GROUNDWATER ECONOMICS

Significance and State of Affairs of Groundwater Economics in the Governance of Transboundary Aquifers

Internship report

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"The things which have the greatest value in use have frequently little or no value in exchange. Nothing is more useful than water: but […] scarcely anything can be had in exchange for it. A diamond, on the contrary, has scarcely any use-value; but a very great quantity of other goods may frequently be had in exchange for it."

Adam Smith, Of the Origin and Use of Money

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1. Introduction

1.1. The Importance of Groundwater

Before discussing the importance of groundwater, it is expedient to clarify some basic definitions. According to article 2 of the Water Framework Directive (2000):

- Groundwater is defined as "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil".
- An aquifer is defined as "a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater".

Water ranges among the most vital natural resources, contributing, inter alia, to human health and wellbeing, economic development and the integrity of ecosystem services (Groundwater Governance, 2013). Groundwater, which amounts to around 98 % of global freshwater in liquid form, constitutes an important part of global water supply, delivering at least 50 % of drinking water (ibid.) and over 40 % of irrigation water (Siebert et al., 2010). It moreover plays an important role as a buffer in dry periods and in regard to climate change adaptation (Groundwater Governance, 2013).

The last decades have witnessed an increased demand for and thus pressure on global water resources, which in the case of groundwater in many instances induced abstraction beyond sustainable levels, as well as increased pollution levels (Groundwater Governance, 2013). As a consequence, while some regions of the world already struggle with physical scarcity, economic scarcity, i.e. inefficient allocation between competing demands, is now an issue nearly everywhere and requires political action and more effective governance of groundwater resources (Titenberg, 2002; Gibbons, 1986). All this is long since known in theory, but the issue of depleting aquifers and adequate resource conservation and protection has so far received relatively little recognition in global debates. Consequently management practices in place are often still far from inducing a sustainable use[1] (Brooks, 2013).

1.2. Increasing Pressures on Groundwater and Market Failure

Although groundwater can in principle be kept in a dynamic equilibrium by maximally abstracting the natural flux, it is primarily a depletable – though replenishable – resource (Koundouri, 2004; Margat and van der Gun, 2013). Globally, groundwater abstractions are already often large enough to irreversibly drain aquifers and consequently drastically modify groundwater regimes; a trend that is expected to intensify through increasing pressures on water resources (Titenberg, 2002; Margat and van der Gun, 2013). Considering the predicted population growth, groundwater - through its relatively good quality and easy cost recovery due to local availability - is an increasingly important drinking water source, and in combination with cheap irrigation systems a possible means to overcome poverty (Llamas and Martines-Santos, 2005). Moreover, depending on the region increased dry spells are expected to additionally increase groundwater dependencies, while direct influences of climate change on groundwater still remain largely uncertain (Green et al., 2011). Lastly, increased pollution levels through, for

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[1] Please note that sustainable use is a socio-economic concept, which has to be distinguished from sustainable yields.

example, agricultural activities also decrease the amount of available, clean groundwater (Koundouri, 2004).

From an economic perspective, it is not per se a problem to follow a strategy of progressively depleting reserves, as long as social welfare is maximised over uses and time[2]; in other words as long as the aggregate utility[3] over all concerned individuals is as high as possible (Titenberg, 2002). In technical terms, maximising social welfare requires that marginal net benefits, i.e. the benefit derived from putting one more unit of water to a specific use, are equalised over all water uses; otherwise the total welfare could be increased by reallocating one or more units of water to the use with the higher marginal benefit. Moreover, when extractions of groundwater exceed recharge rates, the resource availability for future generations is affected, wherefore a time externality needs to be accounted for (for a more detailed description of externalities see Box 2). In other words the net present value, i.e. the discounted net benefits over all periods[4], needs to be maximised as well (ibid.).

When a perfect market is established, the efficient and welfare maximising allocation is achieved through correct pricing via the market mechanism. This is only possible, however, if certain assumptions about human behaviour and institutional arrangements[5], including the assignment of fully specified private property rights, are fulfilled (Perman, 2003). If one of those assumptions does not apply market failure arises. In groundwater-management, establishing property rights is often quite difficult (cf. Box 1).

Box 1: Property rights

Fully specified property rights are (Schiffler 1998, p. 95):

- 💧 Well defined: physical limits, quality and user rights are clearly specified
- 💧 Exclusive: third parties do not have competing rights
- 💧 Secure: expropriation is precluded
- 💧 Indefinite: rights do not expire
- 💧 Enforceable: infringements can be challenged and punished
- 💧 Transferable: rights can be conveyed

Take the example of pollution – giving the polluter the right to pollute or the afflicted party the right to clean water leads to the correct pricing and thus the "efficient amount of pollution" (for economic proof see Perman (2003)). Due to the inherent properties of groundwater, however, the establishment of property rights is - though not per-se impossible – a difficult endeavour (Schiffler, 1998). Firstly, groundwater is a mobile resource, wherefore tying property rights to overlying land is not entirely feasible; over-extraction will still lead to generally lowered groundwater tables and negative consequences for third parties. Schiffler (1998) therefore argues on the basis that negative consequences arise mainly from over-extraction, property rights could be more easily defined if abstractions are limited to recharge. However, in some periods over-extraction can be a welfare maximising choice. On imperfect markets an economic instrument to try to correct market failure would be, for instance, to collect a tax in the height of the externalities imposed on third parties (see Box 2). This again involves complex calculations.

(NAP, 1997).
[3] The following is based on the utilitarian concept of utility, which can lead to equity issues (see 4.1.7).
[4] For more detail on discount rates see section 4.1.6.
[5] For a full list the reader is referred to Perman (2003, p. 116).

In the absence of institutional constraints, aquifers are open-access resources and groundwater is basically a common good, i.e. no-one can be excluded from extracting while extractions of one user affect the resource availability of other users. Consequently, water that is conserved now could be extracted by somebody else either in the present or in the future (Titenberg, 2002). Thus individual agents make their pumping decisions solely on their private costs and benefits; in other words they extract groundwater until their costs for extracting one extra unit of water are larger than the benefits of using this unit, but not taking into account costs that are enforced on other users like increased costs for pumping lower water tables (ibid.). Such a behaviour ultimately results in inefficient extraction across users, space or time and/or depletion.

Though competitive private exploitation can threaten any aquifer, in transboundary aquifers this problem is oftentimes aggravated, for each administrative entity might try to use the resource first (Chermak et al., 2005); a prominent example is the Disi aquifer between Jordan and Saudi Arabia (Linton and Brooks, 2011). As an aside, while Gisser and Sanchez (1980) claimed that the optimal economic solution is nearly identical to the competitive solution in terms of social welfare, recent research showed that this is mainly due to simplified modelling which does not adequately reflect reality (Koundouri, 2004; Tomini, 2014).

1.3. Transboundary Aquifers: A Governance Challenge

The so called "tragedy of the commons" described in the previous section, implies that simple supply-side management, which was often the sole focus in the past, is not sufficient to induce sustainable uses and needs to be complemented by demand-side management (Shah et al., 2000). In other words avoiding excessive exploitation requires the establishment and enforcement of a common set of management and exploitation rules; an endeavour that is, however, likely to be difficult and even more so in a cross-border context. What is therefore needed is a broad, multi-disciplinary approach under the umbrella of governance[6]. Several issues are of prior importance in transboundary water management (TWM) (cf. figure 1), namely maintaining ecological sustainability, maximum utilization of the common good and conflict prevention.

As can be seen in figure 1 an important part in establishing a working set of management rules, is to create a basis for an efficient allocation and thus maximum utilisation of the resource (Kim and Glaumann, 2013). This in turn presupposes cooperation between all multilateral actors, as well as an understanding of the economics of water demand and value (Gibbons, 1986). Being able to present an overview over various uses and their marginal benefits can for instance reinforce the importance of establishing allocation rules and is the basis for allocative efficiency and consequently for maximising collective utility (ibid.).

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[6] Here governance is defined according to Groundwater Governance (2013) as "the process by which groundwater resources are managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law", and thus as "the art of coordinating administrative actions and decision making between and among different jurisdictional levels – one of which may be global".
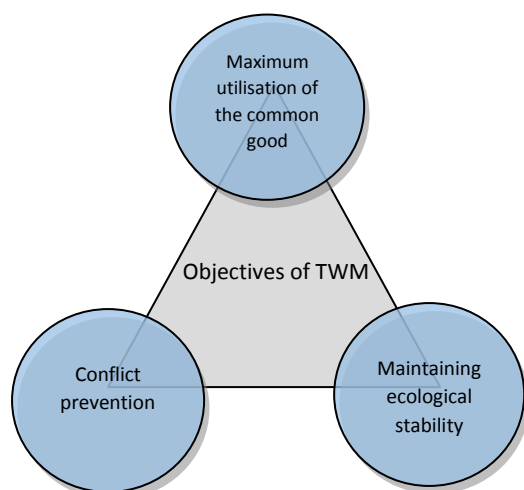
Figure 1. Objectives of TWM. Source: Kim and Glaumann (2013)

ACTIVITIES SPREAD ACROSS BASIN TYPES		
BASIN TYPE	ACTORS	PROJECTS
LME	4	2
Lakes	27	26
Rivers	69	96
Aquifers	7	21

Table 1. Activities Spread Across Basin Types. Source: Kim and Glaumann (2013)

According to Linton and Brooks (2011) in a transboundary context equity is even more essential for successful negotiations, as well as for the adoption of an agreement, than in a single country situation. Since mere quantitative equity is a rather crude measure for realizing an equitable and reasonable resource use, because fifty percent of the resource might produce much higher benefits for one country than the other (Linton and Brooks, 2011), economic efficiency can be deployed as an alternative to formalise allocation decisions (Loomis, 2000). Apart from the rather small quantity of water required for basic domestic use, the value of groundwater lies in the services it provides (Linton and Brooks, 2011). Understanding the different components that contribute to the value of groundwater (including extractive as well as non-extractive values), can thus be seen as an important tool for achieving an efficient allocation of water and sustainable levels of withdrawal (Titenberg, 2002; Chermak et al., 2005). Moreover, according to the UNECE (2013) the stakeholders' understanding of (net) benefits that can be achieved through cooperation, can increase the willingness to participate and is thus in itself an important step toward reaching agreements.

However, while developments in regard to surface water governance have commenced already several years ago, groundwater governance was – and still is – lagging behind (Brooks, 2013); despite programmes like UNESCO's ISARM[7]. This can, for instance, be seen by the relatively small amounts of actors and projects targeting aquifers (cf. table 1).

1.4. Role of Groundwater Economics in TBA Governance

As indicated above, economic concepts can support groundwater governance in several ways. Firstly, it allows the **understanding of market failure and individual behaviour** which deviates from welfare maximisation for the whole community. Secondly, **it facilitates the understanding of trade-offs** between different uses of groundwater (including also environmental benefits it provides) and thus forms the basis for efficient resource allocation. Thirdly, it **supplies**

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[7] ISARM = Internationally Shared Aquifer Resource Management

instruments with the help of which allocation decisions can be enforced or incentivised. All this constitutes valuable input for creating equitable and efficient **evidence-based policies**, i.e. policies integrating the results of systematic research along with political and practical knowledge in order to achieve maximum justifiability (Head, 2008). Moreover, it also presents a basis for **increased transparency** and thus raises awareness and enables a more informed dialogue among stakeholders.

Naturally, economic tools on their own are not sufficient to bring about sustainable water use; rathermore they need to be embedded in a multi-dimensional and multi-disciplinary governance approach, using input from (hydro-)geologists, economists, ecologists and policy advisors to implement a transparent, open and equitable decision making process (de Loë et al., 2008). However, at the moment economic inputs seem to be highly underused in decision making processes. For instance, instead of considering all benefits delivered by groundwater and integrating them into an analysis, so far governance is mostly only concentrated on water in an aquifer, leaving out for instance benefits of discharge[8] (J. Gupta, personal communication, 2014). Moreover, although the actual degree of integration is highly country dependent, so far economic instruments are mainly utilised in the form of specific tools, like taxes, rather than a means for understanding market failure and trade-offs between different uses of groundwater (J. van der Gun and Y. Jiang, personal communication, 2014).

One reason for this, which became apparent in several interviews conducted in the course of this research, seems to be a certain distrust between specialists of the disciplines Economics and Governance; where the former miss a more quantitative approach and studies with a larger n, the latter have the preconception that an attempt at monetisation will ultimately lead to privatisation and undesired results (Y. Jiang and J. Gupta, personal communication, 2014). In an attempt to consolidate the two approaches, this report outlines the usefulness of the concept of "economic value" in allocation decisions of TBAs, in order to enable informed (evidence-based) decisions and an adequate employment of economic instruments.

2. Research Aim and Structure of the Report

This report aims at contributing to the growing body of scientific research, by enquiring into the role of groundwater economics in the governance of aquifers with a specific focus on transboundary aquifers. On a more practical note it seeks to contribute to building a basis for incorporating groundwater economics into the portfolio of IGRAC.

Content-wise, this study is divided into two main parts. Part 1 deals with the description of the economic value of groundwater, which can serve as a guide/framework for decision-making also by non-economists. The rationale behind this is that, before attempting to actually monetise the value of groundwater, it is important for policy makers to understand the underlying theory, as well as the advantages and snares of the methodology. This alone can already foster informed decision making and improve communication with stakeholders. Part 2 then concentrates on one or two case studies by applying the framework outlined in part 1. Thereby an overview over the current state of affairs in the valuation of groundwater in transboundary aquifers is given, although incompleteness might follow from time restrictions.

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[8] See also case study: Stampriet (this report) and Jica Report (2002).

3. Methodology

Due to the limited amount of time available, this research was conducted mainly as a literature study. However, in order to ensure the relevance of the content and tap additional resources - especially in connection with the envisaged case studies - it was deemed expedient to conduct semi-structured interviews with experts in the field; e.g. from IGRAC, UNECE, SIWI and Universities.

4. PART I: Theoretical Underpinnings

4.1. The Economic Value of Groundwater

4.1.1. What is the "Economic Value" of a Resource?

Simply put, valuation is "an attempt to put monetary values to environmental goods and services or natural resources" (Mburu et al., 2006). At its basis lie the assumptions that individuals hold preferences regarding changes in quality and quantity for all goods and services, and that these preferences can be gauged in monetary terms. Two main measures of interest in this regard are (ibid.):

- Willingness to Pay (WTP), i.e. the maximum amount subjects are prepared to pay to either receive a good/benefit provided by groundwater, or avoid a bad.
- Willingness to Accept (WTA)[9], i.e. the maximum amount requested for receiving a bad or giving up a good.

Additionally, the concept of the total economic value (TEV) proved useful when attempting to value a complex resource (NAP, 1997; Perman, 2003; Mburu et al., 2006). Although no standardized categorisation has emerged so far, it is a very useful framework for ensuring the consideration of all aspects of value a resource provides, and for preventing double counting[10]. Generally, the TEV framework distinguishes between two main categories, use-values and non-use values, and several sub-categories (MJA, 2012). Figure 1 gives an overview over a common classification; the sub-categories are explained in more detail in the following.

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[9] In practice, it is usually the WTP that is asked, since it allows for more conservative estimates. Past research has shown that the WTA is often overstated in situations where respondents are not familiar with the good; however, after they have gotten the possibility to "learn" about it in a market-like environment WTA estimates approach WTP estimates.

[10] Double counting refers to the inclusion of the same value more than once in the analysis. This needs to be avoided since this will distort the real value of the resource. Therefore, only "end-products" or "end-benefits" should be valued, leaving out so called intermediary benefits.
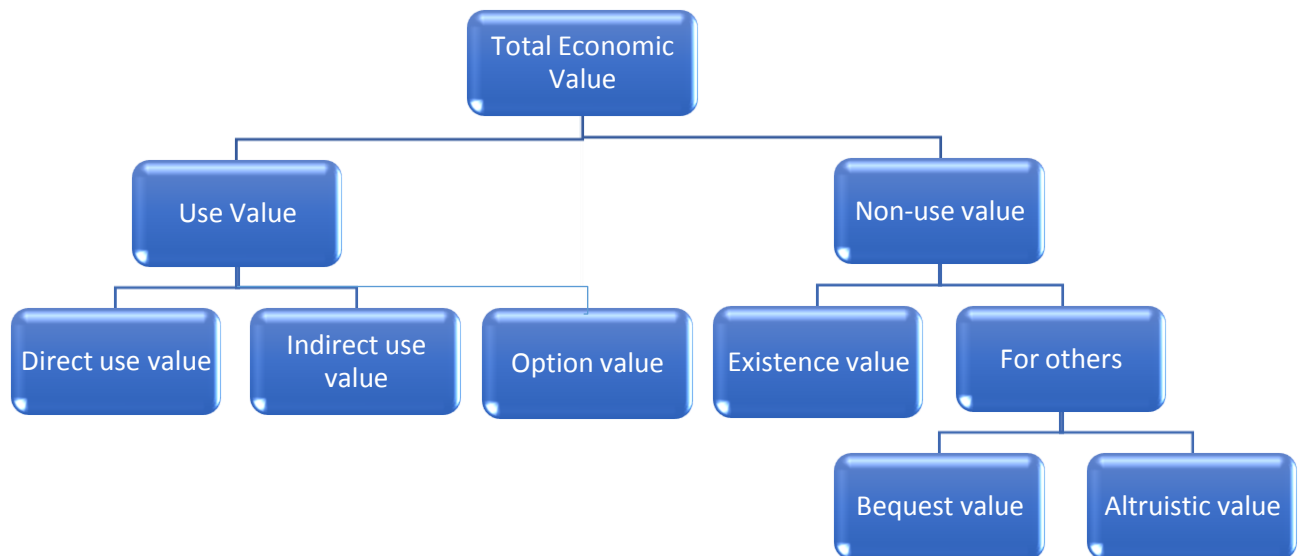
Use Values: Indicate values that arise from the use of the good, be it actual, planned or possible. Thus use values involve either direct or indirect interaction with the good.

> *Direct use value*: Measures the WTP for direct human interaction with the resource; interactions can be either consumptive, e.g. drinking water, or non-consumptive, e.g. recreation.

> *Indirect use value*: Measures the WTP for benefits from indirect utilisation, like through ecosystem functions etc.

> *Option value*: Measures the WTP to preserve a resource.

Non-Use Values: Indicates values from maintaining a resource, although no actual use is either happening or planned; this may also apply to "unseen" benefits provided by the resource. Subcategories usually involve an existence value, a bequest value and an altruistic value.

> *Existence value:* Measures the WTP to preserve a resource, out of concern for the good itself in its own right; satisfaction is drawn from knowing that the resource will continue to exist.

> *Bequest value:* Measures the WTP to preserve a resource, in order to pass benefits on to future generations.

> *Altruistic value:* Measures the WTP to preserve a resource, so that contemporaries can enjoy its benefits.

Please note that the TEV is an anthropocentric concept, i.e. its basis is human welfare, and does thus not include any intrinsic value that the resource might have. Whether this is appropriate or not is a philosophical debate; attempting an inclusion of an intrinsic value in an analysis, however, presents quite some difficulty. If goods indeed have an immeasurable intrinsic value, trade-offs cannot be made. Since in a world of finite resource making trade-offs is a necessity, the TEV is the

> Using the concepts defined above, the TEV of a resource can be expressed as a summation of use and non-use values, i.e. all relevant WTPs, across all services provided by the resource (NAP 1997, p. 48).

standard framework used in environmental economics. As an aside, also note that the TEV comprises more than just the mere market value of a good (Mburu et al., 2006) (see Box 2).

In order to measure the economic value of groundwater, it is thus important to identify the WTP for all services provided by groundwater. Therefore, the next chapters are concerned with which benefits are provided to whom and how the WTP can be elicited.

Box 2: Value, price, costs and externalities

Although the terms price and value are often used interchangeably in colloquial speech, they are distinct economic concepts. In order to understand their relation, it is essential to be aware of the concepts of supply and demand.

Value, as has been described above, can be expressed as an individual's WTP or WTA. Demand then is simply an individual's WTP for – or valuation of – an incremental, i.e. one-unit, increase in quantity delivered. For the first few units of water the WTP of an individual will be highest - one can think of the need for drinking water or other basic needs. With increasing quantity, however, the WTP decreases. To arrive at an aggregate demand curve for the total population, individual demands are simply summed up horizontally. This leads to a downwards-sloping social demand curve (cf. figure 3). Please note that the different points on the demand curve indicate the marginal WTP, whereas the area under the demand curve indicates the total WTP. Importantly, one needs to recognise that demand can change over time and – in this case – with the overall availability of water.

In a perfectly competitive market, i.e. a market without distortions, the costs of providing water, which include fixed costs for the development of the infrastructure and variable costs for operations and supply, like electricity, form the basis for what is charged at each quantity; this is also known as supply curve (cf. figure 3). Since it would not be worth incurring costs that outweigh the benefit (value), the price that will form in the market can consequently be found where supply and demand are equal. As an aside please note that economists often refer to the difference between the total WTP and the expenditure (price times quantity) as "consumer surplus".
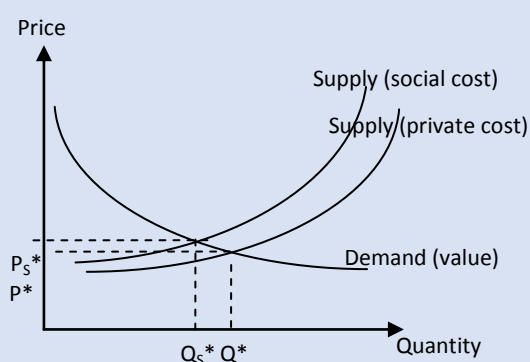
Figure 3. Market Price. Source: own image after Perman (2003)

However, public goods like groundwater are often prone to market failure, which means the private costs of supply are not equal to the actual costs society has to bear. Consequently, the

quantity extracted/delivered is too high. As a consequence the price does not adequately reflect social preferences.

In order to ensure efficiency, the costs of supply should include:
- The marginal user cost, i.e. the present value of opportunity costs imposed on future generations for not being able to consume a unit that is extracted now[11].
- All externalities, i.e. costs that third parties incur which are not compensated via the market mechanism. Those are mainly ecological externalities or ecological side effects from excessive extraction or contamination.
  A common distinction in the literature is between stock externalities (due to over-extraction), technological externalities (in form of increased extraction costs) and strategic externalities (due to a race for the resource) (Ratna Reddy, 2000). Other sources make a distinction between economic externalities (including extra pumping or treatment costs) and environmental   externalities.
  What all definitions have in common is that externalities increase the social supply costs compared to the private supply costs. Consequently, the socially optimal quantity of supply (Q_S*) is lower than the private optimum and the socially optimal price is higher (P_S*).

Handling such inefficiencies is a specific challenge in a transboundary setting, where for instance the race for the resource can be exacerbated and discussions could be complicated by differences in culture and perceptions (ISARM, 2014).

4.1.2. Benefits Provided by Groundwater

TEV-Framework

Table 1 gives an overview over the benefits provided by groundwater in the context of the TEV framework. Although care was taken to compile a comprehensive overview, other researchers may find that they would like to add to the list. It should be noted that, due to the complexity of groundwater systems, it is very unlikely that an aquifer provides all listed benefits at once; rathermore, aquifers will provide their own specific range of benefits.

Mostly, the benefits described in table 1 are self-explanatory; nevertheless some context is provided in the following.

Direct use values are values derived from direct consumption either by individuals or sectors, like the agricultural sector or industry. Due to its generally good quality groundwater is an important source of drinking water, next to other uses like irrigation. Additionally, in karst aquifers water potentials are often big enough to generate hydro-power (Milancovic and Kukuric, 2013).

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[11] Please note that this is sometimes also referred to as scarcity rent or royalty; however, definitions are still not perfectly uniform, wherefore caution need to be exercised (Pongkijvorasin and Roumasset, 2007).

Total Economic Value	Use Value	Direct Use (Priced) Value		Public Water Supply
				Private Water Supply
				Agriculture
				Industry
				Renewable Energy (e.g. Hydropower, Heat Pumps)
			(Unpriced)	Surface Water Recharge and Consequently Recreation, Fishing, etc.
		Indirect Use Value		Flood Control
				Carbon Sink
				Waste Assimilation
				Prevents Subsidence
				Supports Ecological Diversity/Habitats
				Prevents Seawater Intrusion
		Option Value = Buffer Value		Future Direct or Indirect Value (Including Future Drugs Developed on the Basis of Biodiversity, Potential Gene-Pool, Recreational Options, etc.)
	Non Use Value	Existence Value		Satisfaction from Existence
				Hypogene species (Unseen Benefits)
		For Others	Bequest Value	Passing Benefits to Future Generations
			Altruistic Value	Passing Benefits to Current Generation

Table 2. List of Benefits Provided by Groundwater. Source: own table after NAP (1997)

Groundwater discharge naturally occurs into surface water bodies, which especially in dry periods contributes to the support of ecosystems and their services. Hence groundwater ultimately delivers benefits in form of landscapes for recreational activities, as well as biological diversity and habitats. Discharge furthermore sustains brackish waters in estuaries, as well as groundwater dependent ecosystems, like wetlands and their services. As a rough measure, the higher the base-flow index[12], the greater the importance that groundwater plays in sustaining these ecosystems. As an aside groundwater in shallow aquifers can also directly sustain some deep-rooted plants.

Additionally to the above mentioned services, groundwater also delivers more indirect benefits. It does, for instance, act as a carbon sink by dissolving CO_2 which subsequently precipitates as carbonate. Moreover, especially in clay and peat soils, which are prone to subsidence, it contributes to the integrity of the land. Consequently, it also contributes to keeping the risk of flooding at bay[13] (NAP, 1997). A higher groundwater pressure due to larger stocks furthermore prevents the intrusion of seawater into the aquifer. Lastly, groundwater plays an important role in reducing the negative impacts of waste by diluting contaminants.

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[12] Base-flow index depicts the ratio of annual base-flow to total annual runoff, where base-flow is the portion of a stream that comes from groundwater.

[13] Land subsidence can lead to a sagging of ground and thus depressions which are more prone to flooding (NAP, 1997).

Apart from these use values, the TEV also points to additional (non-use) benefits provided by groundwater. Not extracting groundwater, holds for instance an option value of being able to use the water (or elements sustained by water) in later periods; this can in some instances be similar to a so called buffer value of groundwater (see Box 3). Lastly, some people might draw satisfaction/benefits from the mere existence of the aquifer or they value the fact that services can be provided to other individuals and/or other generations.

Box 3: Option vs. Buffer Value

Option Value

An option value, is the willingness to pay for the mere option to consume something in the future. Importantly, whether or not the resource will actually be consumed in the future is unknown. In rational (economic) decision making the option value should influence the decision of whether to use a resource now or to preserve it. However, market mechanisms are generally not able to incorporate an option value into allocation decisions (Weisbrod, 1964).

Buffer Value

A buffer value is usually defined similar to Tsur and Graham-Tomasi (1991, p. 201) as "the difference between the maximal value of a stock of groundwater under uncertainty and its maximal value under certainty where the supply of surface water is stabilized at its mean". In other words, the buffer capacity of groundwater, is its property to absorb shortages that might arise in the future due to droughts and surface water scarcities.

Overlaps between the Concepts

In case where the buffer value refers to the mitigation of fluctuations in surface water supply, i.e. in cases where it is not certain that the use of groundwater is necessary, the two concepts overlap (Y. Jiang, personal communication, 2014). However, if scenarios can already be developed where an overdraft will most certainly be necessary, expected use values should be discounted and aggregated; in this case uncertainties would have to be incorporated via a sensitivity analysis (ibid.).

Extractive and In-Situ Services

A related, more physical terminology in regard to groundwater benefits is the differentiation between extractive values, i.e. values derived from extracting and consuming - e.g. drinking - water, and in-situ values, i.e. values that are delivered by groundwater stock remaining in the aquifer, including discharge values. Although it does not specify the different kinds of values as extensively as the TEV-framework does, an advantage of this depiction is that the dynamics of the system can be emphasised (cf. figure 3). It becomes, for instance, visible that in-situ services depend on the quality and quantity of the groundwater in stock, which is part of a complex system changing over time[14]. In order to avoid confusion, however, the rest of the report is based on the economic concept of TEV.

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[14] Please note that this report will not go into detail about hydrogeological specifications, it is important to bear in mind that every aquifer is different and that models need to incorporate this in an interdisciplinary effort.
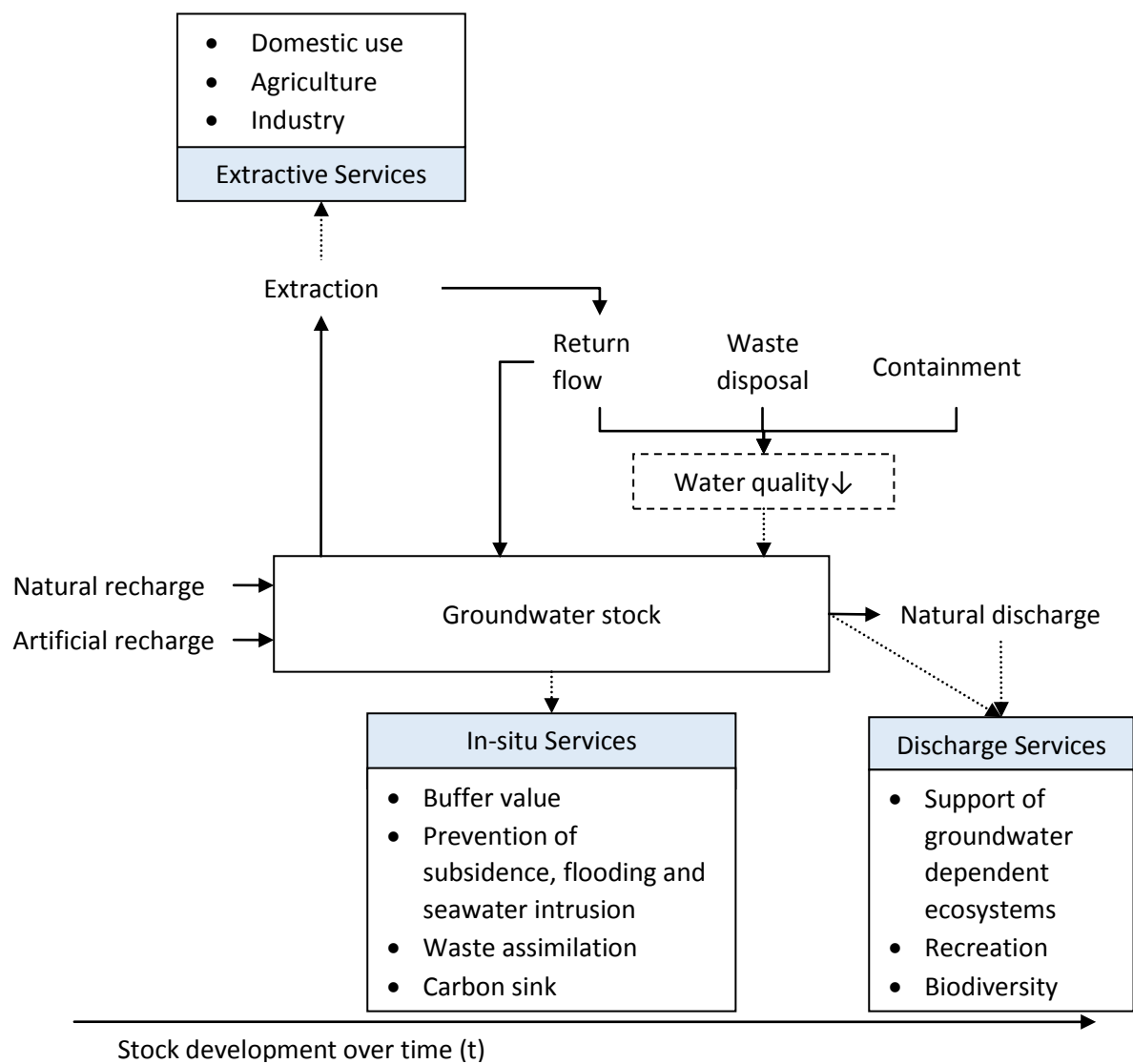
Figure 4. Extractive Versus In-Situ Values. Source: own image after NAP (1997) and Qureshi et al. (2012)

Beneficiaries

In order to quantify and aggregate benefits it is important to know who benefits from groundwater services. In this regard a stakeholder analysis might also be helpful when conducting an actual analysis. This, moreover, helps to identify possible sources of double counting when beneficiaries use private wells for domestic uses, as well as for agricultural irrigation.

Benefit	Beneficiaries
Public Water Supply	Public water users (i.e. users connected to the public water supply)
Private Water Supply	Private water users (i.e. users extracting groundwater with private facilities)
Agriculture	Rural users (e.g. farmers using groundwater irrigation, or water for livestock)
Industry	Industrial consumers (e.g. mining etc.)
Renewable Energy	Electricity consumers or users of heat-pumps
Surface water recharge	Recreationalists and fishermen
Flood Control	Residents of areas with increased flood risk
Carbon Sink	Global population
Waste Assimilation	Water users (beware of double counting)
Prevents Subsidence	Residents of areas with increased risk of structural problems
Supports Ecological Diversity/Habitats	Local population, farmers, recreationalists
Option value	In theory everybody could have an existence value for a certain resource
Satisfaction from Existence	In theory everybody could have an existence value for a certain resource
Hypogene species (unseen benefits)	In theory everybody could have an existence value for a certain resource
Bequest Value	In theory everybody could have an existence value for a certain resource
Altruistic Value	In theory everybody could have an existence value for a certain resource

Table 3. Beneficiaries. Source: own image after MJA (2012)

4.1.3. Quantifying Benefits: Valuation Techniques

Overview Valuation methods

In order to value the benefits identified above, researchers have several methodologies at their disposal. While those methodologies have different data requirements and are thus suitable in specific circumstances, they also have disparate time and monetary requirements and do not all measure the same aspects of the TEV (Mburu et al., 2006).

Generally there are two main categories, namely revealed preference methods and stated preference methods; the former relies on the assumption that preferences are revealed through purchasing behaviour, whereas the latter involves questioning a representative sample about their preferences in hypothetical markets. Additionally, revealed preferences are sometimes divided according to whether they apply to market goods, where market-prices indicate value changes, or non-market goods, where values are inferred from behaviour on related markets. Owing to the sometimes substantial time and monetary requirements, an additional approach has gained importance over the years; namely the utilisation of value estimates identified in other studies (ibid.). Therefore, their advantages and disadvantages are shortly explicated in box 2 and the selection of a valuation procedure is addressed in the following section.

Approach	Valuation Techniques	Nature of Value
Revealed preferences *Non-market goods*	Hedonic Pricing	Use values (related to travel costs)
	Travel Cost Method	Use values (related to changes in environmental quality)
Market goods	Market Price	Use values
	Production Function	Use values
	Preventive Expenditure	Use values
	Replacement Cost	Use values
	Cost of Substitute/Alternative	Use values
Stated preferences	Contingent Valuation	Use and non-use values
	Choice Modelling	Use and non-use values
Benefits transfer	Utilise other study results	Use and non-use values

Table 4. Valuation Techniques. Source: own image after Mburu et al. (2006)

Box 4: Valuation Techniques

Hedonic pricing: Estimates values of goods which are not directly traded in markets, but are expected to affect market prices of another good (Mburu et al., 2006). For instance, environmental attributes are often included among other factors thought to affect property prices and their influence is subsequently measured through a regression (King and Mazzotta, 2000).

Travel cost method: Is most commonly used to estimate the value of sites used for recreation by measuring the amount people are willing to pay in order to get there (Mburu et al., 2006). Underlying economic rational is that the value a visitor experiences from an environmental amenity should be inferable from the costs experienced in order to get to the site, i.e. the travel expences (T) and the entry price (P) (see equation 1) (Perman, 2003).

$$V_i = \alpha + \beta c_i + \varepsilon = \alpha + \beta(T_i + P) + \varepsilon_i \qquad (1)$$

Market price: Estimates values for commercial goods based on their market price (Mburu et al., 2006). In order to estimate a demand function (see Box 1) it is important to observe prices for different quantities delivered (ibid.).

Production function: This method is used to estimate values for products or services that contribute to the production of a commercial/market good (Mburu et al., 2006). For instance, a **residual imputation method** could be employed where the value (or shadow price) of water is calculated by subtracting all non-water factor inputs, like capital, land, or labour, from the total value of the product (see equation 2). In practice, complexities, like for instance market distortions, can complicate such calculations.

$$P_W = (TV - (P_K * Q_K + P_L * Q_L + P_R * Q_R))/Q_W \qquad (2)$$

Where TV = Total value added
P_W = shadow price of water
P_X = price of a factor input (K = capital, L = labour, R = land, W = water)
Q_X = quantity of a factor input (K = capital, L = labour, R = land, W = water)

Cost based methods (damage cost avoided = preventative expenditure, replacement costs, cost of substitute/alternative): Those methods all rely on the assumption that value can be measured by estimating the costs of avoiding damages, replacing ecosystem services, or

providing substitutes or alternatives. Thus rather than the WTP, they measure the costs that would have to be born if the service was lost or to avoid its loss (King and Mazzotta, 2000). An example would be the cost of artificial flood defences in case the flood protecting function of a wetland is lost.

Contingent Valuation (CV): Involves confronting respondents with a hypothetical scenario and directly, i.e. via survey questions, eliciting values for public goods (Mitchell and Carson, 2013).

Choice experiment (CE): Like a CV a CE works with hypothetical markets. However, opposed to a CV, respondents are not asked directly about their valuations, but are presented with a so called "choice situation" in which they are asked to choose between two or more alternatives. Those alternatives are characterised by different attributes with varying levels. The fact that one of the attributes is presented in actual (monetary) costs, subsequently allows the researcher to calculate the marginal willingness to pay for changes in each individual attribute (Meyerhoff et al., 2009).

Benefits transfer: Estimates of economic values are transferred from existing studies (possibly conducted for a different location or issue) (Mburu et al., 2006).

Selection of a valuation method

There are different valuation methodologies available in order to measure benefits provided by groundwater. Which technique is most suitable depends on several factors.

Foremost, it will depend on the **type of benefit and related data availability**; if there is for instance no market (or related market) on which the good is traded, revealed preference methods are out of question.

Additionally, the **inherent features of the valuation methods** themselves will also play an important role. Stated preference methods for instance require the respondent to develop a good understand the changes described to him, wherefore they might not be adequate in regard to complex benefits[15]. Revealed preference methods, on the other hand, only reveal a portion of the value, namely the use value.

Furthermore, the **circumstances of the valuation situation** (e.g. which beneficiaries are affected by certain changes) determine which framing - and hence valuation method - is most suitable. An example is the valuation of a change in water quality versus a change in quantity. Whereas the latter could be valued by the costs of alternative supply that is necessitated, the former can be valued using treatment costs. However, which kind of treatment costs are to be used, again depends on the specific situation. In a context where water companies are required to provide water of a minimum quality their treatment costs are an appropriate measure; otherwise, i.e. when simply water with a worse quality is delivered, increased health costs are a more suitable valuation basis.

The ultimate choice of a valuation technique will also depend on **what is needed for decision making**. Generally, it is desirable that the time and monetary expenditure is considered in regard to what is actually needed. When, for example, an important aquifer is threatened by large changes, the higher expenditures and time requirements (often between six month and a year) of stated preference methods are justified. On the other hand if a quick first evaluation is

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[15] Alternatively, benefits could be dissected into segments that can be more accurately described and several separate studies could be conducted. Especially for a good like groundwater, where benefits might not be immediately visible, a thorough description of the hypothetical market is of utmost importance.

needed, benefits transfers, which usually take several weeks, might be sufficient if similar studies are available.

In a transboundary setting, moreover, different populations have to be considered. This also increases the resource intensity of a study per-se, wherefore the adoption of benefits transfer – especially as a method for a primary evaluation – becomes more attractive. In addition to time and resource savings of benefits transfers, they can also help to increase the **comparability of the valuation of similar benefits across borders.** Especially the benefits measured (i.e. use values vs. non-use values) should be similar for all parts.

Based on the factors described above several questions have to be considered by the researcher when selecting a valuation method for a specific benefit:

1. Are there markets on which the good/benefit is directly or indirectly traded?
2. Who is affected and who has to bear the consequences of a change in benefits?
3. What are the minimum information standards required for the policy problem at hand?
4. Which kind of information is already existent and can be used thus reducing the effort and time requirements of the study?
5. Which information is available for other countries and is the data comparable?

Whereas the first question answers which methods are actually possible, the second gives an answer to which methods are appropriate in the given situation. From the subsequent list, it is important to choose a method, whose time and monetary investments are justified by the study needs (question 3). Of course, even if a benefits transfer would be the adequate methodology, it is still not certain that an appropriate base study is available (question 4). Finally, in transboundary studies valuation methods that are chosen in individual countries should lead to comparable outputs.

The selection of the most adequate valuation instrument relies to a large part on the answers to the questions above. However, in general, methods like the cost of alternative/substitute are used in developed countries to calculate the value of public and private water supply, since reliable market data is often hard to find and stated preference methods require a larger amount of preparation and resources. This is realistic in the short term, since demand elasticities are expected to be more inelastic than in the long term. In developing countries on the other hand WTP estimates are often elicited via contingent studies due to information gaps regarding substitutes. Industries (including agriculture) are mostly evaluated using one version of a production function, since water here is an intermediary input and valuation via the end-product markets is a feasible method of evaluating water as a factor input. Recreational values are often valued using the travel cost method, a contingent valuation or a mixture of the both. Table 4 below summarizes possible valuation techniques for all benefits identified, as well as their data requirements and advantages and disadvantages.

Benefit	Valuation Method	Data Requirements	Advantages/Disadvantages
Public and Private Water Supply	Market price	Groundwater quantity demanded and market price	(-) Lower-bound estimate (only use value) (e.g. Mburu et al. 2006, p. 51) (+) Data easy to obtain.
	Cost of alternative	List of alternatives Costs of alternatives (fixed/infrastructure + variable/operations costs)	(-) These are supply-side measures. It can thus be argued that the actual demand will differ; i.e. demand adjustments could be made in a situation of changed supply.
	Cost of substitute	List of substitutes Costs of substitutes	(-) Costs of alternative might be more difficult to obtain (+) Costs of substitutes are usually easier to obtain
	Mitigation	Definition of mitigation behaviour Costs for mitigating actions	(-) Generally not a very accurate measure of benefits
	Stated preferences	Detailed description of changes in water supply	(-) Time and resource intensive research (+) Measuring of use as well as non-use values
	Hedonic pricing	Data on e.g. housing prices (or other market data) and socio-economics of the population	(-) Limited to issues related to housing prices etc. (-) Only perceived differences can be measured (-) Statistically very complex (+) Based on actual choices (+) Mainly readily available data
Agriculture	Production function	Impact of change in water quantity/quality of crop yields Market prices of crops Factor inputs and input prices Types and area [ha] of irrigated crops in the study area and yields per ha	(-) Specifying a production function can be an intricate matter. If, for instance, important inputs are omitted, long-run effects ignored, the level of production wrongly estimated or opportunity costs misspecified, the estimate will be misleading. Moreover, market failures on other input markets can cause problems (see MacGregor et al., 2000).
	Cost of alternative	List and costs (fixed plus variable) of	(see public/private water supply)

		alternative water supply options	
Industry	Production function	Impact of change in water quantity/quality of production outputs Market price of products Factor inputs and input prices	(See agriculture)
	Cost of alternative	List and costs (fixed plus variable) of alternative water supply options	(see public/private water supply)
Renewable Energy: Hydropower	Cost of alternative	Marginal costs of alternative electricity production (base and peak energy) Cost of additional capacity in an alternative power plant Total cost of alternative energy Marginal and total cost of hydropower	(-) Environmental impacts (both negative and positive) are not included (see public/private water supply)
Surface Water Recharge	Contingent methods	Share of groundwater in surface water changes (base flow) Impacts on welfare	(-) Difficult to identify the actual contribution of the groundwater
	Travel cost method	Travel times of visitors to a recreational site Additional expenditures (entry fees, etc.) Socio-demographics of the sample Share of groundwater in surface water changes (base flow)	(-) Only direct use values (-) Difficult to separate WTP if more sites are visited (-) Difficult to identify the actual contribution of the groundwater (+) Captures recreational value
Flood Control/Risk Regulation	Mitigation	Changes in risk of flooding Mitigation costs	(see public/private water supply)
	Contingent methods	Changes in risk of flooding Subsequent welfare impacts	(see surface water recharge)
Carbon Sink/Storage	Too little is known of this property at the moment, wherefore it is usually not valued.		
Waste Assimilation	Similar to the prevention of saltwater intrusion, this benefit is of an intermediary nature and contributes to the quality of public/private water supply, as well as to the ability of groundwater to sustain habitats. It should thus not be valuated separately.		
Prevents Subsidence	Cost of prevention	Changes in soil stability Definition and costs of preventive	(-) Lower bound estimates since people might be willing to spend more

		measures	(-) Expenditures might prevent not only one event, but also others (+) In cases where people are familiar with the situation forecasts are reasonably easy (+) Preventive expenditures are spent in markets
	Hedonic pricing	Data on house prices and socio-economics of the population	(see public/private water supply)
Supports Ecological Diversity/Habitats	Contingent methods	Description of welfare changes	(see surface water recharge)
Prevents Seawater Intrusion	This is an intermediary benefit and in order to avoid double counting should not be valued separately. Prevented saline intrusion as such is not consumed, but influences other benefits provided by groundwater. Ecosystems, for instance, will change depending on whether groundwater is fresh, brackish or saline, as will agricultural yield.		
Option value	Contingent methods	Description of welfare changes	(-) Larger resource investment necessary (+) Use and non-use values
Satisfaction from Existence	Contingent methods	Description of welfare changes	(-) Larger resource investment necessary (+) Use and non-use values
Hypogene species	Contingent methods	Description of welfare changes	(-) Larger resource investment necessary (+) Use and non-use values
Bequest Value	Contingent methods	Description of welfare changes	(-) Larger resource investment necessary (+) Use and non-use values
Altruistic Value	Contingent methods	Description of welfare changes	(-) Larger resource investment necessary (+) Use and non-use values

Table 5. Benefit Valuation. Source: own image after Mburu et al. (2006) and MJA (2012)

4.1.4. Factors Influencing the Value of Groundwater

From the descriptions above it becomes clear, that - with the TEV being an anthropogenic concept - the value of water is not fixed, but rathermore dependent on several external factors; the current, as well as the future values of groundwater, are influenced jointly by the interplay between geologic/hydrologic factors and socio-economic factors (NAP, 1997). Generally, the value of groundwater is influence by the costs of extraction, depending inter alia on energy costs and opportunity costs, as well as the willingness to pay, depending on inter alia the quality of water (ibid.).

Specifically, an essential factor in the value of water is, for instance, the **availability and the price of substitutes**. If it is possible to obtain water from a different and cheaper source recipients will value groundwater less. Naturally, this can change over time. Considering the net present value approach, the value of groundwater is furthermore higher the **longer it is available for consumption**. Another very important influencing factor is the **water quality**; although the value itself might remain the same to the end-user, additional treatment costs reduce the net value. Regarding the value of **ecosystems, again the value difference** is important; if a wetland is for instance replaced by an equally valued ecosystem the loss and therefore this particular benefit of groundwater is quite low. Also benefits like hydropower do not have a fixed value, since it depends on things like whether it is used for **peak or for base energy** (Gibbons, 1986). Lastly, with the value being a concept collecting data at the individual level, **socio-economics and psychographics** can furthermore influence the value of water. Regarding the total rather than the marginal value, the current value of groundwater is also determined by the current **allocation**; if the allocation is not efficient the total value of groundwater can be improved by reallocating the resource (NAP, 1997).

4.1.5. Accounting for National Differences in Valuations

An additional complication, which arises in a transboundary setting, is that values will most probably differ across countries. Seeing that the concept of WTP also relies on the ability to pay of the population in question, makes comparisons or aggregations across countries with, for instance, different income structures difficult (J. Gupta, personal communication, 2014; IPCC, 1995). The problem here is that value is not absolute, but dependent on various factors of influence (see section 4.1.4 above).

A similar issue arises when valuation studies from different locations or even countries are to be used as the basis for benefits transfer. This is especially pertinent in countries where little studies have been performed, as a way to get some first, rough estimates. Sometimes this is done in order to decide on whether or not to conduct more expensive, side-specific studies. Methodologies to deal with the transfer of site-specific information are the application of (1) simple unit-value transfers, (2) benefit functions transfers or (3) meta-regression models (MRM) (Y. Jiang, personal communication, 2014; Thomassin and Johnston, 2011). Where unit value transfer merely transfers mean WTP values[16], the benefits function transfer also accounts for other cross-border differences. In other words it transfers a benefit function based on individual primary studies. However, the availability of such site-specific functions is limited. A viable alternative in this case is to derive a meta-analytic benefits function. Hereby relevant independent variables, pertaining to the resource, policy, site or affected population, are regressed on the WTP using a large number of primary studies (Thomassin and Johnston, 2011). It should be noted, however, that this method is only feasible when enough studies are

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[16] Values are sometimes also adjusted by the exchange rate.

available[17], and that its viability is still debated in contemporary scientific literature. Interestingly, simple means-value transfers outperform benefit function transfers for countries with similar characteristics.

When data is scarce it might be best, to make a simple adjustment using the GDP per capita based on purchasing power parity. Such an approach is described by Figueroa and Pasten (2011), where the WTP of the project site (PS) is calculated using the WTP of the study site (SS) and the income elasticity according to:

$$WTP_{PS} = WTP_{SS} (GDP_{PS}/GDP_{SS})^{\epsilon}$$

Often ϵ is assumed to equal one, though this assumption has been challenged (Figueroa and Pasten, 2011).

4.1.6. Using the Value of Groundwater in Decision Making

Foremost, the above developed framework for assessing benefits is not so much of importance in itself, but rather as an instrument for informing decision makers by enabling them to evaluate trade-offs between competing uses (NAP, 1997). It is geared towards showing how the TEV of groundwater changes under alternative scenarios; specifically, it relates changes in quality and or quantity, to changes in benefits for society and ultimately to how society values changes in said benefits (ibid., cf. figure 5). Such an approach enables a long-term perspective, which is something that is especially relevant in regard to groundwater management: apart from taking into account the needs of future generations, over-extractions can lead to collapsing layers of soil and consequently to reduced aquifer capacities. Relevant decision processes include assuring efficient allocation between users, as well as efficient extraction levels, but also informing institutional reform, or deciding on specific policy programmes (ibid.).

Figure 5. Change in TEV. Source: own image after MJA (2012)

Very important in regard to decision making is that each step is subject to its own inherent uncertainties, wherefore they need to be made explicit in any analysis. They should, however, not discourage the use of economic analyses. Despite the reluctance of many non-economists to put a value on nature and natural resources, one needs to realise that failing to adequately acknowledge the importance of resources like groundwater in decision making, effectively assigns them a value of zero (Perman, 2003).

As an aside, the reader will have noticed that **economic valuation always refers to the cost or benefit of a <u>change</u>**, never to the absolute value of a stock. Thus, it is nonsensical to attempt a valuation of a groundwater body as such. Rathermore, the assessment of changes in quality and quantity is of importance (ibid.). It also needs to be recognised, though, that the marginal benefit from a unit change in the resource differs with the state of the resource. Whereas the value of a change, signified by the area under the curve, might be small when the resource is abundant or in a good condition (red arrow, cf. figure 6), the same change might be much more valuable if the resource is in rare or in bad condition (green arrow, cf. figure 6) (ibid.).

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[17] To this extend a data-base called EVRI has been created, where valuation studies are collected; access is so far however still restricted to sponsoring countries.
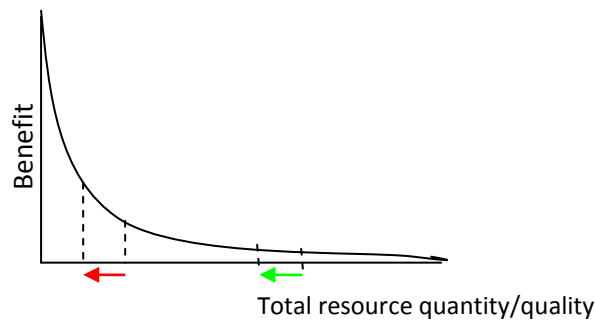
Figure 6. Value Difference with Resource Abundance. Source: own image after Pindyck (2012)

Valuation of Benefits

One way to utilise the approach outlined above in decision making is simply by valuing the benefits of groundwater, or more specifically of its protection or degradation, thereby highlighting its economic importance and creating a basis for a more informed stakeholder-dialogue. In order to do so, several steps need to be performed – all of which need a broad range of input in form of interdisciplinary information; those steps are shortly described in figure 7. Furthermore, both qualitative and quantitative information is needed, whereby the latter is especially relevant in later stages. Sometimes qualitative information is already sufficient to reach a specific aim, like for instance spark a stakeholder dialogue. Mostly, however the aim will be to actually quantify benefits; more specific studies, however, will always require more time and resources.
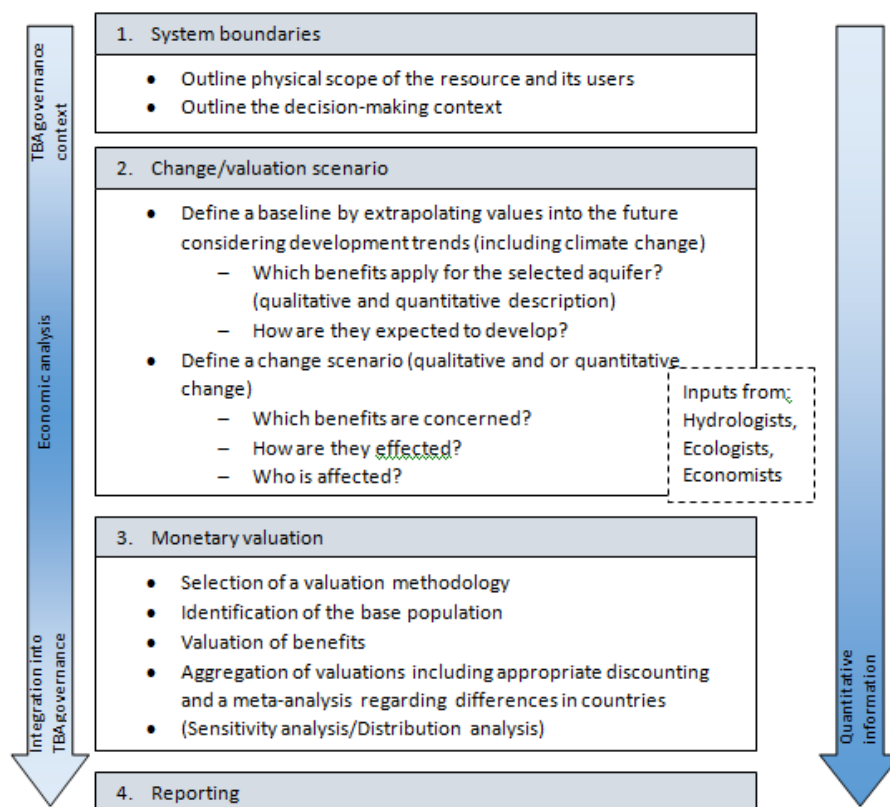
Figure 7. Valuation of Benefits. Source: own image after Johns and Ozdemiroglu (2007)

Alternatively, it might be the aim to assess a specific project or programme; this is usually done with the help of a cost-benefit analysis (CBA). Since any project undertaken today, will not only have an impact on benefits provided or costs incurred today, but also on future benefits and costs, a CBA appraises all consequences of a current commitment in a way that corrects for market failure. More specifically, it is a tool that helps to capture and quantify all costs and benefits that arise as a consequence of a project now and in future periods, as well as make them comparable (Perman, 2003). Two important concepts in this regard are:

- Discount rate (r)

  Due to time preferences of individuals, who generally value consumption today over consumption tomorrow, benefits incurred in the future are said to be worth less today. Therefore, future cash flows are usually reduced using a so called discount rate r:

  Discounted value = Cash-flow / (1 + r)^t

  Theoretically, this way of thinking is justified in that there exists a positive probability of death - or on a social level extinction - for every point in time in the future, preventing future consumption. Moreover, from an investment perspective if consumption is delayed, capital would be worth more in the future due to interest payments (Perman, 2003).

  Nevertheless, valuing benefits incurred by future generations less than benefits incurred by the current population also entails an ethical discussion. Considering the wish for intergenerational equity, the social discount rate is thus usually smaller than a private discount rate (ibid.). However, the question of an "optimal" discount rate is still subject to discussions and a totally satisfactory definition might not even exist (NAP, 1997).

- Net present value (NPV)

  With the help of the social discount rate, the net value (benefits – costs) of future cash-flows can be made comparable in the present period; the summation of all net values is then denoted the net present value (NPV) of a project. This is depicted in equation 3 and figure 8. As can be seen, the NPV depends on added benefits[18] provided by the aquifer in case of an implementation and the costs of the project itself.

$$NPV = \sum_{t=0}^{T} \frac{B(t) - C(t)}{(1+r)^t} \qquad (3)$$
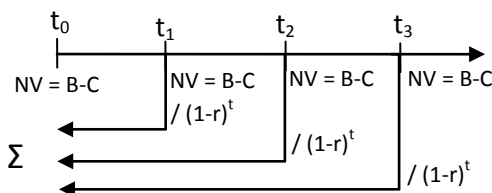

Figure 7. Net Present Value. Source: own image

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[18] The stream of benefits depends on groundwater stocks and actions affecting the groundwater; such actions are again reliant on policies in place and current stocks (NAP, 1997).

Following the above described rational a CBA can help with two kinds of decisions:

1. Whether a project in itself is feasible, i.e. whether the benefits outweigh the costs.
2. Which project from a range of possibilities should be chosen, i.e. which project delivers the maximum NPV.

Projects that need to be evaluated could be, for instance, the implementation of a plan for artificial recharge or a restoration project regarding the quality of the groundwater. On the other hand, a comparison could be made between using groundwater or desalinised water.

One word of caution is needed with regard to the monetisation of benefits, which might not be possible in all instances. In this case a thorough qualitative description needs to accompany the main CBA to be considered by the decision maker.

4.1.7. Limitations

Foremost, one of the main reasons why groundwater valuation is lagging behind surface-water valuation is the complexity of the system. Thus, although the framework itself might appear rather straightforward, the actual quantification relies heavily on the availability of detailed models, which get increasingly sparse and biased with uncertainties with increasing system complexity (MJA, 2012). Naturally, the output is only as good as the input. Consequently, uncertainties or inaccurate assumptions reduce the validity of any conclusions. An accurate estimation of values is particularity challenging regarding environmental benefits, due to the lack of concrete, localised studies (ibid.). Additionally, sometimes it is not possible to quantify every aspect that arises in connection to a project or development. In such cases transparency and clear communication of those aspect to decision makers is of utmost importance. In other cases, it might not be possible to measure a whole demand curve, but only one price at a certain quantity, wherefore simplifying assumptions need to be made.

In addition to the complexities of the aquifer system, it can often be difficult to define the scope of the socio-economic system. It is, for instance, quite difficult to identify all user groups; especially those that hold indirect values. Moreover, apart from the direct benefits an aquifer delivers, regional economic impacts might result from changes in water availability, which are usually not included in the analysis (MJA, 2012).

Another, highly relevant issue is equity. The utilitarian model on which the valuation framework is built, only considers aggregate welfare, but not the welfare distribution. Thus, equity or ethical issues are not taken into account and need to be added alongside the outcome of any economic analysis in the decision making process (MJA, 2012). However, water allocation according to historical rights, which is the prevalent allocation mechanism in many cases, does also not take equity concerns into consideration (J. Gupta, personal communication, 2014; Tarlock, 2000). In this regard it might be beneficial to, as a last step, perform a distribution analysis to see who benefits from a specific policy and who has to bear the costs; such an analysis can form the basis for devising a compensation scheme where "winners compensate losers". Fairness does, of course, not only pertain to the present population. Discounting, for instance, is sometimes seen as unfairly reducing the claims of future generations (NAP, 1997).

Connected to the aforementioned issue of equity is another important limitation of environmental valuations. Since at the basis of all valuations lies the concept of the willingness to pay an additional issue is raised. The willingness to pay of a person does not only rely on their personal preferences, but also on financial (income) constraints. Unfortunately, this not only means that poorer individuals have no choice but state a lower valuation and hence might be deprived of water shares, but also that differences arise between countries and regions of

the world. The IPCC, for example, showed that forests in the western world were valued much higher than forests in the third world, although the biodiversity in the latter was pronouncedly higher, simply because of the income difference (J. Gupta, personal communication, 2014; IPCC, 1995). This is expected to be especially problematic in transboundary aquifers.

Despite all those limitations, an economic valuation can provide valuable insights for decision makers by accounting for people's preferences and delivering a basis for effective allocation and the optimisation of welfare benefits. What is important is to see it as a link between natural sciences and social sciences, and in this respect as a way to quantify natural systems from an anthropocentric perspective. It is not, however, the sole key to an optimal social allocation. Although efficiency is an important concept, since it enables humans to make optimal use of a resource, it needs to be considered alongside other concepts, such as equity (Y. Jiang, personal communication, 2014; Perman, 2003).

4.2. Summary

Water constitutes a vital foundation for human well-being and activities. Aquifers specifically provide people with a multitude of benefits in various forms, ranging from drinking water, over flood-protection to the provision of ecosystems and ecosystem services. However, increasing pressures on these elementary resources, through population growth or increased human activities, frequently diminish the quality and/or abundance of water, resulting in economic or even physical scarcities. In the absence of a functioning market, due to the public goods characteristic of an aquifer, water resources are subsequently often misallocated.

Therefore it becomes increasingly important that aquifers are managed in a sustainable fashion, considering all relevant stakeholders, as well as economic consequences of allocation decisions. In other words, groundwater supply needs to be considerately distributed among different use(r)s. Questions that are expected to arise in the course of such an endeavour are, inter alia, "To which activity should groundwater be allocated?" or "What do changes in quality or quantity of groundwater mean for the well-being of society?". Economic valuation can provide valuable input to such questions. It constitutes a possibility for comparing marginal and total utilities of different water uses on the basis of a common monetary denominator, thus providing a quantitative basis for allocative decision making. Although studies generally focus on the valuation of one specific benefit, this report describes the valuation of a resource using the total economic value framework. Thereby it gives an overview over what is included in the concept of value, as well as over the multitude of benefits provided by groundwater.

In order to be able to value a groundwater resource several steps have to be performed. In the beginning, the physical and social boundaries of the system have to be defined, whereafter the valuation scenario itself needs to be outlined, bearing in mind that only differences between scenarios, i.e. changes, can be valued. The evaluation itself requires the determination of the affected benefits, as well as the adequate valuation methods. In the following an overview over benefits and valuation methods, described in more detail above, is given.

Total Economic Value	Use Value	Direct Use Value	Public/private Water Supply	Market price, cost of alternative, cost of substitute, mitigation, stated preferences, hedonic prices
			Agriculture	Production function, cost of alternative
			Industry	Production function, cost of alternative
			Renewable Energy (e.g. Hydropower, Heat Pumps)	Cost of alternative
			Surface Water Recharge and Consequently Recreation, Fishing, etc.	Contingent methods, travel cost method
		Indirect Use Value	Flood Control	Mitigation, contingent methods
			Carbon Sink	(Knowledge gap)
			Waste Assimilation	(Intermediate benefit – no valuation)
			Prevents Subsidence	Cost of prevention, hedonic pricing
			Supports Ecological Diversity/Habitats	Contingent methods
			Prevents Seawater Intrusion	(Intermediate benefit – no valuation)
		Option Value	Future Direct or Indirect Value	Contingent methods
	Non Use Value	Existence Value	Satisfaction from Existence	Contingent methods
			Hypogene species (Unseen Benefits)	Contingent methods
		For Others	Bequest Value	Contingent methods
			Altruistic Value	Contingent methods

Table 6. Summary Benefits and Methods. Source: own image

An application of those methodologies returns individual preferences for groundwater uses. These can then be aggregated over the relevant population. In a final step all benefits can be aggregated to show the total value of a change in the quality or quantity of groundwater. Please note that option values and non-use values, are only included when using stated preference methods, whence mostly valuations return a lower bound estimate.

Summing up, economic valuation explicates trade-offs that humans face in using groundwater for different uses. By doing so in a common denominator – namely currency – it furthermore makes these trade-offs comparable, so that they can be used in project evaluation and cost-benefit analyses. Consequently, decisions about an increasingly scarce resource, can be made so as to maximise utility for society as a whole. Naturally, economic valuation is no panacea to the allocation problem and actual decisions should also include considerations about, for instance, equity and political issues. Moreover, a thorough analysis requires a non-negligible amount of data input and relatively high data reliability. For those reasons not all experts are yet convinced of the usability and usefulness of economic valuation of a groundwater resource. Nevertheless trade-offs are made constantly – be it consciously or unconsciously – and a sound economic basis is thought indispensable for rational, justifiable allocation decisions. Communication of the rationale behind an economic analysis and

examples of the existence and magnitude of benefits, is expected to be able to contribute to the increased integration of disciplines.

5. PART II: Case Studies

5.1. Case Study Methodology

Based on the framework developed in part one of this report, two case studies are examined in more detail below. Since no specific policies will be evaluated, the case study methodology followed will be based on a benefits assessment described in section 4.1.5. The exact extent of quantification, though, will depend to a large part on the available data.

Generally, as indicated in the theoretical framework above, several main tasks have to be performed:

1. Outline the project boundaries, including:
   a. A description of the physical boundaries of the aquifer,
   b. Climate and hydrology of the area,
   c. System functions, like recharge and discharge,
   d. Surrounding ecosystems and their connection with the aquifer,
   e. And lastly the social environment, including uses and legal frameworks.

2. Define the problem and the situation to be valued. For this it is important to specify:
   a. A baseline scenario, i.e. development assumptions,
   b. As well as expected impacts of an alternative scenario.

3. Ascertain the consequences of the change scenario, by:
   a. Identifying the (affected) benefits,
   b. Selecting the appropriate valuation method and evaluating the data needs,
   c. Collecting the necessary information and estimating the benefits,
   d. (If it is not possible to estimate all benefits, describing the data gaps,)
   e. Aggregating the estimated individual benefits over the affected users, as well as
   f. Discounting and aggregating benefit classes in order to arrive at a NPV.

4. Draw conclusions and report findings.

5.2. Case Study 1: Stampriet Kalahari / Karoo Aquifer System

5.2.1. Relevance of the Case Study

The first case examined is the Stampriet Kalahari / Karoo aquifer system extending over Namibia, Botswana and South Africa. This aquifer was selected mainly because of its relevance and status within IGRAC. Although a lot of data is expected to be not yet available, it is an ongoing project and could potentially benefit from first tentative valuation approaches.

More specifically, considering the current state of affairs of groundwater management in sub-Saharan Africa, a knowledge of the economic value of groundwater is likely going to be beneficial in regard to future developments. At the moment, for instance, groundwater is in most parts of sub-Saharan Africa still underutilised in comparison to surface water (Braune et al., 2013). Current projects stimulating the use of groundwater are therefore in the

advantageous position of being able to incorporate all relevant information needed for efficient and sustainable decision making and thus to adequately capacitate local institutions. This is especially important, since while there seems to be some level of awareness among decision makers about the importance of groundwater, this is so far not apparent in decision making and practices (ibid.). Specifically the countries sharing Stampriet Kalahari / Karoo, though, are facing pressing needs to sustainably manage their groundwater resources, since all of them are highly dependent on groundwater to sustain domestic, irrigation and industrial water needs (IGRAC, 2013).

Therefore it is expected that also a largely qualitative analysis could provide an interesting basis for further investigations.

5.2.2. Geographic Scope and Resource Characteristics

The Stampriet Kalahari / Karoo aquifer system stretches over an area of 140.000 km², covering parts of Namibia, Botswana and South Africa. In general the system consists of two confined[19] regional sub-artesian[20] aquifers located in the Karoo sediments[21] and one overlying unconfined aquifer system of Kalahari sediments (Braune et al., 2013). The two major, mostly confined aquifers are called Auob (Namibia) / Otshe (Botswana), which is located in the Ecca group of the Karoo sequence, and Nossob (Namibia) / Ncojane (Botswana), which lies at the bottom of the Ecca group and is not only quite thin, but also excessively deep and holds mainly low quality, saline water - especially in Botswana (Braune et al., 2013).

The geographic scope of the system is especially well-researched in Namibia, where it lies within the Orange River Basin, whereas the exact extension into Botswana and South Africa is not known in detail; for a more detailed account regarding the geological boarders of the system see, inter alia, Alker (2009) and Kirchner (2001). The socio-economic scope might differ from the geographical one and is described in more detail in the next chapter.

Regarding the water flows, recharge mainly takes place in Namibia, whereafter the groundwater flows in a south-easterly direction (Alker, 2009). For the Kalahari aquifer recharge is facilitated by calcritic sinkholes and the Auob Aquifer receives indirect recharge through the Kalahari Aquifer; the exact recharge mechanisms in the boundary areas are, however, still largely unknown. Annual rainfall is highly variable across the basin and fluctuates between 120 and 240 mm (ibid.), whereas the mean annual potential evaporation ranges between 3,000 mm in the north and 3,500 mm in the south (Braune et al., 2013). Due to the composition of the ground[22], water quality decreases with its flow from the north-west to the south-east, resulting in areas of brackish or even saline water. The deterioration in quality is moreover much higher in the Kalahari Aquifer than in the Auob Aquifer (Braune et al., 2013). Lastly, there are two types of natural drainage: firstly, to external surface streams and secondly to internal pans (Braune et al., 2013). Two major ephemeral, i.e. not always flowing, streams are the Auob and Nossob rivers.

With regard to ecology, the aquifer system features two distinct biomes. These are tree and shrub savannah featuring mostly Camel Thorn trees in the north and south-east, and dwarf shrub-land in the west and south-west (Alker, 2009). Especially important is the Kgalagadi

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[19] A confined aquifer – opposed to an unconfined aquifer – does not have the water table as upper boundary.
[20] Pressures are high enough so that the water in a well rises above the water table, but too low to flow out of the well.
[21] The Karoo and Kalahari sediments are a specific stratigraphic unit in Africa comprising several groups, i.e. lithostratigraphic units.
[22] The central basin consists to a large part of sand, silt and clay containing accumulated mineral salts.

dryland ecosystem, which has national park status in Botswana and South Africa and despite the harsh conditions features a great variety of plant and animal species (Dikgang and Muchapondwa, 2013a).

Currently, although groundwater is said to be underused in sub-Saharan Africa, scientists witness constantly declining water levels and it is still disputed whether this decline is counterbalanced by significant recharge after exceptional rainfall events. Taking a conservative stance this should not be unconditionally assumed. Declining water levels are most probably due to excessive extractions in Namibia, which is the most arid country in the Southern African Development Community (SADC) (IGRAC, 2013). Furthermore, vast losses are assumed to arise due to inadequately designed boreholes and consequent leakage. All this points to the importance of a common management regime and a solid basis for allocation decisions. Valuing groundwater can contribute to this by highlighting the value of wasted resources and thus the importance of good governance. Moreover, marginal values can assist in allocation decisions, as well as in the choice of appropriate economic instruments to manage water use. So far, although no special institution for joint management is in place, mapping and modelling efforts have started on all sides, as have efforts to synthesise available information (Braune et al., 2013).

5.2.3. Socio-Economic Scope and Resource Use

Due to the varying quality of groundwater in the Stampriet Kalahari / Karoo aquifer system and historical developments, utilisation and consequently data availability differs across countries. This section will therefore briefly give an overview over the socio-economic and legal characteristics within each country as far as they are reported.

Namibia

In Namibia groundwater use is developed furthest, due to its advantageous access to higher quality water. According to Braune et al. (2013) several stakeholders rely to a large extend on groundwater for their water supply. These are firstly *farmers* and the *inhabitants of urban centres* as well as (isolated) *rural communities*; especially the former are expected to show increasing demand in the future since electricity supply augmented the viability of irrigation farming. Regarding the latter, the bulk water supply system (NamWater) supplies the towns Stampriet, Gochas, Aranos, Leonardsville, Aminuis and Onderombapa (Jica Report, 2002). Moreover, *mining* companies are currently exploring the potential of further endeavours and might be in need of water supply in the future. Eleven lodges furthermore are rented out for *tourism*. Lastly, Namibia shares part of the *Kgalagadi Transfrontier National Park* (ibid.). Currently, a population of about 42,000 people (according to extrapolations of data from 2000) are depending on groundwater supply. For more details regarding the population and water usage see tables 7 and 8.

Population (early 2000):	
Village centres	6,186
Commercial farms	16,780
Communal land	12,130

Table 7. Population Relying on GW. Source: Braune et al. (2013)

Water utilisation (2002):	
Irrigation	46 % (6.9[23] Mm³ / annum)
Domestic watering -Urban centres -Commercial farms -Communal land	16 % (2.4 Mm³ / annum) 4% (0.6 Mm³ / annum) 11% (1.6 Mm³ / annum) 1% (0.127 Mm³ / annum)
Industries	0 % (0 Mm³ / annum)
Tourism	0.03% (0.004 Mm³ / annum)
Stock watering	37 % (5.69 Mm³ / annum) (commercial and communal areas)

Table 8. Water Utilisation. Source: JICA (2000)

In 2002 4,915 boreholes were in use, 3,915 of which tapped the Kalahari and 1,000 of which tapped the Karoo aquifers; thus from the 9.8 MCM/year of extracted groundwater 65 % came from the Kalahari aquifer (Alker, 2009).

At the moment water resource management includes a licencing system for the drilling of boreholes and permitted irrigation, as well as institutionalised user participation through Basin Management Committees (Braune et al., 2013). Fundamental management principles include the assurance of equitable access to water and benefits provided by groundwater, the promotion of the sustainable development of the water resource and efficient and effective water use for optimal social and economic benefits (ibid.)

Botswana

Unlike Namibia, the concerned areas in Botswana - or more specifically in the Kgalagadi and Ghazi districts - are sparsely populated, although further developments are foreseen. Right now the nearest major villages are Jcojane (1958), Hukuntsi (4654), Tsabong (8939) and Bokspits (507), which accommodate only one percent of the total population within the districts (Braune et al., 2013). At the moment the main water uses are **irrigation**, **stock watering**, **game** and the **supply of small villages**. It needs to be mentioned that policies to increase farming activities have been put into place, but that so far predictions about changes in water demand are lacking. Importantly, a large part of the **Kgalagadi Transfrontier National Park** lies in Botswana and relies on groundwater resources for tourism and wildlife (ibid.). According to Braune et al. (2013) the use of livestock watering, human consumption and wildlife amounted to 6.5 Mm³ / annum in 2002, with 65 % being for cattle watering.

From a legal perspective Botswana's water sector is currently in a reform process creating a new institutional framework. Main stakeholders in this revised framework are the Department of Water Affairs (DWA), the Water Utilities Corporation (WUC), the Water and Energy Regulator and the Water Resource Board (WRB) (Braune et al., 2013).

South Africa

South Africa is least endowed with high quality groundwater from the Stampriet Kalahari / Karoo aquifer, wherefore the used amounts in 2002 were only reported to be 2.0 Mm³ / annum. Main users are the large game reserve in the **Kgalagadi Transfrontier National Park,**

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[23] This has reportedly increased to 9.1 Mm³/annum in 2013 (Braune et al., 2013); however, no current data for the other uses are available.

rural inhabitants and **commercial** as well as **communal farms for stock watering** (Braune et al., 2013).

Although groundwater is acknowledged as a significant water resource underlying the National Water Act, its proactive protection or the need for specific institutions for its governance have not yet been integrated in official regulations (ibid.).

Overall, envisaged developments in Namibia and Botswana, the decrease of water quantity and deterioration of its quality, the importance of in-situ and extractive services, as well as known conflicts about surface water, make the development of good transboundary groundwater management essential. In Botswana, for instance, estimates are that groundwater supplies will – due to increasing demands - be exhausted before 2020 (Alker, 2009).

5.2.4. General Data Availability

Data availability regarding the Stampriet Kalahari Karoo aquifer system is at the moment still quite asymmetrical although attempts are being made to integrate, synthesise and expand available knowledge. At the moment the majority of information that is available comes from Namibia. Moreover, a literature review by Bann and Wood (2012) found that only five groundwater-specific valuation studies have been undertaken in the SADC region.

5.2.5. What is to be Valued?

As has been mentioned in the framework, it is only possible to value a change in benefits and not a stock. For this reason, it is important to delineate the valuation scenario beforehand. Seeing that this study is just a preliminary attempt to outline the necessities in regard to valuation studies, no specific policy is evaluated. As an alternative it is assumed that the worst case scenario, i.e. the complete depletion of the aquifer, occurs, thereby attempting to assess the current benefits provided by the aquifer. In other words, the baseline assumption is that the aquifer remains as it is at the moment of this study, whereas the change scenario is specified as a situation where the groundwater resource does not exist at all. However, it needs to be born in mind that this in itself does not say very much, since it neither optimises water allocation, nor develops a change scenario. Moreover, no assumptions regarding likely developments, like population growth or adjustments in demand, are included. Nevertheless, it is considered a good starting scenario.

5.2.6. Benefits provided by the aquifer

Based on the framework developed above, this section identifies benefits that are provided by the Stampriet Kalahari/Karoo aquifer system to its stakeholders. Those benefits are expected to vary across countries, though.

In Namibia the identified benefits are mainly of direct use character, namely:
- Domestic water use (mainly publicly supplied)
- Agricultural water use:
  - Irrigation of crops
  - Watering of livestock

At the moment, industrial use of groundwater for e.g. mining is not an issue. Moreover, water is not used for energy production and surface water recharge is very limited.

Regarding indirect water use, groundwater in Namibia provides additional benefits in form of:
- Waste assimilation
- Carbon storage
- Support of groundwater dependent ecosystems (wildlife, drylands)

Land subsidence has proved to be no problem, since no structural changes became apparent during current overdrafts (Jica Report, 2002). Moreover, since the aquifer system is landlocked and precipitation is low, increased flood risk is also not an issue.

In Botswana the main uses remain the same, although less farming activities rely on water delivered by the aquifer system. On the other hand, due to the existence of the Kgalagadi Transfrontier National Park benefits provided in form of support of groundwater dependent ecosystems are larger. It should be mentioned that the aquifer system is mostly very deep and that it is not yet well known in how far vegetation is actually dependent on groundwater (personal communication G.J. Niessen). It is known, though, that Camel Thorn trees can develop very deep roots in order to reach groundwater (Campbell, 2014). At any rate, wells have been dug for wildlife watering, which is essential due to reduced migration possibilities because of human interventions (personal communication G.J. Niessen). In South Africa the situation is similar to the one in Botswana, except that – apart from the national park – there is even less reliance on the aquifer.

The following table shows an overview of the relative uses of different benefits in all three countries. Please note that this is a subjective overview, which has been developed based on literature and by communication with one expert. In future such an overview might have to be updated using input from various experts in order to get a more realistic picture of the situation.

Benefit	Namibia	Botswana	South Africa
Domestic water use	High	Medium	Low
Agricultural water use: irrigation	High	Low	Low
Agricultural water use: livestock	Medium	Medium	Low
Waste assimilation	Medium	Low	Low
Carbon storage	Unknown	Unknown	Unknown
Support of groundwater dependent ecosystems	Low	Medium	Medium

Table 9. Relative Benefits Stampriet. Source: own table

5.2.7. Assessment
Change in Benefits

After defining the scenario to be valued, it is necessary to define the change that this induces in the delivered benefits, as well as the population that is affected by this. Hereby, a difference has to be made between the valuation of qualitative and quantitative change. In the specific scenario chosen and described in the previous chapter, the former is not of much relevance since the complete depletion of the aquifer implies that no more water can be used, wherefore there is no need to measure quality implications. However, the depletion of drinkable water could lead to the intrusion of saline water from over- or underlying aquifers, which potentially has effects on groundwater dependent ecosystems and cropping patterns. In the following the assumed changes are briefly explained and assumptions clarified:

💧 Domestic water use:
Total unavailability of groundwater means that domestic needs need to be satisfied through an alternative water source. The benefit provided by groundwater then equals at least the costs of supplying water from an alternative source; where more than one alternative is feasible they should be ranked according to their cost – the least expensive

being regarded as the most feasible. The intuitive valuation measure is thus *cost of alternative*. Alternatively, a sample of the affected population could be asked for their WTP in a *contingent valuation*.

💧 Agricultural water use:

As with domestic water use, supply needs to be sourced elsewhere if groundwater is no option. In current literature it is often assumed that farmers cannot afford alternative supply, wherefore the value of water equals the total production value. In a more realistic scenario, some farmers would be modelled as receiving supplies from a different source, whereas other farmers might go out of business. The level of detail possible in this step, however, depends to a large degree on the data availability and time or monetary constraints of the researcher. Appropriate valuation methods will therefore either focus on the *production function* and/or *cost of alternative*.

💧 Waste assimilation:

As can be seen in table 5 this benefit mainly concerns the quality of groundwater, wherefore it can be considered an intermediary benefit already included in other valuations. Additionally, as explained above in this specific case quality measurements are not necessary. Thus it will not be separately assessed here.

💧 Carbon storage capacities:

Carbon storage capacities are eliminated with the elimination of the aquifer. However, at the moment too little is known about the dynamics between water and carbon to actually quantify this benefit.

💧 Ecosystem services:

A change in groundwater flow dynamics and consequently in groundwater dependent ecosystems has several implications. First of all, agricultural livelihoods of livestock-farmers can be expected to be threatened due to a loss of fodder and water. However, this is already accounted for above (see agricultural water use). Secondly, the livelihoods of local indigenous people will likely be threatened as well. Their preferences are best elicited via a *stated preference method*, though double counting of benefits for agriculture and native livelihoods needs to be avoided. Thirdly, recreational benefits will be lost to foreigners as well as locals, wherefore tourism will suffer. Preferences of tourists should be evaluated with the help of either a *stated preference*, or the *travel cost method*. Lastly, benefits of biodiversity and habitat will be lost; again due to the lack of markets *stated preferences* will be most appropriate. Here it is particularly important to research the exact connections between changes in groundwater affects vegetation and wildlife, so that realistic consequences can be valued.

In order to evaluate the changes defined above, specific data needs arise depending on the described valuation methods. The next question therefore is whether this data can or cannot (yet) be obtained. The following table 10 gives a brief overview over data needs and the current data quality.

Benefit *(Valuation method)*	Data Needs	Data Quality Status (good/emerging/bad)
Domestic water use (private/public supply) (*Cost of alternative/Contingent valuation*)	*Cost of alternative:* Quantity of water now supplied by the aquifer, as well as a separation in public and private abstractors. Fixed and variable costs of alternative supply options (e.g. different infrastructure) including costs for connecting so far private abstractors. *Stated preferences:* Stated preferences regarding domestic water supply.	Bad/emerging
Agricultural supply (*Production loss/function or cost of alternative*)	Ability of farmers to change supply. *Cost of alternative:* Costs of alternative supply options. *Production loss:* Types and area [ha] of irrigated crops in the study area, yields per ha, as well as market prices. *Production function:* Factor inputs and input prices, as well as the total (economic) value of the produced goods.	Emerging
Ecosystem services (*Contingent valuation, Travel cost method*)	List of groundwater dependent habitats and degree of dependency, as well as population dependent on these ecosystems. Connection of loss in value of attributes and groundwater changes. Stated preference or travel cost studies investigating the value of changes in ecosystem attributes.	Bad

Table 10. Data Needs and Quality Stampriet. Source: own table

As has been mentioned above, benefits transfer is a valuable alternative to primary studies where time and resources are limited. Thus in the following some studies conducted in the past are listed grouped after their area of origin.

Previous Literature – Stampriet Region

Valuation context	Name and location of groundwater resource	Methlolodogy (and WTP definition)	Values	References
Dryland Ecosystem Services	Stampriet (South Africa)	Choice experiment on some dryland attributes to tourists	See text	Dikgang and Muchapondwa (2013a)
Dryland Ecosystem Services	Stampriet (South Africa)	Choice experiment on the value of drylands to locals	See text	Dikgang and Muchapondwa (2013b)
Agricultural Benefits	Stampriet (Namibia)	Production function (Residual Imputation)	Economic price of 0.64 N$/m³	MacGregor et al. (2000)
Agricultural Efficiency	Stampriet (Namibia)	Production function	Value added Crops (0.89 N$/m³) and livestock (43.75 N$/m³)	Jica Report (2002)
CBA of alternative groundwater use and supply-options	Stampriet (Namibia)	Benefits transfer	Net present value of different scenarios	Bann and Wood (2012)

Table 11. Previous Valuation Literature Stampriet. Source: own table

Previous Literature – Other

Valuation context	Name and location of resource	Methlolodogy (and WTP definition)	Values	References
Water value in domestic, agricultural and industrial uses	Several	Domestic: mostly WTP Agricultural/ Industrial: mostly production function	Domestic: 0.0008 to 2.88 $/m³ Agricultural: 0.01 to 2 $/m³	Aylward et al. (2010)
Recreational benefits of a national park	Arusha National Park (Tanzania)	Travel Cost Method	Avg. consumer surplus US$ 13 to US$ 38 /day	Van Winkle (2013)
Value of aquatic ecosystems for tourists	Crocodile catchment	Travel Cost Method	Consumer surplus SA: 43.35 US$ to 593.11 US$ /trip Tourists: 65.26 US$ to 1,156.53 US$ /trip	Trpie and Joubert (2001)
Value of wildlife viewing	Lake Nakuru National Park (Kenya)	Contingent Valuation	75 – 79 US$ /day for non-resident visitors 68 – 85 US$ /day for resident visitors	Navrud und Mungatana (1994)

Table 12. Previous Valuation Literature Other. Source: own table

Domestic use: As has been mentioned above, the domestic use can be estimated by the cost of an alternative or substitute. Unfortunately, so far no studies have been found, which enumerate and evaluate alternative water supply options for the Stampriet area. Tuinhof et al. (2012) mention reclaimed waste water, an Okavango pipeline or managed aquifer recharge (MAR) as possibilities for supplying central areas in Namibia. Hereby a pipeline is the most expensive option, before MAR and reclaimed waste water. However, without knowing the exact calculations used it such estimates cannot be used for the current study.

Alternatively, the value of domestic water could be evaluated using contingent studies and asking people directly for their WTP for water. Naturally this is heavily dependent on the context in which the study is placed. In a research prepared for FAO, Aylward et al. (2010) reviewed an extensive body of literature regarding the use of valuation methods in domestic, agricultural and industrial uses, though they did not focus on groundwater studies specifically. They found that mainly contingent studies have been employed, producing a great array of values ranging from 0.0008 to 2.88 \$/m³.

As an aside, regarding the quantities of domestic water use it might be expedient to – at least in a first study – aggregate domestic water use with domestic water use of tourists.

Agriculture: Since farmers usually have less means than industrial companies, a common assumption in contemporary literature is that the unavailability of groundwater leads to a production stop, wherefore the value of groundwater can be calculated by the total income forgone due to a 100 % decrease in production. Whereas some researchers (see e.g. Johns and Ozdemiroglu, 2007) present this as an acceptable assumption, others (see e.g. MJA, 2012) do not. Fact is, that any other assumption requires much more data input, since the percentage of farmers staying in business, as well as their courses of action need to be estimated.

Crop	Gross Income (N\$/ha)	Irrigated area (ha)	Total value
Maize	8,000	85	676,000
Wheat	6,000	unknown	unknown
Lucerne	12,000	233	2,793,600
Grapes	40,000	15	600,000
Cotton	11,000	unknown	unknown
Sweet Melon	40,000	3	120,000

Livestock	Gross Income (N\$/ha)	No. in study area	Total value
Sheep	230	582,363	133,943,490
Cattle	1,750	134,771	235,849,250
Goats	unknown	135031	unknown

Table 13. Total Value Farming Namibia (Values from 2000). Source: own table.

Gross income, as well the number of livestock and irrigated ha for **Namibia,** according to Jica Report (2002), can be seen from table 13. Gross income is given in N$/ha and equals the average price per tonne (N$/t) times the average yield per hectare (t/ha). Unfortunately, not all data regarding irrigated areas or gross income could be obtained at this point. This might change once the envisaged data collection under the GGRETA project is completed.

Naturally, a total loss in production is a quite strong assumption and might very well not hold for several reasons. Firstly, a total depletion of drinking water might lead to the intrusion of salt-water from surrounding aquifers. Since some crops might cope better with different degrees of salinity, various scenarios are possible. Secondly, some farmers might be able to finance irrigation water from a different source. Moreover, this is a yearly estimation, which is reasonable only for the first or initial year(s); over time it is quite possible that people would adapt or resettle. Consequently, discounting these same losses over a fixed period of time in order to aggregate benefits might lead to an overestimation of benefits, although in such an arid region this is less likely.

Overall, for a more exhaustive picture, an in-depth analysis is needed incorporating an actual scenario analysis. For such an analysis different data needs arise. What will definitely be needed is information about baseline developments regarding the types of cultivated crops, the irrigated area per crop, yields and prices for yields, as well as types and numbers of livestock and prices. Furthermore, information about probable adaption mechanisms by farmers and consequences on productivity will be required. Lastly, for a more detailed study of marginal values the types and prices of other inputs are needed (see below).

Groundwater is also used for agricultural purposes in Botswana and South Africa; however data for these regions is even scarcer than for Namibia.

As an aside, in Namibia several studies have been conducted with the aim of analysing the marginal productivity of water in agricultural activities. Although this was done in order to analyse efficiency (MacGregor et al., 2000; Jica Report, 2002) or evaluate potential policy scenarios (Bann and Wood, 2012), rather than to assess the total value of the groundwater resource, it provides valuable first insights. Unfortunately, so far no such studies could be found with regard to Botswana or South Africa.

Additionally, several studies were performed in the Stampriet area in Namibia, determining the marginal value of agricultural products. The usual way to do this – as has been mentioned in the framework above – is via a production function, which is used to calculate the so called shadow price of water (see Box 2). MacGregor et al. (2000) constructed a "typical farm" from the information of several farmers interviewed in the Stampriet area and calculated the shadow price, or marginal value product, of water, arriving at an economic value of 0.64 N$/m³ (0.088 US$/m³), which they argue indicates a generally low economic efficiency. Jica Report (2002) paints a more detailed picture estimating the value added per m³ of water for different crop and livestock types; they arrive at quite a large range from 0.165 N$/m³ (0.016 US$/m³) for wheat and 2.083 N$/m³ (0.2 US$/m³) for sweet melon, as well as 29.68 N$/m³ (2.84 US$/m³) for sheep and 66.97 N$/m³ (6.42 US$/m³) for cattle. One of their main conclusions is that a changing of crop types and the application of more efficient irrigation methods can lead to substantially lower abstractions, while keeping the income at least at the current level.[24]

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[24] Please note that a 2000 exchange rate average is used for all conversions.

These studies show that while the total value of water has so far not been investigated, the value of economic instruments for an increase in efficiency has already been acknowledged in resource planning in Stampriet, Namibia.

Ecosystem services: The most important ecosystems in the Stampriet area are drylands. Unfortunately, they have been subject of less research than wetlands, for whose functions, like e.g. biodiversity, a medium economic value has been estimated by the WWF (2004). For several reasons it is expected that the value of drylands is lower than for wetlands. First of all, biodiversity is expected to be lower; furthermore, less chemical processes are expected to contribute to the ecosystem's multifacetedness (personal communication N. Ansems). Regardless, no definite assumptions about the relation of the value of wetlands to the value of drylands are possible and hypotheses need to be tested first. The importance of dryland ecosystems and their valuation has been acknowledged by the UN, which already in 1994 launched a Convention to Combat Desertification (UNCCD). In "The Forgotten Billion" (Middleton et al., 2011) it is, however, stated that although "natural systems should be properly evaluated, particularly in economic terms, most current methods for assessing dryland ecosystem services are far from comprehensive". A start for this particular case study has been made by Dikgang and Muchapondwa (2013a, 2013b), who conducted choice experiments to elicit the valuations of tourists and locals regarding some dryland attributes for the Kgalagadi Transfrontier National Park. However, it should not be forgotten that the evaluation of the aquifer system was not the aim of their studies. Rathermore, they were attempting to visualise the trade-offs between consumption and conservation of the drylands.

Dryland ecosystems in this region deliver a wide variety of benefits, a large part of which will likely be lost in case of the total depletion of the aquifer system. As has been mentioned above the exact effects of course depend also on the availability and salinity of other aquifer water and actual ecological dependencies. It is therefore of utmost importance to understand the consequences of a loss in groundwater; some fauna might for instance not be affected, whereas the consequences for wildlife are expected to be much greater. Apart from benefits for agriculture and recreation (tourism), drylands also delivers benefits for the local community in form of medical plants, wild fruits, fuel wood, grazing, erosion control, climate regulation, as well as cultural and spiritual benefits (Dikgang and Muchapondwa, 2013b).

In their study of tourists Dikgang and Muchapondwa found that tourists are, for instance, willing to pay US$ 0.01 for improved chances of viewing predators, as well as US$ 0.70 and US$ 0.01 respectively for discouraging locals from harvesting firewood and grazing more livestock. This shows that a WTP for dryland attributes which are part of the recreational experience does exist. However, this study was not aimed at valuing the whole recreational value provided to tourists and neither at an aggregation over the population of interest, wherefore a complete picture does not emerge. It will thus be more expedient to attempt a benefits transfer from another study at a similar site. A basis for this can be either valuation or travel cost studies. However, although generic estimates can be a good beginning especially in the case of time and monetary restrictions, it has to be considered that ecosystem services are very context specific and transfer might not always be easy. Especially problematic is that only few studies have been conducted in developing countries, and of those studies none could be found that deal with drylands. Nevertheless, some studies were found that can give a first idea about value ranges, though they are deemed unsuitable for an actual unit-value transfer; a follow-up study could possibly attempt to create benefit transfer functions.

Van Winkle (2013), for instance, applied the travel cost method (see Box 2) to study the recreational benefits that locals enjoy from visiting the Arusha National Park in Tanzania – a park consisting largely of grasslands and swamps. They found an average consumer surplus of US$ 13 to US$ 38 per day (US$ 60 to US$ 180 per year), which is the additional value derived on top of the money spent to access the park as well as money spent on other expenditures like food or gifts (ca. 55 US$ per household). Turpie and Joubert (2001) assessed the value of aquatic ecosystems by estimating the value of rivers in the Crocodile Catchment for tourists. They found that among South African visitors consumer surplus ranged from R 368 (43.35 US$) to R 5.035 (593.11 US$) per trip, and among foreign visitors between R 554 (65.26 US$) and R 9,818 (1,156.53 US$) per trip. In the Okavango Delta, a large wetland, Mladenov et al. (2007) analyse the value for tourism and its variation with changes in biodiversity. Like Dikgang and Muchapondwa (2013a) they found that wildlife viewing opportunities play an important role in an individual's WTP. Based on a CV and TCM they found a mean consumer surplus per visitor per year of US$ 225. Lastly, Navrud and Mungatana (1994) found a recreational value for wildlife viewing in Lake Nakuru National Park of 75 – 79 US$ per day for non-resident visitor, and 68 – 85 US$ per day for resident visitor. All these are, when aggregated, substantial sums and thus show the importance of valuing impacts on groundwater dependent ecosystems. It remains to be studied how those values change when applied to dryland ecosystems instead of wetlands.

Moreover, Dikgang and Muchapondwa (2013b) found that the indigenous population of the South African Stampriet area exhibits a positive WTP for dryland services. Specifically, they found a WTP of R 9.64 (1 US$) for increased availability of bushmeat and R 0.08 (0.008 US$) for increased grazing opportunities, as well as a WTP of R 112.36 (11.67 US$) to maintain the current bushmeat levels and R 139.24 (14.46 US$) to maintain current firewood collection levels. Here, measures need to be taken to avoid double counting; in other words if farming activities of local communities are already included in the valuation of agriculture it should not be part of the ecosystem services. On the other hand, estimates derived by the above mentioned methods are usually on the conservative side. Travel costs, for instance, only present a lower limit of the actual value to a visitor; they are "valid, but totally conservative" (Mladenov et al., 2007). Moreover, the option value of biodiversity, i.e. a possible future benefit arising of drug development, as well as the existence value, are usually not included.

A last word of caution – in cases were not a total deterioration of the resource is assumed, a good understanding of the effects of changes in groundwater levels on ecosystem attributes is quintessential. If one were to estimate the actual value of groundwater in supporting ecosystem services, one would have to define all services delivered by the ecosystem, and subsequently estimate and extrapolate changes in the different services that will arise due to changes in groundwater.

Aggregation and sensitivity analysis: Most benefit estimates are derived on an individual level, wherefore they first need to be aggregated, in order to reflect the total value of the population of interest. In a transboundary setting it is expected to be expedient to include an intermediary step here and aggregate benefits first within one country and then across countries. Thereafter, all aggregated benefits need to be summed up.

One strongly simplified method is to take all benefits except one-time investments as yearly, e.g. agricultural losses will be the same for each year, and discount them over a fixed period, e.g. 10 years. Unfortunately, this is not possible in this case study due to insufficient data at this

point. As has been mentioned before such a methodology is only suitable for primary studies, since it does not take time trends and developments into account.

Future focus: The fact that an aggregation is not possible, which also precludes the estimation of a total value per benefit, made it important to visualise preliminary results in an effort to guide future research. The following graph therefore shows the expected relations between total values per benefit. These are, however, based on studies that are largely not from this region, wherefore care needs to be taken in their interpretation. For ecosystem services the value for Namibia is expected to be lower than for Botswana or South Africa, due to the fact that less biodiversity is dependent on the aquifer. Moreover, due to the absence of a national park the number of stakeholders is expected to be considerably smaller. It needs to be emphasised, though, that the fact that this value is higher than the others might change if valuations are done with a specific focus on drylands. However, seeing that the WTP for tourists can be expected to be much higher than that of the local population, due to less income constraints, the difference might not be that pronounced. For agricultural as well as domestic use a distinction between countries was not possible due to limited data availability. They are thus presented as single dots in the graphs[25]. According to Aylward et al. (2010) domestic water use furthermore has a higher marginal value than agricultural water use. Methodologically this points to the importance of estimating demand functions instead of single values. Practically this points to the importance of analysing and improving water efficiency in irrigation agriculture.
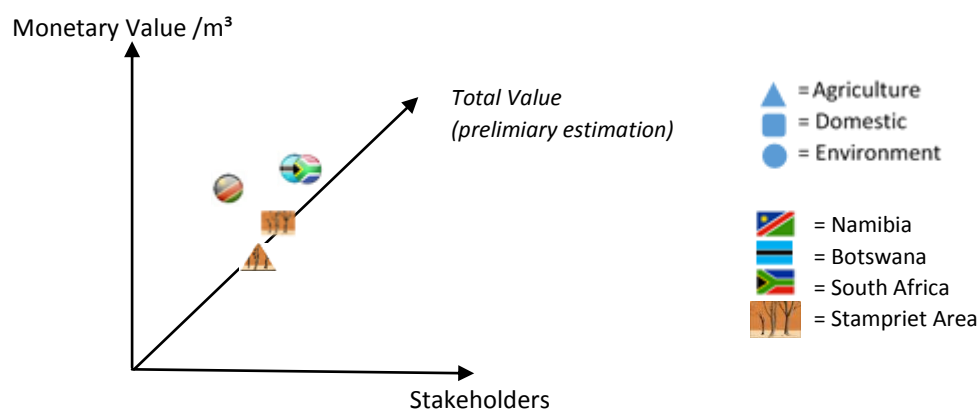

Figure 8. Expected Total Value – Benefits Stampriet. Source: own image

Figure 10 subsequently shows the current data availability plotted against the expected difficulty in obtaining data. As discussed above the overall data availability is quite low, and the complexity for obtaining new data increases with the need to understand bio-physical relations as well as with the necessity for stated-preference studies.

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[25] It should be noted, however, that it is expected that agricultural values are higher in Nambia, where crops are produced for the market, than in Botswana, where crop production mainly sustains the own population.
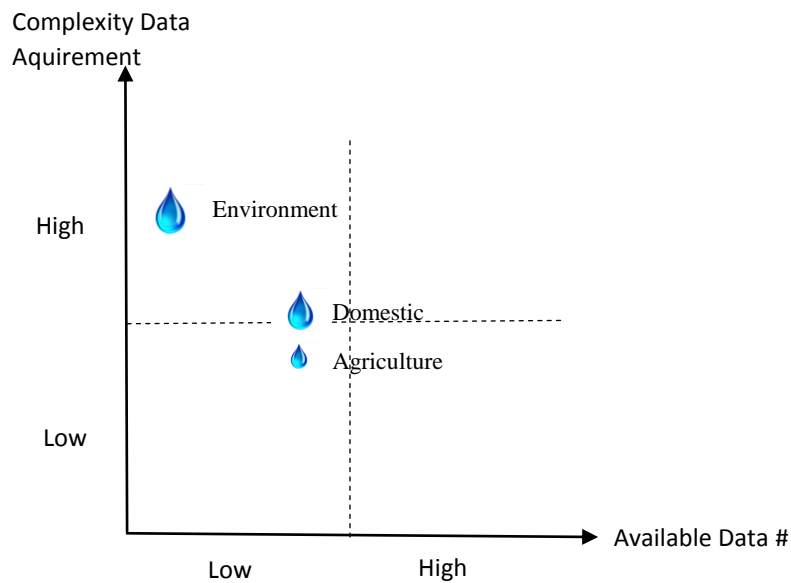
Figure 9. Data Requirements – Benefits Stampriet. Source: own image

5.2.8. Reflection

In order to show the application of a theoretical valuation framework, the Stampriet aquifer presents a good initial case study, since it provides an overseeable number of benefits. Moreover, as the first pilot area for testing transboundary aquifer management principles within ISARM-SDAC (Braune et al., 2013), it is an appropriate site for integrating economic principles into the institutionalisation of groundwater management.

Most importantly, the study showed that there are different kinds of benefits apart from obvious extractive benefits delivered by the aquifer and that those benefits have varying importance across countries. Consequently, actions one country takes with regard to groundwater can have – sometimes high – economic consequences for other countries. Although no exact values could be estimated, it becomes clear that economically all benefits are non-negative and if no ways are found to balance different needs, some might get lost. Furthermore, on a national level the study highlights possibilities to improve allocative efficiencies, measure efficiency gains in, for instance, agriculture or provide a basis for the issuing of permits.

However, what has also become clear is that there is still a severe lack of data. Therefore in future one focus should be on data collection regarding quantities applied to different uses. At the moment collecting data on use-based abstractions is already envisaged by the research team on Stampriet. As a small addition, it might be interesting to enquire in more detail into agricultural use, including not only information on the total irrigated area, but also on irrigated area per crop. This way an easy initial analysis is facilitated and it should be possible to update the results obtained in this report. Moreover, information should be collected on aspects like the values of ecosystems. Finally, different scenarios should be investigated, like alternative water supply options and their costs, or water productivity in agriculture. For some of these points it might be expedient to collaborate with universities or other knowledge institutions. Future research in this area should also gradually relax the simplifications made above, since rough estimates will always just provide an indication for policy action rather than definite conclusions. As a final remark it should be noted that an option value is only included in stated preference methods, wherefore estimates obtained from market data might be seen a lower bound values.

A more detailed analysis in this case study is desirable, since it is expected to help not only with increasing allocation efficiency, but also in transboundary as well as national negotiations. Furthermore regarding single benefits efficiency can be promoted and efficiency gains measured. Finally, the importance of enforcing a permit system can be emphasised.

5.3. Case Study 2: DIKTAS

5.3.1. Relevance of the Case Study

Although the DIKTAS project is officially already in its final phase, it is expected to constitute an interesting case study for this report. So far, the project has concentrated on collecting and synthesising information on the state of groundwater, as well as pointing out information gaps and areas for further research. A central conclusion from the final TDA Report (2013) is, that it is of primary importance to improve monitoring and management in the individual countries, but also to establish a common basis and criteria for the selection of management and protective measures. For both these tasks knowledge about economic trade-offs can give important input and provide a solid basis for dialogue. This is especially significant due to the presence of pressing issues concerning the costs and benefits of hydropower and insufficient waste treatment, as well as the lack of consideration for the unique karst ecosystems and the incomplete implementation of the polluter pays principle. Thus this case study can provide a basis for further developments in the region.

5.3.2. Geographic Scope and Resource Characteristics

DIKTAS is focused on the Dinaric system, which is a "geologically heterogeneous, south European orogenic belt of the Alpine mountain chain". This system is an example of a classic karst region and accommodates very special and fragile ecosystems. It parallels the Adriatic Sea, in a NW-SE direction, from the Sava River in the north to the Vjosa River in the south. Groundwater is present in the form of various aquifer systems, which show large fluctuations in both, water tables and discharge. Owing to the low retention capabilities of the rock – mainly limestone –, the differences in temperatures during seasons, and the fact that the main precipitation events occur between October and April, summer periods are marked by visibly lower discharges. Moreover, since the disintegration of Yugoslavia, the system contains eight distinct TBAs (TDA Report, 2013).

In the following, for complexity reasons, it was considered opportune to focus on one such system only, namely the transboundary aquifer *Trebišnjica*. This aquifer was selected for several reasons. Firstly, the presence of a hydropower plant (HPP) makes it not only an interesting object to study, but also of particular importance for the local population, which is interested in costs and benefits of such undertakings. Secondly, data availability was considered most appropriate.

Trebišnjica is a transboundary aquifer system consisting of 77.8 % (or 1,379 km²) karst, which is shared by Croatia and Bosnia Herzegovina (BiH) whereby Croatia owns 340 km² and BiH owns 1,334 km². Its exact location can be seen in figure 11 and a more detailed description can be found in the TDA Report (2013). It should be mentioned, however, that the boarders at the moment still are an educated guess and that in a karst region the definition of distinct aquifer systems is a very complex undertaking requiring still further research.
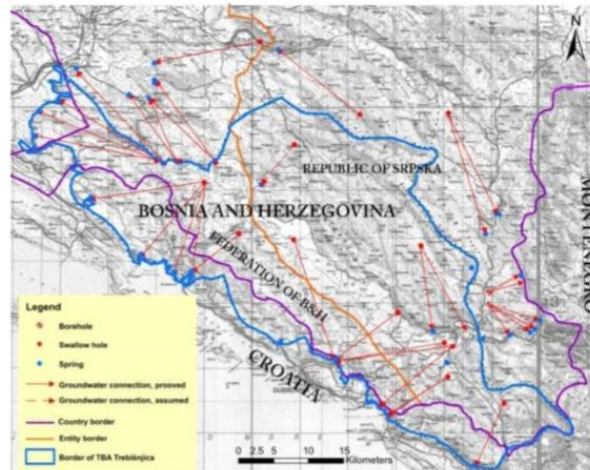
The Trebišnjica aquifer belongs to the Adriatic Sea basin. It does not feed any major permanent surface streams into the Adriatic Sea; however, there are several important sinking streams. Some major karst springs are the Ombia spring, the Doli-Slano spring, the Konavska Ljuta, springs next to the River Neretva, as well as the springs Bistrina, Zaton, Zavrelje und Duboka Ljuta. These springs at the moment deliver water of drinking-water quality, thought they are subjected to highly variable flows.

Average precipitation in the area is around 1,900 mm/year, which in a karst region is the main recharging mechanism. Please note that due to the larger surface area in BiH this is also where the main recharge happens, resulting in a groundwater flow exclusively from BiH to Croatia. Additional recharge comes from sinking streams, like the river Trebišnjica. These systems have been recently altered, however, by the construction of the Trebišnjica hydrosystem – a hydropower generating system of several dams, reservoirs, tunnels and channels, which, with the exception of the Power Plant Dubrovnik, is mainly situated in BiH.

Although karst regions generally boost an abundance of pristine nature areas and unique cave ecosystems, no distinct nature areas or park have been mentioned in the TDA Report (2013) as being located in the vicinity of the aquifer.

Due to different pressures the region faces several difficulties and challenges. For one, there is no comprehensive groundwater monitoring and a general lack of data; in Croatia, for example, there are no accurate statistics on economic activities in the catchment area. Moreover, there are no frameworks for common management. The situation is further aggravated by unregulated sanitary outflows in combination with an expected increase in tourism (in Croatia) and often inefficient water use (TDA Report, 2013).

5.3.3. Socio-Economic Scope and Resource Use

As with the Stampriet aquifer, water use as well as data availability is not similar across countries. In the following, therefore, a short overview over the resource use and relevant socio-economic and legal aspects is given.

BiH

Several stakeholders in BiH depend on groundwater from the Trebisnjica aquifer. First of all *inhabitants and tourists* of the area use groundwater for domestic purposes. A Country Report (2012) revealed that the TBA supplies inhabitants of several municipalities, i.e.

Trebinje, Neum, Ljubinje and Revno, with a consequent estimated total water use of 0.046 m³/s/day. The share of the population connected to the public supply varies, though details are unknown. Moreover, *agriculture and animal husbandry* (mainly cattle), which are the main economic activities in the TBA area, rely on water from the aquifer. It should be mentioned, that agriculture in a karst area is quite difficult due to the interplay between floods and droughts and tends to be dictated by the weather. There are no big industries in the TBA area, although water is needed for *small industries*[26], which were defined as including tourism, hospitals and public greenery (Country Report BiH, 2012). Please note that measurement-wise these needs were included in the domestic use. Moreover, after the construction of the Trebisnjica hydrosystem, *power plants* rely on karst groundwater in form of sinking streams.

Croatia

Although no specific information on water use in Trebisnjica could be found in the Country report Croatia (2012), the *HPP Dubrovnik* is an important user of groundwater from the aquifer. Other uses are expected to be largely similar to the ones in BiH, although *tourism* is expected to play a larger role, due to the fact that Croatia has a longer coastline.

Both countries have several institutions and ministries in place to deal with water issues; usually on a river basin level. However, the process of implementing EU water acts is at the moment still slow. Moreover, although monitoring policies for surface as well as for groundwater are in place, their enforcement is still lagging behind. An additional problem is, that although a system for sanitary protection zones has been developed, specifications are lacking for karst-systems and implementations are weak. Also groundwater dependent ecosystems are inadequately considered in the legislation of both countries. Finally, in both countries the 'polluter pays' principle and the principle of 'recovery of the costs' are promoted and embedded in the current respective legislations. However, they are not fully implemented – neither in national regulations nor in water management practices. All in all, while the legal foundations are there, enforcement is still weak. Showing the value of groundwater could help to emphasise the importance of acting fast, as well as provide a basis for actual implementations.

5.3.4. General Data Availability
Since the project is as good as concluded, the data availability was expected to be higher than in the case of Stampriet. However, the project so far mainly concentrated on obtaining hydrogeological information and did so on a country basis. Thus it was discovered that there still is an information gap to be closed in order to obtain a complete picture of the value of change in the aquifer.

5.3.5. What is to be Valued?
As has been mentioned in the case study above, the main purpose of this report is to give a first overview over what is important to consider in regard to the valuation of a groundwater resource. Since this is quite a large – some might argue a too large – task, the picture that has to be drawn is a complex one. Therefore, once again, a simplified scenario is depicted here, creating a basis for more specific analyses late on. As above the simplification concerns the whole body of groundwater. However, instead of a change in quantity, a change in quality is

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[26] In the country report for BiH several industries are named as being of importance for the country. However, which industries are also affecting or using water from the Trebisnjica aquifer does not become apparent; only that it are mainly meat and fishing industries.

considered. More specifically, based on current waste flows, a contamination with municipal waste is assumed. Again, the baseline assumption is that the aquifer remains as it is, without taking into account specific development variables, like population growth. A decrease in groundwater quality was used since it is considered a more realistic scenario in a karst region. In addition to the fact that at the moment extractions are estimated to be quite small compared to the available reserves, recharge is high in wet seasons, wherefore it is unfeasible to consider a total depletion. Moreover, quality deteriorations are a realistic danger due to inadequate waste treatment and a lack in enforcing sanitary protection zones.

5.3.6. Benefits provided by the aquifer

On the basis of the theoretical framework outlined in part one of this report the following benefits have been identified for each country.

In BiH water from the Trebisnjica aquifer is mainly used for:

- Domestic purposes
- Agricultural purposes (irrigation and livestock)
- Industrial purposes
- Touristic purposes
- Hydropower
- Support of groundwater dependent ecosystems
- Support of karst underground species (endemic)
- Waste assimilation
- Prevention of seawater intrusion
- Carbon storage
- Sinking rivers and reservoirs: Recreation

In Croatia uses are expected to remain largely the same though with a stronger focus on tourism.

The following table shows an estimation of the relative reliance on specific benefits for both countries:

Benefit	BiH	Croatia
Domestic water use	High	High
Agricultural water use: irrigation	High	Medium
Agricultural water use: livestock	Medium	Low
Industry (incl. mining)	Low	Low
Tourism	Medium	High
Hydropower	High	High
Support of groundwater dependent ecosystems (including nature parks)	Medium	Medium
Endemic species	Medium	Medium
Waste assimilation	Medium	Medium
Prevention of sea-water intrusion	Low	Medium
Carbon storage (not relevant here)	Unknown	Unknown
Sinking rivers and reservoirs: Recreation	Medium	Medium

Table 14. Relative Benefits Trebisnjica. Source: own table

5.3.7. Assessment

A change in quality, as a change in quantity, has several implications for the benefits delivered:

- Domestic water use:
  A decrease in groundwater quality can lead to the use of *substitutes* like surface water or bottled water. The former is, however, only feasible if the source of the surface water has little or no connection with the contaminated groundwater. In case that polluted groundwater is still used for domestic purposes, either the *treatment costs* of water – for water supply companies or concerned individuals – and/or the *healthcare costs* of people who consume untreated water are expected to increase. In case that concerned parties themselves take avertive measures, like changing supply or treating water before consumption, one can also speak of *avertive expenditures*. As an aside, it is assumed that at the moment no water treatment is needed, since water quality provided by the aquifer is currently still of a high quality (TDA Report, 2013).

- Agricultural water use:
  Impacts on agricultural production strongly depend on the kind of pollutant. As mentioned above pollution is expected to stem mainly from municipal wastewater, whence the impact on irrigation agriculture is assumed to be small or even positive, since "polluted" groundwater potentially has a high fertilizer value (FAO, 2014). Nevertheless, impacts can be expected through commodities adsorbing toxic substances or pathogens which are then passed on to the population, thereby *increasing health costs*. Impacts on livestock are expected to be similar, leading to increased sickness and thus production losses.

- Industrial water use:
  Depending on the industry, water quality can have a big or small effect on the industrial output. Whereas in the food industry the impact is more pronounced, in mining it is negligible. Thus in order to estimate the effects, a comprehensive list of industries is needed. Generally, the same intuition as for domestic water use applies; either a *substitute* source is found or *treatment costs* have to be born.

- Tourism related water use:
  Since tourism related water use is mainly domestic use of visitors, the implications of a quality deterioration are the same as described above under "domestic water use".

- Hydropower:
  Quality deterioration is not expected to have a significant impact on the generation of hydropower, since it only uses the kinetic energy potential of water.

- Ecosystem services:
  As with endemic karst species, the impact of waste disposal and groundwater quality deterioration on ecosystems, depends on the kind of pollutant and can furthermore be quite ecosystem-specific.

- Karst underground species (endemic):
  In the last decade several studies have been conducted regarding species endemic to karst environments and caves. However, they are still not entirely understood (Van Beynen, 2005). What is known is that they are quite sensitive to disturbances in their environment including changes in water chemistry due to, inter alia, sewage (ibid.). Thus it is assumed here that a stark deterioration in water quality would also lead to a great impact and decline in endemic species. Exact relations between different kinds

and concentrations of pollutants and species decline still need to be researched in more detail, though.

💧 Waste assimilation:
As has been mentioned above this is an intermediary benefit. Moreover, assimilative capacities of karst systems are low from the beginning.

💧 Seawater intrusion:
Since seawater intrusion is prevented by water pressure, water quality does not effect this intermediary benefit.

💧 Carbon storage:
So far this property of (ground-)water has been researched too little to define any specific consequences of a change in quality.

💧 Recreation:
Although recreation has not been mentioned specifically in country reports, especially Croatia is a tourist country. Therefore, water quality decreases and subsequent eutrophication of sinking rivers and reservoirs could lead to decreased utility from fishing and other recreational activities.

Data needs versus data availability

Regarding the changes described above, specific valuation methods lend themselves more than others. Those methods, data needs and the expected data quality is summarised in table 15 below.

Benefit *(Valuation method)*	Data Needs	Data Quality Status (good/emerging/bad)
Domestic water use (private/public supply) (*Cost of alternative/Cost of treatment*)	*Cost of alternative:* Quantity of water now supplied from the aquifer, as well as a separation in public and private abstractors. Fixed and variable costs of alternative supply options (e.g. different infrastructure) including costs for connecting private abstractors to the public system. *Avertive expenditures:* Avertive strategies. Quantities (incl. extrapolations) and costs of bottled water sales, water treatment equipment etc. *Cost of treatment:* Quantity of water now supplied from the aquifer, as well as a separation in public and private abstractors. Increase in costs of treatment for private and public supplies. Costs of connecting private abstractors. Alternatively: increased risk of illness and costs for increased hospital treatment costs.	Bad/Emerging
Agricultural supply (*Production function/cost of treatment*)	*Production function:* Impact of quality decrease on crops and livestock. Factor inputs and input prices, as well as the total (economic) value of the produced goods. *Cost of treatment:* Increased risk for human and animal health.	Bad. Data about actual abstractions often missing.

	Treatment costs for sick individuals.	
Industrial abstraction (*Cost of alternative/Cost of treatment*)	Industries relying on groundwater from the aquifer and the quantities abstracted. Depending on the industry data needs are either zero or equivalent to private/public supply; especially for hospitals the latter is expected to be more feasible. (Tourism is treated here as an extra category.)	Bad. Data about actual abstractions often missing.
Ecosystem services (*Contingent valuation, Travel cost method*)	List of groundwater dependent habitats and degree of dependency, as well as population dependent on these ecosystems. Connection of loss in value of attributes and groundwater quality changes. Stated preference or travel cost studies investigating the value of changes in ecosystem attributes.	Bad/Emerging
Karst (endemic) species (*Contingent valuation*)	List of endemic species and degree of dependency on the groundwater quality. Connection of loss in value of attributes and groundwater quality changes. Stated preference studies investigating the value of changes in ecosystem attributes.	Bad/Emerging
Tourism related water use (*Cost of alternative/Cost of treatment*)	Quantity of water now supplied from the aquifer for touristic purposes (beware double counting with private/public supply). Other information needs are similar to public/private water supply.	Bad. No specific abstraction quantities known; no extrapolations for the expected increase in tourism.
Hydropower	Hydropower in this case is not expected to be effected, because the water quality has no effect on the machines or energy produced. However if quantity issues were to be reviewed, the following data would be required. *Cost of alternative:* (Marginal) cost of making one KWh in an alternative plant (this will include mainly fuel expenses and part of operation and maintenance costs) for both base and peak energy. Cost of new electric capacity (e.g. thermal electric capacity). Total cost of alternative electricity (capital plus production).	Emerging.

Table 15. Data Needs Trebisnjica. Source: own table

Domestic water use: As described above, domestic water use can be valued in several ways, such as by the cheapest alternative to get water of the original drinking water quality or by the cost of treating groundwater in order to reach the original quality. Which option is the most feasible to choose, depends on several factors (see part I). In this case, as in most others, using market data for domestic water use is not expedient, since prices are distorted: prices paid by domestic users often do not even cover operations and maintenance costs of water supply facilities (Country Report BiH, 2012[27]). Therefore, other methodologies have to be found.

Cost-based methods are a feasible alternative, since they provide a realistic scenario for water quality problems. Furthermore, they do not suffer from the criticism of contingent studies and information needs are reasonable. Although generally water supply companies should be responsible for ensuring a certain quality of the distributed water, the "number and standard of sewerage systems and wastewater treatment plants in B&H is unsatisfactory"[28] (Country Report BiH, 2012). Thus, currently the measure most suitable for the scenario at hand are avertive expenditures by people wanting to avoid negative impacts from contaminated water. Rainwater collection has been named as a principle avertive measure in the advent of groundwater unavailability (correspondence N. Kukuric) and other known avertive measures are the purchase of bottled water or filtering devices. However, neither the exact quantities extracted for domestic use on an aquifer level, nor people's behaviour in case of a qualitative decrease in groundwater are known. Estimations are more difficult, since at the moment the drinking water supplied is still of quite high quality. Thus although information does not need to be very detailed in a primary study aimed at identifying the most important benefits which can then be evaluated in more detail, obtainable data is at this moment still insufficient.

An example of a study estimating the value of drinking water by avertive expenditure is published in the Arab Water Report (2013). Here the costs for buying water from vendors or bottled water due to insufficient water supply and sanitation is aggregated with the cost increases due to diarrhoeal death and morbidity, where the latter includes the cost of illness, as well as the cost of treatment. For selected Arab countries (see Arab Water Report 2013 for details) the estimated total costs amount to 99,364.5 Million $. Since these values are very country specific, a simple transfer is not possible. However, if scenarios for disease development and sales trends for bottled water could be estimated, a similar methodology relying on GDP measures could be applied in this case study. At any rate it is shown that such values are non-negligible. Please note furthermore that costs were in 10 out of 13 cases found to be substantially higher than the costs of improved water provision and sanitation (Arab Water Report, 2013). This means that were water treatment costs to be estimated, they would most probably constitute a lower bound estimate for the value of domestic water quality improvement.

Alternatively, WTP estimates for domestic water use can be obtained from contingent studies. This also seems to be the currently prevailing approach - at least in developing countries (Aylward et al., 2010; Arab Water Report, 2013). Hence, in absence of cost data, it could be a good starting point to perform a benefits transfer from a WTP study made in a comparative context.

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[27] Please note that this has not been explicitly mentioned in the Country Report for Croatia, but the situation is expected to be similar.

[28] Again a similar situation is expected for Croatia.

Naturally, it should not be forgotten that people will probably adjust their behaviour and thus demand. Thus it might be a good next step to also research people's WTP including the demand elasticities.

Agricultural water use: Since the main problem in the DIKTAS region is that waste water is not treated and since there is no heavy industry in the vicinity of the aquifer, it is assumed here that main contaminants are of an organic nature and agricultural produce in form of crops etc. is not going to be negatively affected; on the contrary increased nutrient inputs are expected to positively contribute to yields (Hussain, 2002). However, the risk for humans consuming contaminated food are expected to increase, as are subsequent hospitalisations and/or healthcare costs. Livestock is also expected to be negatively affected resulting in production losses.

No general studies could be found regarding the increased health risks associated with insufficient wastewater treatment or increased healthcare costs, wherefore no definite number can be quoted; however, based on studies qualitatively discussing health consequences from contaminated food sources (Drechsel et al., 2010), it is assumed that costs would be positive and most certainly considerable. In order to be able to assess these costs a risk assessment, like a quantitative microbial risk assessment, is needed first. Furthermore, Hussain et al. (2002) developed a holistic methodology for evaluating the impacts of wastewater in agriculture in terms of costs and benefits for society. They propose to measure changes in productivity using information on yield change, acreage and current prices[29]. Additionally, savings in fertilizer expenditures are considered a supplementary benefit, whereas the application of gypsum or green manure to counteract increased salinity is a supplementary cost. Finally, increased morbidity due to wastewater pathogens result in loss of earnings and extra healthcare expenditure. As in the Arab Water Report (2013) the former is calculated using a human capital approach, where information on the time off work and a daily wage rate is used.

Industrial water use: Since the small industries named in the Country Report for BiH (2012) (no information available for Croatia) are hospitals, tourism and public greenery, mostly the same arguments as for domestic water supply apply. This means that it might be possible to evaluate both jointly, which is useful since a separate assessment it is at any rate not possible at the moment, because used quantities for industry are included in the domestic water supply. However, there might be industries, like public greening, which are not vulnerable to contaminants or only to very specific contaminants. Thus, in future an inventory of the industries is needed, as well as abstracted quantities form the TBA.

Ecosystem services: Although values of wetlands have been researched in more detail than drylands, studies for karst environments are not abundant. Generally, the WWF (2004) found a medium economic value for specific wetland functions, like recreational fishing (374 $/ha/year), biodiversity (214 $/ha/year) and amenity/recreation (492 $/ha/year). For a more specific analysis, however, important wetlands in the area need to be defined in more detail. Moreover, it might be expedient to enquire into marine ecosystems which could be disturbed by a change in freshwater quality.

Endemic karst underground species: For endemic species a valuation deficit seems to exist. This might on one hand be due to a lack of understanding of cave ecosystems and on the other hand to the fact that the description of a scenario involving species that are mostly

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[29] As an aside, different models, like optimisation models or econometric models can be applied, which are more sophisticated, but also require more complex data (see xxx, p. 23).

unknown to a large part of the population is rather difficult and prone to criticism about the validity of found values.

Tourism related water use: As water use for small industries, the valuation of tourism related water use will be very similar to the one for domestic water use. Again, at the moment data availability is quite limited and water quantities used for tourism per groundwater source, i.e. aquifer, should be measured in a first step. Moreover, it would be beneficial for scenario analyses, if extrapolations of expected uses for the next years were made.

Recreation: Decreases in recreational utility should be valued through contingent studies of the relevant affected population segments, whereby care should be taken to avoid double counting.

Hydropower: In this specific scenario of quality deterioration, benefits from hydropower do not change compared to the baseline and hence do not need to be valued. However, there are a number of scenarios where valuation of hydropower is essential, wherefore box 5 goes into a little more detail.

Box 5. Hydropower

Valuing hydropower is usually done via an alternative cost method, although it is also thinkable to use residual values. The latter, however, requires that electricity markets are not regulated (Lange, 2014). In the short run, capital investments are taken as being fixed, whence the lost value of water is defined as "the marginal cost of making up the kilowatt-hour in an alternative plant less the marginal cost of making a kilowatt-hour at the hydropower facility". Those marginal costs consequently only include fuel expenses and some operations and maintenance expenses, but not depreciation, capital costs or taxes (Gibbons, 1986).

Since, apart from water, coal is the main source of energy in BiH (Pasic, 2011), it is reasonable to think that a kilowatt-hour lost in a hydroelectric plant is replaced by a kilowatt-hour generated by a coal powered plant. Since this is also a base load power plant, it is moreover a conservative estimate. In other words the value of water is calculated by multiplying the kWh lost with the difference between the average production cost for a coal powered plant and the average production cost for the hydro-electrical plant (Gibbons, 1986). However, it should be mentioned that this method does not take into account any negative environmental impacts of hydropower like ecological effects of an increased water temperature.

Aggregation: As with the Stampriet Kalahari/Karoo case study, time and data constraints did not allow the estimation of explicit values, wherefore an aggregation – simplified or not – is not possible. Should an aggregation be envisaged at a later stage, principally the same arguments as above apply; it is possible to get a first rough estimate by specifying a timeframe for all benefits, and discounting them to calculate a NPV, using, for example, a formula like the following (Lange, 2014).

$$V_0 = \sum \frac{RR_t^1 + RR_t^2}{(1+r)^t}$$

Where
V = Asset value of water
RR = value of water for 2 different uses
in a given year, p_w x q_w
r = discount rate

Future focus: As in the case of Stampriet an attempt has been made to provide an overview over future research needs. Unfortunately, too little information was available to determine the relative values of benefits, but the data availability could still be plotted and can be found in figure 12.
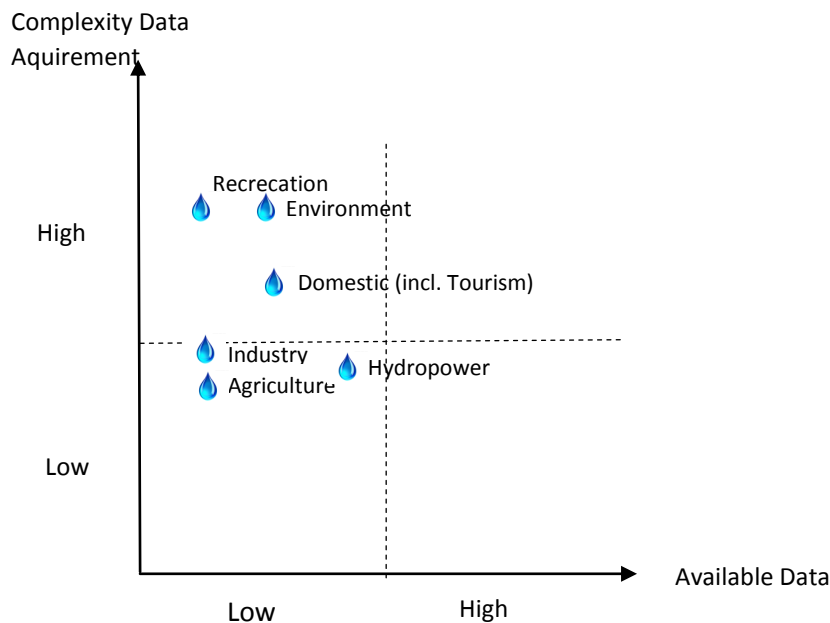

Figure 11. Data Requirements – Benefits Trebisnjica. Source: own image

5.3.8. Reflection

What became immediately apparent in the case of the Trebisnjica aquifer, is that most data on extractive uses is only available on a country level, but missing on an aquifer level. This is partly due to difficulties in delineating aquifer boundaries in karst regions. In future projects care should be taken to measure not only total extractions, but as far as possible also extractions per aquifer and use.

Regarding the aquifer assessment, Trebisnjica provides more individual benefits than the Stampriet aquifer, which makes sustainable water allocation between uses even more important. Seeing that there are quite a number of extractive uses and that groundwater pollution is becoming an increasing problem, further research is especially important regarding fragile karst ecosystems. Although so far no major protected areas were reported in the vicinity of the aquifer, karst cave ecosystems are not yet well known or understood.

Furthermore, a main policy aim regarding future developments is the introduction of sufficient waste management (TDA Report, 2013). Although actual optimisation calculations in this regard are not yet feasible, showing the potential economic impacts of insufficient waste management can highlight the necessity of immediate action. Moreover, similar to the study in the Arab Water report (2013) economic valuation can be used as a basis for finding cost efficient solutions. This, however, requires the development of scenarios in case of non-action, like an increase in water related diseases.

Lastly, found values for domestic water use should be compared to currently paid water prices, on the basis of which future strategies and policy actions should be developed.

6. Conclusions

6.1. Review of the Case Studies

Looking at the two case studies above, the main issue catching ones eye is the limited data availability. This is not at least due to the high site-specificity of groundwater related benefits, which necessitates tailored studies for each aquifer, and the high complexities of aquifer systems. However, it is also due to data collection gaps. Since the economic importance of benefits provided by groundwater often justifies valuation studies in order to lie a solid foundation for resource management decisions, a future focus should be on collecting information in a way that it can be more easily processed for economic assessments.

Although the case studies had to be kept on a rather abstract level, some initial conclusions can already be drawn. On the basis of studies conducted on similar aspects, for example, it is expected that all identified benefits are non-zero and most even substantially so. Thus, while groundwater itself might be a hidden resource, the economic benefits humans derive from it are visible and non-negligible. Furthermore, decisions taken in one country can affect several benefits in its neighbouring countries. Focussing on these visible benefits is therefore expected to not only help improve decision making, but also strengthen the argument for the implementation of transboundary management regimes.

6.2. Barriers and Drivers

Time and monetary requirements of conducting an economic valuation study, paired with sometimes high uncertainties of the results, are expected to be among the main barriers limiting their usage so far. Difficulties of obtaining reliable data arise next to methodological issues like determining the population of interest and uncertainties in the analysis. Additionally, there also seems to be some distrust regarding economic concepts – especially monetisation of environmental goods, as well as "language barriers" due to different terminologies between disciplines. Nevertheless, it is expected that valuation studies, if conducted conservatively and under the provision of explicitly stating uncertainties, can provide valuable input for decision making processes within sustainable transboundary aquifer management (cf. figure 13). They should therefore be embraced by governance specialists as possibilities for acquiring additional input.
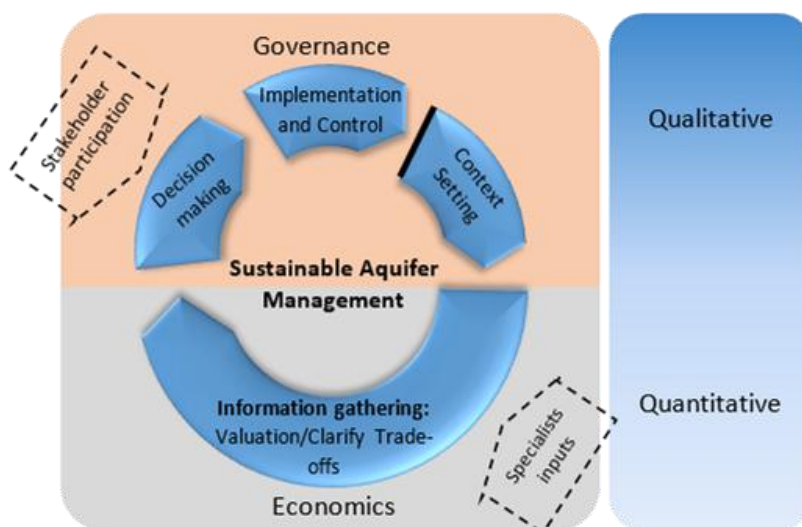

Figure 12. Integration Governance and Economics. Source: own image

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In order to facilitate an integration of economic tools into governance processes, economists should make an effort to translate their concepts into more easily applicable and implementable solutions and ensure that technical terminology can be universally understood. Moreover, a distribution analysis should accompany valuation studies, so that the distribution of the negative as well as positive changes in benefits is visible and can be taken into consideration. Governance specialists on the other hand need to make sure that processes are in place which allow an appropriate consideration of different aspects and inputs.

Therefore, making economic frameworks more accessible and comprehendible also for non-economists is seen as a necessary step towards an improved integration of economic concepts into governance efforts. This is especially important since increasing pressures and subsequent increasing economic scarcity, are augmenting the need to evaluate trade-offs and provide sufficient information to all involved parties. UNECE made a good start by informing stakeholders of the existence and importance of economic benefits provided by groundwater. However, in a next step attempts at actual quantifications should be made. For this an interdisciplinary effort, including ecologists, hydro-geologists, biologists and economists, is quintessential – especially in regard to filling in persisting research gaps.

6.3. Research Gaps

Academically a lot has been accomplished since the first applications of economic environmental valuations about hundred years ago. There are still some aspects in the valuation of groundwater resources, though, that require additional research. For example, although some progress has been made over the last years, an improved understanding of threats to groundwater resources and their exact influence on specific benefits is indispensable for an accurate valuation study.

Moreover, some benefits, like carbon storage, ecosystem dynamics, or endemic karst species, are still not very well researched, whereas for others, like drylands, empirical studies are missing. The latter can also undermine the adequate acknowledgement of the value of groundwater dependent ecosystems. For an accurate valuation it is moreover important to understand how exactly groundwater maintains ecosystems and what would replace such an ecosystem if the groundwater regime were to change.

Data-wise, knowledge about extracted amounts and uses is essential. Additionally, knowledge about likely developments and extrapolations over use-changes are important for scenario analyses.

6.4. Recommendations

With regard to this report and especially the two cases studied in more detail, some recommendations are formulated in the following.

In order to lower the barriers for economic valuation studies, it is proposed to gather data with regard to its applicability in economic studies. IGRAC is in an advantageous position in this respect and can make a start with collecting information on groundwater use on an aquifer level and at a later point maybe even more complex data like expected development scenarios. A good start are the indicators of the GGRETA project, although some refinements for, for instance, agricultural uses and a more detailed inventory of different industries, might be beneficial. For other projects, like DIKTAS, information on additional benefits, as hydropower, should be added to the list of uses. Information that is of interest with regard to an economic valuation can be found in tables 10 and 15. Other input should come from research and knowledge institutions, filling in the research gaps mentioned above. Such activities are

expected to also spark more discussion and thus possibly facilitate discourse between different disciplines, as well as raise awareness for the importance of evaluating trade-offs.

For conducting an analysis at a new site, several aspects should be considered. Firstly, taking into account the efforts connected to a holistic assessment, some intermediary steps should be taken. It will, for example, be expedient to mainly use benefits transfers to get a first, rough picture about the number and magnitude of benefits provided by an aquifer. Subsequently, further studies should focus on those benefits which were found to be of high economic importance. More detailed studies should moreover be conducted with a specific aim in mind, facilitating the definition of the scope of the research. Please note that for each project the population of interest should be defined beforehand. Finally, time specific developments should be incorporated where appropriate.

6.5. Discussion and Limitations

Although it was mentioned several times above, it should be emphasised that assessing a whole body of groundwater is not that simple. Benefits respond quite differently to external stimuli and an exact understanding of pressures and responses is essential for the determination and subsequent valuation of realistic scenarios. Moreover, the baseline is unlikely to remain static, wherefore extrapolations of current trends are an important extension. In a similar vein human responses, i.e. changes in demand, have to be expected with changes in a groundwater regime. For a primary study stark simplifications regarding these things are often necessary due to the high time and monetary requirements of more extensive studies. However, at least for benefits identified as having a high economic value, more detailed follow-up studies should be conducted. Within this report only a first, abstract overview of benefits and their importance based on previous literature, as well as of current data availability, could be given.

Moreover, only stated-preference methods are able to capture existence, altruistic and bequest values, wherefore estimates using market data will only provide a conservative, lower-bound estimate.

Concluding it should be emphasised that for above mentioned complexity reasons valuations for a whole body of groundwater are usually not done. In this report doing so served the purpose of giving an overview over all relevant aspects included in such a valuation, as well as over benefits and data needs in two specific cases. It is hoped that such an overview can show a bigger picture and thus contribute to reduce misunderstandings between disciplines and create a basis for discussion. Nevertheless, it should be kept in mind, that all aspects and benefits mentioned are in themselves quite complex, wherefore usually studies are done with a much more narrow focus.

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