) for instance.

Figure 10.7: Daniel Bernet sitting next to Fidel Devkota and Pema Chewang who are assisting the experiment. The probe head of the conductivity meter is immersed in the water (orange arrow) and is sending the measurement values to the connected laptop. The flow direction is indicated by the blue arrow. On the right hand side the GPS antenna (red arrow) mounted on a tripod can be seen. With the GPS device the elevation of the spring could be approximated (photo: 24/09/2013, Marco Baumer).

A.4 Estimation of the hydraulic conductivity

A hole was dug (29° 3'54.49"N / 83°57'35.12"E) with the dozer until the groundwater table was hit. After the water had accumulated in the pit during the night, water was extracted with buckets. Counting the buckets, the volume of the extracted water could be estimated. Furthermore the drawdown and especially the time until the water table was at its original level were measured.

Figure 10.8: Marco Baumer is standing in the dug hole reaching down into the groundwater table. He is filling the buckets and hands them to Pema Chewang who empties them and passes them back. Daniel Bernet is keeping track of how many buckets of water are being removed from the pit (photo: 24/09/2013, Fidel Devkota).

The hydraulic conductivity was then determined with the Lefranc test (Figure 10.9). Due to the large uncertainty inherent to the measurement method, the k values range from $3 \cdot 10^{-3}$ to $3 \cdot 10^{-4}$ m/s. Thus, the experiment was not accurate enough to obtain precise results. Nevertheless, it seems that the permeability is too low to satisfy the irrigation demand.

Lefranc test

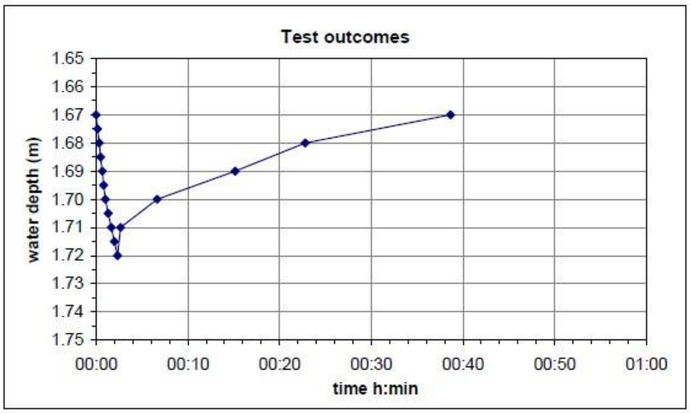
Well depth:	2.0 m
Depth of infiltration area:	1.5 m

Permeability after **Lefranc formula:**

Depth of water before test (Hr):	1.669 m
Final water depth (Ho):	1.7 m
Length of well (l):	0.5 m
Well diameter (d):	2.00 m
Shape correction (G):	2.40E-01

average k (m/s)	k regression (m/s)
3.6E-03	**3.4E-04**

time elapsed	water depth (m)	ΔH = (h_{i-1}-H_r)/(h_{i-}	lnΔH	ΣlnΔH	ΣΔt (sec)	Δk (m/s)
00:00:00	1.67					
00:00:10	1.68	0.1667	-1.7918	-1.7918	10	-4.3E-02
00:00:20	1.68	0.5455	-0.6061	0.6061	20	1.5E-02
00:00:30	1.69	0.6875	-0.3747	0.3747	30	9.0E-03
00:00:40	1.69	0.7619	-0.2719	0.2719	40	6.5E-03
00:00:50	1.70	0.8077	-0.2136	0.2136	50	5.1E-03
00:01:00	1.70	0.8387	-0.1759	0.1759	60	4.2E-03
00:01:20	1.71	0.8611	-0.1495	0.1495	80	1.8E-03
00:01:40	1.71	0.8780	-0.1301	0.1301	100	1.6E-03
00:02:00	1.72	0.8913	-0.1151	0.1151	120	1.4E-03
00:02:20	1.72	0.9020	-0.1032	0.1032	140	1.2E-03
00:02:40	1.71	1.2439	0.2183	-0.2183	160	-2.6E-03
00:06:40	1.70	1.3226	0.2796	0.2796	400	2.8E-04
00:15:10	1.69	1.4762	0.3895	0.3895	910	1.8E-04
00:22:49	1.68	1.9091	0.6466	0.6466	1369	3.4E-04
00:38:40	1.67	11.0000	2.3979	2.3979	2320	6.1E-04



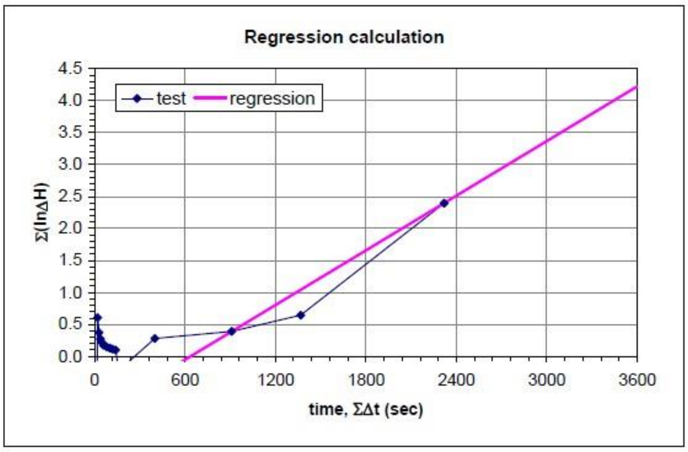


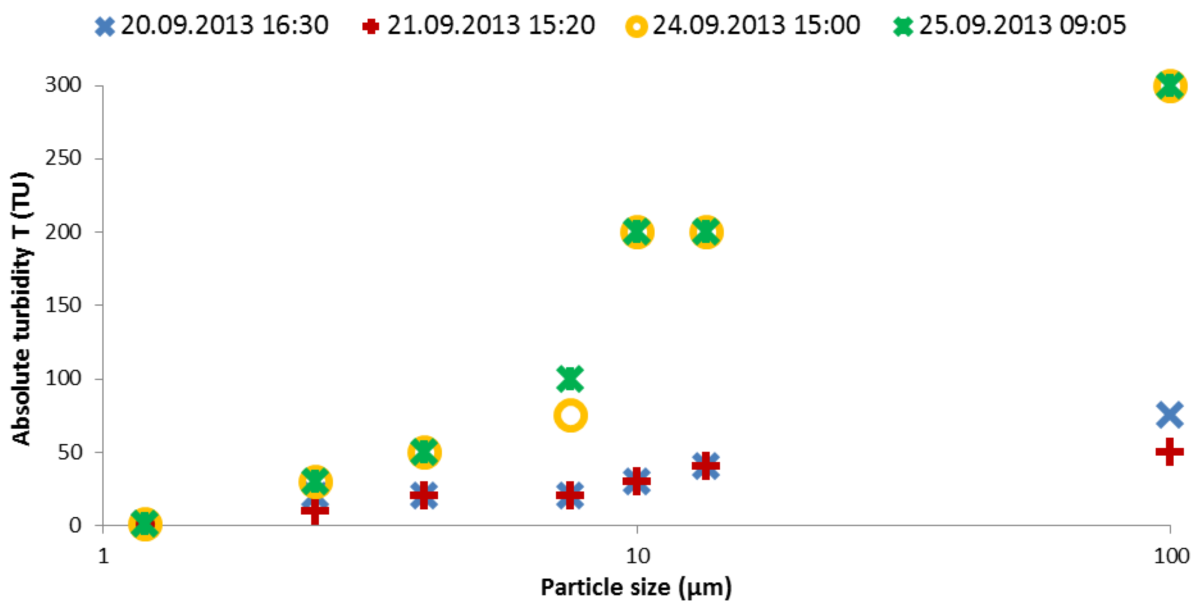
Figure 10.9: Input data and results of the Lefranc test used to estimate the hydraulic conductivity of the soil in Chawale.

A.5 Filterability of Dhey Chang Khola's surface water

Water was abstracted from the Dhey Chang Khola (29° 4'5.04"N / 83°58'10.04"E) and put into a bucket. The turbidity of the raw water was determined visually with turbidity tubes. Then, the raw water was filtered by inserting filter papers with decreasing pores (15-12, 12-8, 8-5, 5-3, 2-3, 1.2 µm). For the filtration a syringe and a filter holder were used. The raw water in the bucket was stirred, taken in with the syringe and directly filtered into the turbidity tube until the black ring at the bottom of the tube disappeared. The corresponding turbidity was recorded (Figure 10.10).

Figure 10.10: Marco Baumer using the syringe (red arrow) to successively filtering the abstracted water with the graded filter paper inserted into the filter holder (orange arrow). Daniel Bernet is holding on to the turbidity tube with which the turbidity can be assessed visually (photo: 24/09/2013, Fidel Devkota).

Due to the coarse measurement method, the experiment's results are difficult to interpret. The absolute turbidity distribution (top, Figure 10.11) shows that the turbidity of the abstracted water was much higher during the later two experiments. This considerable change in turbidity was due to rain- and snowfall in the mountains on September 23rd 2013. After that day, the color of the river water changed from previously grey to dark brown, which is supported by the turbidity measurements. It does not seem possible to draw conclusions about the particle distributions using the relative turbidity distribution (bottom, Figure 10.11) due to the coarse measurement method.



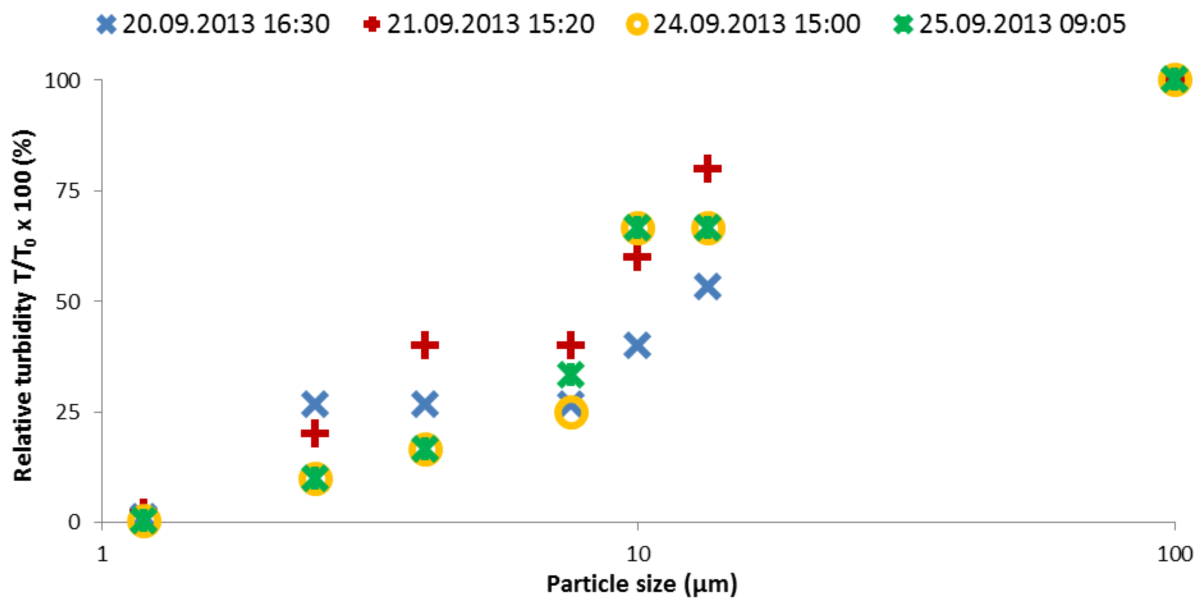
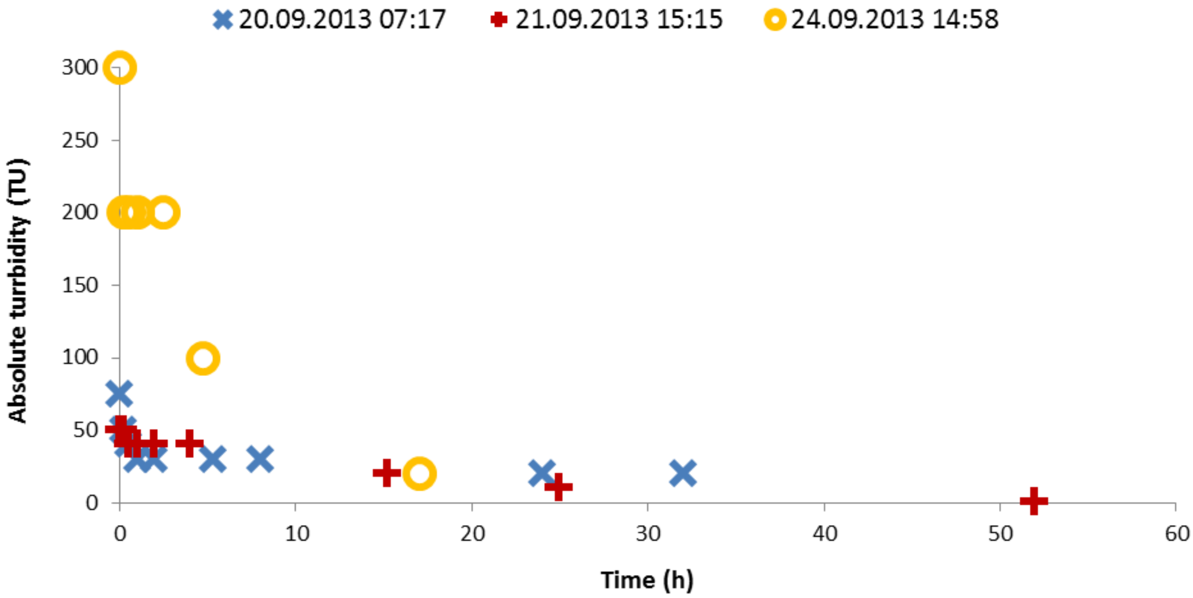


Figure 10.11: Absolute (top) and relative turbidity distribution (bottom) of the filterability tests with samples taken on different days at different times.

A.6 Suspension stability of Dhey Chang Khola's surface water

Water was abstracted from the Dhey Chang Khola (29° 4'5.04"N / 83°58'10.04"E) and set to rest in bucket. In increasing intervals a small amount of water was abstracted from the bucket trying not to disturb the still water. The turbidity of the abstracted water was then determined visually with a turbidity tube.



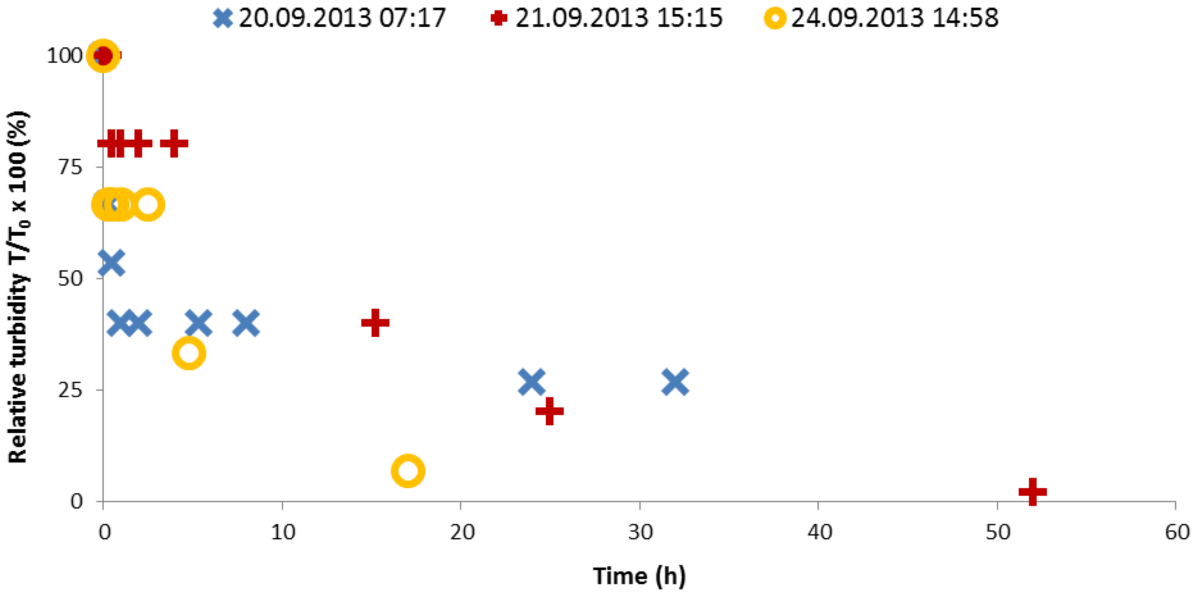


Figure 10.12: Absolute (top) and relative turbidity (bottom) of the suspension stability test with samples taken on different days at different times.

The results show nicely that the turbidity, after the before mentioned precipitation event (Appendix A.5), was much higher than during the two previous measurements (top, Figure 10.12).

The experiment also shows that especially in case the turbidity is increased due to higher discharges in the river, for instance caused by rainfall or snow and ice melt, letting the water sit is a very efficient method to increase the water quality (bottom, Figure 10.12). However, if the turbidity is smaller during normal flow conditions for example, the relative turbidity only decreases very slowly. This suggests that the suspension is very stable during normal flow conditions. However, if the discharge is increased, small particles get mobilized and are transported along. These particles are settling down quickly again, once the water is moving slower or even stops completely. Therefore, a settlement pond is particularly efficient to remove suspended particles during turbidity peaks.

A.7 Settleable solids of Dhey Chang Khola's surface water

Water was abstracted from the Dhey Chang Khola (29° 4'5.04"N / 83°58'10.04"E) and set to rest in a 1'000 ml Imhoff cone. In increasing intervals the amount of settled solids was recorded.

The experiment shows that suspended particles of the abstracted water are settling down slowly once the water is still (Figure 10.13). Furthermore, it highlights the fact, that during normal flow conditions, as found on September 20th and 21st, there are no or very few settleable solids transported along in suspension. Higher discharges like on September 24th caused by precipitation events with generally higher turbidities are associated with rather high amount of suspended solids, which can settle down easily. Letting the water sit is a good measure to remove these particles from the suspension. While a lot of particles already settle down within few hours, the smaller ones take around 24 hours to sediment. According to these experiments, the water should sit for 24 hours to get best results.

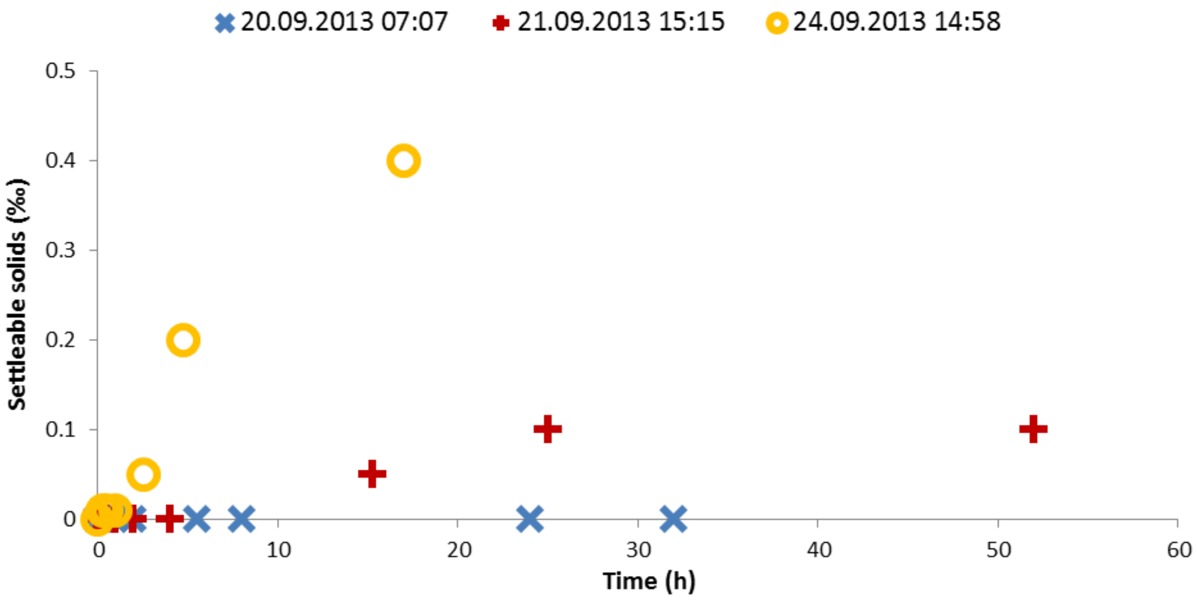


Figure 10.13: Evolution of the settled solids' volume relative to the total abstracted water volume with increasing time the water is sitting still.

A.8 Assessment of the horizon at different places in and around Thangchung

To assess the suitability of different locations for the use of a solar system, the horizon of three different places was assessed using a geologic compass. The data was then inserted into a sun path diagram, with which the effect of the horizon on sunshine duration can be compared.

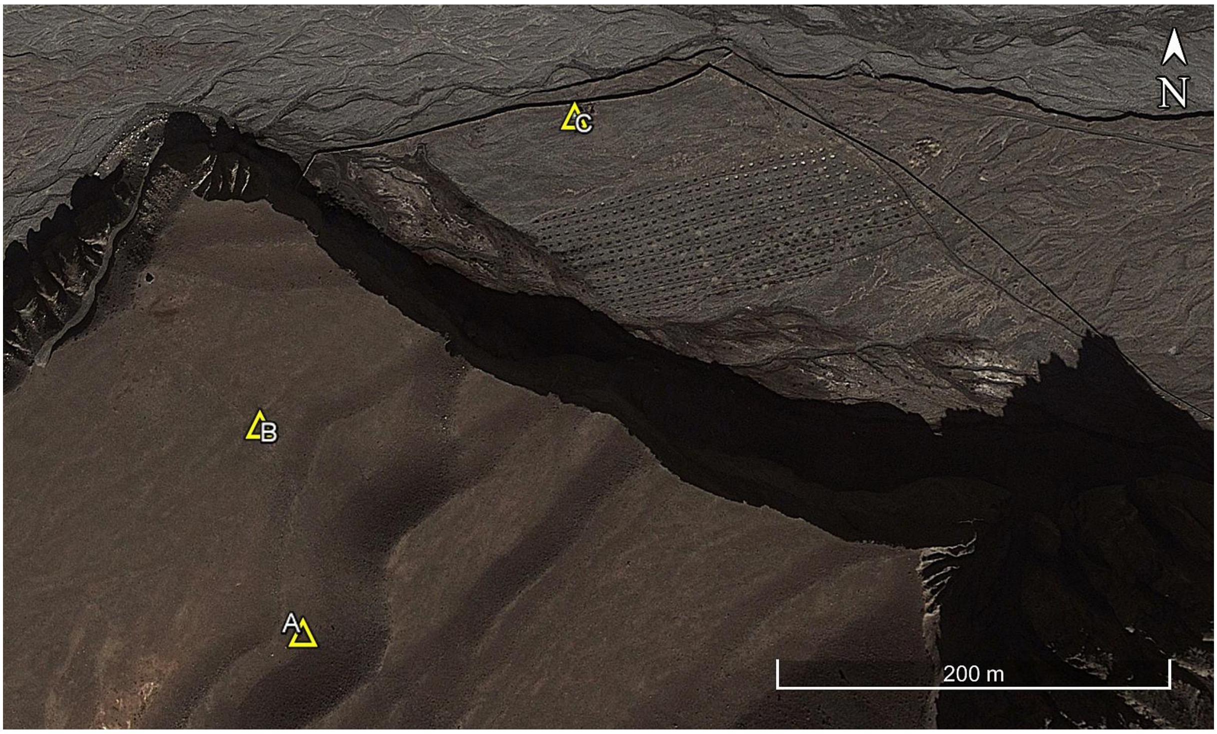


Figure 10.14: Location of the three different spots for which a sun path diagram has been assessed. The corresponding diagrams are presented in Figure 10.15, Figure 10.16 and Figure 10.17, respectively (source: Google Earth Pro, accessed 19/01/2014).

The major difference between the three locations is that on the second level (A) the sky is more obstructed, to the effect that the sun rises almost an hour later. For all assessed locations, the horizon is similar towards west, so that the sun sets at all three locations at about the same time.

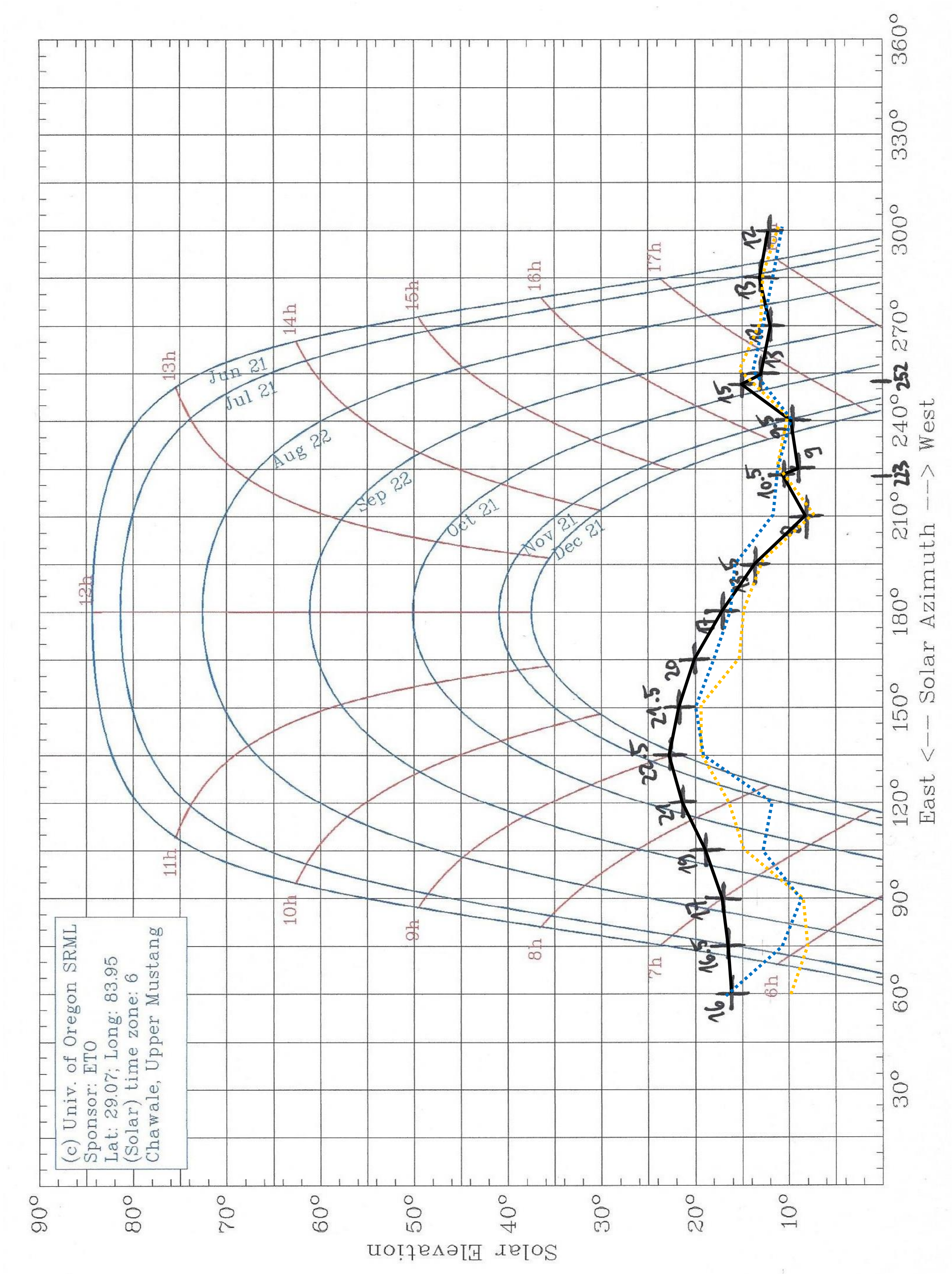


Figure 10.15: Sun path diagram for the place A (29°04'01.81"N / 83°56'41.40"E) located on the second level of Thangchung (L2), as further specified in Figure 10.14. The orange dotted line indicates the horizon of location B (Figure 10.16), and the blue line of the location C (Figure 10.17).

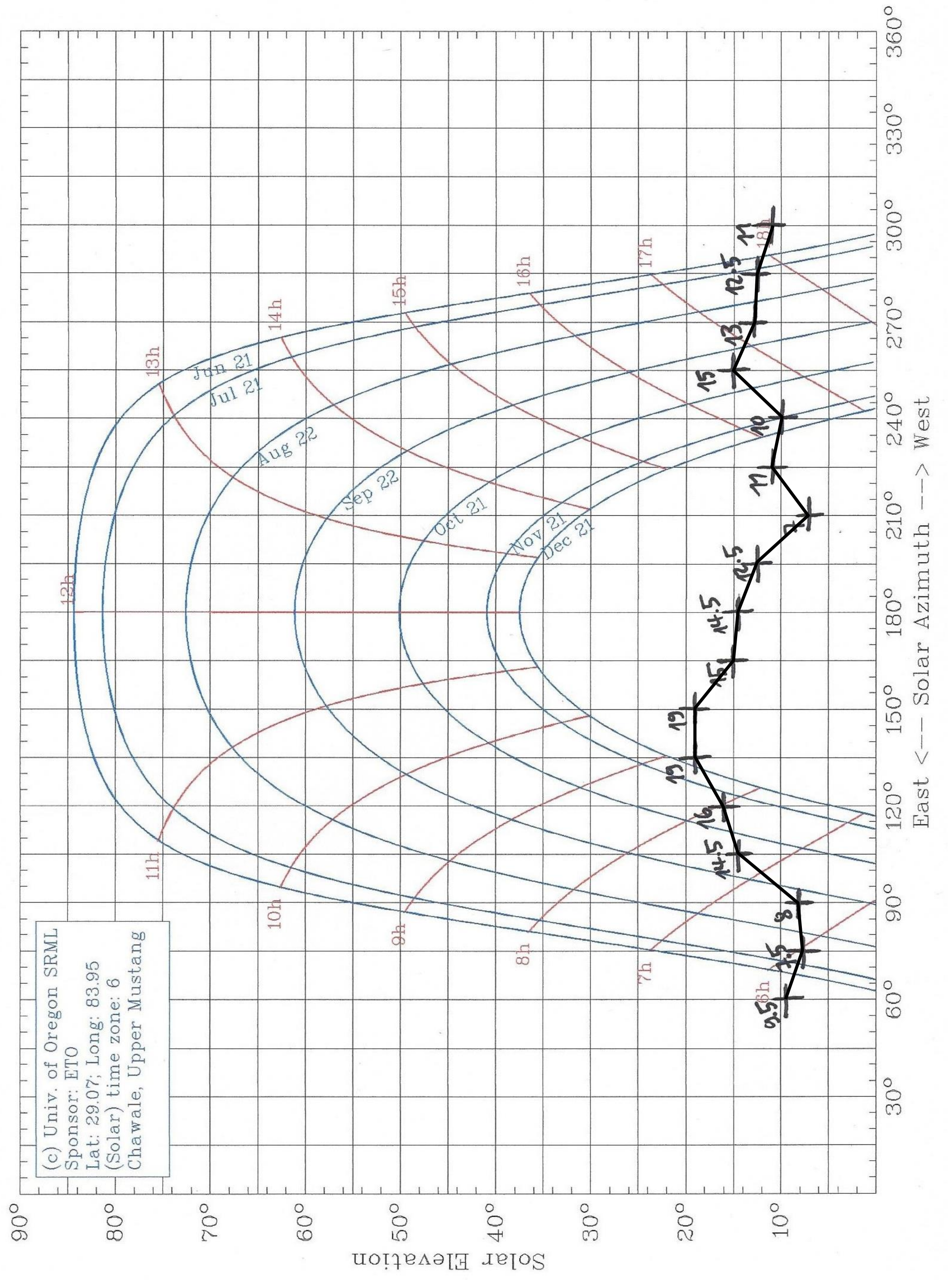


Figure 10.16: Sun path diagram for the place B (29°04'05.74"N / 83°56'40.40"E) located on the first level of Thangchung (L1), as further specified in Figure 10.14.

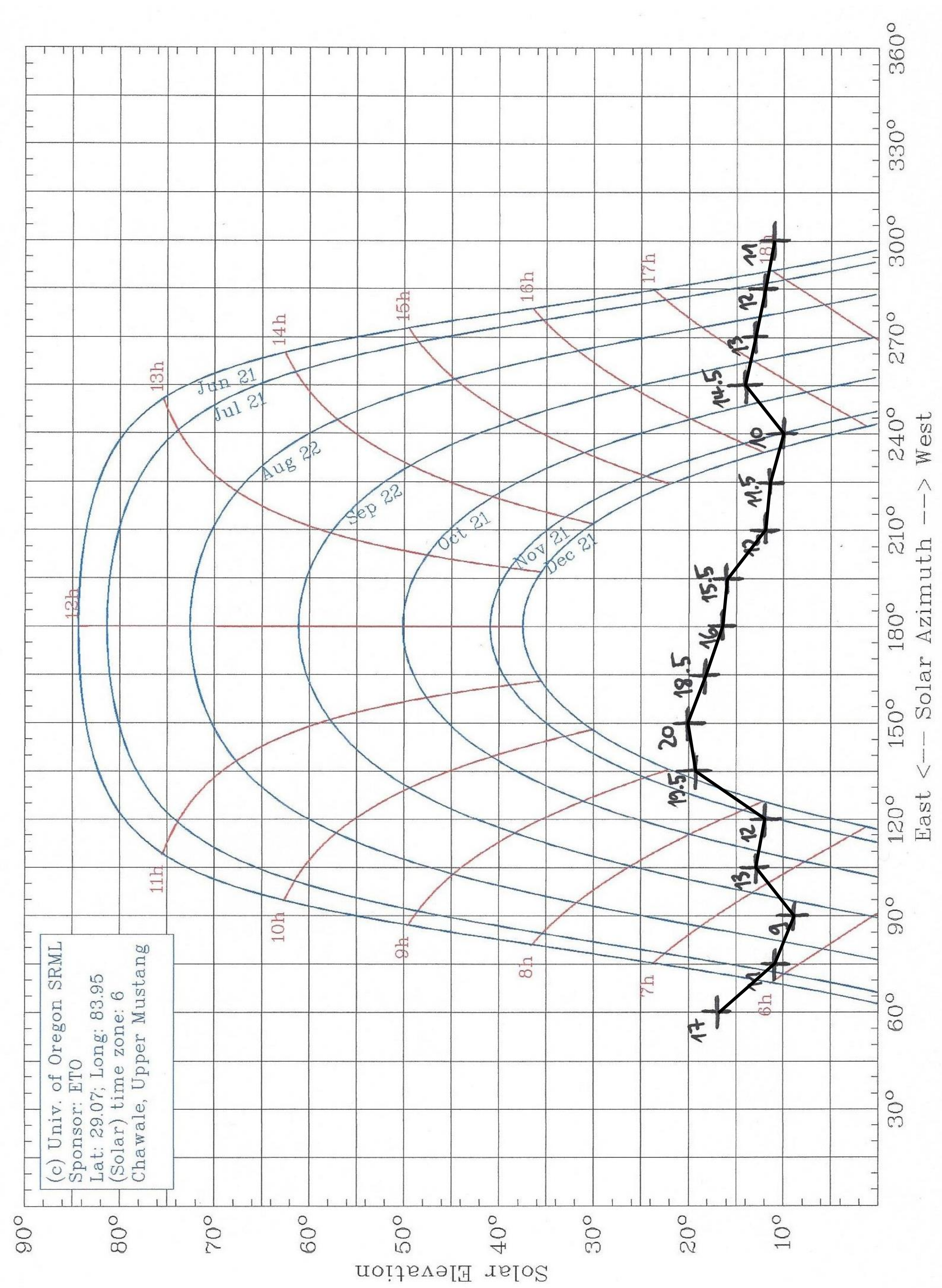


Figure 10.17: Sun path diagram for the place C (29°04'11.88"N / 83°56'47.31"E) located on the first level of Thangchung (L1), as further specified in Figure 10.14.

B Data and calculations

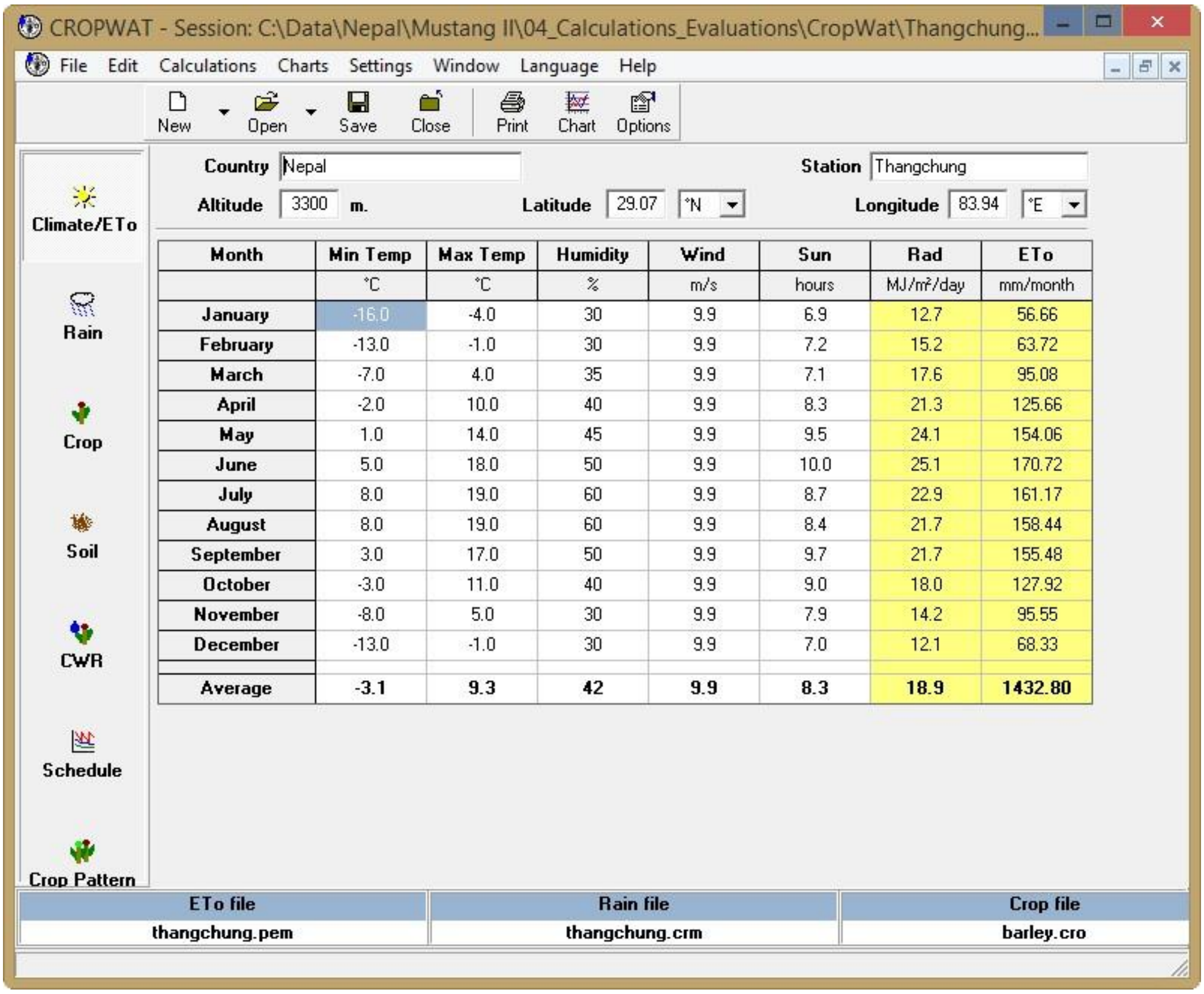
B.1 Population and households from Dheye

Table 10.4: List of all 24 households in Dheye, whereof ten moved to a different place within the last two decades (Devkota 2013). Out of the total population 146 wish to move to Thangchung. In addition Karchung Gurung who has roots in Dheye, together with her husband and two children, would like to join Dheye's community in Thangchung. Thus, the total expected population in Thangchung amounts to 150 people and 24 households as of January 2014.

Household ID	Head of the family	Family members	Current residence	Move to Thangchung?
1	Decchen Gurung	3	Dheye	Yes
2	Dorje Chopten Gurung	8	Kathmandu	Yes
3	Jamyang Wangchuk Gurung	10	Dheye	Yes
4	Karma Gurung	7	Dheye	Yes
5	Kungsan Rinzin Gurung	8	Dheye	Yes
6	Norbu Wangchuk Gurung	2	Charang	Yes
7	Pasang Gurung	9	Dheye	Yes
8	Pasang Wangdu Gurung	5	Dheye	Yes
9	Chewang Rinzin	4	Pokhara	Yes
10	Pema Tsewang Gurung	6	Dheye	Yes
11	Sangbo Gurung	7	Dheye	Yes
12	Sonam Gyaltsen Gurung	4	Dheye	Yes
13	Tachung Gurung	5	Tsusang	Yes
14	Tashi Choden Gurung	9	Dheye	Yes
15	Tashi Chopel Gurung	13	Dheye	Yes
16	Tashi Phuntosk Gurung	12	Charang	No
17	Tashi Rinzin Gurung	4	Muktinath	Yes
18	Topri Gurung	3	Dheye	Yes
19	Tsering Butti Gurung	4	Jomsom	Yes
20	Tsering Choedup Gurung	12	Charang	Yes
21	Tsering Dhake Gurung	8	Dheye	Yes
22	Tsering Largyal Gurung	7	Pokhara	Yes
23	Tsonam Tsering Gurung	7	Dheye	Yes
24	Yangchen Gurung	1	Senegal	Yes
Total		**158**		**146**

B.2 Estimation of crop water requirement with CROPWAT 8.0

As mentioned in Section 3.1, the required mean monthly minimum and maximum temperatures were guessed based on data from Mustang, Lobuche (Nepal) and Leh (India) by Giovanni Kappenberger, an experienced meteorologist and climatologist. These temperature values were fed into FAO's CROPWAT 8.0 (Figure 10.18). Furthermore, the humidity and the maximal wind speed were adjusted to reflect the observed conditions in Upper Mustang.



Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/month
January	-16.0	-4.0	30	9.9	6.9	12.7	56.66
February	-13.0	-1.0	30	9.9	7.2	15.2	63.72
March	-7.0	4.0	35	9.9	7.1	17.6	95.08
April	-2.0	10.0	40	9.9	8.3	21.3	125.66
May	1.0	14.0	45	9.9	9.5	24.1	154.06
June	5.0	18.0	50	9.9	10.0	25.1	170.72
July	8.0	19.0	60	9.9	8.7	22.9	161.17
August	8.0	19.0	60	9.9	8.4	21.7	158.44
September	3.0	17.0	50	9.9	9.7	21.7	155.48
October	-3.0	11.0	40	9.9	9.0	18.0	127.92
November	-8.0	5.0	30	9.9	7.9	14.2	95.55
December	-13.0	-1.0	30	9.9	7.0	12.1	68.33
Average	-3.1	9.3	42	9.9	8.3	18.9	1432.80

Figure 10.18: Screenshot of the climate tab of CROPWAT 8.0. Note that first only the mean monthly minimal and maximal temperatures were entered. All other values were automatically calculated according to (Allen et al. 1998) based on temperature, as well as altitude, latitude and longitude of the chosen location. The standard values for humidity and wind were adjusted afterwards to reflect the harsh climatic conditions in Upper Mustang (source: CROPWAT 8.0, downloaded from http://www.fao.org/nr/water/infores_databases_cropwat.html, accessed 13/12/2013).

As the precipitation rates are extremely low (Bernet et al. 2012b) in Upper Mustang, the effective rainfall, which can be entered in the rain tab in CROPWAT (Figure 10.18), were set to zero.

In the crop tab, the crop factors could be entered. The standard values based on Allen et al. (1998) were loaded (Figure 10.19). Following the crop water requirement could be calculated (Figure 10.20).

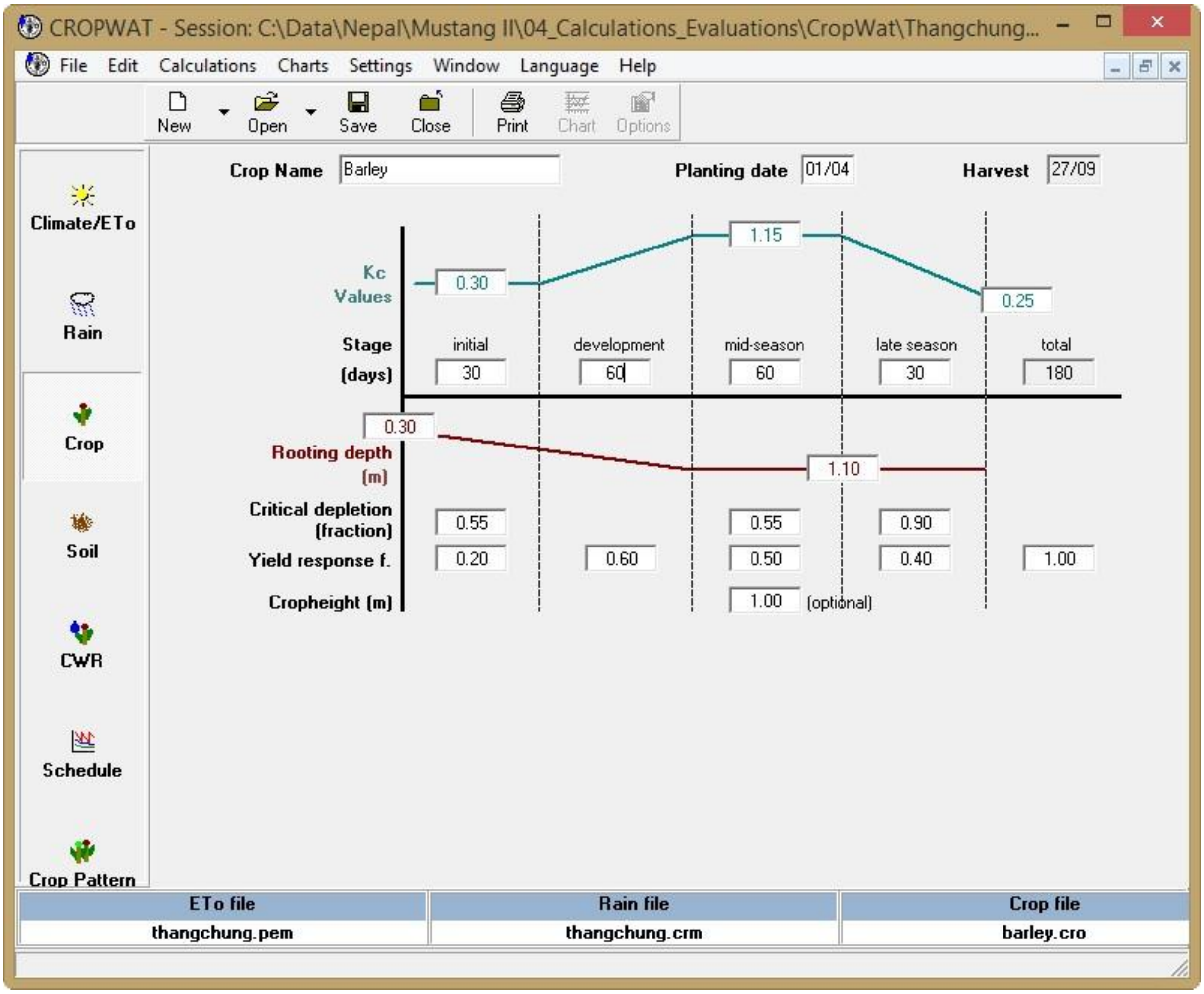
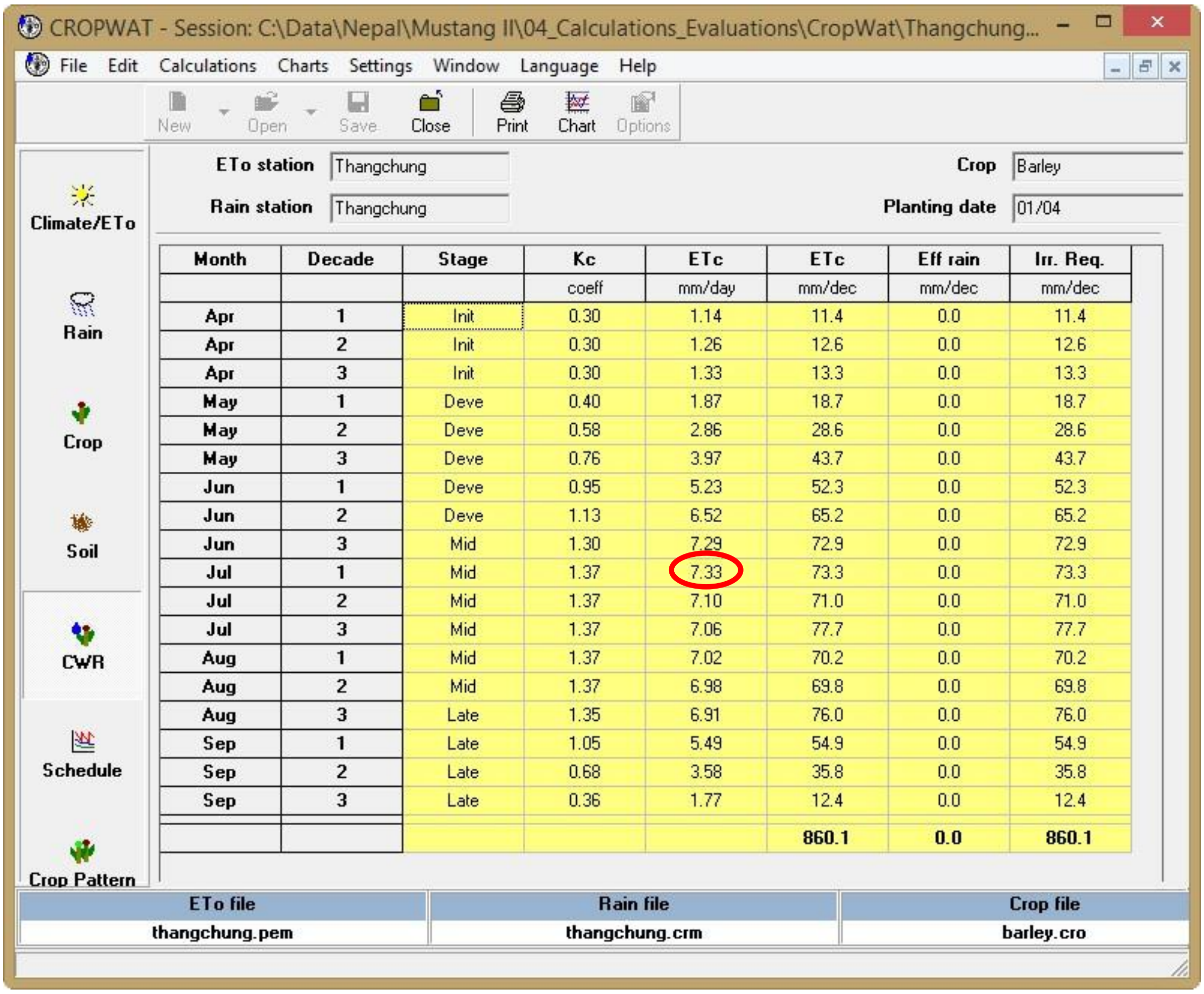


Figure 10.19: Screenshot of the crop tab of CROPWAT 8.0. The predefined standard values of barley and oats, which corresponds to the main crops harvested in Dheye, were loaded. Depicted are the values for barley. Only the stage and the planting date were adjusted to match the local harvest practice in Dheye (source: CROPWAT 8.0, downloaded from http://www.fao.org/nr/water/infores_databases_cropwat.html, accessed 13/12/2013).



Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.30	1.14	11.4	0.0	11.4
Apr	2	Init	0.30	1.26	12.6	0.0	12.6
Apr	3	Init	0.30	1.33	13.3	0.0	13.3
May	1	Deve	0.40	1.87	18.7	0.0	18.7
May	2	Deve	0.58	2.86	28.6	0.0	28.6
May	3	Deve	0.76	3.97	43.7	0.0	43.7
Jun	1	Deve	0.95	5.23	52.3	0.0	52.3
Jun	2	Deve	1.13	6.52	65.2	0.0	65.2
Jun	3	Mid	1.30	7.29	72.9	0.0	72.9
Jul	1	Mid	1.37	7.33	73.3	0.0	73.3
Jul	2	Mid	1.37	7.10	71.0	0.0	71.0
Jul	3	Mid	1.37	7.06	77.7	0.0	77.7
Aug	1	Mid	1.37	7.02	70.2	0.0	70.2
Aug	2	Mid	1.37	6.98	69.8	0.0	69.8
Aug	3	Late	1.35	6.91	76.0	0.0	76.0
Sep	1	Late	1.05	5.49	54.9	0.0	54.9
Sep	2	Late	0.68	3.58	35.8	0.0	35.8
Sep	3	Late	0.36	1.77	12.4	0.0	12.4
					860.1	0.0	860.1

Figure 10.20: Screenshot of the crop water requirement (CWR) tab of CROPWAT 8.0. The maximal daily irrigation water requirement (in this case corresponding to ETc) was needed. Under the given conditions, the maximal irrigation intensity corresponds to 7.33 mm/d, as highlighted by the red circle (source: CROPWAT 8.0, downloaded from http://www.fao.org/nr/water/infores_databases_cropwat.html, accessed 13/12/2013).

B.3 Solar pumping scheme for irrigation

To evaluate the potential of solar pumping, the freeware tool CASS from NOV Mono was used (Jeffery 2013). The results of this simulation are shown in Figure 10.21. It shows the capacity of one single solar pump. To supply the necessary water volume, 49 such pumps would be necessary as shown in Table 4.2 in Section 4.4.1.

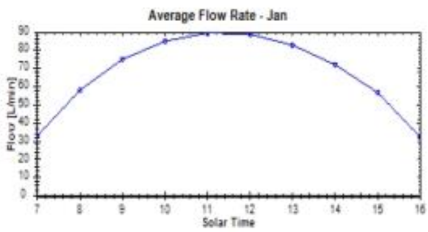
Mono Pumps Computer Aided Solar Simulation

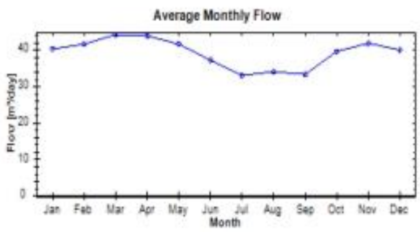
Quotation Number	Thangchung
System Type	Sun Sub
System Size [W]	1600
Array Type	Stationary
Country	Nepal
Location	Kathmandu
Latitude	27.40
Longitude	85.20
Array Tilt Angle	27
Static Head [m]	36
Pipe Length [m]	600
Pipe Size	1½" Rural Class B
Cable Length [m]	50
Cable Size[North]	2.50
Water Temperature [deg C]	10
% of Max Flow	100.0 %
MPPT Size	Series 3000 SMC
Motor Size	Series 3000
Pump Size	SS062
Drive Ratio	1.0
SystemPartNumber	SS1600MC090P

Typical Performance at 1000W/m²	
Flow [L/min]	91.7
Friction Head [m]	33.3
Total Head [m]	69.3
Pump Speed	3080
Cable Loss	3%

Month	Daily Flow [m³/day]	Horizontal Irradiation
January	40.4	4.3
February	41.7	5.2
March	44.3	6.2
April	44	6.8
May	41.7	6.7
June	37.3	5.8
July	33.1	4.8
August	34.1	4.8
September	33.4	4.6
October	39.7	5.1
November	41.9	4.7
December	40.1	4.2
Average	**39.3**	**5.3**

Notes





"The Flow performance estimates are based on the displayed horizontal irradiation values. The data provided with this program should be used as a guide only should be verified with measurements of other external sources for the actual site

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Figure 10.21: Calculation result of the CASS. The results show the capacity of one single solar pump powered by a 1600 W PV array. For the design, the minimal yield, 33.1 m^3/d in July, is relevant (source: CASS, Jeffery (2013)).

B.4 Solar pumping scheme for drinking water

Using the freeware tool CASS from NOV Mono (Jeffery 2013) the potential of a solar pumping scheme to supply drinking water to Thangchung was assessed. The results of this simulation are shown in Figure 10.21.

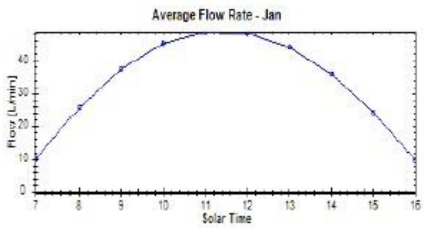
Mono Pumps Computer Aided Solar Simulation

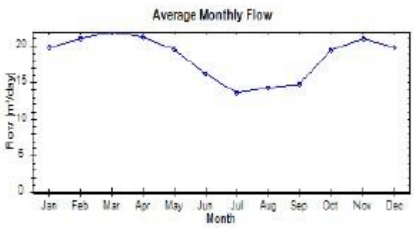
Quotation Number	Drink final
System Type	Sun Sub
System Size [W]	1200
Array Type	Stationary
Country	Nepal
Location	Kathmandu
Latitude	27.40
Longitude	85.20
Array Tilt Angle	27
Static Head [m]	71
Pipe Length [m]	1100
Pipe Size	1½" Rural Class B
Cable Length [m]	20
Cable Size[North]	2.50
Water Temperature [deg C]	10
% of Max Flow	100.0 %
MPPT Size	Series 3000 SMC
Motor Size	Series 3000
Pump Size	SS062
Drive Ratio	1.0
SystemPartNumber	SS1200MC090P

Typical Performance at 1000W/m²	
Flow [L/min]	51.2
Friction Head [m]	20.7
Total Head [m]	91.7
Pump Speed	2697
Cable Loss	1%

Month	Daily Flow [m³/day]	Horizontal Irradiation
January	19.8	4.3
February	21	5.2
March	21.9	6.2
April	21.2	6.8
May	19.5	6.7
June	16.2	5.8
July	13.6	4.8
August	14.3	4.8
September	14.8	4.6
October	19.4	5.1
November	21	4.7
December	19.8	4.2
Average	**18.5**	**5.3**

Notes





"The Flow performance estimates are based on the displayed horizontal irradiation values. The data provided with this program should be used as a guide only should be verified with measurements of other external sources for the actual site

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Figure 10.22: Calculation result of the CASS. The results show that one single solar pump powered by a 1’200 W PV array is sufficient to supply the necessary amount of drinking water corresponding to 13 m^3/d including 10 % losses to Thangchung (source: CASS, Jeffery (2013)).

B.5 Comparison between HDPE and MS pipes

Table 10.5: Qualitative comparison between Mild Steel (MS) and High-Density Polyethylene (HDPE) pipes.

Property	MS	HDPE	Comments
Buried / Above ground	Both	Buried	HDPE degenerates exposed to sun
Flexibility	Rigid	Flexible	
Expansion joints	Necessary	Not necessary	HDPE is flexible enough to accommodate thermal expansion and contraction
Joining on site	Welding or via flanges	Welding (heating plate) or via flanges	If not welded, pipes require extra flanges
Weight	Heavy	Light	Important related to transportation
Length	Up to max 6 m	Up to maximal 6 m	
Prize	High	Medium – Low	
Durability	Corrosion is an issue	Rather high	
High pressure	Suitable	Not suitable	

C Prize lists

C.1 HDPE pipes, Panchakanya

Panchakanya
PLASTIC INDUSTRIES (P) LTD.
Head Office: Krishna Galli, Lalitpur, Nepal,. Tel.: 977-1-5526357, 5526551, Fax: 977-1-5526529
E-mail: pkplast@panchakanya.com.np, www.panchakanya.org, Mailing Address: G.P.O. Box: 2743, Kathmandu, Nepal

Manufacturer of HDPE Pipes & Accessories
Price for HDPE Pipes Manufactured as per NS 40/040
(Effective from July 16, 2008)
2065 Sharawan 1

Size in Mm	Size in Inch	Pressure (2.5 Kgf/cm²)	Pressure (4 Kgf/cm²)	Pressure (6 Kgf/cm²)	Pressure (10 Kgf/cm²)
		Price/Mtr.	Price/Mtr.	Price/Mtr.	Price/Mtr.
16 mm		-	-	-	21.62
20 mm	½"	-	-	-	31.49
25 mm	¾"	-	-	-	47.47
32 mm	1"	-	-	53.11	78.49
40 mm	1¼"	-	58.99	82.25	120.79
50 mm	1½"	-	88.83	127.37	187.06
63 mm	2"	94.71	137.48	199.75	298.22
75 mm	2½"	130.90	198.81	279.89	418.77
90 mm	3"	187.77	286.70	403.50	603.48
110 mm	4"	278.48	400.21	598.08	893.24
125 mm	4½"	359.55	537.92	773.86	1166.07
140 mm	5"	445.80	681.74	975.25	1459.12
160 mm	6"	576.46	886.66	1258.43	1898.57
180 mm	7"	739.78	1119.07	1598.00	2410.16
200 mm	8"	910.63	1384.15	1971.89	2965.70
225 mm	9"	1133.17	1749.58	2477.84	3763.29
250 mm	10"	1412.82	2158.95	3064.64	4642.90
280 mm	11"	1755.69	2691.93	3836.85	5806.38
315 mm	12"	2213.00	3409.38	4863.09	7322.60
355 mm	14"	2989.25	4595.50	6560.75	9908.75
400 mm	16"	3653.04	5602.32	7994.16	-

TERMS & CONDITIONS :–

1. Above prices are Ex-Factory Bhairahawa, exclusive of 13% VAT.
2. This price list supersedes all our previous price list.
3. The prices are subject to change without any prior notice.
4. 100 % payment should be made before delivery.
5. Force majeure clause shall apply.

ISO 9001:2000
Factory: Kotehawa. Siddhartha Nagar. Bhairahawa. Nepal. Tel: 977-71-560371, 560571, Fax: 977-71-560574

Figure 10.23: Panchakanya HDPE pipe prize list as per spring 2013. Note that generally at least 13 % discount is granted, so that the 13 % VAT do not have to be considered in addition to the stated rate.