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The significance of spatial scale and knowledge exchange in irrigation water management

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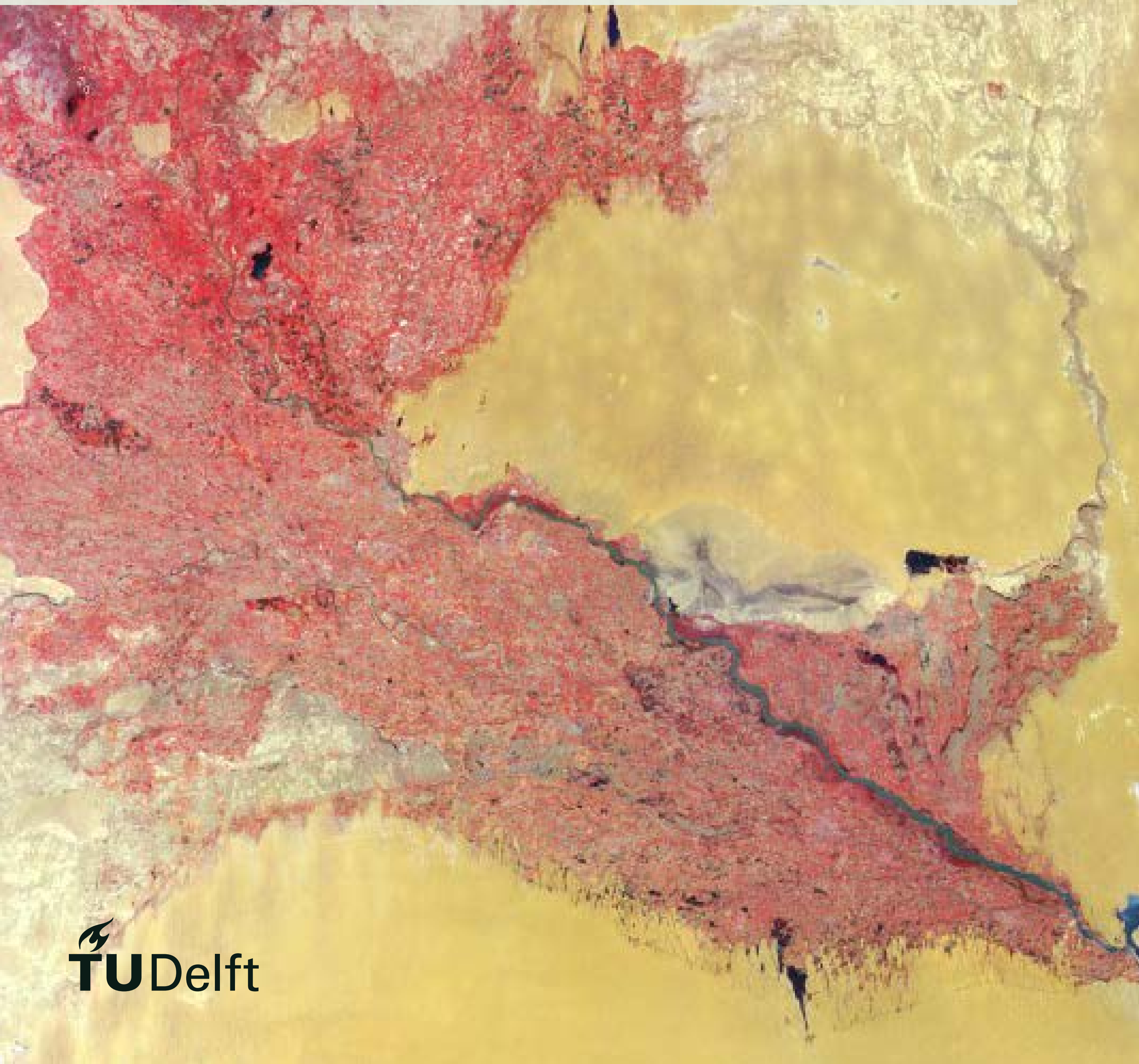

TU Delft

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by

Joreen Merks

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Cover image: Remote sensing image with alternative coloring of downstream Amu Darya river. The river flows from the lower right corner into the Aral Sea in the upper left corner. Vegetation, mostly irrigated, is shown in red. By: NASA/GSFC/LaRC/JPL, MISR Team, June 2002

TU Delft

Preface

To finalize my two master degrees of Water Management and Science Communication, I decided to do something big and something completely to my interest. Basically I wanted to use my thesis to create a better world, a pretty high goal. I spoke with many people, both within the TU Delft and outside, who helped me curb my ambitions and specify my thoughts. Finally I defined my research topic, a topic with societal relevance, linking science with implementation and containing a technical analysis in which my inner nerd could go free: **the water efficiency paradox**. During this research I dove into many rabbit holes to gather details and understanding of Remote sensing products, the World Bank, and the psychology of people. From these rabbit holes I brought back snippets of information and pieces of the puzzle, that were put together into my final thesis.

One of my motivators, for the moments when I got lost in one of my rabbit holes, was a quote attributed (but not without doubt) to Albert Einstein: "if we knew what we were doing, it wouldn't be called research". Making me realize that it is alright to not understand everything and that the goal of this research is to explore questions that are not readily answered. I also got great inspiration from works of fiction. As one of my favorite authors Patrick Rothfuss wrote: "All truth in the world is held in stories", and as Ivan Illich says: "Neither revolution nor reformation can ultimately change a society, rather you must tell a new powerful tale, one so persuasive that it sweeps away the old myths and becomes the preferred story ... ". This thesis is not a novel or a storybook you read at night, but it will provide an alternative tale of irrigation water management, the tale of **the water efficiency paradox** and the relevance of different perspectives and scale.

I want to thank my supervisors for assisting me during this research, greatly value your input in the research process. I want to thank Wim Bastiaanssen, for steering me towards this most interesting topic, guiding me through the world of remote sensing and opening doors for my interviews. Maarten van der Sanden, for his creative insights and stimulating discussions, especially at the start of my thesis. Eva Kalmar, for her practical guidance, keeping me on track and helping me believe in the work that I was doing. And finally, Erik Mostert, for his critical views and helping me to bring water management and science communication together.

During my thesis, I had the pleasure to speak with many inspirational people, in sparring sessions, interviews and open discussions. My special thanks goes to the World Bank staff, consultants and researchers that took the time out of their full schedule to be interviewed by me. I very much appreciate your time and the invaluable insights you gave me. Also, I want to thank the SIC-ICWC and UNESCO-IHE collaborators of the Aral Sea Basin management model for answering my questions and providing additional information to work with the data from the model.

Last but not least I want to thank my friends and family for supporting me through the ups and downs of this thesis. By helping me believe in myself, proofreading parts of my thesis, distracting me, understanding that I was sometimes preoccupied, sparring with me and making me laugh, you played a great and essential role in the successful completion of this thesis.

Joreen Merks
Delft, June 2018

Abstract

Water scarcity is a growing issue across the globe (Rijsberman, 2006) and because agriculture is the main consumer of water, investing in irrigation efficiency seems like a good solution to this problem. However, local gains in efficiency can reduce runoff and hence, have an adverse effect on downstream water availability (o.a. Perry (2018, 1999) and Simons et al. (2015)). The core of **the water efficiency paradox** lies in the positive connotation of efficiency, even though increasing irrigation efficiency can have negative consequences.

The World Bank is a leading global organization that invests in irrigation efficiency improvements. The Bank often invests in these efficiency improvements without conducting a proper basin analysis, even though World Bank staff and consultants are well aware of the relevance of the basin perspective. Therefore, this research aims to shed light on the water efficiency paradox and how basin analysis can be included in World Bank financed irrigation projects. This is done in two parts.

The first part of this research looks into irrigation water consumption in the Amu Darya river basin in Central Asia. With the research question: «To what extent is it possible to analyze irrigation water consumption in Central Asia using a locally developed model combined with open source remote sensing data?». Global open source data for evapotranspiration (ET), precipitation (P), areas equipped for irrigation and storage change are combined with outputs from the Aral Sea Basin management model (ASBmm). These are used to determine the actual irrigated areas, check the model data with water balances and calculate consumed fractions (CF, the fraction of the withdrawal that results in ET). The results from the analysis clearly shows a trend of increasing CF with increasing irrigated area and also larger CFs in downstream areas compared to upstream areas. It also shows a big difference (40%) for calculations without and with complete reuse of upstream drainage water in downstream irrigated areas. These trends conform to the expectations. The actual values of consumed fractions are less certain. Due to underestimation of sparsely irrigated areas, the upstream consumed fractions are also underestimated. Additionally, the ASBmm is a black box model with some inconsistent outputs, hence the validity of the data can be questioned.

Open source remote sensing data provides a reliable basis for basin analysis which van be supplemented with local data. This analysis was successful in showing the dynamics of water consumption in the Amu Darya river basin. However, it is recommended to look at different local data sources to verify the CF calculations.

The second part of this study investigates why basin analysis is not structurally included in World Bank financed irrigation projects. Knowledge exchange is crucial for innovation and adopting new paradigms (Filieri et al., 2014; Walter et al., 2007), also in the World Bank who presents itself as a knowledge bank. This is researched with the research question: «To what extent can a social capital analysis of knowledge exchange between academic hydrologists, World Bank staff and World Bank water and irrigation consultants aid the incorporation of the basin scale perspective on water consumption in World Bank financed irrigation projects?». The social capital perspective provides a systematic way to look at the structural, relational and cognitive dimensions of knowledge exchange in a social network (Adler and Kwon, 2002). Knowledge exchange at the World Bank is investigated with semi-structured interviews combined with documents. The results from these interviews are compared to the conceptual framework. This framework is deduced from a systematic literature review on knowledge exchange combined with social capital, social networks and the science-policy interface.

One of the main obstacles in knowledge exchange and including basin analysis in World Bank financed irrigation projects is lack of time and resources for staff and consultants. Proper basin analysis is not conducted because it is not a formal requirement. Additional issues are: multiple interpretations of the term efficiency, spatial distance between network nodes and differences in visions, goals and perspectives within the Bank and between the Bank and client countries. The client countries are leading in project development. They often focus on small scale development and infrastructure because these projects are easier to conduct than projects on the basin scale. At the moment the Bank has flexible background role.

The application of basin scale analysis in World Bank financed irrigation projects has to be formalized. This does not mean that investments in irrigation efficiency must stop, it means that a basin analysis is necessary to make an informed decision about that investment. Basic basin accounts based on remote sensing data can be combined with local data to analyze water consumption, return flows and reuse. For the implementation and level of detail of the analysis, a balance has to be found between costs and benefits. Including the client country can raise their awareness of the basin perspective where basic accounts by a select team within the bank might be more cost and time efficient.

Contents

Glossaries

Definitions

Aquifer	Underground water body
Closed basin	A basin where water demand is higher than water supply
Consumed fraction	The portion of withdrawn water that is consumed
Downstream	At a lower location along the river
Effective precipitation	Precipitation that is used for transpiration
ET$_{ensemble}$	Global evapotranspiration model
ET$_{monitor}$	Global evapotranspiration model
Evaporation	Water changing from liquid to gas into the atmosphere
Evapotranspiration	Evaporation and transpiration
Google Earth Engine	Online tool facilitating computations with open source data stored on Goolge hard drives
Infiltration	Permeation of water into the soil
Non-recoverable fraction	The portion of water that is withdrawn, not consumed, and not recoverable for reuse
Paradox	Something that seems self-contradictory
Precipitation	Rainfall, snow or other moisture that falls onto the ground
Recoverable fraction	The portion of water that is withdrawn, not consumed, and recoverable for reuse
Remote sensing	Earth observation through satellites or aircrafts
River basin	The area of land draining into a river and its tributaries
Salinification	Land that is turning more saline
Social capital	Social network including resources
Social network	Network of individuals that are connected
Transpiration	Water consumption by plants evaporating through its pores in leaves, stems and flowers
Triangulation	The combination of two or more data sources or research methods to increase the internal valitidity
Tributary	Stream or river flowing into a larger river
UNESCO-IHE	Delft institute for water education
Upstream	At a higher location along the river
Water scarcity	Water availability of less than 1000 m^3/capita/year
Water stress	Water withdrawal over availability ratio close to one
Waterlogged field	An irrigation field that is over saturated with water

List of acronyms

ASBmm	Aral Sea Basin management model
BBL	Brown bag lunch
CAEWDP	Central Asia Energy and Water Development Program
CDF	Collector drainage flow
CF	Consumed fraction
CHIRPS	Climate Hazars Group InfraRed Precipitation with Station data
CSR	Center for Space Research (University of Texas)
FAO	Food and Agriculture Organization of the United Nations
GP	Global Practice
GRACE	Gravity Recovery and Climate Experiment
GSG	Global Solution Group
ICWC	Interstate Coordination Water Commission of Central Asia
IFAS	International Fund for saving the Aral Sea
JPL	Jet Propulsion Laboratory (NASA)
NASA	National Aeronautics and Space Administration
PAD	Project Appraisal Document
PIU	Project implementation unit
SIC ICWC	Science information center of ICWC
TTL	Team task leader
UNEP	United Nations Environment Program
WPP	Water partnership program
WRM	Water resources management
WSS	Water supply and sanitation
WUA	Water user association
[C]	World Bank consultant interviewee
[H]	Academic hydrologist consultant interviewee
[WB]	World Bank staff interviewee

List of symbols

CF_C	Cumulative consumed fraction
CF_{C_reuse}	Cumulative consumed fraction with reuse
ET	Evapotranspiration
$\Delta S/\Delta t$	Storage change over time
P	Precipitation
P_e	Effective precipitation
Q_{CDF}	Collector drainage flow (ASBmm)
Q_{GW}	Withdrawal from groundwater
Q_{LOC}	Discharge/withdrawal from local resources
Q_{NRF}	Non-recoverable fraction
Q_{RES}	Discharge/withdrawal from reservoirs
Q_{RF}	Recoverable fraction
Q_{RIV}	Withdrawal from transboundary rivers
Q_W	Total withdrawal

I

Thesis Introduction

1

Introduction to the water efficiency paradox

1.1 Water as a resource

Water is our most valuable resource, we cannot survive without it. It is a finite resource which is used more and more. This can be related to increasing population and an increasing production of food and products (Mekonnen and Hoekstra, 2016). Over the coming decades the number of people affected by water scarcity[1] will increase to about two thirds of the population (Rijsberman, 2006). Only a small portion of our daily water requirement comes from domestic use of drinking water. The majority is used in food production. Almost 70% of the water withdrawal in the world is from agriculture (Molden et al., 2007), in developing countries such as Asia and Africa it even exceeds 80% of the withdrawal (FAO, 2016) and in Central Asia it is more than 90% (Abdullaev et al., 2010; AQUASTAT, 2013). The Aral Sea in Central Asia is a striking example of the impact of extensive irrigation on the environment (see Figure 1.2). The UN Secretary-General Ban Ki Moon called it "One of the worst environmental disasters in the world" (Worsnip, 2010). Figure 1.1 shows water stress[2] across the world, with most of Central Asia in a high water stress zone (Dumont et al., 2013).

Central Asia is a semi-arid region dealing with a higher water demand than supply, this deficit is increasing (World Bank, 2016b). The region has two major rivers feeding into a saline inland lake: the Aral Sea. However, the amount of water feeding into the lake has diminished due to heavy withdrawals for irrigation. It lost 88% of its surface area and 92% of its volume between 1960 and 2009 (Micklin, 2010)(see Figure 1.2). The diminishing lake has caused entire fishing villages to be deserted (Micklin, 1988) and resulted in an area covered with salty sand(Shen et al., 2016).

[1] Water scarcity is defined though the 1000 m^3/capita/year threshold which is related to domestic water and water for food production.

[2] Water stress is indicated with the withdrawal to availability ratio. In an area with high water stress this value is close to one.

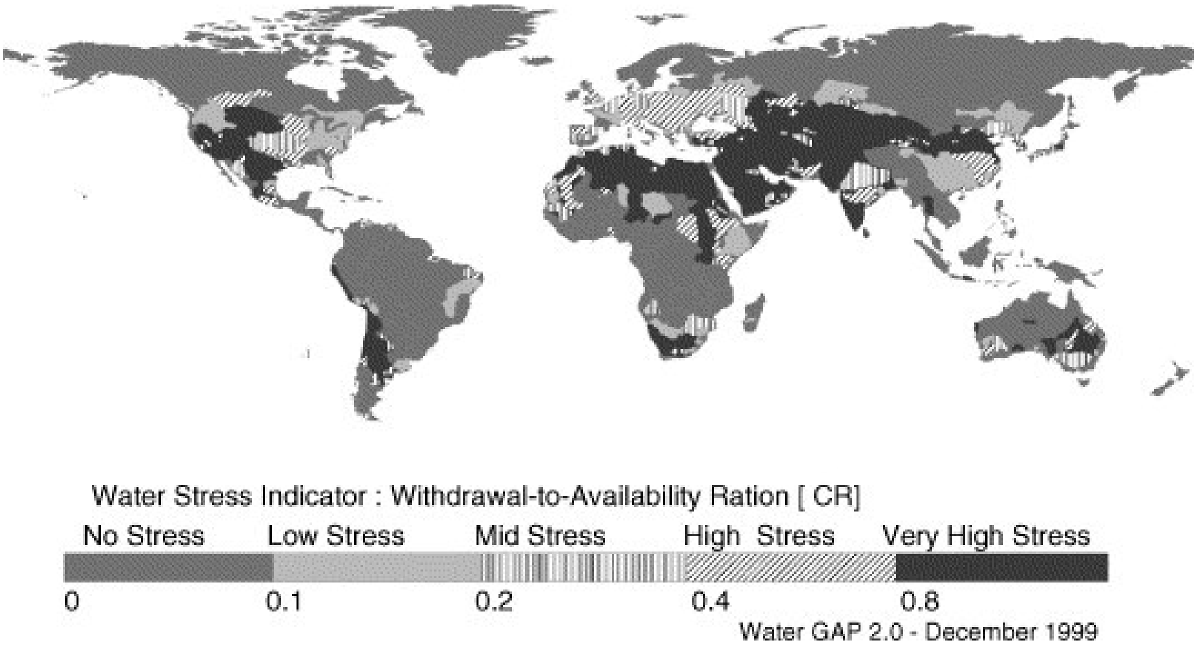


Figure 1.1: Water stress levels across the world by 2025 (Rijsberman, 2006).

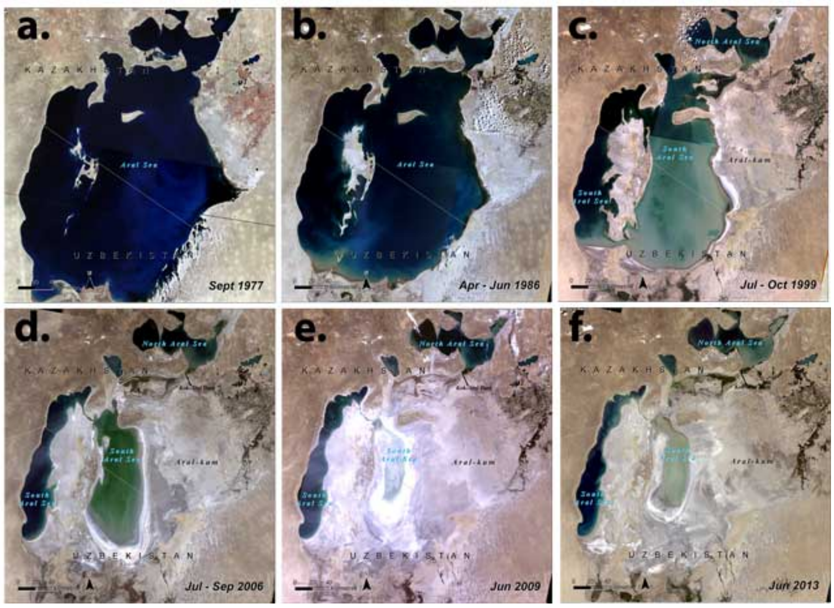


Figure 1.2: The decline of the Aral Sea visualized with Landsat images. Source: USGS/NASA; visualisation by UNEP/GRID-Sioux Falls (UNEP, 2014).

1.2 The water efficiency paradox

A natural response to disasters like the decline of the Aral Sea is to try to save water in agriculture. Investments are done in irrigation modernization, improving irrigation canals and preventing leakage of withdrawn water, generally trying to improve irrigation efficiencies and reduce 'losses' from the system (Ward et al., 2008). The essence of the water efficiency paradox lies in the fact that it is assumed that increasing efficiency is something positive even though it can have negative consequences. It is natural to expect that an increase in efficiency will decrease the demand and consumption of a resource, however, this is not necessarily the case.

In 1905 Jevons published a theory based on developments in the coal market (Alcott, 2005), now known as the Jevons paradox. He saw that the technical efficiency of coal use increased dramatically, but the demand for coal increased instead of the expected decrease. This was caused by the drop in the cost of coal relative to the production, so coal became a cheaper resource because a lesser quantity was necessary for the same monetary gain. This made it a viable resource for people who, before the efficiency improvement, could not afford it and allowed companies to expand. Thus, an increase in efficiency increased the demand and consumption of coal.

A parallel can be drawn to increasing irrigation efficiencies, as was done by Berbel et al. (2015); Berbel and Mateos (2014); Dumont et al. (2013); Loch et al. (2015) and Perry and Steduto (2017). Increasing irrigation efficiency means that with less withdrawal, the same quantity of crops can be produced. Less withdrawal leads to a reduction in pumping costs, causing a relative drop in costs of the resource (water) to the production (crops). From an economical perspective, a logical next step is to increase production and consequentially the use of the resource. More so because increasing efficiency requires an initial investment which is usually done to increase crop production. As Perry (2018) [p. 5] states, it can be seen that "As long as water is scarce, demand tends to increase as irrigation efficiency and water productivity improve".

But this is only a part of the paradox. With coal the increase in efficiency means that, at least, less of the resource is wasted. So, even though the demand and use of coal increase, less of the resource was lost or wasted. With water for irrigation, this somewhat different. Increasing efficiency is often aimed at reducing losses from an irrigation field perspective. A farmer will see all water that is not transpired[3] through his crops as a loss. Reducing these losses seems like a good option so more crops can be produced with the same withdrawal. However, it might not be as simple as that. Water that is not evaporated[4] or transpired is not lost, as it will flow into the groundwater or is drained to the river, to be used downstream or at a later time (Pereira et al., 2002; Perry and Steduto, 2017; Perry, 1999; Simons et al., 2015; Ward et al., 2008). For the farmer it might seem like a loss but when looking from a wider perspective this water is not lost (see Figure 1.3).

When a farmer improves her efficiency without reducing withdrawal, this leads to higher evapotranspiration (ET)[5] and might result in problems for downstream users(Contor and Taylor, 2013). In Figure 1.3, the actions of farmer A affect the natural reserve, but if farmer A decides to increase his efficiency even more, farmer B could feel the consequences. These possible negative implications of improving irrigation efficiency have been present in water resources literature since the 60s (Perry, 1999). Simons et al. (2015) named this sequence of reuse by downstream water users as the cascade effect.

Another issue in this paradox is the use of the term efficiency. Improving efficiency and reducing losses has a positive connotation to it despite possible negative consequences (Perry, 2011). When looking at water scarce regions, it is important to be aware of the water that is actually consumed through ET. It is not argued that investing in irrigation efficiency has no positive effect. It is argued

[3] Plants take up water through their roots which is then used in the internal metabolism and other processes necessary for the plant to survive. The water leaves the plant in the form of gas.

[4] Evaporation is the process water turning from liquid to gas, for example occurring from streams, land or leaves. This is a different process than transpiration.

[5] Evapotranspiration is a term used to encompass both transpiration and evaporation from a surface area

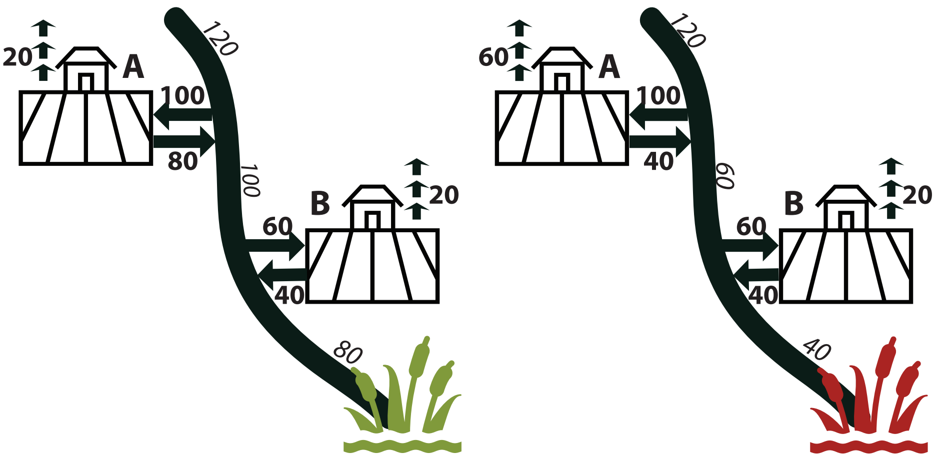


Figure 1.3: The cascade effect describes the interconnection between different water users in a river basin. When for instance irrigation efficiency is increased at farm A, this affects the discharge into the wetlands downstream. If the withdrawal stays constant and the efficiency increases, this means this increases the consumption and reduces the return flow to the river, if farmer A increases her efficiency even more this might impact farmer B. (Based on Simons et al. (2015))

that there can also be negative consequences of which people are not always aware (Frederiksen et al., 2012; Molden et al., 2010; Ward et al., 2008) and that the positive impact of water saving technologies is often overstated (Perry et al., 2009). There is a need for caution when investing in irrigation efficiency as well as an awareness of the implications on a basin level. One way to mediate the ambiguity of the term efficiency in water management in by using fractions (Lankford, 2012; Perry, 2007; Willardson et al., 1994). This research uses the consumed fraction (CF, see Equation 1.1[6]) to analyze water consumption in irrigation. Even though people investing in improving irrigation efficiency try to fight water scarcity, their actions might actually increase water consumption, having a counter intuitive effect.

$$CF = \frac{ET - P_e}{Q_W} \tag{1.1}$$

The water efficiency paradox becomes more prominent when it is linked to policy decisions. Water allocation is often managed through the right of volume withdrawal. Improving farm level efficiency will increase water consumption and deplete the resource when the water withdrawal rights are fixed or based on an upstream measurement and independent of water consumption (see Figure 1.3). The investments used to tackle water scarcity and aimed at water conservation actually have an opposite effect (Loch et al., 2015; Samani and Skaggs, 2008) as there will be no reduction in withdrawal and an increase in consumption. For example, Dagnino and Ward (2012) show that subsidies for installing drip irrigation in the Rio Grande basin in North America resulted in a depletion of the water resources.

The paradox has a most significant impact in closed basins (Samani and Skaggs, 2008). In a closed basin there is more water demand than supply, for part of the year or for the whole year (Molle et al., 2010). All water is already accounted for by water users. This means that there is no flexibility in the water allocation and return flows are often fully reused. An increase in consumption with a decrease in return flow will cause issues.

[6] $ET - P_e$ is evapotranspiration from irrigation and Q_W is withdrawal for irrigation, more on this in Chapter 3 and Chapter 5

1.3 The World Bank

The World Bank (WB) is a large international bank that loans money to lower and middle income countries to stimulate investments in development projects (World Bank, 2011). The Bank also works on knowledge development and global visions. The Bank's main focus is fighting poverty; in terms of water the aim is to create a 'Water Secure World for All' (World Bank, 2016a). The Bank is an international institution with worldwide influence on water and irrigation practices. The World Bank shows itself to be an advocate of river basin planning, on the other hand the Bank invests in irrigation modernization projects where the main result is an increased irrigation efficiency. The High and Dry strategy report (World Bank, 2016b) calls for an increased efficiency within all sectors, including increasing water use efficiency in the agriculture sector. The document does mention the possible negative consequences of increasing efficiencies in a footnote, showing an awareness of the issue. Regardless of the awareness, this is not always translated to practice. As an example, Figure 1.4 shows World Bank irrigation projects in Central Asia active at the search date (February 20, 2018). These are 12 projects in different locations of which eight include an irrigation efficiency and infrastructure rehabilitation component.

1.4 Knowledge exchange

Access to knowledge is crucial to keep up with new theory arising in the changing world (Alguezaui and Filieri, 2010; Walter et al., 2007). To be able to change current practices, an organization needs to be able to access, absorb and apply knowledge (Díez-Vial and Montoro-Sánchez, 2014). This knowledge can be accessed and transferred through connections with other people (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Widén-Wulff and Ginman, 2004). To improve access to knowledge and knowledge management you can increase the access to the amount of knowledge or you can improve dissemination of knowledge that you are already accessing (Brookes et al., 2006). For the World Bank it is important to remain up to date with current developments in academics and to be able to translate that to projects. Knowledge is accessed through their external network and spread through their internal network. This knowledge has not been translated to practice in the case of water consumption and efficiency in irrigation projects and the importance of the basin perspective. This could be because this knowledge is not available to the Bank staff, or because there are some other obstacles because of which the available knowledge cannot be put into practice.

Figure 1.4: Currently active World Bank water and agriculture projects in Central Asia (World Bank, 2018a).

1.5 Problem statement and research objective

There is theoretical consensus on the possible futility of investing in irrigation efficiency as a measure for saving water. These investments often do not save water and sometimes even increase water consumption on a basin scale. Institutions like the World Bank invest in projects aimed at improving irrigation efficiencies without looking at the effects at a basin scale. The hydrological characteristics of different basins vary, therefore simply theorizing about the basin scale is not enough. An actual analysis needs to be done which is sometimes challenging due to limited data availability.

With this research I hope to shed some light on the relevance of the basin perspective on efficiency and water consumption in irrigation water management. It will help overcome the division between the basin scale irrigation efficiency theory and the irrigation project scale. In order to accomplish this, the problem is approached from two different angles. The first objective is to translate the relation between small scale and large scale efficiencies to an actual basin, the Aral Sea basin (Part II). The second aim is to identify reasons why the World Bank is not always taking the basin perspective into account in their irrigation projects, specifically focusing on the process of knowledge exchange (Part III). Together these will give insight into the basin perspective on irrigation efficiency.

1.6 Research approach

These two aims were approached in two significantly different ways. Part II dives into the theory of efficiency and water consumption on different scales. Here the case study of the Aral Sea basin was used to see if the theory can be showcased in a real basin. This was explored by using mostly open source data, combining data from remote sensing with a locally developed model. This is a mostly deductive research where knowledge from theory is applied in a practical scenario.

Part III explores the application of the theory by the World Bank, or more so, why it is not applied. To do this, the study looked at the way knowledge is accessed externally and how it is transferred within the organization. This research was an exploratory research into the processes of knowledge exchange within the internal and external network of the World Bank. This included both the availability of knowledge and the process of access and dissemination within the organization. This topic is approached from a social capital perspective which provides a framework and context for knowledge exchange (Adler and Kwon, 2002; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998).

1.7 Reading guide

This first part of the document gave an introduction to the context and research aim of this thesis. This study revolves around the application of the basin perspective in practice, where the theory is brought closer to reality. This section gives a short outline of the report while more specific reading guides for Part II and Part III can be found in the introductions of each of these parts.

This research is divided into four parts. Part I contains the general introduction, of which this reading guide is a component. Part II is focused on showcasing the water efficiency paradox in Central Asia and Part III dives into knowledge exchange and the implementation of basin analysis in World Bank irrigation projects. Finally, Part IV knits Part II and Part III together, coming back to the problem statement discussed in this general introduction.

Part II and Part III are written in such a way that they can be read separately. They answer two separate and specific research questions and provide insight on their own, addressing their own part of the general research problem. However, they are not presented together without reason. These parts together provide new insight combining to an integrated analysis and advice on how to improve the incorporation of the basin perspective in World Bank financed irrigation projects.

II

Irrigation water consumption in Central Asia

2

Introduction to the analysis of water consumption in Central Asia

2.1 Introduction

Part I showed that the Aral Sea is declining, which signifies over exploitation of water in Central Asia. The Agriculture sector uses over 90% (AQUASTAT, 2013) of the withdrawn water and is the largest consumer of water in the region. Irrigation is seen as a very inefficient water user and investing in irrigation efficiency is stimulated to fight water scarcity in Central Asia (Cai et al., 2003; Törnqvist and Jarsjö, 2012). This can in theory have negative consequences for downstream users as was discussed in Part I. This part will give insight into water consumption in the Aral Sea basin and the use of open source data to relate water consumption to the basin perspective.

2.2 The Aral Sea basin

The Aral Sea basin is a large hydrological system in Central Asia, it covers most of Central Asia. The basin has a total area of 1.76 million km^2 (AQUASTAT, 2013) and hosts 54millon people (Dukhovny and de Schutter, 2011). The region was formerly part of the Soviet Union and now holds the republics of Kazakhstan, Uzbekistan, Tajikistan, Kyrgyfzstan, Turkmenistan and a small part of Afghanistan. Central Asia is a region where there is a high demand for water resources while there is limited availability. The decline of the Aral Sea, as shown in Part I, is a vivid example of this limit. The Aral Sea basin consists of two mayor rivers: the Amu Darya and the Syr Darya which both used to drain into the Aral Sea (see Figure 2.1). More on the Aral Sea basin can be found in Chapter 4. This research will mainly focus on the Amu Darya river within the Aral Sea basin.

2.3 Basin scale consumption in the Aral Sea basin

Previous research on basin scale water consumption in the Aral Sea basin is limited. The most related research was done by Törnqvist and Jarsjö (2012). They conducted a study on the effects of changing irrigation technologies on basin level water savings in the Aral Sea basin. They compare the reduced withdrawals with the reduction in basin water consumption. This was done through a distributed hydrological model in which the evapotranspiration (ET) is estimated through water balance closing and crop water requirements. The aim of their research was to show that irrigation technologies do not always save the water they are said to do and to indicate which areas in the basin are most suitable

Figure 2.1: Rivers and flow distribution in the Aral Sea basin (CAwater-info, 2011).

for irrigation efficiency investments. Törnqvist and Jarsjö (2012) do not use ET measurement data in their research and their model is not openly accessible for further research. Other water research on water consumption in Central Asia has mainly focused on the small scale (Bekchanov et al., 2015; Conrad et al., 2013; Thevs et al., 2015), not looking at the basin perspective but at only at the field level.

2.4 Data availability

Conducting a basin analysis is challenging because of the limited and varying availability of data (Karimi et al., 2013). This is also an issue in the Aral Sea basin (UNEP and ENVSEC, 2011). Remote sensing data can help mediate this limitation, however, it is still underused (Bastiaanssen et al., 2000). ET, precipitation (P) and land cover data can for example be deduced from actual measurements through remote sensing. Especially for ET this is significant as as these data is now often indirectly calculated because it is hard to measure on the ground. Remote sensing data is collected with areal instruments, for example areal photographs from drones or satellites. This research is limited to satellite data, so the term remote sensing will be solely used for satellite based data sets. Even with remote sensing data it is a challenge to find the right data sources for a specific analysis. The use of open source remote sensing data provides a window into new data use, however, this is sometimes received with skepticism. It is necessary to find a way to incorporate these new data sources in an acceptable manner.

2.5 Scope and research questions

This research combines remote sensing data with a locally developed hydrological model, the Aral Sea Basin management model (ASBmm), to analyze water consumption through irrigation on different scales in the region. The focus lies on using open source data and using relatively simple calculations. This leads to the following research question:

> **To what extent is it possible to analyze irrigation water consumption in Central Asia using a locally developed model combined with open source remote sensing data?**

This research question needs to be explored in parts. Firstly irrigation water consumption limits the research to ET from irrigated areas. This means that the irrigated areas have to be determined, which is sub-question one. Secondly the data sources need to be checked to find out if they match together, this is researched through sub-question two. Finally the data are used to to calculate the consumed fractions per planing zone and related to the spacial scale, which results in research questions three and four.

1. Can irrigated areas in Central Asia be determined using open source data?
2. To what extent can the water balance of irrigated areas in the Amu Darya river basin be used to check the data sources?
3. How can consumed fractions for the irrigated areas in the Amu Darya river basin be determined?
4. How can spatial scale be related to consumed fractions of irrigated areas in the Amu Darya river basin?

The analysis of water consumption for irrigated areas is limited to planning zones. These are administrative districts for water allocation used in the ASBmm. Using these limits allows the combination of the output of the ASBmm with remote sensing data. The boundaries of these districts are only available for the Amu Darya river basin and not for all planning zones in that basin, this is a restriction on the analysis.

With this analysis I do not want to dictate what is good or bad nor is my aim to provide a water-tight water balance of the region. With this research I simply want to find out whether water consumption on different scales can be showcased in Central Asia. I want to shed light on this theory and its application in Central Asia as well as the possibility to combine remote sensing with a local model.

2.6 Reading guide

Part II of this thesis first dives a bit deeper into the hydrological concepts concerning the water balance and water consumption in Chapter 3. This will give some more insight into the theory and concepts behind the water efficiency paradox. Secondly, Chapter 4 gives some background information on the Aral Sea basin where climate, history of irrigation and hydrology of the basin are discussed. This is necessary to understand how things stand in the basin. After this, the research methods are explained in Chapter 5, giving insight into the research steps necessary to analyze irrigation water consumption related to scale. Chapter 6 shows the results of the study, elaborating on defining the boundaries of irrigated areas, the water balance and consumed fractions. This leads to the discussion in Chapter 7, where the results are discussed with relation to the method, theory and Central Asia. It gives a critical look on the results leading up to the conclusions and recommendations in Chapter 8.

3

Hydrological concepts

3.1 Introduction

This chapter will provide an introduction to the hydrological concepts used in this research, starting with a basic water balance, followed by the concepts of water use, water losses, consumption and efficiency. These will lead to a more expansive description of the cascade effect that was already shortly introduced in Part I. The concepts provided in this chapter provide insight into the hydrology that is necessary to understand the dynamics of water consumption and consumed fractions across different scales. It forms the foundation of the of the analysis.

3.2 The water balance

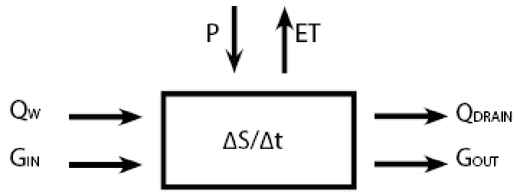
The water balance of an hydrological system contains all fluxes and stocks that are present. A flux is a quantity of water that flows in and out of a system and is measured in a volume over time, rainfall is an example of a flux. A stock is a quantity of water that is present in a system which can decrease or increase over time because of incoming and outgoing fluxes, for example a reservoir that empties and fills. The water balance essentially represents the accounts of the water coming into the boundaries and the water flowing out of the boundaries of the system (see Figure 3.1a). Fluxes into the system can be rainfall or river flow, evapotranspiration (ET) and river flow into the ocean can be flows exiting the system, and change in groundwater storage or reservoirs are examples of the change in stock. Changes in the groundwater stock can occur through percolation. Which fluxes are defined as in and out is dependent on the boundaries of the hydrological system, these boundaries and fluxes are different for different scales of analysis (see figure 3.2).

In an irrigated area the inflows are precipitation (P), Irrigation water (Q_W) and subsurface groundwater flow (G_{in}). The water that goes out of the area is the ET, the drainage water (Q_{drain}) and the outflow of subsurface water (G_{out}) (see Figure 3.1b). The groundwater subsurface flow is considered to be low as compared to the other fluxes, it is also hard to measure(Bos et al., 2008). Therefore it was not included in this analysis (see Figure 3.1c).

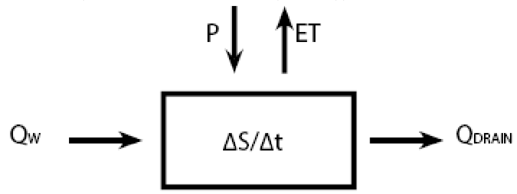
3.3 Water use and water losses

Water use can be defined as any application of water for a purpose, this can range from fishing and hydro power to irrigation and drinking water. Not all water in a system can be used, of the water that is used not everything is consumed. Understanding the difference between water use and

(a) The water balance.

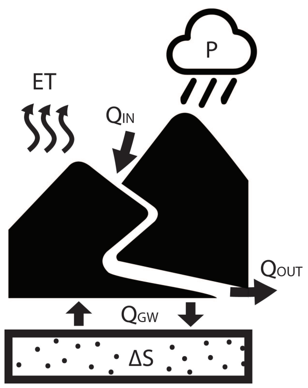


(b) The water balance of an irrigated area (based on Bos et al. (2008)).

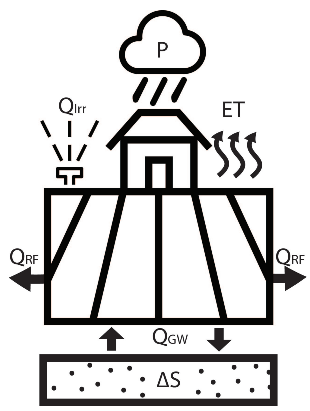


(c) The water balance of an irrigated area without subsurface flow.

Figure 3.1: A simple depiction of the water balance.



(a) Example of a basin water balance, without surface storage.



(b) Example of a farm water balance, without surface storage.

Figure 3.2: The water balance on different scales.

water consumption is crucial in effective water resources management (Allen et al., 2003; Pereira et al., 2002; Perry, 1999). To better understand this distinction, water use can be classified into the categories shown in figure 3.3, all water use fits into one of these categories.

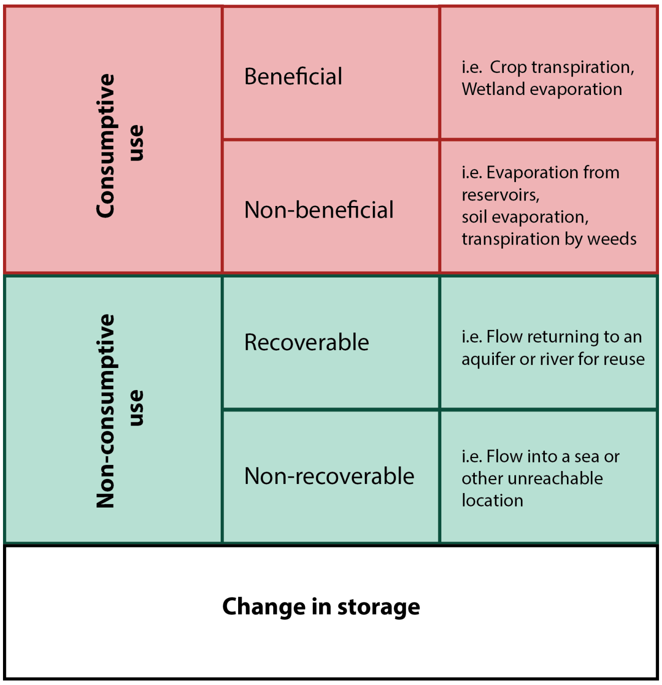


Figure 3.3: Water use classification (based on Allen et al. (2003); Perry (2011); Willardson et al. (1994)).

The first distinction is made between consumptive use and non-consumptive use. Consumed water is defined as water that leaves the boundaries of the water system, for instance through evaporation. Consumptive use can be divided into beneficial and non-beneficial consumption. Crop transpiration is an example of beneficial consumption while reservoir evaporation is usually classified as non-beneficial. The boundary between these two is not solid (Simons et al., 2015), for instance transpiration by weeds can be classified as non-beneficial by a farmer but beneficial by an environmental agency. With non-consumptive use the water is still within the boundaries of the system after usage, water use for boating and fishing are examples of non-consumptive water use, but also the flow that returns to the river after irrigation. Looking more closely at agricultural use there is a distinction between the recoverable fraction and the non-recoverable fraction, water that is discharged into the groundwater or back into the river is recoverable for later use while water that is discharged into the ocean or a saline groundwater body is classified as non-recoverable (Willardson et al., 1994). Water is non-recoverable when reaching it is not economically viable (Perry, 2011). The last category of water use distinguished in figure 3.3 is the change in storage this is neither consumptive or non-consumptive use as it is still within the system boundaries but not directly available for use.

In irrigation water management, water that is not directly used by the crops is seen as a loss (Bucknall et al., 2003; Jumaboev et al., 2015; Rogers and Lamm, 2017). Figure 3.4 shows the fluxes of water that leave an irrigated area after and during irrigation, in classical irrigation management these are all seen as losses (Allen et al., 2003; Willardson et al., 1994). Improving irrigation efficiency focuses on reducing one or more of these 'losses'. On the scale of the irrigation field this results in an increase of the percentage of irrigation water that is consumed by the plants, this is experienced as an improvement. This gain on a small scale might have implications for the basin scale as the fluxes with potential for reuse are decreased (e.g. flux D, E and F in figure 3.4), this relationship can be shown with the cascade effect.

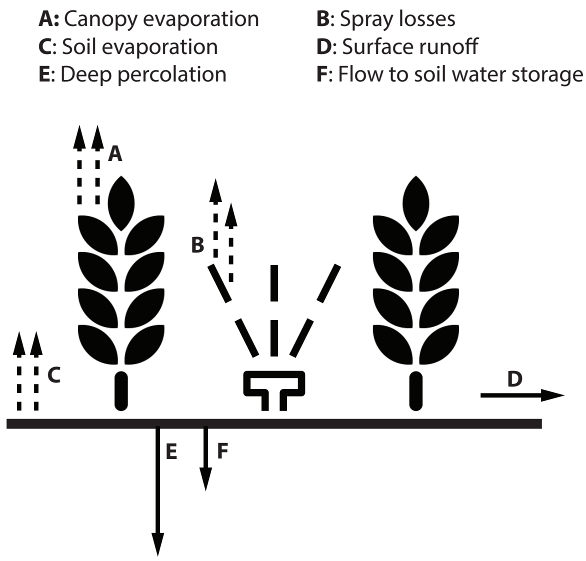


Figure 3.4: Typical fluxes defined as 'losses' in irrigation management. Fluxes A, B and C evaporate, they leave the irrigation field and also leave the river basin, these can be seen as losses in the sense that they leave the river basin. However, A and C can be beneficial by, for example, the cooling effect of evaporation. Fluxes E and F leave the irrigation field and flow into the groundwater, whether these fluxes are lost or not depends on the state of the aquifer and the ability to retrieve groundwater. Flux D is surface runoff that flows to a water body, if this water body is saline it can be seen as a loss, however, if it is a freshwater body it can be reused.

3.3.1 The cascade effect

The cascade model provides insight into the implications of changing water management on a user scale. On a basin scale these can be felt by downstream farms, wetlands or other users in the system. The model shows the relevance of looking at irrigation water management from different scales. Figure 3.5 shows a hypothetical river basin and illustrates the effect of an upstream efficiency intervention on the water availability in the basin. It can be seen that throughout the system the discharge is lower because the return flow generated by farm A is decreased due to its increased irrigation efficiency. This farm might increase its production, but it comes at the cost of a higher water consumption. Water can be reused throughout the basin, sometimes even more than once.

The representation of the basin in Figure 3.5 is a simplified version of reality, for example in reality not all runoff will flow into the river and be reused (Lankford, 2012) and there might be other water sources available to the water users. However, it gives insight into a very real issue. The implications of increasing efficiency and the cascade effect have the greatest potential impact in closed (endorheic) basins[1] with a limited water supply (Simons et al., 2015).

3.3.2 Irrigation efficiency and consumed fractions

As stated in the introduction, improving irrigation efficiency is often seen as a solution to water scarcity. There are some issues with this term. Firstly the term irrigation efficiency in water management is ambiguous. Secondly increasing efficiency has a positive ring to it even though it can have negative consequences.

As an example of the ambiguity of the term, engineers usually make a distinction between conveyance efficiency, application efficiency and distribution efficiency (Boelens and Vos, 2012). This research focuses on water consumption through irrigation therefore the definition of efficiency will be: the

[1] In a closed basin water supply is less than the water demands for part of the year or for the whole year (Molle et al., 2010)), all water is already accounted for by water users

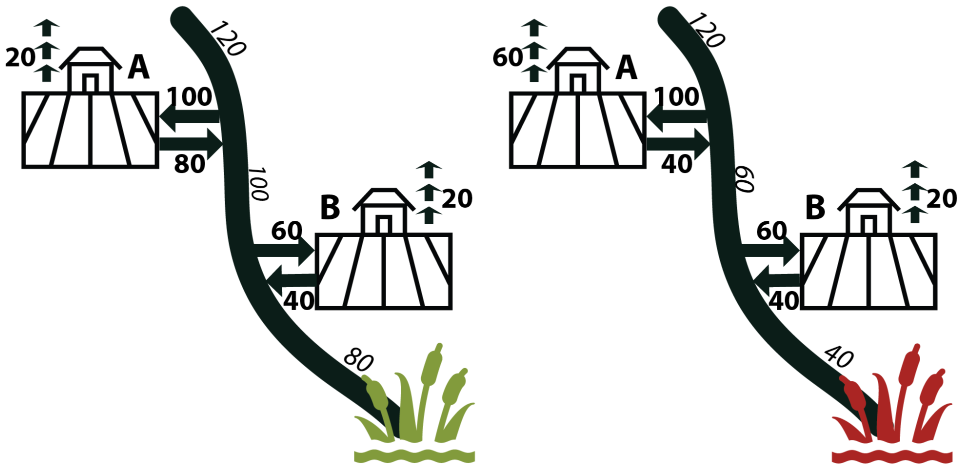


Figure 3.5: The cascade effect describes the interconnection between different water users in a river basin. When for instance irrigation efficiency is increased at farm A, this affects the discharge into the wetlands downstream. If the withdrawal stays constant and the efficiency increases, this means this increases the consumption and reduces the return flow to the river, if farmer A increases her efficiency even more this might impact farmer B. (Based on Simons et al. (2015))

fraction of withdrawn water that is consumed by the crops through evapotranspiration ($\frac{ET-P_e}{Q_W}$), this fraction is also known as the consumed fraction. This is a dimensionless fraction that can be used to analyze water consumption and efficiency on different scales. Measures improving irrigation efficiency will increase this ratio. When an increased consumed fraction is combined with a reduction of withdrawal this will not increase total water consumption. However, if the withdrawal stays the same, it will increase the total water consumption. This increase of water consumption can have negative effects on downstream users in water scarce areas.

Another benefit of using the consumed fraction is that it does not give an implicit sense of good or bad. Increasing efficiency sounds positive while increasing the consumed fraction does not have that connotation. It is a more objective indicator which gives openness to both positive and negative implication. Therefore there is a call for using the more neutral and scientific term of the consumed fraction and abandoning the term efficiency in irrigation water management (Lankford, 2012; Perry, 2007; Willardson et al., 1994).

Within the field of water and irrigation management there are also voices advocating the use of irrigation efficiency and critical of the basin perspective. Gleick et al. (2011) argues that the benefits of improving irrigation efficiency are substantial for irrigation management practices, water quality and energy savings. They also say that there should be a distinction between beneficial consumption and non-beneficial consumption. The main criticisms focus on adding an extra interpretive layer to the quantitative analysis (Frederiksen et al., 2012).

In a quantitative analysis the focus lies on the fluxes and the assessment of the benefits of consumption or the quality of return flow is not taken into account. These are important aspects to a hydrological analysis. However, Simons et al. (2015) argues that it is necessary to first have the quantitative analysis of the fluxes in place before the step to these more subjective assessments can be made.

4

The Aral Sea basin

4.1 Introduction

This chapter will shortly introduce the study area: the Aral Sea basin. Aral Sea basin is a closed basin in Central Asia. It consists of two major river basins, the Amu Darya and Syr Darya rivers, which both used to drain into the Aral Sea. The Aral Sea is called the Sea of Islands, Aral translates to island in Kazagk. This name refers to the location of the Sea as an island in the surrounding desert as well as to the islands that formed in the Delta of the Amu Darya river before draining into the Sea (IFAS, 2018). Farming is seen as one of the most honorable occupations in this region and water is glorified in stories and legends, life and water go hand in hand (Dukhovny and de Schutter, 2011). The basin is internationally famous for the Aral Sea depletion which is seen as a large ecological disaster. The great drop in the water level of the Aral Sea is caused by the combination of extensive irrigation and meteorological variance (Dukhovny and de Schutter, 2011; Micklin, 2010, 1988, 1991).

This chapter firsts discusses the geography and climate. Second it goes into the history of irrigation in the region. Third and last, the current hydrology and water governance are discussed. This background information is necessary to understand the dynamics of water in the study area. All catchments are different so knowledge of aspects like climate and water allocation is essential to understand and analyze a specific area.

4.2 Geography and climate

The region is highly diverse in climatic factors, ranging from a mountain climate at the origins of the rivers to a desert climate in the lower regions (Dukhovny and de Schutter, 2011) (see Figure 4.1). In between there are fertile valleys, like the Fergana valley. The majority of the land is classified as arid or semi-arid (Asian Development Bank, 2010a). Precipitation (P) falls mostly as snowfall in the mountainous regions. It falls between November and April, with a peak between January and March(Glantz, 2005). Average temperatures increase from north to south, while they decrease for higher altitudes in the mountains, where temperatures can be close to 0°C all year. Winter temperatures can drop below -20°C the north of Kazakhstan. Most of the region will be covered in snow in winter, deserts included (Asian Development Bank, 2010a). In summer temperatures in the flat lands will rise to an average of 25°C (Dukhovny, 1996).

The mountain ranges cover approximately 10% of the region. They follow the borders with Iran, Afghanistan and China and cover parts of Turkmenistan and Kazakhstan and most of Kyrgyz Republic and Tajikistan. Peaks can be up to 7,500 meters high (Asian Development Bank, 2010a) and have permanent snowfields and glaciers (Murray-Rust et al., 2003). They end into a vastly flat and windy area with steppes and deserts.

Deserts cover more than 40% of the Aral Sea basin (Asian Development Bank, 2010a), the largest of which is the Karakum Desert. They have a harsh climate with warm and dry summers and sandy desert winds. In some parts yearly precipitation is not more than 70mm (Asian Development Bank, 2010a) (see Figure 4.2 for the rainfall distribution of 2011).

4.3 History of irrigation in Central Asia

Central Asia is host to some of the oldest irrigation systems in the World, with the first irrigation systems dating back to the 6th century (Abdullaev and Rakhmatullaev, 2015). Nomadic farmers roamed the region until 1860. In the south they were ruled by Khans (Kings) from who they rented farm lands (Iskender-Mochiri and Gough, 2003) while the north had a more tribal nature. The water systems were managed by the Khanate and by the farmers (Abdullaev and Rakhmatullaev, 2015), who chose a representative to speak on their behalf. Maintenance to the irrigation system by the farmers was obligatory and free of wages once per year (Dukhovny and de Schutter, 2011). The upstream water users had to put more labour to compensate for their advantage of being upstream (O'Hara, 2000).

By the mid 19th century Central Asia was colonized by Russia and put under Tsarist rule (Dukhovny and de Schutter, 2011). The Tsar decided to work with the existing irrigation management system but greatly elaborated on it to become self sufficient in cotton production (Dukhovny and de Schutter, 2011; O'Hara, 2000). The ideas of great irrigation schemes started during this time but they were never put in motion (O'Hara, 2000).

A great reorganization of the irrigation management came after the collapse of the Tsarist Empire (Abdullaev and Rakhmatullaev, 2015). Great investments were done to construct gigantic irrigation canals, reservoirs, pumps and other structures (Abdolvand et al., 2015; Dukhovny and de Schutter, 2011; O'Hara, 2000). There was a shift from local use to regional management and use through large canals, like the Karakum canal. The large scale irrigation schemes were state-owned (sovkhoz) or cooperative (kholkhoz) farms, respectively paying a fixed wage or paying from farm revenue (Abdullaev and Rakhmatullaev, 2015) however, by the end of the soviet era, most were state owned. The investments caused an increase of water use from 64.7 km^3 to 103.5 km^3 (O'Hara, 2000). This increase in irrigation caused a dramatic decline in the river flows (Aladin et al., 1995). The return flows to the rivers have decreased with 90% since the soviet irrigation expansions (Saiko and Zonn, 2000). In the mid-1980s the government switched from investing in more irrigation to improving water use efficiency (Dukhovny and de Schutter, 2011).

Investments in agriculture plummeted after the soviet breakup due to lack of resources in the new countries (García, 2008). There was no regional financing and it became hard to maintain the system in the five separate countries who followed a more capitalist approach (Abdullaev and Rakhmatullaev, 2015; Rakhmatullaev et al., 2010). The countries aimed to become energy and economically independent (Abdolvand et al., 2015). Farmers had to transition from state management to unregulated management (McDonnell, 2008). Water User Associations (WUAs) were instated by government and donors (Abdolvand et al., 2015; IWMI, 2016), lacking overall consistency (Yakubov, 2012).

The breakup turned national management into international policy (AQUASTAT, 2013). The countries instated the Interstate Commission on Water Coordingation (ICWC), in which deputy ministers for water and natural resources decide on country water allocation every year. They meet four times a year to keep track of the allocations (Abdullaev et al., 2010). The ICWC uses two river organizations to manage local water allocation and has a Scientific Information Center (SIC) as well as a meteorological organization (CMC). Another basin initiative is the International Fund for Saving the Aral Sea (IFAS) that was constructed to attract regional investments.

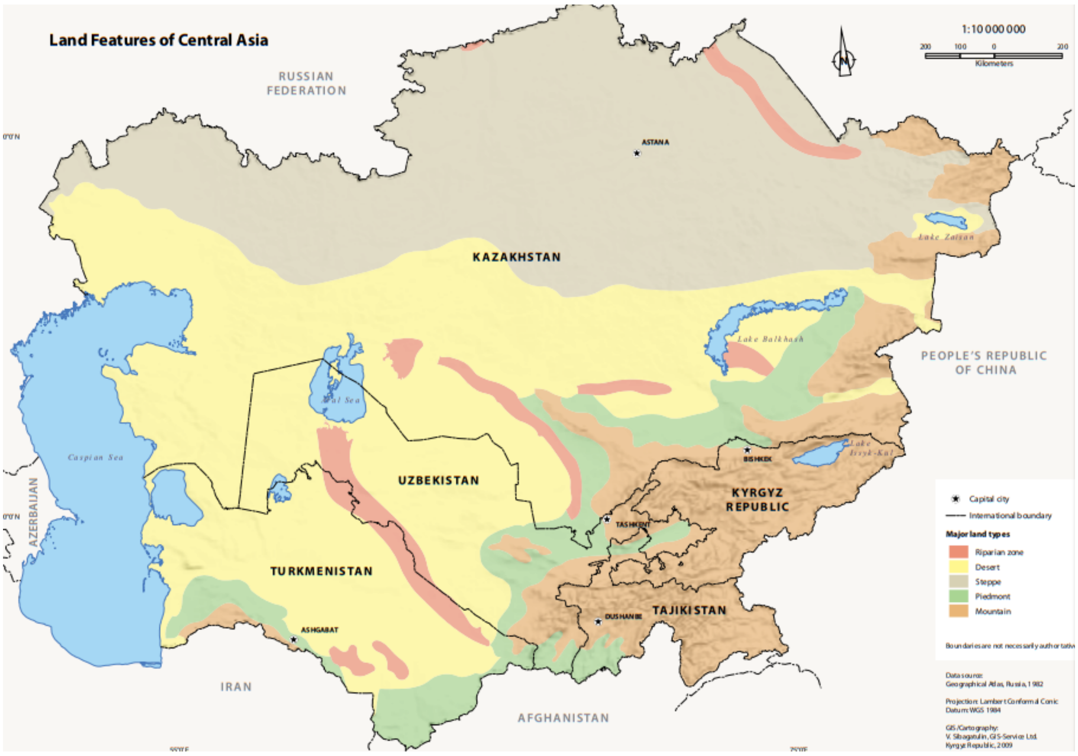


Figure 4.1: Deserts in Central Asia (Asian Development Bank, 2010a).

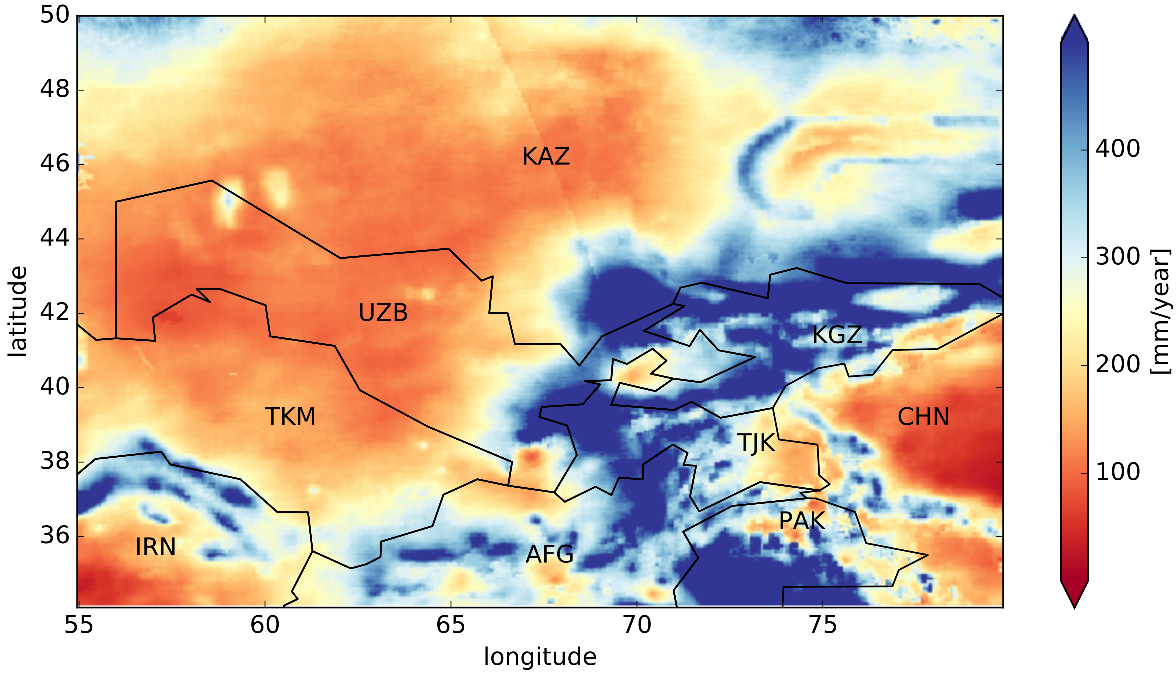


Figure 4.2: Precipitation in Central Asia in 2011 (Data source: CHIRPS).

Disagreements between the states remain even though these basin organizations exist. They mostly concern the conflict between the upstream energy production and downstream irrigation (Dukhovny and de Schutter, 2011; Wegerich et al., 2015). Especially dialogues between Uzbekistan and Tajikistan are fragile, even though collaboration is on the rise (World Bank, 2017). Inadequate distribution of the water resources combined with mismanagement of irrigation water increase the tensions and potential conflict (Jumaboev et al., 2015).

For a more elaborate explanation of the history of irrigation in Central Asia see Appendix A.

4.3.1 Water allocation agreements

Due to the limited water resources, there is a need for the countries to agree on water allocation. The countries decide on water allocation every year in a meeting of the ICWC based on the current annual flow. The percentages of the division were agreed upon in 1992, this agreement includes operational schedules for reservoirs as well as withdrawal limits (Raghuveer et al., 2004).

In the Amu Darya river basin Uzbekistan and Turkmenistan are allocated most of the water. Uzbekistan is allocated 48.2%, Turkmenistan 35.8%, Tajikistan 15.4% and Kyrgyz Republic 0.6% of the projected flow according to the 1992 agreement (ICWC, 2000). This allocation is based on 67% of the total flow generated in the Amu Darya river basin (AQUASTAT, 2013).

In the Syr Darya river basin the agreement on water allocation is less straightforward. There is an allocation decided of 50.5% for Uzbekistan, 42% for Kazakhstan, 7% for Tajikistan and 0.5% for Kyrgyz Republic, however, there is discussion on the timing of these flows (ICWC, 2000). There is a battle between the upstream and downstream countries on whether to give a priority to irrigation or hydro power, the first wanting high flow volumes in summer while the latter needs high flows in summer. This agreement is revised often and signed yearly since 2005. It includes energy compensation for the upstream countries if they supply water during the irrigation season. Countries often exceed their abstraction limits (ICWC, 2000).

4.4 Hydrology

The two main rivers of the Aral Sea basin are the Syr Darya and Amu Darya rivers. They originate in the mountains(Wegerich et al., 2015), passing hills, valleys and deserts and finally ending at the saline Aral Sea. The basin has a high spatial inequality of water consumption and precipitation, with a low consumption and high precipitation in the mountains and a high consumption and low precipitation in the deserts (Micklin, 1991) (see Figure 4.3).

The Syr Darya originates from the Tyan-Shan mountain range in Kyrgyzstan (Wegerich et al., 2015) while the Amu Darya originates in the Pamir and Alai mountain ranges in Tajikistan (Micklin, 1991). The Amu Darya does not feed into the Sea anymore (Asian Development Bank, 2010a). The Amu Darya river is the largest in discharge and the Syr Darya is the longest (Dukhovny and de Schutter, 2011).

The rivers are fed by glacier melt from the mountains (Dukhovny and de Schutter, 2011; Malone, 2010) where water is abundant (Asian Development Bank, 2010a). The region is sensitive to climate change(Lutz et al., 2012), showing a trend of 1-2 degrees rise in temperature by 2030-2050 which will have an impact on the precipitation patterns and water availability (Lioubimtseva et al., 2005). The glaciers are expected to reduce in size by at least 45%, impacting the total flow and the seasonal variance (Lutz et al., 2012). Siegfried et al. (2011) predicts this will result in increased water stress, a lower water availability and more climate hazards.

The Amu Darya river originates from the Pyanj (Afghanistan) and Vaksh (Tajikistan) rivers and is fed by multiple tributaries. The river follows the border between Afghanistan and Tajikistan and between

Uzbekistan and Turkmenistan, where it crosses the border multiple times. The Amu Darya has an average annual flow of 74 km^3 ranging from 109.9 km^3 in a wet year to 58.6 km^3 in a dry year (CAwater-info, 2011) . The maximum flow occurs in summer as the river is mainly fed through glacier melt (Malone, 2010). 76% of the total flow of the Amu Darya originates from Tajikistan, 15% from Afghanistan, 2% from Tajikistan 1% from Turkmenistan and 6% from Uzbekistan (AQUASTAT, 2013).

The Syr Darya starts from the Naryn river in Kyrgyzstan and the Karadarya river in Uzbekistan. The river has an annual flow of 36.57 km^3 of which 75% is formed in Kyrgyz Republic, 3% is generated in Tajikistan, 13% by Uzbekistan and 9% by Kazakhstan (AQUASTAT, 2013) (see figure 4.4). The discharge in the Syr Darya varies from 51.1 km^3 in a wet year to 23.6 km^3 in a dry year (CAwater-info, 2011).

4.4.1 Current irrigation practices

Irrigated agriculture is by far the largest form of water use in the basin, as it comprises of almost 90% of the water withdrawal in Central Asia (see Figure 4.5). Most of the irrigation water is withdrawn from surface water (see Figure 4.6) and transported via large canals. This is supplemented by ground water extraction. Ground water use is increasingly exceeding the sustainable amount (Rakhmatullaev et al., 2010). Irrigation takes place in the dry and warm spring and summer (see Table 4.1). The most intense irrigation takes place between May and September (Ibragimov et al., 2007). The Main crops grown in the region are potato, cotton, wheat and maize (Dukhovniy et al., 2015), other crops include pumpkin, sugarcane, rice, cassava, soybeans and hay CAwater-info (2011). They have slightly different irrigation seasons (see Table 4.2).

Season	Spring	Summer	Autumn	Winter
Month	Feb-Apr	May-Aug	Sept-Nov	Dec-Jan
Duration	3 months	4 months	3 months	2 months
Precipitation kind	Rain/snow	Rain	Rain/snow	Snow
Precipitation intensity	Medium	Low	High	High
Irrigation	yes	yes	(winter wheat)	-

Table 4.1: Irrigation seasons in Central Asia based on Dukhovny and de Schutter (2011).

Crop	Irrigation months
Potato	March-October
Cotton	May-September
Winter wheat	November, April-June
Maize	May-September

Table 4.2: Irrigation seasons per crop based on Dukhovniy et al. (2015).

The large scale irrigation fields of the soviet era have been redistributed to the farmers, resulting in large subsidized farms and small family farms. They are not always able to maintain the canals the way it was done before, leading to a reduction in crop production and abandonment of fields (UNEP and ENVSEC, 2011). The amount of irrigation varies between large fields in the downstream areas and smaller irrigated areas upstream (see Figure 4.7 for an indication of the irrigated areas).

A limited amount of the farmers in CA uses sprinkler systems but most irrigation is in the form of surface irrigation. This method can reach a 50% irrigation efficiency at most (Bos and Aart, 1996).

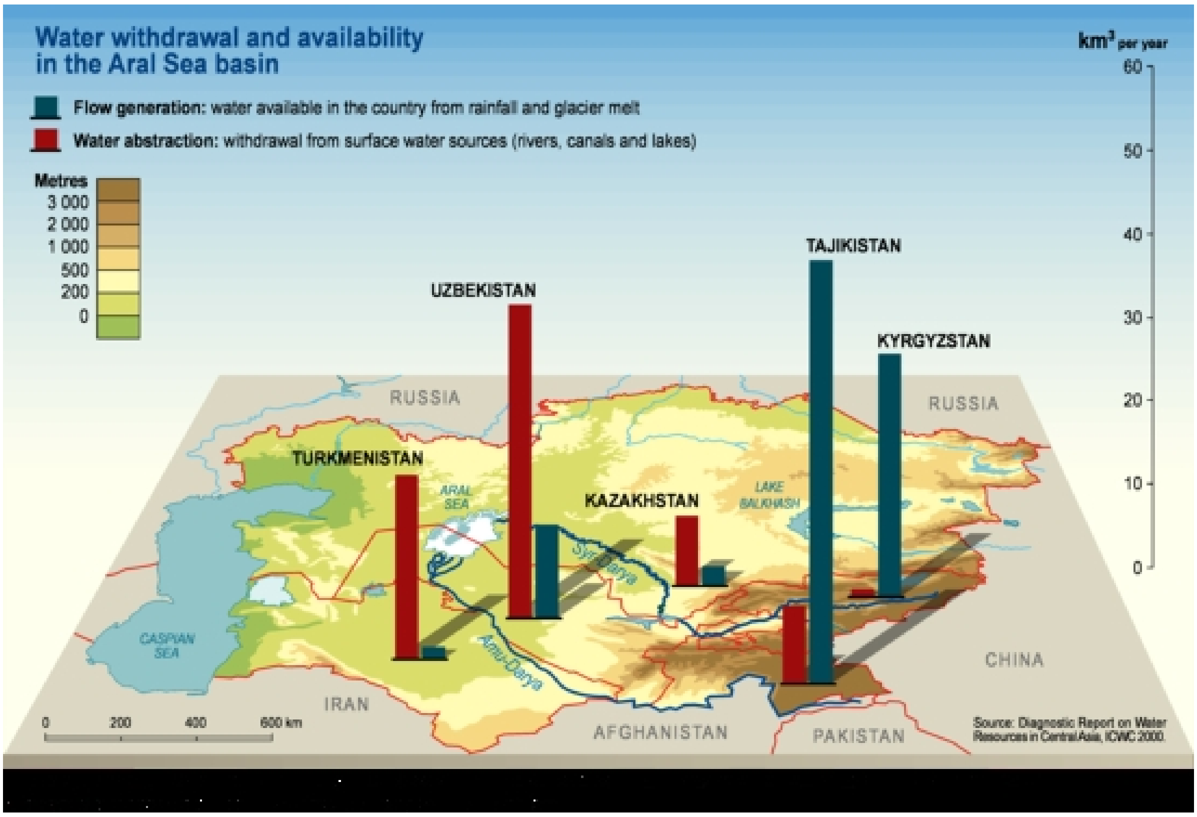


Figure 4.3: Water demand and flow generation per country, showing high supply upstream and high demand downstream (UNEP, 2005).

Country	River basin			Total Aral Sea basin	
	Syr Darya	Amu Darya	Tedzhen-Murghab	km³	%
Kazakhstan	3.30			3.30	2.8
Kyrgyzstan	27.42	1.93		29.35	24.8
Tajikistan	1.01	*59.45		60.46	51.0
Turkmenistan		0.68	0.3	0.98	0.8
Uzbekistan	4.84	4.70		9.54	8.1
Afghanistan		11.70	3.1	14.80	12.5
Islamic Republic of Iran			n.a.	-	-
Aral Sea basin	**36.57**	**78.46**	**3.4**	**118.43**	**100.0**

Figure 4.4: Average annual flow and country distribution in Aral Sea basin [km$^3/yr$](AQUASTAT, 2013).

Of the irrigation 'losses' 50% is seepage from the canals, 20-25% comes from the field distribution and 25-30 % is infiltration (Berdjansky and Zaks, 1996). In some parts of the region this is a valuable source to restock the aquifers (Rakhmatullaev et al., 2010). Part of the losses are captured in drainage canals, some of them feed back into the river, while others flow into human-made drainage lakes (CAwater-info, 2011).

The irrigation practices in Central Asia are said to be inefficient, a lot of water is withdrawn of which only a small amount is used for crop transpiration (UNEP and ENVSEC, 2011). 95% Of the return flow generated in the Aral Sea basin comes from irrigation, and of the return flow 16% is directly reused for irrigation. The remaining part is not used because of the deteriorated water quality, 51% flows back to the rivers while 33% is discharged into local lakes (ICWC, 2000). Increasing irrigation efficiency is seen as an essential measure to deal with this inefficiency (Cai et al., 2003; Törnqvist and Jarsjö, 2012).

Some issues that arise due to mismanagement in irrigation are waterlogging[1] (Jumaboev et al., 2015), increasing salinity (O'Hara, 2000) and an overall decreasing water quality due to contaminated runoff (Asian Development Bank, 2010c; UNEP and ENVSEC, 2011). More than half of the irrigated land in the Aral Sea basin is estimated to be saline or waterlogged, with 80% of the irrigated land in Turkmenistan and 35% of the irrigated land in Tajikistan damaged (Asian Development Bank, 2010c).

[1] Over irrigation results in over saturation of irrigated lands making it unsuitable for farming

Country	Year	Annual water withdrawal								
		Agriculture		Municipalities		Industries		Total		
		Volume	% of total	Volume	% of total	Volume	% of total	Volume	% of region	per inhabitant
		million m³	%	million m³	%	million m³	%	million m³		m³/inhab
Afghanistan *	2005	20 000	98.2	203	1.0	170	0.8	20 373	14	937
Kazakhstan	2010	14 002	66.2	878	4.2	6 263	29.6	21 143	15	1 319
Kyrgyzstan	2006	7 447	93.0	224	2.8	336	4.2	8 007	6	1 575
Tajikistan	2006	10 441	90.8	647	5.6	408	3.5	11 496	8	1 762
Turkmenistan	2004	26 364	94.3	755	2.7	839	3.0	27 958	19	5 952
Uzbekistan	2005	50 400	90.0	4 100	7.3	1 500	2.7	56 000	39	2 158
Central Asia		**128 654**	**88.7**	**6 807**	**4.7**	**9 516**	**6.6**	**144 977**	**100**	**1 811**

** Agricultural water withdrawal refers to 1998*

Figure 4.5: Withdrawal per sector in Central Asia (AQUASTAT, 2013).

Country	Year	PRIMARY AND SECONDARY FRESHWATER WITHDRAWAL					USE OF OTHER SOURCES OF WATER						
		Surface water		Groundwater		MDG Water Indicator	Direct use				Desalinated water		
		Volume	% of total	Volume	% of total			Treated waste-water	Agricultural drainage water	% of total		Volume	% of total
		million m³	%	million m³	%	%	Year	million m³	million m³	%	Year	million m³	%
Afghanistan	1998	17 317	85.0	3 056	15.0	31							
Kazakhstan	2010	18 959	89.7	1 029	4.9	19	2010	194	108	1.4	2010	853	4.0
Kyrgyzstan	2006	7 401	92.4	306	3.8	33	1994	0.14	300	3.7			
Tajikistan	2006	8 936	77.7	2 260	19.7	51	2000		300	2.6			
Turkmenistan	2004	27 237	97.4	305	1.1	111	2004	336	80	1.5			
Uzbekistan	2005	44 160	78.9	5 000	8.9	101	2000		6 840	12.2			
Central Asia		**124 010**	**85.5**	**11 956**	**8.2**			**530**	**7 628**	**5.6**		**853**	**0.6**

Figure 4.6: Withdrawal by source in Central Asia (AQUASTAT, 2013).

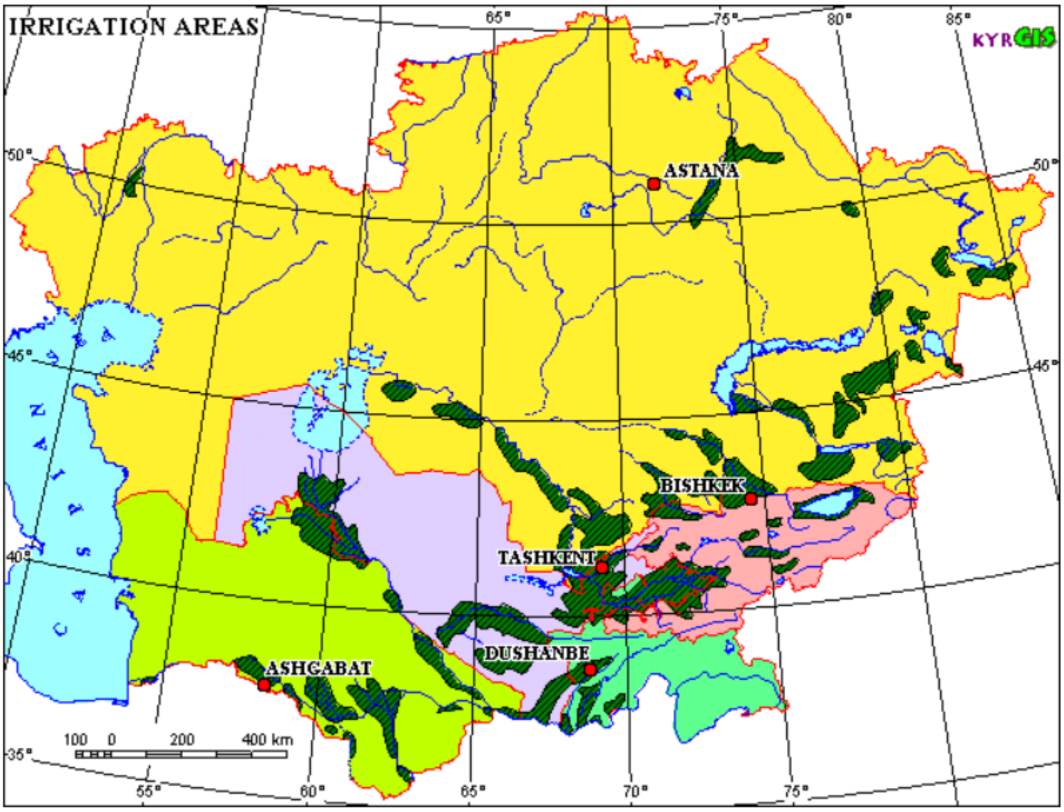


Figure 4.7: Irrigated areas in the Aral Sea basin (CAwater-info, 2011).

5

Research methods

5.1 Introduction

This research aims to argue that increasing the irrigation efficiency on a small scale does not contribute to saving water on a basin scale because increasing irrigation efficiency increases the consumptive water use. Consumptive water use is determined as water that evaporates and therefore leaves the system (see Chapter 3). This phenomena is explored in the case of Central Asia, and specifically the Amu Darya river basin. This research is limited to irrigated agriculture, as agriculture is the main water consumer in the region. The study combined a locally developed model with remote sensing data.

In this chapter, the methodology of calculating the consumptive use is discussed, starting with the general method outline, and then going into the different parts of the research more in depth. The different data sources are discussed in this chapter and more in depth in Appendix B and C.

5.2 Method outline

This research looks into the water consumption in irrigated areas in the study region. The fluxes flowing in and out of a system depend on the boundaries of that system. Hence, the definition of the boundaries of the irrigated areas is an important initial step in the methodology. Determination of the water consumption requires only a selection of water fluxes. The other present water fluxes are used to check the data sets and models used in the analysis.

An available data set of areas equipped for irrigation by the Food and Agriculture organization (FAO) was combined with evapotranspiration (ET) and precipitation (P) data to find the actual irrigated areas. Additional water is evaporated from an area if ET is higher than P, one of the main culprits is irrigation. This was used as an indicator to determine the actual irrigated areas (see Subsection 5.5).

The water balance was computed for the irrigated areas. The water balance can be seen in Equation 5.1 and Figure 3.1c.

$$\frac{\Delta S}{\Delta t} = Q_W + P - Q_{CDF} - ET \tag{5.1}$$

Data needed to calculate the water balance included data on withdrawal for irrigation, precipitation, drainage water (Q_{CDF}), evapotranspiration and storage change. The data on withdrawals and return flows were obtained from the Aral Sea Basin management model (ASBmm). A global evapotranspiration model ($ET_{monitor}$) was used to determine ET and the Climate Hazars Group InfraRed Precipitation with Station data (CHIRPS) were used to find P. Furthermore, this research attempted to use the Gravity Recovery and Climate Experiment (GRACE) data on change in land water content to calculate storage change. More on the model and the data follows in Section 5.3 and Section 5.4.

The consumed fraction was used as an indicator for irrigation water consumption. The consumed fraction was determined through Equation 5.2.

$$CF = \frac{ET - P_e}{Q_W} \tag{5.2}$$

Where $ET - P_e$ is the water consumed through irrigation and Q_W is the water withdrawn (Frederiksen et al., 2012). The remaining water is divided into the nonrecoverable fraction (Q_{NRF}) and the recoverable fraction (Q_{RF}). In this research the focus lies on the consumed fraction, that is the fraction of the withdrawn water that is consumed through evapotranspiration ($ET - P_e$) where ET is the total evapotranspiration and P_e is the effective precipitation, more on this in Subsection 5.7. Data on withdrawal are again derived from the ASBmm and data for the ET and P_e are obtained from remote sensing products.

5.3 Aral Sea Basin management model

The Aral Sea Basin management model (ASBmm) is a regional model developed by the Science Information Center of the Interstate Coordination Water Commission of Central Asia (SIC ICWC) under advice of the UNESCO-IHE, Delft institute for water education. It is a black box model, the code is not available but it is accessible through an online interface[1]. It contains four sub models: the flow formation model, the water allocation model, the planning zone model and the socio-economical model. Only the output of the second and third model are used in this research, which are partly fed by the first model. The ASBmm is a forecasting model based on historical data up to 2010. This research made use of the data for the first computation year (2011) which gives the least errors due to prediction.

The ASBmm contains separate models for the Amu Darya and the Syr Darya river basins. These basins are divided into planning zones based on administrative districts (see Appendix B).

The model contains water balances per planning zone providing information on water demands by agriculture, industry and domestic actors as well as water allocations based on the predicted flow (see Figure 5.1 and Figure 5.3). Only the water allocation from transboundary rivers is dependent on water availability. After the water allocation, the model calculates the collector drainage flow. This is done through the water balance or with the ratio of reduction depending on the data availability. The flows and allocations are calculated with a monthly time step, however, the output is only available per year.

The model provides the option to change settings in the initial scenario, the data used in this research were generated with the standard scenario. Changes in the user scenario were used to assess sensitivities in the model (see Appendix B).

This research used the withdrawals per planning zone. This includes the withdrawal from rivers, groundwater, local resources and reservoirs, depending on the boundaries of the irrigation scheme. The water demand for industry and domestic use were subtracted from the withdrawal as this research solely looks at agricultural water use.

[1] As of January 2017 the model has been offline

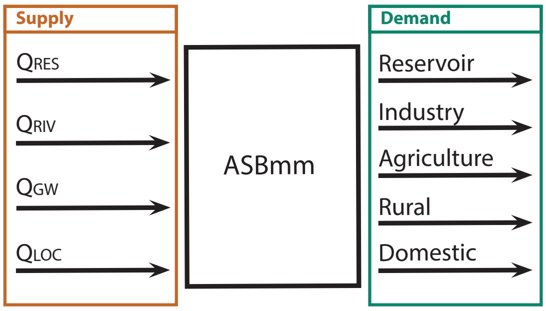
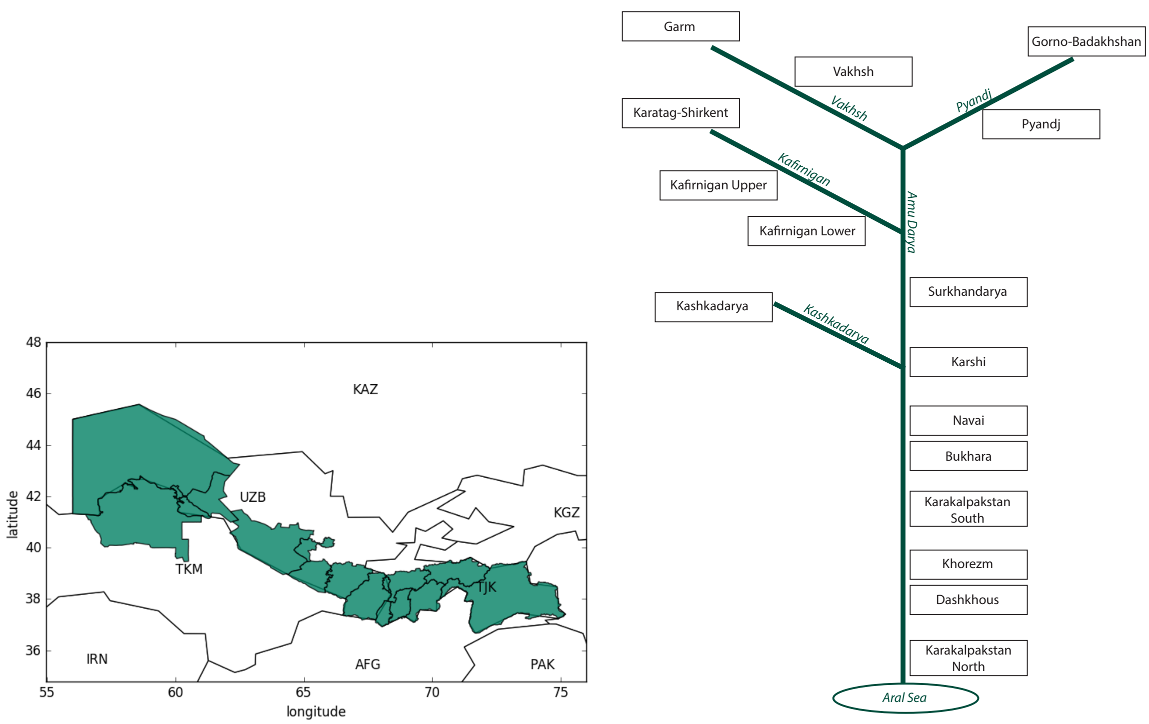


Figure 5.1: Water supply and demand fluxes in the Aral Sea Basin management model (ASBmm) Q_{RES} = water supply from reservoirs, Q_{RIV} = water supply from transboundary rivers, Q_{GW} = water supply from groundwater and Q_{LOC} = water supply from local rivers.

5.3.1 Boundaries of planning zones

The SIC ICWC provided some spatial maps of the planning zones used in the ASBmm (see Figure 5.2a). These were necessary to conduct the water balances per planning zone. The spatial maps were only available for a limited number of planning zones in the Amu Darya river basin. The planning zones are distributed over the schematic river basin as depicted in Figure 5.2b. This schematization is a simplification of the actual locations of the planning zones and the irrigated areas. In real life the withdrawals are not from one location in the river, some of the planning zones or irrigated areas are farther away from the river and not directly linked to the next planning zone as is depicted in the schematization. The schema was developed in order to allow the computation of the cumulative consumed fractions. This schema was based on the ASBmm and the spatial location of the river relative to the planning zones.



(a) Planning zones of the Amu Darya river basin spatial location in the Central Asian countries.

(b) Planning zones of the Amu Darya river basin schematized along the river.

Figure 5.2: Planning zones in the ASBmm.

5.3.2 A critical look

The ASBmm is a black box model which makes it difficult to asses the internal model dynamics. Some insight into the inner workings of the model was gained through the ASBmm final report (Dukhovny et al., 2012) and discussions with people who were involved in the model development. Some of the main critical observations about the model are mentioned below. These observations had to be kept in mind in the data analysis and the interpretation of the results.

- The planning zone models do not contain a water balance with the classical fluxes. Evapotranspiration and precipitation are included in the calculation of the crop water demand and not included seen in the water balance as separate indicators. The flow formation model does take evaporation from open water into account.
- Groundwater recharge is not taken into account in the model.
- The withdrawal of local water, groundwater and reservoirs is independent of water availability.
- Not all data is available for all planning zones and some planning zones have no data. It is hard to assess the quality of the data used.
- It is unclear which method of calculation is used for the collector drainage flow per planning zone. It is also unclear how the ratio of reduction is determined.
- In one case the collector drainage flow has a negative value (see Figure 5.3b, Navai).
- In some planning zones the withdrawal for irrigation is suspiciously low relative to other withdrawals, people from SIC ICWC mentioned that those regions have very little irrigation.
- The term withdrawal from local resources gives positive and negative values. This suggests that this term sometimes relates to recharge into local resources but we cannot be sure.
- The model is said to have a reuse component but it does not have any effect on the water allocation or fluxes in the model.

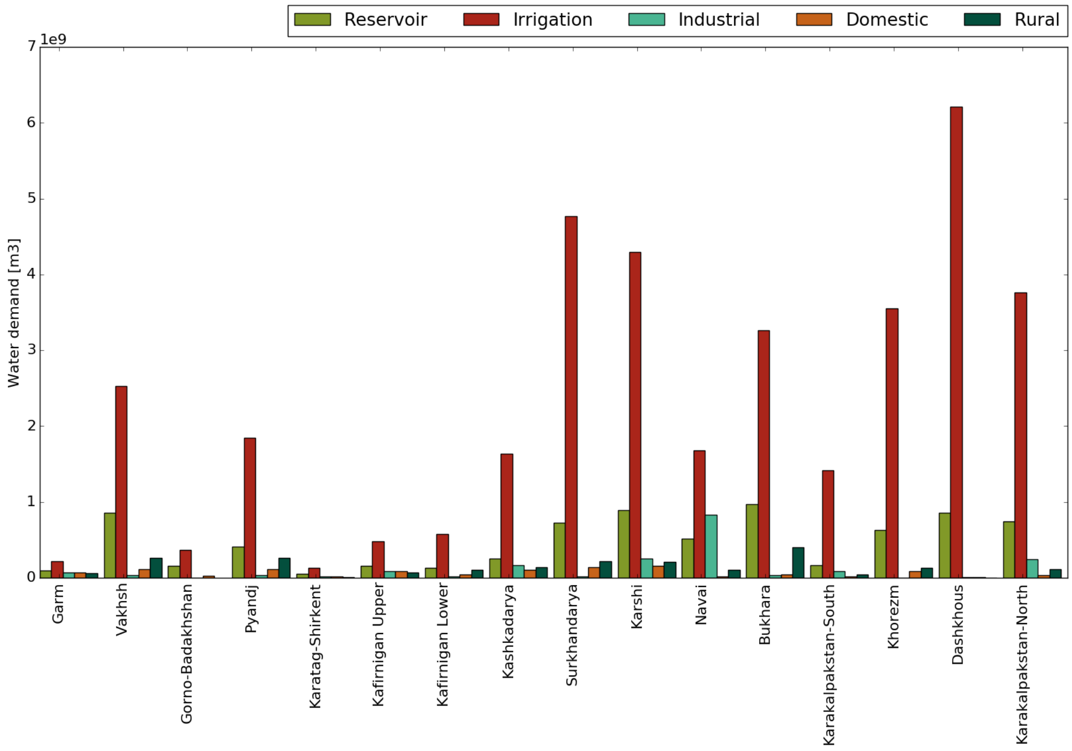
5.4 Data sources

This research used: CHIRPS precipitation data, $ET_{monitor}$ evapotranspiration data and the FAO AQUASTAT areas equipped for irrigation database. For the ET and P the data for the year 2011 were used because this was the best available year in the ASBmm. These data sets are further introduced in the following sections. The motivation for the choice of the data sets and a more extensive description of the data sets are included in appendix C.

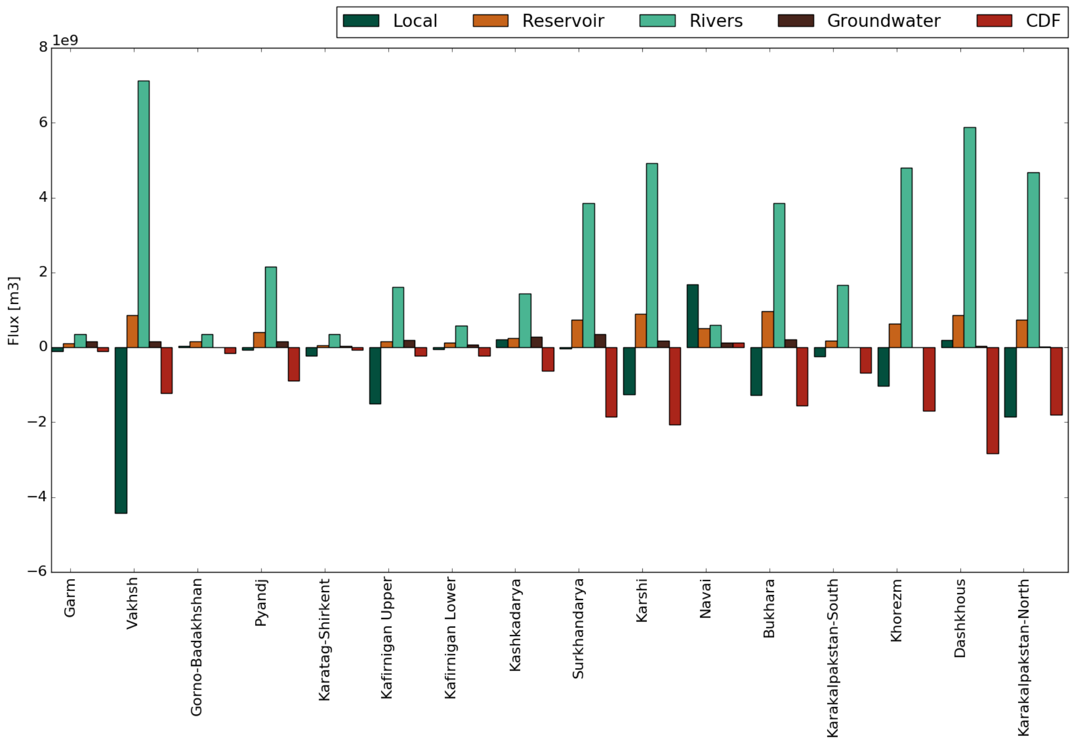
5.4.1 Precipitation

This research used the monthly data of the CHIRPS precipitation data set[2]. CHIRPS stands for Climate Hazards Group InfraRed Precipitation with Station data. It combines 0.05° resolution satellite imagery and in situ monitoring to create a precipitation time series (Funk et al., 2015a). This gridded time series stretches most of the world, including the research areas in Central Asia. The data is represented in millimeters per cell and per time period, e.g. per month (see Figure 5.4).

[2] ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0



(a) Water demand per planning zone per sector according to the ASBmm.



(b) Water fluxes per planning zone per sector according to the ASBmm.

Figure 5.3: Water demand and fluxes derived from the ASBmm.

5.4.2 Evapotranspiration

The ET$_{monitor}$ data set was used for evaporation and transpiration, this data set contains the flux that leaves the earth surface and plants in a vaporized form (Zheng et al., 2016). Evaporation and transpiration are not easily measured directly, ET$_{monitor}$ combines existing methods for these processes to create a combined flux. This is determined from satellite measurements. This includes soil evaporation, plant transpiration, plant interception and evaporation, evaporation from surface water and sublimation for snow and ice surfaces. These modules are combined in areas with varying land cover to create a global evaporation model. The data set shows evapotranspiration in millimeters per grid cell per time period, e.g. per month (see figure 5.5). The ET$_{monitor}$ grid has a 0.005° spatial resolution and is the only one available to cover the Aral Sea basin completely.

ET$_{monitor}$ was used in this research but is not available in the public domain. Another global evapotranspiration data set called ET$_{ensemble}$ will be available in the public domain and can be used for future research, however, during this research ET$_{ensemble}$ was not yet available for the research area. Once it is available, ET$_{ensemble}$ can be used in a similar fashion as ET$_{monitor}$ (see appendix C).

5.4.3 FAO map of areas equipped for irrigation

The FAO created a global map of areas equipped for irrigation by combining sub national statistics and maps with digital land cover maps (Siebert et al., 2005b). This map was made for the year 2000 showing irrigation densities in grid cells with a resolution of 0.083° in % per pixel (see Figure 5.6). This map shows areas equipped for irrigation and not actual irrigated areas. The FAO also looked into the actual irrigated areas but did not find good quality data for the countries in Central Asia (see appendix C).

5.4.4 GRACE terrestrial water storage

The GRACE twin satellites measure changes in the gravitational field (JPL, 2014). Changes in the gravitational field show changes in landmass which can be related to changes in terrestrial water storage (Landerer and Swenson, 2012). The terrestrial water storage is shown relative to a baseline average between 2004 and 2009 (JPL, 2012). The data are available in a spatial grid of 1° which is much coarser than the other data sets (see Figure 5.7). GRACE is generally used for large scale analysis, on global (Syed et al., 2008) or watershed scale (Billah et al., 2015).

There are three organizations who develop the terrestrial water content maps. This research explored the use of the maps developed by the Center for Space Research at the University of Texas(CSR) and the Jet Propulsion Laboratory (JPL). The different institutions have a different processing method so the provided data sets are different.

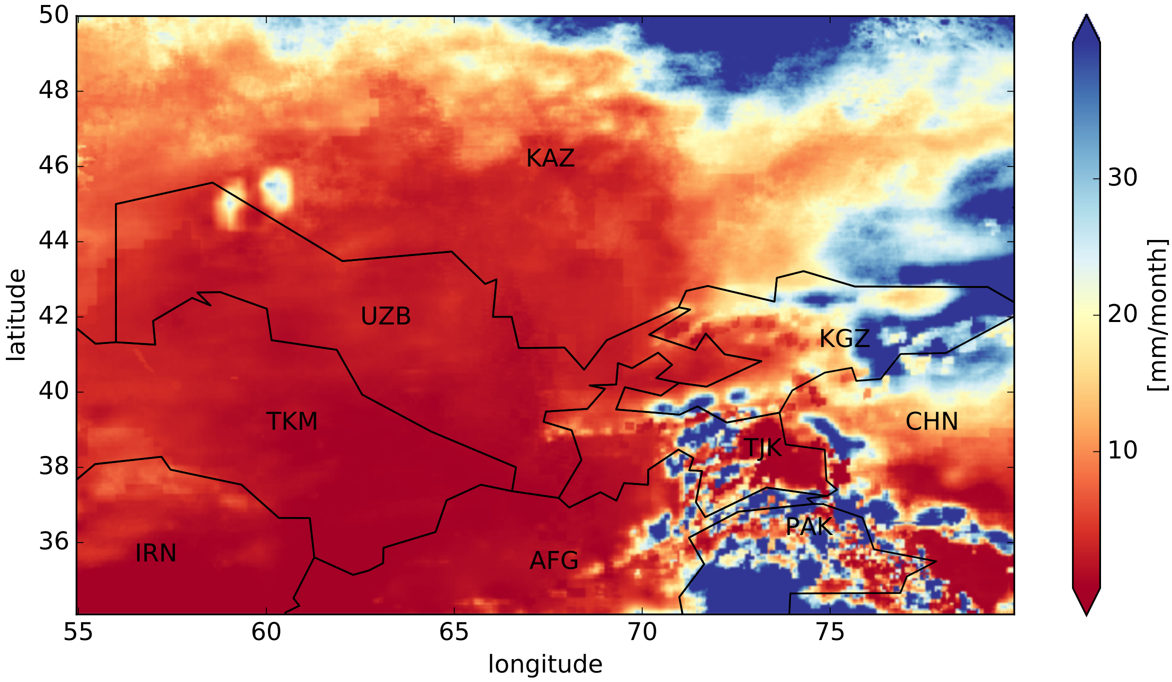


Figure 5.4: Precipitation for the month July 2011 for Central Asia (Data source: CHIRPS).

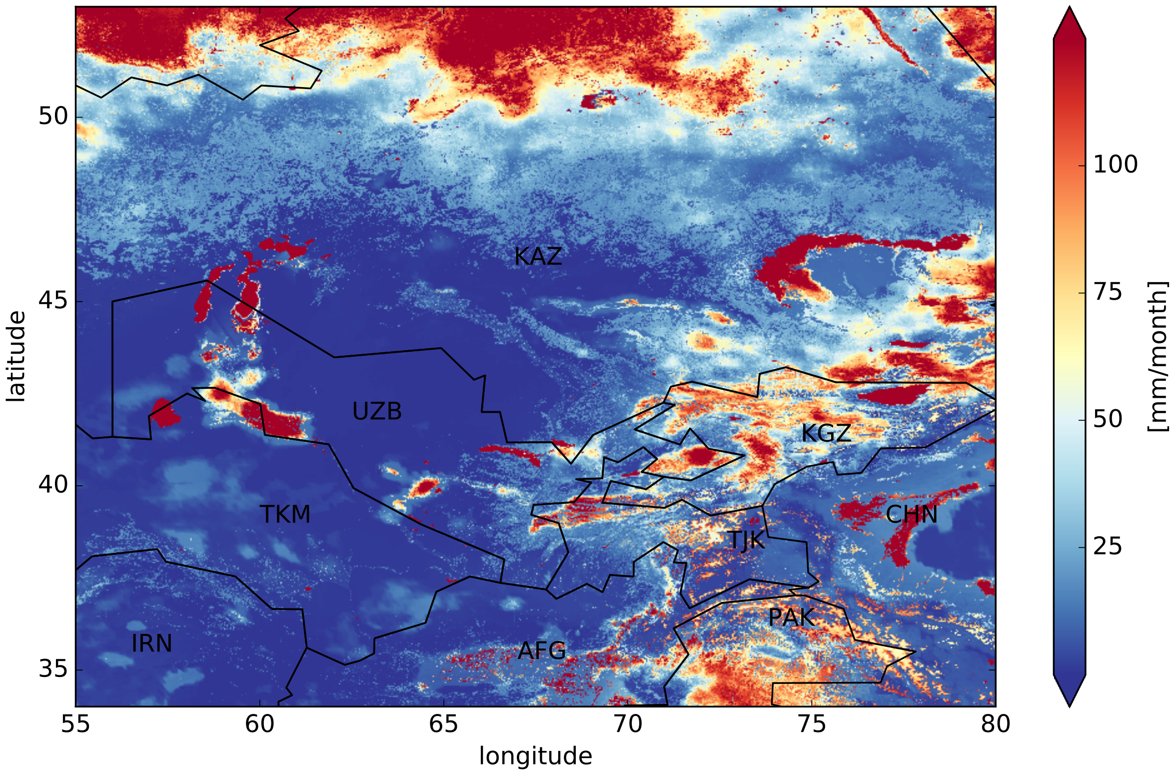


Figure 5.5: Evapotranspiration for the month July 2011 for the Aral Sea basin (Data source;ET$_{monitor}$).

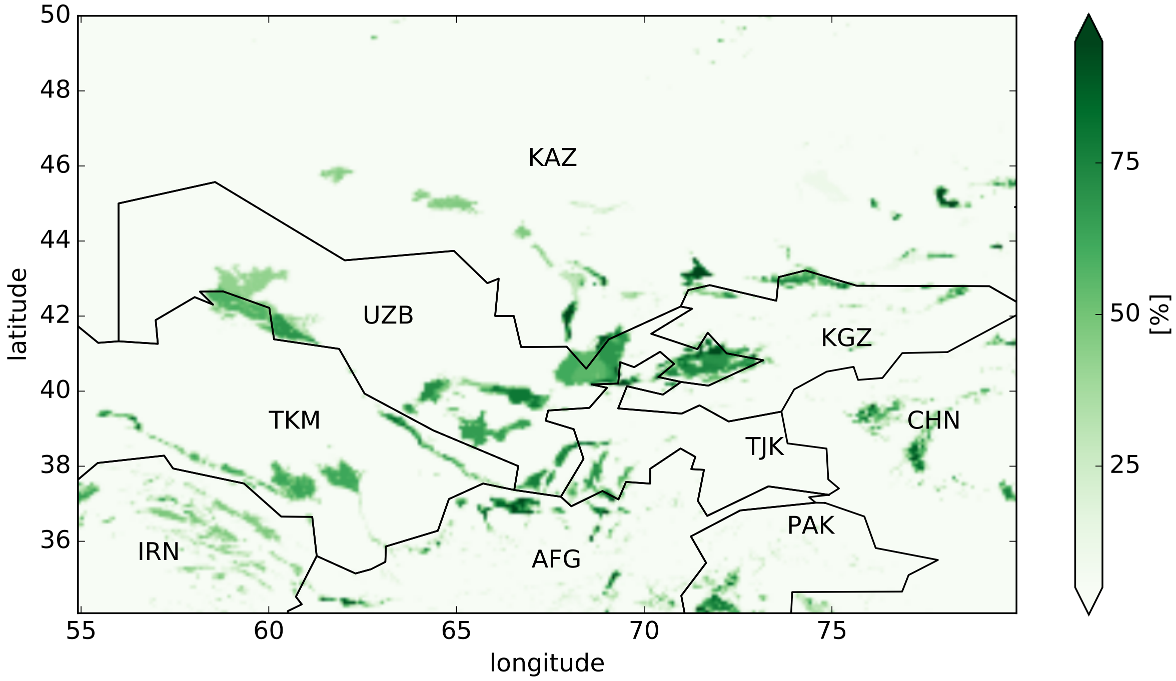


Figure 5.6: Areas equipped for irrigation in the Aral Sea basin in % per pixel (Data source: FAO map of areas equipped for irrigation).

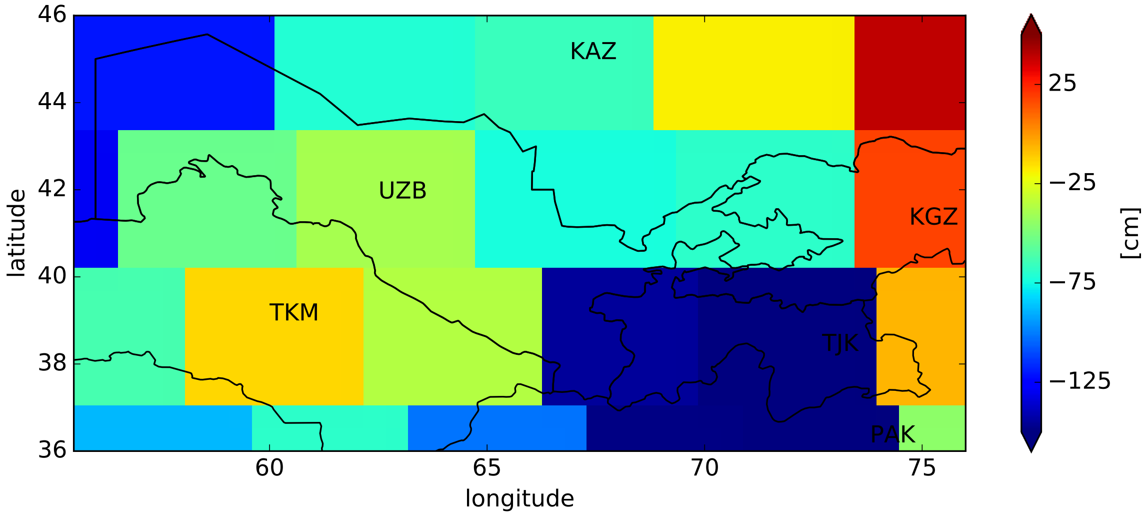


Figure 5.7: Terrestrial water storage in Central Asia for April 2011 as compared to time-mean baseline (Data source: GRACE CSR).

5.5 Determining irrigated areas

For the development of the scaled model it is very important to define the boundaries of the different scales. Because the available withdrawal data are related to irrigated areas, these are the boundaries that were determined. Irrigated areas are areas where agriculture is not only rain fed but also fed by irrigation, actively adding water to the fields. In Central Asia 34.9% of the cultivated area is equipped for irrigation (Siebert et al., 2005b). Siebert et al. (2005b) mentions the Aral Sea basin with the Amu Darya and Syr Darya basins as areas with high irrigation density and regional importance.

As was said in subsection 5.4.3 the FAO global map of areas equipped for irrigation does not show the actual irrigated land but just the areas equipped for irrigation. This was combined with evapotranspiration and precipitation data to filter out the areas that are not actually used for irrigation.

The irrigation season was used for this analysis. In the Aral Sea basin the main irrigation practices occur in the months April to September (AQUASTAT, 2013) (see Chapter 4). In these months precipitation is low and temperatures are high, it is the growing season for the crops and therefore farmland is irrigated. The cumulative P and ET were used for months in the irrigation season.

The data were all presented in a raster format, a georeferenced matrix. This means that a cell size, location and data value is known for every cell in the matrix. For every location in the raster the different data sets were combined to identify the irrigated areas. However, the cell of the rasters were not the same size for every raster, therefore they had to be resampled.

As the $\mathrm{ET}_{monitor}$ data set has the smallest cell size, all other data sets were resampled accordingly. They were resampled using the bilinear interpolation method in which the new value of a cell is calculated according to its four nearest cells. After resampling the data sets were combined according to their geographical locations.

First the $\mathrm{ET}_{monitor}$ and CHIRPS data sets were combined. Water supply is needed for ET, this can come from precipitation or from man-made water supply. When the monthly evaporation exceeds the monthly precipitation it can be assumed that there is another (man-made) water supply, which can point to irrigation. This was analyzed by subtracting the ET from the precipitation during the irrigation season. A threshold was used to find the actual irrigated areas.

Thresholds were set differently for upstream and downstream areas because of the difference in the kind of irrigation fields. Fields are generally smaller in the upstream mountainous areas, so the percentage of irrigation per cell is low while in the extensive downstream fields the percentage of irrigation is higher. Setting a lower threshold for the full basin resulted in a general overestimation of irrigated areas while separating the thresholds gave a more balanced view of the region.

Pixels with a negative $ET-P$ value lower than -40 mm/irrigation season and a percentage irrigated higher than 10% in the FAO map were classified as actual irrigated areas in the downstream planning zones. For the upstream areas this threshold was set at -40mm and and 2%.

5.6 Water balance

The water balance per planning zone was calculated to check the fluxed from the used data sets. This analysis was again done for the irrigation season of the year 2011. The total withdrawals for irrigation per year were assumed to be applied solely during the irrigation season as irrigation water use is limited outside this season. The storage change was calculated with all the fluxes in and out of the boundaries of the system (see Chapter 3). The ASBmm provided withdrawals from transboundary rivers (Q_{RIV}), local resources (Q_{LOC}), groundwater (Q_{GW}) as well as flows to and from reservoirs (Q_{RES}) and collector drainage flow (Q_{CDF}). Of these flows the Q_{LOC} and (Q_{GW}) are internal fluxes, which means they come from within the boundaries of the research area therefore they are not part of the water balance (see Figure 5.8). The ASBmm gives the same value for flows in and out of the reservoirs which cancel each other out. Additionally, the precipitation (P) and evapotranspiration (ET) and the storage change in the planning zone irrigated area ($\frac{\Delta S}{\Delta t}$) were used. This results in the water balance as seen in Equation 5.3 and Figure 5.8

$$\frac{\Delta S}{\Delta t} = Q_{RIV} + P - ET - Q_{CDF} \tag{5.3}$$

The analysis of the water balance explored the effect of the internal fluxes Q_{LOC} and Q_{GW} on the balance. The nature of these fluxes and the point of extraction are not decidedly clear. It can be argued that while these terms are internal to the planning zone, they might be external to the irrigated areas in the planning zone.

The CHIRPS data set was used to calculate the precipitation and ET$_{monitor}$ for the evapotranspiration, the data were already prepared in the process of defining the irrigated areas. To determine the total ET and P of an irrigated area in a planning zone, the cell data are multiplied by the area of the cell all the cells are summed. The size of the cells was given in degrees so a conversion was necessary to get the area in meters. The aggregated data result in a flux for the total irrigated area.

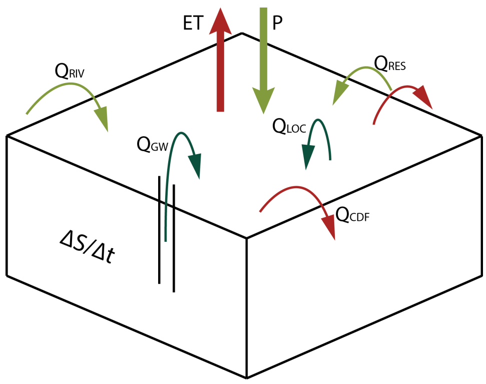


Figure 5.8: The water balance per planning zone, without subsurface flow. The red arrows show outgoing fluxes, the green arrows show incoming fluxes and the blue arrows show water withdrawn from within the boundaries of the planning zone.

5.6.1 Storage change

The difference between the fluxes in and out of the system, can result in storage change. The water balance was judged based on this value and the way it relates to our knowledge of hydrology in Central Asia. The study explored the possibility to validate the balance with land water content change models based on data from the GRACE satellite. For this the storage change given by two different land water content change products based on the GRACE satellite data for the irrigated areas per planning zone were compared. The data was judged as suitable for use if these two products gave similar values.

Before use, the GRACE data sets had to first be multiplied by a grid of scaling factors (JPL, 2012) based on a global hydrological model. The monthly data from the GRACE models are labeled on the 15th, 16th or 17th of the month. Storage change between the first of April and the first of September was needed for the water balance calculation of the irrigation season. First the data were interpolated between March and April and August and September to get the data for the first of the month. Then the data for the first of April was subtracted from the data for the first of September to get the storage change per grid cell. Finally the cell values were multiplied by the relative area they cover in the planning zone irrigated area to get the proposed storage change.

5.7 Consumed fractions

In this research the consumed fractions (CF) of the irrigated areas were determined, the fraction of the water applied by irrigation that was actually consumed as can be seen in equation 5.2. The ET from irrigation and the withdrawals for irrigation are necessary to calculate this consumed fraction. No distinction between beneficial and non-beneficial ET was made in these calculations.

$$CF = \frac{ET - P_e}{Q_W} \tag{5.4}$$

$$Q_W = Q_{RIV} + Q_{GW} + Q_{GW} \tag{5.5}$$

The ASBmm was used to determine Q_W, where the withdrawal for irrigation comes from river water (Q_{RIV}) and groundwater (Q_{GW}). The withdrawal from local water (Q_{GW}) was only taken into account when positive as a negative value does not add to the withdrawal for irrigation. ET was determined through ET$_{monitor}$. This research was specifically focused on water consumption through irrigation. ET$_{monitor}$ gives the total ET, however, part of this is generated from precipitation (P). Therefore the effective precipitation (P_e) was subtracted from the ET. The CHIRPS data set was once more used for the precipitation.

For this research P_e was approximated by using the semi-empirical Curve Number (CN) method (Bos et al., 2008) to determine the runoff from rainfall(see Appendix D). Based on the cropping patterns and soil conditions a CN was determined with which the runoff of the precipitation was calculated. For this research the CN of 78 was fitting for the dominant irrigation method discussed in Chapter 4. How much precipitation will actually turn into runoff is dependent on the CN and the precipitation intensity. The curve number method was developed to analyze daily or event based precipitation, applying it for monthly and seasonal precipitation is possible but can lead to an overestimation or underestimation of the runoff as soil moisture and intensity variability are not taken into account. As this research looked at the dry months, the runoff was probably slightly overestimated with the CN method. There are other fluxes apart from runoff and ET like percolation to the groundwater. These were not taken into account with this method which resulted in an over estimation of the effective precipitation.

First, the consumed fractions were calculated for the irrigated areas per planning zone. The same method as in the water balance exercise was used to calculate the total P_e and ET per irrigated area and planning zone. The area covered per cell was calculated and multiplied by the ET or P_e value after which they were added together to get the value for the full irrigated area. The other fluxes were already readily available from the ASBmm. The CF per planning zone was related to their location in the basin as well as their total irrigated area.

Second, the progression of the CF along an increasing scale was calculated, this is defined as CF$_C$. CF$_C$ was calculated as ET minus P_e divided by the withdrawals for the total irrigated area upstream of that point, as can be seen in Equation 5.6.

$$CF_{c_n} = \frac{\sum_{i=1}^{n} ET_i - P_{e_i}}{\sum_{i=1}^{n} Q_{W_i}} = \frac{ET_1 - P_{e_1} + ET_2 - P_{e_2} + ... + ET_n - P_{e_n}}{Q_{W_1} + Q_{W_2} + ... + Q_{W_n}} \tag{5.6}$$

Where n indicates the planning zone until which the consumed fraction is calculated, including everything upstream of its location, and where i is the counter referring to all the planning zones upstream. This calculation was also conducted for the tributaries. They were added to the main river calculation at the point of intersection, e.g. the CF$_C$ at the intersection of the Kafirnigan river with the Amu Darya river contains the complete area upstream, including all tributaries.

As some of the water that is withdrawn is drained back to the river and reused downstream, this results in an overestimation of the total withdrawal in Equation 5.6. This overestimation translates to an underestimation of the consumed fraction. Thus, another calculation was done where reuse of drainage water is taken into account (see Equation 5.7).

$$CF_{c\_reuse_n} = \frac{\sum_{i=1}^{n} ET_i - P_{e_i}}{\sum_{i=1}^{n} Q_{W_i} - Q_{CDF_{i-1}}} = \frac{ET_1 - P_{e_1} + ET_2 - P_{e_2} + ... + ET_n - P_{e_n}}{Q_{W_1} + Q_{W_2} - Q_{CDF_1} + ... + Q_{W_n} - Q_{CDF_{n-1}}} \quad (5.7)$$

Here Q_{CDF} refers to the collector drainage flow from the upstream planning zone with the indicator(i-1). Q_{CDF} of the upstream planning zone was subtracted from the withdrawal, to make sure this reused water is not counted double as withdrawal in the cumulative consumed fraction.

Equations 5.6 and 5.7 were used to calculate the cumulative consumed fraction without and with complete reuse of drainage flow to the river. In reality not all but a percentage of the drainage flow is reused downstream, this percentage is unknown. The two calculations provide an upper an lower boundary for the consumed fractions in the basin, the actual consumed fraction are expected to be somewhere between these two boundaries.

6 Results

6.1 Introduction

The results of the analysis of water consumption in the planning zones of the Amu Darya river basin are presented in this chapter. Starting with defining the actual irrigated areas in the region and in the planning zones, followed by the water balance per planning zone and concluding with the consumed fractions.

6.2 Irrigated areas

The actual irrigated areas were calculated with the Food and Agriculture organization of the United nations (FAO) areas equipped for irrigation map (see Figure 5.6) a map showing the difference between evapotranspiration (ET) and precipitation (P) per pixel (see Figure 6.1). Two filters were applied to find the actual irrigated areas. They both use a threshold of $P - ET$ < -40mm. The first used a threshold of >10% (see Figure 6.3b) for the irrigated area per pixel in the FAO map and for the second a threshold of >2% (see Figure 6.3b). The first threshold will from now on be named FAO10PET40 and the second FAO2PET40.

The $P - ET$ map is red where there is a high evaporation relative to the precipitation. In these areas evaporation is generated from another source than rainwater. This is the case for open water bodies as well as irrigated areas. The outline of the Aral Sea is recognizable as an open water body. The areas that are indicated with a dark red color in the $P - ET$ map but are not seen in the FAO map are most likely open water bodies. These open water bodies are filtered out by combining these data with the FAO map.

Focusing on the FAO map of areas equipped for irrigation, it can be seen that the map shows low percentages of areas equipped for irrigation per pixel in the upstream planning zones. Mainly the upper half of Tajikistan is very sparsely irrigated (see Figure 5.6). When the FAO map is compared to the irrigated areas that are mentioned in the Aral Sea Basin management model (ASBmm) it can be seen that the FAO generally overestimates the irrigated areas (see Figure 6.2a). Especially in the planning zones with a substantial irrigated areas this overestimation is significant.

For the FAO10PET40 threshold it can be seen that large irrigated areas are more similar to the areas mentioned in the ASBmm. However, the planning zones with smaller irrigated areas are underestimated (see Figure 6.2b). The FAO2PET40 threshold shows some improvement, as can be seen in the close up in Figure 6.2b. Therefore the thresholds are combined in the analysis of the consumed fractions. The complete maps for the FAO10PET40 threshold and the FAO2PET40 threshold are shown in Figure 6.3a and Figure 6.3b and the final map of irrigated areas per planning zone can be found in Figure 6.3c.

6.3 Water Balance

The distribution of evapotranspiration (ET) for the irrigation season can be seen in Figure 6.4 and the distribution of precipitation (P) can be seen in Figure 6.5. These data are aggregated for the irrigated areas and combined with the fluxes of the Aral Sea Basin management model (ASBmm). The fluxes for the water balance per planning zone irrigated area are based on equation 5.3 and can be viewed in 6.6a.

The 'rest term' indicates the water that is left over after calculating the water balance, ideally this is the change in storage ($\frac{\Delta S}{\Delta t}$) but can also include other unknown fluxes that are not included in this research. It can be seen that the rest term of the water balance is mostly positive, this means more water is coming in than going out through the collector drainage flow (Q_{CDF}) and ET. This water can cause storage change in the planning zone, or it can leave the irrigated area through other means than drainage, for example overland flow. Only in some of the downstream planning zones (Dashkhous, Karakalpakstan-South and Navai) the rest term is negative. In those planning zones more water is going out than coming in, which can result in a negative storage change or a depletion of the groundwater.

The planning zones are arranged from upstream to downstream in Figure 6.6a, showing that the quantities of water consumed are much higher in downstream planning zones than in the upstream zones. This can be related to the arid downstream climate and the large irrigation fields. Furthermore it is observed that more planning zones with low withdrawal are located upstream than downstream. The figure also shows some planning zones with a high withdrawal and a high positive rest term, of which Vakhsh is a very prominent example. This means that Vakhsh has a very high surplus of water.

If the ASBmm flux from and to local resources (Q_{LOCAL}) is added to the water balance, this large rest term might be explained. In Figure 6.6b it can be seen that a lot of the surplus in Vakhsh goes to local waters. A negative Q_{LOCAL} means water is supplied to local resources. This also happens in, for example, Karshi. In some cases, like Kafirnigan-Upper and Karakalpakstan-North, a supply to the local resources is combined with a negative rest term, this might cause depleted groundwater levels. In the case of Navai, the withdrawal from local water results in a positive rest term. Dashkhous is the only planning zone where withdrawal from local resources is combined with a negative rest term.

The results for Navai need to be looked at critically as the ASBmm gives a negative Q_{CDF} for this planning zone. A negative drainage flow is theoretically not possible so the data given for Navai might not be reliable.

Withdrawals from groundwater are relatively low so adding them to the water balance does not have a lot of influence (see Figure 6.6b). This observation is in line with the limited role of groundwater in irrigation as was mentioned in Chapter 4.

6.3.1 Storage change

The possibility of using data for land water storage from the Gravity Recovery and Climate Experiment (GRACE) to determine storage change was explored. Data from the GRACE satellites are usually applied on a larger scale due to the grid size of $1°$. There is a mismatch with the grid size of GRACE and the irrigated areas determined in this research (see Figure 6.7a). This makes it doubtful that the storage change value based on GRACE data will be a valid source to use in the irrigated area water balance. Figure 6.7b shows that the two data sets developed by the Jet Propulsion Laboratory (JPL) and Center for Space Research (CSR) give completely different values for the storage change. Therefore GRACE data is, in the end, not used in this water balance analysis.

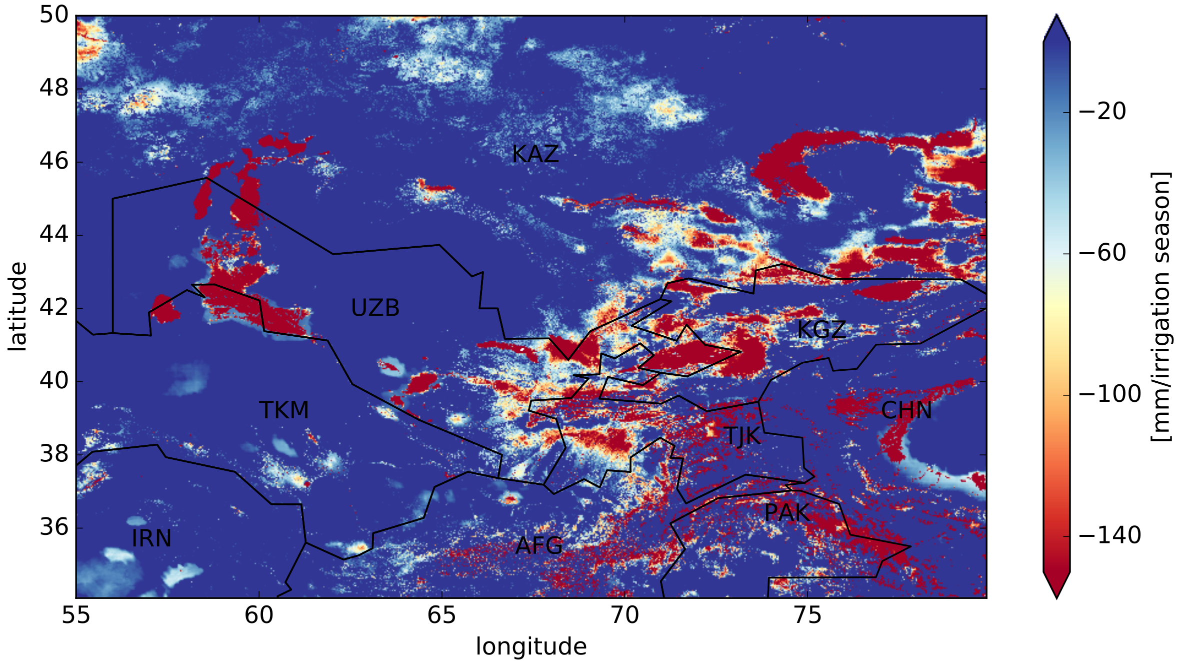
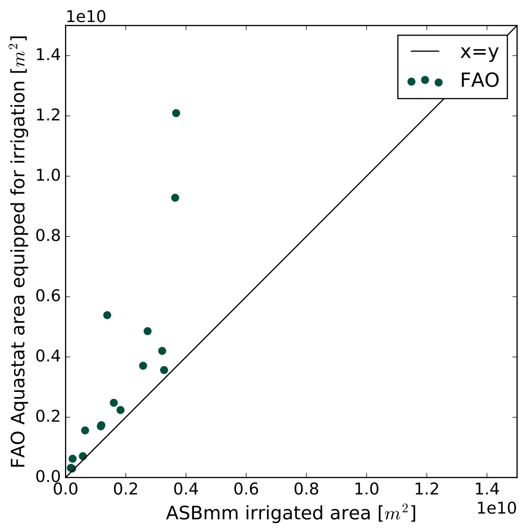
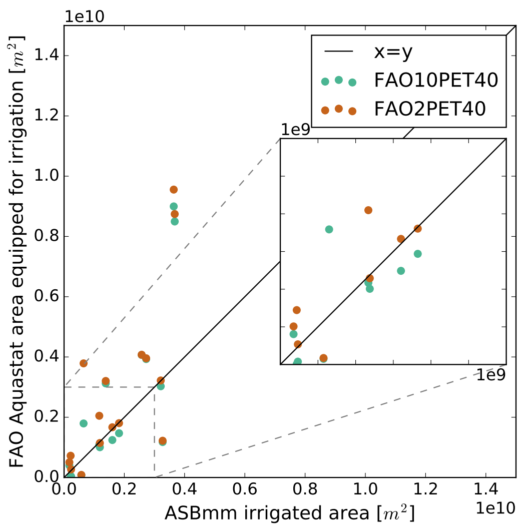


Figure 6.1: Precipitation minus evapotranspiration for the irrigation season (04-09).

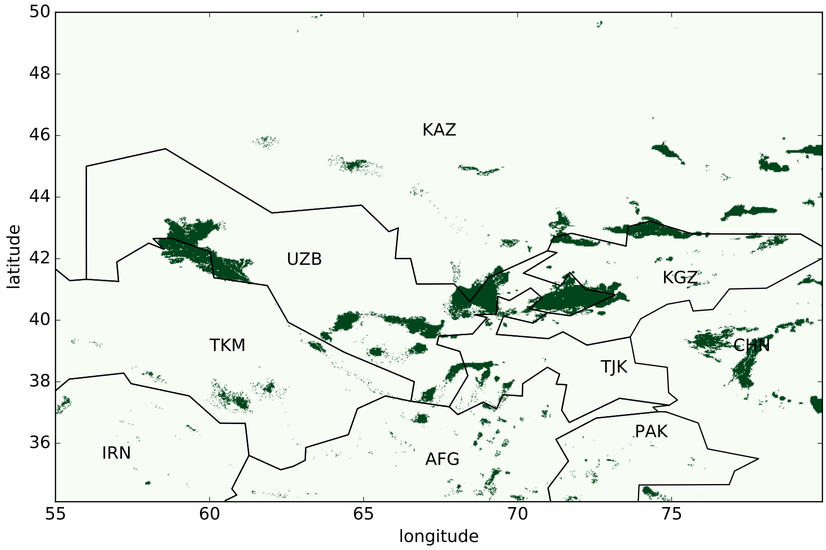


(a) FAO areas equipped for irrigation per planning zone compared to data from the ASBmm.

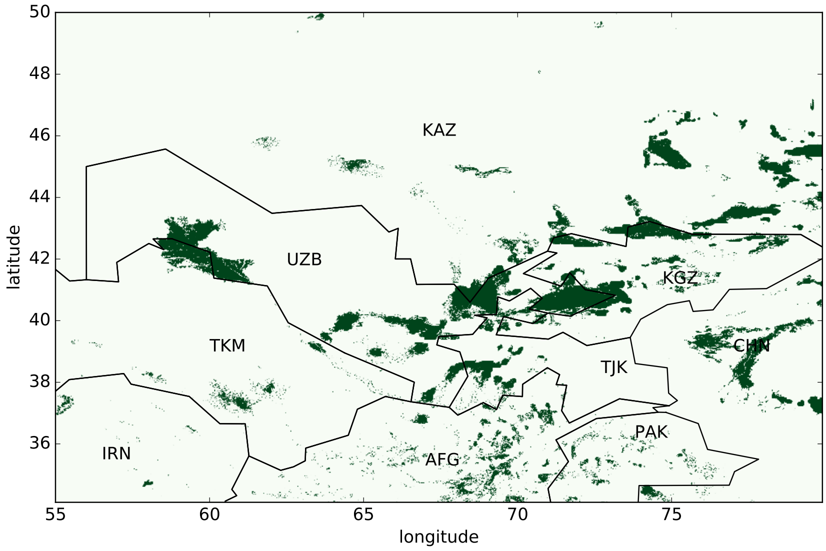


(b) Irrigated areas per planning zone for the FAO10PET40 and FAO2PET40 thresholds compared to data from the ASBmm. The zoom shows that the FAO2PET40 threshold is more suitable for the areas with a low irrigation density.

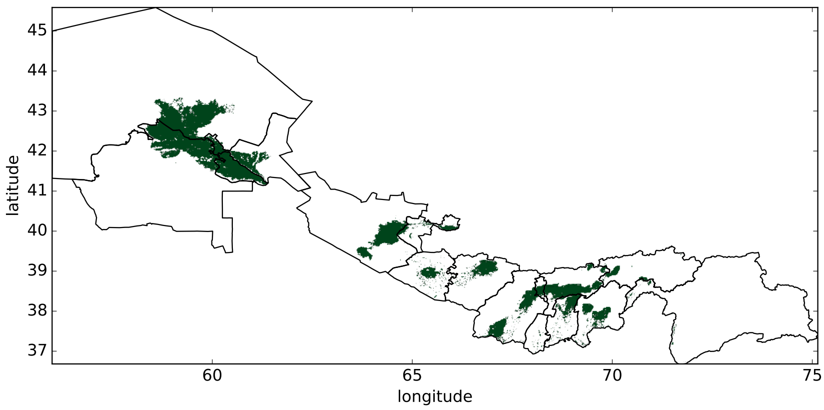
Figure 6.2: Irrigated areas compared to data from the ASBmm.



(a) Actual irrigated areas with the threshold P-ET<-40mm and FAO>10%.



(b) Actual irrigated areas with the threshold P-ET<-40mm and FAO>2%.



(c) Actual irrigated areas per planning zone with the threshold P-ET<-40mm, and with FAO>10% downstream and FAO>2% upstream.

Figure 6.3: Actual irrigated areas

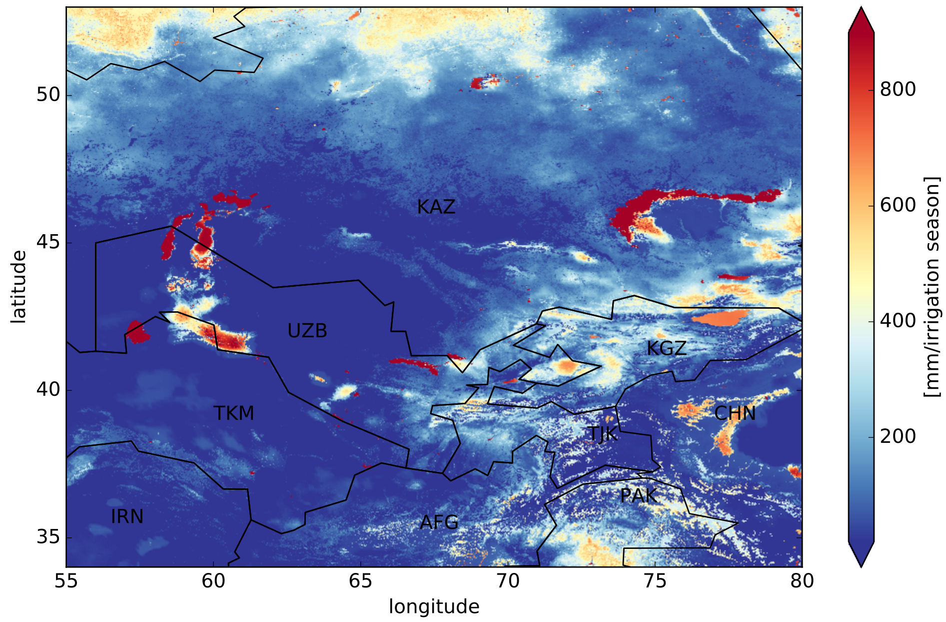


Figure 6.4: Evapotranspiration for the irrigation season between April and September 2011 in Central Asia (Data source: $ET_{monitor}$).

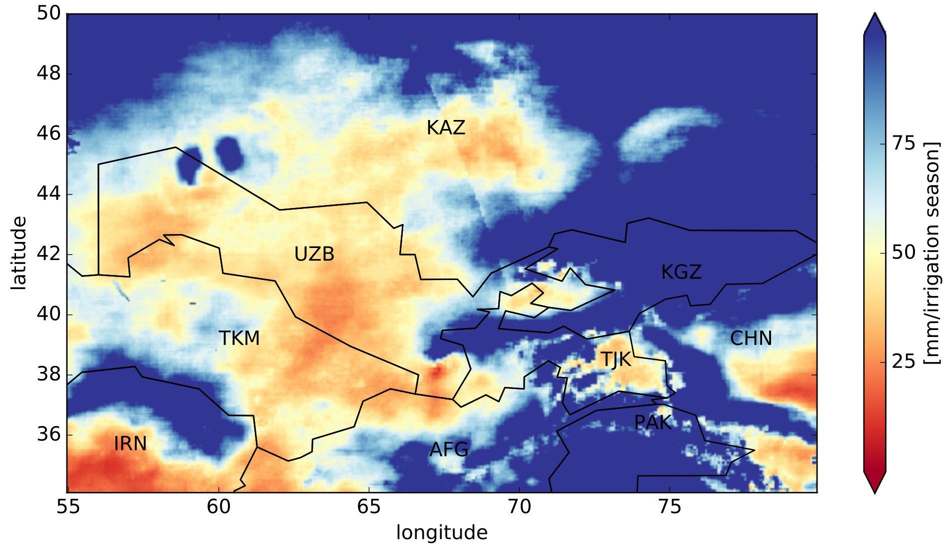
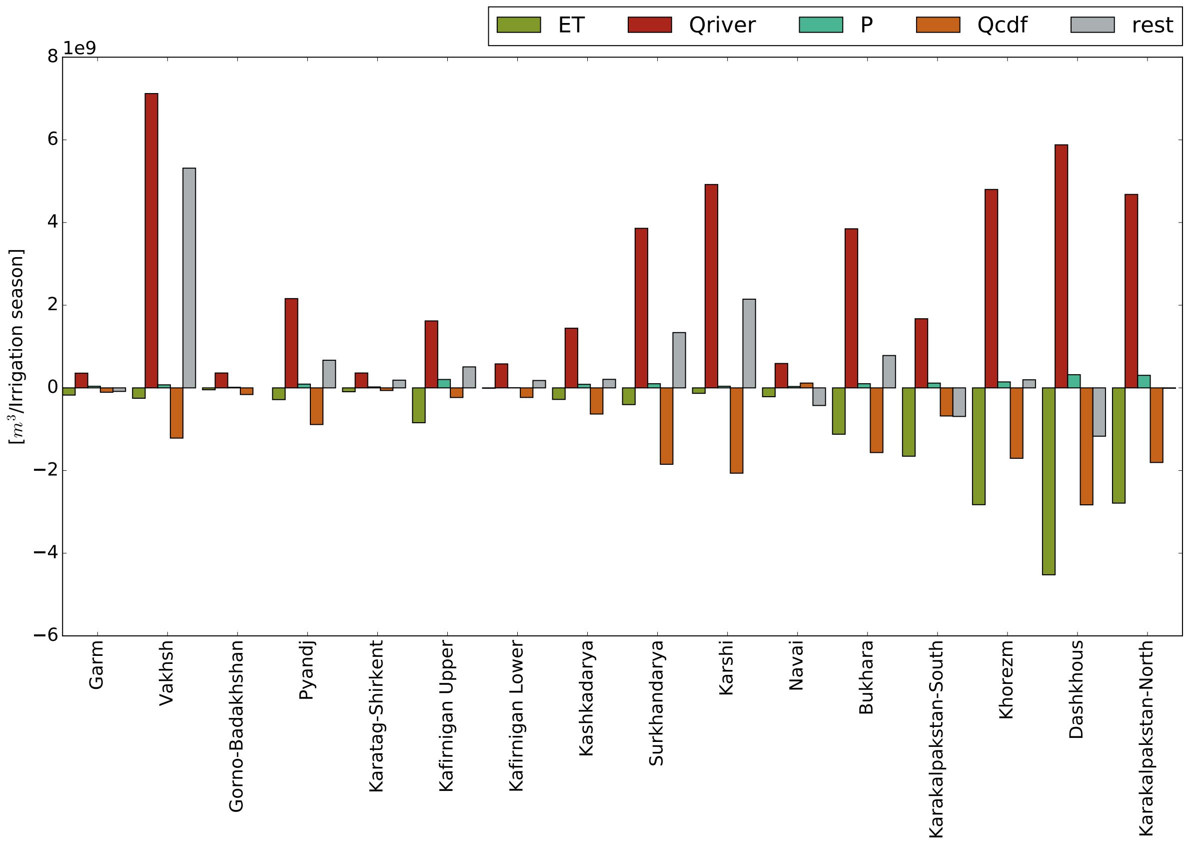
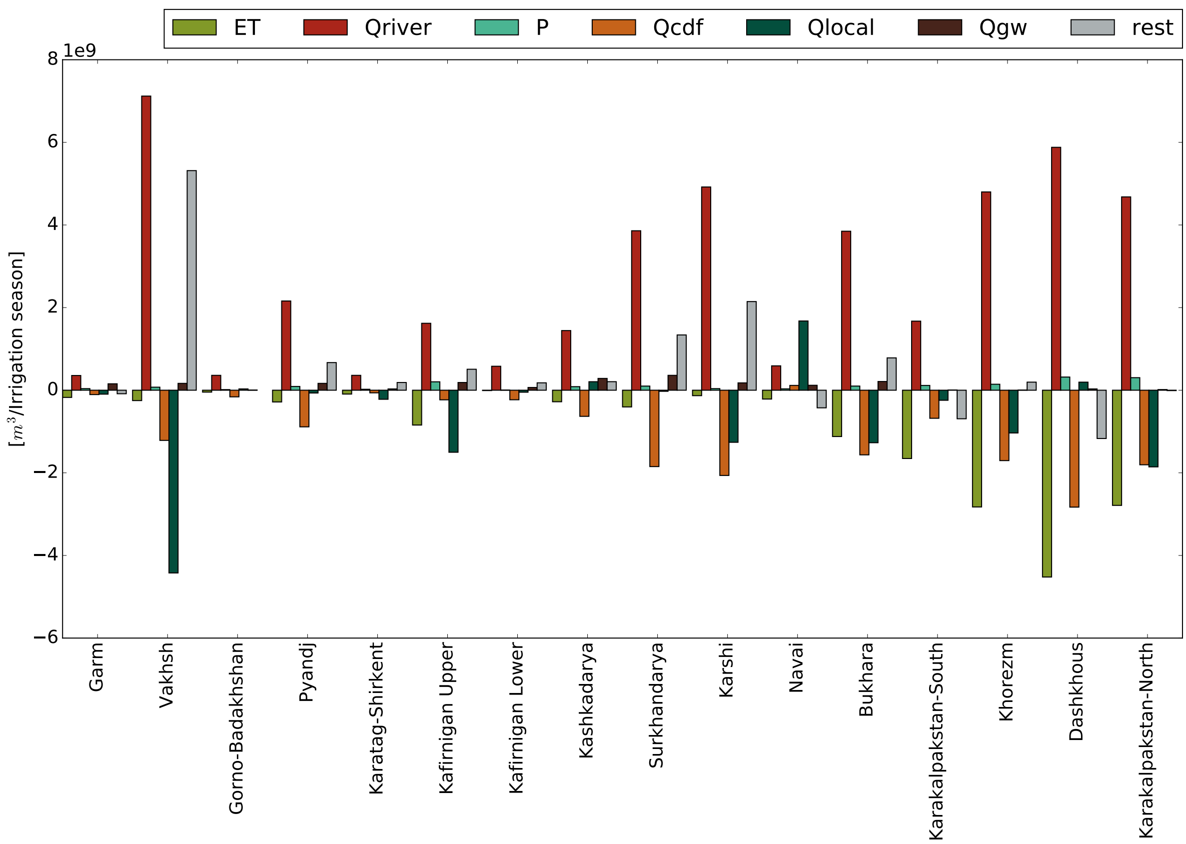


Figure 6.5: Precipitation for the irrigation season between April and September 2011 in Central Asia (Data source: CHIRPS).

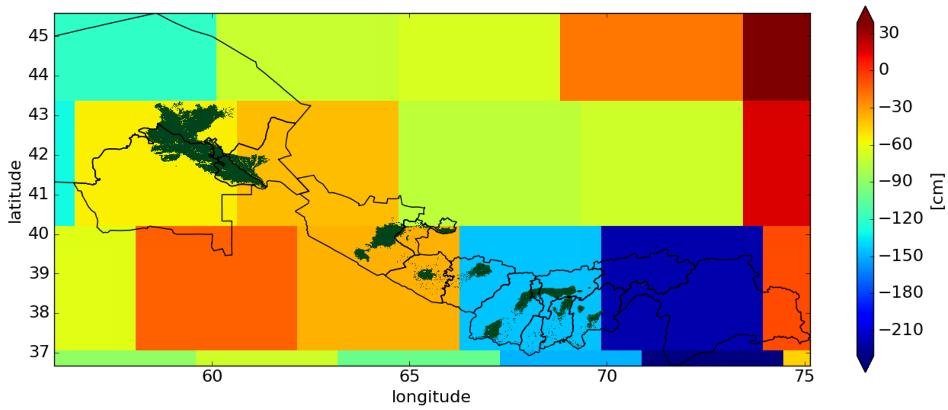


(a) The fluxes per planning zone not taking internal water into account.

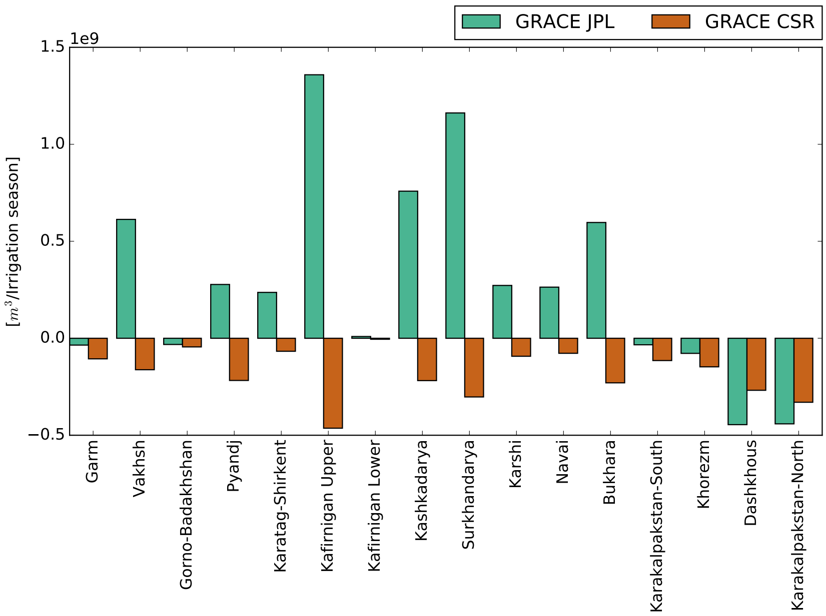


(b) The fluxes per planning zone, including both groundwater and local water.

Figure 6.6: Water balance per planning zone.



(a) GRACE pixel size compared to determined irrigated areas.



(b) GRACE JBL and CSR data compared.

Figure 6.7: GRACE storage change.

6.4 Consumed fractions

This section looks into the consumed fractions of irrigated areas in the Amu Darya river basin. In the following subsections, first, the consumed fractions per planning zone are addressed and second the progression of the cumulative consumed fraction along the river basin with and without reuse of drainage flow. The consumed fractions were calculated for the irrigated areas per planning zone. Equation 6.1 is used as a basis for all calculations.

$$CF = \frac{ET - P_e}{Q_W} = \frac{ET - P_e}{Q_{RIV} + Q_{GW} + Q_{LOC}} \tag{6.1}$$

With $ET - P_e$ as consumption and $Q_{RIV} + Q_{GW} + Q_{LOC}$ as withdrawal. The portion of evapotranspiration from irrigation is calculated by subtracting the effective precipitation (P_e) from the evapotranspiration (ET). The total withdrawal is based on fluxes from the Aral Sea Basin management model (ASBmm), where Q_{RIV} is the withdrawal from transboundary rivers, Q_{GW} is withdrawal from groundwater and Q_{LOC} is withdrawal from local resources. Q_{LOC} is only taken into account when it is positive. This equation is adjusted to calculate the cumulative consumed fractions along the river basin where the fluxes are summed in Equation 5.6, and again adjusted to account for reuse of drainage flow in Equation 5.7.

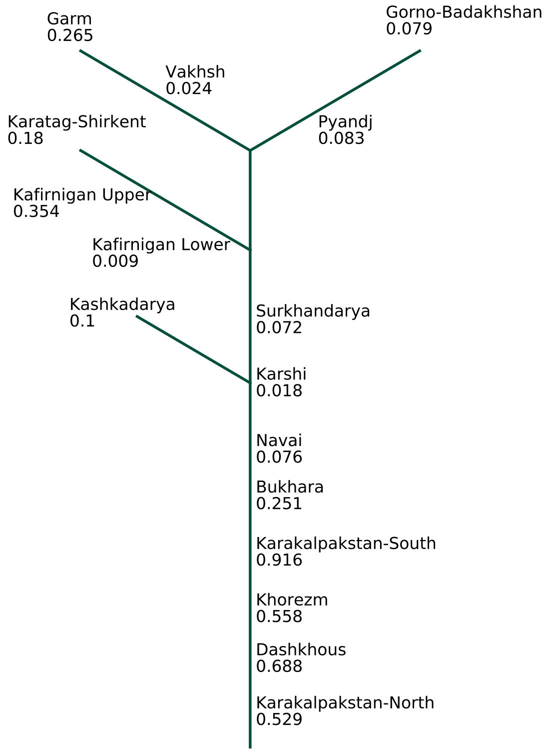
6.4.1 Consumed fractions per planning zone

The consumed fractions (CFs) per planning zone are depicted in Figure 6.8a. It can be seen that there is a great variability between the planning zones. Figure 6.8b shows the CF organized from upstream to downstream planning zones. In general the downstream planning zones have a higher consumed fraction than the upstream planning zones. As was discussed before, the downstream areas usually have larger agricultural areas that are highly dependent on irrigation.

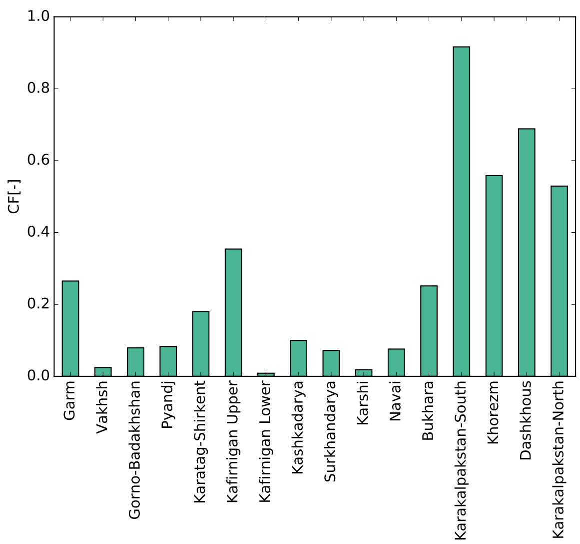
The results show very low consumed fractions, of less than 10%, in the upstream areas. Low consumed fractions were expected based on the analysis of the region in Chapter 4. Irrigation is said to be very inefficient in Central Asia (UNEP and ENVSEC, 2011) which leads to a low consumed fraction. Much more water is withdrawn than than actually consumed. Part of this surplus is collected in collector drainage flow and discharged back to the river. Water is also discharged into local depressions in some planning zones, e.g. Vakhsh and Karshi.

Figure 6.8c shows the consumed fractions related to the total irrigated area of the planning zone. Here it can be observed that the planning zones with a lower irrigated area tend to have a lower CF. Karakalpakstan-South is the outlier in the plot. This planning zone has a CF of 0.926 with a relatively low area. This can be related to the fact that the planning zone itself is quite small and almost completely covered in irrigated land, so even though the total area is small the amount of irrigated area relative to the planning zone is very large. Additionally the irrigated area of this planning zone is overestimated compared to the ASBmm.

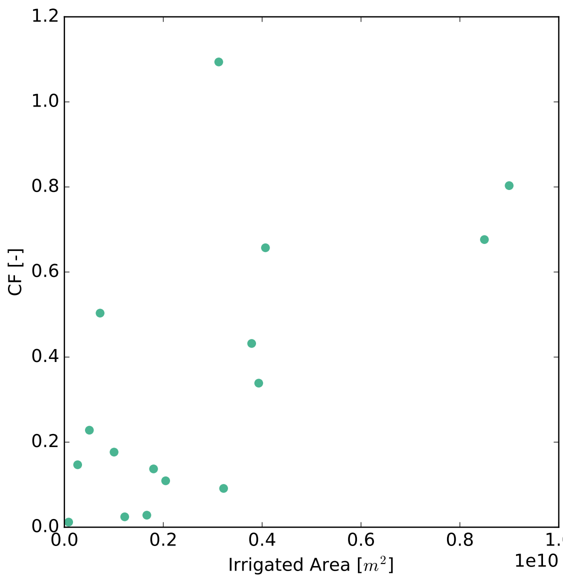
The consumed fractions are dependent on the irrigated areas as the values for ET and P_e are aggregated over these areas. An over estimation of the irrigated area results in an over estimation of ET and P_e. Because ET is significantly higher than P in the irrigation season, this results in an over estimation of the CF. Similarly an underestimation of the irrigated areas results in an underestimation of the CF. Therefore, the very low consumed fractions in Kafirnigan-Lower (0.009) and Karshi (0.018) can be partly explained because the method of defining the irrigated areas underestimates the irrigated area in those planning zones as compared to the ASBmm. Because of this underestimation the ET computed for that planning zone is very low. The CF of Kafirnigan-Upper (0.354) is relatively high for an upstream planning zone, this can be related to the overestimation of the irrigated area in that planning zone compared to the ASBmm. Something similar but less extreme can be said for Garm (0.265).



(a) Consumed fractions per planning zone placed in the schematic river basin.



(b) Consumed fractions per planning zone, organized from upstream to downstream.



(c) Consumed fractions per planning zone related to their irrigated area.

Figure 6.8: Consumed fractions per planning zone.

The very low CF of Vakhsh (0.024) can be related to the high negative value of Q_{LOC} in that planning zone. Much of the withdrawn water goes to local water sources like local depression which means not much is consumed by irrigation.

6.4.2 Cumulative consumed fractions

The consumed fraction of a basin can be significantly higher than the low consumed fractions of up-stream areas. Therefore this section describes the progression of the consumed fraction over the cumulative irrigated areas of the planning zone (CF_C). In this, the scenarios with and without reuse of collector drainage flow (Q_{CDF}) are compared.

Figure 6.9a shows the consumed fractions aggregated along the river basin, every value showing the CF_C for the irrigated areas including all the planning zones upstream of that point. The calculation gives a total CF_C of 0.289 at Karakalpakstan-North, the most downstream point of the basin. The tributaries have relatively high consumed fractions compared to the main river (see Figure 6.9c) for the Vakhsh and Kafirnighan rivers. This is related to the high consumed fractions calculated in Garm and Kafirnigan Upper as discussed in the previous subsection.

The cumulative CF is related to the aggregated area in Figure 6.9c. It can be observed that the CF_C increases with an increasing aggregated area, moving more downstream. This can be related to the trend that was seen in Figure 6.8b, where the upstream fractions are lower than the downstream fractions. The cumulative CF_C decreases where Karshi and Navai are added to the area, relating to their very low own consumption compared to withdrawal. There is a steep rise when the four most downstream planning zones come into play due to their high consumed fraction.

Planning zones where the water balance with high quantities of withdrawal, have a large impact on the total consumed fraction of the basin. These are the areas where much water is withdrawn and/or consumed relative to the other planning zones. Vakshs and Karshi are a planning zones with a high withdrawal and low consumption, so they will bring down the total CF_C. Alternately, Khorezm and Dashkhous are examples of planning zones that increase the total CF_C as they have a high quantity of withdrawal and consumption relative to the other planning zones.

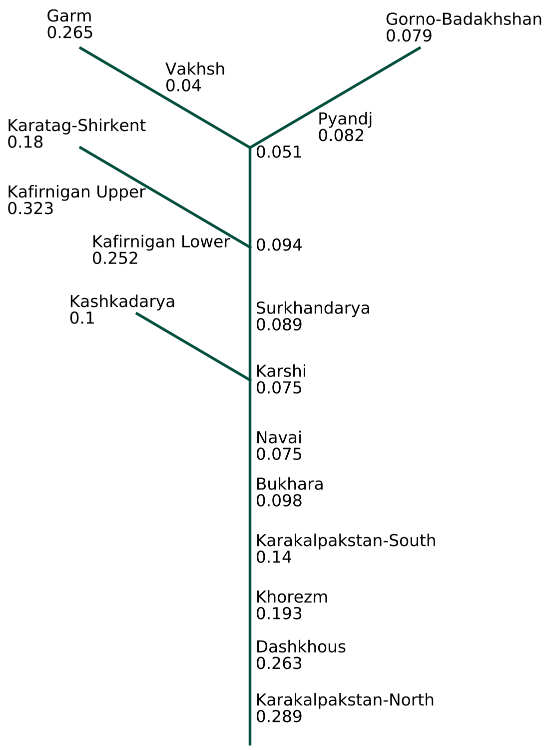
In total the planning zones analyzed in this research withdraw 44.25 km^3 from the Amu Darya river. This is 57% of the total yearly withdrawal in the Amu Darya river basin. Additional irrigation water is 2.0 km^3 from groundwater and 2.1 km^3 from local resources. This leads to a water consumption of 12.79 km^3.

6.4.3 Cumulative CF with drainage flow reuse

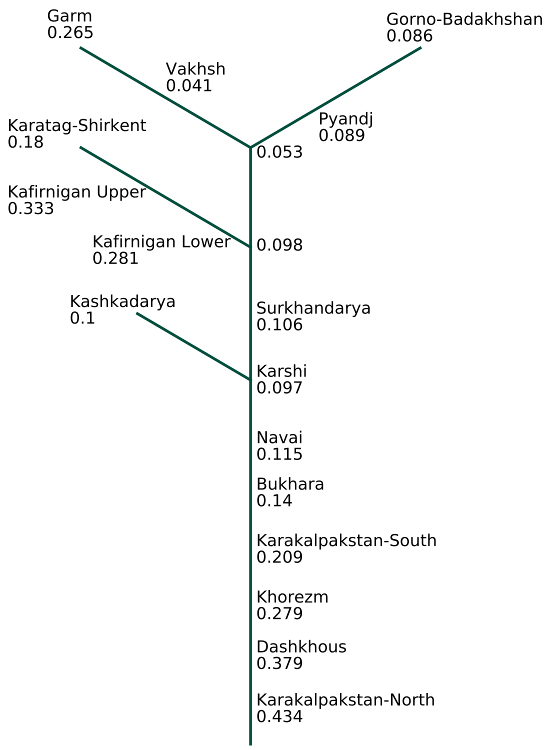
Figure 6.9b shows the cumulative consumed fractions with reuse (CF_{C_reuse}) of the collector drainage flow (Q_{CDF}). In this case the drainage water of the planning zone upstream is part of the withdrawal of the following planning zone. The impact propagates through the basin as was seen in Section 5.7.

The consumed fractions with and without reuse show a similar trend moving downstream along the river (see Figure 6.9d). However, the dip caused by Karshi and Navai is reduced when there is reuse of Q_{CDF}. This can be explained by the high drainage flow generated in Surkhandarya (upstream of Karshi) and Karshi (upstream of Navai) which is then reused in these planning zones causing a reduction in the withdrawal term and an increase in the CF_C.

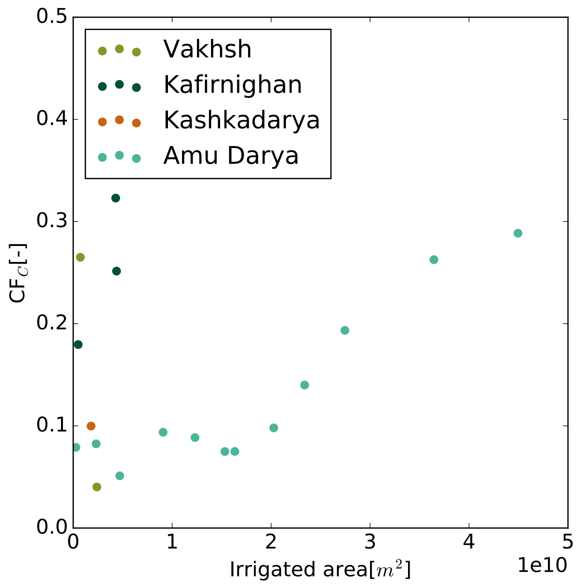
The difference between the scenario with and without reuse is shown in Figure 6.10a and Figure 6.10b, the first relating them to the cumulative area and the second to planning zone. These images only depict the main Amu Darya basin starting at Gorno-Badakhshan and taking the tributaries into account as one area. These images show that the division between the scenario with and without reuse increases when moving downstream. This is because the quantity of reused water accumulates, impacting the CF_C. The total basin CF_C is significantly higher for the scenario with reuse, at 0.434 instead of 0.289.



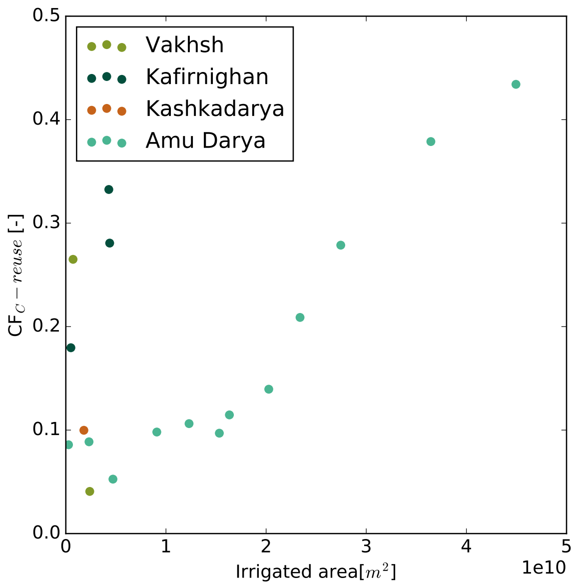
(a) Consumed fractions along the river basin based on the cumulative area placed in the schematic river basin (CF_C).



(b) Consumed fractions along the river basin based on the cumulative area with drainage reuse placed in the schematic river basin (CF_{C_reuse}).

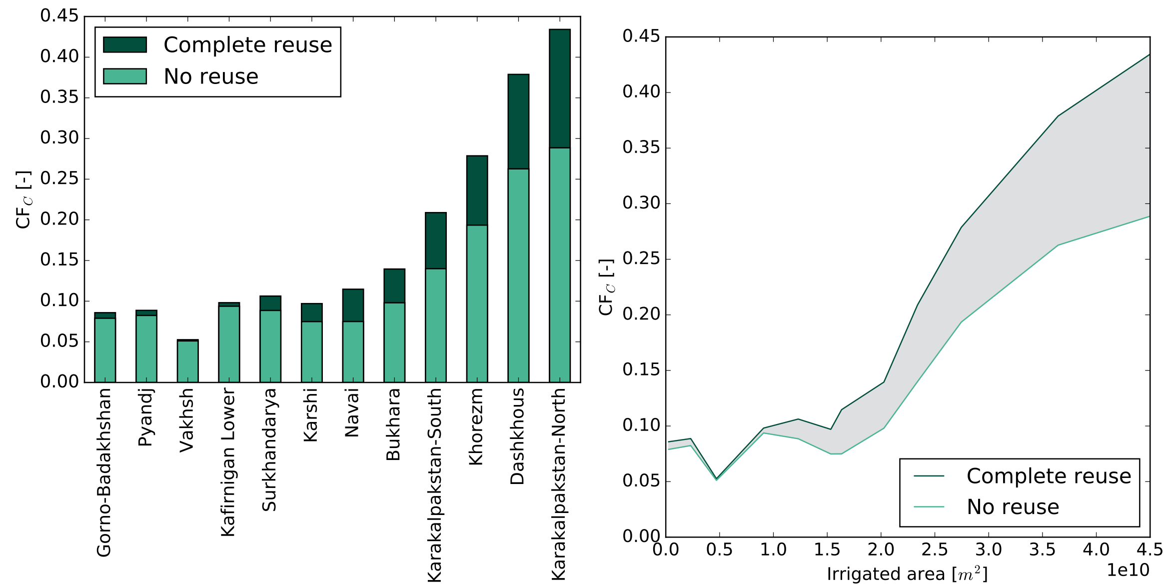


(c) Consumed fractions along the river basin related to the cumulative area (CF_C).



(d) Consumed fractions including reuse of return flow along the river basin related to the cumulative area (CF_{C_reuse}).

Figure 6.9: Cumulative consumed fractions along the river basin.



(a) Cumulative consumed fractions along the main river basin (Amu Darya) with and without reuse.

(b) Cumulative consumed fractions in the main river basin (Amu Darya) related to irrigated area with and without reuse.

Figure 6.10: Cumulative consumed fractions along the river basin with and without reuse or drainage flow. The CF_C is related to the location along the main river, Pyandj showing the CF of everything until Pyandj. At a tributary connection, the lower planning zone in the river is the point of calculation, e.g. Kafirnigan lower contains everything until Kafirnigan Lower in both the Amu Darya and the Kafirnigan rivers.

7 Discussion

7.1 Introduction

This section provides a critical look at the study, discussing the limitations of the results and linking them to theory and the situation in Central Asia. First the results will be discussed per section, then the reliability of the data, concluding with a link to the literature.

7.2 Irrigated areas

The irrigated areas were defined as the base other analyses in this research. The locations of the irrigated areas defined in this research are similar to the locations shown in Figure 4.7 made by CAwater-info (2011), thus the locations seem to be correct. The data of irrigated areas from the Aral Sea Basin management model (ASBmm) were used to judge whether the defined irrigated areas compared to what was used in the model. The reliability of the area mentioned in the ASBmm is difficult to judge, however, it is related to the flows in the model so it is justified to use it as a reference.

Combining the Food and Agriculture organization (FAO) map for areas equipped for irrigation with the $P-ET$ (precipitation minus evapotranspiration) computation is preferable over using the FAO map because it gives more strict boundaries for the computation. This method provides the actual irrigated areas in a spatial format. The chosen threshold has a great impact on the identified irrigated area. This gives an overestimation of some areas and an underestimation of others. The overestimation of irrigated area compared to the FAO data is much reduced. The method devised in this research is considered more effective in estimating the actual irrigated areas than the FAO map despite the fact that it is not foolproof.

There is a difference in agricultural practices in the upstream and downstream areas of the Amu Darya river due to a different climate and geography (CAwater-info, 2011) as well as historical development (Abdullaev and Rakhmatullaev, 2015). This makes it hard to capture all irrigation fields in one threshold. The used method has difficulty capturing the sparsely irrigated areas in the upstream regions. This is partly mediated by choosing a different threshold for the upstream areas, including grid cells with an irrigation density as low as 2% as opposed to the original threshold of 10%. The method used in this research is an improvement on using the FAO map its success is limited in sparsely irrigated areas. This can be improved by using data sets with a smaller grid size.

It can be seen that the irrigated areas identified with the method of this research also correspond with the areas shown by a local source in Figure 4.7. The local map is not very precise but does show the same general areas. As a curious extra observation the pattern of the downstream irrigated areas can also be observed in the NASA picture on the front page of this thesis. That picture was not meant to determine irrigated areas. NASA used a Multi-angle Imaging SpectroRadiometer to device this image which shows highly vegetated areas in red (NASA, 2002). As the downstream part of the basin is arid, the picture shows a similar area as the calculations from this research.

7.3 Water Balance

The trends of withdrawal and water consumption, with higher values for withdrawal and consumption in the downstream areas as compared to the upstream areas, correspond with the expectations for the region (UNEP, 2005). Figure 4.3 shows the distribution of flow generation and withdrawal between the countries. The most upstream country in the basin has a much lower withdrawal than the downstream countries which can be related to the trend seen in Figure 6.6a.

The calculated boundaries of the irrigated areas have an impact on the results in the water balance and consumed fraction analysis, as was seen in Chapter 6. The evapotranspiration (ET) and precipitation (P) are based on these areas. An underestimated area can therefore translate in an underestimation of the water consumption whereas an over estimated area translates to an overestimated water consumption. This can skew the water balance as the other fluxes are independent of the calculated area.

The black box model of the Aral Sea basin that was used in this study gives a lot of uncertainty. A critical look on this model was already given in Chapter 5. Precipitation and evaporation are included in the crop water demand and are not available as output data, this is mediated by using remote sensing data for those fluxes. However, some other doubts remain. The calculation of the drainage flow to the river is unclear and in one case turns out to be negative, which arouses suspicions. Other return flows, apart from the collector drainage flow, are not taken into account. It is unclear what portion of the water is discharged as groundwater recharge or overland flow, even through literature mentioned that these fluxes exist (ICWC, 2000).

The model also does not take storage change into account, unless the flux to/from local resources and the supply and demand of reservoirs are considered as storage change. This was tackled by using Gravity Recovery and Climate Experiment (GRACE) data for land water content. However, these open source data are not suitable for the scale of this analysis. The grid size is too large and two products from the same data showed completely different results. The best match data could have been used but the choice was made not to do so because of the mismatch in scales.

The large rest term seen in many planning zones can be related to some processes in irrigation practices. The flux to/from local water in the ASBmm can partly explain the large rest term in some planning zones. This can be related to the flux to local drainage lakes (CAwater-info, 2011; ICWC, 2000). The large rest term can also be related to water logging that occurs in a large portion of the irrigated areas in Central Asia (Asian Development Bank, 2010b; Jumaboev et al., 2015), and the irrigation 'losses' due to infiltration and seepage (Berdjansky and Zaks, 1996). The impact of horizontal subsurface flow is also not taken into account, however, this is expected to be relatively low (Bos et al., 2008).

This research did not take the discharge to and from large reservoirs into account. The ASBmm gives the same value for the in and out flow so they cancel each other out when looking at the annual water balance. However, there is a seasonal variability in the reservoir discharge. More water is released from the reservoirs in winter for energy production in the upstream countries and more water is supplied to the reservoirs in summer to keep the water level steady (ICWC, 2000).

The results from the global ET data set, $\text{ET}_{monitor}$, and P from Gravity Recovery and Climate Experiment (CHIRPS) link to the expectations of the region. P is very low in the irrigation season which fits the statements by Glantz (2005). Evapotranspiration is high in the lower regions, resulting from high temperatures (Dukhovny and de Schutter, 2011) and high irrigation density.

$\text{ET}_{monitor}$ is not (yet) an open source data set even though it was freely available for this research. It is used to demonstrate the possibilities of using those data in a study like this. An alternative global ET data set, $\text{ET}_{ensemble}$ (see Appendix C), will be open source and can be used in a similar way. However, $\text{ET}_{ensemble}$ was still under construction at the time of this research and did not cover the study region.

7.4 Consumed fractions

For the calculation of the consumed fractions (CFs) there are some similar concerns as with the water balance exercise. The data from the ASBmm are generated in a black box and some of the irrigated areas are under or over estimated. However, interesting trends can be observed.

The CF increases from upstream to downstream, showing a relation between the CF and the location along the river and the irrigated area. This can partly be related to the higher temperatures in the downstream areas (Dukhovny and de Schutter, 2011), leading to more ET. Törnqvist and Jarsjö (2012) suggests that this area also has a higher non-beneficial consumption compared to the upstream areas because of the climate.

ET from irrigation water was used as water consumption in this research, as was defined by Perry (2007). Judging that ET is the only flux that leaves the basin. In some research it is argued that water consumption is actually withdrawal minus reusable return flow (Rost et al., 2008; Törnqvist and Jarsjö, 2012), which places the non-recoverable fraction of the non-consumed water in the consumption box (see Chapter 3). There is currently no specific data on the quantities of the non-recoverable fraction. However, there are issues with the water quality of the return flow influencing the possibility of reuse, as well as flows to saline local lakes. It can even be argued that not all ET completely leaves the basin because a part of it will precipitate again within the basin (Trenberth, 1999). Because of the low P volumes in Central Asia during the irrigation season, this will not have a large impact on the consumed fraction calculations.

The estimation of the effective precipitation (P_e) was done by using the Curve Number method. This method was developed to estimate runoff generated by precipitation. In this analysis all water that does not result in runoff is considered as P_e, however, this is too simple an assumption. A part of the precipitation, for example, results in percolation to the groundwater. This translates to an over estimation of P_e and an underestimation of $ET-P_e$, so the actual consumed fractions are slightly higher than calculated. Having said that, the effect of this over estimation of P_e is not significant due to the relatively low precipitation quantities in the irrigation season.

The reused return flow in cumulative consumed fraction with reuse ($\text{CF}_{\text{C\_reuse}}$) calculation, is an interesting item to look at. This upper boundary was calculated to show the importance of taking reuse of return flow into account when looking at water consumption on a basin scale. Some of the return form to the river is withdrawn again by downstream users, and by not accounting for this reuse the water availability can be over estimated. This was approximated by assuming that all drainage flow to the river from an upstream planning zone is reused in a downstream planning zone. However, not all drainage flow is reused, this assumption is a simplification of reality (Lankford, 2012; Simons et al., 2015). To find out the range of consumed fractions between no reuse and total reuse of drainage water (Q_{CDF}), the CF_C was calculated with 100% reuse ($\text{CF}_{\text{C\_reuse}}$) as an upper boundary and 0% reuse (CF_C) as a lower boundary. The actual consumed fractions with a percentage of reuse should fit between these boundaries.

This research only concerns the reuse of the drainage flow to the river, however, there are also other fluxes feeding back into the system. Of the 'rest term' in the water balance, some water flows into the groundwater and other water flows back to the river in for example overland flow. This water is also available for potential reuse. The upper boundary of the analysis with reuse is therefore not the actual upper boundary. There is no data available on these overland and subsurface flows per planning zone so it is hard to quantify how much higher the actual upper boundary is.

A schematization was used to calculate the consumed fractions moving along the river basin. This schematization is a simplification of the actual river basin. In practice the planning zones and irrigated areas are located at varying distances from the Amu Darya or tributaries. The withdrawal flows through canals resulting in additional evaporation. This schematization also gives a simplification of the reuse of the drainage flow. The river does not flow from one planning zone to another, it can go back an forth between two planning zones which is the case for Karakalpakstan-South and Khorezm. The tributaries are also not as clearly divided and defined as in the schematization. This has an effect on the calculations and the actual values generated, but should have minimal effect on the trends of consumed fractions.

The special case of Navai planning zone with a negative drainage flow was already mentioned earlier in this research. This planning zone feeds the doubts about the data from the ASBmm. The planning zone has a very low consumed fraction (0.076), the impact on the total consumed fraction is not very big as the withdrawal and consumption in Navai is not one of the highest. It does have some impact though. The ET in Navai mostly comes from local water, it has the highest withdrawal from local water in the basin. This could be explained by the irrigation water use from the lakes or reservoirs in the planning zone, e.g. Tudakul Lake.

This research was bounded to the planning zones schematized in the ASBmm. This is because the fluxes necessary for the calculations that are generated in the ASBmm are linked to these planning zones. This was not ideal. They are based on administrative boundaries and not drainage areas so they do not adhere to the physical properties of water fluxes. They do not cover the full basin and in some parts extend to outside the drainage area. Because of this it was hard to judge the order in which the drainage flow could be reused. Additionally, the spatial outline (shape file) was only available for 16 out of the 24 planning zones in the basin. This means that the consumed fractions for the full basin could not be calculated as the P and ET data could not be determined for the other planning zones. The planning zone boundaries are necessary to map the progression with increasing scale. A total basin calculation is possible with the outline of the basin and the irrigated areas that were determined in this research. This basin calculation was not done in this research but would be interesting to assess the total consumed fraction.

7.5 Reliability of the data sets

Multiple remote sensing data sets were used as an alternative for the unavailable or unclear model data. As direct measurements, they can be a good alternative to ground data (Karimi and Bastiaanssen, 2015). Karimi and Bastiaanssen (2015) conducted a literature review of comparing the accuracy of remote sensing based data for evapotranspiration, precipitation and land cover. In this research he found that the average Mean Absolute Percent Error (MAPE) is 5.4% for ET data and 18.4% for P data as compared to other methods of estimating these values. In the case of precipitation there is room for improvement, however, Karimi and Bastiaanssen (2015) did not look at the CHIRPS data set, which was tested as the best available data in at leas two cases (Dinku, 2014; Hessels, 2015). The ET data sets were generally harder to validate as there is no easy and cheap way to measure ET on the ground (Wu et al., 2012). However, comparing the remote sensing data to other available methods results in a low MAPE. Remote sensing ET models have a high spatial variability in their reliability. Currently $\text{ET}_{ensemble}$ is under development in which several available data sets are combined in order to minimize errors. It is stressed that currently ground data are seen as the best available data with which satellite data need to be validated, however, these ground measurements also have their own errors which increase with a low spatial density of point measurements (Karimi and Bastiaanssen, 2015).

The FAO areas equipped for irrigation data set was used as a base for defining the irrigated areas.

The reliability of the map is labeled as 'good' or 'very good' for the countries in Central Asia (Siebert et al., 2005a). For the FAO map of actual irrigated areas this label is set at 'low' reliability (FAO, 2016). The grid size of the FAO map is 5 arc minute, corresponding to approximately 8km for the study area. For P and ET the approximate grid sizes are 5km (Funk et al., 2015a) and 0.5km (Zheng et al., 2016) respectively. Currently Landsat and Sentinel data are under development with a grid size of 30 or 50m making the analysis more accurate for spatial variability. These can be applied making the definition of the irrigated areas more accurate.

7.6 Link to the Aral Sea basin

So far the discussion has focused on the trends and the data used. In this section the results are linked more specifically to the existing knowledge of the Aral Sea basin. Starting with the elephant in the room, namely the consumed fraction calculated does not seem so high, with complete reuse it does not even reach 50%. This is in stark contrast with the declining Aral Sea addressed by Aladin et al. (1995); Micklin (2010, 1988, 1991); UNEP (2014); World Bank (2016a) etc. The consumed fraction was expected to be much higher, especially in the upstream areas they are extremely low. There are a few theories as to why there is so much excess water in these calculations and where it might end up.

The first relates to the questionable reliability of the data used and the fact that return flows other than the drainage flow were not taken into account. It can be that the withdrawal used for these calculations is not the actual withdrawal for irrigation but is still also used in different ways. The demand for domestic and industrial water is very low, so including them does not have a significant impact on the consumed fractions. There is the issue with the filling and releasing water from reservoirs where there can be a seasonal variance. In some planning zones like Garm and Bukhara this can have a significant impact on the calculated consumed fraction. If the supply to reservoirs is higher in the irrigation season (ICWC, 2000) this means that part of the withdrawal now seen as designated to irrigation is actually flowing to the reservoirs. This is very likely in the upstream planning zones because of the preference to energy production over irrigation. If this is the case the consumed fractions are actually higher than currently calculated. Generally I think the consumed fractions in this method are underestimating the real consumed fractions in the basin, although in practice they still will be quite low.

When it is assumed that the data are to an extent representative for the current situation this triggers the question: where does all that excess water go? Return flow does not all come back to the river. For example water that is withdraw through the Karakum Canal (see Figure 4.3) is not likely to be discharged back into the Amu Darya. This ends up in - sometimes unintentional - man-made lakes like the Golden Age Lake or Sarygamysh Lake (CAwater-info, 2011). Additionally the tectonic plate activity causes a wavy landscape creating depressions and room to discharge irrigation drainage water (World Bank scientific advisor, personal communication, April 24, 2018). These small and large drainage lakes provide an explanation as to where the surplus of water ends up.

Another point to consider is the 'loss' from the extensive drainage canals in the region. Berdjansky and Zaks (1996) mentions that 50% of the irrigation 'loss' is caused by seepage in the irrigation canals and 25-30% is infiltration into the irrigation fields. This water feeds into aquifers (Rakhmatullaev et al., 2010) and can be used at a later time. This dynamic of seepage and groundwater is not quantified in this research as I solely looked at reuse of water that is collected and drained to the river.

Finally the very high inefficiency can be related to the countries and their water security. In an interview with a World Bank expert it was mentioned that inefficient water management provides water security for the future (World Bank staff, personal communication, April 10, 2018). If a country would increase conveyance efficiency or irrigation efficiency such that their production increases, this will be noticed by the other countries. Consequently, this can impact the water allocation agreements and might result in a reduction of the water allocated to that country. Keeping the efficiency low and only gradually improving it provides a kind of insurance policy for the future, so the country will still be able to supply water to its growing population.

7.7 Increasing irrigation efficiency

Even though the calculated total consumption is quite low, it can still be seen that the water consumption on a basin scale is significantly higher when downstream reuse is taken into account. Increasing efficiencies can return this reusable return flow resulting in more 'unique' withdrawal of water and consequences for downstream water availability. If the increased efficiency only tackles the non-beneficial evaporation or specifically looks at the non-recoverable fractions these improvements will not have negative impacts on the downstream water availability.

Apart from saving water, there are other reasons why improving irrigation efficiency is prioritized in the region. Firstly there is the issue of energy and the cost of pumping. Pumping water for irrigation is a very important energy consumer (Gleick et al., 2011) and energy is expensive. Investing in irrigation efficiency is done to use the costly energy, and thus the costly water, in the most profitable way (Bekchanov et al., 2016). Investing in efficiency increases water consumption but also the profit made from the withdrawal. The withdrawal should decrease to not increase consumption, however, this demotivates people to invest in improving irrigation efficiencies as the total profit will not increase.

This relates to the current situation in Central Asia, where more than 90% of the rural population lives in poverty of which 62% in extreme poverty[1] (World Bank, 2009). There is a big potential gain in improving the life standard of the rural population in the region (World Bank, 2016d). Increasing efficiency is seen as a way to make more water available for consumption, however, as said before this should not come at the cost of return flow that is used by downstream users. It is understandable that these investments seem viable but they should be done with the highest care for the implications for downstream users.

Having a low efficiency and a high return flow can also have an impact on the water quality as pesticides and contamination from the irrigated fields, including salt, is discharges into the system (Gleick et al., 2011). In the Aral Sea basin salinity and contamination are major issues (Smedema, 2000). When the efficiency is increased, a lesser quantity contaminated water will run off. However, the absolute amount of pesticides and salt present does not decrease, these contaminants stay on the irrigated fields or the concentration of the contaminants in the water increases. A specific water quality problem is salinification. This is very prominent in the downstream irrigated fields. Large quantities of water are necessary to flush out the salt of the fields, if this is not available the fields become too salty and are abandoned (World Bank consultant, personal communication, April 10, 2018). The quantities and dispersion of contamination do not fall within the scope of this research although it is a big factor when speaking of irrigation water, efficiency improvements and the basin scale.

[1] The extreme poverty line is $2.15 or less per person per day and the poverty line at $4.30 per person per day according to the World Development indicators (World Bank, 2009)

8

Conclusions and recommendations

8.1 Introduction

Part II of this research gives insight into the importance of scale in irrigation water management. The impact of upstream efficiency improvements on downstream users is important to take into account. Water that is not consumed by upstream users might be reused by downstream users as is seen in the cascade effect (Simons et al., 2015). This effect was showcased in the Aral Sea basin where more than 90% of the water withdrawal is for irrigation purposes (AQUASTAT, 2013) and basin water demand is higher than water availability (World Bank, 2016b). One of the main issues in conducting an analysis of water consumption is the limited availability of data. This research aimed to to answer the main research question:

> **To what extent is it possible to analyze irrigation water consumption in Central Asia using a locally developed model combined with open source remote sensing data?**

Which was done according to the sub-questions:

1. Can irrigated areas in Central Asia be determined using open source data?
2. To what extent can the water balance of irrigated areas in the Amu Darya river basin be used to check the data sources?
3. How can consumed fractions for the irrigated areas in the Amu Darya river basin be determined?
4. How can spatial scale be related to consumed fractions of irrigated areas in the Amu Darya river basin?

The conclusions are given by first answering the main research question, after which the topics of the irrigated areas, water balance and the consumed fractions (CFs) will be addressed in line with the sub-questions. This chapter will end with some recommendations for further research.

8.2 Irrigation water consumption in Central Asia

The local Aral Sea Basin management model (ASBmm) was combined with remote sensing data for evapotranspiration (ET) and precipitation (P) to analyze the water consumption in the region. This was done with partial success.

All data used in this research, apart from the ET data, were available in the public domain. In the case of ET, the global data set, ET$_{monitor}$ was used, even though these data are not open source. Another global data set, ET$_{ensemble}$ data will soon be available in the public domain and can then be used in a similar way. The data from the ASBmm were also freely available but the model has been taken offline. The data are still available with the regional science information center (SIC-ICWC) who mentioned that they are improving the model and it will become available online once more.

In terms of reliability, the remote sensing data seem more reliable than the local model, mainly because much is unclear about the data and processing behind the local model which is a black box model. Additionally, the data generated by the model have some inconsistencies. Especially the reliability of remote sensing data for ET is very high, on average ET data have a mean absolute percentage error of 5.4% (Karimi and Bastiaanssen, 2015).

This research was able to show the dynamics of water consumption across the basin and related to scale, however, there are some concerns about the actual values of the consumed fractions. Whether the output of the combination of a local model with remote sensing data is successful depends largely on the reliability of the data provided by the model. The following paragraphs elaborate more on the foundation behind this conclusion by looking at the different sub-questions.

8.3 Irrigated areas

The boundaries of the irrigated areas were defined to be able to check the data in the water balance and to calculate the consumed fractions. Sufficient open source data were available to conduct this step of the research. Combining the Food and Agriculture Organization (FAO) map for areas equipped for irrigation with data on $P-ET$ gave values for the irrigated areas per planning zone that were closer the data from the ASBmm than using just the FAO map. The calculation of $P-ET$ highlights the grid cells with more evaporation than precipitation, indicating an additional water source. In areas equipped for irrigation and during the irrigation season, this additional water source is most probably irrigation water. The method shows large irrigated areas in the downstream planning zones and smaller irrigated areas in upstream planning zones, which are less dependent on irrigation than downstream planning zones.

The irrigated areas are still overestimated in the downstream planning zones but much less than with the FAO data. The areas are underestimated in the upstream planning zones where irrigation density is lower. Using a different threshold of 2% irrigated land per pixel mediated this to an extent. The estimation of the actual irrigated areas improved with a simple analysis. The under and overestimation of the irrigated areas has an impact on the calculations of the water balance and the consumed fractions, because the magnitudes of the ET and P depend on these irrigated areas.

8.4 Water balance

The water balance was used to check if the fluxes generated by the different resources were in line with each other and expectations. The fluxes are in the same order of magnitude and fit each other in that sense. However, in some planning zones the withdrawal is significantly higher than the combination of water consumption and drainage flow. This results in a 'rest term' that cannot directly be explained by the fluxes in the water balance.

A portion of this rest term is storage change. Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage products proved to be unsuitable to investigate the role of storage change in the water balance because the grid size is too large as compared to the irrigated areas. The large rest term can in some cases be related to the discharge to local resources computed in the ASBmm.

The reliability of the data from the ASBmm is unclear. In this water balance analysis it became apparent that the withdrawals are sometimes very high compared to the ET, which creates some doubt. These doubts are intensified after seeing the negative drainage flow in Navai planning zone. This is physically not logical and casts a shadow over the other data generated by the model.

The P and ET values generated for the planning zones are in line with the expectations from literature. Precipitation is low in the irrigation season and ET is high mainly in the downstream planning zones, correlating with the dry and warm months (Glantz, 2005) and high irrigation (Dukhovny and de Schutter, 2011). ET is much lower than the withdrawal in the upstream planning zones. It can be that ET and P are underestimated in the calculations as the upstream sparsely irrigated areas might be underestimated and the calculation of these fluxes is directly dependent on the irrigated areas.

8.5 Consumed fractions

The calculation of the consumed fractions (CFs) gave insight into irrigation water consumption along the Amu Darya river basin. The link between increasing CFs and increasing irrigated areas are clearly seen, as is the connection between higher consumed fractions in downstream planning zones and lower consumed fractions in the upstream planning zones, which is also related to the size of the irrigated areas. This is in line with expectations.

The CFs in some upstream areas are very low, less than 10% of the withdrawal is consumed. They were expected to be low due to the inefficient irrigation (UNEP and ENVSEC, 2011). However, the results are even lower than expected. This can be related to the underestimation of the irrigated areas and maybe the withdrawal for irrigation is over estimated in the ASBmm.

The cumulative progression of the consumed fractions with increasing scale (CF_C) was calculated with and without reuse of drainage water to the river. The expectations of an increasing CF_C with an increase of scale is clearly seen. The effect of reuse in downstream planning zones is significant, the combined CF_C of the planning zones rose from 0.289 to 0.434 when this drainage water is included in the withdrawal of downstream planning zones. Not all water that is drained back to the river will be withdrawn by downstream planning zones, however, a portion of it will be reused. This has an effect on the consumed fraction and the perceived water availability. The dynamics of this reuse can be linked to cascade effect as was introduced by Simons et al. (2015) and the importance to look at the basin scale water use and water consumption.

The analysis of reuse by downstream planning zones is simplified with the schematization of the river. In this analysis only reuse of drainage water to the river is taken into account while there are also other fluxes (e.g. overland flow) available for reuse. It is also too simple to say that all water that is drained to the river is reused. It is safe to say that the calculation should fall somewhere between the upper and lower boundaries of complete reuse and no reuse.

Even though there is some doubt concerning the data from the local model, this analysis gives insight into irrigation water consumption in the planning zones of the Amu Darya river basin. The absolute values might deviate from the actual consumed fractions in the region but the dynamics of the CF and CF_C are clearly witnessed and underline the importance of looking at a basin perspective.

8.6 Recommendations

It is shown that the irrigated area estimates are not always accurate or corresponding with the reference data. This is mainly an issue in the upstream areas with a low irrigation density. The estimation of the irrigated areas could be improved by using data sets with a smaller grid size. These are currently under development, moving to a 20 or 30m grid size with either Sentinel or Landsat satellite products. This provides the opportunity to determine the irrigated areas with low irrigation density more accurately. These products give more detail but the smaller grid size will also increase the number of calculations and computational time. It is recommended to explore the possibilities of these products with a smaller grid size in the determination of actual irrigated areas on a basin scale.

The water balance exercise gave insight into the possible unreliability of the fluxes generated by the ASBmm. It is advisable to calculate the water balance with different data for withdrawal for irrigation to check the ASBmm output. Outside the ASBmm, similar data are available per country. A water balance can be made by using country boundaries and the irrigated areas that were determined in this research. The withdrawal data per country are provided in UNEP (2005) and the ET and P are available in the remote sensing data sets that were also used in this research. SIC-ICWC might have data on a planning zone scale but these will probably be similar to the data provided by the ASBmm. Data on return flow to the river will be harder to find.

This research looked into the CF_C with an upper and lower boundary of reuse of drainage water to the river. However, the data for this were not sufficient to asses the portion of water that is actually reused. Data on the recoverable fraction (Willardson and Allen, 1998) is necessary to further investigate the actual consumed fractions with reuse. This includes an inspection of other fluxes such as overland flow and percolation to the groundwater. It is relevant to look where these fluxes end up as well as to look at the water quality in order to asses if they are available for reuse.

This research focused on an analysis of the consumed fractions in the planning zones for which data were available, moving up in scale. A complete analysis of the full Amu Darya basin and even the Aral Sea basin was not carried out. Future research could focus on such an analysis, linking the findings of water consumption from the irrigated areas to the river flowing in and out of the basin and the river flow at different points in the basin. A more structural basin analysis, not limited by planning zone boundaries, is necessary to be able to make proper basin accounts and to understand the dynamics of water consumption in the Aral Sea basin more completely.

III

Knowledge exchange on water consumption and irrigation at the World Bank

9

Introduction

9.1 Introduction

The possible negative effect of irrigation efficiency interventions on the basin scale and the importance of including the basin perspective was outlined in the general introduction, Part I. There it was also mentioned that the World Bank is currently not incorporating this perspective in all the irrigation projects they are involved in. It will be the knowledge exchange on the topic of irrigation efficiency and water consumption at the World Bank will be explored in this part of the research. The research scope and questions will first be outlined in this introduction.

9.2 Knowledge exchange

The World Bank is a leading investor in water and irrigation projects so its ability to adapt to new paradigms and knowledge on water issues is essential. On the one hand, the Bank develops knowledge and needs to be up-to-date with current research while on the other hand the staff need to translate this knowledge into practical projects. Filieri et al. (2014) [p. 729] said "knowledge is the raw material for innovation". Applying new paradigms in practice is a form of innovation (Alguezaui and Filieri, 2010) which is necessary if an organization is to be productive and effective (Walter et al., 2007). Therefore an organization needs to be able to access, transfer, absorb and apply knowledge (Díez-Vial and Montoro-Sánchez, 2014) and knowledge needs to be nourished and actively developed (Widén-Wulff and Ginman, 2004). Such knowledge becomes available through connections and exchange in social networks (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Widén-Wulff and Ginman, 2004). Lacking these connections might lead a person or organization to become stuck in tunnel vision, not open to views of others (Lee, 2009). This is very relevant to the World Bank as it is known as a knowledge bank. Delivering experts with cutting-edge knowledge is one of their main selling points.

9.3 Introducing social capital

A social network consists of people or organizations and the links between them. Social capital is a social network in which resources - for example knowledge - are available and can be exchanged (Brookes et al., 2006). Social capital provides the context in which knowledge exchange can occur (Adler and Kwon, 2002; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998) which makes it a suitable framework for analyzing this exchange. Adler and Kwon (2002) [p. 36] state that a social capital perspective "... can reveal features of reality that otherwise remain invisible". It is more preferable than just the network analysis because it includes the resources. The definition of social capital is much discussed in the literature. In this research it is the definition by Nahapiet and Ghoshal (1998) [p. 243] that is used: "the sum of the actual and potential resources embedded within, available through and derived from the network of relationships possessed by an individual or social unit" . It is a potential that is embedded in the relationships between people.

The World Bank has a vast internal knowledge base including research documents, project documents and people with a variety of skills and backgrounds. They access external expertise in the form of scientific advisers and consultants hired for project preparation, implementation and evaluation. These people and their knowledge are part of the social capital of the World Bank.

Social capital can be interpreted through the structural, cognitive and relational dimension (Nahapiet and Ghoshal, 1998). These three dimensions give insight into the different layers of the complex context in which knowledge exchange takes place. The first dimension can be related to the ability to access knowledge and the availability of knowledge while the other two dimensions refer to the conductivity, or the process of exchange between two nodes. The relational dimension looks at the quality of the link between two people (Filieri et al., 2014), the cognitive dimension at the commonalities between them, e.g. in shared meaning, understanding and goals (Inkpen and Tsang, 2005). The dimensions allow a systematic analysis of knowledge exchange (Adler and Kwon, 2002), together they paint the full picture of the knowledge exchange environment without losing track of the details and the importance of the individual aspects. This makes it a highly suitable theory to give insight into where knowledge resides and how it moves and is applied in the World Bank network. Analysis on knowledge exchange and social capital has been done from the individual and organizational perspective, mostly focusing on competitive advantage (e.g. Ali-Hassan (2009); Brookes et al. (2006); Inkpen and Tsang (2005)), but it has not been done in the context of the World Bank. The Bank investigates the application of social capital theory in projects to look at stakeholder involvement and the availability of local knowledge (Grootaert and Bastelaer, 2001) but it has not used this theory to analyze its own knowledge exchange, that is where this research comes in.

Knowledge exchange between World Bank staff and their network of external sources is essential for the implementation of new paradigms in World Bank financed projects but it is not always successful. This can, for example, be because they do not have access to the right people (the structural dimension) or because they do not understand each other due to differences in the terminology used (the cognitive dimension).

9.4 Research scope and research questions

With this study I wanted to find out why the basin perspective on water consumption is not always included in World Bank irrigation projects. The framework of social capital is applied as a guideline to investigate a wide range of possible mishaps that can occur in the journey of the theory to projects. This research focuses on the knowledge exchange between World Bank staff, academic hydrologists and World Bank water and irrigation consultants on the topic of water and irrigation. This leads to the research question:

> **To what extent can a social capital analysis of knowledge exchange between academic hydrologists, World Bank staff and World Bank water and irrigation consultants aid the incorporation of the basin scale perspective on water consumption in World Bank financed irrigation projects?**

Other actors involved in the project implementation are, for example: local government, local project staff and regional institutions. Even though they are an important knowledge source for country-specific details they are not considered in this research. This research looks at the inclusion of theory in World Bank financed projects and how this theory is internalized by the World Bank. World Bank staff, science advisers and project consultants are considered to be the most relevant actors in this process.

In this study the social capital perspective on knowledge exchange is used to see how the implementation of the basin approach in World Bank financed projects can be improved. This topic is dealt with in three sub-questions. First the the characteristics of a network that promotes knowledge exchange are identified, then the current situation at the World Bank is explored and finally these two aspects are combined to see where improvements can be made. This is investigated through the following sub-questions:

1. What are the characteristics of a social capital network that facilitates knowledge exchange and implementation?
2. How does knowledge exchange on water and irrigation occur in the network of World Bank staff, World Bank water and irrigation consultants and academic hydrologists?
3. To what extent is knowledge exchange between World Bank staff, World Bank water and irrigation consultants and academic hydrologists comparable to the characteristics of a social capital network that facilitates knowledge exchange?

This research looks at the general incorporation of the basin scale approach into World Bank irrigation projects. However, there is an emphasis on World Bank activities in Central Asia. Some of the interviewees were targeted specifically for a project in that region and the interview guide contained an example from that region. The study is not limited to Central Asia but it does lean towards that region. This also gives extra grounds to link Part II and Part III.

9.5 Reading guide

Part III of the report first elaborates on the research methods in Chapter 10. An outline of the methods is presented and linked to the research questions. After that, Chapter 11 introduces the literature used in this research and analyzed with a systematic literature review. Chapter 11 forms the basis from which the research questions are answered. The three sub-questions are addressed in chapters 12, 13 and 14. Chapter 12 introduces the conceptual framework, including the social capital network characteristics facilitating knowledge exchange as well as the research variables. Chapter 13 gives an outline of knowledge exchange in the World Bank on water and irrigation, linking to the second subquestion. Chapter 14 links the current situation at the World Bank to the conceptual framework. The main research question is answered in the conclusions in Chapter 15 which is followed by a discussion in Chapter 16. The discussion includes views on social capital as a research framework, the results and synthesis and the research limitations. This finally leads to the recommendations in Chapter 17, including recommendations for future research and recommendations to improve knowledge exchange and the application of basin analysis in the World Bank.

10

Research methods

10.1 Introduction

The research question was approached from several angles, using and combining different methodologies (see Figure 10.1 and Table 10.1). First the preliminary literature research was conducted, scanning scientific literature and secondary literature. From this followed preliminary interviews which were used to define specify extent of the research. A systematic literature review was conducted, starting from the findings of the preliminary literature search. This was combined with the insights obtained from the preliminary interviews to form a conceptual framework. The framework was then used to answer the first sub-question of this research and formed the basis of the semi-structured interviews. The semi-structured interviews were used to further investigate the second sub-question. A document search was also conducted to support the second research question. The third research question was answered by combining the results from the literature, interviews and documents.

Social capital was used as a framework to analyze knowledge exchange between World Bank staff, hydrologists and project consultants. This means that the research was mainly deductive (Bryman, 2012), starting with a theory and looking at its application in a case study. In this research social capital theory was combined with other literature and applied to knowledge exchange at the World Bank. This combination led to a fresh perspective on social capital.

	Preliminary interviews	systematic literature review	Interviews	Documents
Scoping	✓			✓
Q1 Criteria	✓	✓		
Q2 Current situation	✓		✓	✓
Q3 Comparison	✓	✓	✓	
Context	✓		✓	✓

Table 10.1: Research methods.

10.2 Preliminary interviews

In addition to the preliminary literature search, six preliminary interviews were held to further identify the research boundaries and link the literature to experiences from practice. The subjects of the preliminary interviews were selected through expert sampling, they were academics who have experience

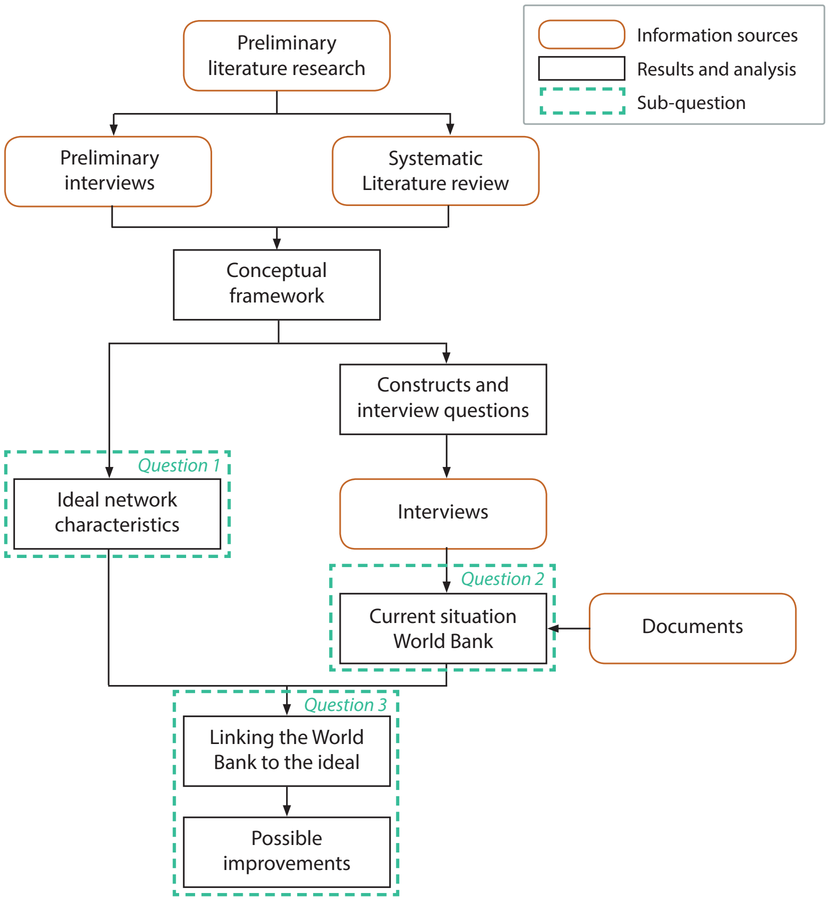


Figure 10.1: Research framework.

in linking their research to policy and specifically to the World Bank. Among the interviewees were two professors in water resources management, one lecturer in water and law, one lecturer in water resources management, one consultant for World Bank financed projects on water and irrigation and one World Bank advisor on transport and logistics.

The interviewees were asked to give their view on the obstacles they observe in knowledge exchange between them and policymakers or them and World Bank staff. The research boundaries were stretched from just the World Bank to also include policymakers in these preliminary interviews because it was expected that there were similarities in these experiences. The World Bank is a for profit organization that works in the public domain. This broader view gave new insight into the determination of the scope of the research.

10.3 Systematic literature review

The systematic literature review was conducted to gain scientific reasoning behind the project analysis. This was used to answer the first sub-question as well as for the design of the interviews for the second sub-question. The focus was to get a framework for knowledge exchange from a social capital perspective with insight from social network theory and theory on science-policy communication. The approach was systematic, starting both specifically and globally to find the right searching breadth. The search was done in the database of Web of Science[1], also the Scopus[2] database was checked for

[1]https://webofknowledge.com
[2]www.scopus.com

extra sources. All searches were first done for the publishing dates between 2008 and 2018 and then repeated for the publishing dates between 1998 and 2018 if there were no results. This section gives a rough outline of the approach of the literature review, more detail and exact search terms can be found in appendix F.

First, search terms for the World Bank and water were combined with terms like knowledge and communication, social capital to see what the literature says about this specific case. These searches resulted in no relevant articles. Therefore for the rest of the literature review a broader scope was taken, not specifically looking at literature about knowledge exchange with the World Bank and on water. The more global searches were limited to the the publishing dates between 2008 and 2018. They included capital and the combination of social capital with communication or knowledge transfer. These search queries resulted in 15436 articles for social capital and 1139 and 245 for social capital combined with communication and knowledge exchange. Another global search was conducted with knowledge, communication and experts and policymakers. This also resulted in a large body of literature. The final systematic literature review deals with the topics of knowledge, communication between experts and policymakers, knowledge exchange and information sharing in social networks and knowledge exchange combined with the term social capital.

The articles were assessed on the basis of their title and abstract to determine their relevance to the study. Articles that were too case specific or not from a relevant field of research were excluded from the literature review. For example, a study on the relational dimension of social capital in a virtual community of website programming (Tan et al., 2015) was not included in the literature review even though it was found in one of the searches. The literature search resulted in three articles on the science-policy interface, five on social networks and five on social capital with some overlap in the last two categories.

Because of frequent citations and references in the social capital field in general and in the literature found in this review, Nahapiet and Ghoshal (1998) and Adler and Kwon (2002) were included in the review. Nahapiet and Ghoshal (1998) give the basis of the social capital dimensions that were used in this analysis while Adler and Kwon (2002) give more depth to the concept of social capital. Additionally, Colemans (1988) and Burt (1992, 2000) were included as they give two perspectives on social networks that are significant to this research. This resulted in a total of 18 articles that were thoroughly read and analyzed and then combined in the systematic literature review and conceptual framework (see Chapter 11 and Chapter 12).

The literature review also resulted in the definition of constructs and variables which were used to structure the interviews. These variables are not very specific as this is an exploratory research. Another result deduced from the literature was a descriptive model (Bhattacherjee, 2012) of the network characteristics that are relevant for a social network facilitating knowledge exchange.

10.4 Interviews

This study used semi-structured interviews to gather qualitative data. An interview guide based on the literature review and preliminary interviews was used to structure the interviews. The interview guide was slightly adjusted depending on the actor that were interviewed. This semi-structured interview approach gave the interviewer room to elaborate on interesting topics that came up by asking followup questions. It also allowed flexibility in the order in which the questions were asked. The interviews consisted of an introduction, opening questions, questions about network and knowledge exchange, a short case with related questions and closing questions. The questions were a combination of closed questions, with possible follow up questions, and open questions. The an example of the interview guide can be found in Appendix H, and the connections between the interview questions and the research variables can be found in Appendix I. The interview guide was not always followed to the interviews were semi-structured. For example, if issues planned for the case were already mentioned by the interviewee during earlier questions, the case was skipped or partially skipped.

A case was used to trigger views on the basin scale perspective in a concrete context. First a simple World Bank project investing in irrigation modernization in Uzbekistan was introduced. This was a simplified description, partly based on a real World Bank project. This case contained an investment on the scale of an irrigation scheme. Then, a simple model of a basin was introduced where the effect of the upstream increased irrigation efficiency on downstream water users was shown. Finally, a World Bank project focused on basin wide management was introduced. This part of the interview was used to research the interviewee's attitude to this kind of World Bank project and large scale theory as well as their opinion on the practical relevance. It also gave insight into the transfer of knowledge and lessons learned between World Bank financed project teams.

The interviews were designed to take 60 minutes, however, due to circumstances the time per interview varied. One interviewee was only available for 30 minutes and due to technical difficulties one interview was cut short to 40 minutes. Seven interviews took between 55 and 65 minutes and two extended to 100 minutes. The length of the interviews depended in part on the conversation style of the interviewee. The interviews were conducted face to face or over Skype. In two instances the interview was conducted over the phone. Face-to-face was preferable but due to the location of the respondents this was not always possible. Skype was a good alternative as it gave the opportunity to share images during the call to support the conversation.

The interviews were recorded to be transcribed and coded later. Before the recording the interviewees were asked to give their consent for the recording. All participants gave their consent. Recording the interviews gave the interviewer the opportunity to fully focus on the interviewee and it gave access to exact quotes quotes as well as a detailed analysis through interview coding.

10.4.1 Sample

In this research expert sampling and quota sampling was combined with snowball sampling to find interviewees. The first sample followed from the preliminary document search, the preliminary interviews and tips. Experts were selected in following three categories: World Bank staff working on projects and policy, academic hydrology advisers in contact with the World Bank and water and irrigation consultants working on World Bank financed projects. The research required at least three interviewees per category to get a balanced view. this criterion was not met after the first sampling round, which resulted in a second round.

To increase the sample size, the first respondents were asked if they knew other people fitting these categories. This resulted in a sample of eleven people spread evenly over the categories (see Table 10.2). These categories were not mutually exclusive, some hydrologists had previously worked as a consultant, some World Bank staff had previously been consultants and some consultants and World Bank staff had also been active in academia. The experts were sampled in the category that they were most active in at the time of this research.

	Number of interviewees	also Bank staff	also academic hydrologist	also consultant
World Bank staff	4	-	0	2
Academic hydrologist	3	1	-	2
Consultant	4	1	2	-

Table 10.2: Sample of interviewees.

Because of snowball sampling, three of the project consultants and one of the World Bank respondents were involved in the same project team in Central Asia. This gave insight into the subtle differences between the members of a World Bank project team. The combination of snowball sampling and the network of the researcher also resulted in a high number of participants with the Dutch nationality (45%). The sample contained only people with a western background (USA and Europe), this was partly due to the sampling method and partly due to the general prominence of western people in

World Bank financed projects on the topic of water. The evaluation interviews did include two people with an Asian background.

10.4.2 Coding

The interviews were transcribed in clean verbatim using Inqscribe transcription software[3]. Clean verbatim transcription removes repetitions and small hesitations in speech but keeps the message intact, pauses and long hesitations were included as they can indicate the strength of opinions and thoughs, impacting the interpretation of the data. The transcripts were coded in NVIVO 11 starter[4]. The coding was done with a predefined code tree derived from the systematic literature review. This was combined with bottom-up coding to leave room for interesting observations that do not fit into the predefined code tree (see Appendix J).

Some of the interviews were conducted in Dutch and others in English. They were transcribed in the original language and coded according to an English coding tree. The relevant quotes from the Dutch interviews were translated to English to use in this document.

10.5 Document search

The interviews were combined with a document search to get a better insight into the World Bank structure, their activities in the field of water resources management and irrigation and their activities in Central Asia. This search mainly focused on policy and project documents of the World Bank. The document search was mostly carried out on the World Bank website[5] but also on websites of linked organizations like the Food and Agriculture Organization (FAO)[6]. The credibility of the documents was assessed based on the source. All documents used were available in the public domain.

10.6 Reliability and validity

Reliability refers the reproducibility of the research if it would be repeated, where validity concerns the accuracy of the research. In qualitative research, external validity and reliability are not easy to achieve (Bryman, 2012) because it is based on subjective and contextual data, still, research rigor should be a priority. A thorough description of the methods made the research reasonably reproducible which enhanced the reliability.

External validity, or transferability was hard to ensure as this research was conducted with a small sample case study and was exploratory in nature. Including people from different backgrounds and different roles ensured that a variety of insights were taken into account, these insights could be relevant for other Bank themes. Linking the interviews to the systematic literature review provided a way to generalize parts of the research. Even though, this research does not have a high external validity in general.

The internal validity, or credibility refers to the trustworthiness of the research. This can be improved by building a checkup mechanism into the research method. One method to improve internal validity is triangulation (Flick, 1992; Golafshani, 2003). With triangulation, different research methods or data sources are combined to get a more balanced view and to verify the results from one source with the results from another. In this research triangulation was used by combining interview data with data from documents to get an understanding of the current situation as well as by linking these results to literature. Additionally, the perspectives of the different actor groups gave a more complete

[3] https://inqscribe.com/
[4] http://www.qsrinternational.com/nvivo/nvivo-products/nvivo-11-for-windows
[5] http://www.worldbank.org/
[6] http://www.fao.org/home/en/

view. Using recorded and transcribed interviews instead of notes from an interview also improved the internal validity of the research.

Another important aspect of research rigor is the researcher bias. As this research was carried out by one researcher it was important to use external verification moments to minimize researcher bias. The research method was discussed with a science communication professional. The interview guide was discussed with a water management professional as well as a communication professional and tested with two external people who work in the science-policy interface on the topic of water. Additionally some evaluative interviews were carried out during the data analysis to improve the research rigor. During these conversations the results and conclusions were discussed with a scientist, a World Bank employee and a short term consultant. This was done to reflect on the interpretation of results and to see if the conclusions correlated with their views. Where necessary the results were adjusted based on these interviews.

Researcher bias can also occur in the data analysis. My perspective will be similar to the hydrologist perspective as I am very familiar with the field of Water Resources Management and Hydrology. This was taken into account constantly during the data processing phase of the research.

10.7 Research ethics

In social research it is important that the research is conducted in an ethical manner (Bhattacherjee, 2012). Participants need to be well informed and have the opportunity to ask questions. In this case the participants were informed about the scope of the study through email and orally before the interview. They were given the opportunity to ask questions before, during and after the interview. Participating in this study was voluntary, respondents could quit the interviews at any time without consequences. The participants were asked if they consented with the recording of the interview before the recording device was turned on.

Confidentiality in data processing was guaranteed for the interviewees. The recordings and transcripts were saved without the name of the participant in the file and names mentioned by the participants were blacked out in the transcripts and quotes used in the thesis and other documents following from this research. The audio files and transcripts will not become publicly available and will only be shared with the consent of the participants. The only record of the names of the participants were held in the email contact of the researcher with the participants.

11

Systematic literature review

11.1 Introduction

The World Bank (WB) aims to reduce poverty and tries to do this in the most effective way possible. It is important for the Bank to be able to innovate in their approach and invest without unintentional harm. This includes being open to new ideas as well as being able to put them into practice. Social capital and social networks provide a context for knowledge exchange in which the innovative capacity of an organization can flourish (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998). In this research the social capital perspective is used to analyze and possibly improve knowledge exchange and incorporation of research in irrigation projects of the World Bank.

The dimensions of social capital provide a framework through which knowledge exchange can be analyzed in a systematic way (Adler and Kwon, 2002). Research on social capital is mainly done from an individual or business perspective, aiming at improving their competitive advantage. As the World Bank is a complex organization having both business and public service characteristics, these perspectives do not fit seamlessly. Therefore literature on knowledge exchange in the science-policy interface is added to the analysis.

This chapter is the result of the systematic literature review and will introduce theory on social networks and social capital in the context of knowledge exchange as well as the science-policy interface. The relevance of these theories to the World Bank and this research will also be addressed. This chapter forms the basis on which the conceptual framework is built. It aided the identification of network characteristics necessary for knowledge exchange and helped to identify the variables on which the interview questions were based to analyze the current situation at the Bank, corresponding with the first and second sub-question of this research.

11.2 Social capital

Social capital theory provides a framework and a context for knowledge exchange analysis. Adler and Kwon (2002) [p.18] say that skeptics call social capital "a wonderfully elastic term" and a term that means "many things to many different people". And it is true that there are many different definitions for social capital, a term that is used in many disciplines (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998; Rutten et al., 2010). This research works with the definition introduced by Nahapiet and Ghoshal (1998) [p. 243], who define social capital as “the sum of the actual and potential resources embedded within, available through and derived from the network of relationships possessed by an individual or social unit". It is specifically applied on knowledge transfer, as suggested by Adler and Kwon (2002). Where social network theory gives insight in the network and interactions in this network, social capital theory adds a layer of resources embedded in that network (see figure 11.1). Social networks are a crucial part of social capital and social network theory is included in this chapter on social capital.

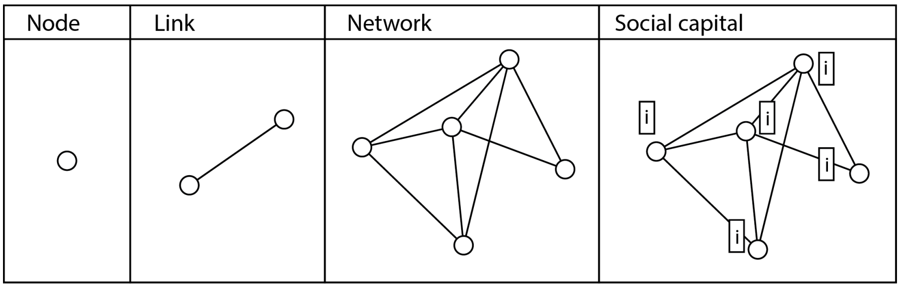


Figure 11.1: A node, link, social network and social capital. In social capital resources, like knowledge, are embedded in the social network network (based on (Brookes et al., 2006)).

Two organizational advantages of social capital in this context are: increased access to knowledge and improved knowledge exchange (Adler and Kwon, 2002; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998) which increase innovative capacity (Alguezaui and Filieri, 2010; Filieri et al., 2014). Investing in social capital and social network development is encouraged to increase knowledge exchange (Inkpen and Tsang, 2005), however, how to invest is context and culture dependent (Lee, 2009). Research on the negative implications of social capital is limited (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Lee, 2009).

Social capital can be individual and organizational, originating from a personal network or an organizational network (Alguezaui and Filieri, 2010). These two forms of social capital are linked, a resource accessed from a personal network can add to the organizational social capital (Inkpen and Tsang, 2005; Walter et al., 2007; Widén-Wulff and Ginman, 2004).

Nahapiet and Ghoshal (1998) introduced three dimensions of social capital: the structural dimension, the relational dimension and the cognitive dimension. Where the structural dimension involves the network configuration, the relational dimension deals with network ties and the cognitive dimension considers the shared culture and language of the network nodes. Inkpen and Tsang (2005) add shared goals to the cognitive dimension. These dimensions are used in research focused on knowledge exchange (e.g. by Widén-Wulff and Ginman (2004) Inkpen and Tsang (2005) and Alguezaui and Filieri (2010)). In the analysis they are used as different entities. However, they are highly interlinked (Díez-Vial and Montoro-Sánchez, 2014; Filieri et al., 2014; Lee, 2009; Nahapiet and Ghoshal, 1998; Widén-Wulff and Ginman, 2004) which makes it important to include all dimensions in a social capital analysis (Walter et al., 2007).

In context: The World Bank is a highly complex international investment organization. It is crucial for the Bank to have access to and apply new knowledge to be able to function at the highest possible effectiveness. Currently the Bank often does not take the large scale into account in irrigation water projects, it is operating in an outdated paradigm. To figure out the reasons behind this a wholesome analysis of the knowledge exchange within the Bank and with external parties is necessary. The social capital perspective provides the opportunity to look at the World Bank network structure, the internal and external relations and effects of differences in cognition on knowledge exchange between scientific advisers, World Bank staff and consultants.

11.2.1 The structural dimension

The structural dimension of social capital includes aspects of social capital inherent to the network structure. This dimension provides the context in which knowledge exchange can take place, it facilitates knowledge exchange but does not cause it (Alexander and Armitage, 2015; Inkpen and Tsang, 2005; Widén-Wulff and Ginman, 2004).

A social network consists of nodes and ties which form a structure together (see figure 11.1). Depending on the scale, nodes can be people, organizations or business units. In this research the nodes were individuals. A network can be analyzed in terms of cohesion, size, stability and node centrality (Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Lee, 2009; Schultz-Jones et al., 2009) which influence the flexibility of the network and the effort needed for knowledge exchange (Inkpen and Tsang, 2005; Walter et al., 2007). This research mainly focuses on network cohesion and the difference between a cohesive network (Colemans, 1988) and a network with structural holes (Burt, 1992, 2000), keeping in mind the concepts of stability and centrality. Additionally, the influence of spatial proximity of network actors on knowledge exchange was taken into account, as was introduced by Rutten et al. (2010).

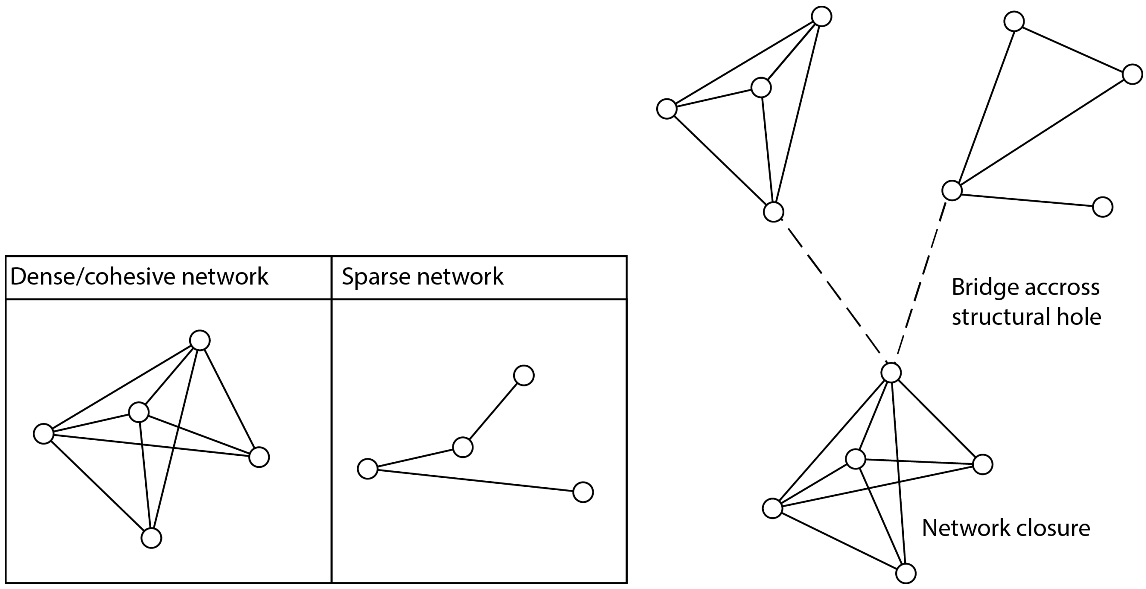
Knowledge exchange is facilitated by the network structure but there is not one network structure that always works. This depends on the purpose, context and culture (Adler and Kwon, 2002; Inkpen and Tsang, 2005; Lee, 2009; Walter et al., 2007). The three dimensions of social capital can still always be used (Inkpen and Tsang, 2005).

Network cohesion

A network can have a high or a low cohesion (see Figure 11.2a). Network cohesion or density is determined by the number of links relative to the number of possible links in a network: tie redundancy. Colemans (1988) advocates the advantages of a cohesive network for knowledge exchange while Burt (1992) argues for a more sparse network with bridges across structural holes (see Figure 11.2b).

A sparse network characteristically has a low tie redundancy. The network has unique bridges across structural holes (Burt, 1992) where a structural hole separates non-redundant sources. Burt (1992) argues that this is the most effective network for knowledge exchange and provides access to a heterogeneous pool of knowledge (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Filieri et al., 2014; Lee, 2009; Schultz-Jones et al., 2009; Walter et al., 2007). These ties across structural holes give an organization the opportunity to learn and develop (Inkpen and Tsang, 2005). A sparse network requires less resources to maintain than a cohesive network (Díez-Vial and Montoro-Sánchez, 2014; Walter et al., 2007) and provides efficient inter-organizational knowledge exchange (Alguezaui and Filieri, 2010). This seems to be a good network structure for external knowledge acquisition. The person bridging the structural hole has a central position and derives power and influence from her crucial role (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Walter et al., 2007). When they move to a different position this has consequences to the network's access to knowledge (Lee, 2009).

For the internal network a sparse network might not be as suitable, it can lead to inefficient knowledge sharing, unstable organization (Walter et al., 2007) and lack of action (Alguezaui and Filieri, 2010). In this case a cohesive network will be more suitable. This is a network with a high tie redundancy which is called network closure (Colemans, 1988). Apart from tie redundancy, a cohesive network is also characterized by strong, bonding ties with frequent interactions (Alguezaui and Filieri, 2010; Colemans, 1988; Lee, 2009; Rutten et al., 2010). Network closure facilitates quick and easy knowledge transfer (Walter et al., 2007), makes it easy to built a shared culture and language (Alguezaui and Filieri, 2010; Filieri et al., 2014; Rutten et al., 2010; Walter et al., 2007) and to build trust(Burt, 2000; Colemans, 1988). This comes at a higher cost of network maintenance. A risk of a cohesive network is that it might result in an inwardly focused information flow with no openness to external information (Alguezaui and Filieri, 2010; Burt, 2000; Lee, 2009).



(a) A dense and a sparse network.

(b) Bridging structural holes between dense networks.

Figure 11.2: Different network structures.

Networks with high and low cohesion complement each other in the process of knowledge acquisition (Burt, 2000; Filieri et al., 2014). In the external network bridges across structural holes are necessary to access new and unique knowledge (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Filieri et al., 2014; Lee, 2009; Walter et al., 2007) while internally a cohesive network is necessary to spread and adapt it within the organization (Colemans, 1988; Walter et al., 2007). However, too much of a cohesive internal network might lead to inflexibility (Lee, 2009) and blind spots (Filieri et al., 2014; Inkpen and Tsang, 2005).

Network stability

Network stability is assessed through changes in a network and their impact on the network (Inkpen and Tsang, 2005). This has to do with the movement of actors within a network and is closely related to centrality of actors and the density of the network (Schultz-Jones et al., 2009). If a central node moves with crucial bridges to knowledge leaves the network this can result in some structural holes without bridges (Lee, 2009), knowledge and resources that were previously available are now not available anymore. In a dense network there are other links that still bridge the holes, in a sparse network there is a higher risk of losing access.

Spatial proximity

The geography of a social network, that is the distance between network actors, influences the costs of knowledge exchange (Rutten et al., 2010). Ties are easier to maintain over short distances, it is easier to contact someone and meet someone when they are close at hand. For both a dense and a sparse network close spatial proximity of the actors is advantageous (Rutten et al., 2010). This effect is decreased with current developments in communication technologies, although it is still present.

In context: It is important for the World Bank to have access to and apply the best available knowledge. This requires diverse links to outside sources which can be accessed through a sparse network. By making these bridges, the Bank can become a central organization in their network. If one person within the Bank has a lot of connections they become a node with a high centrality, crucial for knowledge acquisition. If such a central person moves, this makes the network unstable which can have a negative effect on the knowledge access of the Bank. As the Bank has a complex internal organization it is vital to have sufficient connections and knowledge exchange in the internal network as well. Also here stability is important.

Special attention has to be given to the effect of spatial proximity on knowledge exchange due to the international nature of the World Bank. Both the internal and the external network is spread around the globe which makes knowledge exchange and application challenging.

11.2.2 The relational dimension

In the relational dimension of social capital the focus lies on quality of links between actors (Filieri et al., 2014). This dimension is more difficult to measure than the structural dimension. The strength of a relationship is related to trust, obligations and expectations, identity (Alguezaui and Filieri, 2010; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998), mutual respect and friendship (Díez-Vial and Montoro-Sánchez, 2014; Widén-Wulff and Ginman, 2004) as well as reciprocity and strong social norms (Walter et al., 2007). These factors are closely related and interdependent. The most researched factor to influence interpersonal relations is trust (Lee, 2009; Widén-Wulff and Ginman, 2004). In this research trust and tie strength were used to look into the presence of the relational dimension in the World Bank knowledge exchange network.

Interpersonal trust

Developing trusting relationships is essential for knowledge transfer (Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Lee, 2009; Schultz-Jones et al., 2009; White et al., 2009). Interpersonal trust is dependent on the expectations of the relationship (Widén-Wulff and Ginman, 2004) and the degree to which these expectations are are met (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Lee, 2009). Additionally in a knowledge transfer relationship trust is dependent on the value of the shared information (Filieri et al., 2014) and institutional trust (Inkpen and Tsang, 2005) which is the reputation of the institution. Interpersonal trust is vital in knowledge exchange between academics and policymakers as the policymaker does not have time to verify all the work (White et al., 2009).

Trusting relationships are easier to develop in an environment with a shared culture and language (Díez-Vial and Montoro-Sánchez, 2014) although it still takes time (Inkpen and Tsang, 2005; White et al., 2009). Face-to-face interactions foster interpersonal trust (Filieri et al., 2014; White et al., 2009). These face-to-face meetings are harder to maintain when spatial distance is high.

Tie strength

Tie strength is closely related to trust. Strong ties encourage complex knowledge exchange and the creation of a shared long term vision (Colemans, 1988; Filieri et al., 2014; Inkpen and Tsang, 2005) while weak ties facilitate experimentation (Lee, 2009). Tie strength can be indicated by frequency of contact and friendship (Schultz-Jones et al., 2009), the time spent on the relationship and the intimacy of the relationship (Díez-Vial and Montoro-Sánchez, 2014). Strong ties can have a high frequency of contact and a close intimate link while in weak ties both are low. However, when there is good friendship with a low frequency of contact this can still be a strong tie. Still generally cohesive networks are related to strong ties while sparse networks are associated with weak ties (Lee, 2009). Both strong and weak ties are easier to develop in close spatial proximity, once established a strong tie is easier to maintain over a long distance than a weak tie (Rutten et al., 2010).

In context: Because the World Bank advocates itself as a knowledge bank it is expected that relationships are strongly dependent on skills. However, personal networks with strong ties based on history and friendship are also expected to be important as these are less difficult to maintain over a long distance.

For both World Bank staff and advisers, trust is expected to be an important aspect of the relationship. For Bank staff this is trust in skills and the ability to deliver. The adviser needs to be assured that their work is not in vain.

11.2.3 The cognitive dimension

The third dimension of Social Capital introduced by Nahapiet and Ghoshal (1998) is the cognitive dimension. This dimension looks into the shared mental models between nodes (Filieri et al., 2014) shared culture (Díez-Vial and Montoro-Sánchez, 2014) and shared understanding and and goals (Inkpen and Tsang, 2005). A shared context is very important in meaningful communication (Nahapiet and Ghoshal, 1998). One part of this is sharing a language, codes and narratives which enhance common interpretations (Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998). Having a shared history or common background (Díez-Vial and Montoro-Sánchez, 2014) and staying in close proximity (Rutten et al., 2010) stimulate the development of a shared context. Close cognitive proximity generally has a positive effect on knowledge transfer (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Walter et al., 2007), people with a shared context look at an issue from a similar angle and tend to give similar priorities. However, it is also seen that extremely new concepts are easier learned across large cultural differences (Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998). In the cognitive dimension the focus lies on shared culture and shared goals in combination with perspectives on basin scale theory.

Shared culture

As was said a shared culture enhances the ability of mutual understanding. This shared culture looks at the perspective of a person and her ability to see the perspective of others. This is rooted in shared language, narratives, background (Inkpen and Tsang, 2005; White et al., 2009) and knowledge (Sterman, 2011). If one party tries to push their perspective and culture this causes problems in the relationship and knowledge transfer (Inkpen and Tsang, 2005). A shared language includes sharing the same vocabulary as well as their interpretation (Nahapiet and Ghoshal, 1998).

Shared goals

Having shared goals is another important driver for successful knowledge transfer that resides in the cognitive dimension (Filieri et al., 2014; Inkpen and Tsang, 2005). This includes having a consensus on goals but also on what those goals entail, a common clarity (Filieri et al., 2014). This common clarity combined with a proactive approach towards the goals leads to fruitful knowledge exchange (Nahapiet and Ghoshal, 1998; Walter et al., 2007) and improved common understanding (Inkpen and Tsang, 2005)

In context: The World Bank is a very diverse organization, both the internal and the external network exists of people with different nationalities and professional backgrounds. These differences are a great asset to the Bank but can cause difficulties in knowledge exchange. Due to the diverse organization Bank staff are expected to be more adaptable to different perspectives although it is also possible that the Bank has developed its own culture within their internal cohesive network. This development can be obstructed by the spatial distance between the different staff members.

The differences between Bank staff and their external network are expected to be more pronounced than the internal differences. They are not part of the World Bank culture and way of working which can complicate goal and perspective alignment. The difference in professional backgrounds that are put together in a project can cause difficulties in understanding jargon and interpretation of terminology.

This research focuses on the difference in cognition in the topic of irrigation water consumption. This can be in the form of language and terminology, goals and perspective in both the internal and external network of the Bank.

11.2.4 Linking the dimensions

The dimensions of social capital are separated but highly linked. The dimensions can enhance one another (Widén-Wulff and Ginman, 2004) but one can also compensate for the absence of another (Walter et al., 2007). In their study of knowledge sharing in a Madrid science park Díez-Vial and Montoro-Sánchez (2014) show that especially the correlation between the cognitive and relational dimension is very high (see Table 11.1).

	Structural capital	Relational capital	Cognitive capital
Structural dimension	1		
Relational dimension	0.483	1	
Cognitive dimension	0.466	0.971	1

Table 11.1: Correlation between social capital dimensions and knowledge sharing (Díez-Vial and Montoro-Sánchez, 2014).

The distinction between a sparse and a cohesive network can show the link between the dimensions. A dense network (structural) is characterized by frequent interactions and strong ties (relational), in such a network it is easier to build a shared language and culture and to develop shared goals (cognitive) which enhances the trust between actors (relational).

11.3 Science–policy interface

Adopting scientific theory into practice involves communication between scientific experts and policymakers. The literature on knowledge transfer in the science-policy interface will add a focus layer to the social capital approach. Because of the complexity of natural systems our understanding of them is still under development, this understanding is developed in universities, in the field and through other research (Balian et al., 2016). It is important that these natural systems are managed based on the best-available knowledge (Sterman, 2011).

Understanding the needs of policymakers is crucial in successful knowledge transfer (Balian et al., 2016), demand driven research and communication of research increases its relevance (Balian et al., 2016; Sterman, 2011). Supply driven research enhances credibility. In communication of science to policymakers there should be a balance between simplicity, tailoring to the needs of the policymaker, and credibility (Balian et al., 2016). This related to the language domain in the cognitive dimension of social capital.

There are issues to be tackled on both sides of the science policy-spectrum. One is the overwhelming amount of publications available (Balian et al., 2016). This results in two problems, the first being that it is impossible for a policymaker to be aware of all this research, the second is that within the research there is always something that fits with the motives of the policymaker, which can result in cherry picking. It costs time to filter out what is the best available knowledge, relevant for the policymaker. For the scientist this is not the main task they get rewarded for so it is not their priority (Balian et al., 2016; Lee, 2009; White et al., 2009). Additionally there are often bureaucratic obstacles interfering with successful knowledge exchange (White et al., 2009). This is a structural part of the network of knowledge exchange, and can therefore be included in the structural dimension of social capital. The lack of time also means that trust is very important in science to policy knowledge transfer (White et al., 2009), linking to the relational dimension.

A second barrier lies in the communication, people in science and policy generally come from a different background and reside in a different community (White et al., 2009; Widén-Wulff and Ginman, 2004). They use an inconsistent vocabulary and narratives (Balian et al., 2016; Sterman, 2011; White et al., 2009) and look from contrasting perspectives and scales (Alexander and Armitage, 2015; White et al., 2009). Additionally they can have very different goals (Inkpen and Tsang, 2005). These issues fit within the cognitive dimension of social capital.

In complex natural systems an additional barrier is rooted in the mental models of humans in general (Sterman, 2011), this can be placed in the cognitive dimension of social capital. Changes in the natural system often have impact on a large temporal and spatial scale, includes positive and negative feedback mechanisms. Sterman (2011) argues that these are processes that our brain finds hard to grasp. Additionally people have a tendency to find knowledge that support their current opinion and they tend to judge their own experiences as more valuable than other sources, people try to avoid cognitive dissonance. This can be related to both the cognitive and relational dimension of social capital as it deals with our perspective and the way we trust others. The mental models which Sterman (2011) puts in the context of climate change are also relevant for the introduction of other large scale theories in practice.

In context: The body of literature in this section gave insight into knowledge exchange between policymakers and researchers on complex natural systems. This research focuses on the incorporation of the large scale perspective on irrigation water consumption in World Bank financed projects. World Bank staff can be related to policymakers, they also access specific knowledge for policy and projects and have different priorities than researchers therefore similar issues will arise.

11.4 Conclusion

This systematic literature review resulted in an outline of social capital theory and knowledge exchange in social networks as well as the science policy interface. It was seen that all three dimensions of social capital are relevant in the analysis of the context of knowledge exchange. The science policy interface gave insight into the specific barriers in the transfer of new paradigms in natural sciences. The theory was briefly related to the World Bank to give some context. The next chapter brings the key findings from this systematic literature review together with results from preliminary interviews to get to the conceptual framework.

12

Conceptual framework

12.1 Introduction

The systematic literature review was combined with the preliminary interviews to come to a conceptual framework for the analysis. This conceptual framework consists of two parts. Section 12.2 identifies the network characteristics facilitating knowledge exchange as well as the obstacles for knowledge exchange. This section is aimed to answer the first sub-question of the research. Section 12.3 elaborates on the research constructs and variables that were used to structure the interviews, giving the foundation for answering the second research question in Chapter 13. These constructs are rooted in theory and the preliminary interviews. The exact theoretical connections can be found in Appendix G.

Both sections are structured according to the three dimensions of social capital: structural, relational and cognitive. Figure 12.1 shows how the literature and preliminary interviews are linked to these different dimensions. Section 12.3 will conclude with the connections between the constructs and the dimensions.

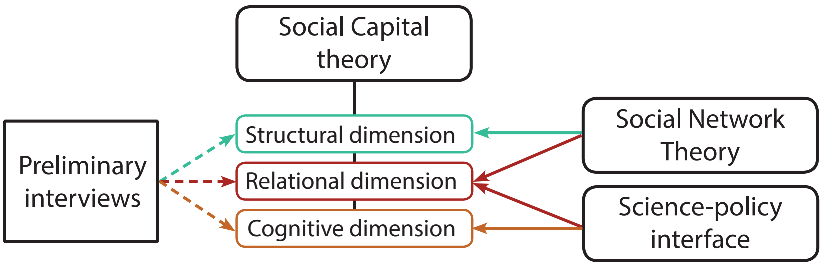


Figure 12.1: Connecting the literature with preliminary interviews.

12.2 Network characteristics

This section will give insight into the specific network characteristics for knowledge exchange. This will include criteria which should ideally be present in the World Bank network as well as aspects that will hinder knowledge exchange. The criteria are based on the systematic literature review, presented in Chapter 11, and preliminary interviews with academics and consultants involved with the World Bank and policy development.

Figure 12.2 shows the configuration of a network ideally structured for knowledge acquisition form external sources and knowledge dispersion within the organization. In short this consists of a sparse external network and a dense internal network with shared goals, language and perspectives along trusting strong ties as well as weak ties. The criteria (see Table 12.1) and the obstacles are discussed according to the three dimensions of social capital, starting with the structural dimension.

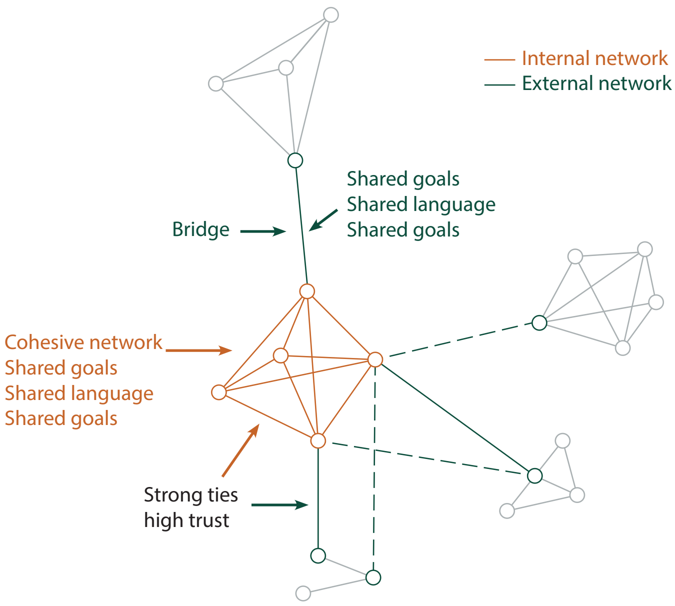


Figure 12.2: Ideal network configuration for knowledge acquisition and diffusion from a social capital perspective.

12.2.1 The structural dimension

From the social capital and social network theory it can be deduced that a sparse external network should ideally be combined with a cohesive internal network to obtain and disseminate knowledge effectively(Walter et al., 2007). The sparse external network gives access to a variety of knowledge sources with low maintenance costs, while internal cohesion facilitates effective distribution within the organization (see Table 12.2). Ideally an external knowledge source is accessed by one or two people within an organization, when the number of connections to one source increases this causes an increase in maintenance costs. The knowledge accessed by this one person will then spread through her direct links and via them to the rest of the network. A risk of a sparse network is that it is very sensitive to changes in the network. When there is only one connection to an external organization and that node leaves the network, it can have a great impact on knowledge availability.

While the external network provides access to a wide variety of sources, the cohesive internal network gives the opportunity to create a shared culture. Having a cohesive network means there is a high connective density among the people, the network nodes know each other and are regularly in contact. This makes it easier to build a shared vision, shared language and shared goals. They use similar narratives and can relate to each others' perspectives. This brings the risk of an inward focus which can result in blind spots. The closedness of the World Bank network was named in two preliminary interviews as an obstacle. Therefore, the combination with the sparse external network is crucial.

In the international network of the World Bank, spatial proximity is also addressed as a factor influencing knowledge exchange. Networks crossing continents make it harder to arrange face to face meetings which improve the success of knowledge exchange. These distances result in high costs and effort to maintain ties.

From the literature on the science-policy interface and the preliminary interviews a couple of other

Dimension	Required for optimal knowledge exchange
Structural dimension	Cohesive internal network Sparse external network High network stability Reward system and time allocation for knowledge exchange
Relational dimension	Trusting ties Strong ties
Cognitive dimension	Shared goals Shared language Shared or flexible perspectives

Table 12.1: Network characteristics facilitating knowledge exchange.

Network	advantages	disadvantages
Cohesive internal network	Fast communication Effortless knowledge diffusion Resilience to instability Ease of building a shared culture Ease of building a shared language Ease of building shared goals Ease of building strong ties	Inward focus High maintenance costs
Sparse external network	Low maintenance costs Access to heterogeneous knowledge Power as knowledge broker Efficient knowledge exchange	Low resilience to instability
Stable network	Resilient to changes in network	
Incentives for knowledge exchange	Knowledge exchange actively pursued	High costs

Table 12.2: Indicators influencing knowledge exchange in the structural dimension.

aspects influencing knowledge exchange on a structural level arose (see Table 12.3). When looking at knowledge exchange between scientists and the World Bank it is indicated that a translation is necessary. It costs time to do this which is not always available, on both the policy and the science side, people are busy and often do not time specifically allocated to knowledge exchange. This was stressed in four of the six preliminary interviews. A related matter arose in five of the interviews as well as in the literature (Balian et al., 2016; Lee, 2009; White et al., 2009), the actors are not judged or rewarded on knowledge exchange but on publications or project deliverable. Having a specific time allocation and reward system dedicated to knowledge exchange will shift this priority.

12.2.2 The relational dimension

The main relational points influencing knowledge exchange from the social capital and social network literature are interpersonal trust and tie strength. In which the importance of interpersonal trust and the personal relationship were stressed in three preliminary interviews. Trust can be based on skills and ability, reliability as well as the reputation of the institute the actor employed by. Interpersonal trust affects the choice of knowledge source and the readiness of acceptance of the knowledge. The indicators and obstacles for knowledge exchange in the relational dimension are shown in Table 12.4 and Table 12.5.

When a policymaker has a high opinion of the ability of a knowledge provider they do not spend a lot of time on assessment and critical evaluation. For a policymaker, time is often an issue (Balian et al., 2016), which means strong trust is necessary for knowledge adoption. On the other hand if the trusting relationship is with one scientist this might result blind spots, therefore there should be trusting links to different knowledge sources.

Reliability is linked to predictability of a person meeting their agreements. If in the past expectations have not been met, this will instill a sense that the relation is unreliable which influences trust. In a network promoting knowledge exchange the network nodes have a high reliability as well as trust in ability.

The change in the network was mentioned as an issue in the relational dimension. When someone leaves a project or initiative, someone else with a different approach will join the team. When this someone is in a leading position and has a strong opinion, this can influence previous agreements and some initial expectations might not be met. This impacts trust in the project or the institution and might influence future involvement of the actor.

It is easier to transfer knowledge across a strong tie than across a weak tie. Tie strength is closely related to trust, strong ties usually have a high trust, however, a weak tie in which there is high trust can be very valuable (Lee, 2009). Strong ties arise through frequency of contact and closeness. When there is a lot of friendship the frequency of contact is less crucial to maintain the strong tie. It takes time to build strong ties. A network with high trust and strong ties improves the effectiveness of knowledge exchange both in the internal and external network.

12.2.3 The cognitive dimension

The cognitive dimension looks for the existence of common ground between the actors, the cognitive similarity. This similarity can be found in sharing goals, language and perspectives. Sharing these facilitates effective knowledge exchange. Having different goals, different perspectives and a different professional language was named as a profound obstacle in knowledge exchange. Differences in goals were mentioned in six interviews and different perspectives and language in four preliminary interviews. These issues were also stressed in science-policy interface literature (Balian et al., 2016; Sterman, 2011; White et al., 2009). The indicators and obstacles form the literature and preliminary interviews can be found in Table 12.6 and Table 12.7.

Obstacle	Results in	Improvement
No reward system for knowledge exchange	No priority for knowledge exchange Only on own initiative No structural approach	Include in project terms Include in job description
Time pressure	No priority for knowledge exchange	Allocate specific time
Low spatial proximity	Difficulty building ties Difficulty building shared vision High costs tie maintenance	Face to face visits Communication technology
Closed internal network	Low innovative capacity Difficult to approach	open attitude

Table 12.3: Structural obstacles from preliminary interviews and literature.

Indicator	Advantages	Disadvantages
Trusting ties	Ease of knowledge exchange	Less critical judgment Focus on limited sources
Strong ties	Ease of knowledge exchange	Maintenance costs

Table 12.4: Indicators influencing knowledge exchange in the relational dimension.

Obstacle	Results in	Improvement
Low trust in ability	Low acceptance of knowledge	Second opinion
Change in network	Commitments not met Reduced trust	Make clear commitments Conveyance of commitments

Table 12.5: Relational obstacles from preliminary interviews and literature.

Indicator	Advantage	Disadvantages
Shared terminology	Common understanding Ease of knowledge exchange	
Simple language	Common understanding	Lost nuances
Shared project goals	Common expectations Working towards the same goal Shared project success	
Understanding of different goals	Managing expectations	Difficult to obtain
Understanding different perspectives	Shared perception Ease of knowledge exchange	Hard to find commonalities

Table 12.6: Indicators influencing knowledge exchange in the cognitive dimension.

Obstacle	Results in	Improvement
Personal goals - corruption - model promotion	Difference in expectations Deviation from project goals Cherry picking of models	Being aware Working in the system
Different terminology - efficiency	Miscommunication Difference in expectations	Clear agreements of terminology Open discussion
Difficult terminology	Misunderstanding Confusion Difference in expectations	
Different focus - abstract vs practical - large scale vs small scale - content vs process	Difference in goals Difference in expectations Miscommunication	Open discussion

Table 12.7: Cognitive obstacles from preliminary interviews and literature.

Sharing a language with the same terminology, the same interpretation of terminology and the same vocabulary prevents misunderstanding. Having a similar understanding of the vocabulary makes sure both parties understand the discussion, having the same interpretation ensures that they both understand the same thing and not only think they understand the same thing. Another issue that was mentioned in this is that some academics tend to use terminology and language that is too difficult to understand. This can be intentional, for example to sound impressive or to remain relevant, or unintentional.

Goal alignment is important to make sure the actors are working towards the same goal or at least are aware of the goals others are working towards. This results in more effective knowledge exchange. A specific obstacle that was mentioned in this domain is the interference of personal goals with project goals. In a country borrowing money for a World Bank project this can be because of personal gain through corruption. Another example of personal goals reaching into a project is when knowledge supplier are trying to promote their own model or technology. Additionally it is important that a vision or general goals of a project are clearly communicated. Difference in goals can influence expectations and harm trust in a relationship.

Academics often have more scientific or abstract goals while policymakers and World Bank project staff focus on practical application in the field. Their goals and perspective are very different, this is one of the biggest obstacles in applying theory in practice. Academics focus on content, while policymakers look at the process and application. A perspective issue in the case of water consumption is that hydrologists focus on the large scale, while project funding is mostly on a smaller temporal and spatial scale. This also arises in communication about climate change (Sterman, 2011). It is important to align these perspective to obtain application of theory in practice. The actors should be flexible in changing their perspective and seeing the perspective of the other.

12.3 Research variables

This section concisely outlines the research constructs and variables on which the interviews are based. The constructs are defined in accordance with the social capital dimensions. The focus within the dimensions is based on social capital and social network literature, literature on the science-policy interface and the preliminary interviews. The exact connections between the sources and the variables as well as a more extensive description of the variables can be found in Appendix G. The constructs are abstract concepts fitting with the literature while the variables are more concrete. The variables are mainly qualitative which means they are not measured with a numerical value, range or order. They were used to define the interview questions for the semi-structured interviews. How these constructs and variables translated to interview questions can be found in Appendix I. The operational definitions of the constructs are given in Table 12.8 and the constructs are linked to the research in Figure 12.3.

12.3.1 The structural dimension

The constructs in the structural dimension are: network closure, network stability, embedded systems and spatial proximity of actors. These constructs are analyzed in both the internal and external network. See Table 12.9 for the variables in the structural dimension.

Network closure is analyzed through tie redundancy, which looks at the unique ties between people and organizations. Within the domain of network closure we also asses the perceived importance of bridges across external structural holes, or unique links to external sources.

Network stability is assessed through the variables: changes in network nodes and the perceived effect of changes in the network nodes. Stability is based on the network changes but if there are changes and no effect is noticed the network stability is still sufficient.

Embedded systems looks at the systems inherent to the network structure that enhance knowledge exchange. In this case the variables will be the reward system and time structurally allocated to knowledge exchange, and the knowledge exchange methods embedded in the network structure.

Spatial proximity is the actual distance between network actors. This will not be measured in kilometers or miles but qualitatively in whether the actors are located in the same city, country or on the same continent. Additionally the perceived effect of this distance will be a variable.

12.3.2 The relational dimension

The relational dimension is researched through two highly interlinked constructs: interpersonal trust and tie strength. These are used to assess the relation between external contacts and World Bank staff. See Table 12.10 for the variables in the relational dimension.

Interpersonal trust is analyzed through the manner in which the actors think their connections are reliable, if they will come through on their promises and if agreements are met where previous experience influences expectations. Secondly it is assessed through the perceived ability of the other actor to do the task they are given.

Tie strength is judged based on the frequency of interaction in combination with the friendship between the actors. If there is a low frequency of contact but a high level of friendship there can still be a strong tie.

12.3.3 The cognitive dimension

The cognitive dimension looks at the commonalities between the actors. The constructs analyzed in this dimension are: goal alignment, language alignment and perspective alignment. Here we look at

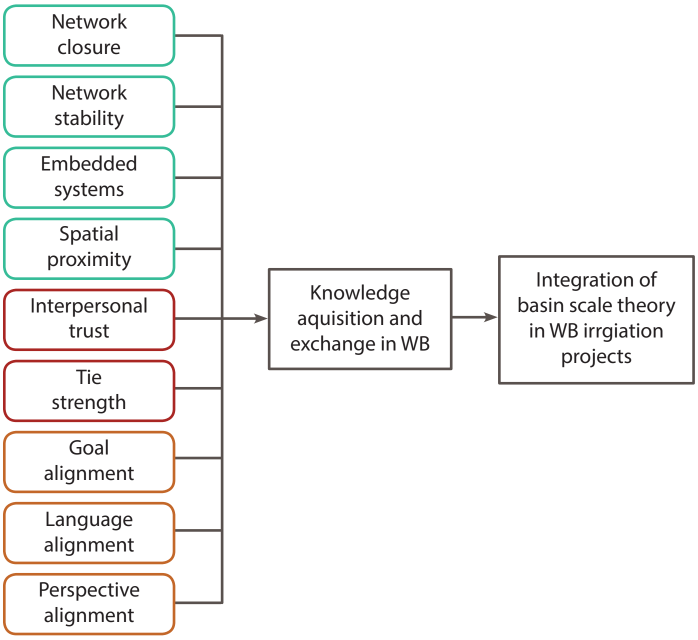


Figure 12.3: Linking the constructs to the research question.

Construct	Definition
Network closure	The density of connectedness within a network. In a closed network everyone is connected to everyone, in a spare network the number of connections are limited.
Network stability	The movement of nodes in a network, to different positions or out of the network.
Embedded systems	Systems inherent to the network that stimulate or prevent knowledge exchange.
Spatial proximity	The spatial distance between actors.
Interpersonal trust	Belief that someone is reliable and worthwhile to communicate with.
Tie strength	Intensity of the relationship.
Goal alignment	The level to which the goals of the project, actors and the organization align when looking at initiatives related to water consumption and efficiency in agriculture.
Language alignment	Common used terminology and level of language when talking about projects and theory concerning water consumption and efficiency in agriculture.
Perspective alignment	Way of looking at the world based educational and cultural background and the extent to which these align on the topic of water consumption and efficiency in agriculture.

Table 12.8: Operational definitions research constructs.

the commonalities but also to what extent the actors are aware of differences. While the other two dimensions are focused on the World Bank and water expert, this dimension is even more specified to look at the case of knowledge exchange concerning large scale theories and the incorporation in the World Bank. See Table 12.11 for the variables in the cognitive dimension.

Goal alignment is the construct that will give insight into the common goals and the obstacles experienced in goal alignment. To find out commonalities or differences between goals we will look at several variables: personal goals, perceived World Bank project goals, perceived World Bank vision and perceived differences in goals.

Language alignment will give insight into the degree to which the actors use a common language as well as their interpretation of the language. The variables of this construct are: clarity of language, similarity of used language and narratives and their interpretation. For the interpretation of used terminology the focus will be on the use of the terms: efficiency and consumption because they relate to the link between the project scale and basin scale.

Perspective alignment will be used to assess the different perspectives and the openness to large scale theories. For this we use the variables: scale of thinking, opinion of large scale theory, observed acceptance of large scale theory in the World Bank and the perceived knowledge gap. The perceived knowledge gap is included to detect if the actors feel that the integration between large scale theory in projects is due to lack of understanding or something else.

Construct	Variables
Network closure	- Tie redundancy - Perceived importance external bridges across structural holes
Network stability	- Changes in network nodes - Perceived effect of changes in network nodes
Embedded systems	- Reward system for knowledge exchange - Time structurally allocated to knowledge exchange - Knowledge exchange methods
Spatial proximity	- Distance between network nodes - Perceived effect of distance between network nodes

Table 12.9: Variables in the structural dimension.

Construct	Variables
Trust	- Ability - Reliability
Tie strength	- Frequency of contact - Friendship

Table 12.10: Variables in the relational dimension.

Construct	Variables
Goal alignment	- Personal goals - Perceived World Bank project goals - Perceived World Bank vision - Perceived differences in goals
Language alignment	- Similarity of used terminology and narratives - Clarity of language
Perspective alignment	- Scale of thinking - Opinion of large scale theory - Perceived acceptance of large scale theory in the World Bank - Perceived knowledge gap

Table 12.11: Variables in the cognitive dimension.

12.3.4 Linking the constructs

The importance of the links between the dimensions was already mentioned at the end of Chapter 11, especially showing a very high correlation between the cognitive and relational dimension. The relations between the dimensions can be translated to links between the constructs that were previously identified (see Figure 12.4). These links are based on the literature from the systematic literature review and the preliminary interviews. In the synthesis of the results the links between the constructs will be addressed to enrich the answer to the third research question.

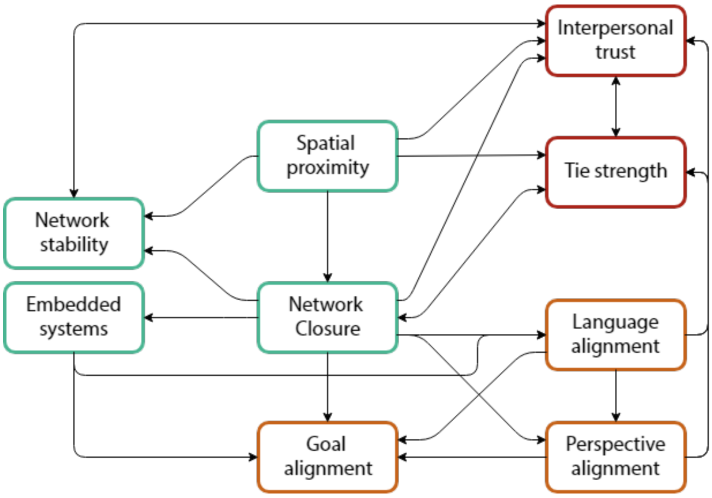


Figure 12.4: Links between the constructs. The constructs for the structural dimension are shown in blue, for the relational dimension in red and for the cognitive dimension in orange.

The links between constructs mean that they affect one another in the direction of the arrow. Linked constructs can simply affect one another as a closed network provides an environment where a shared language is easily developed. They can also compensate for each other. For example, spatial distance is less of an issue in the case of a strong tie and network closure reduces the effect one unstable node, increasing network stability.

The constructs are very closely linked within their dimension. The link between interpersonal trust and tie strength is for example very strong. A strong tie often also contains a high level of trust. Another example is the link between language and perspective alignment. Where a shared language increases the ability to develop a shared perspective and a they both increase the ability to develop shared goals.

Network closure is linked to all other constructs in one way or another. A cohesive network provides an environment where developing a shared language, perspective and goals is easier as compared to a sparse network. Additionally it is easier to develop trusting relationships and strong ties, where strong ties also provide a gateway to develop a cohesive network. A cohesive network is easier to maintain when there is low spatial proximity and makes a network more resilient to changes, thus making it more stable. It also provides an environment where embedded systems like time allocation, reward systems and knowledge exchange methods, are generally better defined than in a sparse network. This last link is specifically visible within an organization. These connections are there but this does not mean that a cohesive network is without question better for knowledge exchange than a sparse network, as was discussed in Section 12.2.

A more subtle link between two constructs is the one between embedded systems and language alignment. This arises in the process of knowledge exchange. When there is no structural time allocation or reward system for knowledge exchange, people will spend less time on it. Knowledge exchange takes more time when there is a low level of language alignment, consequently knowledge exchange will be less fruitful when both language alignment and time allocation are low.

Another example of a subtle link is that between the constructs in the cognitive dimension, trust and network stability. When for example a consultant is working with an organization, it can come to pass that the organization switches representatives for the project. This new person brings their own expectations and perspective with them, which will increase the time spent on goal alignment. Changing to a new person can alter the project and previous agreements can be changed. This means the consultant has to adjust their expectations. If this happens too drastically or too often it can result in a degradation of trust.

12.4 Conclusion

This chapter outlined the conceptual framework of this study, identifying the indicators of and obstacles in a network facilitating knowledge exchange and introducing the research constructs and variables of the research. The first section of the conceptual framework answers the firs sub-question of this research. The second section gave the structure of variables from which the investigation into the World Bank knowledge exchange network was started. Chapter 13 follows from interviews based on that structure which was combined with knowledge from World Bank policy and project documents.

13

Results: Knowledge exchange at the World Bank

13.1 Introduction

The World Bank (WB) is a knowledge bank and thus knowledge exchange is very important in the Bank. The opinions on whether the current practices of the Bank are sufficient to ensure learning and knowledge acquisition are divided as is shown in the following quotes from an interview with a scientist (referred to as [H]) and a World Bank employee (referred to as [WB]).

> "There is also a knowledge exchange person, whose job is to ensure knowledge is exchanged. In the group that I run, we have a discussion paper series as well. So, I think, I could be wrong, but for any institution outside of academia, . . . there is not a lot of knowledge exchange and more emphasis on knowledge that I have seen anywhere." [WB]

> "I don't think it's a learning environment. They produce a lot of reports. Like our report will be another of these reports that no one has time to read them. They are all running around doing projects, supervision, preparing projects and all the rest of it. But in my opinion, there's not enough time spent sharing the knowledge that they have and learning from each others' experience." [H]

This chapter dives into the knowledge exchange processes present in the World Bank. This includes its knowledge acquisition as well as the diffusion within the organization, answering the second research question of this part of the thesis. This chapter contains results from interviews and documents (see Figure 13.1). The results are presented through the dimensions of social capital even though the lines between the dimensions are blurred in some of the observations.

This chapter will first elaborate on the structure of the World Bank and what systems of knowledge acquisition and internal knowledge exchange are present in the organization. Then it will touch upon the concepts of network cohesion, stability and spatial proximity. After this, the relational aspects of knowledge exchange and the general observations will be discussed. Lastly some emphasis is put on the cognition of the interviewees concerning water consumption in agriculture and the integration of large scale concepts in projects.

As was mentioned in Section 10, interviews were conducted with three stakeholder groups. In this section the quotes for these interviews are referenced with abbreviations where hydrologists are referred to with [H], World Bank staff as [WB] and consultants as [C]. A number is added when two different interviewees of the same stakeholder group say something about the same topic, resulting in [H1] and [H2]. The choice of number is arbitrary, meaning [H1] in one section can refer to a different interviewee than [H1] in the next section.

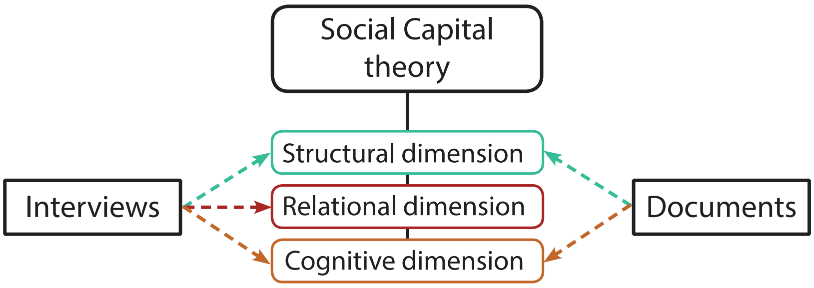


Figure 13.1: Connecting literature with interviews and documents.

13.2 World Bank structures for knowledge exchange

The World Bank is focused on knowledge development and knowledge exchange in its structure. The Bank went through a restructuring in the last five years which made the knowledge more global oriented instead of focused on the regions (see Figure 13.2). The Bank still works in its regional teams but the thematic knowledge exchange is facilitated on a global level. This was mainly done to make the functioning of the Bank more cost efficient but the result is a more structured knowledge exchange, however, not everyone is enthusiastic.

> "They will spend five years reorganizing something, come up with another department name with the same people in it, and they will dissolve it and change it again. It's a very, very large bureaucratic organization in that sense, which is frustrating and it really hinders the knowledge development for sure." [WB1]

> "So the last restructuring was three or four years ago ... This has had a great impact on knowledge exchange. Before we were very much organized per region and then they said 'well hello, we are the World Bank so knowledge should be exchanged at a global level'. Because of that we now have one water department ... and there is a group of people with 'helping the task team to find knowledge and innovation' in their terms of reference. ... so knowledge exchange has improved a lot over the past five years." [WB2]

13.2.1 Projects and consultant hiring

The World Bank hires consultants for large lending projects and separate research projects. A lending project generally consists of project preparation, implementation and evaluation. Three of the consultants in this research were currently involved in project implementation. To be hired in the project implementation phase of a project, a company or consortium should subscribe to an international open tender. The consortium is then hired by the project implementation unit (PIU), which is led by the borrowing country. The World Bank approves this contract after the country has made the choice of consultants. The consultants are generally hired for the full project duration which can be three years but also eight years depending on the project.

Consultants are hired directly by the World Bank for project preparation and short term projects as well as project evaluation. The duration of these contracts is dependent on the mission. These contracts can for example be used for research, crisis projects and project preparation. The Bank hires consultants directly through single source recruitment and also has an agreement with the Food and Agriculture Organization (FAO) to hire through them. These consultants are paid through trust funds from donors.

> "The Bank has an agreement with FAO, the investment center in the Food and Agricultural Organization ... That's a packet of money that FAO then uses to find consultants for the Bank on projects." [H]

Technical analysis in a project preparation often follows from a crisis situation. A country has lost sight of what to do, there is no budget, no staff and a lot of problems. This is when they ask the Bank for a loan to help them. In this phase the Bank hires consultants for a short term contract. It is often unclear if a project will continue after the first contract ends.

> "So it is always on short notice, when you know the project will stop even though there are plans to continue. Often the government changes its views or there are problems finding subsidies." [C]

The initiative for a project can also come from within the World Bank. For example in Eastern Europe a task team leader (TTL) felt like they were investing in a lot of small projects without a coherent vision. The TTL initiated a current project preparation where disciplines from energy to water to transport are integrated in a common strategy. The project started as a research and grew into a proper project team. The preparation is in collaboration with the involved countries and in this case the European Union.

Sometimes projects follow from a large scale trust fund initiative like in the Central Asia Energy Water Development Program (CAEWDP). This program is sustained by trust funds and will continue for as long as donors want to invest money. From this initiative several projects followed based on grants (World Bank, 2017).

13.2.2 Global Practices and Global Solution Groups

The World Bank has fifteen Global Practices (GPs) (World Bank, 2018b) that are organized in the thematic vice presidencies of Human Development, Sustainable Development and Equitable Growth, Finance, and Institutions. The water GP and agriculture GP are most important when looking at irrigation management and they are both allocated with the sustainable development vice presidency. The GPs are tasked with the development of knowledge and the strategy of the Bank in their field and the implementation of this knowledge in integrated solutions with the clients. Within the Global Practice, field trips are organized to gain specific knowledge from a region which can be internalized into the Global Practice of the Bank.

Figure 13.2: World Bank knowledge management structure.

Within these GPs there are Global Solution Groups (GSGs) which cover a specific theme, for example water and agriculture, or hydropower. These GSGs can exist within one GP or cover multiple GPs. Hydro power fits into the water GP as well as the energy GP. They are headed by a Global Lead.

The purpose of a Global Solution Group is on the one hand building a strategy or vision and on the other hand managing the knowledge exchange on their theme. They link TTLs with internal and external knowledge sources, help tailor presentations from external knowledge sources and generally support technical staff in knowledge exchange and acquisition. If a TTL or other staff wants to bring in someone to speak about a topic, the GSG makes it happen. They are the direct contact to external knowledge sources and try to build partnerships. Additionally the GSG facilitates knowledge development on their theme. Some GSGs are more active and developed than others because of trust fund availability.

> "So, in my case, I'm working on a theme which is called a Global Solution Groups, which is called water and agriculture. The study tour that I just did in Italy was part of this. We went to a very specific area with a very specific idea and expectation what we wanted to see, what we wanted to learn from this area, in order to learn from the context and from the previous development that has taken place, basically to stimulate and improve our projects." [WB1]

> "In the water practice the GSGs are quite mature, because they are supported by trust funds." [WB2]

Global Solution Groups are linked to knowledge development initiatives like the Water Partnership Program (WPP), now replaced by the Global Water Security and Sanitation Partnership (GWSP). The WPP was a partnership between the Bank and five European governments focusing on water security and climate resilient growth. The knowledge exchange strategy in the WPP can be seen in Figure 13.3.

> "The WPP is helping client countries enhance water security by mainstreaming climate resilient growth and pragmatic approaches into WRM and WSS. The WPP remains committed to its initial goal—providing water security for all—by continually building on the experiences of its partners to expand its repertoire of tools and methodologies." (Dani et al., 2015) [p. 8]

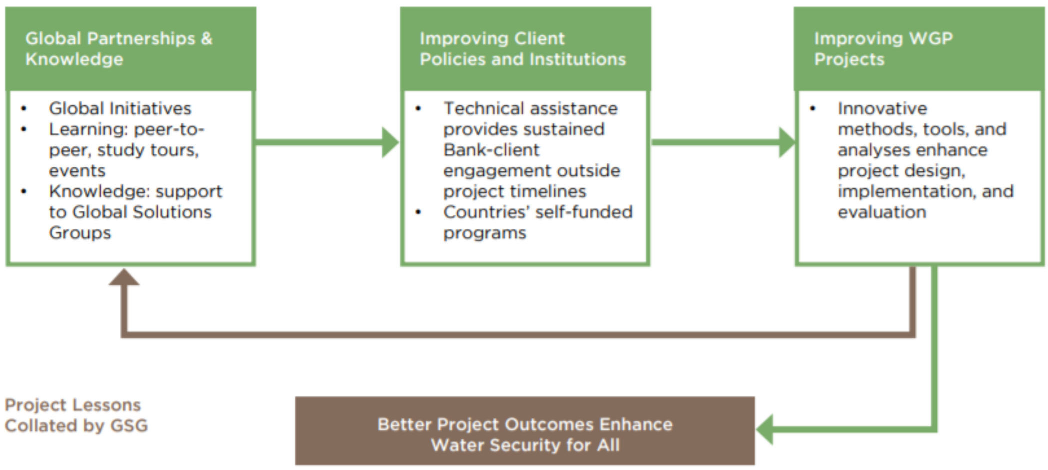


Figure 13.3: Knowledge management in the Water Partnership Program in the water GP (Dani et al., 2015).

13.2.3 Key figures for knowledge acquisition and diffusion

Within the World Bank there are a few key figures in knowledge acquisition and diffusion. There are people responsible for knowledge development in specific themes and people responsible for implementing knowledge in practice. The Chief Economist and Global Lead are identified as key figures for knowledge acquisition on themes and the task team leader as a key figure in bringing this knowledge to the projects. They are connected in the internal network of the Bank. Furthermore, there are consultants hired in short term contacts and the consultants working on project implementation.

Chief Economist

The Chief Economist is generally based in Washington and focuses on knowledge development in their Global Practice as well as channeling this knowledge through projects. They focus on developing unique knowledge that has not been conducted before, bringing in expertise from within as well as outside their network. A research results in a research report which is then diffused through the Bank in formal and informal channels. The Chief Economist is involved in projects in an advisory capacity, this can sometimes result in an extension for the research in a specific region.

> "I mean quite a lot of what I do is quite original research that has not been done by people outside the Bank, which is why I take it on. If it were done, then I don't really bother with it, because that's a summary paper." [WB]

> "A lot of them are outside the Bank. I mean you make contact with people and you make contact with new people through sometimes people that you know. . . . the economics of water is not a very big field. If you try to push the frontier, that often means you're not working with people that are not actually already in the field, you're trying to bring new skills in. ... A little bit of that. A little bit of your other best friend, which is called Google." [WB]

Global Lead

A Global Lead heads a GSG and propagates the World Bank stance in their theme. A Global Lead can be the only person representing their GSG. They are involved with strategy development, they can for example hire external consultants to help with strategy development. Together with others in their staff they link World Bank staff to knowledge sources within or outside the Bank. They are more practice oriented than the Global Economist. The way a Global Lead manages his position is very much dependent on the person in the position.

> "The Global Lead is kind of the Godfather of whatever the theme is." [WB1]

> "We have Global Leads for water supply and sanitation for irrigation and for water resource management. So, they get much more into the nuts and bolts of projects." [WB2]

Task team leader

Task team leaders (TTLs) are directly involved with projects. They are specialists working within a specific GP, for example an irrigation engineer or a water supply specialist. They can be located in Washington or in a specific region. The TTL is responsible for the entire project cycle. The TTL is supported by other World Bank staff and short term consultants. The TTLs work on a more practical level than the Global Economists and Global Leads, translating the knowledge from the Bank and external sources into projects. They have access to organized seminars and presentations, the GSG and GP staff and the extensive internal database.

> "From the identification towards assessment and the preparation of the concept note. Then, to initiate a feasibility assessment, to carry out an appraisal of the project preparation document, and then eventually have it approved and implanted, monitored and completed." [WB1]

> "When you are working on a project, you see that things could be done differently. Then you remember a presentation you have seen on that topic and then you decide if you reach out to someone." [WB2]

The TTL is responsible for the connection between the consultants in a project and the World Bank during the project implementation. They organize the World Bank evaluation missions, stay in contact with the local project team and keep an eye on everything that is going on. They are tasked with bringing knowledge from the Bank to the consultants. Also in the project preparation the TTL is the key contact for a consultant on a short term contract.

> "He has to be aware of everything that happens in the project, he is leading in the World Bank missions to the project. He decides what information is collected, how the mission is organized and how it is reported on afterwards ... Fieldtrips are organized and workshops are organized, many documents are written beforehand." [C]

Short term contract consultant

The consultant with a short term contract is a specialist helping in project preparation and research. This can be someone in academia as well as someone from the private sector. Of the interviewees, all of the interviewed academics were involved with the World Bank like this. One of the consultants works as a short term contract consultant full time, while two of the project implementation consultants also do this kind of consultancy sometimes. These consultants are hired for very specialized jobs that cannot be filled from within the World Bank due to lack of expertise or time availability. They are hired on very short notice and have to have direct contacts with the World Bank. During project preparation they are directly in contact with the TTL, sometimes as often as on a daily basis. When they work on a general research they are in contact with the person supplying the assignment. They can be in contact with other external knowledge sources during their research, however, they are usually hired through the TTL.

> "When you are hired as an external consultant, those are very short contracts, very limited." [C]

> "Yes, the TTL is the person you report to, this is also the person you have to understand very well." [C]

Project implementation consultant

These consultants work on the project implementation, they bring their expertise and experience from previous projects. They work in the local project team. They are hired as a company or a consortium of consultants. The World Bank comes with an evaluation mission once a year. The regularity with which the consultants are in contact with the TTLs differs per project. They usually have some other connections with the World Bank, however, the main connections are the ones they have in the ongoing project. There is little to no interaction between the project consultants from different projects and a low awareness of other World Bank projects in the region apart from the ones the consultants were involved with. The knowledge from other projects that they bring, comes from their own experience. In hiring the team they do look at the backgrounds of consultants and what experience they can bring in. Sometimes there is a budget for a field visit but they are not always seen as effective.

> "What you do is, I was one of the chief advisers ... And we had to build a team, so we could hire other people ... For the international consultants we really focused on finding the people with the right expertise." [C]

> "So, one way that that knowledge gets captured is by the consultant working on other projects. You're bringing their power and their work from other projects. They institutionalize whatever it is they're bringing." [WB]

13.2.4 The World Bank Water network

The world of experts in water and irrigation is very small. As an outsider, it is hard to initially get into the inner circle of World Bank and water, but inside everyone knows each other directly or indirectly. For short term contract consultants, this network is very important, when you are known you are more easily hired. This makes investing in the personal network a crucial part of the job. The project consultants also rely on their network but more on their network with peers than their connections with the World Bank, as they are hired through a PIU in a project team. They have World Bank staff in their LinkedIn connection list but are not regularly in contact. Even some World Bank staff got to know about a possible position at the World Bank through their personal network.

> "So in water, there's probably two degrees of separation to begin with, before you know somebody that knows somebody. In the World Bank in water, I think that's even less than that because there's so few people in power positions that focus on these issues." [WB]

> "Yes, you should extend your network. I spend one or two, weeks per year ... then I go to Washington ... and I try to meet as many people as possible." [C1]

> "Yes there is one specific person who knows where to find me and he connects me to other people in the Bank." [C2]

Another important part of the World Bank water network is their link to other institutes. Even though there are not a lot of water and irrigation knowledge institutes in the world, the Bank does not have very strong formal connections with all of them. In this sense the world of water is quite small but not fully utilized. Relations with institutes are often based on relationships between people and not the organizations.

Universities and knowledge institutes are mostly contacted for research documents and related to short term consultancy in project implementation the involvement is low. Contact with local universities is on personal initiative during the project implementation. During project preparation the team does search actively for NGOs and other organizations that have conducted relevant research or implemented relevant projects.

Most of the interviewees think the World Bank should develop better or more formal connections with external knowledge partners. The Bank does reach outside its network for research and development on new topics. However, this results in project based partnerships and not formal long term partnerships.

> "There should be perhaps more formal partnerships. People are invited, but they are not part of the team." [H]

13.2.5 Network stability

World Bank staff changes positions about once every seven years. During the project preparation a consultant generally works with the same TTL for the whole course of the project, however, in the project implementation it happens quite often that a TTL changes. This has an effect on the project as the new person brings their own background and priorities to the table. The interviewees generally do not see negative implications of the changes in TTLs. It takes some time to make the transition but a change in staff can give a project a new impulse. The new TTL is generally selected based on their background and experience in the region.

> "The project ran for eight years, then the World Bank people, the team leaders, get changed regularly, in this project we had four." [C1]

> "A new person always comes with their own background, their own backpack, they have their own preferences but you always try to find someone who has already been involved in the past to make the transition smooth." [WB]

Changes in a personal network can have implications for a short term consultant. If a contact TTL moves to a different position within the Bank or away from the Bank this means that one of her possible employers is not in a position to hire her anymore. That is why a consultant has to keep investing in the network. However, if a TTL moves to a different location, they can also just take their consulting connections with them. Another reason why a consultant might lose touch with the World Bank is age. When a consultant ages so do the contacts, if they retire the contact is gone.

> "We were only working for a year and the guy who gave me my contract changed position, he went up in the ranks so he was not going to hire me anymore. Then you have to start over." [C2]

The external network of the Bank is very person oriented, this means that when a person moves out of an institute this can have a great impact on its access to knowledge. This can be remedied by a stronger connection to the institute.

13.2.6 Spatial proximity

Most of the interviewees did not think spatial proximity was an issue in the functioning of their projects and knowledge exchange when asked directly. They see communication technology such as e-mail, Skype and the telephone as tools that counteract the negative effects of spatial distance on connecting with people. However, in other questions some difficulties with spatial distance arose. For one, there is a difference in culture between the projects in different countries which influences how to approach the people. Also, spatial proximity is important to build and maintain a network. When someone is not in Washington it is hard to participate in informal gatherings.

For the knowledge management team it is hard to keep the task team leaders that are located all over the world involved in the global knowledge development and exchange. For the TTLs, joining presentations is difficult when they are in a different time zone, even though they are aired on WebEx. Similarly it is hard to maintain the external network over such large distances. The institutes the Bank is connected with are generally not located in Washington which makes it harder to drop by. External institutes and consultants hired for research are not hired because of their spatial proximity but it does add a level of convenience.

> "One of the issues with the exchange of information is that it is very much focused on Washington. A presentation airs at 1am India time, so you have to be very interested to attend those presentations." [WB1]

> "Then you have the country office folks that are based in the country offices. They tend to focus much more on their projects ... I do think there is a bit of challenge with sinking country office staff into global knowledge work, because proximity does matter. If you have a team that's spread all over the globe, unless you have somebody in the middle of it, who is really pulling, pulling, pulling, there are challenges there. I would say also that there's definitely resource challenges." [WB2]

The face-to-face contact with the TTLs is greatly appreciated by the project consultants, it improves the alignment of goals and expectations within the project. Sometimes the consultant needs to share sensitive information that cannot be put in writing. For international consultants it is also important to be on the project location to steer the local project team.

> "For some reason it was not possible to meet each other during the project ... sometimes you just want to share something sensitive with someone of the World Bank. You cannot put everything in writing ... for example if we see issues in the relationship with the client country." [C]

13.2.7 Time and resources

One of the main obstacles for proper knowledge exchange within the Bank is the lack of time. This is closely related to the spatial proximity of network nodes. This became more of an issue after the reorganization. The TTLs work on large projects and are mostly trying to keep these projects running. They do not have time to go to presentations and read documents. The TTLs fly around the world and the short term staff are under constant pressure of deadlines and finding new contracts. This pressure can be a cause of stress and interferes with the informal knowledge exchange processes. Also for the consultants the time pressure is an issue, they work from deadline to deadline.

> "You do not take anything in when you are stressed ... the knowledge exchange stops. Yes I will do my job, I have deadlines. Oh I finished my deadline, I send the document and continue with the next one. But I do not have time to just have a coffee with someone." [C]

> "You should not underestimate ... my TTL, he is 57 years old and flies into a different time zone every week ... if he wouldn't run marathons, he wouldn't be able to do that job ... sometimes I'm happy I do not work for the Bank ... too many TTLs I work with let their marriage derail, because finding the balance between home and work life is so hard." [C]

> "The thing is, you cannot be everywhere as a member. We are operating almost at the limits of our time and our capacity. Sometimes, there's such an overwhelming number of information and seminars and so on, on disposal. Whereas, you know sorry, I have no time. I cannot go." [WB1]

There are a few people in the Bank who specifically focus on the knowledge acquisition and dissemination through the Bank. However, they are too few to complete the task of keeping the widely spread network together as well as making sure the right knowledge reaches the Bank.

> "I would say also that there's definitely resource challenges. ... So, in the case of something like irrigation where that specialty is less common than say somebody who specializes in water supply, you have less irrigation staff working on irrigation projects. Those same staff are also committed to this global knowledge creation. So, there's just not necessarily the man hour power." [WB2]

13.2.8 Reports and electronic database

Within a project a lot of reports are written. The readership of these reports is not very high, more than 31% of the policy reports are never downloaded and even more (87%) are never cited (Doemeland and Trevino, 2014) (see Figure 13.4). There is a vast amount of knowledge available within the World Bank through reports, however, these are hard to find and not for everyone accessible. The TTLs often do not have the time to scour the database for interesting and new information and even for the people in the GSGs who are hired to help in knowledge management it is hard to find information. Some reports do get a lot of reads, for example the policy report High and Dry already had 13,000 reads one year after publications (World Bank, 2016a). Generally documents with a more international focus tend to be downloaded more (Doemeland and Trevino, 2014)

> "It's a fairly pervasive symptom of ... these so called knowledge organizations, where you're producing a bunch of stuff, but how many eyeballs are actually looking at it. Of course, number of eyeballs is only one way of assessing reach, but it is an important metric, particularly if you're trying to sell your competitive advantage compared to other lending institutions as the keeper of global knowledge and then global expertise." [WB1]

The World Bank staff can access documents through its internal database. This holds all policy reports, research reports, project preparation reports and other project related reports. This is a much larger collection than the reports available online. The internal database is not easy to navigate, some staff resort to Google to find project documents.

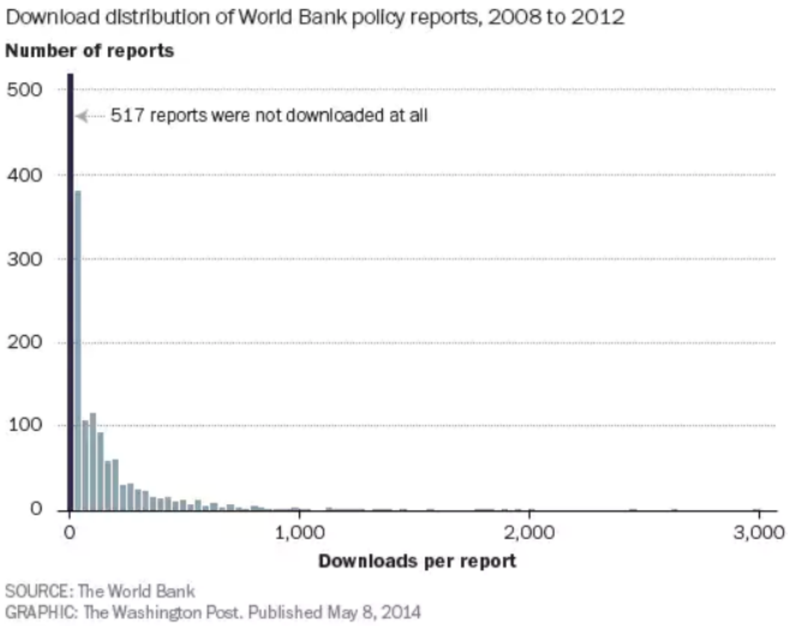


Figure 13.4: Number of downloads of documents produced by the World Bank (Ingraham, 2014).

> "I think where the Bank has really, really, really, really criminally behind is in our acknowledgement systems. I think I have never worked in an organization that had such a difficult to access knowledge system." [WB1]

> "Yes, I can also learn from my own initiative. We have a system that you can actually look at the documents of every project in the Bank. ... It's not very easy to search. Googling for instance, is helping a lot. ... Then you know, okay, there is this project. Then I go back into my system." [WB2]

13.2.9 Events

Events are organized within the Bank in several forms. The most known way in which this is done continuously is the brown bag lunches (BBLs) which are lunch seminars where both internal and external people can share their knowledge. The Bank also organizes the World Water Week once a year where experts come together to exchange knowledge for a week. Additionally Bank staff also participates in and sometimes helps organizing external events. For the internal knowledge events there is usually a high supply of external sources that want to present their work, they actively approach the Bank. The last kind of knowledge exchange event addressed in this subsection are field visits.

> "So, a lot of the time they come to us. The Bank more than anything else, I think where the Bank really has a role is in its convening power." [WB2]

World Water Week

The World Water Week is a yearly returning event where all World Bank staff working with water come together to exchange knowledge and experiences. Interesting World Bank financed projects are presented and lessons learned from these projects are shared. It is also a place where external experts as well as consultants, who have worked on a Bank research, come to share their latest discoveries. External sources need to be invited to be able to join this World Water Week, it is quite challenging to get an invitation. Even for consultants working on World Bank projects it is hard to get invited, they can only join if they have something substantial to contribute in the form of a presentation. Getting invited is dependent on what you know but also who you know within the Bank. The World Water Week mainly consists of presentations and informal exchanges, it used to be very focused on talks from people with a water background but it is getting broader.

> "An important event is also the annual water week, ... A lot of projects present there, projects which do something innovative and have results from that innovative approach, but also people from outside the Bank that have new technologies to share with the Bank .... There is no end to all the people who come with innovations. This is a very important source of innovation." [WB]

> "The Water Week is only partially accessible for consultants, you need to get an invitation ... you really have to fight to get an invitation for that, and that is if you have good connections, and then the managers have to approve it ... the costs have to be reduced and the people they keep in the boat are the people with a fixed contract." [C]

Brown bag lunches

The lunch seminars known as brown bag lunches (BBLs) are another platform in which project leaders and external knowledge sources can share their findings. These are broadcasted on WebX so TTLs all over the world can follow them. The BBLs can be organized by a GSG but are not solely organized by them. As an external party you need to be invited to conduct a BBL, this can be on very short notice. The Bank is also actively approached by people who want to share their technology. The effectiveness of the BBLs depend on the person conducting them, they need to be to the point and quite practical. The amount of people joining an event is often based on the topic and the title, for example a presentation with the word Blockchain in the title will generally gather a large crowd. The TTLs take the knowledge from a BBL to their project, it might be through a partnership with the presenter or just incorporating the idea.

> "So, what is important is that these seminars are very tailored to the Bank projects. ... They really show value added. There are too many which don't do that." [WB1]

> "Then you run into someone and they say, can't you come to Washington next week or next month to give a lecture for our people." [H1]

> "For me they are successful, I always learn something and I apply it in the projects I am working on, a lot of the seminars are on ICT and monitoring and the use of satellite data. We always try to learn and implement in projects." [WB2]

External events

Apart from the knowledge that is shared inside the World Bank, staff also actively participates in events organized by other parties. They go to conferences, workshops and events on a local and global scale. Sometimes they also help organizing events, for example with the Water For Food institute in Nebraska.

> "The Water For Food Institute came across our radar because one of our colleagues found them, and looked up they have an annual conference ... he noticed that there was a significant gap in the global experience at this global conference ... So, we had like a seminar workshop with them, and then we attended their conference." [WB2]

Field visits

Field visits are organized and funded in project budget. These visits are aimed to learn from other projects or other irrigation systems around the world. For example a field visit could be to a region where high-end irrigation equipment is implemented. The effectiveness of these field visits is disputed as a lot of time is often spend on sightseeing and shopping.

> "International field visit can be useful, but in my experience they are usually more touristic than useful." [C]

13.3 Relational aspects of knowledge exchange

The formal connections between the World Bank and outside knowledge sources are mainly through project contracts, both with consultants and research organizations. Apart from these contracts the links are mainly build on the relationships between World Bank staff and the consultants or people working at research organizations. This makes the way people access knowledge sources very person dependent.

13.3.1 Frequency of contact

Project consultants are in contact with the World Bank through the task team leaders or through the project director. They see each other during the missions and apart from that they are in contact over email, only with specific questions. The regularity of the contact differs depending on personal preference and the role in a project. A chief advisor has more regular contact than a consultant who is there only for technical support. The contact with the local project team is more regular, as the international consultants are there to support the local project team. The project consultants have little to no contact with the World Bank outside projects, the contacts are just kept over LinkedIn and through an infrequent email. They mainly maintain ties with other consultants to be hired together for new projects.

> "No, those are LinkedIn contacts, you see them very occasionally but not regularly, but it is my network." [C1]

> "Occasionally a World Bank mission comes by and then we try to make sure I am also there. Then I talk to those people for a bit but it is mainly indirect. ... sometimes you send an email or a report but that is about it." [C2]

The consultants hired as short term staff are more regularly in contact with their World Bank counterparts. They need to maintain contacts to stay on the radar, as they are hired directly by the Bank. Also during project preparation their contact is more frequent, this can be a Skype call every week or even every day depending on the project and the stage of the project. Between the internationally located short term contract consultants there is virtually no contact outside projects. They are mainly competitors. For the short term consultants who live in Washington this might be different, they do unite through a union.

> "Oh every week, and in [X] every day." [C3]

13.3.2 Friendships and historic ties

The network of water and irrigation is quite small, especially when looking at people in influential positions. This means that, within the network, many people know each other. It also means that a lot of these people have historic ties. Many have studied at the same universities, worked on projects together or were collegues in one of the few institutes working on water and irrigation. An external knowledge source can have ex-colleagues, students or peers at the World Bank. These historic links enhance the tie strength.

> "Some of our people have been his students, have been his colleagues, have worked directly with him on projects. So, when you have that level of relationship coming from any directions, a partnership like the one ... I think even if there's not a formal partnership document in place, task teams know ..." [WB]

Additionally, a connection of trust and friendship can build during the professional career of a task team leader and a consultant. When a TTL and consultant have worked together successfully in previous projects they are likely to stay linked in future projects. This link is dependent on their opinion of skill and way of working as well as the personalities of the connections.

> "Then [X] moved to India. So, he asked me if I'd like to go and work in India. So, I went and worked with him in India." [H]

Even if a specific friendship is not formed, the reputation from previous experience with a TTL is often a reason to be hired in future projects. Within the World Bank people recommend consultants to each other. This is a confirmation of the reliability and ability of a consultant. The staff will look outside the network if there is no expert in the network that fits the requirements for a project or research, this is then still based on the capabilities of the consultant.

> "I now started in [X] because of a previous job, because that man said, use that lady, she helped me and I was very happy with her." [C]

13.3.3 Trust in the World Bank

The interviewees generally have a very high trust in the capabilities of World Bank staff. They are seen as some of the best of the world in their specific fields. However, some interviewees are concerned about the decline in expertise at the Bank because amount of irrigation engineers working at the Bank is decreasing. This leads to a shift in focus and people working on irrigation projects who do not necessarily have experience in that specific field. The topic of water and irrigation is more and more discussed and decided on by people who do not have a background in water. Another concern is that people higher up in the Bank are too much theory oriented and not linking to the goal of "improving the life standard of people" [C1].

> "In the global water practice, there are 300 staff. There are only 8 staff who designate themselves as irrigation specialists, irrigation engineers or irrigation whatever. ... The rest call themselves water resources people ... This is where the other criticism of the World Bank, and a huge criticism of our recommendation, they don't have management operation and maintenance engineers ..." [H]

Especially the TTLs are praised by the interviewees. They are said to be working on a very high level. Of course this is dependent on the person, but the general opinion is very positive. One interviewee suggested that the TTLs are very engineering oriented while another misses the operation and maintenance expertise.

> "Yes they are the best of the world, the people who work there, they are very good people." [C1]

When looking at the reliability of the Bank some other issues are raised. In a project mission it is sometimes unclear what is expected of the consultant and when they will see the delegation. For the short term consultants there is a lot of uncertainty in the renewal of contracts, even if there are plans to continue a project. When advising on the World Bank structure, the consultants are not certain their advice will be taken to heart. The Bank does not always learn from past mistakes which makes the consultant reluctant to give future advice.

13.3.4 Relations with universities and institutes

Even though the amount of institutes working on water and irrigation is limited, the World Bank does not have strong partnerships with them. They are mainly build on personal relations. It is suggested by three interviewees that the Bank could profit from more formal partnerships by having a more structural and stable access to cutting-edge knowledge.

There is also some skepticism towards including scientists in projects and World Bank practice. Scientists are said to be too much focused on the scientific method and reliability of a study. Because of this their involvement in projects and even inviting them to speak at the Bank is not always relevant. The trust in their ability to link to the practical application in World Bank financed projects is questioned.

> "Let's say, because of experience, with academics that join projects, there is often a big divide between what they think is possible and what is really possible, between their expectations and reality." [C]

13.3.5 Relations with client countries

In relations with client countries some mistrust on both sides can occur based on previous experience. The World Bank has a lot of rules a country needs to follow to be able to loan money for a project. However, these rules are not always equally followed for all projects. Sometimes the Bank bends its own rules, which can cause distrust with a client country. Also, previous experience with Bank staff and how they deal with the country officials can have an impact on the relationship, this was for example the case in Central Asia (Dukhovny and de Schutter, 2011). Distrust can also come from previous experience of working with another international organization, e.g. the European Union.

> "Yes because there are these rules, where they say that is not allowed by the World Bank ... and then you realize other projects financed by the World Bank do not follow those rules." [C1]

From the perspective of the Bank, previous experience and the country culture impact the relationship. The Bank invests in project preparation, so if in a previous project a country backed out after preparation, this might impact the way the Bank works with this country in the future. Furthermore, corruption is mentioned as a big issue inside projects. Corruption can for example result in unreliable local staff in high positions as well as hiring friends for construction jobs.

> "A few years ago we had everything figured out, the loan was ready and at the last moment a country didn't want to sign. The procurement process was already set in motion so the Bank was already moving money." [C2]

13.4 Large scale concepts and World Bank financed projects

There are many people at the World Bank that know about the importance of the basin analysis in irrigation water management, still, this is currently not applied in many irrigation focused projects. People do not know the basic accounts of water before they make decisions about allocations, the simple basin water balance is not a required part of irrigation projects. This is a big issue because without an initial analysis and account of the basin you do not know how much water is consumed by which user and it is hard to measure the impact and effect of a project. This is not only an issue for investments of the World Bank in third world countries, but also for countries claiming to be in the forefront of water management like Australia (Perry and Steduto, 2017) and Belgium.

> "No I really think, and not only with the World Bank. Even in Belgium the water balance is not taken into account." [C]

The interviewed consultants, academics and World Bank staff are largely aware of this issue. They stress the importance of a basin analysis in projects and see the importance of water consumption in the water balance. Still, many projects do not look at the big picture or only look at it on paper without incorporating it full heartedly. This section explores the cognitive differences between actors as well as issues addressed by the interviewees that interfere with this incorporation of the basin perspective. First, the different interpretations of efficiency that were raised by the interviewees are addressed, this is linked to water consumption and the basin perspective. Second, the World Bank vision and local perspectives are explored, after that more emphasis is put on the relation between project scale and the basin scale. Then the issues related to shared language and narratives are addressed. And finally there will be some observations about basin accounting and observations about the role of age.

13.4.1 Concept of efficiency and consumption

Linking the concepts of irrigation efficiency and consumption is one of the main issues to address when looking at the integration of the basin and field scale perspective. Efficiency is a term that is often misused in the field of water management. It was introduced as a tool to design and manage irrigation schemes so that you know the amount of water to let into the system to ensure the crops get sufficient water. There are two issues with the term efficiency: (1) the term efficiency in the context of water management is ambiguous, (2) increasing efficiency on a field scale can have negative implications for downstream in a river basin.

> "There is the trouble in the distinction between water use and consumption, these concepts are often used interchangeably but they are very different, even some professors in The Netherlands mix them up." [H]

Defining efficiency

There are many different interpretations of the term efficiency in the context of water management. Only two interviewees said that they did not experience any difficulties or confusion because of these different interpretations. The terms named by the interviewees can be seen in Table 13.1. There are different definitions for different scales and different parts of the system, e.g. the field or the canal system. When looking at a complete irrigation system, the most common use for irrigation efficiency is $\frac{ET}{Q_W}$. Where ET is water consumption through evapotranspiration. This was named by five of the interviewees as the definition for irrigation efficiency, some adjacent definitions included: $\frac{T}{Q_W}$, $\frac{ET_{beneficial}}{Q_W}$ and $\frac{Q_{rootzone}}{Q_W}$. Other definitions preferred by the interviewees relate to biomass production per consumed or withdrawn unit of water. One interviewee grouped water with all other inputs which he related to the outputs in a more economic approach while another interviewee thought of efficiency in a social context, linking it to the equal distribution of water in a system. One of the interviewees stressed the importance of looking at the difference between efficiency in the night and during the day, from an operational perspective.

> "It is often divided in transport efficiency, say for the channel, what goes into the channel at the beginning and what comes out at the end. And then there is on-farm efficiency how much water actually reaches the plants." [C]

In the Sustainable Development Goals efficiency is used as an indicator of good water use. It is defined as average growth value of production per unit of water delivered. This indicator shows a great improvement if a country in drought allocates all its water to industry instead of agriculture because Q_W is smaller and the value of production is higher. One of the hydrologists argues that this is a leading example of a wrong definition of efficiency in water management and says that even the people who came up with this SDG are aware of that. However, the most important thing is that people are committed. These different definitions generate discussion and fuel doubts. However, within the World Bank and in exchanges with between World Bank staff and consultants there is an open discussion which often results in common understanding. In these discussion it helps when the interpretations of efficiency are defined mathematically for clear exchange of perspectives. It is harder to get this level of open discussion with the client country, depending on the country.

> "So, if you write down the definition exclusively as a mathematical formula, this is what I mean by water efficiency or irrigation efficiency, then we can all be on the same page. You can offer me one definition, I can offer you another one. But at least we know where your definition differs from mine." [WB]

Increasing irrigation efficiency

Another issue arises with the most used definition of irrigation efficiency ($\frac{ET}{Q_W}$). Initially, a system with an efficiency of 70% or 50% was not labeled as good or bad, it was just used as a management indicator. Later the term efficiency got value loaded, the irrigation sector got labeled as inefficient by economists and social scientists and improving efficiency was seen as increasingly important. Inefficiency is seen as something bad while high efficiency has a positive connotation. Hence, investments

Name	Mathematical definition	Interviewees
Irrigation efficiency	$\frac{ET[m^3]}{Q_W[m^3]}$	5
Irrigation efficiency	$\frac{T[m^3]}{Q_W[m^3]}$	1
Irrigation efficiency	$\frac{ET_{beneficial}[m^3]}{Q_W[m^3]}$	1
Irrigation efficiency	$\frac{Q_{rootzone}[m^3]}{Q_W[m^3]}$	1
Efficiency	$\frac{P_{crop}[kg]}{Q_W[m^3]}$	3
Efficiency	$\frac{P_{crop}[kg]}{A_{farm}[ha]}$	1
Efficiency	$\frac{P_{crop}[kg]}{ET[m^3]}$	2
Application efficiency	$\frac{ET_{crop}[m^3]}{Q_{field}[m^3]}$	1*
Technical efficiency	$\frac{\text{Output}}{\text{All inputs}}$**	1
Distribution efficiency	$\frac{Q_{field}[m^3]}{Q_{farm}[m^3]}$	1*
On-farm efficiency	$\frac{T[m^3]}{Q_{farm}[m^3]}$	2
Conveyance efficiency Off-farm efficiency Transport efficiency	$\frac{Q_{farm}[m^3]}{Q_W[m^3]}$	4*
Social efficiency Equality of distribution	-	1
SDG	$\frac{G[\$]}{Q_W[m^3]}$	1
SDG should be	$\frac{M[\$]}{ET[m^3]}$	1

Table 13.1: Definitions of efficiency given by interviewees. ET = Evapotranspiration, Q_W = Withdrawal, T=Transpiration, $ET_{beneficial}$ = Evapotranspiration that is beneficial,$Q_{rootzone}$ = irrigation water that ends up in the root zone of the crops,P_{crop} = crop production, A_{farm} = farm land surface, ET_{crop} = crop water requirement, Q_{field} = the water that reaches the irrigation field through the internal distribution system, Q_{farm} = the water that reaches the farm through the main irrigation canal, G = average growth value of production, M = Marginal net value of production, P = production. *Also mentioned as indicator in Bos et al. (1994) **All inputs includes water, financial inputs, workforce etc.

are done to increase irrigation efficiency. These are often aimed at reducing flows labeled as losses like runoff, drainage water, percolation and non-beneficial evapotranspiration (see Chapter 3).

Water draining from an irrigation field might be lost for that specific farmer but it is not lost to the river basin. It can flow back to the groundwater or the river, where it becomes available for other users in the basin. Increasing efficiency can reduce return flow and impact the water availability for downstream users. There is a distinction between consumptive use and non-consumptive use of water. This is a very important distinction which is not always made. When people talk about increasing irrigation efficiency they either want to produce more with the same amount of withdrawal, they want to produce the same with less withdrawal or they want to reduce the non-beneficial ET. It is argued by several interviewees that we should move to a more objective indicator like ratios or fractions.

> "Sure there are some people of course the sound of efficiency is good, you invest in efficiency and the farmer has more production ... I don't see anything wrong in the project manager or farmer pursuing efficiency. What is wrong is in the broader perspective of the basin or the river or the aquifer people do not understand the implication of the increased efficiency." [H]

> "So, you think you do the right thing and your intention is good to improve the application efficiency by shifting from gravity to pressurized systems on the field level. But you may deprive downstream of their return flows and their availability of water. So, it's a tricky thing. It took 20, 25 years for many people to understand this. Still, we are struggling to explain this. You are confronted with engineers who had training many, many years ago, and they don't get it." [WB]

Water consumption

Increasing efficiency results in more water consumption or ET per withdrawn water, which means the fraction of consumed water is higher. If the total water consumption on the farm increases depends on the withdrawal combined with the efficiency, if the withdrawal remains constant, consumption increases. If the withdrawal is decreased in combination with the efficiency improvement, consumption might not increase. In a water scarce region it is important to look at water consumption. The interviewees are divided on whether increasing water consumption is positive or negative.

Crop production and water consumption are linearly connected, increasing production with the same crop in the same place will also increase consumption. If the goal of a project is to improve agricultural production in a region, then increasing consumption is necessary and seen as positive. In a water scarce regions with little to no outflow to the sea, water that is not consumed upstream is usually consumed by other users downstream. This means that in these regions, investing with the purpose of increasing production and consumption upstream might have negative consequences downstream. If the investment in increasing the efficiency or consumed fraction is combined with reduced withdrawals. The effectiveness of the investment is questioned as the water that is 'saved' in withdrawals would have ended up at the downstream users in any case.

> "For a certain crop there is a linear relationship between ET and biomass production. So if there is a linear connection, you cannot get more crop per drop because if you want more crop you need more drop, this does not get through to people." [H]

Increasing the efficiency with reduced withdrawals does have some advantages. If the runoff is contaminated, it is harder to use it downstream as opposed to the clean water that is now just let through. It also leads to a reduction in pumping costs if the water is pumped into the irrigation system. However, investments in improving efficiency are often high, so it is a matter of weighing the advantages and disadvantages. The problem of over-consumption of water mainly occurs when groundwater reserves are used for irrigation, which causes depleting groundwater tables. When percolation feeds the groundwater, increasing irrigation efficiency would interfere with groundwater recharge.

Blindly investing in increasing irrigation efficiencies is the main issue. This does not mean that there should never be investments in improving irrigation efficiency. It just means that a proper basin and local analysis is necessary before these investments are carried out, to be aware of the downstream impacts. Whether increasing efficiency is a suitable investment depends on the water accounts as well as the project goals.

Measuring efficiency

Irrigation efficiency is used as an indicator in projects. The trouble is that even if it is defined in the common definition of ET/withdrawal, it is not properly measurable. In this ET is usually calculated through the Penman Monteith equation (Allen, 2005) which is an estimation of the potential evapotranspiration. It is argued that because of this estimation, it is only possible to calculate the potential increase and not the actual increase in efficiency. Remote sensing data can be used to calculate actual increased efficiency, however, this is not yet widely done. Another issue is the use of contaminated water and deep percolation in this equation. It is not uniformly defined whether this is a loss or not, these fluxes are not easily reused in the basin.

> "Irrigation efficiency, that is preposterous, because you cannot measure it." [C]

13.4.2 World Bank vision on water and irrigation

The main aim of the World Bank is to reduce poverty across the world. The World Bank vision is less clear on the theme of water and irrigation, more specifically, there is no one vision. When asked about this vision the interviewees named: sustainability, fighting climate change, engagement of the private sector, more crop per drop, water governance, poverty reduction, water security, disaster prevention, increasing productivity, food security and economic growth. In this, fighting climate change and engaging the private sector are World Bank global themes and poverty reduction is the main driver for the World Bank. The interviewees did not come up with one consistent vision. Two interviewees noted that there is a clear division in approach between the water Global Practice and the agriculture Global Practice. They both work in irrigation projects but have a completely different strategy.

> "Right now, there isn't one. To be very honest, there is not a cohesive vision on irrigation inside the World Bank. There are some competing visions on irrigation in the World Bank." [WB]

> "... always sustainability and climate ... and governance is also very high on the list." [C]

High and Dry (2016), A Water Secure World For All (2016) and Unchartered Waters (2017) are three vision documents by the water GP. The first document links climate change and economy with water. In terms of irrigation it focuses on the impact of climate change and exploitation on water availability. Proposed interventions include governance change and increasing irrigation efficiencies (World Bank, 2016d). The second document mentions water security as the main vision of the World Bank, linking this to ending poverty and shared prosperity. It shows an irrigation modernization project in morocco as an example project (World Bank, 2016d). The third document focuses on the link between water and economy. Here the importance of governance is stressed as well as the paradox of water savings and water consumption. From these documents, it is hard to deduce a clear vision of the World Bank in water for irrigation. The basin perspective is mentioned but the highlighted projects mostly focus on modernization.

Apart from its vision to reduce poverty, the Bank also has its own performance goals. It is a Bank, a for profit organization, so one of its main goals is to provide loans to earn interest.

13.4.3 The local perspective

The client country applies for a loan with the World Bank, the country do not specifically relate to the World Bank vision but look at what is necessary in their country. The country perspective is very important to consider in the application of the basin perspective in World Bank financed projects, especially concerning transboundary river basins.

> "... the government also has certain ideas, and they need to be exchanged with the World Bank, that is a long process. They have different expectations, they want more money for hardware while the World Bank wants to focus more on institutions, the soft package." [C]

Managing projects that span multiple countries is very hard when there is no strong transboundary river basin management institution in place. This is one of the reasons why most projects are on a country scale. On this scale governance oriented projects are often not popular, especially if corruption is present in the project country. Governance projects are much harder to carry out and there is less money necessary, so there is less money available to divert into corrupt pockets. Apart from that, it is also easier to get quick wins in infrastructure oriented projects.

Additionally, people developing drip irrigation and other infrastructure, often have very good sales pitches. From a country or farmer perspective, the promised water savings sound like a very good deal. The sales people are often engineers who sound credible, you cannot blame a politician for making a decision to improve efficiency when she is misinformed by an engineer.

The institutions in place to manage water allocation and water rights differ greatly per country. Sometimes they can be based on inherited rights and they are often not related to the water availability. Sometimes the only way of recording is on cloth or in a basic Excel file. A project with a basin perspective is hard to launch in such a situation. World Bank financed projects are sometimes too ambitious for what is possible.

The problems from a country perspective are often related to diversion channels which have not been maintained and ineffective irrigation directly affecting local farmers. The local farmers are generally not well off and mainly care about their food production and ability to sustain economically. They do not care about the water that percolates into the groundwater and can be used by someone else somewhere else, for them it is a loss of water on their field which they could have used to produce more. The basin perspective is not a priority. People do not want to invest to help their neighbor, they want to invest to help themselves. So if they invest in improving efficiency they want to use the water they save in their own production.

On a country scale you can see something similar happening, for example along the Amu Darya river in Central Asia. In the downstream end, the Amu Darya crosses the border between Uzbekistan and Turkmenistan several times. If Turkmenistan would invest in more efficient water use and they had to reduce their withdrawal, Uzbekistan would reap the benefits as more water would flow into that country. The countries in Central Asia have a high water insecurity and a high inefficiency of water use. Increasing their efficiency and production in one country will cause protest among the other countries who will petition for a reduction in water allocation to that country. If you want countries to invest in saving water and making water available downstream, the water security has to be guaranteed.

> "The Amu Darya River crosses the border between Uzbekistan and Turkmenistan five times. If Uzbekistan is going to invest money to improve irrigation efficiency, Turkmenistan is going to say thank you very much, so the only thing that makes sense, if you want to improve the efficiency in that kind of environment is that you reallocate it within sectors in the same country otherwise you cannot sell it." [WB]

Generally, the main goal of a farmer and a country is their own development. The basin approach is sometimes not understood, in other instances it is understood but not prioritized.

> "Not many people want to hear that message, farmers do not want to hear they have to reduce consumption; the engineers don't want to hear that they have to reduce the supplies to the farmers; the politicians don't want to tell their farmers they are going to take their water away; the people with all high tech irrigation equipment want to be able sell it and want to defend their claim that they are saving large quantities of water, but they don't. So who wants to bring the bad news and certainly who wants to hear the bad news." [H]

13.4.4 Projects, infrastructure and the basin scale

Some interviewees mention that there is a mismatch between some of the stated global views of the World Bank, focusing on governance and the basin perspective, and the actual work in projects. There are still a lot of modernization and rehabilitation projects where the Bank loans money to countries to invest in physical structures. All four of the World Bank staff, the tree hydrologists and three of the consultants interviewed in this research said that the Bank should emphasize the basin approach and use basin scale water balances. However, some of the staff and consultants are still involved in projects focusing on modernization and rehabilitation without the basin component solidly in place. Partly this can be explained through the local perspective presented in the previous paragraph, the country is the one borrowing the money and is leading in project decision making. An additional explanation can be found when looking at the difference between what people think is important and what they apply in practice.

> "The only thing that surprises me, it that people stick to improving irrigation efficiencies. We have talked about it a lot in the past, that they are not sufficiently looking at the water balance, or sometimes not at all. And even now people are stuck in increasing the efficiency of water use. I am not saying that there are no circumstances in which improving irrigation efficiency is important, but always in the context of the water balance" [H]

> "Eight years ago, I was talking to a director at the Bank and he said: 'Irrigation is not something we should do anymore, irrigation is something for the national experts and governments and not the Bank, we have to move on to something more complex' basin management." [C]

As was said in Section 13.2.7 Bank staff and consultants working on projects are under extreme time pressure. They are mostly busy running the project and knowledge acquisition. Including new approaches and innovations as well as a basin analysis are seen as nice additions, if there is time, but they are not part of the core business of the project. Having basin water accounts is not an official requirement, even if it is in the project requirements it can be that it is only on sub basin scale.

Some consultants say the basin perspective is very important but not in the project they are working on now. Three of the consultants interviewed are currently working on the same project in Kyrgyzstan. This project is focusing on restructuring governance and water user associations as well as infrastructure modernization. Two of the consultants mentioned that the river perspective is not very relevant for this project as there is enough water available in Kyrgyzstan. Another reason they mentioned is that this project is first focusing on the basics before looking at the big picture. However, when looking at the basin scale, downstream water scarcity issues are very much present.

There is consensus on the responsibility of the World Bank to look at the big picture in irrigation projects, still it is not always easy to put it into practice. In projects there are always trade-offs in what to focus on, there time and resources are not available to focus on everything. The main themes the World Bank is focusing on in the region of Central Asia are irrigation modernization, governance and the competition between water and energy.

13.4.5 Differences in language, narratives and perspectives

Between the consultants and the TTLs there were almost no issues in communication. They have the same level of understanding, have similar backgrounds and speak with the similar Jargon. If there are differences in interpretation, the working culture at the Bank is such that there is an open discussion. There are some issues observed in the knowledge exchange between the technical water people and people outside their field.

An economist observed that there is a big difference in the way they talk about an issue as opposed to the water people. For example a rule for an engineer is a strict rule while for an economist it is a rule for as long as benefits outweigh the costs. The economist used the example of trash, it is a universal rule that you do not throw trash on the ground, but this rule works a lot better with the enforcement in Singapore than in India.

> "One big hurdle that I get I find because I'm an economist, and most water people are not economists is that it can be very difficult coming from a different discipline to really understand what the other person is saying and doing." [WB]

From the water background it was observed that more and more people without a background in water have an opinion about water. At the World Bank water week, there are more people speaking from outside the field of water. The sociologists and economists are said to pretend to know everything about water when they do not.

> "they cannot see all the opportunities that are there, and that is fine, I do not know everything about economy, but I also do not pretend that I do." [H].

For specialized people it is sometimes hard to speak outside of their own niche, both within the Bank as for external knowledge sources. It is an important skill to be able to explain yourself as simple as possible. This is a skill that is also requested in the presentations given at the World Bank. The presentations need to be tailored to the needs of the staff; practice oriented, not too much background and not too long with room for discussion. Not all knowledge suppliers get this, they sometimes get stuck in the scientific method. It is the responsibility of the knowledge suppliers and the knowledge managers at the Bank to bridge this gap.

An issue that does occur between the Bank and the consultants is the formulation of indicators. They should be formulated following the SMART method[1], this is not always the case. The definitions of indicators are often vague, for example the term beneficiaries. This can mean farmers, farmer families, or it can include people who work on the projects or the hotels that get filled because of these workers. The boundaries for these indicators are often not properly defined. Discussing these terms gets even more complicated when working in a country where they do not speak English. In Central Asia everything has to be translated to Russian.

> "Beneficiaries, that sounds nice, but what is a beneficiary? If you say the number of beneficiaries in the statistics, do you mean the farm owners, that is easy because they own a farm, but there are also people working int he fields who are not registered, and is the staff working on the project also a beneficiary?" [C]

13.4.6 Accounting and bench marking

All but two interviewees explicitly mentioned the importance of initial basin wide water accounts before starting a project. An analysis of ET in the basin is seen as a very important part of this analysis, as a start for policy discussion and strategic planning. They should do it everywhere, but even in Australia and Belgium it is not yet done.

[1] https://www.smartsheet.com/blog/essential-guide-writing-smart-goals

An initial benchmark of the status of the basin is necessary to be able to measure the success of the project. You need to have starting values of efficiency if you want to know how much it increased. These benchmarking exercises are now not done in a consistent manner. Water accounts can provide a framework to measure the initial status and the changes due to the project. One possibility to create consistency is to have the accounts calculated by a special calculation unit within the Bank.

> "There should be a unit, in the 80s there the Bank had a group of people who calculated the amount of water there was and what was running off, to help the manager if he didn't know who was telling the truth anymore." [C]

One of the interviewees suggests that the Bank should have a central team, making the accounts for all the project countries. In this way a task team leader, and other staff working on a project, gets a sheet with the basin accounts to take with them to a project. The accounts make strategic planning possible and, if they are based on remote sensing data, they can also help overcome the problem of countries lying about their withdrawal and water consumption. The environment of data and calculation for this should be hosted in the public domain or by the Bank. Such a calculation environment is currently not available in the public domain, an example in the private domain is Google Earth Engine[2].

> "It should be an agreed set of accounts, you know any company that is operating in different countries should have their accounts. They sit around the table and see this is what we have and this is what we want. They don't just start randomly investing all over the place and then realize they don't know if it was worth it?" [H]

The biggest issue for using ET as a management tool is the institutional support in the countries. There is a successful World Bank project in China (World Bank, 2012) where ET management was administered. However, China has a very strong institutional power and the basin was not transboundary so it is hard to directly translate the results to other projects. For now, day-to-day management based on ET is still hard to accomplish but strategic planning is very relevant and definitely possible.

Water accounts can help making informed decisions and can also be used as an eye opener. One of the interviewees stated that, in 80% of the irrigation projects he was involved in, people had no idea how much water was flowing through the canals. The water accounts do not need to be flawless, a work-around method has to be found. Even that will increase understanding of the basin perspective. The ecological safeguards of the World Bank can be used as a way to practically introduce the concept.

13.4.7 Age

It is observed that people of age occupy most influential positions at the World Bank, in the field of consultants and in the countries. Someone of 40 years old calls themselves young in the field. One of the main criteria for hiring consultants is their experience. It takes time to rise through the ranks, and experience is important but having the older generation making the decisions can interfere with innovations and new ways of thinking entering the field. The people in charge did not learn how to program and work with remote sensing when they were studying. Everyone is still working with FAO tables from 1956, it is easy for them to go back to that because it is familiar.

The interviewees notice this age gap in even more in client countries. The high posts are filled by old people who are still learned in the old school of thinking. The priority of basin thinking has not reached them yet. For example in Central Asia, hierarchy is very important. It is hard for the younger generation to speak up, once they have risen to the top they will be completely trained in the soviet way. Changing the focus of the elders is very hard, investing in the younger generation is necessary introduce a new paradigm, it will take time until this new generation is in power and this investment has effect.

[2] https://earthengine.google.com/

> "There's a joke that's called waiting for the dinosaurs to die, where basically our generation has to sit around and wait for 20 years while the people that are knowledge keepers retire. But now retiring isn't enough, because they retire and still stay involved, so for them to retire and die. When they've done that, we're now probably in our 50s. We're no longer cutting edge, and then we become the dinosaurs. I think it's a very, very dangerous demographic pattern we're running into. I think that we really need to evaluate, is it necessary to have somebody with 20 years experience on this consultancy contracts ... Why don't we hire the one with five years of experience? Yes, you need to do a little bit more work with them. But you're investing in that person's future as opposed to just getting the guy because you know that he's going to do a great job, which fills the immediate need. But then in the long run, what are the young people going to work on?" [WB]

13.5 Conclusion

In this extensive outline of the World Bank network structure, knowledge exchange in this network and the inclusion of the basin perspective in World Bank financed projects it can be seen that the Bank is a complex organization. Within this complex organization there are many factors influencing knowledge exchange, from the nature of the connections to external sources to the age of the people working at the Bank. The Bank has a vast structure facilitating knowledge acquisition and diffusion, including events and a knowledge data base. However, some interviewees questioned the effectiveness of these initiatives. There are obstacles, like the time pressure, of which the interviewees are very much aware. But, others, like the subtle differences between their definitions of irrigation efficiency, are less obvious.

In Chapter 14, the main results from the current chapter are linked to the indicators and obstacles of the conceptual framework. Answering the third sub-question of this research.

14

Synthesis: The World Bank in the social capital framework

14.1 Introduction

The network characteristics required to facilitate knowledge exchange were introduced in Chapter 12. In Chapter 13 the way knowledge is exchanged in the World Bank (WB) was presented. The aim of this chapter is to link the main concepts from these two chapters and discuss their relevance, linking the theory to the situation at the World Bank. With that, this chapter answers the third sub-question of the research.

The differences between the network requirements and the actual situation at the World Bank were analyzed and the impact of these differences on knowledge exchange was assessed. Where necessary, new literature is included in the analysis. This chapter is structured along the three dimensions of social capital, concluding with a section that links the dimensions.

14.2 The structural dimension

The literature suggests that a sparse external network combined with a cohesive internal network is what is best suited enhancing the innovative capacity of an organization (Alguezaui and Filieri, 2010; Filieri et al., 2014). The World Bank has a cohesive internal network in the field of water (see Figure 14.1). Especially the links with the people based in Washington are solid. The connection with the staff based in other regional offices is harder to make due to distance and time differences. Wei et al. (2011) found that the negative impact of spatial distance on knowledge exchange is mitigated by network cohesion. In the case of the World Bank this spatial distance was not seen as a big issue which can be related to the high network cohesion.

People who are hired as short term consultants become part of the team. They can access all written documents. However, they are not part of the internal knowledge exchange structure through seminars and the Water Week.

The external network of the World Bank is more cohesive than the literature suggests is preferable (e.g. Adler and Kwon (2002); Alguezaui and Filieri (2010); Burt (2000); Díez-Vial and Montoro-Sánchez (2014) and Inkpen and Tsang (2005)). The external consultants who mainly work on short term assignments for the Bank have several contacts within the Bank as their main employer. When

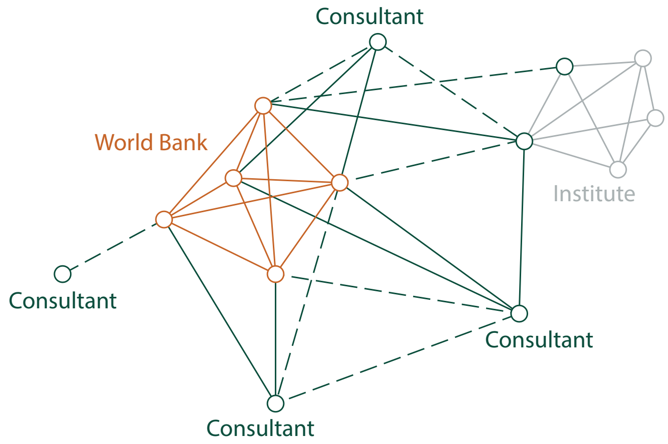


Figure 14.1: World Bank network structure with short term consultants.

there is a key advisor on a specific topic, many people within the Bank know this person and are connected to her. The inner circle of consultants and advisers of the Bank is said to be quite closed and hard to enter. It is said that the world of water is quite small in general that and the Bank is in contact with all the main people in this network. When the Bank is looking for specific expertise it does reach beyond this closed circle. People from outside the closed circle can theoretically also reach out to the Bank to present in one of their lunch seminars or the Water Week, however, it is not easy to penetrate it. When looking at lending projects, the Bank also reaches out because a consultancy group is hired through an open tender.

The external network cohesion has its risks and benefits. One of the risks of the cohesive external network is the blind spots in knowledge acquisition (Alguezaui and Filieri, 2010; Burt, 2000; Lee, 2009). The external network of the World Bank is cohesive, however, the ties are often weak. Levin et al. (2004) suggest that this provides a sturdy base of non-redundant information so the cohesive external network is actually an asset. The high potential costs of a cohesive external network are not present because the ties are not actively maintained by the Bank. Additionally, the Water Global Practice (GP) and the water and irrigation Global Solution Group (GSG) are dedicated to the acquisition and diffusion of knowledge in the field of water and irrigation and basin planning. They are focused on making sure cutting edge expertise is brought to the Bank and limit the risks for blind spots. Network stability is not seen as an issue, this is partly due to the high network cohesion.

One of the main structural issues in knowledge exchange between scientists and policy makers is lack of time (Balian et al., 2016; White et al., 2009). This is also a point of concern at the World Bank. The staff are under a lot of pressure and are busy running the projects, this means knowledge exchange does not have the highest priority. This is especially an issue for the TTLs who are crucial in delivering the knowledge of the World Bank to the projects. Also, none of the knowledge exchange activities are compulsory, they are all voluntary and based on personal interest. There are many possibilities to access information - for example through seminars and documents - but there is not enough time. Time is an issue, resources are an issue, but not the availability of knowledge.

> "They have things like brown bag lunches. So, someone will advertise and say, they are going to give a presentation on such and such a project, which is okay. But it's informal and it's not compulsory. It depends on whether someone's interested or not . . . " [H]

14.3 The relational dimension

Knowledge exchange in the World Bank is said to be very much relational and person dependent. Trust (Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Widén-

Wulff and Ginman, 2004) and tie strength (Díez-Vial and Montoro-Sánchez, 2014; Schultz-Jones et al., 2009) are important indicators from the literature, where trust is based on the ability (Filieri et al., 2014) and reliability (Inkpen and Tsang, 2005; Lee, 2009; Widén-Wulff and Ginman, 2004) of the connection and tie strength relates to the frequency of contact and friendship (Schultz-Jones et al., 2009; Widén-Wulff and Ginman, 2004).

The Bank mainly bases its knowledge acquisition on the ability of a consultant. This can be based on previous experience or the previous experience of a colleague but it can also come through personal judgment of their work. The staff basically works together with people they judge are able to accomplish the assignment. Once someone is judged able, the staff recommend consultants to one another.

The people from the consultant side are quite positive about the capabilities of the World Bank staff. They are very knowledgeable and able in managing the projects. There were two criticisms that stood out. The first is that the Bank is not always open to messages it does not want to hear, unpopular messages are not always internalized. This tarnishes the perceived reliability of the Bank. The second is that the number of people with experience in the irrigation management field has declined.

Consultants and World Bank staff are in contact quite frequently during projects, depending on the stage of the project. Face-to-face contact can be limited but modern communication technology is a great help there. The short term consultants need to maintain contact outside projects to stay on the radar for new assignments, keeping the tie strength high.

The connections between the World Bank and outside knowledge advisers and institutes are often based on a relationship between two individuals. A friendship or connection was built during previous work or studies together. The number of institutes active in water and irrigation is limited, so people at the Bank and other institutes often have a connection as ex-colleague, student or project team member. The connections with institutes are generally not formal but based on project contracts and personal bonds.

14.4 The cognitive dimension

The cognitive dimension looks at the commonalities and differences between the actors on a cognitive level (Nahapiet and Ghoshal, 1998). Some important indicators from theory relate to having common goals and clarity of goals (Adler and Kwon, 2002; Balian et al., 2016; Lee, 2009), using a similar language and narratives (Alguezaui and Filieri, 2010; Balian et al., 2016; Sterman, 2011; White et al., 2009) and being able to see the perspective of the other person (Alexander and Armitage, 2015; Sterman, 2011; White et al., 2009). In the context of this research the cognitive dimension is related to the basin approach of thinking in projects on an irrigation system scale as well as the use of efficiencies in irrigation.

The World Bank is very clear on their main vision: reducing poverty. However, the Bank has many other visions related to water and irrigation. On water and irrigation there is no one vision, there are actually two competing visions from the agriculture perspective and the water resources perspective and these visions result in projects with vastly different approaches and no clear message to staff and clients. The GSG for water and irrigation is working on a clear vision on this theme. Most of the interviewees though the World Bank should include the basin perspective in their key vision for water and irrigation. Apart from their ideological vision, the Bank has another purpose which is lending money.

Policy makers borrow money from the Bank to invest in development in their country. Many a time they do not relate to the basin scale approach that is on the agenda of the Bank. Countries see a neglected irrigation system and want to borrow money for a modernization project. After a thorough project preparation the World Bank often invests in these kinds of projects, where the basin perspective is not or only marginally taken into account. It is easier to invest in infrastructure than to look at basin management. The Bank staff want to include the basin perspective but does not hold firm to these views, and for local countries it is easier not to do it. The sentiment is often to first fix the low level infrastructure and management that directly affects the local farmers, and then look at the basin as an afterthought. There is a mismatch in perspectives and goals.

Adding to this are the people with personal gains who are involved in projects. For one, there is corruption in many client countries, an infrastructure oriented project brings in more money. Consequently, more money can be channeled off for personal gain. A second issue of personal gains has to do with the people selling drip irrigation systems and other technical solutions. They promise water savings and have a nice sales pitch. It can clearly be seen that there are many conflicting goals present in projects which make the implementation of a basin scale approach in irrigation projects difficult.

These goals are partly rooted in different perspectives. A farmer struggling to produce enough crops, does not care that the drainage of her farm will be used downstream. In improving his irrigation efficiency, the farmer sees an opportunity to increase her production and build a more stable living even though the initial investment might be high. If you tell her she cannot use the saved water for herself, but that she has to reduce her withdrawal, she will be shocked. To her it would seem as if she did an investment for the gain of her neighbour, this is similar with countries as is outlined in Chapter 13. For the farmer, the water that flows into the drains or goes into the groundwater is seen as a water loss while these waters are not lost when looking from a basin perspective. The farmer perspective, country perspective and basin perspective are all very important and need to be respected and used in projects.

These different perspectives are closely related to the terminology of efficiency. The manager thinks about conveyance efficiency while a farmer thinks about application efficiency. The term efficiency has many different definitions. Even if people think they have the same definition this is not always the case. The interviewees rarely perceived lasting difficulties of different interpretation of efficiencies in projects. Open discussions often clear up differences and they say there are no differences among the consultants. This study showed that there actually are differences in interpretations, more than they thought themselves.

When looking within the Bank these differences in perspectives, narratives and terminology are most prominent between people from different backgrounds (White et al., 2009; Widén-Wulff and Ginman, 2004). The people with a water background have the same approach but people with a background in economy and sociology have a different way of thinking. Within the Bank this is also experienced, it is difficult to find common understanding.

There is also a gap between the Bank and external knowledge sources that work on an academic level. The Bank is interested in new technology and innovation, but mostly in a practical approach. Their goal is to implement these innovations while academics are often focused on research rigor and the scientific method. When academics present their research this often does not fit the expectations of the audience, they are unable or unwilling to explain in a simple and practical manner. For knowledge transfer to be successful it is important to talk to people in their own language (Balian et al., 2016; Sterman, 2011) and avoid jargon and vague language (Balian et al., 2016; White et al., 2009).

Another obstacle for innovation at the World Bank and in projects is age. People working for the Bank as staff and as consultant are often very experienced. They have grown up with certain approaches and concepts which are hard to let go off. The new generation has been taught cutting edge knowledge but is not in a place to put this into practice. This is something that hinders the implementation of for example ICT and remote sensing technology. In the relatively flat organizational structure of the World Bank, the young people do have a voice. In highly hierarchical client countries this is even more of an issue.

14.5 Linking the dimensions

The dimensions of social capital do not stand alone, they are linked (Walter et al., 2007; Widén-Wulff and Ginman, 2004), as was discussed in Chapter 12. The links between constructs within the dimensions were already discussed in their respective sections. This section will focus on the links of constructs and variables that cross dimension boundaries.

Time and resources are observed to be two of the most limiting factors for knowledge exchange. This is a limiting factor in the development of most other variables and is enhanced by spatial distance. The restricted time availability limits the possibility to focus on other things outside the direct project goals which hinders the implementation of the large scale perspective. Time also has an effect on the possibility to learn new things, including learning the terminology and understanding new initiatives shown by external knowledge sources. TTLs call for a simple and quickly applicable presentation in a Brown Bag Lunch while an advisor stresses the importance of context. The TTL does not have the time to learn the context and the advisor might not have the time to create a simple and applicable version of their innovation. The GSGs form a node between the two to help with this translation, however, their time is also limited.

Spatial distance in itself also has links with the other dimensions. For a consultant located in Europe it is harder to maintain ties and create strong ties with World Bank staff. This distance makes it harder for them to attend social meetings like running groups or Friday night drinks. Trusting relations need (occasional) face-to-face meetings and these are easier to plan with people who are close by. Even though it is often not a selecting criteria for hiring a consultant, close proximity does enhance the ability to verify whether someone is able and reliable and thus suitable for the job.

With respect to the lending countries, spatial location has an impact on culture, knowledge and language. The World Bank works from a western perspective which does not always resonate with people with other backgrounds. The interviewees mentioned issues with South Asia, Central Asia and Eastern Europe, it is safe to assume that they are not limited to these countries. The way of implementation and level of acceptance of basin analysis in irrigation projects will vary between different project countries.

The World Bank structure of different Global Practices links to different goals and perspectives in irrigation management. There is a significant divide between these two departments which translates to two very different approaches to a similar topic. This hinders the adoption and implementation of a large scale theory in World Bank projects. The water and irrigation GSG might provide a solution for this problem but it is questioned whether their time and resources are enough to solve it.

Network stability is strongly connected to the relational dimension as the connections of the World Bank staff with external sources is very relational. When a connection at a research institute is replaced and the 'click' is not there, this can make the connection go sour. The connection between the World Bank and a department, institute or consultant depends on the people sitting on both ends of this relationship. If one of them changes this affects the dynamics and the success of the partnership.

> "I think the message is that as long as it is the right partner, whether it's the individual or the organization, or both, [pause] you keep it up. That said, I've seen cases where somebody new comes in somewhere, and the partnership just completely flounders." [WB]

There was a high trust in the ability of individuals at the World Bank. However, several interviewees mentioned that there was some expertise missing, specifically their own expertise. This influenced their opinion of the ability of the Bank. An irrigation specialist missed irrigation engineers and someone with a more social background missed the social science expertise. This indicates that the interviewees were looking for people with their expertise, sharing their perspective.

15 Conclusions

15.1 Introduction

Part III of this study elaborated on knowledge exchange on water and irrigation in the World Bank, including knowledge exchange within the Bank and between World Bank staff and external partners. Knowledge acquisition and dissemination are crucial in the adoption of new paradigms and to ensure the competitive advantage of an organization. As a knowledge bank, this holds even more for the World Bank. The Bank wants to fight poverty and new paradigms help to do this in the most effective way without posing unintentional harm.

The Bank is currently investing in irrigation projects without always conducting a proper basin analysis. Upstream irrigation efficiency investments can can result in an increased water consumption and reduced return flow. This in turn results in a decrease in the downstream water availability. A basin analysis is necessary to ensure this effect is taken into account.

Social capital provides insight into the different dimensions of knowledge exchange in a social network. It provides a framework in which a structural analysis of knowledge exchange processes can be conducted. This research explored the application of the social capital framework on knowledge exchange on water and irrigation in the World Bank. This was done through the main research question:

> **To what extent can a social capital analysis of knowledge exchange between academic hydrologists, World Bank staff and World Bank water and irrigation consultants aid the incorporation of the basin scale perspective on water consumption in World Bank financed irrigation projects?**

This main research question is supported by the following sub-questions:

1. What are the characteristics of a social capital network that facilitates knowledge exchange and implementation?
2. How does knowledge exchange on water and irrigation occur in the network of World Bank staff, World Bank water and irrigation consultants and academic hydrologists?
3. To what extent is knowledge exchange between World Bank staff, World Bank water and irrigation consultants and academic hydrologists comparable to the characteristics of a social capital network that facilitates knowledge exchange?

The conclusions to this part of the research are presented by first answering the main research question. After this, the sub-questions are answered to provide more detail and to give insight into the reasoning behind the main conclusions.

15.2 Social capital analysis

The social capital perspective gave a structural insight into the knowledge exchange within the Bank and between the Bank and external advisers concerning water and irrigation. It allowed an investigation into the structural, relational and cognitive processes facilitating knowledge exchange. As the literature on social capital was not specifically tailored to the World Bank as an organization, literature on the science policy interface was added to make the framework more suitable. This helped to identify why basin scale analysis is not always applied in World Bank irrigation projects.

One of the main findings of this research is that knowledge on the importance of basin scale analysis is mostly present with World Bank staff and their advisers. The issue lies in the implementation of this knowledge. One of the main obstacles is lack of time and resources available to staff and consultants. This causes an inability to investigate new topics and makes it difficult to find the time to apply new findings that are not strictly required in projects. It is not that the actors do not want to do it or are cognitively not able to apply basin analysis, they are limited by the hours in the day. Even though the World Bank is a knowledge bank, its first and foremost task is to provide loans and manage projects.

15.3 Network characteristics facilitating knowledge exchange

Characteristics of a social network, necessary to facilitate knowledge exchange, were deduced from social network and social capital theory combined with literature about the science policy interface and preliminary interviews. On a structural level this provides a basis of a cohesive internal network combined with a sparse external network, creating an environment of easy and efficient sharing and access to a great variety of knowledge.

This combined network is related to the relational and cognitive dimensions. A cohesive network, with many strong and trusting ties, forms the basis in which shared goals, perspectives and language are easily formed within the organization. Strong and trusting ties to the external sparse network also ensure the development of shared goals and perspectives. This enhances knowledge exchange.

Literature on the science-policy interface added some important characteristics necessary for knowledge exchange. The availability of time and resources are identified as crucial elements for knowledge exchange. They fit in the structural dimension. Additionally, the importance of a shared language and shared mental models is stressed.

15.4 Knowledge exchange at the World Bank

Semi-structured interviews tailored to the variables in the conceptual framework were conducted. They were combined with policy documents to get insight into knowledge exchange at the Bank. The World Bank provides many opportunities for staff to gain new knowledge and exchange experiences from their projects. This is mainly done through reports, lunch seminars, a yearly water event and personal communication. The success of these tools is disputed. Most reports are read by a limited number of people and the lunch seminars do not always resonate with Bank staff.

The incorporation of new knowledge in projects is very much dependent on the people involved. If a new idea resonates with the people is dependent on the capability of the presenter to speak in the World Bank language and perspective. On the other hand it depends on the personal preference of the World Bank staff if they apply an idea in practice. Relationships with external knowledge sources depend on the 'click' between two people. If a new person moves into a position with whom this 'click' is not there, this might very well result in a break of the bond.

Another main issue is the time available to the World Bank staff. Especially the task team leaders are under extreme pressure. They are very dedicated but do not have time to do everything, this takes its toll on their personal lives as well as knowledge exchange. It hinders the dispersion and incorporation of new knowledge in projects. Because knowledge exchange activities are not compulsory, it is easier to stick to the tasks that have to be finished. The Bank does have some people in Global Solution Groups (GSGs) dedicated to knowledge exchange but also their time and resources are limited.

Additionally there is the issue of differences in goals and perspectives. This occurs within the Bank, between consultants and the Bank and between the Bank and client countries. The actors are aware of some of these differences but to others, like different interpretations of efficiency, they remain oblivious. Within the Bank this is seen in different interpretations of the term efficiency between economists and water managers as well as the very real difference between the approach for irrigation projects by the Agriculture Global Practice and the Water Global Practice.

Client countries are seen as one of the reasons why the large scale perspective is not incorporated in irrigation projects. They apply for a loan and are mainly responsible for the project setup. The Bank has a say, but its voice is not always strong and its power not always wielded. For a client country it is easier to invest in local infrastructure than to look at the basin perspective. This is complicated more by people selling irrigation modernization technology who sway policymakers with stories of water savings. Also within project teams, 'first we need to fix local problems and then we will look at the basin scale' is not uncommon resulting in an emphasis on the irrigation scheme scale.

15.5 The World Bank in the social capital framework

The insights from the literature were combined with results from the interviews and documents to put the World Bank in a social capital perspective. Both the internal and external network of the World Bank were found to be cohesive. Especially the short term consultants and advisers have three, five or more strong links to the Bank. This is partly a result of the limited number of people that are active in the field of water and irrigation. Here, a lot of ties are built by previous experience in studies and work. This closed network makes it hard for outsiders to enter even though new consultants are recruited based on their skills. The theory suggested that a cohesive external network results in tunnel vision, begin closed to new ideas and innovations. However, in the case of accepting of the significance of basin scale analysis this does not seem to hold. The knowledge acquisition methods of the GSGs and the consultant selection process based on skills mediate the closed traits of the cohesive network.

As was said before, the importance of a basin analysis is acknowledged but it is not applied in practice. One of the reasons is that advisers and consultants do not always present their findings in a way that is directly applicable by the World Bank, impacting the trust of World Bank staff in these advisers. On the other hand, the demand for an easily digestible message without background information impacts the trust advisers have in the Bank.

Another aspect that influences the implementation of knowledge, is the spatial distance present in the internal network of the Bank. This makes it difficult to spread knowledge, practical applications and lessons learned from other projects. This distance also impacts the informal knowledge exchange, it is simply very hard to get a coffee when you are not in the same office. Combined with the high time pressure this creates an atmosphere in which the natural diffusion of knowledge within the organization, and also with the short term consultants, is hindered.

The difference between applying knowledge in practice and being aware of a concept manifests in a difference in perspective of scale. Irrigation projects take place on a small scale, a scale that is most relevant for client countries. Translating the priorities to a larger scale is difficult. Consequently, the effect of increased consumption on the basin scale is often an afterthought. This relates to the term efficiency. Efficiency improvements are positive when looking at an irrigation scheme or one user but can have negative consequences for downstream users. When increasing efficiency is a project goal it is not always clear for the project team what that efficiency increase entails. This difference in terminology, perspective and goals hinders the practical application of basin analysis.

16

Discussion

16.1 Introduction

This chapter will discuss the results from the research and put them into context. It contains a discussion on the application of social capital in this research as well as observations on the variables used in the interviews. After this the chapter gives a critical analysis of the results and finally the research limitations will be discussed. The research limitations include a discussion of the sample, scope and author bias.

16.2 Social capital as a research framework

Social capital, and specifically the dimensions of social capital, was chosen as a framework because it provides a basis for a systematic analysis of knowledge exchange (Adler and Kwon, 2002). The framework allowed an extensive and detailed analysis of the context in which knowledge exchange occurs at the Bank. Combined with literature on the science-policy interface this resulted in a wholesome analysis. There are, however, some critical notes to be considered.

One of the main critiques on social capital is that it is more an umbrella concept than a clean theory (Haynes, 2009), it is like "a sack of potatoes" in which many other concepts and theories are renamed (Stirrat, 2005) [p. 28] and it is a most flexible term (Adler and Kwon, 2002). This is both a blessing and a curse at the same time. It gives different fields the opportunity to work with social capital which means that there is much research on the topic giving insight into social capital and the fields where they are applied. On the other hand, the many different interpretations result in misuse of the term when other concepts might be more applicable (Clardge, 2018). Also, the original purpose of the term, to link the social and the individual, is often forgotten (Fine, 2002). The concept is adjusted and redefined so the popularized term of social capital can be used in research. This often results in a simplification of the complexity of the concept (Hauser et al., 2007), while the inclusion of all dimensions is crucial for a solid understanding and use of social capital in research (Walter et al., 2007). Another criticism is that the concept is not measurable due to its complexity and the interrelationships.

This research considered all three dimensions of social capital, exploring the concept in its full complexity. As it is an exploratory research, the dynamics of these variables within the dimensions were not researched in full depth. The research did not look into correlations between dimensions and did not try to measure any variables quantitatively. It explored the relevance of the dimensions for the implementation of basin scale theory in World Bank financed projects. With this also the connection between the network connections and the nodes was taken into account, linking the social and the individual aspects central to social capital. Using social capital in this gives a structural insight into the network, knowledge and knowledge exchange, finding links between cognition, relationships and network structure.

Chapter 11 introduced the definition used for this research given by Nahapiet and Ghoshal (1998) [p. 234]: "the sum of the actual and potential resources embedded within, available through and derived from the network of relationships possessed by an individual or social unit". By defining social capital clearly the issue of the flexibility of the term is counteracted. The use of the dimensions introduced by (Nahapiet and Ghoshal, 1998) provided boundaries and context to the research.

The variables provided by Nahapiet and Ghoshal (1998) and other social capital literature were not sufficient to analyze knowledge exchange specifically in the World Bank and focused on the incorporation of the basin scale approach in irrigation projects. Literature on the science-policy interface in complex natural systems provided extra insights. Adding the important component of time and reward systems to the structural dimension was crucial in understanding dynamics of knowledge exchange.

This study put some emphasis on the cognitive dimension of social capital, the least researched dimension (Díez-Vial and Montoro-Sánchez, 2014; Lee, 2009). In the cognitive dimension, it is very important to add a more context specific layer. The implementation of a new paradigm in complex natural systems encounters specific obstacles, including our inability to intuitively look at large spatial and temporal scales. Essential insight on this was taken from literature on the science-policy interface.

This research explored the importance of goal, perspective and language alignment by looking at the differences and their perceived effect on the incorporation of basin scale analysis in practice. Clarity of language was not as much of an issue as expected. This was only noted as an issue between very specialized people and Bank staff or consultants but not specifically between staff and consultants or advisers.

The difference between individual and organizational social capital (Alguezaui and Filieri, 2010) was not discussed explicitly in this research. The connections that were considered arose both from the organizational and the personal network of the actors. The effect of these connections and knowledge exchange through these connections was mostly concerning the World Bank as an organization. The research did look into personal goals, but personal benefits were not explored extensively.

16.2.1 Variables

In this research the social capital concept was applied in all its complexity, using the three dimensions. The variables within these dimensions were chosen based on the literature and preliminary interviews. The manner in which these variables give the best indication can be discussed. Literature provides many variables which can be cherry picked by a researcher (Fine, 2002). The literature review in this research also gave more variables than the ones that are used. Reciprocity for example, was not taken into account while it is an often mentioned variable in the literature. This variable was not stressed in the preliminary interviews and did not arise during the semi-structured interviews. Centrality was another variable that was not explicitly taken into account, although the centrality of the World Bank as an organization can be deduced from the results.

Of the chosen research variables, most seem to influence knowledge exchange at the World Bank, although their influence varies. Time and resource availability seem to be the most crucial factors, these were more important than expected. The level of network cohesion of the external network was, on the other hand, less important than expected. The network is more cohesive than theoretically optimal, but a tunnel vision and closeness to external knowledge does not seem to occur.

Because of the preliminary interviews, network stability was expected to be a very important factor in knowledge exchange. It was interesting to see that changes in network nodes had positive as well as negative effects on projects. On the one hand a change means that goals and perspectives have to be aligned once more and a relationship has to be built again. On the other hand a new person brings in new expertise and a new perspective which can have a positive effect on a project that is stuck. Another interesting note is that network stability does not positively or negatively influence the incorporation of a basin analysis in a project. This is very much dependent on the person that moves out or comes into a project. The perceived impact of the changes in the network were most interesting.

The importance of the relational aspects of social capital was stressed by the interviewees. However, this was hard to measure with the variables, for example, tie strength. The network consists of weak and strong ties. Frequency of contact is seen as important during a project but less so during the time in between projects, as long as the World Bank staff know where to find a consultant or advisor with the right skills. Trust did seem to greatly relate to the ability, reliability was only occasionally in question. Many the relations are based on history in work and study and depend on the 'click' between two people. This was now categorized in the variable: friendship. However, this variable does not fully cover these subjective observations.

The link between goals, language and perspective is prominent in this research. The World Bank vision on water and irrigation was even more divided than expected, however, this did not seem to cause distress in the project implementation where the project goals are most important. The interpretation of efficiency depends much on the goals, perspective and the scale that is prioritized by the actor. These variables were important to understand the differences and similarities between the actors. It was deduced that the knowledge gap between the actors is not a most relevant variable, even though this was expected to be very important.

16.3 Discussion of the results and synthesis

The literature review and preliminary interviews resulted in a research framework that included network criteria stimulating knowledge exchange. This framework was combined with the results from interviews in Chapter 14. This section discusses some of the observations from the synthesis and the interview results.

The World Bank external network was expected to be closed and not open to new paradigms. The World Bank external network is quite cohesive where the literature suggests this external network should be more sparse to provide openness and access to new knowledge (Burt, 2000; Filieri et al., 2014). The cohesive network of the Bank did not generate the closed perspective that was expected. The knowledge exchange structures in place and the general attitude of many of the staff ensure that there is a limited risk for tunnel vision.

The external network cohesion can be related to the small number of people who are active in the world of water, although it remains to be seen how small this world actually is. In the semi-structured interviews, the limited number of people active in water and irrigation was stressed. However, in one of the evaluation interviews this was countered with the suggestion that the number of people active in water and irrigation and connected to the Bank is limited and that there are many more people active outside of that circle. Only the 'best' are part of the World Bank water network.

Many of the connections of Bank staff with external sources come from recommendations, personal bonds and previous experience in projects. People outside of this network are approached when they have a specific necessary skill. The World Bank has an external network of strong and weak ties, where the weak ties provide non-redundant information (Levin et al., 2004).

The internal network of the World Bank is cohesive. Having said that, there is an issue of goal alignment and perspective alignment. Literature suggests that this is relatively easy in a cohesive network (Alguezaui and Filieri, 2010; Colemans, 1988; Filieri et al., 2014; Rutten et al., 2010; Walter et al., 2007), still there are two visions on water and irrigation. One in the water Global Practice and one in the agriculture Global Practice (GP). This suggests that even though the cohesion within the GPs is high, the connections between these entities are not that good. The Global Solution Groups (GSGs) provide some links but do not seem to be sufficient. The differences in backgrounds (e.g. economics, agriculture and hydrology) makes this goal alignment more difficult as they bring their own perspectives, narratives and terminology to the table. This includes all the different views on efficiency and water consumption.

As expected there was a lack of incentives for knowledge exchange at the Bank. Knowledge is available and distributed through seminars and because of the GSGs, but the step from available to implementation is not stimulated by a reward system. This means that knowledge implementation is very much person dependent. The Bank is an institution that provides loans for projects and the task team leaders (TTLs) are tasked with the successful implementation of those projects. This research did not go into the way in which the TTLs are evaluated, but the importance of the project tasks was stressed as well as the lack of emphasis on knowledge exchange and implementation. It is safe to say that more concrete incentives are required. If time is structurally allocated to knowledge exchange it will become more than just an afterthought (Balian et al., 2016; Lee, 2009; White et al., 2009).

Similarly there are no incentives to include a proper basin analysis in projects. There are environmental safeguards and regulations about affecting downstream users, however, these are vague and do not require basin accounts to be carried out. There is also a question of what is defined as a river basin. In Central Asia the Aral Sea basin consists of the Amu Darya river basin and the Syr Darya river basin, they in turn accommodate smaller tributaries that can be labeled as river basins. A proper basin analysis includes a river and its users, from origin until it feeds into an ocean or sea. In the case of Central Asia this is the Aral Sea. Because there is no structural incentive to include a basin analysis it is dependent on the people working on a project whether it is incorporated or not. This was confirmed in one of the evaluation interviews.

Spatial proximity seemed to be less of an obstacle than expected as modern communication technologies allow them to meet over Skype. However, some issues do arise with the high spatial distance. It puts an extra strain on the time and resources that are already limited because it takes more effort to meet face to face. Only a few face-to-face meetings are necessary but due to limited time and spatial distance, even this is often not possible. This impacts the internal goal alignment as well as the communication with external consultants and the possibility to share sensitive information.

Trust in the ability of World Bank staff and the ability of consultants is high. For the consultants this is related to the large role of perceived ability in the hiring process. The Bank is said to have the best of the best. However, there are some important side notes to this statement. For one, it was observed that the specific expertise of the Bank on water and irrigation is declining. The number of people with experience in the field has decreased as well as the number of people with a background in water who actually make decisions about water-related topics. This reduces the trust in the Bank as a whole.

The ability of the Bank to completely adapt to new paradigms and not just be aware of them was also questioned. World Bank staff and consultants are hired based on experience and skills, these are skills they acquired through years of experience. However, they often do not have experience with new technologies. Additionally it is hard for the people working at the Bank to adopt to new paradigms when they do not have the time to submerse themselves into the background of a study. One of the interviewees showed their concern that the advisory reports he supplies are not read, only the summary. This is understandable because of the time constraints, but on the other hand it is hard to internalize a new concept or lessons learned if the context and background is unknown. There is a battle between time efficient knowledge acquisition and really understanding an advise or technology.

Trust in the ability of the World Bank staff was high, although this was person dependent. A Central Asian science advisor noted that he had very good experience with the reliability and ability of World Bank staff in a previous project but that his trust in the Bank deteriorated with experiences in a follow up project. The new project team did not take his country perspective into account and the project did not result in anything. Trust in the World Bank from the client countries and other involved parties will be different than the trust of consultants and academic advisers. This trust is mainly built on the perceived ability while the trust of client countries and non governmental organizations may relate more to the physical impact and political power of the Bank. There is critique on the Bank, including from within the Bank. For example, William Easterly - who was a research economist at the Bank for 17 years - is critical of the World Bank development strategy (Easterly, 2007).

Most of the interviewees saw increasing efficiency as something positive, even though most were aware of the effects on a basin level. It became clear that even in this limited sample there were many different definitions of efficiency, and whether increasing efficiency has negative implications is mostly dependent on this definition. If only the non-beneficial evapotranspiration is decreased this will probably not have any negative effects. The difficulty is that even though many of the interviewees thought they had the same definitions, there were still (slight) differences. It is crucial that actors are aware of these differences. When this is not the case the actors will be working on the same project and think to work to the same goal with the same indicator when this is not actually the case. There is already an open atmosphere in which differences are easily discussed. The definitions of indicators like efficiency should be discussed there regardless of whether a misunderstanding is experienced. The unknown unknowns are the most dangerous unknowns.

The role of the client countries in the project goals was more prominent than expected. Their focus and perspective is crucial in directing the project. The Bank does have a role in forming the plans during the project preparation and the writing of the project appraisal document (PAD) but the client country is leading. If the client country focuses on irrigation scale and there is no specific clause by the World Bank that points towards a basin analysis, the focus of the project will be on irrigation scale. It was mentioned that awareness of the basin scale is often lacking in client countries. The people in charge are often experienced but not open to change which makes it hard to introduce a new paradigm. It is easier to not look at the basin scale and work on infrastructure oriented projects.

Basin policy is very hard to get right, especially when there is no river basin authority or a limited institution in place, however, a rudimentary basin analysis should be possible. It is a misconception that a basin analysis should immediately lead to a basin policy approach. It gives insight into the effects of local projects in the basin. So the interventions can still take place on a local level as long as possible basin scale implications are taken into consideration.

16.4 Research limitations

This research was focused on knowledge exchange and implementation in World Bank financed irrigation projects, limited to knowledge exchange between World Bank staff and international consultants and academic advisers active in the field of water and irrigation. This means an important party, the client country, was excluded from the research. This decision was made to enable a focus on knowledge internalization within the Bank. The importance of this other stakeholder group was foreseen and exceedingly confirmed during the interviews. The client countries are leading in a project so even if the Bank and consultants are fully committed to including a basin analysis, they still need to convey this ambition to the client country for it to become reality.

The gap in knowledge, goals and perspectives between the Bank and the local team was often stressed. The research observations on the local project teams came from secondary sources. The perceived gap was not confirmed in an exchange with a Central Asian scientific advisor. This local advisor was aware of the basin perspective and stressed integrated projects. This one advisor is, however, not a project team. More research is needed on the perspectives and goals of local actors as well as their trust in the Bank. These local perspectives are country and context dependent.

This research used the case of Central Asia to get a more detailed view of knowledge exchange, perspectives and goals in a specific situation. The policy and project documents used in the results were mainly from the Central Asian region as well as the case that was used in the interviews. This should be kept in mind when the results of the research are generalized, because of the country dependent nature of knowledge exchange and the implementation of basin analysis. The focus on Central Asia was not very prominent and observations and experiences from other countries were also taken into account, still it limits the research.

The Central Asian case that was used in the interviews, was inspired by an existing World Bank financed project. This allowed for an insight into the opinions of the interviewees on an actual project without striding too far from reality. However, two of the interviewees had already been involved in this specific project. Therefore, their answers to the questions related to the case might be skewed compared to the other interviewees as they had more background information. As this research does not make comparisons between the interviewees and mainly focused on getting insight into details of experiences and opinions, this did not impact the results substantially.

Irrigation projects are very complex on both the small scale and the large scale. One of the issues that arose was that the people in these projects already deal with many different variables. A basin analysis adds another level of complexity and it is impossible to focus on everything in a project, there simply is no time. This research touched upon the different perspectives and goals present in World Bank financed irrigation projects but did not look into the different analyses that already take place in irrigation projects. Apart from the basin scale, other things are also underrepresented. For example, operation and maintenance was mentioned as a part of irrigation projects that is often not taken into account properly. Better insight is needed into the current practice of irrigation water management projects and which crucial analyses are not taken into account.

Another limitation of this research was the sample, in both size and composition. As this was an exploratory study, the sample was aimed to be diverse but limited in number. The network of the researcher and the use of snowball sampling resulted in a high percentage of Dutch interviewees (45% of the total and 75% of the consultants). The other interviewees were not Dutch but they did have a western heritage. The evaluation interviews included an Asian perspective. The representation within the Bank and of scientific advisers is expected to be representative for the situation at the Bank. The high Dutch representation in the consultants gives a bias for the Dutch culture, in the observations on the project implementation level.

The diversity of expertise in the sample might also not be representative to the Bank. Most interviewees have a background in irrigation or water engineering, with only two economists and one sociologist. The Bank is said to have a high number of economists in charge. A difference in language and perspective between economists, water engineers and sociologists was mentioned as an issue inside the Bank. This issue was not directly observed in the communication between consultants and World Bank staff. This can be explained by the fact that the World Bank staff in contact with these consultants generally had a similar background. In different projects, where people with a different expertise are in charge, the issue of different perspectives can be more prominent. There is a need to explore the importance of expertise and educational background in World Bank knowledge exchange.

The study will be hard to replicate. The findings were person dependent so it is probable that the findings with another sample will be different. If the same research is conducted with the same sample, the results will also be different as the interviews may have impacted the perspectives and opinions of the interviewees. Two of the interviewees specifically mentioned that the interview opened their eyes to a new perspective. A replication of the research with a different or larger sample will add richness to the data and will allow verification and questioning of the findings of this thesis.

The last research limitation to be discussed is the researcher bias. The researcher has a background in hydrology and has an inclination to believe a basin analysis is very relevant. This can have impacted the way the interview questions were formed, asked and how the results were analyzed. The researcher bias was limited by the verification of the interviews as well as the awareness of the existence of this bias.

17

Recommendations

17.1 Introduction

One of the main issues encountered by the interviewees is the enormous time pressure on World Bank staff, especially the task team leaders (TTLs). They are busy managing projects and knowledge exchange is not prioritized. This is not because there is a lack of motivation but because the time is not structurally allocated. The first recommendation is therefore to create a system where knowledge exchange and the implementation of new paradigms becomes part of the job evaluation system. A system where people are rewarded and paid for their knowledge exchange, with concrete time allocation, will allow the awareness of new paradigms to be translated to actual implementation. This is a tasking recommendation which would put a dent in the resources of the Bank and it might not be possible to carry it out on the short term. Therefore the rest of the recommendations are made in such a way that they require limited time and resources.

This chapter will first present the recommendations for the World Bank. A division is made between improving access and implementation of knowledge, goal and perspective alignment and the implementation of basin scale analysis. This chapter will finish with recommendations for future research.

17.2 Incorporation of basin analysis

Currently there is no clear strategy to apply basin analysis in World Bank financed projects, at the moment it is not a project requirement. This allows there to be financing of projects that are focused on improving irrigation efficiency, without looking at the possible negative implications. One of the interviewees drew a parallel to businesses, suggesting that a business also does not start investing randomly without first looking at the consequences, without doing the proper accounts. There is a high awareness of the relevance of basin analysis but it is not carried out in projects.

This can be dealt with by making basin analysis an inherent part of irrigation management projects. A good place would be in the environmental safeguard in the Project Appraisal Document (PAD). This environmental safeguard should shield against negative implications for the environment. Currently there is a safeguard for transboundary rivers ensuring consent of states on these rivers, however, this is formulated vaguely and does not require quantitative analysis of water consumption. I argue that this should be made more specific. Including it in the PAD requirements ensures that a basin analysis is considered before project implementation.

Just mentioning a basin analysis is not enough. The scale of the analysis should be clear as well as the definitions used. A basin analysis accounting for available and consumed water in the entire river basin, from origin until the mouth where it enters into a sea or ocean is necessary. Just focusing on small sub-basins is not enough. A guideline should include a description of what is considered basin scale. Also the definitions of fluxes need to be clear and measurable. An option is to use the fraction approach, where distinctions are made between the consumed fraction and non-consumed fraction as well as the recoverable and non-recoverable fraction (see Section 3.3). Whether the distinction between beneficial and non-beneficial use has to be made, needs to be further assessed as the line between these fractions is blurred and subject to interpretation.

The accounts can be made by Bank staff or external consultants. When it is organized within the Bank, one suggestion is to have a specialized unit making the accounts and calculations for all projects. This way the number of people that have to be trained in a specific way of data analysis is limited and it ensures a consistent framework of analysis. These people can use open source remote sensing data combined with other data available for a project region. The TTLs get a sheet with the accounts and can use it to asses the possible project and as a background for discussion with client countries.

One of the interviewees of the evaluation interviews mentioned that the Bank is working on an application where Google Earth Engine can be used to combine open source data, this environment is not specifically focused at use by Bank staff. This means that the people who use it, still have to program to work with the data. A pre-programmed environment with the basic available data is necessary to make this app more accessible and quickly usable for Bank staff and maybe project officers. This includes, for example, land cover and precipitation data, and in the future evapotranspiration data.

17.3 Perspective, language and goal alignment

Another very important issue that was flagged is that there is a mismatch between perspectives and goals. This issue arises within the Bank and in project teams with Bank staff, consultants and client countries. People have different interpretations of efficiency, different expectations of a project and look at a project in a different way. Not being aware of these differences hinders knowledge exchange and project implementation

Not being aware of different goals and perspectives in a project can have adverse consequences which can be overcome by investing in alignment exercises. Currently a project budget often has room for field visits, even though these field visits are seen as tourist trips and not always effective. The budget from these visits could be reallocated to a goal and perspective alignment exercise in the form of a workshop or role-playing exercise. It is most important that especially the unknown differences come to the table. In the case of differences in definitions of efficiency this can include everyone writing down their mathematical definition. A role-playing exercise puts people in the role of another person to better understand and see their perspective. An example is the irrigation management game (Burton, 1994) where participants take the role of farmers and a distribution officer to learn about the difficulties of water allocation and crop growth. Another example is Future of water in irrigated systems (FOWIS) (Hertzog et al., 2014), which is focused on future impacts of current water management practices by showing policymakers the local perspective and vice versa. Such a game can be tailored to irrigation project teams, to create awareness of different goals and perspectives and to help gain insight into the importance of a basin analysis. The element of gaming is important in such a role-playing exercise to lower boundaries and make otherwise tense topics easier to discuss. In one of the evaluation interviews it was mentioned that a workshop is a very western approach. Even though there are examples of successful role-plays in developing countries, this observation from the interview has to be kept in mind in the design. Additional research is necessary to develop a suiting role-playing game.

The issue of goal, language and perspective alignment within the Bank is present on a policy level and on a personal level. On a policy level it can be seen that there is a division between irrigation management by the agriculture Global Practice and the water Global Practice. This split vision has an impact on the irrigation management projects and alignment is needed to create a more streamlined approach. The water in agriculture Global Solution Group is working on this shared vision. It is important that this shared vision is formalized and can be found in all irrigation projects, for example as requirements.

Differences in perspective and language within the Bank are somewhat more subtle but very much present. The differences between economists and engineers or hydrologists were mentioned most. They have a different interpretation of efficiency and even though they see the differences they often think their own definition is superior. Using mathematical definitions in discussions is a way to make these differences clear. The differences in narratives and perspectives are harder to overcome. It takes time to learn to see through eyes of another person. A role-playing game could also be useful here although it is not certain that seeing the perspective of the other will result in seeing the value of the perspective of the other. In one of the evaluation interviews it was mentioned that, for example, the interpretation of efficiency has become emotionally loaded. The discussion has become heated and having a different interpretation can alienate someone from a professional discussion group. A very lighthearted game is necessary to remove this emotional layer.

17.4 Access and diffusion of knowledge

Task team leaders (TTLs) are the nodes that link World Bank knowledge, external knowledge, consultants and the local project team. With them lies the responsibility to find knowledge that is applicable to their project and make sure it is applied. They have access to the brown bag lunches (BBLs) and the world water week. This puts a lot of responsibility in one project coordinator who is already very busy. Therefore it is advised to make the BBLs and the water week also open for the short term consultants. Granting them access to this knowledge takes away the sole responsibility from the TTL. It also reduces the personal judgment of what is relevant and what is not as more people are aware of the available knowledge which grants different perspectives. This openness does not mean the TTL should not access new knowledge, it means that the burden can be shared. Granting access to the BBLs is not expected to drain resources.

It was observed that the water week and the BBLs are relatively passive and do not always resonate with the World Bank staff. One of the evaluation interviewees even said he avoided the water week while that is meant to be the main event of the World Bank in water. It is advised for the Bank to change to a more active learning approach. Changing the seminars to discussions or workshops, where people experience a new tool, paradigm or perspective. This includes guiding the speakers in the preparation of their presentation, making sure their message is applicable for the staff and their method of presenting is not passive. The Bank has to guide the speakers but it is also partly the responsibility of these speakers to tailor their message. The World Bank has to find a balance in how much guidance they give. One of the interviewees even suggested the water week should be transformed into a learning week instead of the presentation and networking week it is now.

An extra difficulty was observed in involving TTLs and staff that are located outside of Washington in knowledge exchange. The BBls can be followed online and at a later time so the actual spatial distance does not interfere with watching a presentation. However, the time difference does pose a difficulty, especially with live discussions. A TTL has to be very interested in a discussion to follow it when it takes place at 3am local time. A very easy solution to this problem is to have BBLs scheduled at different times during the day, for example an 8am (GMT-4) brown bag breakfast or a 7pm brown bag dinner. In this way some of the lectures can be followed life from other continents which is now not possible. This is possible with discussions but of course more difficult with interactive workshops, although even for workshops there is much possible in an online open course setup.

Not only the access and diffusion of external knowledge is a problem, also lessons learned from World Bank financed projects are not taken into account sufficiently. The Bank produces many documents which are not read extensively. Most lessons that are taken into account stem from projects where people were personally involved. Some specific projects are presented in BBLs but most projects are just documented in the internal database. This database does not function properly. An upgrade is necessary for the internal database, adding tags for themes, countries, document types and other relevant topics. At least making it easier to browse the database. There are some initiatives already within the Bank to present knowledge in a different way. For example in e-books, giving an overview of a specific research, theme or collaboration. This is still in an elementary stage and more aimed at external users than the World Bank staff.

The last recommendation in this category concerns the hiring strategy of the World Bank. It was seen that the Bank mostly employs people with years of experience, both as staff and as consultant. This experience gives them an edge in the sense that they bring a lot of practice and lessons learned to the table. Another side of the coin is that this experience hinders the openness to new ideas and paradigms. Younger people have learned about the latest developments in the field during their time at the university and are generally more flexible in adapting to new things. They are more adapted to use ICT and for example remote sensing related technologies. Therefore it is advised for the Bank to consider investing more in a younger generation, hiring them both as consultants and as staff. They will need more guidance on a practical level but will bring with them a fresh perspective and flexibility necessary to remain up to date with a quickly developing world.

17.5 Future research

This research was exploratory in nature. The findings are based on a limited number of documents and interviews with an emphasis on finding out details and not generalized comparisons. The study resulted in many small observations which can be researched more deeply to elaborate on and verify the conclusions.

The first recommendation for future research is to carry out a similar research with a different and larger stakeholder group in the same sample categories to see if the findings can be verified. Conducting the same research with the same group would not add much value because the opinions of the interviewees might have changed. Switching to a new and bigger sample will give insight into the effect of the limitations of my small research sample on the conclusions.

Conducting this study with a different and larger sample can provide extra insights. If the focus is on knowledge exchange within the Bank, quota sampling for people with different backgrounds can be used. This will allow an exploration of the different perspectives and narratives on their stance towards basin analysis and efficiency, related to background and expertise. Such a research can also verify the claim of some interviewees that people without a water background are increasingly active and influential in water policy at the Bank. Additionally, a study with a larger or different sample can focus on the internal network structure, looking at the links and communication between Global Practices and Global Solution Groups. This can help gain insight in how to generate a shared vision and bring it into practice.

Extra insight can also be gained from the project and policy documents of the Bank. This research included a limited number of these documents where the policy documents were global and the project documents only for Central Asia. It was seen that lessons learned from previous projects are often not internalized in the Bank and many documents are read by a very limited number of people. A lot of knowledge and experience is buried in these documents. It is recommended to conduct a document analysis to find out in which ways basin analysis was already conducted in irrigation and other water projects, where it was successful and where it was not. This can help with the implementation of a basin analysis strategy in future projects. A document analysis can also give insight into other issues in irrigation projects, like a proper operation and maintenance guideline.

The important role of the client countries in the project preparation and implementation was stressed in the interviews. There are many differences between countries, in their knowledge, institutes, available data and willingness to look at the basin scale. This research did not include stakeholders from client countries and the focus on Central Asia limits the generalization of research findings to other regions. It is advised to conduct a research on knowledge exchange and the implementation of basin scale analysis in which client countries are included. This can be done in a worldwide meta-analysis where some key figures of representative countries are interviewed to gain insight into local perspectives and goals. This will give insight in the differences between countries and the extent to which it is possible to use one approach of the incorporation of basin analysis in different countries. Another option is a more detailed analysis of one region. This allows the development of a tailored approach to this region but limits the extent to which it can be generalized across the globe. A specific point of interest is the trust of client countries in the approach of the Bank.

On a more theoretical level, the link between the incentives in the structural dimension of social capital and personal goals in the cognitive dimensions was not researched extensively while it is very interesting. Motivation to act can be intrinsic and extrinsic, it can come from within because you think it is important or because there is some external factor motivating you. This research suggests that a reward system and time allocation for knowledge exchange and making the inclusion of basin analysis obligatory will increase knowledge exchange and the application of basin analysis. However, the study also showed that personal preferences play an important role in what is included in a project. A future study specifically looking into the role of incentives and the role of personal preferences would be very interesting. This can help judge if it is more effective to invest in a reward system or to look at attitude change. Linking social capital to motivation can give new and interesting insights.

Some variables, like reciprocity and centrality, were not considered in this research. The effect of the choice in variables can be studied by looking at all variables present in literature and conducting a meta study where the effects of these variables are measured. This would be an extensive study, especially when a large sample is used to be able to do statistic analysis. A first alternative is to conduct a literature review of social capital research and the different variables available in the literature. This can focus on comparing the statistical analyses or on the level to which the variables are judged as beneficial by the researcher in a more qualitative manner.

IV

Thesis conclusion

18

Concluding remarks on tackling the water efficiency paradox

18.1 Introduction

Water scarcity is a very real issue. Increasing population growth and life standards will cause this issue to grow and therefore, it is vital to find a solution. As the largest consumer of water, the agricultural sector is pressured to save water. Currently these water saving strategies often focus on increasing irrigation efficiencies, however, whether this is an effective solution to to the water scarcity problem is questioned (Frederiksen et al., 2012; Molden et al., 2010; Perry et al., 2009; Ward et al., 2008). The water efficiency paradox tells us that even though increasing efficiencies sounds very positive, it can have adverse consequences. It can actually increase water consumption and with that decrease downstream water availability. Because of this possible negative impact it is vital to take the basin perspective into account, also for projects that invest in irrigation on a small scale.

18.2 Basin analysis in World Bank financed irrigation projects

As one of the organizations active in irrigation projects on a global scale, the World Bank plays an important role in the acceptance of this basin scale perspective. Although there is an awareness of the relevance of basin analysis among World Bank staff, their financed projects in irrigation management often still lack a proper basin analysis. One of the reasons is that client countries are often leading in project decisions, except for when the World Bank sets specific rules and requirements. This leading role is logical because it is their project and their country and in the end they are responsible for paying back the World Bank loan. The drawback is that their perspective is often limited, leading to a focus of projects with local or country benefits without the broader river basin view. Therefore, the World Bank should be leading in bringing this basin perspective to the negotiation table.

Part III gave insight into the issues with the implementation of basin analysis in World Bank financed projects. Within the Bank there is a lacking common vision on the implementation of basin analysis in irrigation projects, and it is not a set requirement in project preparation. There is an environmental safeguard but at present this does not cover basin accounts. Because there is no guideline for the implementation of basin analysis, the level of importance given to it currently depends on the personal preference of the team task leader and the rest of the project team. And even if this personal preference is there, the implementation is hindered by lack of time and resources.

Basin analysis is further thwarted by poor data availability and high spatial variability of this data, in this respect open source remote sensing data can provide an outcome. Part II explored the analysis of irrigation water consumption and its relation to spatial scale. By combining a local model with remote sensing data, the theorized cascade effect was shown in the Amu Darya river basin. This part of the research showed that remote sensing data provide a great tool to aid basin analysis where it is sometimes hard to judge the reliability of locally generated data.

It is important that a systematic method to include basin analysis in irrigation projects becomes available to World Bank staff. This is best included in the project preparation stage and can be included in the Project Appraisal Document. There are initiatives where open source remote sensing data is combined and made available. These tools are now not specifically aimed at Bank staff but at other users. For example, the World Bank is working on an application where users can use Google Earth Engine to conduct analyses and one of the interviewees is working on an easy way to include produce water accounts with the Asian Development Bank (ADB). For the World Bank application all possible users and the ADB tool is mainly aimed at governments and project teams. These tools are still in the very early stage of development.

The systematic method for the World Bank should include a possibility to make a relatively quick and transparent analysis, giving insight into the water accounts and providing a method to share the basin perspective with other actors.

In these accounts it is advised to use less value loaded terms than the term 'efficiency', for example fractions. If the use of efficiency is necessary, it is advised to make sure that it is clear which mathematical definition is used and that this definition is uniform among the actors. Two of the main fractions that are important to analyze are the consumed fraction and the recoverable fraction, in other words, the portion of water that is currently consumed and the portion that becomes available for reuse. This is necessary to assess possible negative implications of increased efficiencies, and to asses if improving in efficiency is actually beneficial.

These accounts can be set up in the World Bank application that is under development or in a different tool. The use of open source data and remote sensing data allows for some basic basin-wide calculations for most river basins worldwide. Within a tool these basic calculations can be set up and applied to any area the Bank is active in. An example of a basic calculation is defining the actual irrigated areas, as was conducted in Part II of this study. Fluxes like withdrawal and return flow to the river are currently not available as global data sets and to a limited degree available in the public domain (e.g. at the Food and Agriculture Organization). Other analyses, like water balance and water consumption, should leave flexibility to adapt to local data sets.

Adapting to local data and working together with local partners has three main benefits. First of all, it can enhance trust in the analysis because they know their own data. Secondly, working with the local actors on the basin analysis can help create a common framework and increase understanding of the basin perspective. It can be used as a form of experimental learning that improves understanding (Widén-Wulff and Ginman, 2004). Finally, through this collaborative approach extra knowledge on reuse and return flows can be gained from the local project team. There is much to gain from a collaborative approach, but it is time consuming. Further research is necessary to find out what the exact possibilities are for such an approach.

It can be concluded that change is necessary, change in the form of a proper basin analysis before investing in projects aimed at irrigation efficiency improvements. This research does not claim that investing in irrigation efficiency improvements is never beneficial. However, it does call for action and a strong vision of the World Bank to move towards more informed investments where basin analysis gets a prominent role in irrigation project preparation.

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V

Appendices

A

The history of irrigation water management in Central Asia

A.1 Introduction

In Central Asia water resources are temperately and spatially unequally distributed. The region contains many semi-arid and arid areas. The region is known for large fields of cotton and large irrigation channels causing an extreme drain on the water resources. However the region did not always have these extensive farms. Until 1860 the region hosted nomadic farmers. The first irrigation systems were built in the 6th and 7th century when the region flourished due to the Silk Road trade route (Abdullaev and Rakhmatullaev, 2015). From then on many more irrigation canals were build, transferring water to fields and across river basins.

A.2 Khanates

Before the Russian invasion, the Amu Darya river basin (region now mostly covered by Uzbekistan, Turkmenistan, Tajikistan and Kyrgystan) was ruled by Khans (Kings), the Dekkhans (farmers) rented their land from the Khans (Iskender-Mochiri and Gough, 2003) while the northern region around the Syrdarya basin was mostly inhabited by tribes. The Khanates had a central water management structure. The Khan dispatched a Kokhim or Bek (regional manager) who in turn dispatched a Arik Bashi (local manager) to monitor water levels in the main irrigation canals (Abdullaev and Rakhmatullaev, 2015). The Dekkhans in turn c hose a Mirab who represented them with the Arik Bashi. The Mirab and the Dekkhans would decide the amount of water they needed which was then communicated to the Arik Bashi. The Dekkhan would the Khan for the amount of water they used, but what they payed was dependent on their satisfaction of the Mirab. The Khan and the Mirab were paid in a percentage of the harvest. The Mirabs and Arik Bashis mobilized the Dekkhans for maintenance of the irrigation canals, labor was obligatory and done for free in the yearly Hashar or Kazu (Abdullaev and Rakhmatullaev, 2015; Dukhovny and de Schutter, 2011). Upstream constituents had to invest more time and resources than downstream water users, as they had the benefit of being upstream (O'Hara, 2000).

A.3 Tsarist colonization

The colonization of Samarkand (Abdullaev and Rakhmatullaev, 2015) lead to the complete colonization of Central Asia (or Turkistan) by the mid-19th century (Dukhovny and de Schutter, 2011).

Figure A.1: Irrigated areas in Central Asia (AQUASTAT, 2013)

The Tsar wanted Russia to be self-sufficient in cotton production. The Empire left most of the pre-colonization irrigation management intact, even when it expanded the irrigated land, invested in infrastructure and took ownership of the farmland which was then distributed to the farmers (Dukhovny and de Schutter, 2011; O'Hara, 2000). Taxes were now paid to the Tsar instead of the local aristocrats. The first plans for large scale irrigation in the Amu Darya and Syr Darya river basins bloomed during this time, but were never carried out because of lack of funding (O'Hara, 2000).

A.4 Soviet era

A complete reorganization of agricultural management in the region came after the Bolshevik Revolution and the collapse of the Tsarist Empire (Abdullaev and Rakhmatullaev, 2015). All irrigated infrastructure transferred to the rule of the People's Commissariat of Agriculture. Developing the Agriculture of Turkistan further was a prime interest of the Russian government. On May 17, 1918 Lenin allocated 50mn ruble for irrigation works in the region (Dukhovny and de Schutter, 2011), a significant increase to the Tsarist investments (Abdullaev and Rakhmatullaev, 2015). The money was used to construct gigantic irrigation canals, reservoirs, pumps and other structures, mostly based on plans developed during the Tsarist rule (O'Hara, 2000). There was a shift in water use from the small local river to the large regional rivers which could now be accessed through great irrigation canals such as the Kara Kum Canal. Over the 70 years of soviet rule 4.9mn ha of new irrigation land was accessed causing an increase of water use form 64.7 to 103.5 km^3 (O'Hara, 2000). The new large scale irrigation fields were mostly located in the arid areas like the Kara Kum Desert. This increase in irrigation water use caused a dramatic decline of river flow to the Aral Sea (Aladin et al., 1995). In the mid-1980s the government became more aware of the Aral Sea situation, instead of investing in more irrigation channels the 12th 5-year plan focused on improving water use efficiency as a tool to expand irrigated areas. The large scale irrigation schemes were either sovkhoz (state owned farms) or kholkhoz (cooperative farms), the former employing workers with fixed wages while the latter payed workers form farm revenue (Abdullaev and Rakhmatullaev, 2015). By the end of the soviet era most farms were state owned, conform the socialist ideology. The mega farms were generally specialized in one particular crop like rice, wheat or cotton.

A.5 After the Soviet breakup

After the Soviet breakup, investments in agriculture decreased dramatically. Both sustaining the irrigation system present and constructing new channels became difficult to realize. The fall of the soviet union meant a change from state organized agriculture to a more capitalistic approach (Rakhmatullaev et al., 2010), although some state owned cotton and wheat production remained intact (Veldwisch and Spoor, 2008). The region that was managed as a unity under soviet rule, is now divided into five states. This causes tensions in water allocations in a region with resource deficits. The countries strive to become energy and economically independent (Abdolvand et al., 2015). The decentralization of the water resources was not planned but a byproduct of changing politics (Abdullaev and Rakhmatullaev, 2015). This resulted in new local government taking over agriculture management while they lacked the resources (García, 2008). For farmers this meant a transition from state management into unregulated management (McDonnell, 2008). Additionally many Water Users Associations (WUAs) were set up, both by the government and external donors (Abdullaev et al., 2010) where governmental WUAs focus on top down interventions and donor based WUAs, like the ones created by IWMI (IWMI, 2016), follow a bottom up approach. This caused a heterogeneous and inconsistent management of water resources across the region(Yakubov, 2012). Although it is a challenge to govern the interactions between state and water users, there is a move towards Integrated Water Resources Management where water users are included in water management policy.

A.6 Regional collaboration

After the soviet breakup in 1991 the region divided into five countries using the water resources of the Aral Sea Basin which turned national water management policy into international policy (AQUASTAT, 2013). The collaboration lead to the Interstate Commission on Water Coordination (ICWC)[1], which seats deputy ministers relevant for water from each country. The ICWC meets once a year to make the water allocation decisions of that year, after this they have three monthly meetings to keep track of the agreements and problems around water supply (Abdullaev et al., 2010). All states have the right to veto decisions and the ICWC gets most funding from the member states. Although Afghanistan is part of the Aral Sea Basin, the country is not included in the ICWC (AQUASTAT, 2013). The ICWC uses two river basin organizations (BWOs) to manage the water allocation in the Syr Darya and Amu Darya river basins and provide technical interventions when needed. Additionally the Scientific Information Center (SIC) is used to gather information about the basins and conduct analysis and the in 2000 established meteorological organization (CMC).

In addition to the ICWC there the International Fund for Saving the Aral Sea (IFAS)[2] was created to attract funding for regional investments. Interstate Council for the Aral Sea (ICAS) merged with the IFAS in 1997 (AQUASTAT, 2013). The IFAS is headed by the president of one of the member states, rotating every year. This president is supported by relevant members of parliament of the other states. The IFAS and ICWC work on basin scale and international planning while the BVOs work on smaller scales. Apart from these institutions there have been initiatives and programs among others funded by the World Bank to rehabilitate the Aral Sea.

The main disagreements between the states have to do with control and construction of dams which govern energy production and availability of water for irrigation. Hydro power resources are located in the upstream countries of Kyrgyz Republic and Tajikistan (Wegerich et al., 2015). The dialogues between the countries are on a rise in 2016 where before that time the dialogues between Tajikistan and Uzbekistan were at a low (World Bank, 2017). Even though there is a multilateral organization governing international waters, the relations between the countries are frosty when it comes to sharing resources (Dukhovny and de Schutter, 2011).

[1] http://icwc-aral.uz/

[2] http://ifas.kz/en/, http://ec-ifas.waterunites-ca.org/about/index.html

B

Aral Sea Basin management model

B.1 Introduction

The Aral Sea Basin management model is a model developed for the Amu Darya and Syr Darya river basins. These rivers discharge into the Aral Sea. The model was developed by the SIC ICWC under advisory of UNESCO IHE. It consists of four sub-models: the flow formation model, the water allocation model, the planning zone model and the socio-economical model. These are parameterized for the region with historical data until 2010. The ASBmm is developed to forecast the behavior of the basin until 2035. This document will focus on the first three models and not the socio-economic model. The equations presented in this document are extracted from the ASBmm final report by SIC ICWC and UNESCO-IHE. The analysis is based on the final report and an exploration of the ASBmm. The ASBmm can be found on www.asbmm.uz[1].

B.2 Basins and planning zones

The Aral Sea Basin is divided into two river basins. The areas in the river basins are divided into planning zones. In the model the two river basins of Amu Darya and Syr Darya are linked through the planning zone Djizak.These basins are schematized as can be seen in figure B.1 and B.2.

The planning zones are individual areas with their own water balances. In the planning zones all water use activities take place. This consists of domestic, industrial and agricultural water use. The planning zones are determined based on administrative boundaries already existing in the region. The climate and water use differs between the planning zones. In the planning zones higher in the basins the rainfall will be more while the temperatures will be lower. The ratio of domestic, industrial and agricultural water use depends on the dominant activities in the planning zone.

B.3 Initial Settings

Before modelling there are some initial settings to be chosen. Here there is a possibility to see the influence of climate change, determined by a climate change model. It is also possible to choose for a normal continuation of the flow or for a dry scenario. Apart from these preset scenario's it is possible to create a personal user scenario in which individual input parameters can be changed (see section B.6).

[1] As of January 2017 the model has been offline

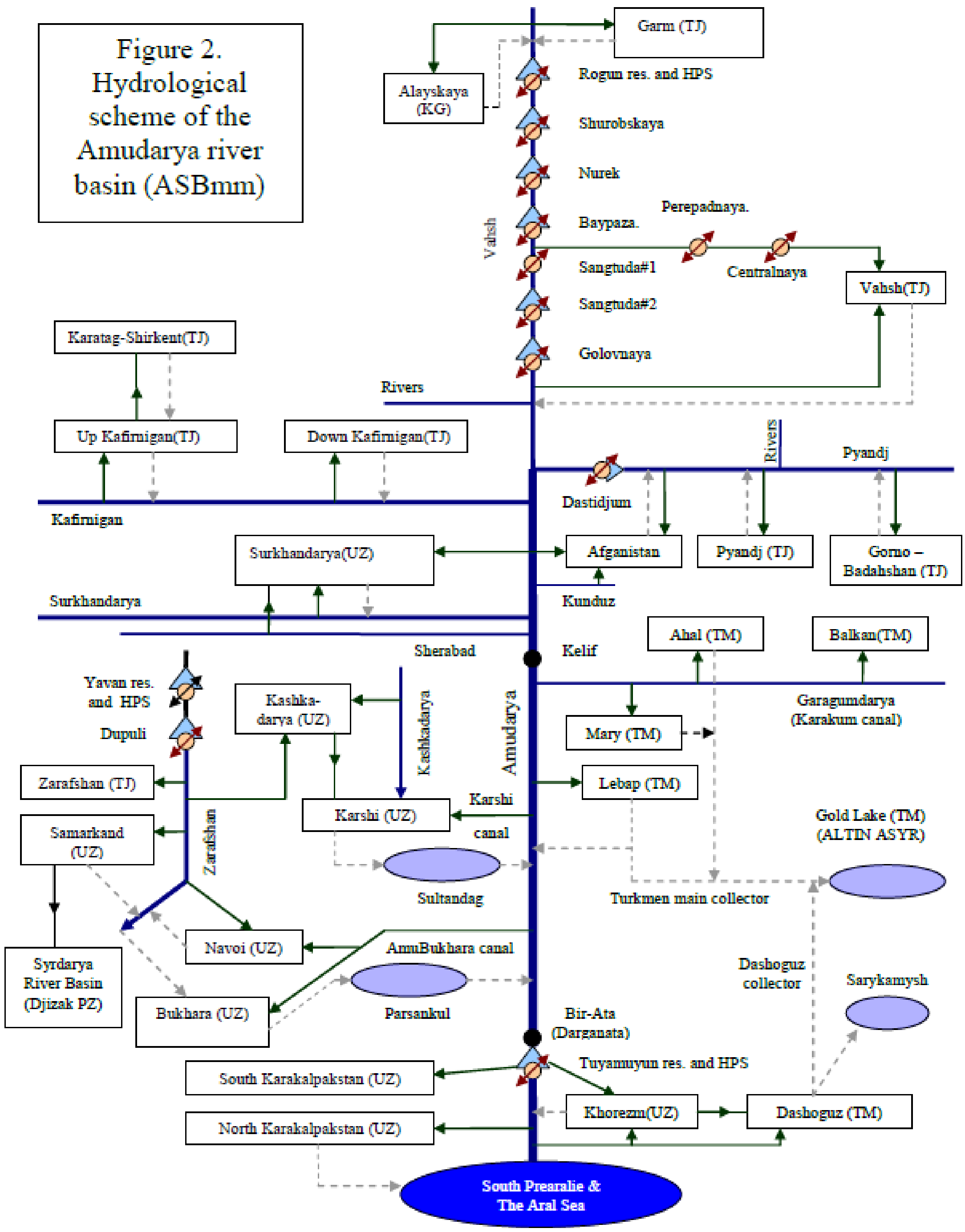

Figure B.1: ASBmm model schematization for the Amu Darya river basin

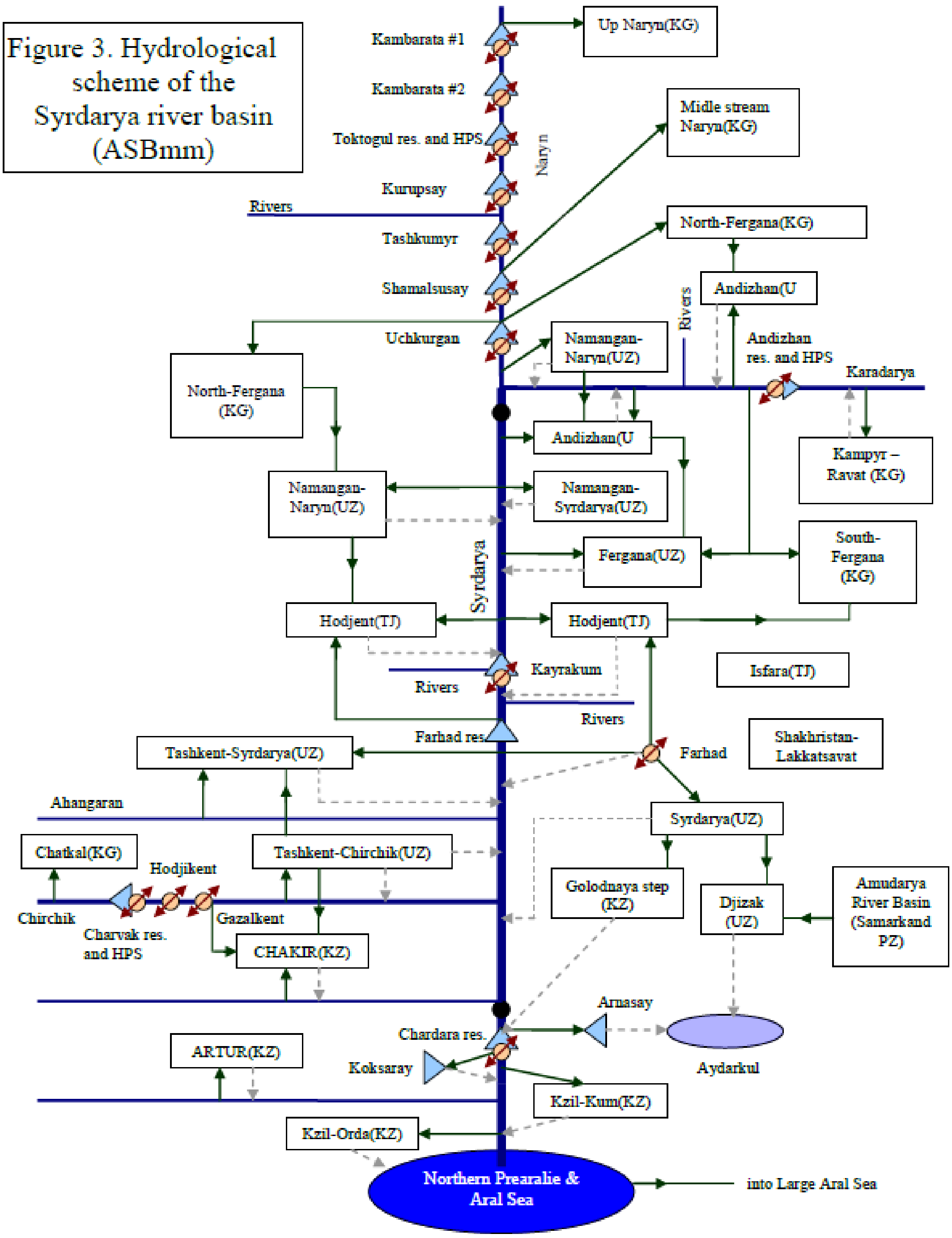

Figure B.2: ASBmm model schematization for the Syr Darya river basin

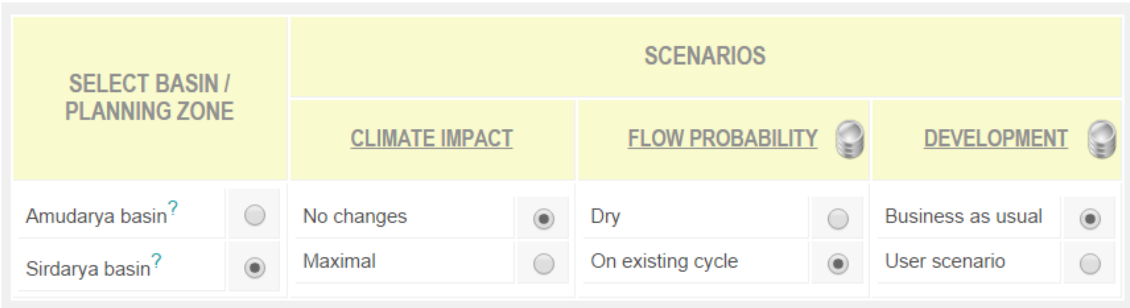

Figure B.3: Initial settings for the Flow Formation Model

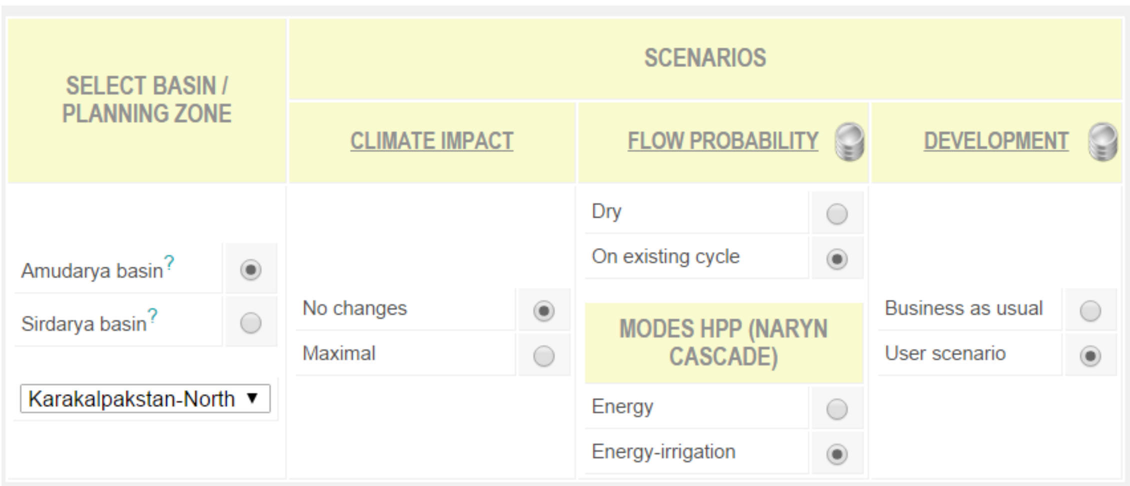

Figure B.4: Initial settings for the Planning Zone Model

B.4 The flow formation model

The flow formation model looks at the water balance in one of the two rivers on a basin level. The water allocation to the planning zones is based. In the flow formation model the water balance of the different components of the basins are calculated and fit together. The components are river reaches, lakes, reservoirs and Hydro Electrical Power Stations (HEPS). Apart from the water balance this model also calculates the salt concentrations in the basin however this document will solely focus on the water balance. The water balance is calculated on a monthly time step. In this part of the model the output data can also be viewed in a monthly time step in the online interface. It can be exported into an Excel file only on a yearly time step. The river flows in the flow formation model is bases on discharge hydrographs created by real data. These are corrected for the influence of climate change on the weather.

The water balance takes the following into account for all components: evaporation, groundwater in- and outflow, seepage, return flow from the PZs, withdrawal by PZs and inflows and discharges into other components. For a river reach the last process can be a discharge into a downstream river reach and for instance for a reservoir this can be a release into a river reach. Some of these releases are man-controlled, for instance in case of the HEPS and the reservoirs.

B.5 Water allocation and Planning Zone models

The second and the third module of the model are the water allocation and planning zone models. The water allocation model looks at the requirements of the planning zones (based on predetermined values for crop water requirements) and the water available from local resources. The requirements that cannot be met by local resources is the demand from the transboundary rivers. In the Planning Zone Model this is linked to the flow formation model and the water that is actually available. This model is also computed on a monthly time step. The monthly output data is however not available.

The steps in this model are as follows: first the water requirements are determined from crop water requirements and preset values for industrial, domestic and environmental needs. Including channel losses this is combined into the water demand. This water demand is firstly met by reuse from the return flow, groundwater withdrawal, water from local resources and releases from the reservoirs. The remaining demand should then be met by the withdrawal from transboundary rivers. This is where the water allocation model stops and the PZ model continues. In the PZ model the water demand from the transboundary rivers is linked to the actual water available for this planning zone. With this a possible deficit is calculated (See Figure 1).

The reuse and groundwater withdrawal can directly be changed as an input value in the user scenario. The releases from the reservoirs and local water use are dependent on input values related to the water demand. Only the withdrawal from transboundary rivers is related to the actual available water computed by the model. In the model the rural water supply is given as an external water requirement, not as a part of agricultural use. An extra requirement is met in the filling of reservoirs. The value for the filling of reservoirs is always the same as the water supply from reservoirs.

The planning zone model takes evaporation into account through crop water requirements and not directly as was done in the river reaches and reservoirs of the flow formation model.

Apart from the water supply and demand also a return flow to the river is calculated. This is the collector drainage flow, water that is collected in the drainage system and returned to the river. According to the manual this is also where the reuse in the planning zone comes from. However if the reuse in the input is increased no changes are observed in the output data. Here the return flow to the planning zones is the same as the return flow to the river, more on this in section B.6.

The collector drainage flow is calculated in one of two ways depending on the amount of data available for the planning zone. The first option is through the water balance. In this the necessary data are the irrigation water demand (Wz_{dir}), the rainfall (pz), the net crop water requirements (Wz_{irn}) and the groundwater in and outflow across the planning zone border. Another way to calculate is to multiply the total withdrawal in the planning zone (Wzi) with a ratio of reduction (Kz).

$$Wz_{dir} + 0.00001 * pz = Wz_{irn} + \Delta GW + Wz_{CDF} \text{ With } Wz_{ZDF} = K_z * W_{zi} \tag{B.1}$$

Which method is used for which planning zone is not disclosed. The method of determination of K_Z is unclear, in the model the value is a preset percentage and varies between 0.14 and 99.98.

B.6 Changes in user scenarios

Different inputs are changed in the user scenario functionality of the model to figure out the relations between input and output. The findings are related to the information provided in the ASBmm final report. For this the dynamics in the planning zone North Karakalpakstan in the Amu Darya river basin are studied. In the planning zone model the indicators that can be changed are shown in the Figure B.6. For this analysis the irrigated area, groundwater withdrawal, return flow to transboundary rivers, reuse and efficiency of inter farm canals are changed to see their effects. The water diversions for uses other than irrigation have a minimal influence on the total water withdrawal in this basin and are therefore not changed in this analysis.

Increase of GW withdrawal slightly decreases the filling of reservoirs and with that the water demand. It is seen to increase the amount discharged onto local waters. Changing the return flow does not seem to have any influence on the output.

Increasing the reuse of the collector drainage flow does not seem to have an effect on any output. This is different from what is expected according to the model description where the collector drainage flow (W_{CDF}) consists of the return flow to the river (W_{CDZ}), the reuse (W_{ZCD}) and the flow discharged into the lakes (W_{CDLZ}). The discharge into the lakes is not found in the output of the model, the reuse is seen in the input data but not in the output of the model where the collector drainage flow is always the same as the return flow to the river except for in the Fergana planning zone (Syr Darya River).

Decreasing efficiency causes a deficit which is met by maximum supply from local resources and the transboundary rivers, first the maximum of the rivers is met and then the local resources are tapped into. These dynamics differ per planning zone as some planning zones have a negative local water intake and still have a water deficit. It depends on what is available filling of reservoir and water release from reservoir is the same number and is dependent on the irrigation water requirements. The maximum available local resources are not used in the model, there is a deficit while in a different scenario more local water is available.

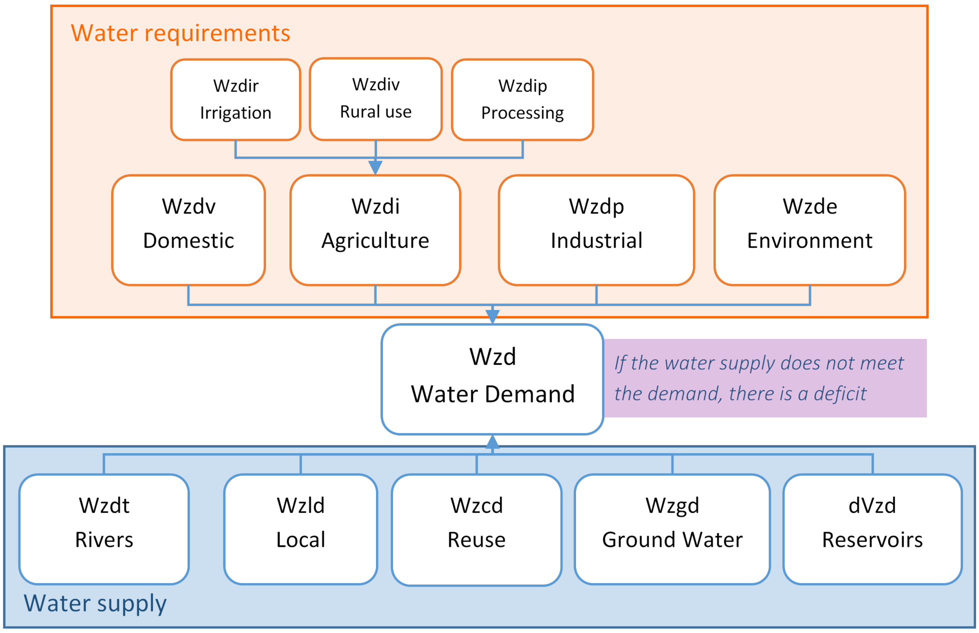

Figure B.5: Supply and demand in the ASBmm

INDICATORS	2010 YEAR		BOUNDARIES			FORECAST				
	UNITS	VALUE	UNITS	MIN	MAX	2015	2020	2025	2030	2035
- Population										
Population in PZ, % of 2010	million people	1232.7	%			100	100	100	100	100
- Cropping patterns										
→ Main crops, % of total irrigated area										
Irrigated area in PZ, % of 2010	thousand ha	367.296	%			100	100	100	100	100
+ Cost										
- Water diversion										
domestic sector	Mm3	35.816	%			100	100	100	100	100
industry, including energy	Mm3	246.693	%			100	100	100	100	100
agriculture (excluding crop production)	Mm3	118.118	%			100	100	100	100	100
Water supply from groundwater	Mm3	15.686	%			100	100	100	100	100
- CDF										
return flow to transboundary rivers	%	1.415	%			100	100	100	100	100
CDF re-use in PZ	%	3.454	%			100	100	100	100	100
- Efficiency										
of interfarm canals			unit			0.9	0.9	0.9	0.9	0.9
of onfarm canals			unit			0.7	0.7	0.7	0.7	0.7

Figure B.6: Variables that can be changed in the user scenario, example North Karakalpakstan. The initial values for 2010 vary per planning zone

	Initial settings	GW *1.5	Reuse *1.5	Canal eff. 0.9 to 0.5	Canal eff. 0.9 to 0.8	CDF *1.5	A_{irr}* 1.5
Irrigated agriculture	3760.3	3760.3	3760.3	6768.5	4512.3	3760.3	5640.4
Domestic user	35.8	35.8	35.8	35.8	35.8	35.8	35.8
Industrial use	246.7	246.7	246.7	246.7	246.7	246.7	246.7
Rural water supply	117.6	117.6	117.6	117.6	117.6	117.6	117.6
Filling of reservoirs	739.6	738.1	739.6	1277.3	874	739.6	1075.6
Total[1]	4900	4898.5	4900	8445.9	5786.4	4900	7116.2
Groundwater extraction	15.7	23.5	15.7	15.7	15.7	15.7	15.7
Intake from local resource	-1855.3	-1863.1	-1855.3	1152.9	-1103.2	-1855.3	24.8
Water releases from reservoirs	739.6	738.1	739.6	1277.3	874	739.6	1075.6
Total[2]	755.3	761.6	755.3	1293	889.7	755.3	1091.3
Water demand of PZ from Rivers (trans-boundary)	6000	6000	6000	6000	6000	6000	6000
Water supply from trans-boundary rivers for PZ	4440	4440	4440	4840	4840	4440	4840
[5] Water deficit in PZ	0	0	0	2312.9	56.8	0	1184.8
Return flow from PZ to Rivers (W_{CDZ})	1804.9	1804.9	1804.9	2138.7	2138.7	1804.9	2138.7
Collector drainage flow formed in PZ (W_{CDF})	1804.9	1804.9	1804.9	2138.7	2138.7	1804.9	2138.7

Table B.1: Sensitivity ASBmm

C

Data sets

C.1 Evapotranspiration

Evapotranspiration (ET) is the term that contains all evaporative processes in the water balance, evaporation and transpiration. Evaporation can come from soil, open water, interception and air, it contains all water that evaporates from surfaces and air. Transpiration is the process by which plants transport water from the roots through the plant to the pores in the leaves, where the plant releases the moisture to the atmosphere. These combined form the ET flux which leaves the local basin, in this research classified as water consumption. In situ evaporation measurements are inefficient and scarce, therefore satellite based models are very attractive to generate global ET estimations (Zheng et al., 2016). $ET_{monitor}$ is chosen for this study as it is the only global ET estimation model covering the study area. It is compared to the $ET_{ensemble}$ model that is currently under development by UNESCO-IHE for validation.

The evaporation model will be used both to determine irrigated areas in the region and to complete the evaporation and transpiration term of the water balance.

C.1.1 $ET_{monitor}$

$ET_{monitor}$ is a semi-global process based model developed to estimate ET (Zheng et al., 2016) developed by the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences in Beijing. The model gives a daily ET estimation for the years 2008-2012, the model used has a 0.00517° resolution. Currently remote sensing models are either based on the surface energy balance with infrared measurements or based on optical and microwave data in micro-meteorological models. The first can only be used in cloudless conditions. The most used of the second is the MODIS (MOD16) algorithm which does not take the constraint of soil moisture into account (Hu et al., 2015) this can be an issue in semi-arid and arid areas.

$ET_{monitor}$ contains separate models for the different evaporative fluxes, including a dual source Shuttleworth-Wallace model for soil evaporation and plant transpiration, the Gash analytical canopy evaporation and a module for open water bodies using the Penman-Monteith equation (Zheng et al., 2016). For snow and ice evaporation a formula recommended by the World Meteorological Association was included. $ET_{monitor}$ aims to combine open access remote sensing data into the global model. It makes use of remote sensing based data for land cover, vegetation and climatic and soil data. A full disclosure of the data sources can be found in Zheng et al. (2016). The data were validated with in situ measurements. The model validation with ground observations show an R^2 = 0.74, Bias = -0.05 mm d^{-1} and

RMSE = 0.87 mm d^{-1}, which are accounted as good results. The validation for global evaporation patterns shows similar patterns for Gleam ET while showing a higher bias and RMSE for the MOD16 comparison.

C.1.2 $ET_{ensemble}$

$ET_{ensemble}$ is also a semi-global ET estimation model. As of yet there are no publications on this model. The model has a resolution of 0.0025° and reaches until 40° north. The model uses Normalized Difference Vegetation Index images and combines it with seven ET remote sensing products. The products used are: GLEAM, SEBS, ALEXI, CMRSET, MOD16, SSEBop and $ET_{monitor}$. The model development is still in progress, at the time of this research $ET_{monitor}$ was not yet included in the $ET_{ensemble}$ product. The ET products are combined in a 0.01° resolution and will be downscaled to 0.0025° resolution combined with the NDVI data.

C.1.3 Comparison

$ET_{ensemble}$ and $ET_{monitor}$ are two global evapotranspiration (ET) estimation models, they differ in their approach and the models used to estimate the evaporation, where $ET_{ensemble}$ will include $ET_{monitor}$ when finished. $ET_{monitor}$ is the only of the two that covers the complete Amu Darya Basin. The two models are compared for the part of the region which they both cover. In general it can be seen that the two models both show high ET in the same regions, the patterns they show are similar, however the absolute values per area can differ (see figure C.2 and C.1).

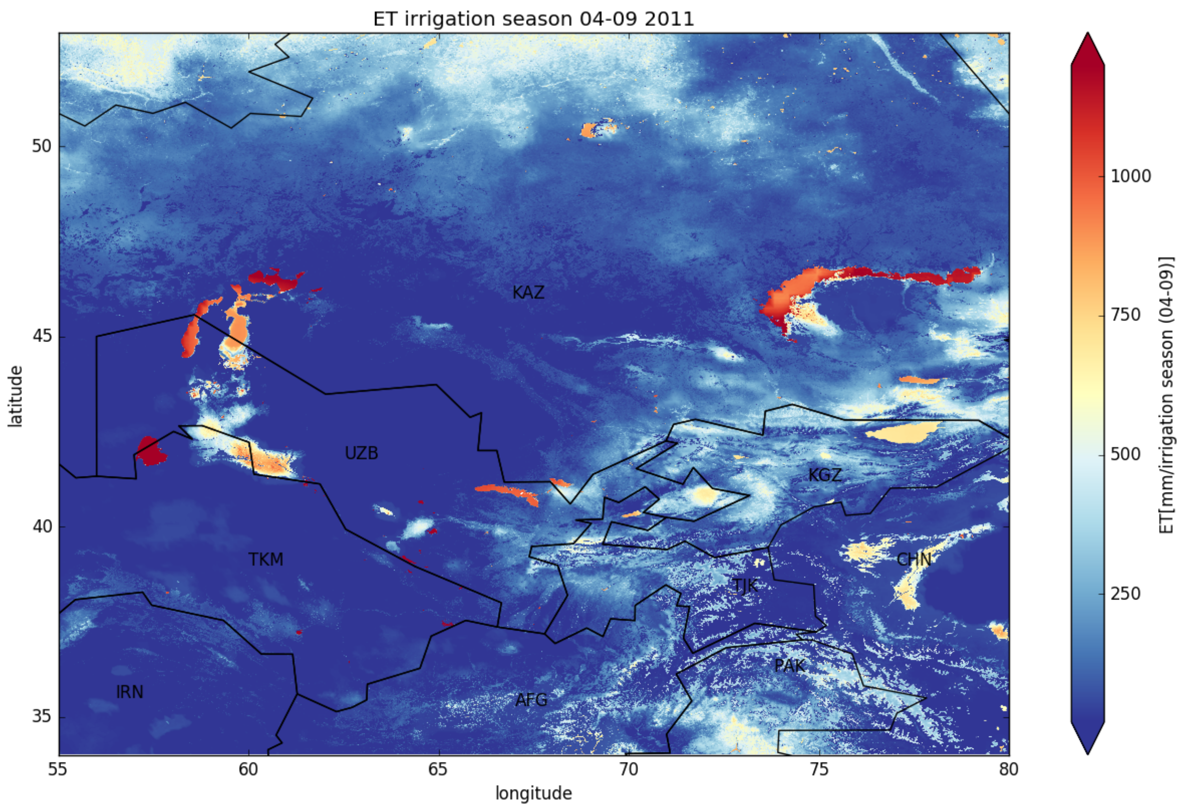

Figure C.1: $ET_{ensemble}$ for the irrigation season 04-09 2011

When looking at the ET maps of both models there are some differences that can be observed. For instance two irrigated patches in China get a higher ETmonitor values than the same pathches in the ETensemble model, shown by a darker yellow shade in the map of the former model. However for an area in Pakistan, at the bottom of the produced maps, the opposite can be observed. Here ETensemble

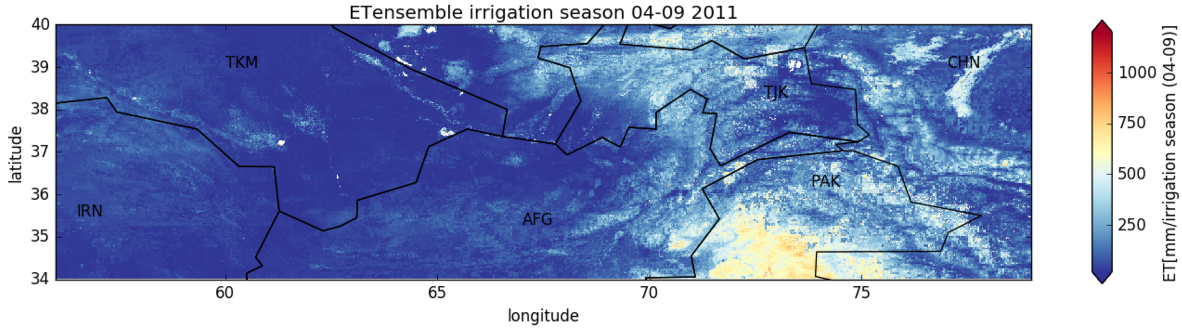

Figure C.2: $ET_{ensemble}$ for the irrigation season 04-09 2011

gives higher values. It is striking that ETensemble shows a much larger area with higher ET. In general ETmonitor shows stronger differences between high and low ET values where ETensemble seems to show a more gradual transition.

This comparison shows that even though the two ET models show similar patterns in recognizing regions with high and low ET, there are still differences. The choice of the used model influences the data entered into the model. ET is classified as the water consumption, which is a vital part of the consumed fraction calculations. Therefore it is important to note that the use of different models can have an impact on the outcome of the study. As of now it is impossible to say which of the models is closer to the truth. However when ETmonitor is completely incorporated in ETensemble and ETensemble covers the full study area, it is be preferable to use ETensemble.

C.2 CHIRPS precipitation

The Climate Hazards group Infrared Precipitation with Station (CHIRPS) is a precipitation dataset covering the world from $50°S$ to $50°N$ with a resolution of $0.05°$. Precipitation includes rainfall, snowfall, hail and other forms atmospheric moisture that falls on earth surfaces. The Chirps datasets include daily, monthly and annual datasets (Funk et al., 2015a). CHIRPS incorporates both satellite data and smart-interpolation for ground measurements. The satellite estimations are based on infrared Cold Cloud Duration (CCD) observations and are mostly relied on in sparsely gauged locations, the gauged data are generally used in a 5km radius distribution using data from local and global databases. The historical climate estimations (CHP$_{clim}$)(Funk et al., 2015b) is combined with the CCD estimates to form the CHIRP dataset, this is then combined with the interpolated Gauge estimations to form the CHIRPS dataset.

There are two versions of the CHIRPS datasets, one with only a two day latency and one more accurate version with a three week latency. This research uses the three week latency monthly data. These are based on the highest resolution CDD estimates combined with the station data. This is a low latency gridded dataset based on long record estimations. The CHIRPS dataset was developed to support the Famine Early Warning System for the United States Agency for International Development. It is therefore aimed at placing current extreme events into a historical context. The validation of the CHIRPS dataset shows that it performs well in data sparse regions with complex terrain (Funk et al., 2015b), it performs well compared to the existing models providing a higher spatial and temporal resolution with a lower latency. However there is still room for improvement, mainly for detecting sub-seasonal extremes (Funk et al., 2015a). The model performs well in correlation but is prone to underestimating extremes.In this research it will be used in the process of locating irrigated areas and in supplying the precipitation flux of the water balance.

C.3 FAO areas equipped for irrigation

The FAO global map of irrigation areas shows areas equipped for irrigation in a 5 arc minute (0.0833°) cell grid size. The map is based on sub-national irrigation statistics and geospatial information. Siebert et al. (2005b) made use of reports by FAO, UN, World Bank, ministries, agriculture associations etc. as statistical data on the one hand and printed maps and digital data sets as geographical information on the other hand(Döll and Siebert, 2000). These were combined in a model prioritizing different levels of geographical information which led to an irrigation density grid with a 0.01° resolution for the included countries, for most countries multiple datasets were used. These country maps were aggregated into a global map of areas equipped for irrigation with a 5 arc minute resolution. For some countries the FAO AQUASTAT database was deemed more representative than national statistics, for those countries the FAO AQUASTAT data were prioritized.If there were no maps for irrigated areas available the statistics were distributed over the USGS land cover data set allocated to the land cover likely to be irrigated. In the final map Central Asia is one of the densest irrigated regions in the world with 34.9% of its cultivated land equipped for irrigation, mostly located along the Amu Darya and Syr Darya rivers.

The FAO map specifically shows areas equipped for irrigation and not actual irrigated areas because the statistics usually refer to areas equipped for irrigation. The actual irrigated areas might be significantly lower due to for example damaged infrastructure.

Country	Area equipped(ha)	Map quality area equipped	Map quality actually irrigated	Map quality source of water
Afghanistan	3 199 070	good	very poor	very poor
Kazakhstan	2 482 500	good	very poor	very poor
Kyrgyzstan	1 045 131	very good	very poor	very poor
Tajikistan	742 051	very good	very poor	very poor
Turkmenistan	1 990 800	very good	very poor	very poor
Uzbekistan	4 198 000	very good	very poor	very poor

Table C.1: Map quality FAO AQUASTAT map of areas equipped for irrigation, Central Asia (FAO, 2016)

C.3.1 Map quality

The map has a varying quality depending on the quality of the source information, no generalized measure for the quality of the total map can be produced. The map could not be validated by comparing it to other irrigation maps on a smaller scale as they were all incorporated in the global map. The researchers developed two country-specific indicators(Siebert et al., 2005b) to asses the quality of the map. The first indicator is based on the density of the information used in defining the sub-national statistics while the second indicator represents the density of the geospatial information. These indicators combined contribute to the judgment of the map quality per country. It is assumed that if one of the indicators is good the overall map quality is good, the better of the two is used to indicate the map quality. However in 64 countries the assessment of the map quality was downgraded because of doubtful quality of the used data. The map quality for the countries in the Aral Sea Basin can be found in Table C.1.

The FAO global map of irrigated areas was also compared to two remote sensing based land cover models that distinguish actual irrigated areas (GLCC[1] by USGC and GLC2000[2] by the European Commission). It was expected that the areas in the remote sensing based models would be smaller

[1]https://lta.cr.usgs.gov/GLCC
[2]http://forobs.jrc.ec.europa.eu/products/glc2000/glc2000.php

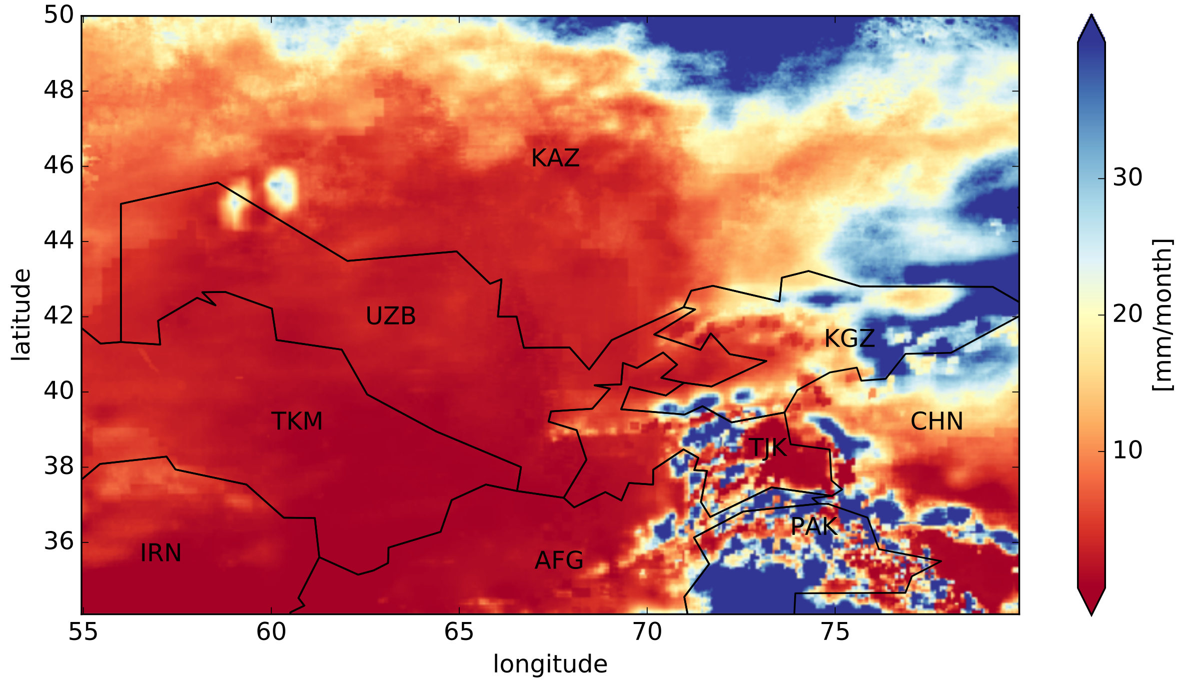

Figure C.3: CHIRPS precipitation for the month July for the Aral Sea Basin

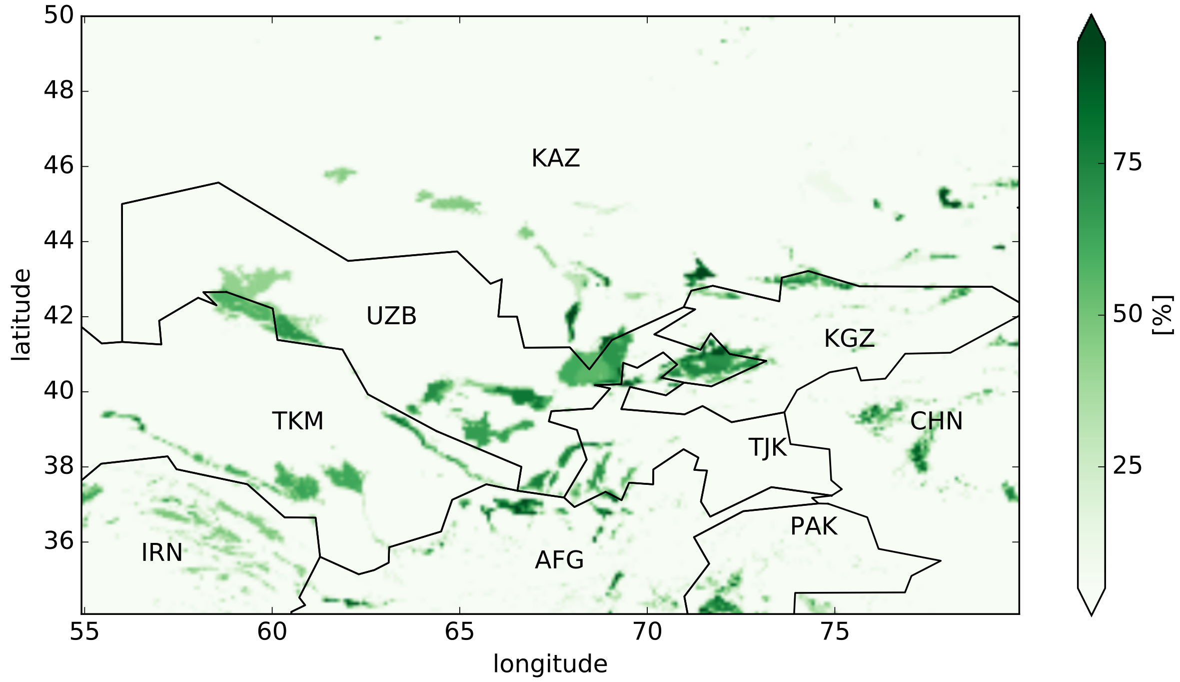

Figure C.4: FAO areas equipped for irrigation in the Aral Sea Basin in % per pixel but similar due to the difference between actual irrigated areas and areas equipped for irrigation. However the comparison shows that there is little agreement between the remote sensing and FAO datasets, with only seven countries having a statistical difference of under 20%. This can partly be explained because the remote sensing maps classify a grid cell in a class if it is covered by this type for 50% or more, this means that small irrigated areas are often not taken into account and that large irrigated areas are often overestimated. Additionally the remote sensing method might not be working for humid areas because of lack of background knowledge. The FAO global map of irrigated areas is assumed to be more accurate in showing areas equipped for irrigation than these global land cover models because the land cover models lack local background information and are not specifically designed to locate irrigation but are designed to identify land cover.

The fifth version of the global map for irrigated areas includes actual irrigated areas(Siebert et al., 2013), however often the quality of these data is still poor. The map quality for areas equipped for irrigation in Central Asia is good or very good, while the data available for actual irrigated areas is very poor. Therefore this research will use the FAO global map of irrigated areas as a reference but not as leading for defining the actual irrigated areas.

The FAO areas equipped for irrigation per planning zone are compared with the areas provided by the Aral Sea Basin management model (ASBmm). Here we see a structural overestimation of the FAO map as compared to the ASBmm.

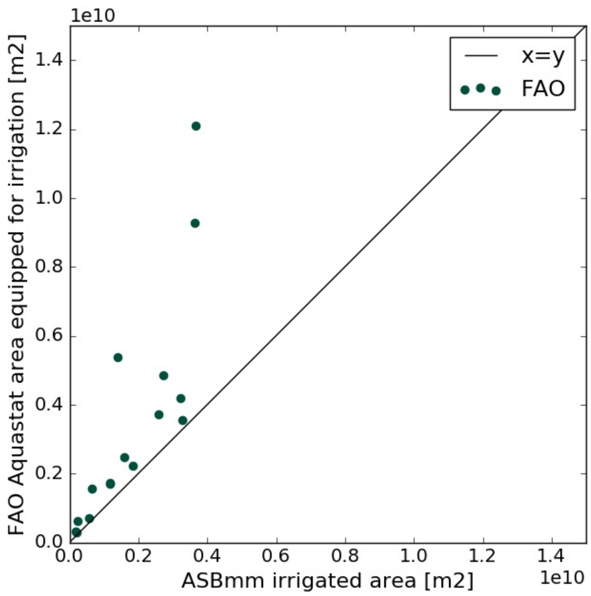

Figure C.5: Irrigated areas ASBmm compared to FAO areas equipped for irrigation per planning zone area

C.4 GRACE storage change

In 2002 the twin satellites of the Gravity Recovery and Climate Experiment were launched. Together they measure changes in the gravitational field of Earth (JPL, 2014), which can be used to calculate mass changes. This mass change can be related to terrestrial water storage change: when water moves, mass changes occur. This results in a global-gridded terrestrial water storage change estimate (Landerer and Swenson, 2012). GRACE terrestrial water storage data are generally used on a watershed and regional scale (Billah et al., 2015) or continental scale (Syed et al., 2008). We are unsure if they are also suitable for the smaller scale of this research.

The data are presented on a monthly basis in cm water thickness compared to 2004.0-2009.999 time-mean baseline (JPL, 2012). So the data are presented as the change in storage since this baseline. If we want to determine the difference in storage between two months, we simply subtract the early month from the last month. The data are available in a 1° in longitude and latitude but the neighboring cells are not independent (see Figure C.6).

The Geoforshungs Zentrum Potsdam (GFS), Center for Space Research at the University of Texas (CSR) and the Jet Propulsion Laboratory (JPL). All developed their own data processing method to get mass change (JPL, 2014). They all use their own parameter choices and calculations, these different approaches increase the understanding of the data.

In this research we look at the JPL[3] and CSR[4]. We compare these two for the analyzed areas to see whether GRACE can be used in this smaller scale analysis, namely the irrigated areas in the planning zones.

A scaling factor needs to be applied to the grace data before use. This scaling grid restores some of the data that was removed in the data processing. The grid is made by applying the filters in GRACE to a numerical hydrological model (JPL, 2012).

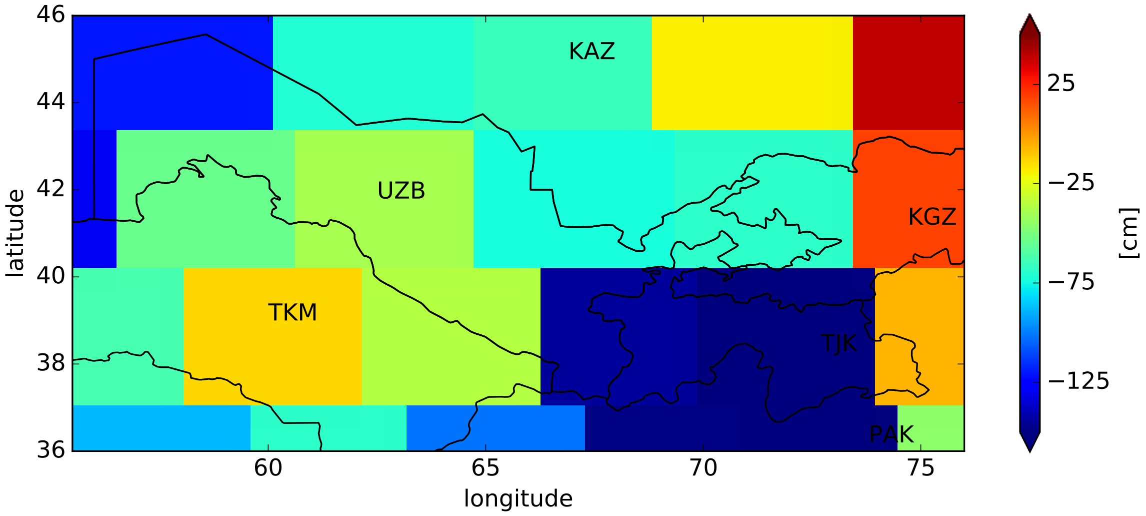

Figure C.6: GRACE CSR storage Central Asia compared to time-mean baseline April 2011

Grace is very useful to see trends in regional storage change (see Figure C.7[5]).

[3] $https://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/$
[4] $https://grace.jpl.nasa.gov/data/get-data/monthly-mass-grids-land/$
[5] http://ccar.colorado.edu/grace/gsfc.html

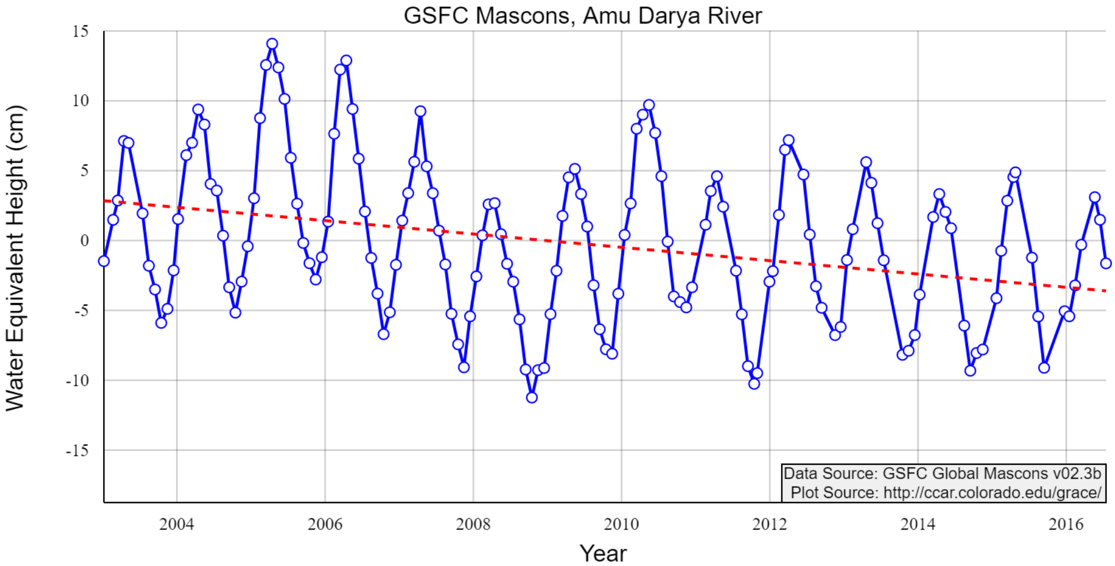

Figure C.7: GRACE annual and seasonal storage change trends

D

Effective Precipitation: Curve Number Method

The curve number method (CN method) is a semi-empirical method to estimate the runoff generated by a rainfall event. It was developed by the Soil Conservation Service(SCS) in the 1960s (Bos et al., 2008). The method is meant for daily precipitation or rainfall events but time is not an explicit variable in the method. Therefore it can theoretically be applied on any timescale, also monthly, seasonal and annual data.

The CN method assumes that precipitation is divided over initial abstraction (I_a), actual retention and runoff (Q) see figure D.1. F and I_a will result in evaporation and transpiration, this is defined as the effective precipitation (P_e), it is the part of the precipitation that does not result in runoff.

$$P_e = F + I_a P_e = P - Q \quad \text{(D.1)}$$

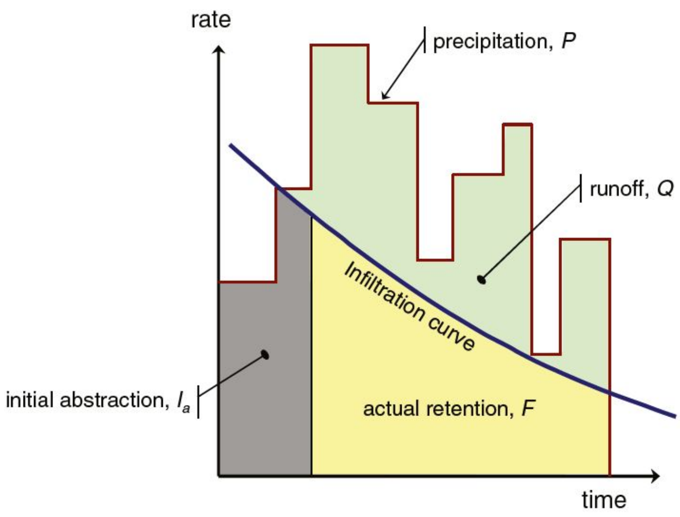

Figure D.1: Division of precipitation over initial abstraction, runoff and actual retention (Bos et al., 2008)

I_a consists of interception, initial interception and depression storage that occurs at the start of every rainfall event. As the method is meant for event based calculations this is only taken into account once. When applying the method on monthly, seasonal or annual precipitation data that consist of multiple rainfall events this causes an overestimation of the runoff. I_a is only taken into account once even though it would have occurred with every event.

Because the precipitation in the research area is relatively low, the precipitation will not surpass the actual retention by much therefore the error will remain low.

The SCS put the runoff in terms of precipitation in equation D.2.

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{D.2}$$

Where S is the maximum retention. Because it is undesirable to have to estimate two retention variables I_a is expressed in S based on a regression model with historical data by the SCS. This relation is not set in stone as the data showed a large scatter.

$$I_a = 0.2S \tag{D.3}$$

Applying this in equation D.2 results in:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} forP \geq 0.2S \tag{D.4}$$

This is the equation used in the CN method to calculate runoff resulting from precipitation. In this S is the estimated maximum retention which is expressed in the curve number.

$$CN = \frac{25400}{254 + S} \tag{D.5}$$

CN is dependent on land use or land cover, the hydrological condition of the soil, the hydrological soil group (includes infiltration and transmission rates) and the antecedent soil moisture conditions (see figure D.2. The antecedent soil moisture condition is applied as a correction on the CN following from table D.2. It is based on the soil moisture caused by precipitation and irrigation on the previous day, as we are working with monthly and seasonal precipitation this is not taken into account. We assume no previous soil moisture to influence the retention of precipitation.

For this research we use a curve number of 78. This is based on straight row crops with poor hydrological conditions and hydrological soil group B (see Figure D.2).

Land use or cover	Treatment or practice	Hydrological conditions	Hydrological soil group A	B	C	D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	81	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Terraced	Poor	61	72	79	82
	Terraced	Good	59	70	78	81
Close-seeded legumes	Straight row	Poor	66	77	85	89
Or rotational meadow	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Terraced	Poor	63	73	80	83
	Terraced	Good	51	67	67	80
Pasture range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadows (permanent)		Good	30	58	71	78
Woodlands		Poor	45	66	77	83
(farm woodlots)		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads, dirt			72	82	87	89
Roads (hard surface)			74	84	90	92

Figure D.2: Curve number table(Bos et al., 2008)

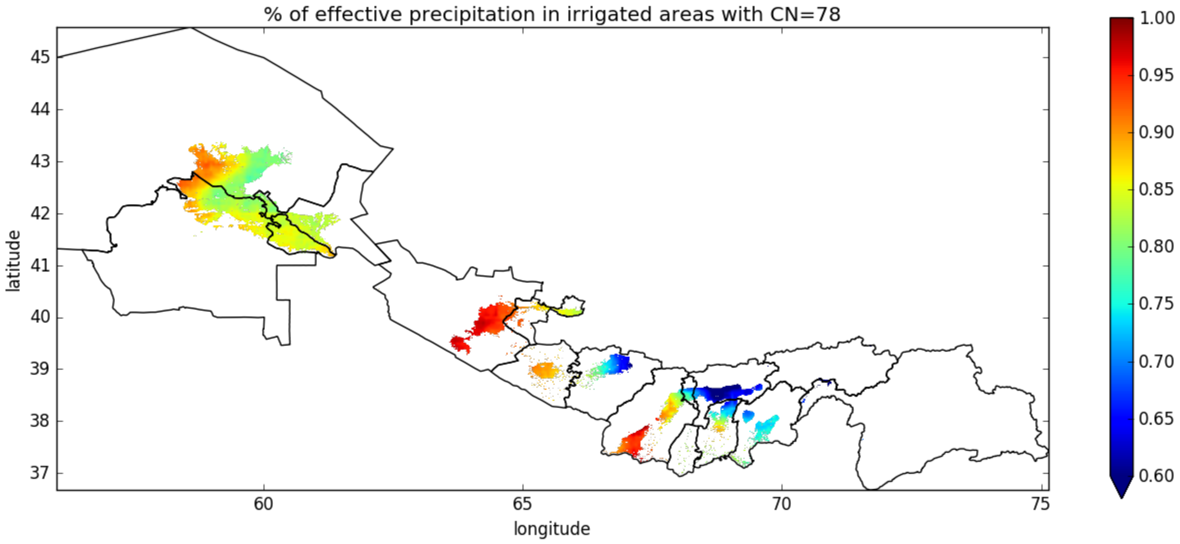

Figure D.3: % of effective precipitation for the irrigated areas in the Amudarya planning zones with CN=78

E

The World Bank

The World Bank(WB) is an international organization that supplies loans to developing countries and stimulates investments in development projects in these countries. Their vision is to reduce poverty and create a world with greater shared prosperity.

The Bank consists of two pillars, the International Bank of Reconstruction and Development (IBRD) and the International Development Association. The World Bank started with the IBRD. This pillar invests in projects in credible lower and middle income countries(World Bank, 2011). The IDA invests in projects in the poorest countries. The IDA offers loans with zero-interest rates on the contrary loans by the IBRD do have interest (Wade, 2002).

The WB is part of the umbrella the World Bank Group(WBG). Apart from the IBRD and IDA the WBG consists of three other agencies. The International Finance Corporation (IFC) promotes investments in the private sector, the Multilateral Investment Guarantee Agency (MIGA) insures political risks for investors and the International Center for Settlement of Investment Dispute (ICSID) mediates in disputes between countries and investors.

The WB was founded together with the United Nations (UN) and the International Monetary Fund (IMF). They were founded after World War II to stimulate international peace and international co-operation(World Bank, 2016c). The IMF supplies loans to countries in crisis, for instance Greece in 2010, to help them get back on their feet. This is different from WB activities as the WB invests in specific projects and not in the countries as a whole. The two are different entities but are linked in some ways, for instance a country has to be a member of the IMF to be able to become a member of the WB.

The WB was founded by the US and UK to help rebuild Europe. Now the IBRD has 189 members and the IDA has 174 members. A country has to be a member of the IBRD to become a member of the IDA. The WBG is ultimately steered by all its member countries, the Board of Governors. Usually the minister of finance is the representative of the country in this board. They come together once a year. In practice the WB is led by the Board of Directors which consists of 25 executive directors (EDs) and the President(World Bank, 2016d). The five largest shareholders (US, Japan, Germany, UK and France) appoint their own ED where the other 20 are elected every two years by the other member states. The rising economies are opting for their own ED. The president is chosen by the EDs and has so far always been an American.

The president is assisted by vice presidents and managing directors to keep an eye on the general functioning of the Bank. Most officers report back to the managing directors. The vice presidents and the chief financial officer report directly to the president. The directors of the inspection panel and independent evaluation panel report directly to the Board of Directors(World Bank, 2011).

Two of the managing directors head the regional offices. The WB decentralized most of its activities into six regions: Africa, Europe and Central Asia, South Asia, East Asia and the Pacific, Latin America and the Caribbean, and the Middle East and North Africa.

Apart from the regional divisions, the World Bank works with Global Practices and Global Themes. These are used to stimulate thematic interaction between the different regions. There are 14 global practices and five cross cutting Global Themes [1].

E.1 Policies

When a policy is made or reformed, the WB involves internal and external experts. The experts range from local experts to internal and international experts on relevant fields. Regional and network staff are brought together and write the policy through an iterative process. The policies are written according to the Comprehensive Development Framework(Eriksson, 2004). It has to be a holistic and long term strategy in which the country takes the lead. The policy promotes stronger relationships between stakeholders and has to be transparent and accountable for success.

Environmental assessment, natural habitats, pest management, involuntary resettlement, indigenous peoples, forests, cultural resources, dam safety, international waterways, and projects in disputed areas are defended by 10 Safeguard Policies(World Bank, 2011).

E.2 Project cycle

The project cycle for World Bank projects is explained in World Bank (2011). A project is always initiated by a country or multilateral organization and then further developed in collaboration with the World Bank. The country develops a national poverty reduction strategy so the donors can invest in projects that align with the countries national policy. The WB has a Country Assistance Strategy (CAS). The bank and the borrowing country provide a strategy after a thorough analysis.

The project concept is outlined in a project concept note. This includes objectives, risks and alternatives and a proposed timetable. The project information document and integrated safeguards data sheet are also produced. These provide insight into public documents and key environmental and social safeguards. This is when the project implementation plan gets formulated. In this phase no consultants are hired or involved.

The country is responsible for the project preparation phase. They can consult the investors, consultants and other companies when necessary. An action plan is created when issues are noticed that are described in one of the WBs safeguard policies.

The stakeholders are given the opportunity to voice concerns and ask questions in the appraisal report. After all aspects are confirmed and agreed to by all parties the project information document is updated and made public. When the project is running there are several review moments. The project is closed with implementation completion reports documenting the results, problems and lessons learned. The independent evaluation group evaluates 1 in 4 projects on impact and performance. The functioning of the project is monitored by the Quality Assurance Group.

Impact evaluation documents identify the relation between changes and the implemented projects. For instance the impact of a poverty reduction project on the poverty in a region or country.

[1] http://www.worldbank.org/en/about/unit

E.3 Partners

The WB works together with its donors and the countries borrowing, with other regional and sub-regional development banks like the Asian Development Bank. The WB also partakes in thematic global partnerships and regional partnerships. It coordinates and works together with bilateral development agencies. The WB involves NGOs in project implementation. Country offices make use of civil society consultation. These organizations range from religion based to trade unions and student organizations. The WB also sees its staff as a great collaborative asset. Many have an academic background and live in the country they work in. At the WB office several programmatic partnerships are hosted. i.e. the Consultative Group on International Agricultural Research (CGIAR) and the Global Environment facility WB in Central Asia Investments in the region are mostly in financial development(World Bank, 2016e). Turkmenistan is not a member of IDA. Kyrgyz Republic and Tajikistan are not a member of ICSID.

E.4 Water

Water resources management is directly linked to five global practices: Water, Agriculture, Environment & Natural Resources, Energy and Transport. Of which the Water and Agriculture Global Practices are most important when looking at irrigation based interventions. Energy and Environment & Natural Resources should also be adressed in the competition for water. The Water Global Practice is based on six pillars: Water Supply and Sanitation, Water Security and Integrated Resource Management, Water for Agriculture, Water, Poverty, and the Economy and Hydropower and Dams(World Bank, 2016a), here we can see the links to the other Global Practices.

Poverty reduction is the first and foremost target of the Bank, water policy is used as a tool to get to this target. The World Bank advocates A Water-Secure World for All (World Bank, 2016a). The World Bank has a water vision described in the world bank High and Dry report (World Bank, 2016b). However there are some differences with policy descriptions between the World Bank website, the actual active projects and the High and Dry report. On the topic of water for irrigation, the website shows insight into the connectivity of hydrological systems, analyzing from a water consumption perspective. However the High and Dry report and the projects currently in progress in Central Asia show a tendency to invest in infrastructure rehabilitation and improving irrigation efficiency. There is a dissonance between the large scale vision in global policy and the small scale approach taken in actual projects.

The agricultural and rural development department (ARD) is a monitoring and advisory department for agricultural related issues. The ARD implements the WB strategy and links different entities that work on agriculture related topics within and outside the WB. The world bank Group's strategic framework on development and climate change guides the world bank policies in sectors that influence or are influenced by climate change. The WB invests in environmental projects in developing countries, the environmental department is responsible for these strategies. Increasing agricultural productivity and sustainable energy are high on the agenda of several WB departments (i.e. agriculture, food and energy departments but also climate change). Water and sanitation and urban water are dealt with by the Infrastructure department. The Sustainable Development Network stands for social, environmental and economic sustainability in projects. They work with the other departments. "Meeting future food needs will require more efficient water use and additional sources of supply to support the increasing demand for water for agriculture."(World Bank, 2011) The water department focuses on i.e. dams, reservoirs, hydropower, irrigation, watershed management and water and environment and economics.

E.5 WB in Central Asia

Investments in the region are mostly in financial development. Turkmenistan is not a member of IDA. Kyrgyz Republic and Tajikistan are not a member of ICSID.

A large project in Central Asia is the Central Asia Energy and Water Development Project (CAEWDP), this is a multi donor trust fund (MDTF) promoting more collaboration among the states in the region. One of the projects currently going on is the promotion of Irrigation efficiency in Tajikistan. A grant of $ 250,000 is used to research how to deal with 'wasteful water use' and improve 'efficiency'(World Bank, 2014). The research found that irrigated areas do not get enough water so the efficiency improving technologies they approach will not decrease abstraction but will increase productivity. The focus is on decreasing pumping and production costs and increasing productivity by promoting new technologies, one of the pillars is to increase awareness of the importance of efficient irrigation water use (World Bank, 2015). Another investment is for strengthening irrigation governance, where $170,000 is devoted to improving local irrigation practices through technology (World Bank, 2014), the main goal is creating cost benefits for the users.

Apart from the CAEWDP, the world bank also invests in country projects in the region. These projects are generally focused on increasing the agricultural production. This usually includes infrastructure rehabilitation. A map of these projects in Central Asia can be found in Figure E.1.

Figure E.1: Agriculture projects in Central Asia currently active source: World Bank[2]

Dukhovny and de Schutter (2011) quotes the World Bank as follows: "although the World Bank encourages solving the Aral Sea issues, it did not accept that the bank's participation in improving transboundary basin management should be a key part of the World Bank's policy for assisting the region and countries". This signifies the Bank in central asia did not focus on transboundary interventions, however with the CAEWDP this might have changed in one of their projects. Dukhovny and de Schutter (2011) also mention bad experiences with the bureaucracy and time delays in World Bank projects in Central Asia.

[2]http://maps.worldbank.org/p2e/mcmap/index.html date accessed: 2018/05/02

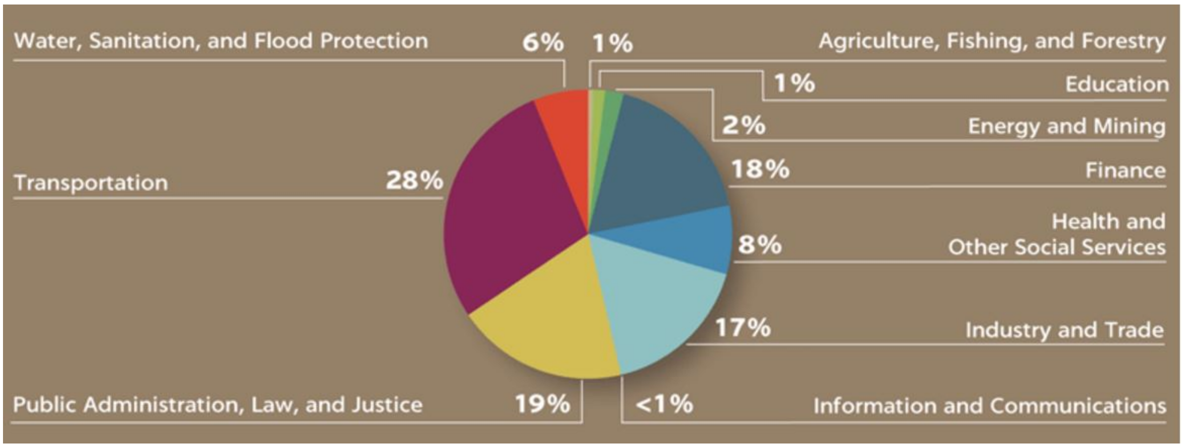

Figure E.2: Europe and Central Asia IBRD and IDA lending by sector, fiscal year 2016, share of total of $7.3 billion (World Bank, 2016f)

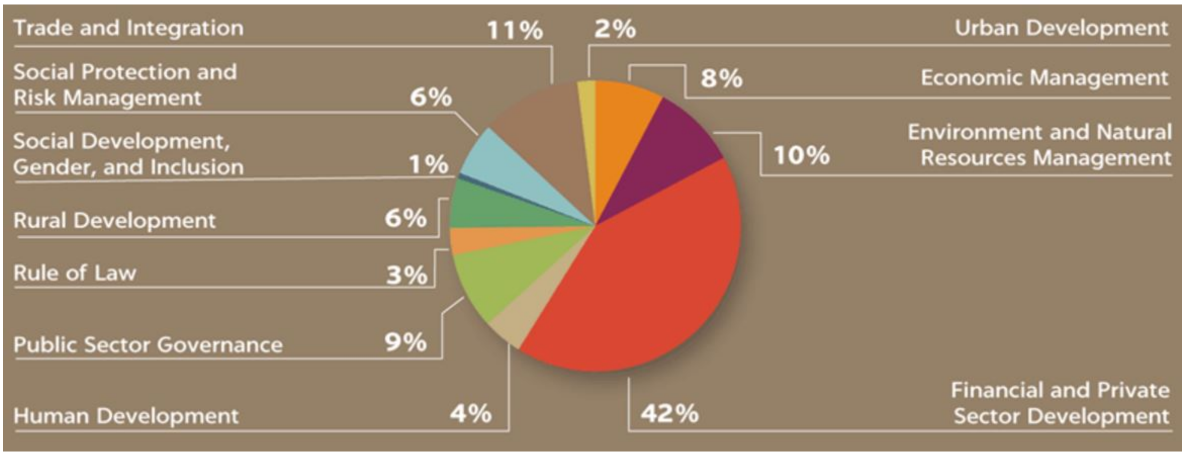

Figure E.3: Europe and Central Asia IBRD and IDA lending by theme, fiscal year 2016, share of total of $7.3 billion (World Bank, 2016f)

F

Systematic literature review

F.1 Introduction

The World Bank wants to reduce poverty and one of the pillars it is working on is improving access to water. To be able to do this as best as possible, providing water for the poor without damaging the ecosystem and environment, the World Bank needs to keep up with scientific developments. Some of these scientific developments are on a different scale than World Bank projects. So on the one hand the World Bank needs to keep up with scientific development while on the other hand it needs to adapt these theories in such a way that they are suitable for application in practice. One of the challenges in adapting large scale scientific theories for practice is communication and knowledge transfer.

This challenge can be researched from a social network and social capital perspective. A social network provides access to knowledge and information (Alguezaui and Filieri, 2010; Hertzum, 2014) and learning through network connections are vital to the effectiveness and innovation capacity of an organization (Adler and Kwon, 2002; Filieri et al., 2014; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998). Innovation is defined by the Merriam-Webster dictionary as "the introduction of something new" or "a new idea, method, or device"[1]. So introducing large scale concepts in groups focused on small scale projects will be seen as innovation. Where social network theory gives us insight in the network and interactions in this network, social capital theory adds a layer of resources (Brookes et al., 2006). Nahapiet and Ghoshal (1998) defines social capital as "the sum of the actual and potential resources embedded within, available through and derived from the network of relationships possessed by an individual or social unit". Development of social capital is key for knowledge transfer (Adler and Kwon, 2002; Brookes et al., 2006; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998), access to information is one of the key benefits of social capital(Adler and Kwon, 2002). There is overlap between social network theory and social capital theory, as social capital exists within a network, together they give us handholds on how to analyze the success of knowledge transfer within a network. In this outline of the literature we will go into scientist-policy interaction, the process of knowledge transfer, and social capital and its three dimensions (cognitive, relational and structural). Lessons from social network theory will be incorporated in the outline of social capital because they are so strongly interlinked, mostly in the structural and relational dimensions of social capital.

For this research we are looking in two directions: (1) the external communication between the World Bank and academics and consultants and (2) the communication between the World Bank general policy level and World Bank project level. In this literature review we will address the difference between internal and external networks.

[1] https://www.merriam-webster.com/dictionary/innovation

Research on social capital and social networks is done from the individual and organizational perspective (i.e Adler and Kwon (2002); Alguezaui and Filieri (2010); Ali-Hassan (2009); Brookes et al. (2006); Filieri et al. (2014); Inkpen and Tsang (2005); Nahapiet and Ghoshal (1998)), where the organizational perspective mostly focuses on the competitive advantage of firms. As we are dealing with the World Bank, which is no regular firm, some of the theories might be adjusted slightly. It will be an extra challenge to see if we can apply the theories on this extraordinary organization.

F.2 Method

This literature review deals with knowledge transfer and communication between experts and policymakers, social networks and social capital. The literature search was conducted in the Web of Science database[2] and were additionally checked in the Scopus database[3], no big differences were found between the two databases. The numbers mentioned in this review are from Web of Science.

The database was searched using search terms combined with the operators to specify the search[4]. The AND command is used to include both terms on either side of this command, with the OR command one of the two terms next to this command occurs in the search items. When brackets are used, the command only works for the terms between the brackets. Quotation marks are used to treat multiple terms as one search term together. Finally an asterisk was used to include different varieties of a term, for example scien* uses the search terms: science, scientific, scientist etc. All searches were first conducted between 2008 and 2018, in a time span of 10 years, however if the search did not result in successful results this was broadened to 20 years. The search terms

F.2.1 Scoping

Some broad and precise searches were done to determine the search boundaries of the literature review. The precise searches were done to explore literature on knowledge exchange between experts or scientists and the World Bank as well as literature in this field with the specific topic of water. Table F.1 shows the search terms used in this exploration. From this table we can see that combining search terms about social capital and social networks with water or "World Bank" does not give a lot of results. The results that do come up in for instance the combination of social networks with water concern involvement of rural communities in water management Horning et al. (2016); Tringali et al. (2017). Therefore we move to a broader literature search.

The broad literature search shows the vastness of the body of literature on social capital, social networks and knowledge transfer. Table F.2 shows some search terms and the number of articles. The articles on social capital and social networks span many different disciplines. For this research the scope needs to be more specifically on knowledge exchange and social capital, but even then the number of articles is too great to be able to analyze in this study. Therefore the search queries were more tailored to the needs of the research.

F.2.2 Queries included in review

This subsection outlines the search terms which resulted in the articles that were included in the literature review. The combinations were chosen based on the outcomes of the broad and narrow searches described in the previous subsection. This includes searches on the expert-policymaker interface, social capital and knoweldge transfer and social networks and knowledge transfer. Some alternative terms were used to cover more subtle language differences between researchers, e.g. transfer and exchange, and knowledge and information. search was conducted on communication between experts and policymakers with the search terms:

[2]https://www.webofknowledge.com
[3]https://www.scopus.com
[4]https://images.webofknowledge.com/images/help/WOS/hs_search_operators.html

Table F.1: Search terms for the narrow literature search

Search term	time range	results
knowledge AND communication AND exper* AND scien* AND "World Bank"	1998-2018	1
"social capital" AND "knowledge transfer" AND ("World Bank" OR water)	1998-2018	1
knowledge AND communication AND exper* AND policymaker* AND scien* AND (water OR "World Bank")	1998-2018	1
TITLE: "social capital" AND "knowledge" AND (dimension* OR attribute*) with TOPIC: water OR "World Bank"	1998-2018	0
"structural dimension" AND "social capital" AND (knowledge OR information) AND (sharing OR exchange) AND network* AND (water OR "World Bank)	1998-2018	0
"structural social capital" AND "knowledge transfer" AND network* AND (water OR "World Bank)	1998-2018	0
"social network" AND "knowledge transfer" AND "World Bank"	1998-2018	0
"social network" AND "knowledge transfer" AND water	1998-2018	4

Table F.2: Search terms for the broad literature search

Search term	time range	results
"social capital"	2008-2018	15436
"social capital" AND communication	2008-2018	1139
"social capital" AND "knowledge transfer"	2008-2018	245
"social network"	2008-2018	28120
"social network" AND communication	2008-2018	4315
"Social network" AND "knowledge transfer"	2008-2018	232
knowledge AND communication AND exper*	2008-2018	31533
knowledge AND communication AND exper* AND policymak*	2008-2018	77

TOPIC: knowledge AND communication AND exper* AND policymaker* AND scien*

The goal was to find literature dealing with the challenges arising from the exchange of knowledge between scientific experts and policymakers. For exper* and scienc* asterisks were used so also words like expertise and science and scientist were included in the search. In this search 11 articles were found, 3 were selected. 8 were discarded because they were to case specific and deemed not relevant based on reading the abstracts.

The body of literature dealing with social capital is very big. For researching this topic two search strings were used. One to find literature reviews on social capital and the other to find literature to deal with the social capital dimensions. These search strings were conducted over the time period 1998 to 2018, 20 years. The first resulted in three hits of which two were included, the second resulted in 2 hits of which one was included in the analysis.

TITLE: "social capital" AND "knowledge transfer" (only reviews) TITLE: "social capital" AND "knowledge" AND (dimension* OR attribute*)

The structural dimension of social capital deals with network structure and is therefore closely related to network theory. Therefore the search continued specifically on the structural dimension of social capital in combination with network and knowledge. This search was done between 2008 and 2018 and resulted in 6 hits of which three were incorporated in the literature review.

TOPIC: "structural dimension" AND "social capital" AND (knowledge OR information) AND (sharing OR exchange) AND network*

As we encountered the structural dimension also as structural social capital, we conducted a search with structural social capital and networks. This search was again done between 2008 and 2018 and resulted in nine articles of which three were incorporated.

TOPIC: "structural social capital" AND "knowledge transfer" AND network*

Next we also want to include literature from the social network analysis body of literature in which networks are central. Just like in the social capital literature we focus on literature reviews, this time between 2008 and 2018. The search resulted in eleven sources of which only two were deemed useful based on the specificity of most of the sources (i.e. focusing on sexual networks or online social networks).

TOPIC: "social network analysis" AND tie* AND (information OR knowledge) TITLE: network*

To go deeper into certain facets of social capital we searched specifically for the impact of the spatial dimension of social capital. As the external network and internal network of the World Bank are geographically sparse. This search was done between 2008 and 2018, it had three results of which one was deemed useful after reading the abstracts.

TOPIC: "spatial dimension" AND "social capital" AND network

Because of frequent citations and references both in the social capital field and in the literature found in this review, I chose to include Nahapiet and Ghoshal (1998) and Adler and Kwon (2002) in this literature review. The article by Nahapiet and Ghoshal (1998) forms the basis of the social capital dimensions to be used in this analysis while Adler and Kwon (2002) gives more depth to the concept of social capital. Additionally Colemans (1988) and Burt (2000) will be included as they signify the two network perspectives that are interesting to look at, an open and a closed structure.

F.3 Knowledge transfer

Keeping up with the ever changing world requires access to new knowledge (Alguezaui and Filieri, 2010). This knowledge is needed to continue to adapt and innovate policy and practice(Walter et al., 2007). Knowledge exists but to get the most out of it, it needs careful development, energy and nourishment (Widén-Wulff and Ginman, 2004). Knowledge can be tacit (based on experience) or explicit (formal and systematic) (Filieri et al., 2014), but is mostly a combination of the two (Alguezaui and Filieri, 2010). Generally more explicit knowledge is easier to transfer. Filieri et al. (2014) said "knowledge is the raw material for innovation", combining knowledge exchange through interactions and cooperation will stimulate innovation (Alguezaui and Filieri, 2010). To get to innovation an organization needs to be able to access, transfer, absorb and apply knowledge successfully (Díez-Vial and Montoro-Sánchez, 2014).

One of the key ways to get access to knowledge and the opportunity of new knowledge development is through connections with other people, through their network and relationships (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Widén-Wulff and Ginman, 2004). These links facilitate the process of knowledge exchange. In this process people or organizations share their ideas and experiences, when successful the experience of one of the parties influences the other (Walter et al., 2007). Learning through these interactions plays a critical role in innovation and in the growth and effectiveness of the organization(Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998). Not only access to knowledge outside the organization but also effective transfer within an organization between business units and people is essential for effective adaptation of knowledge (Walter et al., 2007).

In this research we approach knowledge exchange form a network perspective. In this perspective the ability of an organization to exchange knowledge successfully is dependent on the network configuration and the state of social relations within the network (Díez-Vial and Montoro-Sánchez, 2014), this can for instance be characterized by the number and type of links in the network (Walter et al., 2007). On this topic more further on in the literature review. The extent to which a company is able to innovate is also dependent on its attitude to new knowledge, their ability to recognize the value of new knowledge, its absorptive capacity Alguezaui and Filieri (2010).

F.3.1 In context

The World Bank is an international investment organization with great impact on the world's development projects, therefore it is crucial that they stay up to date to the latest research and different views on for instance environmental impacts of interventions. Knowledge exchange, adaptation and development through their internal and external network is key to the creating successful development projects without creating unintentional harm.

We will now look at the case of consumed fractions, basin efficiency and irrigation efficiency in the context of innovation and adaptation of new knowledge at the World Bank. Currently the majority of the organization is working in the paradigm: increasing irrigation efficiency is a good strategy for poverty reduction and the mitigation of water shortages (see appendix E). Changing to a new paradigm, improving irrigation efficiency can also have negative consequences when looking at the large scale, would mean a radical innovation in the view of the World Bank. To achieve such a radical change a cohesive and high trust network is needed (Alguezaui and Filieri, 2010).

F.4 Science–Policy interface in environmental systems

When we talk about the adaptation of new scientific knowledge in an organization or practice, there is interaction between the science and non-science side. In this case we focus on scientist-policy literature in environmental context.

Natural systems are complex systems, they should be managed based on the best available knowledge (Sterman, 2011), however the best available knowledge does not only include scientific knowledge but also opinions and views of other actors (Balian et al., 2016). Science is not the one and only truth, objective and value free (White et al., 2009). Scientific research is crucial in proper management of complex natural systems. Successful use of scientific knowledge in decision making requires an understanding of the needs of the policy maker(Balian et al., 2016) and human mental models (Sterman, 2011). It is argued that communication of science and even research should be more demand driven (Balian et al., 2016; Sterman, 2011) this increases relevance, while a supply driven approach can enhance credibility. Communication of research has to show the uncertainties of the study but still be clear to read, there needs to be a balance between simplification and credibility (Balian et al., 2016).

In communicating science with policy makers there are some barriers that need to be overcome, from a policymaker perspective and from a scientist perspective. One issue is the overwhelming number of publications (Balian et al., 2016). This makes it hard for a policy maker to choose which publication to use but also makes it possible for policy makers to cherry pick. It can be the role of the scientist to provide the policy maker with the best available knowledge fitting their demand (Balian et al., 2016) however this costs time and does not fit the current reward system for scientists (Balian et al., 2016; Lee, 2009; White et al., 2009). Another barrier in the communication between policymakers and scientists and even between scientists of different disciplines is a difference in background and culture (White et al., 2009; Widén-Wulff and Ginman, 2004) and the use of different jargon, paradigms, language and narratives (Balian et al., 2016; Sterman, 2011; White et al., 2009). Additionally the parties can have contradicting goals (Inkpen and Tsang, 2005), expectations and there can be bureaucratic obstacles (White et al., 2009). Different stakeholders can think on different scales (Alexander and Armitage, 2015; White et al., 2009).

Another obstacle are the previously mentioned human metal models described by Sterman (2011) in the context of climate change communication. These are not specific to the policymaker-scientist interface, but are present in most people. Our brain is not always able to process dynamic and complex natural phenomena. The human brain finds it difficult to understand feedback processes, nonlinearity and probability. We are mentally focused on short timescale and local impact of our actions and tend to have a 'wait and see' approach while with long term effects usually we cannot successfully change our behaviour by the time we see the effect. Additionally we have a tendency to find knowledge that support our current opinion and we tend to judge our own experiences as more valuable than other sources (this is wat we can also see in the polarization processes, i.e. in the US), we try to avoid cognitive dissonance. These mental models which Sterman (2011) puts in the context of climate change are also relevant for the introduction of other large scale theories in practice.

A way to bridge some of these barriers is through inclusion of stakeholders over the research process, from the formulation of research questions to the implementation (White et al., 2009) and stimulating experimental learning in knowledge transfer (Widén-Wulff and Ginman, 2004), where there is attention for the process which leads to better common understanding.

F.4.1 In context

When we look at the adaptation of scientific knowledge in the World Bank on the topic of efficiencies in water management we can learn from the literature on knowledge exchange about complex natural systems. In this case we work with a large scale theory and we want to see how it can be channeled through to smaller scale practice in the World Bank. There will be some differences in knowledge, culture and language between the actors and research is not tailor made for World Bank application. For the involved scientists it is important to take the wider context into account while on both sides we need to look critically at the reward systems and incentives to stimulate knowledge transfer. Because the basin approach of efficiency deals with a complex dynamic system with large spatial and temporal scales, it is important to also keep the human mental models in mind.

F.5 Social capital

Social capital is a term that is used in many different disciplines and has many different definitions (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998; Rutten et al., 2010), Adler and Kwon (2002) cites skeptics who call it a "wonderfully elastic term" and a term that means "many things to many different people". In this literature review we will not focus on all the different definitions of social capital. The used definition is by Nahapiet and Ghoshal (1998) "the sum of the actual and potential resources embedded within, available through and derived from, the network of relationships possessed by an individual or social unit", and is used in knowledge transfer research Adler and Kwon (2002) (see figure F.1). In this research knowledge is the main resource but we need to keep in mind other resources, like monetary resources, solidarity and power and influence. To this definition Adler and Kwon (2002) adds the concept of goodwill, the resources are theoretically available through the network but goodwill of the members is crucial in actual successful transfer of resources. This definition includes both the structuralist (social capital exists in the network) and the interactionalist perspectives (social capital is created through interactions) (Rutten et al., 2010), and includes both a view on internal and external relations (Adler and Kwon, 2002).

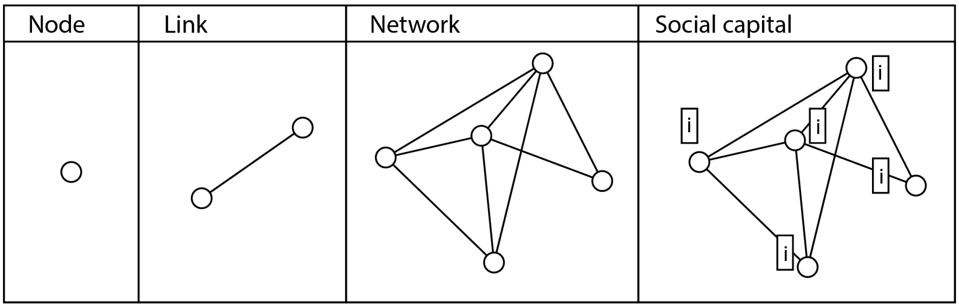

Figure F.1: node, link, network, social capital. In social capital resources, like information, are embedded in the network (based on (Brookes et al., 2006))

Professional network relationships are often formed as a way to access information for the organization (Filieri et al., 2014; Inkpen and Tsang, 2005). Social capital can be individual or organizational, the first originates from an individual's personal network and is used for personal purposes, the second exists within an organization and is a public good (Alguezaui and Filieri, 2010). Individual and organizational social capital are interlinked (Inkpen and Tsang, 2005; Walter et al., 2007; Widén-Wulff and Ginman, 2004), so access to resources in an individual's network can lead to an increased organizational social capital.

The benefits of social capital have been researched extensively, as mentioned before, it supports knowledge exchange and access to knowledge(Adler and Kwon, 2002; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998), and boosts innovation (Alguezaui and Filieri, 2010; Filieri et al., 2014). Other benefits are power and influence and solidarity. Inkpen and Tsang (2005) argues that social capital development should be actively pursued. However pursuing social capital takes time and resources, therefore it is important to weigh the costs and benefits. Sparse and dense networks both have their own risks and benefits (Adler and Kwon, 2002), more on this in section F.5.1 and F.5.2. The impact of social capital development can also be different for different cultures, for instance a dense cohesive network might function better in collectivist cultures while an open network might function better in western countries (Lee, 2009). The World Bank is an international organization, with an international staff and will have to deal with these differences in cultures. Research on the negative implications of social capital development is limited (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Lee, 2009).

Nahapiet and Ghoshal (1998) uses three dimensions to categorize social capital: the structural dimension, the relational dimension and the cognitive dimension. The structural dimension concerns the network configuration and patterns of connections, the relational dimension deals with the network ties and the influence of for example trust on knowledge exchange, the cognitive dimension is the least researched and looks at shared language, codes and narratives of network actors. Inkpen and Tsang (2005) also includes shared goals and shared culture in the cognitive dimension. These dimensions are used research on the role of social capital in knowledge transfer i.e. by Alguezaui and Filieri (2010); Díez-Vial and Montoro-Sánchez (2014); Inkpen and Tsang (2005); Widén-Wulff and Ginman (2004). They are now presented as separate dimensions, they are however very much interlinked (Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Lee, 2009; Nahapiet and Ghoshal, 1998; Widén-Wulff and Ginman, 2004), therefore it is hard to measure them separately and it good to include all dimensions in an analysis (Walter et al., 2007).

F.5.1 Structural dimension

As already mentioned, the structural dimension of social capital deals with the network configuration, the patterns of connections and exchange in a network (Díez-Vial and Montoro-Sánchez, 2014; Filieri et al., 2014; Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998; Schultz-Jones et al., 2009; Walter et al., 2007). We will use social network analysis to look at the structural dimension of social capital. The structural dimension provides the context in which knowledge exchange can take place, the network does not cause the exchange it merely facilitates (Alexander and Armitage, 2015; Inkpen and Tsang, 2005; Rutten et al., 2010; Schultz-Jones et al., 2009; Widén-Wulff and Ginman, 2004).

A network consists of nodes and ties (Alexander and Armitage, 2015), in which nodes can be people, business units or organizations depending on the scale, they are linked by ties and the structure of these linkages provides a network. The network structure can be analyzed in terms of density, size, node centrality and stability (Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Lee, 2009; Schultz-Jones et al., 2009). These variables influence the flexibility of the network and affect the effort needed for knowledge exchange (Inkpen and Tsang, 2005; Walter et al., 2007). In this research we will mainly focus on network density, in particular the difference between the cohesion(Colemans, 1988) and structural holes (Burt, 1992, 2000) approaches. However we will keep the concepts of centrality, size and stability in mind as they are linked.

Thus the manner in which knowledge management within a network is most effective is dependent on the network structure, but there is not one network structure which will always allow the best knowledge management. For different purposes we want a different structure. The dependence of social capital analysis on network structure was outlined by Inkpen and Tsang (2005), where they apply social capital theory on three common organizational networks. This also relates to the difference between the interfirm network and the intrafirm network discussed by Walter et al. (2007) and also highlighted by Adler and Kwon (2002). Even though network typed give different context to personal and organizational social capital, the dimensions are still applicable in all cases (Inkpen and Tsang, 2005).

The majority of research on social networks focuses on networks at a fixed point in time, however the development of a network over time needs to be taken into account (Filieri et al., 2014; Schultz-Jones et al., 2009), this is related to network stability.

Density

Network density is the number of ties relative to the number of potential ties (Walter et al., 2007). So in a sparse network the number of ties is relatively low compared to the number of possible ties between nodes and in a dense network the other way around. This is the difference between a cohesive network (Colemans, 1988) and a network with structural holes (Burt, 1992, 2000). The theory of dense networks and networks with structural holes can be complemented by the bonding and bridging ties.

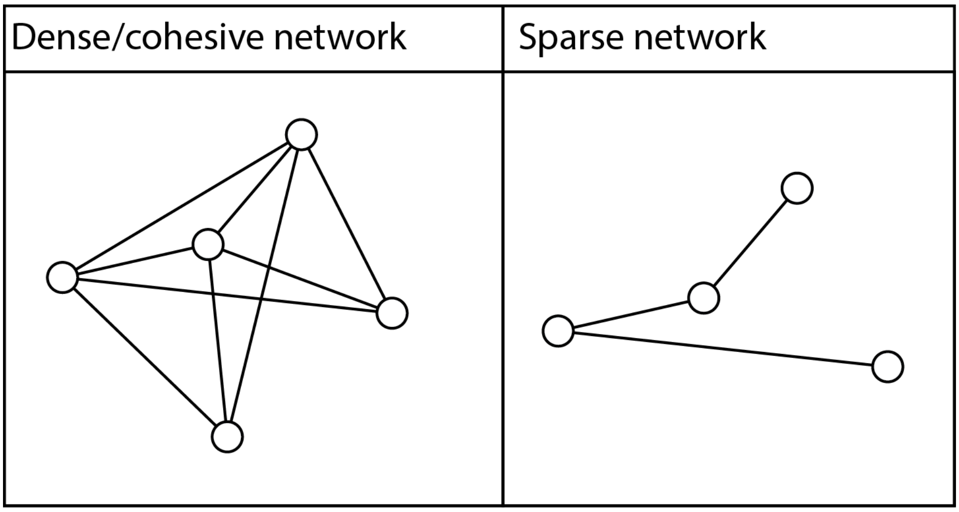

Figure F.2: Dense and sparse network

Structural holes

A sparse network is signified by structural holes and no redundant bridging ties, A bridging tie is a unique link to an actor or actor group which is otherwise not connected to the network, it is the bridge across a structural hole (Burt, 1992). A structural hole separates non-redundant sources (Burt, 2000). Burt (1992) argues bridging ties are the most effective for knowledge transfer (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Rutten et al., 2010; Walter et al., 2007), and provide access to heterogeneous and complementary knowledge (Alguezaui and Filieri, 2010; Filieri et al., 2014; Lee, 2009; Schultz-Jones et al., 2009; Walter et al., 2007). These outward ties provide the opportunity of learning and development for the organization (Inkpen and Tsang, 2005). The network node bridging a structural hole is a broker, she controls the knowledge flow (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Walter et al., 2007). The advantages of a sparse network include: access to new and heterogeneous information (Alguezaui and Filieri, 2010; Filieri et al., 2014; Lee, 2009; Schultz-Jones et al., 2009; Walter et al., 2007), power and influence for the knowledge broker (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Walter et al., 2007), efficient inter organizational knowledge sharing(Alguezaui and Filieri, 2010) and low costs in maintenance(Díez-Vial and Montoro-Sánchez, 2014; Walter et al., 2007) compared to a cohesive network.

However there are also some drawbacks. Within an organization a sparse network can lead to inefficient knowledge sharing, an unstable organization (Walter et al., 2007), and lack of action (Alguezaui and Filieri, 2010). When a node in a brokerage position leaves the network this can lead to problems as they take the bridging link(Lee, 2009). When many nodes try to bridge a structural hole this can backfire as the network will become cohesive and the benefits of a sparse network will disappear (Walter et al., 2007). A persons access to bridges across structural holes determines their centrality(Lee, 2009) and also gives them value to an organization or organizational unit.

Network closure

Contrary to a sparse network, a cohesive and dense network is signified nodes with many redundant connections and bonding ties, here we see what Colemans (1988) defined as closure (Alguezaui and Filieri, 2010; Colemans, 1988; Filieri et al., 2014; Lee, 2009; Nahapiet and Ghoshal, 1998; Walter et al., 2007). A cohesive network requires frequent interactions to develop bonding ties in which trust is central (Alguezaui and Filieri, 2010; Colemans, 1988; Lee, 2009; Rutten et al., 2010), in a dense network there is a kind of social monitoring which makes it less risky to trust (Burt, 2000; Colemans, 1988). A dense network also makes information transfer easier(Walter et al., 2007), when similar information seeps through the network from different sources it is reaches everyone

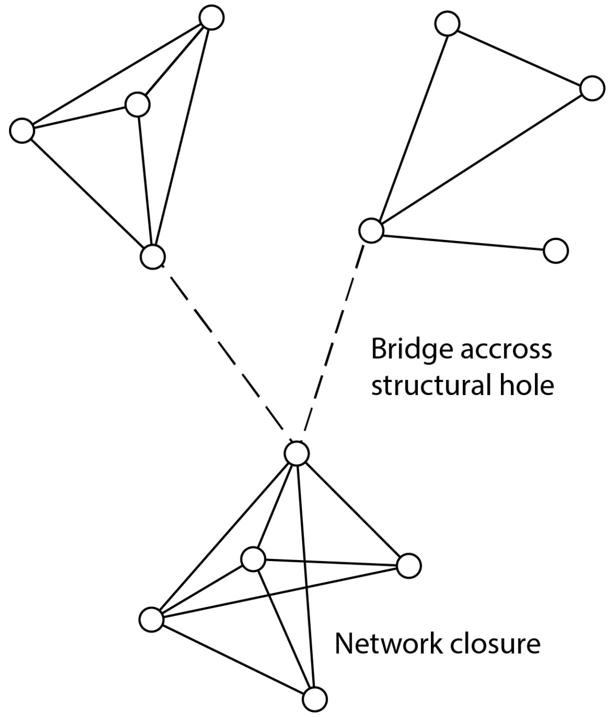

Figure F.3: Bridging structural holes between dense networks

more quickly and is more readily adapted. Additionally it is easier to build a shared identity, language and culture in a cohesive network (Alguezaui and Filieri, 2010; Filieri et al., 2014; Rutten et al., 2010; Walter et al., 2007). These advantages come at a higher cost of network maintenance and inwardly focused information flow, a cohesive network is restrictive for the innovative potential of an organization (Alguezaui and Filieri, 2010; Burt, 2000; Lee, 2009).

The cohesive and sparse network approaches are contrasting and also in a way complementary(Burt, 2000; Filieri et al., 2014), the two can contribute in different stages of knowledge transfer. Burt (1992) and Colemans (1988) both see the value of sparse and dense networks depending on the context and purposes of the network (Walter et al., 2007). External structural holes are necessary to access information and a dense network within an organization are necessary for successful adaptation of knowledge for innovation (Adler and Kwon, 2002; Alguezaui and Filieri, 2010; Filieri et al., 2014; Lee, 2009; Walter et al., 2007). For example, Walter et al. (2007) looked at large pharmaceutical companies and saw that knowledge acquired by one business unit failed to spread throughout the company partly due to lack of cohesion. However too much cohesion might lead to inflexibility (Lee, 2009) and blind spots (Alguezaui and Filieri, 2010; Inkpen and Tsang, 2005). There needs to be a balance between enough internal cohesion while maintaining openness to outside knowledge through an external network that bridges structural holes.

Stability

Network stability is the changing of membership in a network (Inkpen and Tsang, 2005). Social capital is dependent on the changing of the social structure over time(Filieri et al., 2014; Schultz-Jones et al., 2009), as networks change so does social capital (Nahapiet and Ghoshal, 1998). Especially in sparse networks, change over time can have a large impact, when a single knowledge broker leaves this means the organization loses access across the structural hole. A dense network is more stable because when one node or link is removed, there are always other links to the same knowledge.

In context

The World Bank is an organization with a big impact on international development projects, therefore it is important that they use the best available knowledge in their decision making. When we look at access to knowledge and application of knowledge from a structural network perspective, it can be deduced that it is preferable to combine a sparse external network with knowledge brokers that bridge structural holes with a denser internal network.

The World Bank is a large organization containing different thematic working groups, project groups and managing levels. In this it is crucial that there are enough bonding ties within the organization linking the different units or cliques of the internal network. Otherwise it is not possible to successfully spread information accessed through the external network. This should not just be one link but preferably some links linking the different groups to have more effective and timely knowledge sharing that is more easily adapted.

In the external network of the World Bank it is important that there is brokerage across many different structural holes to give access to a variety of views and knowledge. The stability of the external network needs to be monitored to maintain this wide access to knowledge.

F.5.2 Relational dimension

When we speak of the relational dimension of social capital we look at the quality of the links between actors(Filieri et al., 2014), and can be linked to tie strength. It includes the conditions of trust, obligation and expectations, and identity (Alguezaui and Filieri, 2010; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998). Mutual respect and friendship (Díez-Vial and Montoro-Sánchez, 2014; Widén-Wulff and Ginman, 2004) as well as reciprocity and strong social norms (Walter et al., 2007) are also mentioned are relational facilitators of knowledge exchange. In this research we will focus the strong and weak ties argument in the relational dimension, where the role of trust is emphasized as the most important aspect of the relational dimension. Identification is the extent to which nodes feel related to each other(Widén-Wulff and Ginman, 2004) which is closely related to shared culture in the cognitive dimension.

Trust

Of the relational dimension, trust is the most researched and most important variable (Lee, 2009; Widén-Wulff and Ginman, 2004). Developing trusting bonds is essential for knowledge transfer (Alguezaui and Filieri, 2010; Filieri et al., 2014; Inkpen and Tsang, 2005; Lee, 2009; Schultz-Jones et al., 2009; White et al., 2009), not only within a collaboration but also in external communication (White et al., 2009). Here we speak of interpersonal trust. It relates to the expectations of a relationship(Widén-Wulff and Ginman, 2004), the degree to which one can expect the partner to follow through (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005), reliability of fairness and predictability of behavior (Lee, 2009), reciprocity and value of shared knowledge (Filieri et al., 2014), social judgements and perceived risk (Inkpen and Tsang, 2005). High trusts stimulates the willingness to accept and absorb new knowledge(Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005). The judged trustworthiness of an academic sharing knowledge with a policy maker is extremely important as the policy maker does not have time to verify the information shared (White et al., 2009). Trust develops through common moral values (Alguezaui and Filieri, 2010; Lee, 2009) and is highly correlated with the shared culture of actors (Díez-Vial and Montoro-Sánchez, 2014).

It takes time to develop trusting relationships(Inkpen and Tsang, 2005; White et al., 2009), this is mostly fostered by face-to-face interactions(Filieri et al., 2014) which provide room for shared stories and socialization (White et al., 2009). Personalized trust is partly based in institutionalized trust, trust based on the institutions reputation(Inkpen and Tsang, 2005), but will develop more personally once the relationship develops.

Tie strength

Tie strength is determined by frequency of contact, reciprocity and friendship (Schultz-Jones et al., 2009), or put differently by the amount of time, emotional intensity and intimacy of a relationship (Díez-Vial and Montoro-Sánchez, 2014). The argument of strong and weak ties can be related to the bonding and bridging approaches in the structural dimension, where bonding networks are linked to strong ties and bridging networks to weak ties (Lee, 2009). Strong ties are often trusting relations where complex knowledge can be easily exchanged, stimulating a long term vision (Colemans, 1988; Filieri et al., 2014; Inkpen and Tsang, 2005). On the other hand weak ties stimulate experimentation and are host to generalized trust (Lee, 2009). An important thing to note is that it is easier to maintain both strong and weak ties with close geographical proximity due to higher transactional costs when a tie has to function over long distances (Rutten et al., 2010)

In context

In the relational dimension we focus on trust and tie strength. What we expect to see in the network of the World Bank is mostly strong internal ties and weaker external types, however some external ties will also be strong, for instance ties based in an older friendship. Once a tie is strong it is easier to maintain over a long distance than a weak tie (Rutten et al., 2010). This shows us that it will be easier for the World Bank to consult scientists and consultants who are situated close by, which might influence their access to new knowledge.

Mutual trust is essential in both internal and external interactions. For the external interactions the consultants and scientists are expected to have a good track record of delivering valuable information. On the other hand the scientists should also be able to trust that the knowledge they provide will be taken into consideration. This trust is based on experience from previous interactions.

F.5.3 Cognitive dimension

In the cognitive dimension of social capital we look at the shared mental models between nodes (Filieri et al., 2014), shared culture (Díez-Vial and Montoro-Sánchez, 2014), shared meaning and understanding and shared goals(Inkpen and Tsang, 2005). It is the least researched dimension of social capital (Díez-Vial and Montoro-Sánchez, 2014; Lee, 2009) and is closely related to the relational dimension. Nahapiet and Ghoshal (1998) introduced the cognitive dimension of social capital in knowledge exchange because "meaningful communication requires at least some sharing of context among partners". This shared context is shown in a common language, codes and narratives which stimulate shared interpretations (Alguezaui and Filieri, 2010; Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Lee, 2009; Nahapiet and Ghoshal, 1998). This can develop through a shared history or background (Díez-Vial and Montoro-Sánchez, 2014) or spatial proximity (Rutten et al., 2010). The contradiction in this dimension lies in the fact that on the one hand it is harder to exchange knowledge when there is no shared culture while on the other hand we learn extremely new concepts easier across large cultural differences (Inkpen and Tsang, 2005; Nahapiet and Ghoshal, 1998). However research generally finds a positive effect of cognitive proximity on knowledge transfer (Díez-Vial and Montoro-Sánchez, 2014; Inkpen and Tsang, 2005; Walter et al., 2007). People with a similar culture and values will interpret knowledge in a similar way and will see the same view on what is relevant (Díez-Vial and Montoro-Sánchez, 2014).

In the cognitive dimension we want to look at the impact of differences in culture and goals on knowledge exchange. These were also topics that arose in the preliminary interviews.

Shared culture

The analysis of shared culture includes language, perspectives and knowledge. Shared understanding comes from effective communication and influences lasting relations (Lee, 2009; Nahapiet and

Ghoshal, 1998), getting to a common understanding takes time (White et al., 2009) and problems can arise when nodes try to push their own perspective and culture(Inkpen and Tsang, 2005). When looking at a main office with international branches the main office needs to keep the country cultures of the branches in mind (Inkpen and Tsang, 2005; Lee, 2009).

Difference in levels of understanding can be rooted in a knowledge deficit (Sterman, 2011), different language and different perspectives(Inkpen and Tsang, 2005; White et al., 2009). For example: when working with people from different backgrounds it can be that they think on different spatial and time scales(White et al., 2009), a policy maker works within the industrial boundaries while a hydrologist looks at a watershed. Similarly it is important to keep the tendency of human mental models in mind, we tend to focus on the short term and small scale while natural processes work with long term and large scale impacts (Sterman, 2011). In the case of scientist-policy interactions the scientist is can be required to look at the knowledge level and narratives to get to successful communication (Balian et al., 2016; Sterman, 2011).

For knowledge transfer we have to be aware of the differences in vocabulary but also difference in narratives (Balian et al., 2016; Lee, 2009; Nahapiet and Ghoshal, 1998). It is argued that an audience needs to be addressed in their own language (Balian et al., 2016; Sterman, 2011). Specifically in policy-science interaction fuzzy language and jargon should be avoided(Balian et al., 2016; White et al., 2009). An example of confusing terminology is the use of positive and negative feedback loops, for a researcher it is clear that this means two variables both increase or decrease at the same time, however the audience might associates positive with good and negative with bad (Sterman, 2011).

People who can easily adapt to new cultures and new languages and identify with other groups are ideal for a role as knowledge broker, to link different cohesive networks (Lee, 2009; Nahapiet and Ghoshal, 1998).

Shared goals

Another important facet of the cognitive dimension are shared goals. Having a shared goal or vision increases successful communication (Filieri et al., 2014; Inkpen and Tsang, 2005). Shared goals come from the degree to which network actors approach the tasks and understand the preferred outcomes, it is not only having the goal but also having a common understanding of what the goal entails (Filieri et al., 2014). Having a proper understanding of goals and a proactive and cooperative tendency towards that goal leads to better knowledge exchange (Nahapiet and Ghoshal, 1998; Walter et al., 2007) and common understanding (Inkpen and Tsang, 2005).

In context

Both in the internal and external network of the World Bank there are people who have different backgrounds. This comes from growing up and working in different countries, studying different fields and working in different organizations. This can have a great impact on successful communication and interpretation of knowledge. On the one side there are big differences between the network actors while on the other side the actors within the World Bank have a lot of experience with different cultures which can make them more adaptive.

For the internal network we can look at the measure of shared culture that is there, the separateness of the different units within the organization. For the adaption of knowledge within the organization it is important that the core values of the organization are commonly shared among the different units. This gives them a shared vision and shared goals which is positively related to knowledge exchange.

In the external network it can be expected that the differences in culture are larger than in the internal network. There will be different goals from different organizations and actors which might interfere with the knowledge exchange. If we look at the interaction between academics and the World Bank, there will be a wide range of differences in knowledge and semantics. As the World Bank contains people from many different fields these differences will be more prominent in some instances, for example when a hydrologist talks to an economist.

In the specific case of efficiency in water management the term efficiency is a language obstacle. Firstly, efficiency has a positive connotation while increasing irrigation efficiency is not always positive from a hydrology perspective. Secondly when we talk about efficiency there can be many different meanings of this word, from pumping efficiency to basin efficiency, which can cause confusion.

F.5.4 Linking the three dimensions

As was mentioned in the introduction of social capital and can sometimes be seen in the discussion of the dimensions, they are not separate entities but interlinked. For example: when social interactions are intensive (structural) this makes the development of a shared language and shared narratives easier (cognitive) and will lead to more trusting relationships (relational) (Alguezaui and Filieri, 2010). Each dimension enhances the others (Widén-Wulff and Ginman, 2004) and the lacking of one dimension can be compensated by the other (Walter et al., 2007). Díez-Vial and Montoro-Sánchez (2014) shows the correlation between the dimensions in their research of a Madrid science park (see figure F.4). It is hard to research these dimensions separately (Widén-Wulff and Ginman, 2004).

	Mean	*Standard deviation*	*Knowledge sharing*	*Structural capital*	*Relational capital*
Knowledge sharing	0.506	2.964	1		
Structural dimension	0.002	0.018	0.492**	1	
Relational dimension	0.147	18.494	0.735**	0.588**	1
Cognitive dimension	0.271	13.483	0.670**	0.550**	0.967**

Figure F.4: correlation between social capital dimensions and knowledge sharing(Díez-Vial and Montoro-Sánchez, 2014)

We will now look at these links from the distinction made in the structural dimension. There we saw the difference between the network closure and structural hole perspective and we argued that a combination of the two would be most beneficial for the adaption of innovation, internal network closure and an external network of bridging structural holes. For the internal network this would ideally result in a dense and stable network (structural), which is associated with strong trusting ties (relational) and a high degree of shared culture, shared goals and shared language (cognitive). This is a network suitable for complex knowledge exchange and action based application of the knowledge. Having no internal structural holes helps to pursue shared goals (Adler and Kwon, 2002; Walter et al., 2007).

The external network would be a sparse networks, bridging structural holes. A dense network would be to costly to maintain and would hinder innovation. The purpose of this sparse network is to have access to a wide variety of knowledge to facilitate innovation within the organization. In this sparse network (structural) ties are generally (but not always) weak (relational) with lower levels of redundancy (structural) and lower levels of trust (relational). However trust is still very important, especially when there is a difference in knowledge levels (White et al., 2009). The shared culture and shared language (cognitive) will be less obvious than in the internal cohesive network. It is important to find shared goals in the collaboration and actively look for a shared language and common ground (Balian et al., 2016; Sterman, 2011). The adaptive capability of knowledge brokers is very important in accessing new knowledge (Lee, 2009). In a sparse network individual strong ties can provide access to knowledge(Walter et al., 2007). This knowledge broker has a high centrality and is often perceived as trustworthy(Filieri et al., 2014), however when such a broker disappears it can greatly impact the network (Lee, 2009).

G

The variables

G.1 Introduction

In this section we will combine the theory on knowledge transfer, the science-policy interface and the role of social capital dimensions in knowledge transfer. For this we will focus on the attributes that were addressed in the literature as well as important topics that were brought to our attention in preliminary interviews. With this research we want to find out how a social capital perspective on knowledge exchange can help bring water consumption theory and practice closer together.

Social capital as described by Nahapiet and Ghoshal (1998) gives a framework for the analysis of knowledge exchange, explaining its three dimensions. In this the structural dimension gives the context of the network which facilitates the environment in which knowledge transfer can exist. The cognitive dimension gives the mental level of the context, in what way are the nodes mentally on one line. The relational dimension gives insight into the one-on-one relationship between the network nodes. The most important findings from the literature review and the preliminary interviews are linked to these dimensions to create the theoretical framework. The theoretical framework will consist of an outline of the dimensions, the constructs within these dimensions and the variables to be analyzed.

G.2 constructs and variables

The constructs are defined per Social Capital dimension. The constructs are taken from literature and the preliminary interviews to indicate the different aspects that influence knowledge transfer between the actors as well as the incorporation of theory in World Bank projects.

These constructs are still very widely interpretable, therefore the operational definitions of the constructs are included in Table G.1. The constructs are defined in a way they can be used to see their impact on knowledge exchange between the actors.

G.2.1 Structural dimension

The structural dimension provides the environment in which knowledge exchange takes place. This includes the network structure and the systems embedded in the network structure, like a reward system or hierarchy. In the structural dimension we will focus on network closure, network stability and embedded systems. These constructs will be analyzed through variables which bridge the divide between the theoretical constructs and the actual situation (see Table G.2).

Table G.1: Operational definitions research constructs

Construct	Definition
Network closure	the density of connectedness within a network. In a closed network everyone is connected to everyone, in a spare network the number of connections are limited.
Network stability	The movement of nodes in a network, to different positions or out of the network
Embedded systems	Systems inherent to the network that stimulate or prevent knowledge exchange
Spatial proximity	The spatial distance between actors
Goal alignment	The level to which the goals of the project, actors and the organization align when looking at initiatives related to water consumption and efficiency in agriculture.
Language alignment	Common used terminology and level of language when talking about projects and theory concerning water consumption and efficiency in agriculture.
Perspective alignment	Way of looking at the world based educational and cultural background and the extent to which these align on the topic of water consumption and efficiency in agriculture
Trust	Belief that someone is reliable and worthwhile to communicate with
Tie strength	Intensity of the relationship

Network closure In the closure construct we want to find out how closed the network structure is and whether there are many structural holes. This can be analyzed through tie redundancy. Tie redundancy looks at the network the common links between network nodes. For example if A is connected to B and C and B and C are also connected, this means there is a redundancy in the ties. A higher tie redundancy leads to a more closed network.

Another variable to look at closure is looking at the number of bridges across structural holes. A structural hole is a gap in the network where nodes on both sides of this gap can gain something from bridging this gap. A node that makes this link bridges the structural hole and gains access to the resources or knowledge.

In a closed network knowledge transfers more smoothly and quickly as it can be transferred through multiple links, however this might result in the network being closed to input from outside the network. A sparser network is generally more open to external knowledge. Structural holes can be found in a sparse network. Bridges across structural holes give access to different views and knowledge. These networks are often more open to change and innovation than closed networks. These variables will give insight into the structural openness of the World Bank to external knowledge and the internal network structure to facilitate knowledge sharing.

Apart from these structural variables we also include a variable about the perceived importance of network closure and bridging structural holes. This related to the opinion of the actors and the possibilities of change.

Network stability Network stability can have an impact on knowledge transfer between organizations and individuals as the individuals facilitate the links between knowledge sources. In this the

Table G.2: Variables in the structural dimension

Construct	Variables
Network closure	- Tie redundancy - Perceived importance of external bridges across structural holes
Network stability	- Changes in network nodes - Perceived effect of changes in network nodes
Embedded systems	- Reward system for knowledge transfer - Time structurally allocated for knowledge transfer Knowledge exchange methods
Spatial proximity	- Distance between network nodes - Perceived effect of distance between network nodes

variable to look at is the changes in network nodes. If someone leaves the network to retire or go to another Job, they take their specific knowledge and their connections with them. This move impacts first and second connections within the network. In a dense network the stability will be higher than in a sparse network because in a dense network there will be other connections that can easily take over.

Additionally we will look at the perceived effect of changes in network nodes. Which will give insight into both the network density, because in a sparse network the perceived effect of changes might be higher, and the perception of network stability.

Embedded systems The structural dimension also concerns systems embedded in the network structure. In this case we will focus on the reward systems for knowledge transfer and the time that is structurally allocated to knowledge transfer as well as the knowledge transfer methods embedded in the organizational structure. Knowledge transfer is not always an inherent part of the job description even though it is an important aspect of successful collaboration and project development. With this variable we want to find out if the actors are stimulated financially or in other ways to take part in knowledge transfer activities.

Spatial proximity The relative location of the network nodes impacts the effectiveness of knowledge transfer as it effects the ease contact. It takes less effort for actors located in the same city or even state or country to meet or reach out due to travel distance and time zones.

G.2.2 Cognitive dimension

An analysis of the cognitive dimension of social capital will give insight into the shared understanding of the actors. This shared understanding is based on historical development of separate actors and their current stance. It can be found in sharing of goals, language and perspective. Two actors can have aligned perspectives on one topic and completely differ on another topic, therefore the cognitive dimension will be analyzed focused on knowledge exchange on water consumption in irrigation related theory and practice. The variables for the cognitive dimension can be found in Table G.3.

Goal alignment Researching the goals construct has two sides, first we want to find out the goals of the different parties and second we want to determine how they view the goals of the other actors. Goal alignment is important for successful knowledge exchange. The perceived project goals will give insight into the way the actor's view World Bank projects on the topic of water for irrigation,

Table G.3: Variables in the cognitive dimension

Construct	Variables
Goal alignment	- Personal goals - Perceived World Bank project goals - Perceived World Bank vision - Perceived differences in goals
Language alignment	- Similarity of used terminology and narratives - Clarity of language
Perspective alignment	- Scale of thinking - Opinion of large scale theory - Perceived acceptance of large scale theory in the World Bank - Perceived nowledge gap

specifically on a project scale. The perceived WB vision will give insight into the way the actors see the main purpose and goals of the World Bank. Together these two variables will show the perceived differences between the ways the actors see the goals of the WB on two scales as well as the difference between the WB global vision and project application.

The actor-specific goals variable deals with personal goals of the actor, they can be rooted in their organization or personal ambitions. These can be related to the perceived WB goals to see if there is goal alignment on a large scale or on a project scale.

Additionally we want to find out if the actors think they follow the same goals or if they notice differences in goals this will be researched in the variable: perceived goal alignment. This variable will also cover the value given to goal alignment.

Language alignment Sharing the same language is crucial for successful knowledge exchange. This construct includes terminology and interpretation of that terminology as well as the level of the language used. In the variable similarity of used terminology and language we look at the terms used when discussing water efficiency and irrigation projects and theory. However, if the actors use the same terms this does not mean they speak the same language. Therefore a second variable is introduced as interpretation of used terminology. In this variable we investigate the associations and explanations the actors have with the used terms. If these are vastly different it can signify miscommunication.

Another aspect of the language construct is clarity of language. This relates to the mismatch between the language levels of different experts and non-experts in a topic. This is often seen in communication between scientists and policymakers. The language used can either be too complex or too simple which makes it either not understandable or a lot of meaning gets lost. The right level of language is important for successful knowledge transfer.

Perspective alignment The perspective of the actors is closely related to their education, their environment and their goals. In the case of water for irrigation an important aspect of their perspective is scale of thinking which is closely linked to the opinion of large scale theory. These two variables highlight the expected differences between the actors. Abstract theory is usually developed on a large scale while projects are implemented on a smaller scale. These variables will be used to find out what the actual stance of the actor is and how they see the translation of theory to practice. The scale of thinking is closely related to the actor goals. This construct also includes the variable knowledge gap the knowledge gap between experts and non-experts was highlighted as an obstacle in preliminary interviews. Through this variable we will find out whether there is an awareness of large scale theory and if this theory is understood. It will give insight into the perceived knowledge gap that might exist between the actors. This variable is closely linked with clarity of language, shared terminology and scale of thinking.

G.2.3 Relational dimension

The relational dimension of social capital looks at the relation between two individuals in the network. For this research we will look at trust and tie strength as the main constructs of this dimension. When we speak of trust we mean interpersonal trust, trust between network nodes. Tie strength and trust are closely interlinked, high trust enhances tie strength. The variables of the relational dimension can be found in Table G.4

Table G.4: Variables in the relational dimension

Construct	Variables
Trust	- Ability - Reliability
Tie strength	- Frequency of contact - Friendship

Trust Interpersonal trust is dependent on many things. In this research we speak of trust between professionals which influences knowledge exchange. One of the main indicators is ability of the person with who knowledge exchange takes place. This variable indicates the value of the knowledge shared and the perceived skill of the actors. The second variable is reliability, this variable deals with the nature of the relationship in the form of expectations. Trust is based on the degree to which we can expect the other to follow through and handle a situation fairly. This is based on past experiences and hearsay.

Trust is interlinked with most variables, for example trust can develop more quickly in a cohesive network with a high interaction rate. It will also develop more easily in a relationship where people share a language and perspective. This construct is highly dependent on others and hart to measure separately.

Tie strength Tie strength can also be explained in many different ways. In this case the variables to describe tie strength are set at frequency of contact and friendship. Frequency of contact indicated the closeness of the relationship as well as the intensity of knowledge sharing. friendship shows the closeness of the people on a more relational level which is dependent on the history of the actors.

Frequency of contact is closely related to the network structure, in a closed network frequency of contact is often higher than in an open network. Also spatial proximity is an important factor to determine frequency of contact and thus tie strength.

G.3 Linking the variables to theory

Construct	Variables	Literature	Interviewees
Network closure	Tie redundancy	Adler and Kwon (2002); Alguezaui and Filieri (2010); Burt (1992, 2000); Colemans (1988); Inkpen and Tsang (2005) etc.	2
	Perceived importance external bridges across structural holes	-	2
Network stability	Changes in network nodes	Inkpen and Tsang (2005); Lee (2009); Schultz-Jones et al. (2009)	1
	Perceived effect of changes in network nodes	Lee (2009)	1
Embedded systems	Reward system for knowledge transfer	Balian et al. (2016); Lee (2009); White et al. (2009)	4
	Time structurally allocated to knowledge transfer	Balian et al. (2016); Lee (2009); White et al. (2009)	4
	Knowledge transfer methods	Balian et al. (2016)	3
Spatial proximity	Distance between network nodes	Rutten et al. (2010)	2
	Perceived effect of distance between network nodes	Rutten et al. (2010)	2

Table G.5: Variables in the structural dimension related to which literature they come from and how many people from the preliminary interviews mentioned them

Construct	Variables	Literature	Interviewees
Trust	Ability	Filieri et al. (2014)	4
	Reliability	Díez-Vial and Montoro-Sánchez (2014); Inkpen and Tsang (2005); Lee (2009); Widén-Wulff and Ginman (2004)	2
Tie strength	Frequency of contact	Díez-Vial and Montoro-Sánchez (2014); Schultz-Jones et al. (2009)	-
	Friendship	Díez-Vial and Montoro-Sánchez (2014); Schultz-Jones et al. (2009)	-

Table G.6: Variables in the relational dimension related to which literature they come from and how many people from the preliminary interviews mentioned them

Construct	Variables	Literature	Interviewees
Goal alignment	Actor-specific goals	Balian et al. (2016); Lee (2009); White et al. (2009)	2
	Perceived World Bank project goals	-	-
	Perceived World Bank vision	-	1
	Perceived differences in goals	Filieri et al. (2014); Inkpen and Tsang (2005)	6
Language alignment	Similarity of used terminology and narratives	Alguezaui and Filieri (2010); Balian et al. (2016); Díez-Vial and Montoro-Sánchez (2014); Filieri et al. (2014); Inkpen and Tsang (2005); Nahapiet and Ghoshal (1998); Sterman (2011); White et al. (2009,?)	2
	Clarity of language		4
Perspective alignment	Scale of thinking	Alexander and Armitage (2015); Sterman (2011); White et al. (2009)	2
	Opinion of large scale theory	-	-
	Perceived acceptance of large scale theory in the World Bank	-	-
	Perceived knowledge gap	Inkpen and Tsang (2005); Sterman (2011)	2

Table G.7: Variables in the cognitive dimension related to which literature they come from and how many people from the preliminary interviews mentioned them, some are tailored to the specific case of this study, they are not rooted in literature but come from a construct that is rooted in literature

H

Interview guide

The interview guide for World bank Staff is added as an example, the interview guides for the consultants and external advisers were slightly different. They are available upon request. The interviews questions for the consultant interviews can also be found in Appendix I.

PART 0 – Introduction

Thank you for meeting me.

This interview is for my master thesis at Delft University of Technology, where I study Hydrology and Science communication. This research focuses on the communication between hydrologists or consultants and the World Bank and how theory and practice might be brought closer together in the topic of water consumption though irrigation.

The interview will take approximately one hour.

- Role at WB
- Knowledge acquisition from external sources
- Knowledge exchange within WB
- Short hypothetical case

You can ask questions at any time during the interview.

The interview will be completely anonymous, no names will be named. For research purposes I would like to record the interview. Would you agree with that?

*Turn on audio device

Do you agree with being recorded?

PART 1 – Role

1. How did you come to work at the World Bank?
2. How are you involved in the World Bank?
    - How did you get into contact?
    - Work in projects or policy

PART 2 – Network

3. Are you in contact with many knowledge sources outside the World Bank?
    - Consultants, scientists, what kind?
        - backgrounds
    - Many different for different purposes (project, policy)
    - Personal contacts or also with other colleagues
    - How often in contact
4. When you consult someone what do you base your decision on?
    - Personal network
    - Worked with before, hearsay
    - skills, specific knowledge
5. Where are the people in your network located?
    - Same city, Same country, Same continent
    - Do you observe any hindrance?
6. Do you see people in your network move to different positions?
    - Other organization
    - Influence on knowledge and links
    - Influence on agreements
7. How do you see knowledge exchange/acquisition happen at the World Bank?
    - Between projects
    - Projects and science
    - Projects and world bank vision
    - In thematic groups
8. What is your goal in internal knowledge sharing in the World Bank
    - Do you see this happening?
    - Is knowledge incorporated
9. Is knowledge transfer stimulated?
    - How?
    - In project goals?
    - In job description?
10. What would you change to improve knowledge exchange/access to knowledge?

PART 3 – Case

In the Fergana Valley in Uzbekistan the World Bank is investing irrigation and agricultural modernization, improvements in drainage service delivery and irrigation water efficiency. The interventions include lining of the main irrigation canals to prevent leakage, applying modern irrigation techniques to improve irrigation efficiency.

11. What are the first things that come to mind when you hear this project description?
    - Goals (Water, People &poverty, Economic)
    - What are the effects you see? (positive and negative)
    - Is this similar to the objectives of the World Bank projects you are involved with?
12. In the project description we mention irrigation efficiency. How would you define efficiency in this project? (Can be multiple ways)
    - Do you feel increasing efficiency is positive or negative
    - Are there any other water related definitions of efficiency that you use

This project is focused on increasing the agricultural production, because of the increased irrigation efficiency the water consumption will increase.

13. Does this statement change your view on the project?

I want to shortly introduce a basin wide hydrological concept (see figures H.1 and H.2), this is a simplified form of the concept. I will use irrigation efficiency plant consumption/ withdrawal on a field scale and consumed fraction consumption/ withdrawal. The image shows a river basin with two irrigation water users. User A loses a lot of water that he pumps out of the river due to leakage, so he wants to improve his efficiency. After modernizing his irrigation system and lining his canals he improves his irrigation efficiency, less water losses. This sounds very nice. However when we look at the basin it can be seen that what farmer A defines as losses actually flows back into the system and is used by other users. If farmer A keeps his withdrawal the same with this increased efficiency the water consumption (ET) will increase. With limited water available in the basin this might cause problems downstream, in this case with the wetlands. Increasing irrigation efficiency at a small scale might therefore not be the solution to water scarcity problems.

14. Have you heard of this concept before?
    - What is your opinion
    - Do you feel it has practical relevance
    - Relevance for World Bank
15. Are people around you aware of this theory? Why do they or do they not use it?

Between 2010 and 2016 the WB was involved with a project in China where water allocation rights were based on consumptive use (ET) instead of withdrawal.

16. Have you heard of this project?
17. Do you think it could be used in Central Asia?
18. What is the main vision of the World Bank on water for irrigation according to you?
    - Do you see this in the projects you work in?
    - Do you think this is an effective vision?

PART 4 – Context & communication

19. What scale is most important for World Bank projects? And policy?
    - Project, country or basin scale
    - How do you notice different scales and perspectives in your work?
20. Do you see a difference in used terminology between you and the World Bank?
    - Understandability or oversimplification
    - Vague language
    - Different terms
    - Specifically efficiency
    - Effect on your work
21. Is there anything else that you think might have influence on the knowledge exchange?

PART 5 – closing remarks

1. Do you have any other remarks or insights you want to share?
2. Would you like to see the results of the research?

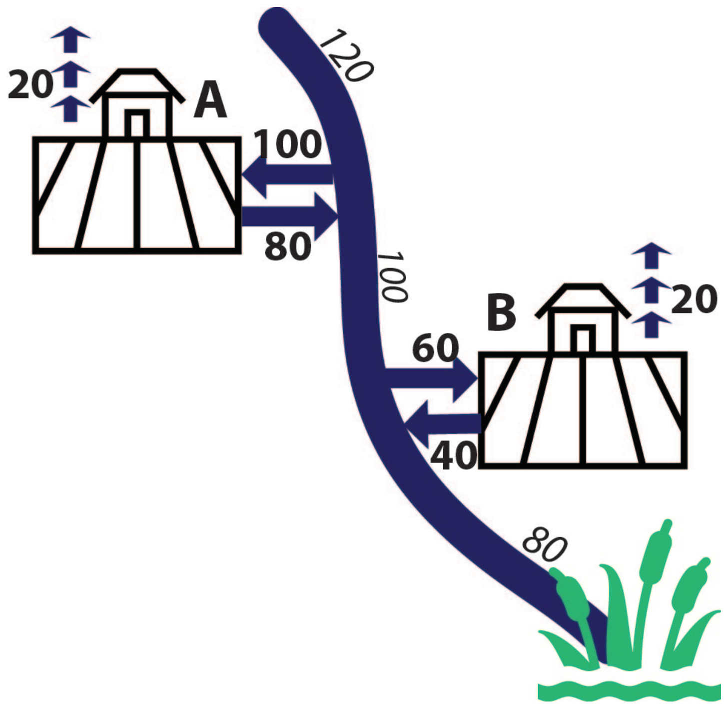

Figure H.1: Simple river basin before irrigation efficiency increase

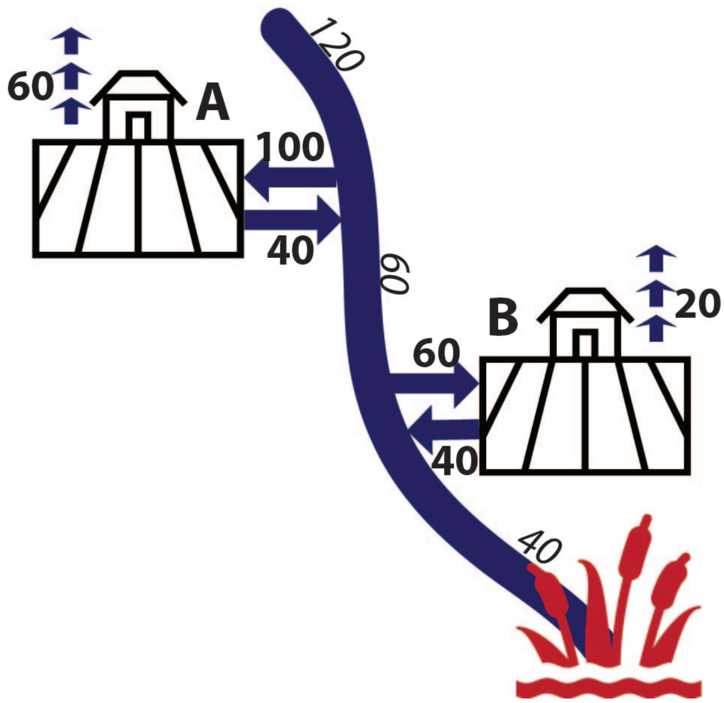

Figure H.2: Simple river basin after irrigation efficiency increase at farm A

Interview questions linked to variables

I.1 Consultant interview

I.1.1 Part 1 – Role

Question	Why ask this question?	Construct	Variables
1. For how long have you been involved with the WB? • How did you first get into contact?	Get to know the background of the actor with the WB and the way the WB reaches out to external people.	Network closure	Tie redundancy
2. How are you involved with the WB? • How did you get into contact? • Hired for projects, advice etc. • Intensity • Related to water and irrigation • Many different projects often consulted?	Find out role of the actor concerning the WB. To relate the answers to the social capital questions to the role of the actor. Find out a about the nature and intensity of their involvement with the world bank.	Tie strength, Network closure	Frequency of contact, tie redundancy

I.1.2 Part 2 – Network

Question	Why ask this question?	Construct	Variables
3. How many different contacts do you have in the World Bank? • Are they with the same project or in many hierarchical groups? • Do they have contact with other people in your network, and outside? • Are you usually contacted by the same or different people? • How often are you in contact and how?	To find out the size and connectedness of the actor. The WB network to the actor is dense or sparse, is he part of a bridge over a structural hole? Tie strength with different people in the network, the connection between the relational and structural dimension	Network closure, tie strength	Tie redundancy, frequency of contact, friendship
4. What is their background? • Are they skilled?	Find out about the knowledge present in the WB and to what extend the consultants feel the knowledge at the world bank is sufficient.	Interpersonal trust, perspective alignment	Ability, perceived knowledge gap.
5. Where are the people in your network located? • Same city, same country, same continent • Do you observe any hindrance?	Find out the relevance of spatial proximity of the World Bank, spatial proximity makes frequent interactions easier. Face to face contact builds interpersonal trust and tie strength which enhances knowledge transfer.	Spatial proximity	Distance between network nodes, perceived effect of distance between network nodes
6. Do you see people of the World Bank move to different positions? • Within the World Bank • Other organization • Influence on knowledge exchange • Are agreements still met?	Find out how stable the network is. In governmental network stability was mentioned as an important obstacle for knowledge exchange. That could also be the case for the WB. Make relation between structural and relational dimension.	Network stability, interpersonal trust	Changes in the network nodes, perceived effects of changes in network nodes, reliability

Question	Why ask this question?	Construct	Variables
7. How do you see knowledge exchange happening in the World Bank? • Between projects • Projects and science • Projects and world bank vision • Internal or external • Is it done enough	Find out something about the knowledge exchange methods in the WB. Does this happen often and in what way. It says something about the internal and external network cohesion and tie strength in the form of links and frequency of contact	Network cohesion, tie strength, embedded systems	Perceived importance external bridges across structural holes, frequency of contact, knowledge transfer methods
8. What are your main reasons for sharing knowledge?	Find out if there are any personal motivations for knowledge sharing, some people might also share organizational or project motivations	Goal alignment	Personal goals, perceived WB project goals
9. Is knowledge transfer stimulated? • How? • from project to other projects, project to science or project • Paid for • In goals of project	Find out if there is a reward system for exchanging knowledge. A reward system is something that can enhance knowledge exchange. E.g. if career advancement only comes from publications or report writing, this might hinder effective knowledge exchange.	Embedded systems, Goals	Reward system, time structurally allocated to knowledge transfer, perceived WB project goals, knowledge transfer methods
10. Is knowledge you share with the World Bank incorporated in your project and in other projects? • Are agreements met?	Find out if the World Bank is perceived as a reliable partner in knowledge transfer	Interpersonal trust	Reliability
11. What would you change to improve knowledge exchange/access to knowledge?	Open question the find out where they see improvements, for example in having more access to external sources. Which construct this relates to depends on the person answering the question.	Network cohesion (and others that are mentioned)	Perceived importance external bridges across structural holes

I.1.3 Part 3 – Case

Question	Why ask this question?	Construct	Variables
12. What are the first things that come to mind when you hear this project description? • Goals – Water, People and poverty, Economic • What are the effects you see? – Positive and negative • Is this similar to the objectives of the World Bank projects you are involved with?	Find out their perceived objectives of WB projects on different topics. Find out if they see the possible negative implications on a large scale. What is their perspective on irrigation projects and their initial reaction on efficiency.	Goal alignment, Perspective alignment	Perceived project goal, actor-specific goals, perceived difference in goals, scale of thinking
13. In the project description we mention irrigation efficiency. How would you define efficiency in this project? (Can be multiple ways) • Do you feel increasing efficiency is positive or negative • Are there any other water related definitions of efficiency that you use	Find out the interpretation of efficiency and how they associate with it, see if there are differences between the interviewees. The terminology and similar interpretation of terminology is very important for successful knowledge exchange	Language alignment, perspective alignment	Similarity of used terminology, similarity of interpretation of used terminology, scale of thinking
Through the project the withdrawal from the river will increase and because of increased efficiency also the water consumption will increase. 14. Does this statement influence your view on the project? • Positive, negative • Why?	Find out if they relate water consumption to positive or negative. What scale are they thinking on? The perspective related to scale will be found in this question. Also their opinion towards withdrawal and water consumption and the way these terms are interpreted	Language alignment, Perspective alignment	Similarity of used terminology, similarity of interpretation of used terminology, scale of thinking

Question	Why ask this question?	Construct	Variables
Introducing theory			
15. Have you heard of this concept before? • What is your opinion • Do you feel it has practical relevance • Relevance for World Bank	Find out perspective and the knowledge of the theory advocated some hydrologists. Is there a large scale perspective and approach of water for irrigation? Do they see the relevance of the large scale perspective	Perspective alignment, language alignment	perceived knowledge gap, scale of thinking, opinion of large scale theory, similarity in interpretation of used terminology, opinion of large scale theory
16. Are people around you aware of this theory? Why do they or do they not use it?	Find out the presence of the perspective and knowledge on this large scale theory	Perspective alignment	Perceived knowledge gap, scale of thinking
Between 2010 and 2016 the WB was involved with a project in China where water allocation rights were based on consumptive use (ET) instead of withdrawal. 17. Have you heard of this project?	Shows us if the lessons of this project were shared within the WB and to the projects.	Embedded systems,	Knowledge transfer methods,
18. What do you think of this project? • Would it be applicable in any projects you are involved with?	Find out if they are interested in new technologies, trigger thinking about basin analysis and large scale thinking. Additionally it	perspective alignment	scale of thinking, Perceived acceptance of large scale theory in the World Bank, Opinion of large scale theory
19. What is the main vision of the World Bank on water for irrigation according to you? • Do you see this in the projects you work in? • Do you think this is an effective vision?	Find out if the WB goal is clear and what they think the goal is. If the goal of the WB is stated similarly by the different stakeholders we can see that there is a clear goal. We can also say something about goal alignment.	Goal alignment, perspective alignment	Perceived WB vision, perceived difference in goals, scale of thinking, Perceived acceptance of large scale theory in the World Bank

I.1.4 Part 4 – Context and communication

Question	Why ask this question?	Construct	Variables
20. What scale is most important for World Bank projects? And policy? • Project, country or basin scale. • Is or should be. • How do you notice different perspectives, scales of thinking or priorities in your work. • Did your opinion change because of this conversation.	To see the different priorities and perspectives. Scale is an important perspective distinction between the actors. Thinking on different scales is one of the main differences between the actors and one of the main differences that need to be crossed. This question gives us insight in the magnitude of those differences.	Perspective alignment	Scale of thinking
21. Do you see a difference in used terminology between you and the World Bank? • Understandability and oversimplification. • Vagueness. • Specifically efficiency. • Effect on your work.	To get to know the actors opinion on the language usage. Language is an important aspect of knowledge transfer. In the preliminary interviews and through the literature this was highlighted. This question gives the opportunity to look into the extent of that issue for this actor.	Language alignment.	Similarity in used terminology, similarity in interpretation of terminology, clarity of language.
22. Is there anything else that you think might have influence on the knowledge exchange?			

J

Code trees for interview analysis

The code trees were used to categorize information from the interviews and link the findings to the theory. These code trees are based on the variables and supplemented by insights from the interviews.

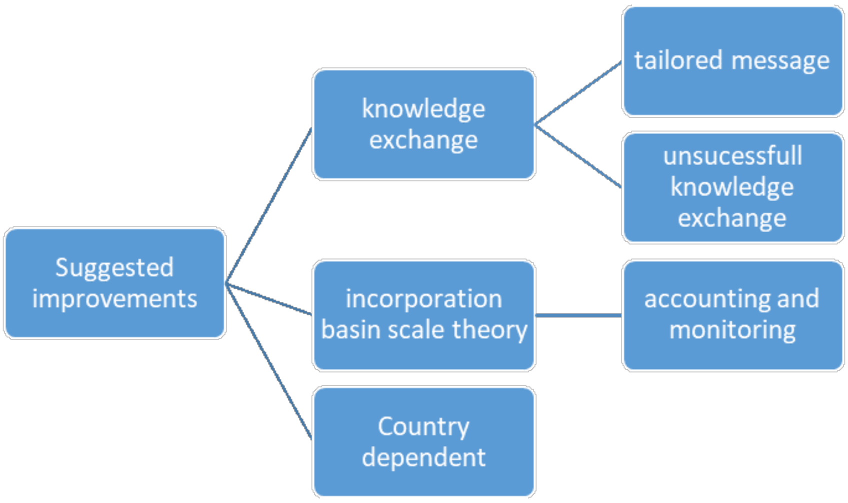

Figure J.1: Code tree suggested improvements

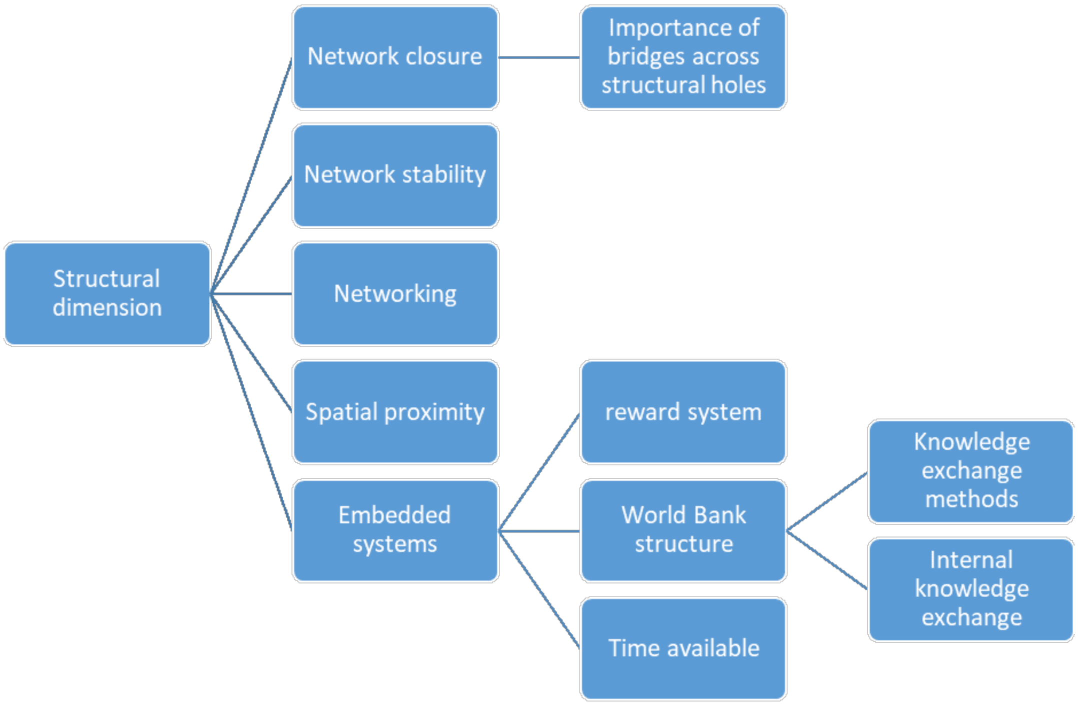

Figure J.2: Code tree structural dimension

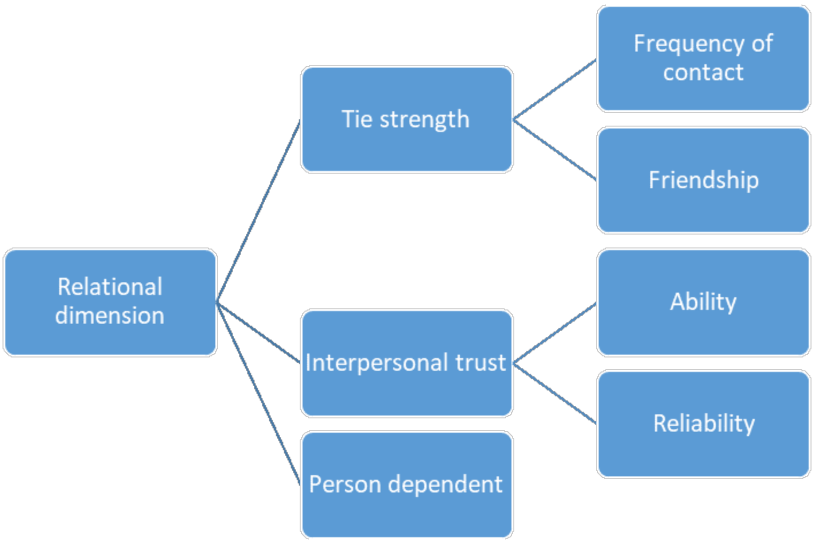

Figure J.3: Code tree relational dimension

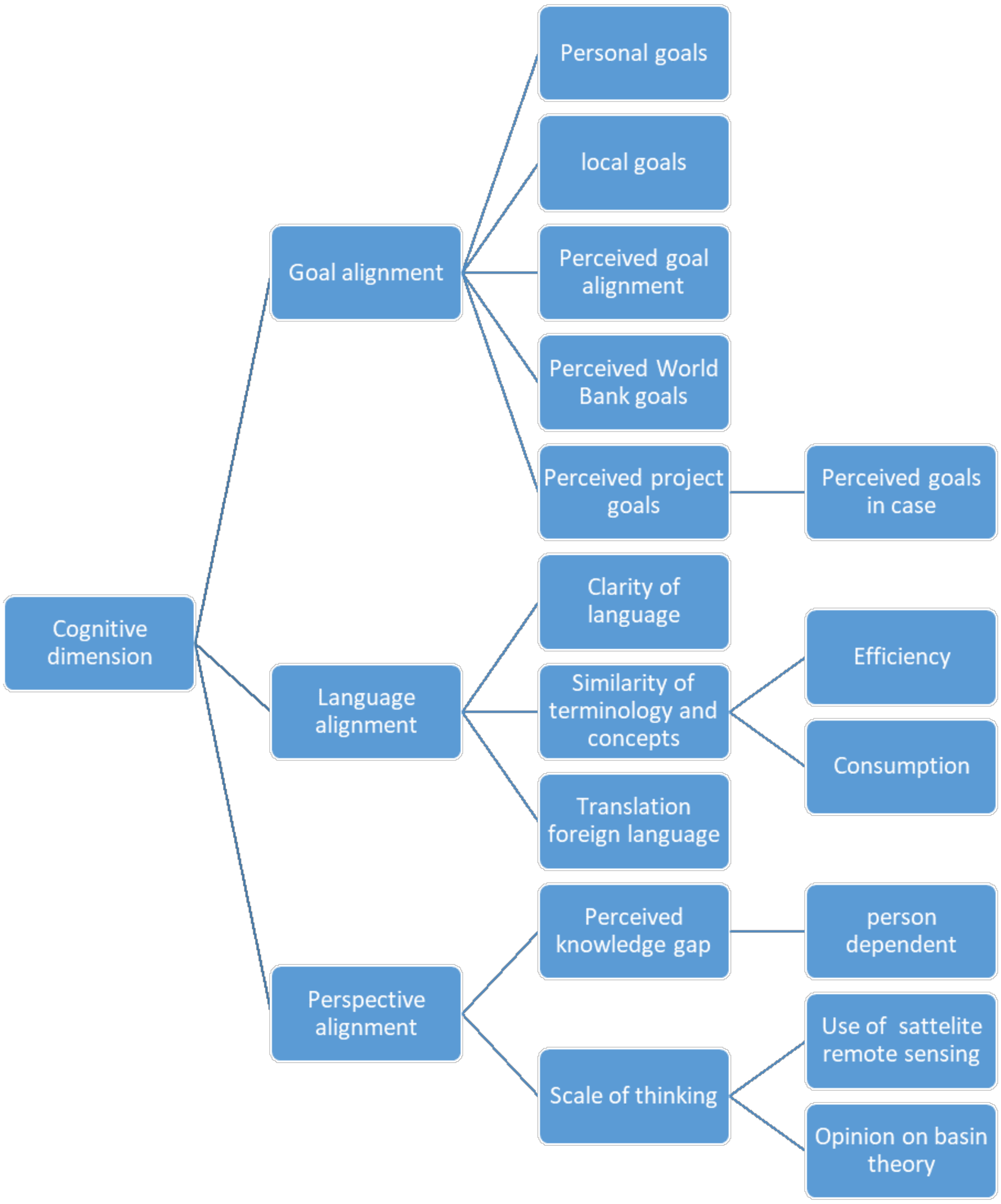

Figure J.4: Code tree cognitive dimension