Water Management in the Upper Catchment of the Kuiseb River Basin

Worcester Polytechnic Institute:
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by

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Report Submitted to:

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Abstract

This study, prepared for the Desert Research Foundation of Namibia, investigated water management practiced by the commercial farmers in the upper Kuiseb River Basin. These stakeholders have faced complaints that their farm dams negatively impact downstream users. Our goal was to assess water management tactics on these farms to develop recommendations for all stakeholders to improve water management and conduct further research. Our data indicate that farm dams contribute to local groundwater recharge and provide an important surface water source and that the water they retain does not significantly impact downstream users.

Authorship

All chapters, unless otherwise noted, were jointly written by Erin Hicks, Justin Johnson and Michael Torilli.

Background:

Erin Hicks:	Sections 2.4, 2.5
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Appendices:

Erin Hicks:	Appendices B, C, D
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Michael Torilli:	Appendices A, C, E

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Executive Summary

The Kuiseb River Basin (KRB) is located among the 12 major ephemeral river basins in the mid-western region of Namibia. This ephemeral river serves as the main source of water for a variety of stakeholders, including commercial farmers, indigenous peoples, and the second largest municipality in Namibia, Walvis Bay. Unfortunately, the current water use and management practices of some users do not support equitable and sustainable resource use, causing many disagreements among the stakeholders. One notable debate occurs between the upper and lower catchment residents.

Currently, many of the stakeholders located in the lower catchment feel that the commercial farmers located in the upper catchment region withhold excessive amounts of water in their farm dams. These farmers, who are largely engaged in livestock farming and/or tourist activities, use their farm dams to retain water on their farms as a surface water source and/or as a groundwater recharge method. Many of the lower catchment users believe that these dams and the water management practices on these farms are decreasing the surface water supply to the lower catchment as well as recharge to their aquifer.

Water use and management on the commercial farms in the upper catchment of the KRB have received little study in the past. The most recent information on these stakeholders is over a decade old, making it difficult to understand this user group. It is essential that additional studies be conducted to further the development of water management and disagreement resolution in the KRB. The Environmental Learning and Action in the Kuiseb (ELAK) Project, under the direction of the Desert Research Foundation of Namibia (DRFN), has been established in part to address

stakeholder debates in the KRB. ELAK's primary goal is "to achieve equitable access to and the sustainable development of fresh water resources…by all sectors dependent on the basin in order to promote long term social and economic development." They place particular focus on developing water management plans that equally include each stakeholder and provide a common platform for decision making. To date, ELAK has yet to completely discover all the sources of stakeholder dissatisfaction concerning water management practices in the KRB. Obtaining this information would help further develop an understanding of these users and their priorities regarding water use and management. ELAK can utilize this information, in conjunction with their present knowledge of the KRB users, to further the process of capacity building and debate resolution amongst the Kuiseb stakeholders.

The goal of our project was to develop recommendations for ELAK, the commercial farmers in the upper KRB and other stakeholders. ELAK can use these recommendations to resolve disagreements among the stakeholders concerning integrated water management in the KRB. Our primary research objective aimed to expand ELAK's current database of information on the commercial farms. Specifically, we focused on determining the water use, supply, needs, and management practices on the commercial farms in the upper catchment. The second objective was to investigate the possible effects of commercial farm dams on downstream users. We applied a variety of methods to achieve the objectives and goal that, in combination, helped us accumulate the information that we needed.

Before we could begin gathering information from the commercial farmers we researched the available archival data on commercial farms. Through archival research we were able to determine exactly what type(s) of questions to ask in order to develop an effective interview protocol. The primary method for our field research entailed personal interviews and communication with farmers in the upper catchment. In total, we interviewed 13 farmers in the upper catchment and visited nine of these farms. By visiting these farms, we were able to use direct observation to further assess how water was used and managed and to see and understand why farmers use certain strategies for water management.

We identified three factors that impact water infrastructure on commercial farms. First, farm location is highly significant in determining the water infrastructure on a given farm. For example, the upper subcatchment farms have a greater number of active boreholes than the lower subcatchment farms. Two reasons may justify this. First, data recorded by the farmers indicate that the eastern region or upper subcatchment of the upper KCA receives an average of 60 millimeters more rain per year than the western region or lower sub-catchment, making their groundwater source more reliable. In the context of this arid region, this is a significant difference. Because of this difference, lower subcatchment farmers appear to rely more heavily on groundwater sources and have more inactive boreholes than upper catchment farms. Furthermore, the geology and hydrogeology of a farm affects where water collects both above and below ground. These characteristics determine where boreholes can be drilled, where dams are the most effective, and the availability of groundwater in an area. Topography was also found to control the course of surface waters, water pumping operations, and even climate of the farms.

In addition, we discovered that the water conservation, recharge and maintenance efforts are not sufficient for sustainable farming operations. Many farmers said that they practice water conservation as a ‘lifestyle’ by avoiding water wastage. Only one used technologies to reduce domestic water consumption. Almost all the farmers surveyed responded that they used automatic ball valves in livestock troughs to prevent water overflow, but very few took measures to reduce physical or evaporative losses from other water reservoirs. Nearly all of the farmers we interviewed said that they use dams on their farms, but only 75% have made measurements or observations proving the effectiveness of these dams on groundwater recharge. Moreover, two thirds of farms with active dams have performed maintenance on their dams; only a few routinely repair their dams even though they are aware that dam maintenance increases groundwater recharge efficiency and reduces evaporative losses.

We found that farm dams, despite complaints from lower catchment stakeholders, do not affect the water supply of downstream users. These statements were further supported by the head of hydrology at the Namibian Department of Water Affairs and the president of the Hydrogeological Association of Namibia. We have discovered three reasons for reduced water supplies in the lower catchment. First, annual rainfall throughout the upper catchment has decreased over the last 30 to 40 years. Consequently, commercial farmers have had to improve land management through the use of rotational grazing, which reduces surface water runoff. The largest problem may be the increase in water consumption by the municipality of Walvis Bay, whose population grows at over 11% per year. Their consumption of water from the lower catchment's aquifer exceeds the amount that is naturally replaced and cannot sustain use at this level for much longer.

After we completed our analyses conclusions, we were able to make recommendations to ELAK, the commercial farmers of the upper KCA and the other stakeholders of the river basin. Our major recommendation to ELAK is further study. Commercial farms and their water management operations need additional research to continue capacity building and debate resolution. Also, ELAK should continue to focus on awareness education, which may rectify some of the existing assumptions that stakeholders make about each other. We recommend that the commercial farmers look into technologies that could possibly reduce water consumption and/or evaporative losses such as low-flush toilets in the home and mesh shade covers for water reservoirs. More routine maintenance of water infrastructure may also reduce physical and evaporative water losses. Additionally, communication among farmers concerning specific water management techniques may further improve operations. The other stakeholders, particularly the municipality of Walvis Bay, need to continue researching alternative water sources. In combination, studies need to be conducted regarding the effects of growth and expansion on the water supply. Overall, all stakeholders need to continue and/or increase communication among themselves, ELAK, and other parties to further debate resolution and possibly augment capacity building throughout the KRB.

These recommendations, along with our main findings, were incorporated into a brochure as our final deliverable. ELAK will make it available to the farmer unions, other stakeholders, and other parties involved in future development and capacity building in the KRB. From the information resources we developed, ELAK may advance the diagnostic phase of capacity building and continue forming a common vision for stakeholder collaboration in the Kuiseb River Basin.

1.0 Introduction

Namibia, the only country in the world named after a desert, contains no perennial rivers within its borders (Namibia Resource Consultants, 2002, p. 13). Limited annual rainfall, intense heat and minimal ground water retention further contribute to the natural water scarcity in this country (Lange, 1997, p. 299). In addition, growing populations, both urban and rural, as well as industrial growth further encroach upon the limited water availability (Le Houerou, 1996, p. 160). As a result, Namibians must rely on effective water management in order to sustain a source of water year-round (Lange, 1997, p. 300). Some of their methods include wastewater recycling, fog catchment, inter-basin water transfers, and borehole drilling to provide water to the people (Forrest, 2002, p. 393; de Villiers, 2002, p. 51). Unfortunately, the water management schemes in most areas of the country do not properly or adequately solve the reoccurring problems of water shortage. The Kuiseb River Basin (KRB), which begins outside of the capital of Windhoek and flows toward the Atlantic Ocean (see Figures E.1 and E.2), is a prime example of an area that struggles with this exact dilemma.

The Kuiseb River is one of the most heavily used rivers in the country (Dausab, et. al., 1994, p. iii). It provides all the water used in the coastal town of Walvis Bay and the Hansa™ Brewery in Swakopmund. The municipality of Walvis Bay currently has a population growth rate over 11% (Seely, M, personal communication, 28 April 2003). At this rate, it has been estimated that the aquifer will be incapable of supporting the municipality past 2020 (Manning, N., personal communication, 28 April 2003). Furthermore, the Kuiseb River supports the farming activities of the indigenous Topnaar people along the lower watercourse, and the operation of 109 commercial farms in the upper reaches of its catchment area. A temporary escalation in commercial farming in the 1960s forced farmers to implement farm dams in order to supplement surface water and groundwater recharge (Dausab, et. al., 1994, p. 4). There are now hundreds of these dams scattered throughout the upper catchment. Many employees of NamWater, politicians and urban dwellers believe that these farm dams withhold too much surface water runoff, which consequently hinders the recharge of the aquifers in the lower KRB (p. 8).

The Kuiseb catchment area provides a perfect example of problems regarding water management and sustainable development in Namibia (Dausab, et. al., 1994, p. 1; Magalhaes, 1994, p. 275; Abu-Zeid, 1998, p. 12). The interactive Environmental Learning and Action in the Kuiseb (ELAK) project, sponsored by the Desert Research Foundation of Namibia (DRFN), was established to address water sharing conflicts throughout the KRB. ELAK's primary goal is "to achieve equitable access to and the sustainable development of fresh water and other natural resources by all sectors dependent on the basin in order to promote long term social and economic development" (DRFN & ELAK, p. 1). The organization particularly focuses on developing water management plans that equally include each stakeholder and provide a common platform for decision making. ELAK has conducted extensive studies of the catchment area regarding the water management practices of the stakeholders. To date, however, ELAK does not completely understand the sources of dissatisfaction felt by the stakeholders concerning water management practices in the KRB. In addition, accurate documentation of the total volume of water used, the proportions used by different consumers and the purpose for which it is used have not been made within the upper KCA (Dausab, et. al., 1994, p. 1).

The goal of this project was to develop recommendations for the commercial farms in the upper catchment that ELAK can use to resolve debates among the stakeholders concerning integrated water management in the KRB. Two comprehensive research objectives aided in accomplishing our goal of developing water management recommendations for ELAK and the KCA stakeholders. Our first objective was to characterize the existing water use, supply, and management practices on the commercial farms in the upper KCA. The second objective was to assess the upper farm dams in the upper catchment and their possible impact on downstream users. We hope that our recommendations will contribute to a better understanding of the water management practices on the commercial farms in the upper catchment for the benefit of all KRB stakeholders. This may in turn facilitate sustainable development in the river basin.

2.0 Background

Water resource management must integrate environmental, social, political, and technological concerns in order to adequately meet the needs of all stakeholders. Due to delicate ecosystems, arid regions must take these factors into heavy consideration to maintain sustainability. The Kuiseb River Basin in Namibia exemplifies this need (Southgate, Masters, and Seely, 1996, p. 267). This river basin is one of the 12 major ephemeral catchment areas in western Namibia (see Figure E.12) that constantly face harsh climatic conditions, particularly limited rainfall. Stakeholders in this catchment must practice efficient water management and conservation as well as cooperation with each other to sustain their water resources.

2.1.0 Characteristics of Arid Regions

In order to address water management issues effectively, it is essential to understand the characteristics of an arid region. There are three main factors that are responsible for the existence of arid regions and conditions. The most important factor is climate. Climatic conditions in any region, arid, tropical or otherwise, largely determine the abundance of vegetation and the capacity to support the lives of all beings. Next, the geologic and surface conditions are also important in determining arability of a region. This includes geography, geology, soil mechanics, and available vegetation. Finally, available sources of water are important in determining where and how often animals can obtain water, where and which crops can be grown and even where humans are able to reside. These topics and their relevance or effects in an arid region, such as the KRB, must be researched before assessing water management practices.

2.1.1 Climate

Climatic conditions are the leading factor in determining environmental characteristics in an area. The weather not only determines vegetation growth, but can also determine geographical features through erosion via water, wind and heat. Arid regions constantly face limited seasonal change which results in highly limited precipitation and continual exposure to harsh and/or direct sunlight – which may or may not include high temperatures. When the extremities of these two conditions combine with wind, more severe problems arise. Problems such as evaporation and evapotranspiration are products of this adverse climatic combination. Exceptionally high rates of evaporative water loss contribute to the general climatic conditions and cause a reoccurring problem in arid regions: drought. This event frequently occurs when precipitation is particularly limited and evaporation is more severe. The combination of these harsh climatic conditions greatly affects and defines the existence of arid environments.

2.1.1a Seasonal Change, Rainfall and Drought

Precipitation is an invaluable commodity in an arid region. According to Qi and Guodong (1998, p. 374), "precipitation is the basic origin of water resources, which not only decides the water conditions, but also affects the amount of recharge water in the rivers." This vital resource is largely dependent upon geographical location and seasonal weather patterns. It is also unpredictable. Currently, in Namibia, there are observations of changing weather patterns. Large irregularity in rainfall can lead to flooding or drought in arid regions, which poses a serious threat to the environment and its residents. Furthermore, rain in these areas can be highly variable and/or localized, adding to the complexity of the water system. The combination of factors that affect seasonal and/or annual precipitation limitations are a crucial feature in an arid ecosystem (Abahussain, et al., 2002, p. 522).

Most arid climates typically have indistinctive seasonal change, outside of the rainy season. For example, Qi and Guodong (1998, p. 377) described the arid regions in north-western China as being "arid in spring, flooding in summer, water shortages in autumn, and waterless in winter." This example not only supports the concept of limited seasonal variation, but also the fact that precipitation is very limited (see Figure E.3 for rainfall distribution throughout the KRB) In Namibia, for the most part, the rainy season occurs between October and May, with the majority of rain falling between December and March (Ward, et al., 1998, p. 360). Even with this large span of "rainy season," there is still infrequency in occurrence. On average, there is a mere 20 to 40 days of substantial rainfall during the season (Heyns, et al., 1998, p. 53). The winter months of June, July and August generally have the driest weather, which is attributed to the weather systems that build over southern Africa (p. 48).

Rain falls sporadically during the rainy season. However, it is often the case that when rain does fall, it falls in large volumes. During a good rainy season, rivers flood; this is generally the only time that ephemeral rivers in arid regions flow. When heavy rains fall in short time periods, runoff increases because the ground is often not capable of absorbing large amounts of water in a short time. However, if flooding becomes too heavy, problems arise. It is common to see roads and bridges washed out, fences damaged, and farm dams burst due to the high water pressure. These consequences apply to most regions during flooding, but are more susceptible in arid regions. Despite the disadvantages of heavy flooding, the opposite weather conditions are worse and more frequent. It is only these heavy or 'hard' rains which have a significant effect on the ground water supply. When rain falls lightly, it evaporates quickly, leaving a negligible effect on soil moisture and ground water supplies. (This problem is discussed further in section 2.1.1b) Light or 'soft' rains are useful for vegetation growth though. A rainfall of 10 mm will cause effective growth in grasses and will maintain growth for 30 to 40 days too (Olszewski, J., personal communication, 16 April 2003). Both hard and soft rains have their advantages and disadvantages, but either type is desired and vital.

Heavy rains and flooding can cause destruction, but drought can seriously affect entire ecosystems. Drought, which should not be confused with aridity or even desertification, is defined by Le Houérou (1996, p. 137) to be "a deficit of rainfall in respect to the long term mean, affecting a large area for one or several seasons or years, that drastically reduces primary production in natural ecosystems and rainfed agriculture." This event is a constant issue of concern for arid regions. In many areas of Namibia, drought occurs regularly and is a normal event (Diener & Graefe, 2001, p. 39). These droughts are one of the leading factors attributed to the annual water shortages that Namibia and other arid regions face.

In arid regions, not only is precipitation irregular during the rainy season, but it also has extreme variation from year to year, which complicates weather predictions. In Namibia, rainfall is highly variable from year to year and from one region to another but does average 250 millimeters (mm) per year (Diener & Graefe, 2001, p. 35; Heyns, et al., 1998, p. 53). Variability in rain patterns makes future weather prediction difficult. Precipitation studies in Argentina showed a steady decrease in annual rainfall during the first half of the twentieth century, leading scientists to believe that they would be able to predict long term weather patterns (Le Houérou, 1996, p. 139). Unfortunately, this pattern was reversed after mid-century, which voided the previous scientific theories. Extensive research is being conducted concerning the effects of El Niño and La Niña on weather patterns in Namibia. No definite patterns have been found to date (Olszewski, J., personal communication, 16 April 2003).

Recent observations in Namibia indicate that seasons are both migrating and changing (Botes, A., personal communication, 14 April 2003). Rain data collected by the Namibian Weather Bureau on several farms in the KCA partially supports this theory (see figures F.1-F.5 for trends). Migrating weather patterns are beginning to cause problems regarding the normal growing season. Ideally, rain should fall during the warms summer months. Ample rainfall received during this time optimizes growth in grazing areas. Now, as rains occur later, grazing areas are becoming less adequate. Additional observations have been made concerning climatic change in central Namibia. It was common, until many years ago, to receive a heavy shower or two in October, natively known as *Kleine Regenze*it; these showers occurred outside of the normal rainy season (Botes, A., personal communication, 14 April 2003). Recent observations show that these October showers are no longer occurring as frequently or at all (see Figure F.6).

Variable rainfall in arid regions forces people to prepare for the worst conditions in a variety of ways. Since rainfall in arid regions is highly variable, in every degree, it is not possible to accurately predict annual weather patterns. Therefore, when problems such as drought occur, people must react accordingly. The commercial farmers in the KRB, for instance, vary their livestock numbers in order to combat water shortages. Some years may be so dry that they are forced to sell all of their livestock. Unfortunately, a majority of Namibians do not give drought significant forethought. As a consequence, they are often forced to turn to the government for assistance (Diener & Graefe, 2001, p. 40). Lack of preparation, expectation, and even acceptance are views that will continue to contribute to water problems in Namibia.

2.1.1b Evaporation and Evapotranspiration

Coupled with precipitation limitations, evaporation is the second most significant reason for limited water supplies. In many regions precipitation volumes would be sufficient, but the effects of evaporation and evapotranspiration greatly reduce the amount of water available for use (Jacobson, et al., 1995, p. 16). In Namibia, evaporation and evapotranspiration are the leading causes for water problems. Approximately 83% of precipitation in Namibia is lost through evaporation and evapotranspiration (Heyns, et al., 1998, p. 47). Evapotranspiration, according to Webster's Collegiate Dictionary, is the "loss of water from the soil both by evaporation and by transpiration from the plants growing thereon" (Mish, 1988, p. 429). Many complications and difficulties arise due to this form of water loss. On the commercial farms, for instance, it is hard to estimate how much will be available after a good rain since so much water is lost from their surface waters.

Commonly, the evaporation of precipitation in arid lands far exceeds the amount of water that is actually available for use (Ward, 2002, p. 119). (See Figure E.4 for a map of evaporation rates in the KRB. This can all be compared to Figure E.3 to show the significance of evaporation versus annual rainfall.) Evaporation combined with evapotranspiration is the leading cause of water shortages outside of limited precipitation (Beaumont, 1989, p. 17). A number of factors contribute to high rates of evaporative losses. Climatic conditions such as temperature and wind are the most significant factors (Ceballos, et al., 2002, p. 502; Le Houérou, 1996, p.

143). Physical conditions, like soil quality and ground cover also contribute to these losses particularly evapotranspirative losses. Exposed surface area of surface waters also yields high losses via evaporation.

2.1.1c Temperature and Wind

Two additional climatic factors play a large role in arid environments: temperature and wind. Both of these significantly affect rates of evaporation and evapotranspiration (see section 2.1.1b). Moreover, temperature and wind can determine vegetation growth and geographic/geologic conditions. Consequently, changes in either vegetation and/or geology can seriously affect the agricultural sector. Wind also influences climatic conditions.

Arid regions are commonly characterized as hot and dry, but this is not always the case. Temperature is a component of location, more specifically altitude (Beaumont, 1989, pp. 13-14). Many arid regions in the Middle East and Northern Africa, which do not lie too far above sea level, suffer from high temperatures. Conversely, the arid mountain steppes of north-western China, experience much cooler conditions (Qi & Guodong, 1998, p. 373). The KCA, on the other hand, does suffer from high temperatures for most of the year. High temperatures in this region, as in most, are the principle component in rates of evaporation/evapotranspiration. Short winters leave this area exposed to high temperatures for most of the year, compounding the problem (Botes, A., personal communication, 25 April 2003). Furthermore, high temperatures limit grazing vegetation and restrict which breeds of livestock can be raised. For example, it has been found that, in arid regions, many breeds of European cattle do not fare nearly as well as the native breeds that have evolved there.

Wind is often the least significant climatic condition that contributes to aridity, but in Namibia it is very substantial (Botes, A., personal communication, 25 April 2003). First, wind has a considerable effect on evaporation and evapotranspiration rates – particularly when ground cover vegetation is sparse (Beaumont, 1989, p. 17). More importantly, wind controls many weather patterns. Wind speeds and direction are responsible for moving weather patterns. If these conditions are not correct, then a major thunder system may bypass Namibia. Localized rain may also be attributed to wind patterns.

2.1.2 Physical Conditions

In addition to climate, the land's physical conditions are an integral part in the definition and formation of arid regions. The geography and geology of an area are important in determining where water will collect and contribute to the arability of an area. Moreover, the soil mechanics of an arid region, which are partially influenced by geology and geography, significantly affect the possible domestic and economic possibilities. Jacobson, et al. (1995, p. 30) described much of the land in Namibia as "bare, because the harsh climate limits soil development and vegetation growth." Limited vegetation and its restricted growth are very serious issues. Many aspects of poor soil quality are attributed to limited vegetation growth (Le Houérou, 1996, p. 147). Furthermore, there are theories that propose that vegetation – trees specifically – may have an affect on the climate (Olszewski, J., personal communication, 16 April 2003).

2.1.2a Geography and Geology

Geographic and geologic characteristics not only determine the physical appearances – both above and below ground – of any given region, but also water movement (e.g., runoff, groundwater flow). In fact, the geology of an area actually determines the geography, for the most part. Supplementary to geology is hydrogeology, which is the study of subterraneous water supplies. Hydrogeology is an important topic of study in Namibia, particularly in western catchments. Depending on climate, these physical characteristics can determine the success of certain flora and fauna through runoff and subterranean water flow. Geography, geology, and hydrogeology are often very specific in a region. The KRB is excellent example of this diversity, even within itself.

Starting from the upper catchment of the KRB, outside of Windhoek, and progressing down to the coastal waters, the KRB varies from sea level to more than 2000 meters (m) in elevation (Dausab, et al., 1994, p. 2). (See Figure E.5 for a topographical map of the KRB) The upper catchment, which is part of the Khomas-Hochland region, is said to have a similar topography to the Badlands in the north-central region of the US; an endless sea of rolling hills (Grünert, 2000, p. 120). Traveling west, towards the coast, one will see the Gamsberg Plateau and the Great Escarpment. These two formations are considered some of the most "striking landforms in Namibia" (Grünert, 2000, p. 124). These formations act as a mountainous barrier between the Khomas-Hochland and the Namib Desert. In the lower half of the KRB, past the Great Escarpment, lay two distinctive regions. To the north of the Kuiseb River lie the extremely arid and flat gravel plains and to the south of the river lies the beginning of the Great Sand Sea (Grünert, 2000, p. 121). (See Figure E.6 for a general landscape map of the KRB) Due to the highly diverse geography, the productive area of the KRB is quite limited. For the most part, only the upper catchment can be used for agricultural purposes, and this is limited to livestock farming. Differences in rainfall between the upper (350 mm) and lower (0 mm) catchments exemplify this condition (See Figure E.3 for rainfall map of the KRB). Since water supplies are so limited in most areas and the geography is not favorable in many areas, crop farming becomes nearly impossible.

Geologically, the KRB is also quite heterogeneous (see Figure E.7 for a basic geologic map of the KRB). Beneath the rugged mountains, rolling hills and desert landscape lay intricate geological layers. A majority of the KRB is composed of schist, more specifically, Damara mica-schist (Kirchner, J., personal communication, 2 April 2003; SDP 8, 2000, Appendix 3). The southern region of the upper catchment, known as the Gamsberg region, is primarily sandstone and other complexes. On the other hand, the lower catchment has large pockets of granite. These are the main geological formations. Geology in the KCA has the most significant affect on the water table and groundwater flow.

Understanding geohydrology is essential in an arid region. The geohydrology of a region determines where groundwater can be found, and where groundwater will transfer to. In the KRB the geohydrological conditions are localized. For example, the upper catchment is composed of secondary, or fractured, aquifers which restrict groundwater movement (Kirchner, J., personal communication, 2 April 2003). These pockets of water are known as alluvium aquifers. Since the geology in this region is primarily schist, the ground is highly impermeable to water absorption. Consequently, the waters in these aquifers are unable to transfer west, towards the lower catchment, at a significant rate. The lower catchment aquifers are therefore not recharged by the groundwater from the upper catchment. Rain that is received in the upper catchment would only reach the lower catchment via runoff in rivers. As a result, the upper catchment benefits more from rains than the lower catchment – with one stipulation. Residents in the upper catchment must find these alluvium aquifers in order to utilize them, which can be a difficult task. Furthermore, if these pockets are found, they may only hold a small volume of water, limiting their efficacy.

2.1.2b Soil Quality

According to Beaumont (1989, p. 36), arid soils, which are often poor, are largely characterized by climatic conditions, and therefore these soils are easily distinguishable. Since precipitation is limited in arid regions, there is a limited abundance of water in the soil. Rainfall restrictions combined with frequent high temperatures, wind and erosion are the leading natural causes of aridity in soils. Additional problems arise when vegetation is sparse.

The physical characteristics of soil, particularly soil texture, control evapotranspirative rates (Ceballos, et al., 2002, p. 502). Observations made by Ceballos, et al. (2002, p. 510) in the Duero River Basin of Spain showed that, depending on the climatic circumstances, water loss in sandy and rocky soils is equal to water absorption – in other words evapotranspiration occurs almost instantaneously. In the KRB, it has been observed that a single hard rain storm would have to deliver at least 25mm of water in order for the ground to absorb a significant amount of water (Olszewski, J., personal communication, 16 April 2003). If the rainfall is less than this, then it is likely that there would be large evaporative losses.

Vegetation limitations also cause a number of problems that supplement poor soil quality in arid regions. According to Le Houérou (1996, p. 147) the desertification and degradation of land in arid regions is largely due to the minimal ground cover. When ground cover is limited, the soil is highly susceptible to erosion from water and wind. Consequently, the development and frequency of poor soil quality has led to the derivation of scientific labels, *Aridosol* and *Entisol*, which are used to describe the characteristics of arid soils (Beaumont, 1989, pp. 37-38). Aridosol conditions are often extremely dry with a high salt content, resulting in a limited arability for a large portion of the year. Entisols, on the other hand, are prone to high erosion rates and limited water holding capacity. Combined, these two soil types are present in more than 85% of Africa's arid regions. These soil conditions are unable to support successful crops as a result. (See Figure E.8 for a more complex map of the soil diversity in the KRB)

2.1.2c Ground Cover

Vegetation plays a vital role in controlling erosion and water runoff and recent observations predict that vegetation may also affect climate. Nonetheless, humans rely on vegetation for their own survival, like most animals, but also for many economic reasons (e.g., livestock farming, crop farming, etc.). When vegetation is sparse, wildlife and people rely on plants that manage to survive the cruel conditions and that store water (Jacobson, et al., 1995, p. 78; Revilio & Revilio, 2000, p. 26). Many scientists believe that water is the principle determinant in vegetation growth and abundance (Agnew, 1997, p. 609). However, in many cases, the need for water is coupled with soil arability – nutrient availability and soil characteristics.

A cornucopia of ground cover is desired in an arid region,\ but is unlikely. Unfortunately, arid regions are considered to have less than 50% ground cover, on average (Ceballos, et al., 2002, p. 501). Furthermore, it is difficult to estimate the quantity of ground cover due to the highly variable rains in these regions. Section 2.1.1a mentions that 10 mm of rain are needed to espouse noticeable growth in grazing areas. Unfortunately, it is difficult to make long-term predictions towards the frequency of even this small amount of rain. Ward, et al. (1998, p. 361) conducted experiments in the Otjimbingwe region in north-central Namibia which showed that over a short time period few predictions could be made concerning the growth of vegetation. For the most part, when growth predictions are attempted, rainfall can no longer be used as a determinant due to its extreme variability; rather, soil quality is often a more accurate indicator of growth capability.

Recent studies are beginning to reveal a correlation in climatic conditions with vegetation abundance (Olszewski, J., personal communication, 16 April 2003). Observations made in Israel and Venezuela indicates that there is certainly a correlation between the quantity of trees and the climate in an area. Both sites observed an increase in annual rainfall when the numbers of trees was increased. Research is still being conducted to determine whether or not trees are the cause for the augmentation in rainfall. The leading theory behind this observation relates to the evapotranspiration of water and other organic molecules from trees (Occidental Oil and Gas Corp., *Trees*, 1997). It is predicted that this causes the development of a "micro" atmosphere above an area with a higher concentration of trees. Theories behind this event are still being researched and debated. However, there is doubt that, if trees could improve rainfall, in Namibia it would be applicable due to the extreme aridity and current physical conditions (Seely, M., personal communication, 16 April 2003).

The combination of moisture content in the soil and precipitation are the primary restrictions that limit vegetation growth in arid regions. Only one event would improve conditions dramatically: more rain. In the meantime, improved grazing practices and research into different types of vegetation are providing the best results.

2.1.3 Water Sources

There are three main inland water sources: precipitation, surface water and groundwater (Qi & Guodong, 1998, p. 374). Precipitation is the initial source of all water supplies in any region of the world. It is the volumes and occurrences of rainfall and the water 'storage' capabilities of a given region that determine most of the visible physical characteristics of any region. Since arid regions cannot rely on rainfall incidences alone for survival, they must turn to other sources that store precipitation. Rivers and aquifers (i.e., underground water supplies) are the predominate sources of water used.

Surface waters in arid regions are invaluable. Lamentably, they cannot be relied upon heavily due to their instability. Rather, groundwater sources are used. Qi and Guodong (1998, p. 375) state that "surface and ground water comprise a whole system and affect each other, although ground water is more significant in terms of water resources and development." But, like surface waters, groundwater sources are also precarious. Ground water recharge is influenced not only by precipitation levels, but also geology. Certain geological formations lend themselves to higher recharge or larger supplies of ground water (see section 2.1.2a). But, like surface waters, ground water supplies can be unstable. If the geology or annual precipitation is not favourable for high recharge, then it is likely that ground water supplies will be limited. On the commercial farms in the KRB, ground water is the most used and reliable source of water. Despite the abundance and relative stability of ground water, surface water is still easier to manifest and more convenient to use. Therefore, surface water is the preferred water source, despite its drawbacks in an arid region.

All of the aforementioned characteristics, when combined, significantly affect how water management in an arid region is practiced and developed. With drastic limits on water input and extreme evaporative losses, it is difficult to maintain an agricultural operation in the KRB. By thoroughly understanding these environmental characteristics, and their variability, it is easier to understand the difficulties that face the commercial farmers in arid regions.

2.2.0 Stakeholders and their Water Usage

In order to solve general water management problems, one must understand the stakeholders and their water needs. Users of a specific water source are commonly referred to as stakeholders. A brief background description of the main users in the KRB as well as the category of water consumer they fall into is helpful for assessing their roles in water management. Furthermore, general descriptions of each group's known water uses, as well as both the constructive and harmful trends that add to the current state of water problems facing the KRB add to this understanding. These stakeholders are commonly placed into four categories: governmental, industry, domestic use, and agricultural use (Heyns, et al., 1998, p. 113). Each user may fall into one or more of these categories, depending on location, social status and/or occupation. Combined, all of these users must share the limited supply of water in the KRB.

2.2.1 Government

The Namibian government is the primary controller of water in Namibia. As stated in the Namibian constitution, "Land, water and natural resources below and above the surface of the land and in the continental shelf and within the territorial waters and the exclusive economic zone of Namibia shall belong to the state if they are otherwise not lawfully owned" (DRFN/ELAK, 2001, p. 9). Therefore, the government has the power to establish policies for water management, determine prices for domestic and urban water, regulate consumption and limit holding capacity, and use water at their discretion (The Namibian Economic Policy Research Unit, 2002). In the KRB, the government not only plays a role in many water management decisions but is simultaneously involved in domestic, industrial, and agricultural development.

Despite having a young government, Namibia has shown impressive motivation towards the development of water management policies but has encountered some difficulties due to its lack of experience. As a sovereign, secular, democratic, and unitary country, Namibia gained its independence on 21 March 1990 (Republic of Namibia, 2003). Ambition from Namibia's young government system, including past policies on water use from South African control, was strong in the early 1990's, but some of their decisions turned out to be incongruous. A chief geohydrologist at Namibia's Department of Water Affairs (DWA) stated that "there was so much money flowing in from South Africa that we did major infrastructure projects without proper study" (Otchet, 2001, p. 3). Construction of large water systems to nourish this dry country was not planned well enough to take into account the future sustainability of water in Namibia (Forrest, 2001, p. 394). The government chose to implement high-profile water management projects out of initiative, unaware of the future water problems that Namibia would face. To address these past water infrastructure problems, the government is currently organizing an integrated water management reformation proposal, otherwise known as the Draft Water Bill.

One of the government's most important tasks regarding water is its pricing. Water pricing is not only necessary for maintaining control but is also essential in an arid region where water is in a limited supply. Household income is a large factor considered when establishing prices in a region. Due to the diversity of income levels throughout Namibia, it is often difficult to measure wealth (Downs, T., personal communication, 5 February 2003). Normally, people would pay for their water, but there are those who have to work (i.e. walk long distances) to obtain and carry water. There have been attempts to develop fixed water prices and policies in the past, but negotiations continue.

The Namibian government attempted a new water pricing policy in 1995 which presented the fact that "historically, low prices for water have discouraged water conservation" (The Namibian Economic Policy Research Unit, 2002). Other important factors of this policy include how water has become more expensive over time and how these increased prices are not adequate measures for conservation. These factors demonstrate that financially secure groups are less affected by the price of water compared to groups who cannot afford it. "If they [industrial and household users of water] are not sensitive to price changes, particularly businesses where water bills are a small proportion of their total production cost, water tariffs alone will not be an effective tool for demand management" (The Namibian Economic Policy Research Unit, 2002).

Water management is still an important topic of discussion and focus in governmental proceedings. Research is continually being done to develop new policies that concentrate on the amelioration of water management and water use capacity. Moreover, the government is beginning to spotlight individual river catchments, which will result in policy development that is more specific and hence may be more effective in a given area.

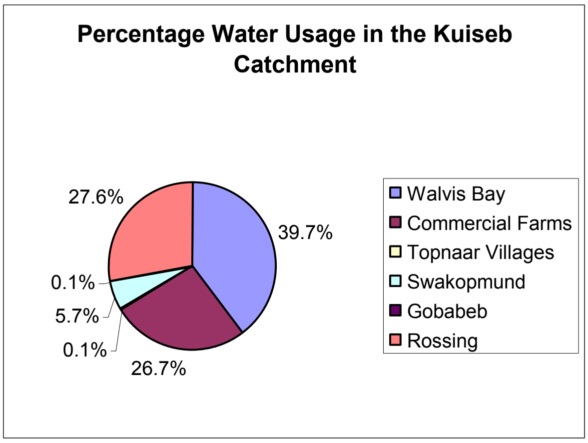

Figure 2.1: This chart represents the percentage of water used by each stakeholder in 1994. The municipality of Swakopmund and the Rössing Mine no longer use the water from the KRB. Use percentages of the Topnaar Villages and the Gobabeb Research and Training Centre are not visible. Their use is almost negligible compared to the other stakeholders in the catchment.

Source: Dausab, et al., 1994, p. 13

2.2.2 Industry

As is the case with any economically active region, industry is an important component of the economy. This is no different for the Kuiseb River Basin. The Kuiseb River is currently the main supply of water to the city of Walvis Bay, which has a prolific industrial economy. Previously, the water from the KRB supported other industries around the catchment. There are four basic industrial uses of water, including heat transfer, materials transfer, washing, and as an ingredient of the product (Vickers, 2001, p. 232). Industrial and economic expansion of cities, including Walvis Bay, increases the nature and growth of businesses there, which directly increases water consumption (Heyns, et al., 1998, p. 113).

Currently, all of Walvis Bay relies on the KRB and the Kuiseb aquifer for all of its water. As Namibia's only deep-sea port, roughly 85% of Namibia's trade is conducted here (Revilio & Revilio, 2000, p. 65; Edgar, 2001). Walvis Bay is one of the most prolific industrial centers in Namibia as well, with a large fishing industry and the Walvis Bay Salt Works, the largest salt producer in Africa. Consequently, Walvis Bay has the highest per capita income in Namibia.

Formerly, the industries in Swakopmund and Arandis, as well as one of largest and most profitable mining operations, the Rössing Uranium Limited, relied on the KRB for their water supplies. As of 2000, after the construction of the Omdel Dam in the Swakop catchment, these users discontinued their reliance on the KRB. The Hansa Brewery in Swakopmund is the only exception. They claim that the water is better in the KRB and that it is necessary to produce a quality product.

Namibia's water supply is continually being overused in all areas and/or aspects of industrial consumption (Heyns, et al., 1998, p. 113). The exploitation of water sources by industrial users in the Kuiseb River Basin, without sufficient recycling or conservation plans, continues to add to the problem of water availability. Although, currently water conservation awareness is on the rise and efforts to apply conservation methods in Namibian industry have been and continue to be taken in order to sustain water supply availability.

2.2.3 Domestic Users

Domestic water use is essential to maintain the subsistence of households in any area (Jacobson, et al., 1995, p. 57). The domestic use of water in Namibia consumes around 16% of the available supply. Of this 16%, approximately 70% goes toward urban use, 28% to rural use, and 2% is used for tourism (Heyns, et al., 1998, p. 113). Generally, domestic water use is described as the processes of drinking, washing, cooking, and bathing. More specifically, a majority of the domestic water use in the KRB relates to the town dwellers of Walvis Bay, the commercial farmers of the upper KRB and the Topnaars, a tribal group of Nama descent living in the lower KRB (Jacobson, et al., 1995, p. 57).

The relative consumption of water amongst each social group is noticeably unbalanced. This is a direct effect of water use and availability in relation to the status and wealth of each group (Jacobson, et al., 1995, p. 57). Water prices negatively affect some people more than others. In most cases, higher income residents use or demand more water than lower income residents in order to retain a luxurious lifestyle (e.g., swimming pools, jacuzzis, and high maintenance estates). The upper class members of society in Namibia consume more than twice the water of middle income residents, more than five times that of low income residents, and over ten times the amount of water that 'squatters' (i.e., poor urban migrant groups) use. When water is easily obtained, more of it is used, and when water is hard to come by, it is valued, saved, and conserved. How water is used domestically is noticeably threatened by Namibia's water shortage.

The largest population of domestic users in the KRB live in the municipality of Walvis Bay, which lies at the end of the Kuiseb River on the Atlantic Ocean. With a population of over 50,000 people, Walvis Bay is Namibia's second largest city (Walvis Bay Corridor Group, 2003, Introduction). Furthermore, it is considered to be one of Africa's "most efficient and best-equipped" seaports (Walvis Bay Corridor Group, 2003, Introduction). According to Dausab, et al. (1994) the city of Walvis Bay used nearly 39.8% (see Figure 2.1) of the water in the Kuiseb River Basin thus making it the largest user of this water supply (p. 13). Walvis Bay, which completely relies on the Kuiseb aquifer, was said in 1998 to have a "constant supply of potable water," (Walvis Bay Corridor Group, 2003, Introduction). Fortunately, this organization realized that under the present circumstances, this is not the case. Current water use rates by Walvis Bay seriously deplete the water levels in this aquifer, despite 1980 predictions of satisfactory sustainability of the aquifer (Jacobson, et al., 1995, p. 12). Further research is being conducted by the municipality concerning the prospects of a desalination facility.

The Topnaars, located not too far upstream from Walvis Bay, are an indigenous tribe that has inhabited the lower Kuiseb River Valley for an unrecorded amount of time (Revilio & Revilio, 2000, p. 25). They rely on the KRB to supply water for domestic tasks as well as for rearing livestock and small-scale gardening (Dausab, et al., 1994, p. 32). Their ancestry traces them to one of the nine Nama tribes, thus making the Topnaars one of the earliest inhabitants of Namibia. Customarily, the Topnaars have been pastoralists who have relied on hunting and gathering methods for survival (p. 26).

Since colonization, the Topnaar peoples have restructured many facets of their lives. Now, rather than being spread throughout the river basin, they are concentrated into 10 small settlements. The population of these settlements includes approximately 400 communal farmers. With the highly industrial municipality of Walvis Bay located at the mouth of the river, many Topnaars have chosen to either move and/or work within the city. They are caught up in a transition era among a technologically based world that relies on high-risk, maximum output industry as opposed to the low-risk survival lifestyles of indigenous people (Ford, R., personal communication, 29 January 2003).

These indigenous peoples have been living in the Kuiseb River Basin long enough to have developed their own water management schemes. Over the long period of time that they have lived in the KRB, the Topnaars have adapted to the intense living conditions, particularly water shortages, of this arid area. They have learned to construct small dams for short-term water storage and simple pits or holes lined with tree trunks known as gorras (Dausab, et al., 1994, p. 3). They have also discerned which vegetation (e.g., the !nara melon) they could rely on which is common to the area as well as a good source of water (Revilio & Revilio, 2000, p. 26). Predominately though, the Topnaars depend on the other available vegetation growing wild in their region for feeding their livestock as well as themselves. In some respects, the indigenous knowledge that they hold concerning water management may far surpass that of any modern scientist. On the other hand, many view their water management strategies as primitive, which continue to lose effectiveness in society today, in relation to the over-use of limited water, despite their success in the past. ELAK and the DRFN still wish to increase their knowledge of these people to better understand their culture and water management systems.

The water consumption by the Topnaars is so small – less than 0.1% of all water in the KRB (see Figure 2.1) – that it is often considered negligible compared to many other KRB users (Dausab, et al., 1994, pp. 13,36). They use 58% of their water supply for livestock purposes and the other 42% for domestic purposes (SDP 8, 2000, p. 54). Since the Topnaars use the least amount of water compared to any other stakeholder group in the KRB, they are affected the most by the limited water supplies. They rely on this small percentage of water for survival and cannot just reduce the amount if prices rise or if supply is restricted, as many industries and average domestic users can. Essentially, the Topnaars are having trouble adjusting to the resource problems that the new, technologically advanced world is bringing with it.

2.2.4 Agricultural Users

Agriculture is the largest industry in Namibia. Consequently, the agricultural industry uses 66% of Namibia's annual water supply (Heyns, et al., 1998, p. 113). There are a variety of farm sizes and types, all of which require different water supplies and refined water management practices. Regrettably, many of these water management techniques are not as efficient and/or conservative as they could be. It is hard to control, understand or standardize the amount of water used relative to the amount of water wasted.

A variety of agricultural practices exist in the KRB. Throughout this basin there are small, dispersed settlements of people. Some of these people are subsistence farmers and pastoralists who work enough ground to support their family minimally, and others are owners or employees of large commercial farms located in the upper catchment. Commercial livestock farming is prominent in the upper Kuiseb area because there is not enough water to make crop farming possible (Dausab, et al., 1994, pp. 16-17). These farms are generally composed of a large tract of land, upwards of thousands of hectares in area. Officially, there are 109 commercial farms in the upper catchment (see Figure E.9 for plot of the commercial farm borders in the KRB); a majority of which are owned by white males living in Windhoek (Seely, personal communications, 18 & 19 February 2003).

Commercial farmers rely on the storage of precipitation to operate their farms. Water is collected using dams and obtained through boreholes, all of which may be located directly on the Kuiseb River, on a tributary, an independent shed or on an isolated underground aquifer. Livestock consume around 90% of the total water, with the remaining 10% used for gardening and domestic purposes (Dausab, et al., 1994, p.

iv). When applicable, tourists and/or guests on these farms use a small percentage of the domestic water supply. All of these farmers rely on relatively large water supplies to run their respective facilities. Unfortunately, the water management and distribution systems on these farms can be wasteful and outdated.

2.3.0 Water Policy in Namibia

The importance of water policy and control varies throughout different regions of the world in relation to diverse climates and relative water availability. Water, along with many other responsibilities, is managed primarily under governmental control. In Namibia the development and implementation of water policies are important contributing factors to the stability of its population as well as its environment. The structure of Namibia's water policy scheme dates back to its pre-independence years. Its earliest modern water control management plan was the South African water Act 54 of 1956, which is still the predominant water policy in Namibia today. This outdated method of water management is becoming less effective as it ages. To counteract this reality of diminishing water control effectiveness, other acts, bills, and proposals had been and continue to be planned, debated, and formed. The most significant reformation bill is the Draft Water Bill, still in the development process. Understanding the existing policies, acts, government and community-based organizations of water management throughout Namibia, the KRB, and other comparatively arid regions throughout the world is an important basis for analyzing the goals and both positive and negative effects of water management schemes.

2.3.1 Act 54 of 1956

Having only been an independent country for about thirteen years, Namibia still retains the centralized, unified and antiquated South African Water Act No. 54 of 1956, introduced by the Republic of South Africa during the pre-independence period, when Namibia was called South West Africa (Heyns, et al., 1998, p. 30). Act 54 is the primary water regulation policy in Namibia. The basic components of Act 54 include: the existence of a Minister to advise all matters/aspects relating to the use of water in Namibia; the establishment of a Water Board; the control, ownership and use of private and public water sources; water resource protection; the development of a State water scheme; the control/prevention of pollution; the production of both boreholes and wells; control over weather modification; and the establishment of general water-related provisions when necessary. Unfortunately, however, this water control policy is currently out-of-date. Relative to other, more advanced acts this document does not provide the necessary current environmental, social, and economic assistance to water administration in Namibia. Water supplies are running low and the reorganization and development of the water management system in Namibia continues to advance. The improvement of this system will remain necessary for guaranteed future water availability in this arid country.

Many aspects of Act 54 do not compensate for the changes in demand, population, and technology that have occurred since it was established about 47 years ago. This not compounded view of a country's water resources, whose regions differ in rainfall as well as water retention, causes predicaments in water management strategy and regulation to specific territories, which require different water needs. As a result of its expired nature, numerous problems have and continue to rise up (Heyns, et al., 1998, p. 30). For instance, the act has limited control over borehole numbers and water abstraction rates (Schachtschneider, 2002, p. 860). This lack of water accessibility, use, and control fuels one of the major debates among the stakeholders in the KRB. Even though there are some restrictions on water use, they are not necessarily as effective as they could be. For example, it is difficult for Act 54 to penalize offenders of these water laws. Also, "it [Act 54] does not recognize the natural environment as a user of water nor as a provider of essential processes and services" (Heyns, et al., 1998, p. 30). Another flaw of Act 54 is the absence of stipulation promoting future water sustainability directly. Overall, this act shows insufficient control over water resources with minimal concern for the outlook of Namibia. In addition, some highly populated districts, in contrast to other rural areas, experience unequal claims pertaining to fresh water availability. The KRB is a prime example of not only a small territory in Namibia as a whole, but as an unequal mixture of environmentally different water retention areas as well as population densities and locations.

This ongoing situation of water related problems without proper regulation adds to the rate of water depletion in Namibia. In simple terms, more water is used every year relative to the amount replaced. However, the future promise of an improved water resource management system in this circumstance is still attainable. Several modern acts, policies, ministries, and committees have been and continue to be set up in order to contribute to the regulation of water aside from Act 54 itself.

2.3.2 Draft Water Bill

The Draft Water Bill, the most up-to-date and influential water-related proposal in Namibia, is still in the formation process, but it looks promising in relation to its most recent developments concerning the progression of Namibian water management as well as its predicted effectiveness to its regional and community-based, water-related ideals (DRFN/ELAK, 2001, p. 9). For continued progressive effectiveness, administrative and political management of all water resources – including aquifers, catchments, sub-basins and wetlands throughout the country – and consideration for sharing policies with the surrounding countries is essential (Ministry of Agriculture, Water and Rural Development [MAWRD], 2000, p. 21). When completed, this bill will continue to implement and standardize water management practices for the betterment of Namibia as a whole, and primarily for its multiple, diverse water catchment areas.

The Draft Water Bill will offer multiple approaches, including more effective localized plans, as well as public and community-based involvement/decision-making toward Namibian water management, which already are considerable improvements compared to Act 54 (DRFN/ELAK, 2001, p. 9). This bill also proposes the formation of an independent water service regulator with standard management and tariff institution responsibilities. When implemented, it will control the amount of water used while standardizing water prices. To reach its full potential, this bill must be implemented gradually while focusing more on rural areas instead of taking a centralized, urban perspective. These provisions will add suitable policies for specific parts of Namibia on a communal and regional basis. "The water policy seeks to address the issues of reforming existing institutions, adoption of new water management practices, and to introduce internationally accepted principles and norms for better water resources management" (p. 2).

Water policy makers of Namibia, government officials, are now focusing more on regional based projects, proposed by the Draft Water Bill, that are more appropriate for the environmentally diversified areas of the country. In the KRB's case, the Environmental Learning and Action in the Kuiseb (ELAK) project was introduced in July 2001 to form a basin management committee. More specifically, the ELAK project is a pilot study that is connected with the Draft Water Bill. The ELAK project is directed by a non-governmental organization (NGO), the Desert Research Foundation of Namibia (DRFN) and funded by the European Union. Currently, ELAK is the only project focused on and administrated in one of the 12 ephemeral river basins in western Namibia (DRFN & ELAK, 2001, p. 2). Its purpose is to establish and address water sharing conflict resolution procedures throughout the Kuiseb River Basin, and its goal is "to achieve equitable access to and the sustainable development of fresh water and other natural resources by all sectors dependent on the basin in order to promote long term social and economic development" (p. 1). There is particular focus on developing water management plans that equally include each stakeholder and provide a common platform for decision making. If successful, the ELAK project will be used as a model for similar community/stakeholder-based, water-related projects in Namibia.

2.3.3 Policies, acts, and government bodies

Along with Act 54 and the Draft Water Bill, many other policies, government bodies, boards, and organizations pertaining to water availability and sanitation, either nationally or community based, have been or are in the process of being developed (Heyns et al., 1998, pp. 30-32). Policies form out of necessity, and, in Namibia's case, a limited fresh water supply and inadequate water control management scheme.

Water policies in Namibia are either physical committees or written documents, known as acts, created to benefit all aspects of water needs to the highest degree possible (Heyns et al., 1998, pp. 30-32). Committees or NGOs often formulate other water policies that tend to be more focused or regionally based. For example, the DRFN created the ELAK project to assist the stakeholders and residents to agree on water management strategies. Some Namibian water policies hold more political and authoritative weight than others do. Nonetheless, they all can be considered positive steps toward water-related improvement or even an up-to-date complete revision of Act 54 all together.

Government policies/acts and government bodies are interrelated and affiliated to one another in a political web. Act 54 is the nucleus and other acts, policies, or committees branch out from it into more focused areas. The successful coordination among certain water related sectors in Namibia, including the Ministry of Agriculture, Water and Rural Development (MAWRD), the Ministry of Health and Social Services, the Ministry of Regional, Local Government and Housing, the Ministry of Works, Transport and Communication, the Ministry of Mines and Energy, and the Ministry of Environment and Tourism, is necessary for the prosperity and improvement of the water management situation (MAWRD, 2000, pp. 21, 22). Cooperation with similar sectors in neighboring countries is also important. Organizations, either governmental or private, have been created as the result of acts or policies previously administered, and/or have been responsible for generating new policies or acts. Regardless if a government body formed an act, or vice versa, the inter-relation of policies, acts, and government bodies contributes to the further regulation, education, control, and conservation of water resources throughout Namibia.

The MAWRD is the most important member of Namibian water-related policy making agencies. It was designed during the post-independence years, among other things, to aid in the focus of water management in Namibia (Republic of Namibia, 2003). This federal agency contains departments of both Agriculture and Rural Development and of Water Affairs. The Department of Water Affairs holds the bulk of managerial and developmental responsibilities concerning water (MAWRD, 2000, p. 22). Under the Department of Water Affairs, there are Directorates for both Resource Management and Rural Water Supply. Achievements by these departments include the improvement to the water supply for a minimum of 300,000 people and a N$50 million project that created 900 water taps using over 800 km of pipelines throughout Namibia. Effective socio-economic development is achieved through proper management and water utilization through the Ministry of Agriculture, Water and Rural Development (Republic of Namibia, 2003).

The Water Supply and Sanitation Sector Policy (WASP), which is responsible for setting up numerous other policies, acts and committees, is the basis for policy framework in Namibia (Heyns et al., 1998, pp. 30-32). It, like the MAWRD, was developed during the post-independence years, and is responsible for the establishment of the Directorate of Rural Water Supply and the Water Supply and Sanitation Coordinating Committee (WasCom). These two organizations are smaller, more focused areas of water supply management for Namibia in conjunction with the larger, more authoritative water management scheme. The MAWRD is also responsible for developing the Namibia Water Corporation (NamWater), Namibia's largest water sanitation company and water distributor. NamWater has been responsible for providing the bulk supply of water in Namibia since 1998, as a result of the NamWater Act of 1997 (Heyns, et al., 1998, p. 39). WASP obtains provision policies for improved water supply, improved sanitation, and irrigation throughout Namibia.

2.3.4 Regional Comparison

The water situation in Namibia is not unique. Other arid and semi-arid regions throughout the world suffer from similar problems. Comparing the water policy practices of other governments (e.g. South Africa, regions of the Middle East, and parts of the U.S.) to those of Namibia will help to offer different approaches to the same fundamental water management problem(s). Namibia can learn and benefit from the accomplishments as well as mistakes of these other areas.

South Africa has better water supply and control procedures than Namibia for basically two reasons. First, the natural availability of water in South Africa is more plentiful. Secondly, South Africa has been organized for a longer period of time compared to the young Namibia. To regulate water supplies, South Africa has implemented two new national water management acts (Moyers, 2002, p. 200). The Water Services Act of 1997 and the National Water Act of 1998 (NWA) both emphasize a decentralized approach to water management while involving public participation and decision making to aid the policy. The NWA, guarantees each citizen approximately 25 liters per person per day under the “basic needs reserve.” This reserve holds water primarily for drinking, food preparation, hygiene, and other human needs. Also, the government can implement water charges, if necessary, to improve the equitability and amount of conserved water. These new water management policies are considered among the most advanced in the world. Although South Africa naturally receives and retains more water, it can still act as an influence toward developing better water management practices for Namibia.

Semi-arid and arid regions in the Middle East suffer similarly to Namibia in terms of water shortages. In these regions water is being used at a rate three times faster than it is being replaced (Peninsula Water Reserves Depleting, 2001, p. 38). It is predicted that fresh water resources will run out in approximately twenty years. This situation is the result of highly disproportionate consumption, and a population increase of five times the original predicted calculation made 50 years ago. Proposed solutions include the general planning and development of new alternative-water-source-based systems and the improvement of water efficiency practices for some agricultural sectors. Water management officials in the Middle East are working to develop fertile agricultural and environmental greening systems that use unconventional water resources such as saline and brackish water. The water crisis in the Middle East will continue to rise in seriousness if effective regulation is not enforced.

Arid parts of California and Nevada, two states in the western region of the U.S., can be compared to Namibia in regards to climate, population growth, and water availability. The increasing population of this region puts stress on the current water management system, while threatening the future existence of fresh water as a reliable resource. California's future scheme of water management plans for the "development of additional water supplies in conjunction with water conservation, groundwater recharge, recycling and water transfers" in order to sustain its current water sources (California Officials Discuss Water Conservation and Management, 1995, pp. 1-2). Nevada currently relies on the Colorado River for most of its water, the result of a political arrangement from the 1920's (Every drop has its price, 1991, p. A28(2)). This system lost effectiveness over time, and Nevada is considering a new, controversial plan. With the assistance of an existing state law, which allows areas to 'claim unused water,' Las Vegas plans to initiate the Co-operative Water Project (CWP). This project proposes to obtain water out of a forecasted large, deep, and untouched aquifer. The CWP is considered both 'uneconomic' and 'dangerous' according to some critics (p. A28(2)). "Environmentalists say that removing water from the aquifer could turn an already arid land into a dustbowl, and threaten the few springs in Death Valley in California" (p. A28(2)). This water resource option must be looked into more before it is implemented to avoid future water problems.

Water policies from different areas of the world can provide information as well as suitable knowledge and appropriate water management practices for Namibia to consider. Namibia may benefit from ideas that these policies present. Also, Namibia can simultaneously avoid future predicaments by studying the effects these policies had on their respective surroundings – environmentally, economically, and socially.

The KRB is influenced by a broad, out-dated national water policy that continues to loose effectiveness as time goes on. Act 54, the continued development of the Draft Water Bill in progress, the ELAK project, NamWater, and the pricing of water all affect the water management situation in the KRB in some form or another. These acts, policies, agencies, sectors, distributors, comparisons, and topics all contribute to the improvement of water management in the KRB and will continue to apply water management strategies that will correct water-related problems in the future existence of this basin.

2.4.0 Water Management Schemes

Scientists and governments in Namibia as well as other arid regions have developed innovative technologies to combat the problem of insufficient water supply. These technologies have sought new sources of water, more efficient water distribution and transfer systems, and even water recycling. The scientific community has classified these technologies as either sustainable or non-sustainable. Sustainability of fresh water in the African context is ensuring a sufficient supply and protecting it from over-use and from contamination over the long term (de Villiers, 2002, p. 51). It must be management under the strain of growing populations and the uncertain effects of global warming too. Both non-sustainable and sustainable forms of technology can manage water. Unfortunately, people in poorer areas often choose non-sustainable methods for their cheaper cost, even though these technologies may worsen the problem of water shortage.

2.4.1 Non-sustainable Technologies and their History

Namibia implements three primary non-sustainable water management technologies and practices to combat water shortage problems. One of the government's most important goals is to rectify inequities in water distribution. Before the country gained independence, the effects of apartheid resonated in water distribution. White settlers used their political power to entrench water resources in white hands for commercial farming purposes, to the disadvantage of the black majority population (Manzungu, 2002, p. 927). In 1990, only 50% of the rural population had access to a reliable source of safe drinking water (Lange, 1997, p. 301). After Namibia gained independence in 1990 and made widespread water availability a priority, the federal government implemented a variety of new water sources and distribution systems for bringing water to poor rural areas. Many of these new water sources, however, do not provide water in a sustainable manner.

2.4.1a Boreholes and Dams

The two most popular methods for obtaining water in Namibia are boreholes and dams. Boreholes are a simple technique for abstracting groundwater and are widespread throughout the country. Dams store surface water runoff for consumption and groundwater infiltration. People throughout Namibia use a combination of these methods for obtaining and storing water, but unfortunately, they cannot sustain future use.

Boreholes (i.e., holes drilled into the ground for abstracting water) benefit users with ease and cheap costs but can lead to aquifer deterioration. They are widely used because they require little capital, maintenance, or skilled workers to supply the water, making them immensely popular in Namibia. More than half of Namibia's water was supplied from groundwater six years ago and the fastest growing users of water – rural and urban households and communal sector livestock – rely disproportionately on groundwater (Lange, 1997, p. 309). While the large aquifers of Namibia supply a substantial amount of fresh water to users, the exploitation of them negatively impacts surrounding environment and the groundwater reserve. Signs of land degradation, such as loss of biomass, have been observed in areas within 1 square kilometer surrounding individual boreholes due to overgrazing of grassland (Forrest, 2001, p. 394). The mass construction of boreholes throughout much of the eastern and central regions of Namibia during the 1990s amplified the rate of subterranean watershed depletion, increasing the potential for desertification.

The lower KRB provides an excellent example of aquifer deterioration. Walvis Bay and the Hansa Brewery in Swakopmund consume approximately two million cubic meters of water per annum more from the system than can be naturally replenished (de Villiers, 2002, p. 56). If this continues, the river basin faces desertification. This cheap, simple, yet limited source of water is not an appropriate choice for prolonged and sustainable water abstraction.

Aquifer deterioration affects a different stakeholder group as well. Commercial farmers located in the upper KCA complain that many of their boreholes have become unproductive due to reduced groundwater availability (Amoomo, et. al, 2000, p. 2). Aquifers remain the primary source of water for all stakeholders of the KRB and thus have a high degree of economic and ecological importance (p. 59). The high groundwater abstraction rates combined with insufficient rainwater have convinced commercial farmers that natural aquifer recharge and local water retention is improbable (Dausab, et. al., 1994, p. 4). Because of this, they build dams on their farms to supplement and recharge boreholes. There is no information on the recharge of aquifers in the upper KRB, however, and it is heavily disputed that these farm dams actually replenish groundwater supplies (Dausab, et. al., 1994, p. 6; Angula, et. al., 2000, p. 1). Dams also cannot provide a long-term solution to water storage. Siltation and sedimentation reduce dam capacity and limit the ability of water to infiltrate the groundwater system (Dausab, et. al., 1994, p. 7). In addition, water evaporative losses in these dams can be higher than abstraction volume (Angula, et. al., 2000, p. 11). However ineffective these dams may prove to be on a local level, commercial farmers in the upper KCA insist that their retention of water has no effect on downstream stakeholders (p. 21). Nevertheless, only 13% of the runoff from the upper Kuiseb reaches lower catchments (Amoomo, et. al, 2000, p. 2). The downstream users that rely on floodwaters to recharge alluvial aquifers may experience a severely detrimental effect from these upstream dams (Dausab, et. al, 1994, p. 21).

Fortunately, other techniques aimed at ground water replenishment have seen some use in other regions of Namibia. During 1997, NamWater treated and injected approximately 300,000 cubic meters of water in a production borehole over a period of six months with good results: no clogging, or evaporative loss, and a recovery rate of nearly four times the norm for boreholes (van der Merwe, 2000, p. 379). This technique enables borehole users to sustain ground water use and reduces the risk of desertification. Future use of boreholes must include borehole recharge to prevent depletion of aquifers and ensure a sustainable fresh water yield for the future.

2.4.1b Inter-basin water transfers

A high-cost, high profile form of water distribution that Namibia employs is inter-basin water transfers (IBTs). IBTs manipulate river basins in an attempt to reconcile the problems of water distribution in parts of Namibia. They are defined simply as the transfer of water from one geographically distinct river basin to another, or from one area of the river to another (Snaddon, et al., 1998, p.159).

Israel began using IBTs in the 1970s when the country faced a desperate water shortage (Snaddon, et al., 1998, p.162). Israeli engineers pumped water from Lake Kinneret into depleted wells in another part of the country. This water then flowed underground and along an aquifer until the water levels in other regions of the country increased. The project was an enormous success because it used existing infrastructure and negated evaporative losses.

Namibia actively employs IBTs in several areas of the country because they are effective and productive. In an arid climate where evaporative loss of water constitutes a significant concern, IBTs that employ underground piping of water make sense (Lange, 1997, p. 301). The Namibian government is currently considering pumping water from the Okavango River as an additional source of water for the more arid regions to the south (p. 302). In the KCA, commercial farmers routinely pump water from one area of their farm to another or even from a neighbor's farm to their own (anonymous, personal communication, March 16 2003). However, the negative effects of IBTs cause concern to those both up and downstream from the water source.

Inter-basin water transfers pose a threat to the biodiversity and socio-political sustainability of the river catchments. They break down natural bio-geographical barriers of river basins, allowing for the transfer of non-native organisms, which contributes to genetic manipulation, and the introduction of exotic species that may overrun native species (Snaddon, et al, 1998, p. 165). In South Africa, numerous new species have invaded the ecology of Lake Gariep due to the Orange River Project, an IBT. In addition to these ecological concerns, water transfer systems pose a threat to human cultures. Because IBTs may occur across national or regional political boundaries, they cause the potential for conflict (Ragab, 2000, p. 30). If, for example, an upstream donor decided to halt the progress of water transport due to a local drought or a political agenda, downstream recipients would be at their mercy if they wished to continue receiving water from the IBT.

The Okavango River scheme exemplifies the drawbacks of IBTs. Namibia wants to divert water from the river, which runs along part of its border with Angola, and pump it uphill through a pipeline towards Windhoek (Thirst: Botswana and Namibia, 1997, p. 48). However, this river feeds one of the most delicate ecosystems in the world: the Okavango Delta. Two schemes are being considered, and the bigger one would draw off 1% of the water flowing through the river. Namibia's water department insists this is insignificant. Botswana disagrees and calls for more study before any decision is made.

Using IBTs requires extensive research to assess the ecological impact of genetic transfers, the possibility of preventing these transfers, general environmental impacts, and socio-economic studies of involved parties to prevent the threat of water wars. Only then could IBTs sustain the water needs of Namibia and the KRB.

2.4.2 Sustainable Technologies

New sustainable technologies, in contrast to unsustainable ones, cause no resource depletion and offer long-term sources of water. Recent developments in the scientific community have seen greater application of these technologies to arid areas in Namibia. They hold great promise for combating the problems of desertification and seek continued study to evaluate their appropriateness to Namibia.

The DRFN has conducted studies on the feasibility of using fog precipitation over the Namib Desert in the lower KRB as a sustainable water source. Fog water precipitation in that area exceeds rainfall, making it a more reliable source of fresh water (Shanyengana, 2002, p. 252). (See Figure E.10 for a chart of the average fog days in the KRB) In addition, the ground water aquifers of the Namib Desert experience periods of high salinity, making them an undesirable primary source of fresh water. The supplementation of ground water with fog water would dilute the source and optimize it for continuous consumption (Shanyengana, 2002, p. 258). Fog water utilization in areas of Chile, Peru, Ecuador, and the Crimean Peninsula has succeeded in providing clean water without depleting ground or surface water sources (Eckardt, 1998, p. 2595; Kogan & Trahtman, 2002, p. 232). Furthermore, no negative environmental effects have been reported. This method requires no skilled workers to maintain the technology, except for routine cleaning of the collection plates, and may be set up nearly anywhere within the desert. While expensive, the continued use of this technology could efficiently provide water to some Namibians.

Desalination, while expensive, may also supplement the potable water source in the KRB (Namibia Resource Consultants, 2002, p. 17). Walvis Bay and Swakopmund lie along the coast of the Atlantic Ocean, a prime location for a desalination plant, and would not require extensive water transfer systems to distribute the water to the end users, as the basin is relatively small. In addition, the almost limitless supply of salt water could provide fresh water for years to come (Ragab, 2000, p. 31). Unfortunately, the brine waste must be carefully disposed of or sold to other parties (such as the salt works plant) to reduce the negative environmental impact. Moreover, the cost of desalinated water exceeds the cost of tapping groundwater by three to five times, and the high capital and maintenance costs deter many investors from choosing this source of water (Assaf, 2001, p. 24; Ragab, 2000, p. 31). Finding an energy-efficient method for desalination may reduce the cost and reluctance in using desalination.

Other alternative sustainable technologies that provide or distribute fresh water have reduced total water consumption without negative environmental impact or pollution. For example, the DRFN is refining drop emitters that carry droplets of water directly to the roots of plants, eliminating water loss due to evaporation during irrigation or surface watering (de Villiers, 2002, p. 56). Another alternative, wastewater reclamation, supplies fresh water without depleting any existing sources. Windhoek is the only city in the world to recycle all of its wastewater, including sewage, into drinking water (p.55). Treatment plants, at maximum output, provide more than eight million cubic meters of water per year. Treatment processes cost less than desalination, the water may be used for irrigation without any harmful effects on crops or soil, and the water it offers has no negative health effects or contaminants (van Leeuwen, 1995, p. 238). The only drawback to waste water reclamation may be purely psychological: when proposing the idea to anyone, they almost inevitably express disgust (p. 239).   Overcoming this obstacle would ensure an inexpensive, safe, and sustainable source of water for many areas of Namibia in the future.

2.5.0 The Roles of Capacity Building and Conflict Resolution in Water Management

The holistic approach to water management is seeing more application in Namibia. Integrated water management (IWM) theorizes that successful policy and reform implementation requires political will and facilitation, but technical, economic, environmental and social considerations are also important (Seppala, 2002, p. 367). It seeks to promote the development and management of water to maximize the economic and social welfare in an equitable manner without compromising the sustainability of ecosystems (Tapela, 2002, p. 993). This strategy requires strong stakeholder participation in both policy development and implementation. Effective and sustainable stakeholder involvement requires capacity building and conflict/dispute resolution strategies. Experts agree that capacity building and conflict resolution are the best ways to meet the sociological needs of all the stakeholders and ensure their socio-economic sustainability (Downs, 2001, p. 525). ELAK has identified an urgent need for shared involvement in the decision-making process of water management in the KRB (DRFN/ELAK, 2001, p. 2; Dausab, et. al, 1994, p. 8). Once stakeholders have an equal capacity to influence water policy, they may settle conflicts caused by sharing water, improve the efficiency of water use and management, and reinforce environmental protection (Tapela, 2002, p. 993).

2.5.1 Capacity Building

The concept of capacity encompasses the skills of cooperation, compromise, and effectiveness assessment with information (Downs, 2000, p. 612). Capacity building utilizes current resources and infrastructure, proposes new infrastructure and management, and only requires teams trained in participatory rural appraisal, workshop moderation, and goal-orientated project planning (Kroll & Kruger, 1998, p. 321). Another benefit of the program is the costs, which fall far below that of technological management and public assistance to drought-stricken areas. Information is the foundation for empowering and encouraging stakeholders to influence management policy (van Rooyen, 1998, p. 294). Empowerment in this context consists of information flow between both the community and researchers. A combination of local knowledge and experience with scientific techniques allows a much more informed approach to the problem. ELAK aims to develop a common vision for water management in the KRB that includes the views of all stakeholders, which may only be accomplished by equal participation in policy-making (DRFN/ELAK, 2001, p. 2). If everyone accepts responsibility for the management of a shared resource, the project will possess long-term socio-political sustainability (van Rooyen, 1998, p. 292). Thus, building capacity amongst stakeholders is vital in order to successfully manage water resources.

Capacity building is a continual, multi-step procedure. It requires the successful completion of five processes (van Rooyen, 1998, p. 295). First, the diagnostic phase, has the sole objective of developing an understanding of the problem. This is often accomplished by holding workshops with all user groups, including scientists, NGOs, youth, women, and the elderly. Focus is placed on locating available information resources, both local and scientific. Next is the conceptualization phase. It aims to form consensus on the actions to be taken. Methods to implement this objective include developing strategies and hypotheses in collaboration with all stakeholders, answering any questions stakeholders may have, and clearly defining each participant's responsibilities. The actual physical work is done in the next phase, execution. Its goal is to take action by the approved strategies while maintaining linkages with all stakeholders throughout the project. Onsite research is also an important aspect of the execution phase because it gives stakeholders a feeling of ownership to the plan, which increases their sense of responsibility for the project's success (p. 292). During the execution phase, the evaluation phase simultaneously assesses project participation, acquired indigenous knowledge, and possible further projects to consider (p. 295). The final phase of capacity building is diffusion, in which project leaders institutionalize the information obtained from the project. This information is disseminated to both stakeholders and the general public to aid in further research and understanding of the problem.

Several stakeholder groups in Namibia have successfully utilized capacity building methods for managing their resources. Namibia's Sustainable Animal and Range Development Program (SARDEP) has used these methods with communal farmers and service institutions to build capacity for land development management in the past with considerable success (Kroll & Kruger, 1998, p. 315). In Tanzania, a partnership between the Tanzanian government and the NGO WaterAid helped villages provide themselves with improved water supply and sanitation systems (de Villiers, 2002, p. 52). The villages also raised their water funds from nothing to US$40,000 in five years. These same cooperative strategies have worked with water management in Mexico and may find useful application in Namibia as a whole (Tim Downs, personal communication, 4 February 2003).

2.5.2 Conflict Resolution

The Kuiseb River is shared by a number of user groups with different needs, uses, and priorities for the water. Conflicting theories of social authority, precedence, and dominance can lead to failure of water management in any area (Crow & Sultana, 2002, p. 709). Misunderstandings and disagreements between parties must be resolved before a conceptualized vision for water management throughout the basin can materialize (Dausab, et. al., 1994, p. 8). Therefore, conflict resolution skills are important to develop amongst stakeholders as part of the capacity building process.

Resolving conflicts, disputes, and debates requires a great deal of compromise, cooperation, and informed understanding among parties. It necessitates impartial but informed mediators to find viable compromises to the inevitable differences in management ideas that involve all stakeholders and will work in the future. Stakeholders must believe that new policies will deliver better outcomes over time and that the overall process and its implementation is fair, reasonable, and realistic for the stakeholders to embrace policy change (O'Meagher, et al., 1998, p. 232). Policy makers and other government officials require even more encouragement to welcome change. Powerful institutions may resist restructuring, even if stakeholders call for it. As an example of this resistance, Zanzibar's leading politicians and decision-makers have acted against the wishes of the citizens and opposed a new national water policy that calls for privatization of water supply (Seppala, 2002, p. 375-376). Also, a new national water policy for Kenya, launched in 1999, has met fierce opposition from the existing government authorities. Government-owned businesses are reluctant to hand over ownership of physical assets and institutional reform has yet to happen. Only widespread public demand for change and building all stakeholders' capacity to make modifications will enable these reforms to take place.

Disproportionate water consumption and political power complicate the process of negotiating a uniform vision for water management in the KRB. The densely populated coastal areas of the lower catchment require more water for domestic and industrial use than the other stakeholder groups (Dausab, et. al., 1994, p. 8). Consequently, populated areas such as these not only consume and need more water, but they often have significant political clout which can play a major role in water management development (Mollinga, 2001, p. 737; Tapela, 2002, p. 998). In addition, many of the officials that develop management schemes reside in more urban areas, adding to partiality (Tapela, 2002, p. 998). This problem is not unique to the KRB. Rural people in Zimbabwe have complained that they are often ill-informed because of locale difference as well (Manzungu, 2002, p. 932). As a result, it is often noted that rural participation in decision making dwindles since many feel that their needs neither are nor will be addressed (p. 932). Stringent water management policies that incorporate the needs of all parties are the only solutions to these geographic problems (Downs, 2001, p. 525).

Education is one of ELAK's goals because only informed stakeholders will push for basin-wide management changes. ELAK disseminates information through workshops, publications, interviews, and meetings with farmers unions in the upper KCA (Botes, personal communication, 24 March 2003). Slowly, farmers have gained an awareness of the project, its aims, and the need to jointly participate in management schemes (Gramm, personal communication, 25 March 2003). It is ELAK's hope that all stakeholders will soon realize the urgent need to conserve water and work together to manage their water resources.

Water resource management must be put into the context of social, technological, and environmental issues in order to attain sustainability. A team knowledgeable in these issues may greatly facilitate a negotiation process involving all stakeholders of the Kuiseb River Basin that will ensure cooperation and sustainability.

3.0 Methods

To achieve our goal of developing water management recommendations for the Environmental Learning and Action in the Kuiseb project (ELAK) and the Kuiseb catchment area (KCA) stakeholders, we conducted research in two primary phases. The first, data collection, used archival research, formal interviews, and direct observation to gather information pertaining to water management strategies on the commercial farms in the upper Kuiseb River Basin (KRB). With this information, we fulfilled our two research objectives – characterizing the commercial farms' water management and assessing farm dams' impact on downstream users. Phase two, data analysis, used statistical tests and qualitative analysis to find patterns in water management practices amongst the stakeholders. The conclusions we made from these analyses were used to compose recommendations regarding water management for ELAK and the KCA stakeholders.

3.1 Research Objectives

The needs of all the stakeholders must be fully understood in order to begin assessing the problem(s) with the current water management strategies in the KCA (Marshall & Rossman, 1995, p. 44). ELAK did not have an adequate needs and problems assessment concerning water use, supply, and management among the commercial farmers in the upper Kuiseb River Basin (Seely, personal communication, 20 February 2003). A majority of the problems that stakeholders have stems from insufficient water distribution and water management schemes (DRFN/ELAK, 2001, p. 5). Based on our preliminary research of the upper catchment conducted before our project and the existing information that the DRFN has collected concerning the remaining users, we developed a set of objectives and methods that we felt would best enhance the current information resources.

Two comprehensive research objectives aided in accomplishing our goal of developing water management recommendations for ELAK and the KRB stakeholders. The first objective was to characterize the existing water use, supply, and management practices on the commercial farms in the upper KCA. Our second objective entailed the development of a more complete understanding of the farm dams in the upper KCA and their impact on downstream users. The research methods that we selected to complete our project were chosen based on the criteria of convenience, accuracy, validity, and stakeholder participation.

Objective 1: Characterization of Water Use, Supply, and Management Practices on Commercial Farms

Method 1: Archival research

Archival research served two primary purposes: first, to study the current knowledge on the KRB, and second, to prepare for the formal interviews. We started our interview preparation by selecting farm owners to survey, and then determined what information we needed about them. A majority of this research included reading various DRFN publications in order to decide which information about commercial farms remained unknown. Specific questions were added to our interview protocol, which were targeted to reveal these unknown facts. In addition, archival research helped us ascertain representation of each user group. There are officially 109 farms in the upper Kuiseb and we were able to survey the managers of 16 of them. We chose these farms based on farm type (e.g., livestock, livestock/tourism), farm size (e.g., <5,000 hectares, >5,000 hectares), farm location within the upper catchment (e.g., upper sub-catchment, lower sub-catchment) and farm location with respect to the course of the Kuiseb River (e.g., on the river, on a major tributary, on neither). The Namibian Ministry of Agriculture and Rural Development (NMARD) aided us by supplying the information (e.g., farm types, distance from main roads) that was necessary to make our selections. This assistance was combined with the examination of maps as well. Our selection process tried to ensure that we included a number of farms from each farm type within the stakeholder group (see Table 3.1 for our site selection data).

With aid from the NMARD we further narrowed our selection to those farmers who have been known to be cooperative with scientific research and particularly with the ELAK project. This selection limitation was necessary in order for us to easily complete our research objectives. The farmers whom we chose were among those who are aware that scientific research is necessary to further improve the current water management issues in the KCA. Many other farmers in the KCA are reportedly reluctant to cooperate. Some fear that controversial information from research interviews may leak back to the government and may result in negative consequences for them. Moreover, there are some farmers who feel that their current water management practices are quite sufficient and have no desire to change the way they operate their farms (anonymous, personal communication, 25 March 2003).

Due to our time frame, we chose not to use simple random sampling. The probability of representing all interest groups would have been very low with such a small sample size because we were limited to working with cooperative farmers. Thus, our data would have inaccurately represented any common and/or unique features of interest groups. When needed, we interviewed some farmers in Windhoek instead of on their farms due to limited availability of field transportation.

Farm Name	Farm Location	Subcatchment Area	Farm Type	Size
7	On the Kuiseb	Lower	small stock	large
15	On the Kuiseb	Lower	cattle + hunting	large
8	On the Kuiseb	Lower	small stock + tourism	large
9	On the Kuiseb	Lower	cattle + hunting	large
6	On the Kuiseb	Upper	Cattle	large
5	On the Kuiseb	Upper	Cattle	small
2	On a tributary	Lower	tourism + cattle	large
3	On a tributary	Lower	Cattle	small
11	On a tributary	Upper	Cattle	large
10	On a tributary	Upper	cattle + hunting	large
14	Off water	Lower	Cattle	small
4	Off water	Lower	Cattle	large
16	Off water	Lower	cattle + hunting	large
13	Off water	Lower	hunting + cattle	large
12	Off water	Upper	Cattle	small
1	Off Water	Upper	tourism + cattle	large

Table 3.1: Site selection data (names deleted for confidentiality purposes; numbers denote database order)

Method 2: Interviews and direct observation

We chose to use interviews for field data gathering rather than other methods for confidentiality assurance, convenience for the farmers, and the ability to directly observe some of the farms. Meeting with farmers on a personal basis rather than through written questionnaires or group workshops ensured that we obtained responses from them, achieved confidential conversations, and received direct feedback about our questions from the farmers. In addition, we chose to utilize direct observation to supplement interviews for clarification purposes. According to Whyte (1984, pp. 27,94), direct observation helps supplement statements made during interviews. When, for example, we commonly encountered a concern shared by a large percentage of the commercial farmers, we could validate and/or better understand the problem by observing it ourselves (e.g., dry dams, locations of water sources). Photographic documentation and video recording, used with permission, aided us in presenting the farmers' concerns to ELAK and the other stakeholders. We felt that direct observation was not possible in every case, however, as it would have been very time consuming and/or not feasible to travel to all of the farms in the time that was available to us.

Prior to implementing our field methods, we prepared three documents to aid us in the interview process. First, we composed a one-page overview of our project that highlighted the purpose and relevance of the study (see Appendix A, p. 95). The second document was a letter of recommendation from the Namibian Agricultural Union (see Appendix A, p. 96). This letter was written to support our research and to assure farmers that conducting our study benefited ELAK and the DRFN in their goal of capacity building. We also developed an interview protocol (see Appendix A, p. 97). This document ensured that each interview effectively contributed to achieving our research objectives. It contained research questions, objectives for the interview, and "icebreakers" to begin the conversation. In addition, we administered preliminary pilot interviews at two farms: one located in the upper Kuiseb and another just outside the catchment. By conducting these introductory interviews, we were able to determine the appropriateness and quality of our interview protocol before we furthered our study. We obtained feedback on the effectiveness of our interview and adjusted our protocol and process accordingly. The information obtained from the pilot interview conducted on the farm within the catchment was also used for our data analysis.

Once the interview protocol format had been finalized and approved, we traveled to seven commercial farms in the catchment and interviewed four farmers in Windhoek. The surveying process took several days each week for four weeks over the course of our eight weeks in Namibia. From these interviews and observations, we characterized the farm type and water use, supply, needs, and management practices on these commercial farms. This included water conservation methods and aquifer recharge information, when applicable. Together, these data helped us identify how water management practices in the upper KCA may affect the rest of the watershed. Information from all these individuals was continuously entered into a spreadsheet and analyzed to attain preliminary results during the course of our field research period. Once we had amassed information from all selected subjects, we analyzed these data and incorporated the farmers' perceptions and opinions into our recommendations.

Method 3: Improving the DRFN's Geographic Information System (GIS) Database

Essentially, a GIS database is an integrated, useful mapping system that can co-ordinate information, data, facts, figures, and geographical locations. The DRFN uses a GIS database to map the KRB farms, but lacked current information on the commercial farms of the upper KCA. During the information-gathering phase of our project, we collected data to update the DRFN's existing GIS database. Using the data we received after applying our chosen methods for the first objective, we simultaneously added this information to the GIS database. Specifically, during the course of interviews, we obtained and added information pertaining to the farm type (e.g., guest ranch, livestock, game farm, and/or farm school) to the database, as the DRFN had requested. The maps we produced using the GIS database enabled us to make comparisons and contrasts between catchment areas and stakeholder groups, thus facilitating the process of developing recommendations for the entire KCA.

Objective 2: Assessing the Impact of Farm Dams on Downstream Users

It was essential for us to understand possible impacts of commercial farm dams on downstream users in order to develop water management recommendations for the KRB stakeholders. Archival research and interviews were used for the data-gathering phase. We compared opinionated responses obtained during interviews with farmers about their dams to previous assessment studies done by the Department of Water Affairs, the DRFN's Summer Desertification Program, and the Hydrogeological Association of Namibia. Furthermore, we considered known effects of these dams as well as other possible sources (e.g., land management, rainfall) for increased or decreased runoff to downstream users when conducting our assessment. Each of these alternative sources that affect runoff was investigated through archival research as well.

3.2 Data Analysis

After understanding what water resources farmers in the upper KRB need to maintain a sustainable farming operation, we compared the water management practices of upper catchment users with those of the other users. We used qualitative analysis to quantify the various responses and uncover patterns of commonality amongst stakeholders. Following the interview and questionnaire period, we categorized responses by interest group (i.e., farm type) and location for easy comparison. Two methods of statistical analysis were then used. First, we used type I analysis of variance (ANOVA) tests. Second, we used unpaired two-tailed t-tests to determine the significance of any discrepancies among interest groups through their responses (Whyte, 1984, p. 116).

Understanding trends in water use places water distribution and management problems within the context of water use amongst stakeholders. Using data from the DRFN, we compared water use for each user group with one-way ANOVA tests to determine the significance of differences among these groups. The water use data included as much past history as possible to determine the trends in water use over the years.

We felt that the type I ANOVA test was the most appropriate statistical test for our interest group analysis for several reasons. First, because our data were unmatched, we were able to compare the differences among group means with the pooled standard deviations of the groups (GraphPad Software Inc., 1998). Second, the error (i.e., the difference between each value and the group mean) was random, making this statistical test sensible. Additionally, a one-way ANOVA test compares the means of three or more groups, so a tiny P value (the probability that the differences between groups is random) - clear evidence that the population means are different – can be achieved even if the distributions overlap considerably. Finally, a type I ANOVA test compares three or more groups defined by one common factor. We defined the groups by farm type, which we felt most influenced how water was consumed and managed. Type I ANOVA does not assume randomly selected groups from an infinite (or at least large) number of possible groups, and because our sample was not selected randomly, this test was ideally suited for our data analyses.

The unpaired two-tailed t-tests, on the other hand, were ideally suited for comparing the upper and lower subcatchments of the KCA for several reasons. First, our data were unpaired. This test can powerfully compare the difference between means with the pooled standard deviations of the two regions. Second, the error was random, which made this test a good indicator of difference between the two regions. Finally, the unpaired two-tailed t-test compares the means of only two groups. Differences in means may indicate that the two regions are independent of each other, thus influencing water management decisions in these areas.

3.3 Recommendations

To accomplish our goal of furthering research and understanding of water management in the upper KRB, we needed to present our information to both the stakeholders and the general public. Information dissemination also ensured that the survey participants received our results and contributions to the ELAK project. At the end of our study, we worked with the DRFN and compiled a brochure of our results and recommendations. Information in this deliverable was submitted with complete confidentially and respect for the farmers whom we interviewed.

The DRFN will help us distribute the brochure to the farmers and farm unions that may or may not have participated in the study, as well as government officials, other political authorities, and other stakeholders. It will also be made available to the general public through the DRFN library. We hope that this brochure will offer stakeholders an informed glimpse at our study and the ELAK project as well as encourage future participation in ELAK's work.

4.0 Results and Analysis

The data we collected show that the commercial farmers in the upper Kuiseb catchment area (KCA) use similar water management techniques with respect to others in the same subcatchment and commercial operation; however, these practices could use improvement. These findings are based on interviews with 13 farmers over the course of four weeks. We sampled 16 farms out of the official total of 109 farms in the upper Kuiseb River Basin (KRB), (see Figure 4.1). Our findings include both quantitative and qualitative data (see Appendix B for our farm database). Many of the quantitative results describe factors affecting water infrastructure (e.g., boreholes, dams) while the qualitative results explain opinions regarding water use and management. Through our analyses of the different variables - farm types, locations, sizes, and ages - we found patterns of commonality for water infrastructure and opinionative responses between interest groups. To better outline these differences, we chose to organize our results by the types of water infrastructure and the major factors that influence them, as well as conservation methods that farmers practice and the possible effects of farm dams on all downstream users.

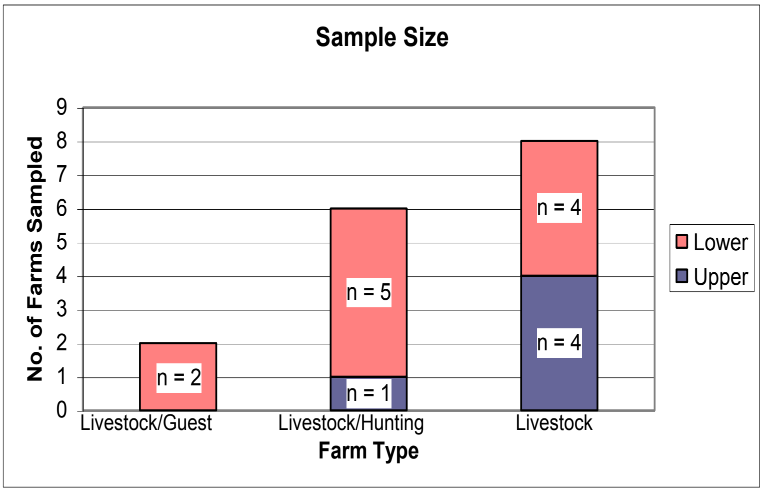

Figure 4.1: Sample Size

4.1 Factors Affecting Water Infrastructure on Commercial Farms

We found that farm location and farm type appear to influence the number of active and inactive boreholes and dams per farm in the upper KCA, although farm type's affects are not statistically significant (Figures 4.2 and 4.3). We were unable to make any conclusive statements concerning the variables of farm size and farm age and their affect on boreholes. Boreholes and dams are important indicators of two

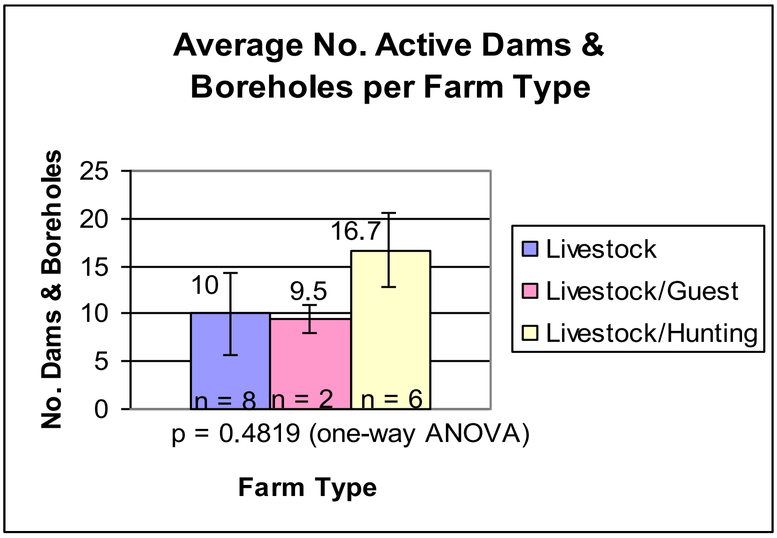

Figure 4.2: Average number of active dams and boreholes per farm type

aspects of our water management characterization objective: water consumption and water management effectiveness. For example, a large number of inactive boreholes may point to high water consumption or poor location choices for the boreholes. Understanding and evaluating water infrastructure on the commercial farms was necessary for the water management characterization process.

We found that the upper subcatchment farms had more active and less inactive boreholes than the lower subcatchment farms (Figures 4.4 and 4.5). We speculate that water input (i.e., rainfall) affects the drilling of boreholes for two reasons. First, according to measurements made by farmers, the lower subcatchment receives less rain than the upper subcatchment (Figure 4.6). Perhaps because of this, farmers in the

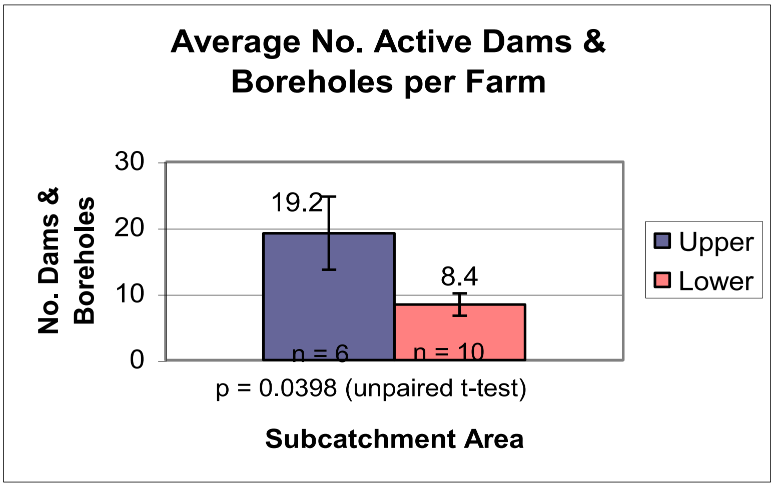

Figure 4.3: Average number of active dams and boreholes per farm for each subcatchment

lower subcatchment rely more on groundwater drawn from boreholes than the upper subcatchment farmers, who rely more on surface water. These higher abstraction rates could render boreholes inactive in the lower subcatchment more quickly than in

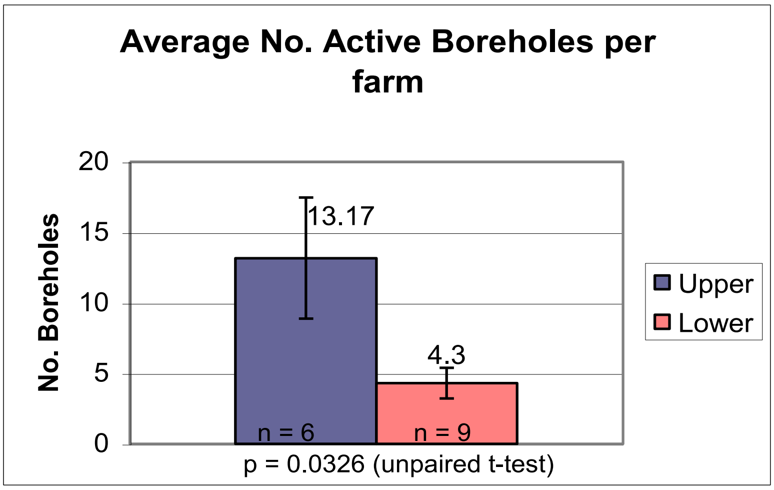

Figure 4.4: Average number of active boreholes per farm for the subcatchment areas

the upper subcatchment. In addition, the geology of the lower subcatchment may be less conducive to the use of boreholes. Since the lower subcatchment geology has a large amount of granitic and gneissic formations, it is possible that groundwater in the

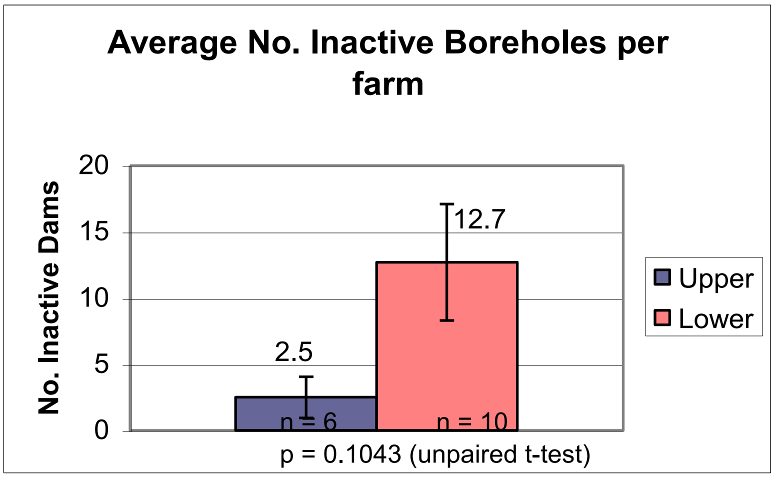

Figure 4.5: Average number of inactive boreholes per farm for each subcatchment

lower subcatchment may flow underground toward the lower catchment. The water table west of the escarpment is closer to the surface than in the eastern region. Because of this, evapotranspirative losses are greater in the lower regions of the KRB. These factors may render boreholes inactive at a quicker rate than in the upper

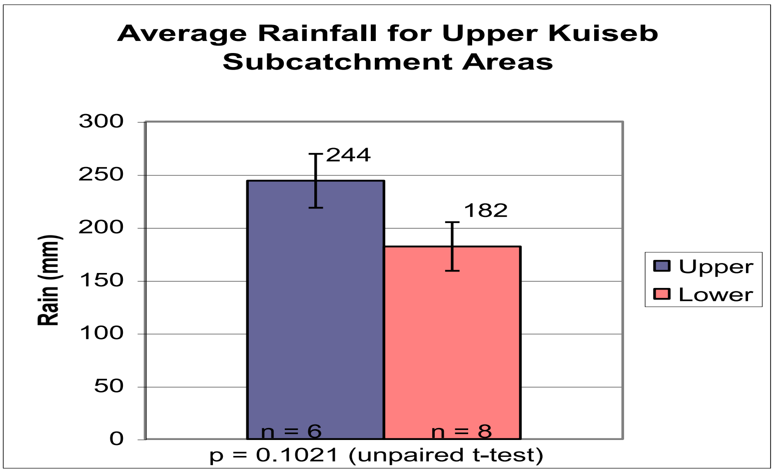

Figure 4.6: Average rainfall for upper Kuiseb subcatchment areas

subcatchment area. Farm topography may also be a factor. Topography can not only influence weather patterns, but also where boreholes (and even dams) can be implemented. Unfortunately we were not able to study this possibility to great depths. All of these reasons may explain why there is a difference between the number of boreholes among farms. These results require more study for to support these conclusions.

Farm type may affect the number of boreholes per farm as well. As seen in Figure 4.7 and Figure D.5 (Appendix D), livestock and livestock/hunting farms appear to have a greater average number of active and inactive boreholes than livestock/guest farms. We found two explanations for this observation. First, seven of the eight strictly livestock farmers we interviewed stated that they left their water troughs and dams available for game to use. They said that if they didn't allow game to water there, animals such as zebras and baboons would break pipelines and fences in order to gain access to water. Since both livestock/hunting and only livestock farms allow game to water on their farms, it is hard to make conclusions on water consumption because water troughs are not metered and farmers lack accurate

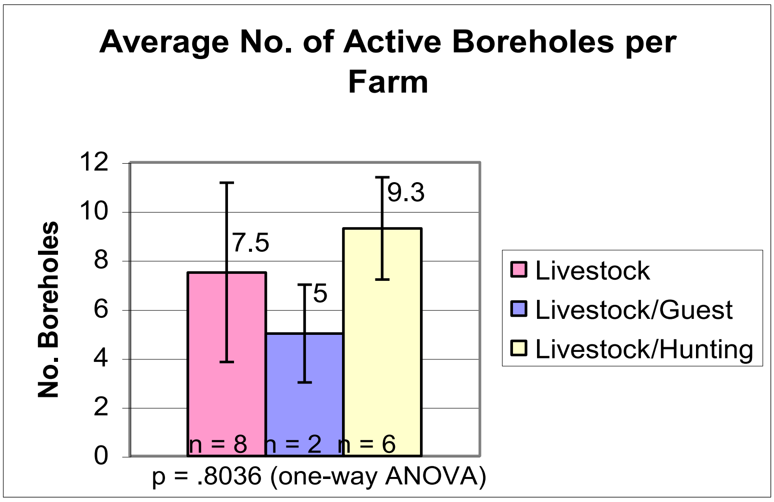

Figure 4.7: Average number of active boreholes per farm for each farm type

population data on game. Furthermore, migratory patterns of animals does not allow for accurate analysis. Second, cattle populations consume more water in total than human populations do per farm. According to officials at the Ministry of Agriculture, Water and Rural Development (MAWRD) cattle consume an average of 45 liters of water per head per day. Comparatively, many farmers claim that they and their guests only use 20 to 40 liters per day (for drinking, bathing, cooking, etc.), even though the MAWRD estimates human on farms at 200 liters per day. Farms generally stock a large number of cattle, while tourist numbers on guest and hunting farms are generally quite small. For example, one livestock/hunting farm averages 30 to 40 visitors while maintaining 150 to 200 cattle every year. A strictly livestock farm of comparable size, rainfall amount, and location in the river basin stocks 1000 head of cattle each year. Assuming cattle and people may consume roughly similar amounts of water per day, the ratio of people to cattle is small enough to be almost negligible on all of these farms. These factors may contribute to livestock/hunting and livestock farms having approximately the same number of active and inactive boreholes (their main water sources), and a greater number than livestock/guest farms (see Appendix D for these graphs). It is also possible that that livestock/hunting farms have strong water sources on their farm, which is why they may have expanded into an operation that has high water demand. Conversely, livestock/guest farms may have expanded into tourism because their water infrastructure is not as strong. Since guests require less water than livestock it would be a logical direction to expand.

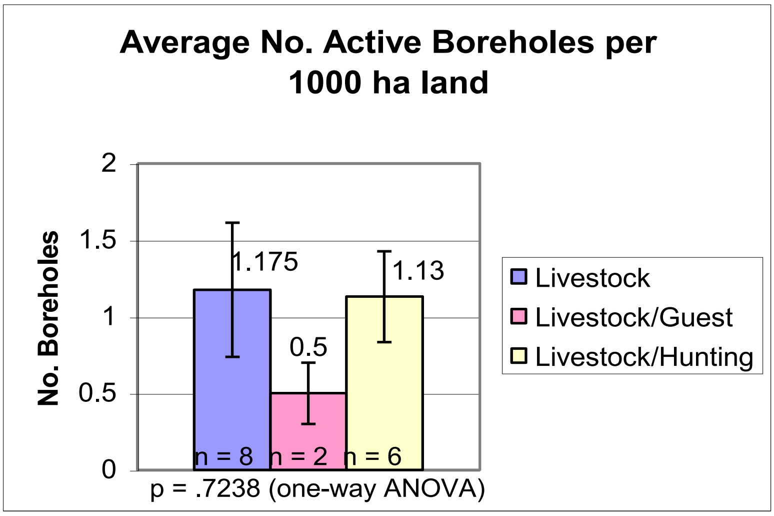

Figure 4.8: Average number of active boreholes per 1000 hectares of land for each farm type

Water consumption rates between farm types may, however, differ, which makes making conclusions about water infrastructure difficult. According to one farmer, some types of game prefer to drink from dams and natural water sources rather than man-made troughs. This may reduce the amount of water consumed by game that the farmers provide to them since the animals prefer the open water, which is not monitored. Since most livestock farms do not allow their herds to water from open waters, it may appear that they are consuming more water. Our data, however, do not indicate this, and further research is needed to confirm the actual water consumption rates on livestock and livestock/hunting farms. In addition, more accurate population information on wild game would greatly help estimate water consumption on all farms. When considering our findings, it must be kept in mind that our sample size was quite small, (especially with only two livestock/guest farms) and thus our results could change if we interviewed more farmers (e.g., we could obtain statistical significance for Figure 4.5).

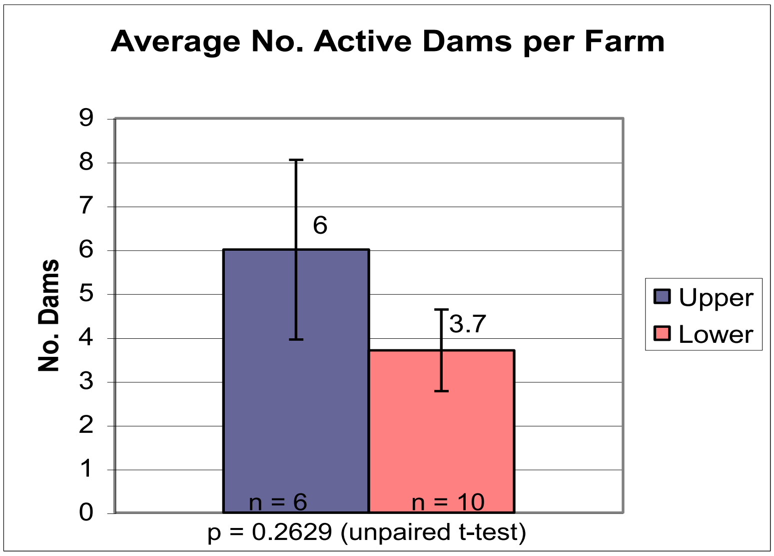

Figure 4.9: Average number of active dams per farm for the subcatchment areas

Farm size did not factor greatly into water infrastructure or farm type. We found no relationship between the size of farms and their commercial operations.

When comparing the number of active and inactive boreholes per 1000 hectares (ha) of land to the raw numbers of boreholes, there were no distinguishable differences among farm types or locations (see Figures 4.7, 4.8 and 4.9 as an example comparison). Because farmers rotate their livestock throughout camps and stock their farms based on farm type and water input, farm size does not affect water consumption or water infrastructure. Costs of drilling multiple boreholes could be an additional factor that limits the number of boreholes per farm.

Farm age may play a role in water management and infrastructure on commercial farms. It can also help determine how diversification into tourism affects water consumption and management. Age data can indicate the number of changes made to infrastructure due to diversification, improved water management practices, and simple wear-and-tear of infrastructure due to the natural aging process.

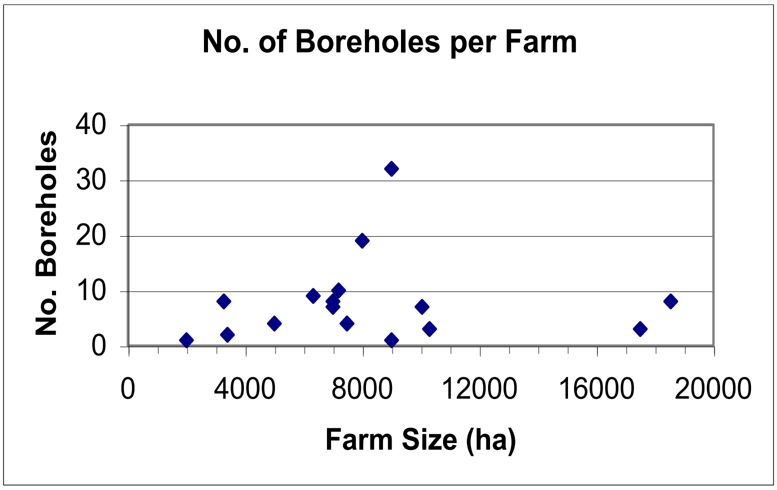

Figure 4.10: Number of boreholes per farm with respect to farm size

Unfortunately, most farmers do not keep detailed historical records of changes to water infrastructure, nor do they often have access to records from the previous owners. While they are generally knowledgeable about how long the land has been in their family's possession (if that is the case), they often do not have information about the previous owners or when the uncultivated land became used for farming purposes. Therefore, it is difficult to distinguish water infrastructure advances by the time period in which they were made. Because of this, we were unable to make substantial conclusions on how age factors into the drilling of boreholes on commercial farms. Although we see indications of a diversification trend from interview responses, we cannot say how expansion into tourism will affect water consumption or management on commercial farms without supporting age data.

We found no noticeable differences between the number of active or inactive dams on farms with respect to farm location, type, size, or age. We offer a number of reasons for this. First, while the average annual rainfall amount is greater in the upper

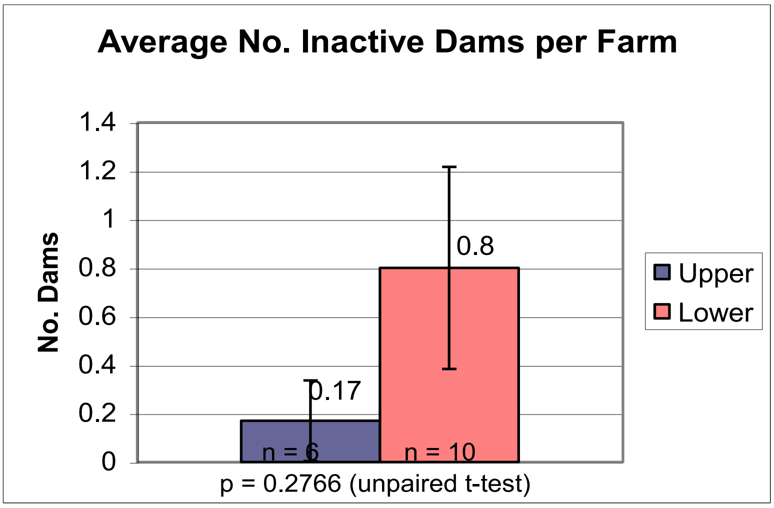

Figure 4.11: Average number of inactive dams per farm for the subcatchment areas

subcatchment, the vegetation in this area is also more abundant. Vegetation reduces runoff, which in a sense could equalize the effect of the greater rainfall. The lower subcatchment has a higher percentage of water runoff but less rain, so when the factors of rainfall and runoff are combined, both subcatchments withhold approximately equal amounts of water through the use of dams on average (Figures 4.10 and 4.11).

Furthermore, most farmers do not directly use dams as their main source of water, but rather as a recharge method for their boreholes. Water consumption and use (which is affected by farm type) therefore have a minimal effect on the building and use of dams. This is supported by the absence of observed correlations between the number of boreholes and the number of dams per farm. Farm size also appeared to have no effect on the number of dams per farm for the same reasons that it does not

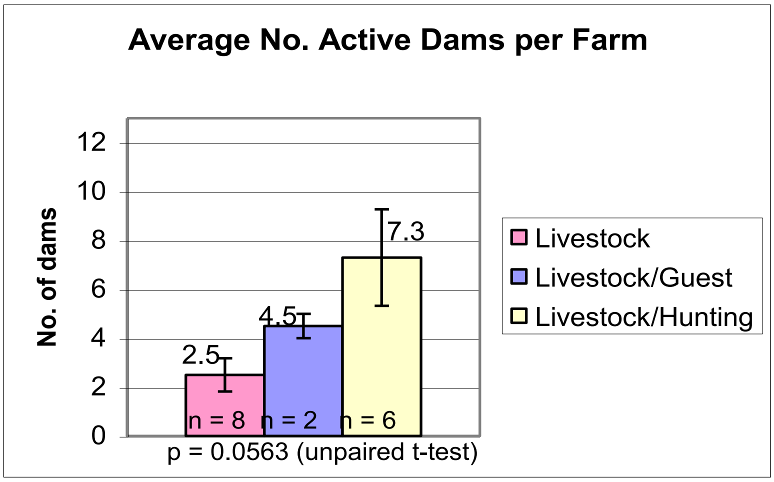

Figure 4.12: Average number of active dams per farm for each farm type

affect the number of boreholes per farm (see Figures 4.12 and 4.13 for comparison). However, farm age could factor into the number of active and inactive dams. Older farms could have a greater number of dams, especially inactive ones (due to the high costs of maintenance). Unfortunately, most did not know the exact ages of all their dams. Many farmers said that the dams on their property were built by previous owners at unknown times. Since we were unable to accurately ascertain farm and dam age for most farms, we cannot conclude whether age plays a role in the number of dams per farm.

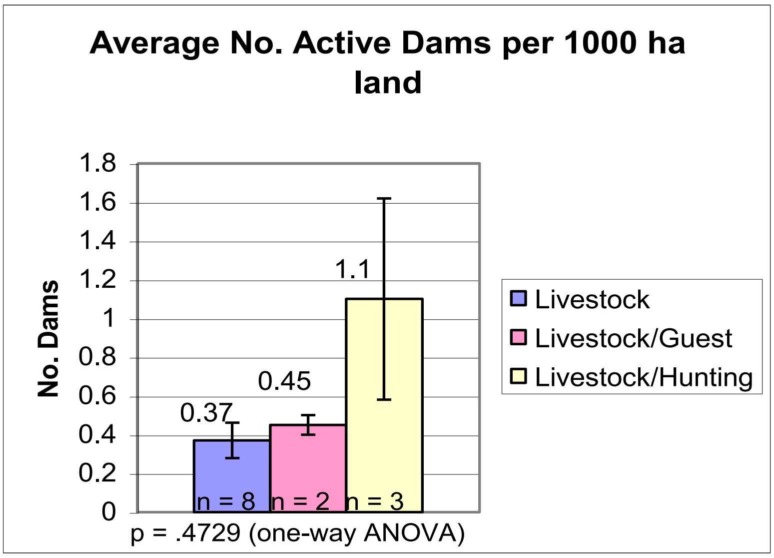

Figure 4.13: Average number of active dams per 1000 ha land for each farm type

4.2 Water Conservation and Dam Maintenance Efforts

We found that most water conservation and dam maintenance efforts are limited by costs. As a result, these techniques can be inefficient and/or unsuitable for their purpose. Lack of water-conserving technologies and maintenance options increase the risk physical losses in domestic use as well as high evaporative losses in water storage facilities.

It was found that farmers practice water conservation as a 'lifestyle' instead of an effort aided by technology regarding domestic use. Automatic troughs, which reduce overflow, are the most common implementations of conservation technologies in livestock corrals. However, only two of the farmers surveyed recycle 'grey' water or use technologies that reduce their domestic water usage (e.g., low-flush toilets, low-flow showerheads). One farmer uses low-flow showerheads and low-flush toilets to reduce domestic consumption as well as drip irrigation to reduce evaporation in her garden. Another farmer shades the water behind his dams with a wire matrix to reduce evaporation. None of the other farmers used water conservation tactics. Eight of the thirteen farmers responded that domestic water needs were 'negligible' compared to the needs of commercial operations, and/or that there was not 'any water to conserve.'

Regular maintenance of dams is time-consuming and expensive. Because of this, some farmers remove silt and sediment from behind dams every two to three years, while others only every 15 years. Some farmers do not maintain their dams at all. As a consequence of normal use, dams retain silt and sediment, which reduce dam capacity, increase evaporative losses, and diminish the dam's ability to replenish ground water sources.

4.3 Effects of Water Infrastructure and Possible Causes for Groundwater Shortages

Water infrastructure on commercial farms seems to have a small but insignificant effect on all downstream users. Hydrogeology, dam maintenance, rainfall, and land management all influence surface water runoff and groundwater recharge. With this in mind, more research is needed before forming final conclusions on the cause of water shortages in the lower KCA.

Boreholes do not appear to directly affect any downstream users, but they are important indicators of water management on a local level. Because the aquifers of the upper and lower catchments do not connect, ground water dynamics of the upper catchment should not influence the aquifers in the lower catchment (Kirchner, J., personal communication, 2 April 2003). Both active and inactive boreholes have an indirect effect on surface water runoff to downstream users though. For example, if boreholes draw water from adjacent dams (as we suspect) then these dams will require more water to continue the recharge process, thus reducing runoff to downstream areas. Boreholes are important indicators of water management on a local level only, as dry ones may correlate with high water abstraction or poor location. It is, however, important to assess how and when farmers choose to drill new boreholes. One farmer, for example, chooses the location of his boreholes with a divining rod, while several others consult geohydrologists before drilling. Knowing how farmers choose to locate their boreholes can aid in making recommendations to farmers on how to drill and use boreholes more economically by determining the best locations for drilling and pumping water from boreholes.

All of the farmers surveyed believe that their dams have no effect on any downstream users. There are four reasons supporting this belief. First, the Department of Water Affairs (DWA) stated that dams have no significant effect on others downstream (van Langenhove, G., personal communication, 12 March 2003). Second, the president of the Hydrogeological Association of Namibia (and former head of Geohydrology at the DWA) has found that flood waters can overrun dam walls and flow to downstream users late in the rainy season (Kirchner, J., personal communication, 2 April 2003). These intense rains are also the only rains that have a recharge effect on the aquifers in the lower catchment. Third, most of the commercial farm dams continue to gradually gather silt and sediment from lack of maintenance, which reduces their capacity and increases water runoff (Dausab, et. al., 1994, p. 7). Fourth, rain in the river basin is highly localized, and even without farm dams in place, normal rainwater would not reach downstream users (Kirchner, J., personal communication, 2 April 2003; van Langenhove, G., personal communication, 12 March 2003).

However, three of the 13 farmers interviewed complained that farm dams upstream negatively impact them. Two of these farmers were located in the lower subcatchment and the third was located in the upper subcatchment. These three farmers claim that there are numerous large dams upstream that withhold too much water. Because many farmers lacked accurate data concerning their dam sizes, we cannot verify this response. We also were not able to interview all of the farmers directly upstream from these three individuals to obtain information about their dam sizes to support this theory. If we had been able to interview more farmers in the catchment instead of just the cooperative ones, we may have found that some farmers had illegally large dams. There is scientific evidence that farm dams can retain most water from early floods (Kirchner, J., personal communication, 2 April 2003). A complete assessment of how farm dams impact downstream users has not yet been made and could clarify the debate. It is interesting to note that farmers did not exchange information concerning many their water management strategies with each other. Perhaps sharing more ideas and knowledge among themselves would alleviate this discrepancy between the perceived impacts of farm dams.

Many of the farmers surveyed believe that the cause for the decline in water availability in the lower KRB is due to high ground water abstraction by coastal users, better land management in the upper catchment (the prevention of overgrazing reduces runoff) and decreased rainfall over the last 30 years (Botes, A., personal communication, 11 April 2003). Since the 1980s, water consumption by all sectors of Walvis Bay (i.e., industrial and domestic) has steadily increased along with the city's population (Department of Water, Waste & Environmental Management, 2002, p. 16). Annual rainfall data from the Weather Bureau on five farms in the upper KCA (three in the upper subcatchment, two in the lower) suggests a decreasing trend in rainfall throughout the upper KCA. The record of time in which measurements were made ranged from 24 to 78 years, and four of these farms experienced a noticeable decrease in average annual rainfall over the recorded time periods, as indicated in

Appendix F. However, it is currently unknown if the KRB follows patterns of rainfall that exceed 78 years. While this rainfall information is compelling, we cannot conclude whether this trend is transient or will continue indefinitely.

The water shortage problem experienced by all users of the Kuiseb cannot be solely attributed to the water management and farming practices of commercial farmers upstream. Very few new dams are being built in this region and the existing capacities of the dams reduce each year, which increases runoff. Dams are not the only factor in water flow to downstream users. Improved land management practices such as rotational grazing have reduced overgrazing and runoff. Also, a decreasing trend in annual rainfall and booming population growth (and increasing water abstraction) in the coastal regions further compound the problem. For these reasons, a single party or stakeholder group cannot be criticized for the reduction in water availability to the entire catchment.

4.4 Recommendations to Commercial Farmers

While we found that these farmers are very knowledgeable about water management on their farms, they applied their insight to limited water conservation methods. Our recommendations to the commercial farmers, which are based on our findings, seek to promote increased water conservation and improved groundwater recharge on these farms. Unfortunately, we do not know the exact costs of implementing our suggestions and therefore encourage commercial farmers and ELAK to investigate their feasibility. We have grouped our recommendations by physical measures that could be taken and communication strategies that could benefit the farmers.

Because the main source of water loss on farms with active dams appears to be evaporation, any water conservation strategy should address the problem. One possibility of reducing evaporative losses would be to cover dams and reservoirs (i.e., water storage facilities), but this is often very difficult and impractical to implement (only one farmer surveyed could afford to cover his dams). However, we found three possible alternatives. The first, which is already practiced by one farmer in the lower sub-catchment, is to pump water directly from the dam catchment area into covered reservoirs and/or closed tanks for use, thereby reducing groundwater dependence and evaporative losses. Unfortunately, this water often needs to be processed before it could be used for domestic consumption. The possible high costs of pumping and processing this water may necessitate the continued use of boreholes for domestic use. In addition, less water behind the dams (due to pumping) could contribute to less borehole recharge (when they are located next to dams). The other two alternatives we found are more passive in nature. On the same farm previously mentioned, dams are deep and mostly located within draws and gullies. There often is a reduction in evaporative losses when dams are placed in such locations, but the geography of a farm may not allow this to work. While most farmers do not plan to build new dams, they could plant trees to shade the dam catchment areas and/or excavate their current dams to deepen them. Both of these passive methods could reduce evaporative losses. The second alternative, however, is expensive and therefore infeasible for some farmers. Furthermore, trees could abstract an excess of water from the ground, reducing the recharge capability of the dam.

Reservoirs also suffer water loss from evaporation and require improved water conservation practices. Few farmers surveyed actually cover their reservoirs due to cost, increased bacterial growth, or worries that restricted access to surface water would induce wild animals to damage the covers. Past studies found that covering reservoirs may be more beneficial than maleficent (Dausab, et. al., 1994, pp. 17-23). First, it can reduce incidences of wild animals accidentally drowning in the reservoirs. Occasionally animals fall into reservoirs, where they often drown. Farmers must then empty the reservoir due to the resulting unsanitary conditions, resulting in a large amount of wasted water. Second, covering reservoirs could greatly reduce evaporation. We recommend mesh shade covers to reduce evaporation while still allowing for rainfall and fresh air to enter the reservoir. Mesh shade covers would not prevent animals from accessing the reservoirs however, which could lead to accidental drowning deaths, but prevent wild animals from vandalizing the covers in an attempt to reach the water.

We discovered through our interviews that commercial farmers do not communicate as much as they should with each other about water management on their farms – this limits the spread of effective ideas among farms. For example, several farmers expressed surprise that one farmer pumps water from his dam into his borehole in a recharge effort. Exchanging knowledge about which practices work and which do not could greatly improve water management on these farms and lower water-related costs (e.g., leaky pipes, insufficient boreholes) as well. This could be accomplished by facilitating more discussions at farmer union and association meetings or by publishing information in AgriForum™, a magazine published by the Namibian Agricultural Union.

Farm dams require regular service to function properly. We propose that farmers perform maintenance on their dams *at least* every eight to 10 years (the average maintenance response we received). It would also be ideal for farmers who do have maintenance equipment to rent these tools to neighboring farmers who lack them. Because routine maintenance improves dam capacity and the ability for water to infiltrate the ground, the financial investment could prove to be less than the cost of building new dams or drilling new boreholes in the long run.

We urge commercial farmers to incorporate more water conservation tactics into their farming practices as well. Farms, especially guest farms that have greater domestic water use, should investigate the use of recycled water (i.e., gray water from baths, washing machines, etc.) for gardening purposes. We also suggest these farms determine the feasibility of using technologies (such as low-flow showerheads) to reduce their domestic water consumption even further. Albeit, domestic use may be negligible on a farm, these improvements can only meliorate situations and possibly alleviate stress from other stakeholders.

4.5 Limitations of Our Study

Our research cannot be considered an exhaustive study of the commercial farmers in the upper KRB. Several factors limited the scope of our research and thus made our findings vulnerable to bias and/or inaccuracy. For these reasons, we do not intend for our findings and recommendations to be the final authority on commercial farmers. Rather, our project serves as a starting point for continued development of an understanding of stakeholders throughout the river basin. Additional research will contribute to this effort.

Due to limited time and transportation availability, we were only able to survey 16 farms. This is about 15% of the commercial farms in the river basin, and they were not randomly selected. The 13 farmers we surveyed were limited to those individuals that have been known to be cooperative with ELAK and other research in the past. While they were very accommodating and open to helping with our study, we were unable to accept all of their statements at face value without access to objective data (e.g., water meters and third party rainfall measurements) to confirm them. A much larger and/or more systematic study of the commercial farms should be conducted to form solid conclusions about water management practices on these farms.

The findings we have made were based entirely on our farmer interviews, observations of some farms, and background research on water management in the KRB as well as other parts of Namibia and the world. Our limited time in Namibia and lack of previous experience with farming in arid regions may have biased our observations and recommendations. On the other hand, our outside perspectives may be useful to the KRB stakeholders in obtaining different ideas for water management.

5.0 Conclusions & Recommendations

The findings from our study on water infrastructure, water conservation methods, and groundwater recharge methods were used as a foundation for our recommendations. After a thorough analysis of our findings, we have developed a set of recommendations for the Environmental Learning and Action in the Kuiseb project (ELAK) and the Kuiseb River Basin (KRB) stakeholders. These recommendations include topics that should receive additional study from ELAK and suggestions for commercial farmers that could possibly improve water management practices throughout the upper catchment of the KRB. Implementing these recommendations will help begin the process of addressing disagreements among stakeholders concerning the water management practices on the commercial farms in the upper KRB. We hope that our recommendations initiate more communication among stakeholders to assist ELAK in their goal of developing a conceptualized vision for water management throughout the KRB.

5.1 Conclusions

Our conclusions on water infrastructure, water conservation methods and groundwater recharge methods were used as a basis for our recommendations. The main quantitative findings indicate that variations in water infrastructure among the commercial farms may be due to the different commercial operations and locations of these farms. We also found that regular maintenance of farm dams can meliorate dam capacity and recharge capabilities. Of the farmers we interviewed, only one planned to change his farm's water infrastructure – indicating a stable trend in dam use. Finally, we discovered that none of these farmers believe their dams negatively impact downstream users, but argue that the dams benefit the local ground water table. In summary, we used the following four main findings as a basis for our recommendations:

i. Location within the upper catchment and farm type appeared to influence the number of boreholes per farm, but not dams. Farm age and size had no visible effect on water infrastructure.

ii. Boreholes only affect local groundwater dynamics and do not directly influence the aquifer in the lower catchment. The geology of the upper catchment prohibits water flow to the lower catchment, creating a physical barrier between the upper and lower catchment aquifers. Farmers do not believe their dams negatively impact downstream users. However, three of the thirteen farmers (two located in the lower subcatchment, one in the upper) claimed that larger dams upstream withheld too much water from them. Nine farmers believe their dams recharge ground water sources. Five of these nine report physical or visual measurements to substantiate their claim.

iii. Farmers practice conservation as a lifestyle but use limited technological water conservation methods, especially in regard to reducing evaporative losses from dams and reservoirs. Evaporation is the biggest source of water loss on all the farms with active dams, according to farmers.

iv. Farmers have been very resourceful in their water management methods, but need to communicate more of these ideas with other farmers.

5.2 Recommendations

Our recommendations apply to ELAK, the commercial farmers of the upper KRB (as detailed in Chapter 4), and all other KRB stakeholders. These recommendations encourage further research and discussion among the stakeholders, as well as improved water management practices for the commercial farmers. Our proposals include brief overviews of our findings chapter as well as implications for our findings in the form of additional studies and suggestions for improving water management on commercial farms.

Recommendations to ELAK

Because our research is not comprehensive to all aspects of water and land management on the commercial farms, we urge ELAK and other bodies to further research these farms. Additional study of this stakeholder group is necessary for a complete understanding of their management practices. Obtaining complete records on water infrastructure changes, water use measurements, factors affecting surface water runoff, and the consequences of diversification on water management would strengthen recommendations for the entire river basin. These additional studies and a continued water awareness campaign will aid ELAK in their goal.

Our findings cannot conclusively suggest causality between farm location/type and water infrastructure. Many farmers had incomplete records of previous ownership and/or the dates when their farms were started. Because of these missing data, we were unable to determine exactly when all boreholes and most dams were built, and how diversification affected water infrastructure. From interview responses, we see indications of a diversification into tourism trend, but cannot say how that will affect water consumption or management on commercial farms. We suggest that future studies of the commercial farms incorporate accurate farm age information into their analyses of water management practices, to see if farm age factors into water management at all, as we expect it to.

None of the commercial farmers we surveyed had accurate records of their water use. We obtained only rough estimates of water consumption by livestock, and statements claiming that domestic use was negligible. Unfortunately, this lack of information made it impossible for us to conclusively determine how farm type or location could affect water abstraction levels. Water meters would greatly improve an understanding of how much water commercial farms use. This kind of understanding is necessary in order to judge which water conservation methods may benefit these farmers. Moreover, it would help ascertain if diversification into tourism increases water consumption on a farm (as we found may not be the case in section 4.1).

Land management practices affect runoff volumes to downstream users. Rotational grazing (the practice of shifting livestock throughout the farm to prevent overgrazing) results in more vegetation on grazing lands and a reduction in surface runoff (Dausab, et. al., 1994, p. 18). An investigation that relates the implementation of rotational grazing to trends in runoff volumes would be extremely useful for understanding the relationship between the two. Other factors that influence runoff such as the dimensions of dams should be considered as well. Exact measurements of farm dams, taken over time to account for the effects of siltation, could vastly improve the current knowledge of how retained water affects runoff patterns. These measurements could also validate or refute claims by those farmers that feel upstream dams negatively impact their water supplies.

During our study, we discovered that several farms had expanded, partitioned, or changed ownership since the last census in 2000. As a result, the exact number of farms, their farming practices and area of these farms in the upper KRB is in question. We recommend that ELAK and the Namibian Agricultural Union (NAU), among other stakeholder representatives, thoroughly investigate this matter. Studying these factors will help characterize water management practices in conjunction with these categories and the number of similar farms. This characterization is necessary for making catchment-wide conclusions about water management on these farms.

Finally, our study focused on water management practices and possible alterations to improve them. A feasibility study concerning the recommendations we have made to the commercial farmers would support and/or uncover alternatives to our suggestions. We understand that financial cost, ease of implementation and maintenance of water infrastructure or management changes must be heavily considered. It is therefore imperative that the viability of our recommendations be extensively studied in order to encourage the best possible water management practices on commercial farms.

The completion of these additional studies are crucial for the progress of capacity building and debate resolution in the KRB. In addition, ELAK needs to continue educating stakeholders about water management and use. Raising awareness to these issues will facilitate ELAK's goal of developing a basin-wide consciousness about water resources.

Recommendations to Commercial Farmers

Commercial farmers need to consider increasing the intensity of their water conservation practices to reduce water consumption and wastage as well as lower the costs of operation (as detailed in section 4.2). They should also communicate more often with other farmers to spread knowledge about the effectiveness of these practices. A combination of these efforts may promote more efficient use and management of water.

Farmers that practice water conservation as a 'lifestyle' must look into the practicality of recycling water and reducing water consumption on their farms if they haven't already. While domestic use of water may be much less in comparison to cattle consumption, it would still be beneficial for these farmers to reduce their domestic consumption. Doing this may lower operating costs of farms, reduce dependence on certain water sources and increase sustainability of their use. With these justifications in mind, we recommend three possible modifications to the current water management practices and beliefs of farmers. First, farmers should seek to reduce evaporative losses from their water storage facilities. Shades and covers for dams and reservoirs can accomplish this. Second, farmers should reduce their domestic water consumption. Low-flush toilets, low-flow showerheads, water recycling, and other technologies can easily conserve water around the home. Finally, farmers need to communicate with each other more to spread knowledge about specific water management tactics that work for them. Sharing ideas personally, communicating them to their local unions, and/or passing them on to the Namibian Agricultural Union are all possible forums to achieve this suggestion. By utilizing these suggestions, farmers may increase the sustainability and profitability of their farms.

Recommendations to Other Stakeholders

Since we were unable to interview other stakeholder groups, we were only able to develop limited and broad recommendations for them to consider. First and foremost, we recommend that the other stakeholder groups look into alternative water sources and water management practices based on synthesis of outside research with our own. Keeping in mind the knowledge that many lower catchment stakeholders claim to receive less runoff now than in past years, we recommend two possibly viable potable water sources. Further research should be conducted to understand the effects of farm dams as well. Alternative water sources combined with additional research knowledge may reduce inter-stakeholder group tensions as well as relieve stress on the aquifer in the lower KRB.

Based on our findings, reduced runoff to lower catchment users cannot be attributed solely to commercial farm dams. We recommend that more downstream stakeholders join ELAK's research in determining the factors affecting runoff in the upper catchment (e.g., land management, variable rainfall) before agreeing or disagreeing with the opinions from the Department of Water Affairs (DWA) and the Hydrogeological Association of Namibia stating that farm dams in the upper catchment do not significantly influence lower catchment users.

Factors other than runoff must be studied to understand why the water supply in downstream aquifers is decreasing. For example, high abstraction and low recharge rates could exacerbate water scarcity. We recommend that the downstream stakeholders investigate the feasibility of artificial aquifer recharge, as natural recharge does not seem to be sufficient. We know that NamWater has successfully injected water into boreholes in the past, and we encourage them to aid the KRB in this feasibility study (van der Merwe, 2000, p. 379).

Alternative water sources for the lower catchment may be the best solution for reducing stress on the KRB's aquifers. We understand that the municipality of Walvis Bay has used wastewater reclamation as an additional water supply of non-potable water for some time. The Ministry of Health has recently approved for this water to be purchased for human consumption. We suggest that that the municipality continues to expand this source of water. For the coastal regions, desalination may be an expensive, but sustainable option too (Namibia Resource Consultants, 2002, p. 17). The Desert Research Foundation of Namibia (DRFN) has already concluded that fog water in the Namib Desert is a sustainable water source because it is more reliable than rainfall (fog precipitation exceeds rainfall precipitation) and, in addition, causes no harmful environmental effects (Shanyengana, 2002, p. 252). This source could not support a sizeable community, but could be used to supplement other water sources. Joining the DRFN in assessing the feasibility of this water source along the coastal regions is highly recommended. We suggest that downstream stakeholders study the possibility of using alternative sources of water. Moreover, they need to look closer at the effects of population growth on the carrying capacity of water resources in this area. Reducing groundwater abstraction could allow the Kuiseb aquifer to better recharge and decrease dependence on this limited water source.

The implementation of our recommendations could greatly improve water management practices and the understanding of stakeholder groups in the KRB. Additionally, other ephemeral river catchments of Namibia with similar water shortage problems could benefit from our research. The methods we used may also apply to other places in the world that are attempting to develop capacity and widespread cooperation among stakeholders concerning the sharing of a vital resource such as water.

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Appendix A: Interview Protocol

Interactive Qualifying Project

Students:	Erin Hicks, JR Johnson, Mike Torilli
Sponsors:	Desert Research Foundation of Namibia (DRFN) & the Environmental Learning and Action in the Kuiseb Project (ELAK), Polytechnic of Namibia, and Worcester Polytechnic Institute (WPI)
Contact:	Phone- 061-22-9855 Email- elak@wpi.edu

- *Who we are*

We are third year students at WPI, located in Worcester, Massachusetts, U.S.A. We study engineering and sciences at our institution. During the months of March and April 2003 we will be completing a project in cooperation with the DRFN, which will fulfill one of our requirements for graduation. This project is meant to beneficially apply technological, scientific, or managerial engineering disciplines to the culture, values, laws, and practices of society.

- *What we are doing*

Under the guidance of the DRFN, we will be working to gather more information concerning the water use and needs of the various commercial farmers of the Kuiseb's upper reaches. Obtaining this information will help further develop an understanding of their priorities regarding water supply, distribution, use, needs, and future management plans.

Once we have amassed information from all selected subjects, we will gather raw, roughly analyzed data and present it to the farmers, farmer union, and Farmers' Association to obtain their perceptions. We will incorporate their feedback into our research, and then begin the final process of data analysis and forming conclusions.

We intend to formulate recommendations to ELAK for utilizing our information. These recommendations may include ways to fulfill these farmer's water supply needs in the context of the downstream users as well as suggestions to ELAK for additional research. This information will contribute to ELAK's efforts at forming a conceptualized vision for stakeholder collaboration in the river basin.

- *What we will contribute*

Through our research, we intend to develop a brochure and/or other material that will be available to the DRFN and all those involved in commercial farming in the upper catchment. This document will present an overview of our finding and will include our recommendations for further research and development of water use and management in the upper Kuiseb River Basin. We intend to ensure that all people that we meet and speak with will receive a copy of the brochure and any other materials that we assemble. Furthermore, the information that we gather will be presented to the government, other political authorities, and other stakeholders. Relaying this information will inform them of your views and opinions concerning water management as well as the rationale of your current practices in order to rectify any previous misconceptions.

051 220793

Namibia Agricultural Union
Namibia Landbou-unie

TEL. INT. CODE [illegible]
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FAX. INT. CODE [illegible]
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PRIVATE BAG 13255
WINDHOEK
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PRIVAATSAK 13255
WINDHOEK

NAU - NLU

H8/12:30 Verwysing A 9/10 Navrae O Horsthemke

14 March 2003

TO WHOM IT MAY CONCERN:

We confirm that the following students, namely Erin Hicks, J R Johnson, Mike Torill, are conducting an Environmental Learning and Action in the Kuiseb Project (ELAK) survey and would appreciate it if you would give them your full cooperation. This survey will be under the guidance of DRFN (Desert Research Foundation of Namibia) and its aim is to gather more information concerning the water use and needs of the various commercial farmers of the Kuiseb's upper reaches. Obtaining this information will help further develop an understanding of their priorities regarding water supply, distribution, use, needs and future management plans. Roughly analysed data will then be presented to farmers, Farmer Unions and Farmers Associations to obtain their perceptions. Their feedback will be incorporated into the research and then the final process of data analyses and forming conclusions will begin.

We thank you in anticipation.

Yours sincerely,

O HORSTHEMKE
MANAGER: SPECIALITY FIELDS

Involvement • Unity • Prosperity • Betrokkenheid • Eenheid • Voorspoed

Interview Protocol

Administered By: Erin Hicks, JR Johnson, Mike Torilli

Sponsored by: Worcester Polytechnic Institute, the Desert Research Foundation of Namibia, and the Polytechnic of Namibia

Objectives: To determine the needs, uses and management of water on commercial farms in the upper Kuiseb River Basin. This will include domestic and agricultural use, as well as any additional enterprises (e.g., farm schools, tourism). The following questions will be addressed to farm owners and farm laborers with the intent of obtaining information that will satisfy our objective.

Icebreaker: In order to establish a friendly and open relationship with the interviewees, it is suggested that simple, indirectly associated friendly conversation be established with the survey subject (Ford, personal communication, 21 February 2003). This 'small talk' will hopefully ease any uncomfortable feelings between the interviewer and the interviewee. Methods for engaging in conversation in this context will be best learned by talking with fellow Polytechnic students and representatives at our sponsoring agency. Hopefully, they will be able to help us in developing proper and/or appropriate techniques in speaking with the survey subjects.

Additional Activity: If possible, it would be ideal to look at a map(s) and/or aerial photo(s) of the property in order to have a better understanding of the property and all of its elements. This will particularly useful for us, the researchers, in understanding the constraints and situations concerning water on these farms based on location, topography, and so forth. Additionally, a copy of these charts would be most helpful for supplementary research outside of the interview.

Farm: ______________________________________

Farm Owner: ________________________________

Date: ______________________________________

Relative Location: ___________________________

Relative Size: _______________________________

Questions: These questions may be either directly or indirectly asked, depending on the context of the interview.

FARM TYPE

- ☐ What type of farm establishment are you involved in?
    - ☐ Livestock
    - ☐ Game
        - ☐ Hunting
        - ☐ Photo Safari
    - ☐ Guest
    - ☐ Farm Schools
    - ☐ Crop Farming
        - ☐ What types of crops are you raising?
    - ☐ Other
- ☐ How long has your farm been _______?
    - ☐ What was it previously?
        - ☐ Why was it changed?
- ☐ How many people live on your property?

WATER SOURCE(S) & STORAGE

- ☐ What is your source(s) of water (e.g., ground water, dams, etc.)?
    - ☐ What source do you rely on the most?
        - ☐ What are your different water used for specifically?
- ☐ Do you know how much rain you receive per year?

- ☐ What are your perceptions on localized rainfall?
  - ☐ Do you feel your rainfall is localized?
- ☐ <u>Dams</u>:
  - ☐ What types of dam(s) do you have and how many of each are you currently using and how many are inactive?
  - ☐ Where are these dams located on your property?
  - ☐ What is the surface area and/or volume of these dams?
  - ☐ How old are these dams?
  - ☐ Do you repair or clean any of your dams? If so, how often?
  - ☐ How long do your dams last during a good year? How long during a bad year?
  - ☐ Do you have any plans to build new dams? If so, what type? If not, why?
- ☐ <u>Boreholes</u>:
  - ☐ How many boreholes do you have on your property?
  - ☐ What types of power are you using for these boreholes? And, how many of each type of power supply are you using?
  - ☐ How many of these boreholes are currently being used and how many are inactive?
  - ☐ Where are these boreholes located on the property?
  - ☐ Do these boreholes draw water from the river or isolated groundwater sources?
  - ☐ In a good year, how long will the boreholes sufficiently last? How long during a bad year?
  - ☐ How often do you service your boreholes?
  - ☐ Do you have any plans to build new boreholes? If so, what type? If not, why?

☐ Do you have any additional water storage facilities? If so, what are the dimensions?

- ☐ How often are these facilities replenished?

DISTRIBUTION & USE

☐ How is this water distributed throughout your property (e.g., piping, irrigation, etc.)?

- ☐ Do know what your current pumping rates are throughout your property from boreholes, dams, etc.?
- ☐ How far is your water pumped from each source?

☐ How is water used on your property, both domestically and commercially (e.g., game, livestock, guest)?

- ☐ Do you have any records of your water use?
- ☐ Do you have any records of any recharge committed to the water supply?

☐ Do you have any current plans to change your current methods of supplying, distributing, or using water to your household, workers, to the farm, etc.?

RECHARGE & CONSERVATION

☐ What are you doing to recharge water supplies?

☐ Are you taking any steps to conserve water usage?

MAINTENANCE & FUTURE PLANS

☐ Farmer: What are your most essential water needs, outside of human consumption?

☐ Farm Laborer: Where do you get your water? If water supply and/or distribution changes, how would your use practices change?

☐ What do you think is main source of water loss on your farm?

☐ Do you have any future plans to change your farm (i.e., expand to guest or tourism)?

- ☐ If so, how do think this will change water consumption? Increase or decrease?

FARM SPECIFICS

Livestock

☐ What types of livestock are you keeping on your property? How many head of each do you have?

☐ What methods and sources do you use to supply water to these animals?

☐ How much water do they consume on a daily average?

Game

☐ What types of animals are living on your property?

- ☐ Do have any population data concerning these animals?
- ☐ How much water is available for them?

Guest

☐ What technologies do you implement to conserve water (e.g., low flush toilets, low flow showerheads, etc.)?

☐ Approximately how many guests do you host annually?

☐ Do have an idea of much water each guest uses and/or how much is used to host a guest?

☐ Do you have any regulations on water use towards the guests (i.e., laundry, bathing limitations, etc.)?

School

☐ How many students attend this school? How many instructors are there?

☐ Do you use any additional sources of water solely for the school?

☐ Is water conservation taught in your school?

OPINIONS/SUGGESTIONS

☐ Do you feel that your dams are with holding water from the users in the lower catchment areas? Why or why not?

☐ Do you have any suggestions on how we should publicize and distribute the information that we are gathering, especially amongst other farmers and authoritative parties?

☐ Other Comments

Thank you for your time and cooperation!

Appendix B: Farm Database

The following pages are the raw data of all the farms. Farms and farm owners have been numbered to distinguish each farm and farm owner while maintaining confidentiality.

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
1	1	16/3/03	*upper, off*	lg. 10,046	guest, livestock	12 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	boreholes	storage,sand	4 Act.	3 -150x200m, 1 3x size	40 yrs	Yes 1 deepened
Dam lifespan	**Dam plans?**					
lg 3 mo., sm 6 mo.	No, but weirs					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
7 Act, 2 Inact.	5m^3	wind	all over prop.	all year	1 for eco cottage	2-10000L 1-2500L tank
H2O distribution	**Pump rate**	**Water use**	**Use records?**	**Recharge records?**	**Supply plans?**	
pipe 14mm, 32mm	2 1/2 m^3/hr	D,L	No	No	Chng pipe diam.	
Recharge H2O?	**Conserve H2O?**	**If more H2O?**	**Water loss?**			
No	no baths, cover	Plant food -	evaporation			
	dams, recycle	grains, alfalfa,	infrastructure			
	H2O, silver paint	wonder trees	(valves, lime)			
Livestock type	**H2O supply?**	**Consumption**				
500 cows 73 horse	troughs	50 L/day				
Guest conserve?	**Guests/year?**	**Water used?**	**Regulations?**	**Suggestions for info?**	**Rain**	
Recycle 20,000L/	10,800 max	20L/person/day	No	cite penalties, give data,	200 mm	
2 weeks				why we address them,		
				why H2O use different		

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
2	2	24/3/03	*lower, trib*	lg. 10,300 ha	guest, livestock	7 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	boreholes	storage,sand	5 Act. 1 In.	750m^2, 1125m^3	45 yrs	Yes deepened
Dam lifespan	**Dam plans?**					
7-10 months/yr	No					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
3 Act, 2 Inact		wind	all over prop.	all year	Yes, 1 in April	6 reservoirs, 4 tanks
H2O distribution	**Pump rate**	**Water use**	**Use records?**	**Recharge records?**	**Supply plans?**	
pipe 40 mm	Unknown	D,L,game	No	No	Change household	
					and garden	
Recharge H2O?	**Conserve H2O?**	**Biggest need?**	**Water loss?**		consumption	
Yes - pump H2O	Yes - low flow	Livestock	evaporation			
into 1 borehole	showerhead, low					
	flush toilet					
Livestock type	**H2O supply?**	**Consumption**				
500 cows	troughs	40 L/day				
Guest conserve?	**Guests/year?**	**Water used?**	**Regulations?**	**Suggestions for info?**	**Rain**	
No	225/yr max	50L/person/day	No	very brief exec summ	230 mm/yr	
				presentation at FA		
				meeting		

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
3	3	25/03/03	*lower trib*	sm. 3000 ha	livestock	17 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	boreholes	sand	1 Act 0 Inact	9000 m^3	Unknown	No
Dam lifespan	**Dam plans?**					
7 months/yr	No, weirs					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
1 act. 3 inact.		wind, solar	next to dam	all year		4 metal tanks, no cover
						2 - 20,000 L
H2O distribution	**Pump rate**	**Water use**	**Use records?**	**Recharge records?**	**Supply plans?**	1 - 50,000 L
pipe 30 mm	Unknown	D,L, garden	No	No	Build 3 sets of	1 - 70,000 L
					weirs	fountain
Recharge H2O?	**Conserve H2O?**	**Biggest need?**	**Water loss?**			
Yes - dam	toilet, shower,	Livestock	evaporation			
infiltration	no H2O plants,					
	drip water in eve					
Livestock type	**H2O supply?**	**Consumption**				
300 cows 100 oth.	troughs, dam	35-50 L/day				
				Suggestions for info?	**Rain**	**Other**
				distribute through farm	160 mm/yr	moon cycles influence
				unions or NAU		fountain refill rate, no
						H2O flow in flood yrs

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
4	4	25/03/03	*lower off*	lg 9000 ha	livestock	1970s
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
borehole,well,dams	borehole	sand	2 act.	unknown	55-60 yrs	Once - 1 cleaned
Dam lifespan	**Dam plans?**					
3-4 days	No					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
1 act, 18 inact	100-200 m	diesel	700 m away	all year	No	Well - wind power
						1 - stone/concrete tank
H2O distribution	**Pump rate**	**Water use**	**Use records?**	**Recharge records?**	**Supply plans?**	(3000-4000 L)
pipe 40-50 mm	Unknown	D, L, Gar, game	No	No	Wants to cover	1 - metal tank
					water tanks	(2000 L)
Recharge H2O?	**Conserve H2O?**	**Biggest need?**	**Water loss?**			1 - plastic tank
Nothing	Nothing	Livestock	Evaporation,			(1000 L)
			wildlife break			
			things			
Livestock type	**H2O supply?**	**Consumption**		**Suggestions for info?**	**Rain**	
300 cattle,	automatic trough	20 L/day cow		H2O undercontrolled	150-180 mm	
100-150 goats		Unknown goat		before, now new control		
				has made it worse		

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
5	5	O1/O4/03	*upper on*	sm. 3275 ha	livestock	1947
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	borehole	1 storage,	1 act., 3 dry	5000 m^3	1 - 53 yrs	Remove silt every
		3 sand		1500 m^3	1 - 31 yrs	10 yrs
Dam lifespan	**Dam plans?**			8000 m^3	1 - approx 80 yrs	
1mo, 3-7mo, 10 mo	No			last - unknown	1 - 48 yrs	
1 only when floods						
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
8 act, 2 inact	122 m	7 wind, 1 diesel	next to dams	all year	Yes, 1 near house	7 corrugated metal tanks
						(none are covered)
H2O distribution	**Pump rate**	**Water use**	**Use records?**	**Recharge records?**	**Supply plans?**	all 25 ft x 6 ft
galvanized pipe	1 m^3/hr diesel	D, L, Gar, game	4000 L/day	Water table rises 56 m	No	
(b.hole to reservoir)				when dam is full -		
plastic pipe to	**Conserve H2O?**	**Biggest need?**	**Water loss?**	approx. 60% recharge		
laborer's houses	Maintain pipes	Livestock/game	Evaporation,			
all 40 mm	prevent wastage		baboons			
	bath H2O to lawn					
Recharge H2O?						
Dams	**H2O supply?**	**Consumption**		**Suggestions for info?**	**Rain**	
	automatic trough	30 L/day cow		Put it in perspective,	300 mm	
	dams			it's a world-wide problem		
				manage H2O demand		
Livestock type						
350 cattle						
40 goats						
25 horses						
5 donkeys						
200 game						

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
6	6	O1/O4/03	*upper on*	lg. 6332 ha	livestock	bought in 1974
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	borehole	storage	3 act.	15,000 m^3	unknown	No
				others unknown, but		
Dam lifespan	**Dam plans?**			smaller		
1 - 1.5 yrs	No					
others 2-3 months						
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
9 act.	200-350 ft	7 wind, 1 diesel	next to dams	all year	No	8 corrugated metal tanks
		1 solar				(none are covered)
H2O distribution	**Pump rate**		**Use records?**	**Recharge records?**	**Supply plans?**	1 - 25 x 8 ft
PVC pipe	1.5 m^3/hr	**Water use**	D - 500 g/day	No	No	4 - 18 x 8 ft
25 km total		D, L, Gar, game				3 - 25 x 6
	Conserve H2O?		**Water loss?**			
	Maintain pipes	**Biggest need?**	Evaporation			
	prevent wastage	Livestock/game				
Recharge H2O?						
Dams	**H2O supply?**			**Suggestions for info?**	**Rain**	
	automatic trough	**Consumption**		Put it in perspective,	250-275 mm	
	dams	40 L/day cow		it's a world-wide problem		
				manage H2O demand		
Livestock type						
400 cattle						
50 goats						

Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
7	7	O3/O4/03	*lower on*	lg. 17,500 ha	small stock	1954
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, fountain	boreholes	storage	2 inact, 0 act	800 m^3	40-50 yrs	No
Dam lifespan	**Dam plans?**					
N/A	No					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
3 act 0 inact	100, 70, 120 m	2 wind, 1 elctrc.	Kudu trib.	All year	Yes, some day	4 plastic tanks
						3- 5000 L, 1 - 10,000 L
H2O distribution	**Pump rate**		**Use records?**	**Recharge records?**	**Supply plans?**	150x150 m fountain
above ground pipes	700-800 L/hr	**Water use**	No	No	No	
(plastic&galvanized)		D, L, Gar				
40 mm	**Conserve H2O?**		**Water loss?**			
	No	**Biggest need?**	None			
		Livestock				
Recharge H2O?						
No	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	manual troughs	**Consumption**		Add map showing # of	80-100 mm	Feels upstream dams
		5 L/sheep/day		dams in upper vs		prevent water from
				lower subcatchments		coming to him, spoke
Livestock type						to farm manager, not
60 sheep, wild						owner (Mr. Martins)
game						
Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
8	8	O7O/4/03	*lower, on*	18,535 lg.	L, Game, Guest	14 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	boreholes	sand, storage	4 act, 4 inact	Unknown	1 - 70 yrs	No
					7 - 50-60 yrs	
Dam lifespan	**Dam plans?**					
1 - 6 mo., 1 - 2 yrs	No					
6 - 2-3 mo.						
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
8 act, 42 inact	Unknown	4 wind, 2 diesel	Diesel in river,	all year	Yes - wind power	3 underground reservoirs
		2 - none yet	others all over			that collect rainwater -
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	unknown dimensions
Plastic piping,	800L/hr	**Water use**	**Use records?**	No	Give laborers	7 plastic tanks - unkn d.
above ground,		D, L, Ga, Gar	No		another toilet &	
25, 32, 40 mm	**Conserve H2O?**				shower	
	Recycle H2O	**Biggest need?**	**Water loss?**			
	to water plants	Everything	Evaporation			
Recharge H2O?						
No	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	Open holes,	**Consumption**		Send info directly to	101 mm	Has records for rain on
Livestock type	troughs	3-5 l/sheep/day		Kuiseb farmers - obtain		each part of farm.
1300 sheep, 33		10 l/cow/day		addresses from NAU		Has used IBT from farm
cattle	**Guests/year?**					25 km away
	300-400	**Water used?**	**Regulations?**			Has received 1/3 less
Guest conserve?		Unknown	No baths			rain over last 20 yrs
No						

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
9	9	O7/04/03	*lower, on*	lg. 7483 ha	L, Game, Guest	5 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	dams	sand	6 act	Unknown	1 - 1 month	Yes, every 3-4 yrs
					5 - 20-30 yrs	excavated w/ bulldozer
Dam lifespan	**Dam plans?**					
2 - more than 1 yr	Yes, 3 more					
4 - all yr	gravel soon					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
4 act, 2 inact	Unknown	1 wind, 3 disel	next to dams	2-3 yrs, then replenish	Yes - type unkn	each borehole has a
						reservoir, 10 extra
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	reservoirs (metal, 1.8x
Plastic piping,	1.4-3.3 m^3/hr	**Water use**	**Use records?**	No	No	~5 m)
above ground,		D, L, Ga, Gar	No			
40 mm	**Conserve H2O?**					
	Maintain pipes	**Biggest need?**	**Water loss?**			
	no H2O wastage	L + Game	Evaporation			
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	automatic trough	**Consumption**		No	218 mm	Wants to expand trophy
Livestock type	dams	40-50l/cow/day				hunting aspect of farm
500 cattle		same for horse				Big dam broke in 2000,
40 horses	**Guests/year?**					no H2O level increase
	40-50	**Water used?**	**Regulations?**			noticed downstream
Guest conserve?		Unkn, very sm.	No			Keeps rainfall records
Limited tank cap.						

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
10	10	O8/04/2003	*upper, trib*	8000 ha lg.	L, Game, Guest	5 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	boreholes	sand	16 act, 0 inact	Unknown	Most - 30+ yrs	Yes, every 8-10 yrs
					Newest - 15 yrs	
Dam lifespan	**Dam plans?**					
4 - all yr	Maybe 3-5 gravel					
12 - 2 mo.	in next 3 yrs					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
19 act, 0 inact	Unknown	1 Disel 18 wind	behind dam	1 - all yr 18 - unreliable	No	16 reservoirs - 120 m^3
			walls			(2 cement, 14 metal)
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	& 5000 l tanks for camp
Plastic & PVC pipe	2000l/hr x4 hr/dy	**Water use**	**Use records?**	Not measured - visible	Add more pipeline	
all underground		D, L, Ga, Gu	No	increase in water table		
40 mm	**Conserve H2O?**			when dam full		
	Doesn't water	**Biggest need?**	**Water loss?**			
	gardens & lawns	L, Game	Evaporation			
			(50% lost)			
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	automatic trough	**Consumption**		No	140 mm	Rain has decreased by
Livestock type		50 l/cow/day				100 mm over last 20 yrs
150-200 cattle		25 l/game/day				
30 goat unkn horse	**Guests/year?**					
	30-40	**Water used?**	**Regulations?**			
Guest conserve?		40 l/guest/day	No baths			
No						

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
11	11	O3/04/03	*upper trib*	lg. 9000 ha	livestock	1970
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
dams, boreholes	dams	storage	6 act, 0 inact	6 - over 5 m deep	1 - 1980's	Yes, every year
			20 sm. Dams	others - unknown	others - before '70	
Dam lifespan	**Dam plans?**				all dams made	
Varies on rainfall	No				bigger constantly	
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
32 act, 10 inact	Unknown	7 diesel	next to dams	Varies	If necessary	20+ reservoirs (40-120
		15 wind				m^3, metal, uncovered)
H2O distribution	**Pump rate**		**Use records?**	**Recharge records?**	**Supply plans?**	70-80+ troughs in camp
PVC piping, below	2500l/hr	**Water use**	No	No measurements,	No	
ground, 32-50 mm		D, L, Gar		when dam full, water		
	Conserve H2O?		**Water loss?**	level rises		
	No	**Biggest need?**	Evaporation			
		Livestock	over 3 m/yr			
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	troughs, dams	**Consumption**		Let govt. & stakeholders	300 mm	Wants to expand to
		50l/cow/day		know dams are		hunting within 1 yr
		same for horse		necessary for farms		Hopes to host 8-10
Livestock type		10-15 l/goat/day				guests/yr
1000 cattle, 150		100l/zebra/day				
goats, 30 horses						

Farm	Farm Owner	Date Surveyed	Rel. location	Rel. Size	Farm Type	Type since?
12	12	O8/04/03	*upper off*	sm. 5000 ha	livestock	1976
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
dams, boreholes	boreholes	2 storage, 1	3 act, 1 inact	1 - 400 m long, shallow	1 - 60 yrs	Last done 10 yrs ago,
		sand		1 - 100x400 m	1 - 30 yrs	tractor broke, needs to
Dam lifespan	**Dam plans?**			1 - 'large', but silted	2 - 20 yrs	rent one now
1 - 1 yr	No					
2 - 10 mo.						
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
4 active, 1+ inact	Unknown	3 wind 1 diesel	2 near dams,	all yr	If necessary	8 open reservoirs (2
			1 inside dam			stone, 6 metal) - all
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	50-100 m^3
Plastic piping,	diesel 1-1.5m/hr	**Water use**	**Use records?**	When dam full, water	No	
most below ground		D, L	No	level in borehole can		
20-40 mm	**Conserve H2O?**			rise up to 20 m		
	No water for gar.,	**Biggest need?**	**Water loss?**			
	no H2O wasting,	Livestock	Evaporation			
	auto troughs					
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	auto troughs	**Consumption**		Distribute info through	260 mm	Was previously a guest
		Unknown		AgriForum (NAU mag)		farm (hunting), but no
						guests anymore
Livestock type						
400 cattle						
50 goats						

Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
13	13	11/O4/03	*lower off*	lg. 7200 ha	livestock+hunting	1978
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	dams	storage, sand	3 storage	Unknown	89 yrs	Yes, every 15 yrs (take
			1 sand			out silt & stabilize walls)
Dam lifespan	**Dam plans?**					
6-8 mo	No					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
10 act, 29 inact	Unknown	8 wind, 2 solar	next to dams	all yr	Yes, 4-5 new	8 tanks - (6 plastic/PVC
		rest diesel				1 metal, 1 asbestos)
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	each 5000-10,000L
Plastic pipes	1.5 m^3/hr	**Water use**	**Use records?**	No measurements, but	No	8 reservoirs - (metal)
below ground		D, L, Ga, Gar	4000L/day	when dams full, bholes		each 150 m^3
1.5"-2.5"	**Conserve H2O?**			recharge after 10-14 dys		
	No - covering	**Biggest need?**	**Water loss?**			
	reservoirs would	Livestock	Evaporation			
	make game mad					
Recharge H2O?		**Consumption**				
Dam infiltration	**H2O supply?**	40 L/cow/day		**Suggestions for info?**	**Rain**	**Other**
	reservoir, trough	5-10 L/goat/day		Show farmers don't	277 mm over last	May be additional inact
Livestock type		horses same		affect downstream users	30 yrs (avg)	bholes from previous
100 cattle, 12 goat		as cows		Problem is due to less		owners, uses IBT from
20 horses	**Guests/year?**			rainfall, Desalination		other farm 6.3 km away
	14 hunters/yr	**Water used?**	**Regulations?**	for coast recommended		has ladder in reservoirs
Guest conserve?		40-50L/day	Asked to use			so baboons can climb
No		when in camp	very little			out

Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
14	14	11/O4/03	*lower off*	sm. 3400 ha	livestock	1970
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	dams	storage	1 storage, 1	Unknown	89 yrs	One repaired every 15
			inact storage			yrs, other not (bhole is
Dam lifespan	**Dam plans?**					still strong though dam
6-8 mo	No					silted up)
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
2 act, 4 inact	Unknown	1 wind (dry one)	next to dams	all yr	Yes - 1	2 metal tanks (5000-
		2 solar				10,000 L), 4 metal
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	reservoirs (150 m^3)
Plastic pipes	1.5 m^3/hr	**Water use**	**Use records?**	No measurements, but	No	
below ground		D, L	56,000 L/day	when dams full, bholes		
1.5"-2.5"	**Conserve H2O?**			recharge after 10-14 dys		
	No - covering	**Biggest need?**	**Water loss?**			
	reservoirs would	Livestock	Evaporation			
	make game mad					
Recharge H2O?		**Consumption**				
Dam infiltration	**H2O supply?**	40 L/cow/day		**Suggestions for info?**	**Rain**	**Other**
	reservoir, trough			See above	>277 mm over last	
Livestock type					30 yrs (avg)	
1400 cattle						

Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
15	9	O7/04/03	*lower, on*	lg. 7000 ha	L, Game, Guest	5 yrs
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	dams	sand	10 act	Unknown	20-30 yrs	Yes, every 3-4 yrs
						excavated w/ bulldozer
Dam lifespan	**Dam plans?**					
all yr	Yes					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
7 act, 10 inact	Unknown	2 wind, 5 diesel	next to dams	2-3 yrs, then replenish	Yes - type unkn	each borehole has a
						reservoir, 6 extra
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	reservoirs (metal, 1.8x
Plastic piping,	1.4-3.3 m^3/hr	**Water use**	**Use records?**	No	No	~5 m)
above ground,		D, L, Ga, Gar	No			
40 mm	**Conserve H2O?**					
	Maintain pipes	**Biggest need?**	**Water loss?**			
	no H2O wastage	L + Game	Evaporation			
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	automatic trough	**Consumption**		No	218 mm	Wants to expand trophy
Livestock type	dams	40-50l/cow/day				hunting aspect of farm
500 cattle		same for horse				Big dam broke in 2000,
	Guests/year?					no H2O level increase
	40-50	**Water used?**	**Regulations?**			noticed downstream
Guest conserve?		Unkn, very sm.	No			Keeps rainfall records
Limited tank cap.						

Farm	**Farm Owner**	**Date Surveyed**	**Rel. location**	**Rel. Size**	**Farm Type**	**Type since?**
16	13	11/04/03	*lower, off*	lg. 7000 ha	L, Game, Guest	1978
Water source(s)	**Main source**	**Dam type(s)**	**No. dams**	**Dam SA/Vol**	**Dam age**	**Dam repair?**
boreholes, dams	dams	3 storage	4 act.	Unknown	89 yrs	Yes, every 15 yrs
		1 sand	0 inact.			remove silt & stabilize
Dam lifespan	**Dam plans?**					walls
6-8 mo.	No					
No. boreholes	**Borehole depth**	**Power type(s)**	**Location**	**Borehole lifespan**	**Borehole plans?**	**Other storage?**
8 act, 17 inact	Unknown	5 wind, 3 diesel	next to dams	all yr	No	1 plastic tank (5,000-
						10,000L), 5 reservoirs
H2O distribution	**Pump rate**			**Recharge records?**	**Supply plans?**	(1 brick, 4 metal) - 150
Plastic piping,	1.5 m^3/hr	**Water use**	**Use records?**	No measurements, but	No	m^3
below ground,		D, L, Ga, Gar	56,000 L/day	when dams full, bholes		
1.5"-2.5"	**Conserve H2O?**			recharge after 10-14 dys		
	Maintain pipes	**Biggest need?**	**Water loss?**			
	no H2O wastage	L + Game	Evaporation			
Recharge H2O?						
Dam infiltration	**H2O supply?**			**Suggestions for info?**	**Rain**	**Other**
	reservoirs,	**Consumption**		Show farmers don't	>277 mm (over	May be additional inact
Livestock type	troughs	40-50l/cow/day		affect downstream users	last 30 yr avg.)	bholes from previous
500 cattle				problem is due to less		owners, uses IBT from
	Guests/year?			rainfall, Desalination		other farm 6.3 km away
	14/yr	**Water used?**	**Regulations?**	for coast recommended		has ladder in reservoirs
Guest conserve?		40-50 L/day	Asked to use			so baboons can climb
No		when in camp	very little			out

Appendix C: Additional Comments

During the course of our interviews, farmers responded to our questions with additional information that we found very informative, interesting, and unique. Many of these responses, however, were not appropriate for discussing in our results or recommendations chapters. Therefore, for the sake of recording this information, we decided to provide additional comments on some of these farmers.

Suggestions for Info:

We obtained a variety of responses when we asked farmers how best to publicize, portray, and distribute the information we received from our study. While we attempted to incorporate as many of their ideas as possible into the final deliverable, we were unable to use everyone's suggestions. The following are responses from farmers to the question, "Do you have any suggestions on how we should publicize and distribute the information that we are gathering, especially amongst other farmers and authoritative parties?"

Farmer 1: Explain why we are addressing commercial farmers, explain why water use is different among stakeholders, cite penalties to not reacting to water shortages.

Farmer 2: Write a very brief executive summary of your project and give a presentation at the next upcoming Farmers Association meeting in late May/early June.

Farmer 3: Distribute information through farm unions and the NAU, not the government.

Farmer 5: State that water shortage is a worldwide problem, recommend population growth control and resource demand management.

Farmer 7: Present a map of the number of dams in each subcatchment.

Farmer 8: Send information directly to the people of the Kuiseb after obtaining their addresses from the NAU.

Farmer 11: Let government and other stakeholders know that dams are necessary for farms.

Farmer 12: Distribute information through AgriForum (the Namibian Agricultural Union magazine).

Farmer 13: Show that farmers need little water and don't affect downstream users, compare water use for user groups, recommend desalination to coastal users, state that few dams have been built since 1970 and the runoff decrease is due to less rainfall.

The problem of localized rain:

Many farmers gave us specific incidences of how localized rain can be on their property. We commonly heard that only certain areas of their farms received rain or that the neighboring farm received rain while their farm didn't. The following are the uncommon stories we heard.

Farm 3: During the '97 and '00 flood years, this farm experienced no river flow at all.

Farmer 9: This farmer owns two adjacent properties. According to this farmer, the average annual rainfall for the larger farm is 242 mm, while the other farm is approximately 100 mm less – 140 mm.

Farm 11: During the '97 and '00 flood years, "only some dams filled" and only parts of the farm flooded.

Farm 13: A 600 ha area of this farm has received no rain at all in the last three years.

Attempts at Water Conservation and Aquifer Recharge:

Most farmers surveyed expressed the opinion that water conservation was a lifestyle and because they didn't waste water, they didn't need to take extra steps to conserve water in their domestic or livestock use (other than the use of automatic valves in troughs). The most common conservation response we heard was withholding water from gardens during drought years. Almost every farmer believed that passive dam infiltration was enough for ground water recharge, but some took additional measures to replenish boreholes. The following are the unusual responses we received when we asked farmers how they conserve and replenish water supplies.

Farm 1: The dams on this farm are "covered with a wire matrix", which the farmer believes reduces evaporative losses from the dams. Baths are forbidden on this guest farm because they consume too much water, and sewage water is recycled for garden use.

Farmer 2: This was the only farmer to experiment with additional ground water recharge methods. He observed that one borehole was not significantly replenished by the neighboring dam, so he now pumps water from the dam directly into the borehole. He does not have any data on how effective this method has proved to be so far.

Farmer 3: This farmer uses the greatest number of water conserving strategies. She raises only indigenous cattle because they consume less water per day than European breeds. She only waters her garden in the evenings and uses drip irrigation to reduce evaporation. Additionally, this farmer uses reservoirs that are deeper, rather than wider. This decreases the exposed surface area, thus reducing evaporative losses. She also uses low-flush toilets and low-flow showerheads in her home.

Farmer 5: Maintaining water infrastructure is important for minimizing water loss, in this farmer's opinion. He regularly checks his pipelines for leaks. In addition, laborers' shower taps close automatically after a preset time (to reduce domestic water consumption) and gray water is used for watering the lawns.

Farm 8: On this farm, recycled water from baths and dishes (gray water) is used for watering the garden.

Farmer 10: If the rainfall this year continues to be insignificant for charging boreholes and filling dams, this farmer plans to cut down trees located near boreholes in an effort to reduce water consumption on the farm.

Farmer 11: This farmer tried to cover his reservoirs with nets in the past to reduce evaporation, but noticed no significant decrease in evaporative losses.

Farmer 13: This farmer commented that covering reservoirs results in baboons breaking the covers and poor water quality from the proliferation of microorganisms in the water.

Miscellaneous Stories:

We heard many interesting stories that we could not classify into the above categories or present in our results chapter. It is our belief, however, that these stories may have research value.

Farmer 3: This farmer noticed that the lunar cycle affects borehole pumping rates on her farm. When the moon is full, she observed that the water level rises and she can pump water from the borehole at a quicker rate than when there is a new moon.

Farmer 10: After deeming rain gauges 'too morbid', this farmer decided to remove all of them from his farm. He now estimates his rainfall by digging into the earth after each rain and measuring the depth to which water has infiltrated the ground.

Farm 15: During the '00 flood year, this farm's largest dam (3000 L capacity) broke. Before the farmer repaired this dam, he observed no increase in surface water runoff on the farm. He uses this claim to support his belief that farm dams do not affect downstream users.

Appendix D: Other Charts

All charts pertaining to water infrastructure on commercial farms that were not previously displayed are below.

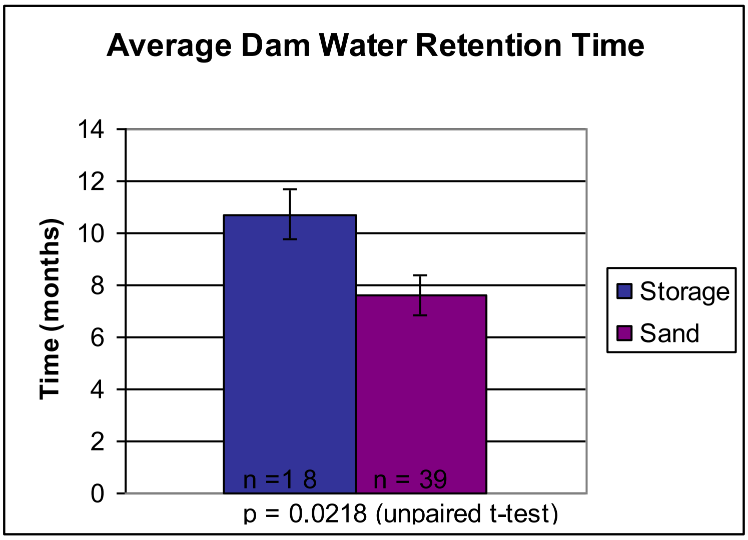


Figure D.1: Average dam water (both surface and subterranean) retention time for each dam type

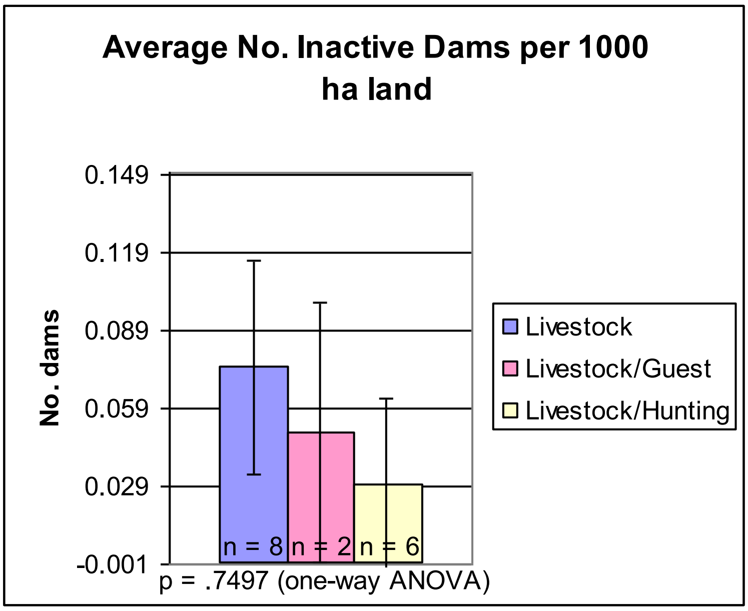


Figure D.2: Average number of inactive dams per 1000 ha land for each farm type

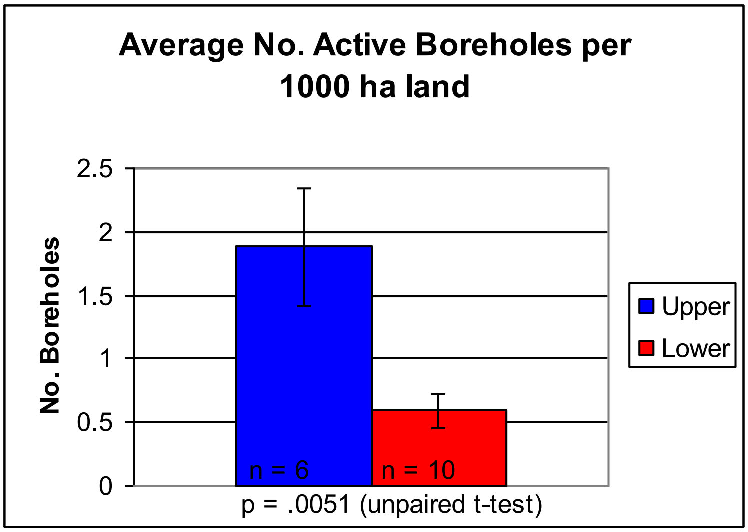


Figure D.3: Average number of active boreholes per 1000 ha land for each subcatchment

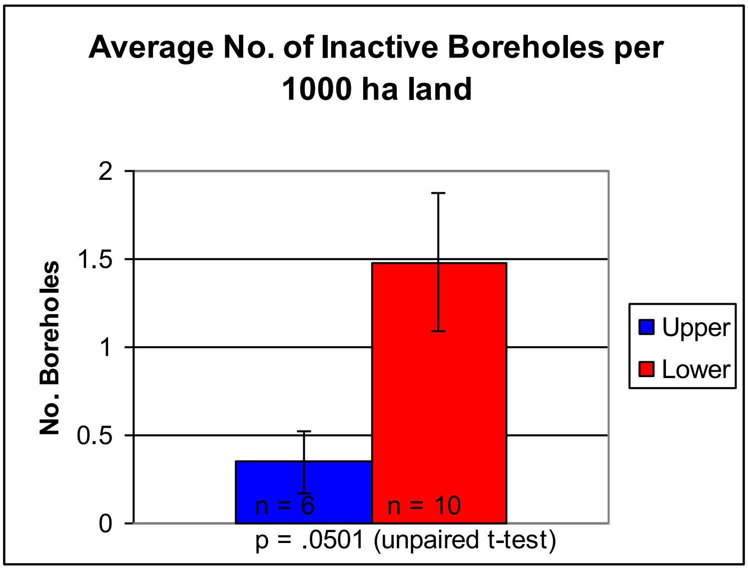


Figure D.4: Average number of inactive boreholes per 1000 ha land for each subcatchment

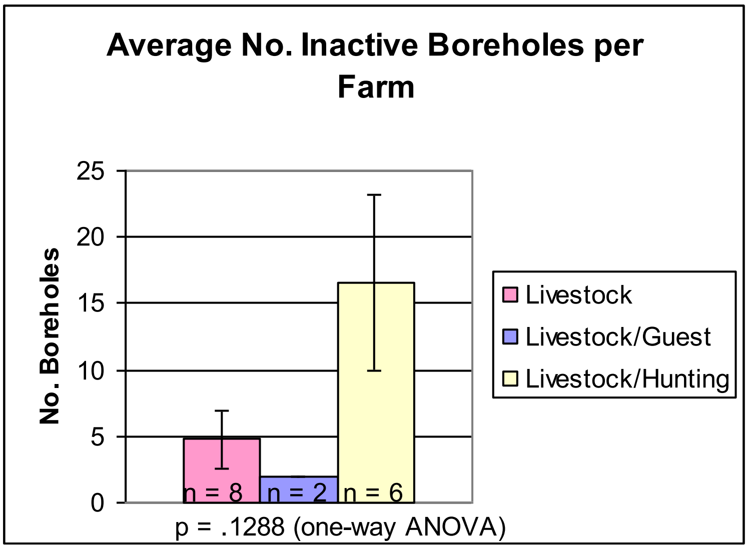


Figure D.5: Average number of active boreholes per farm for each farm type

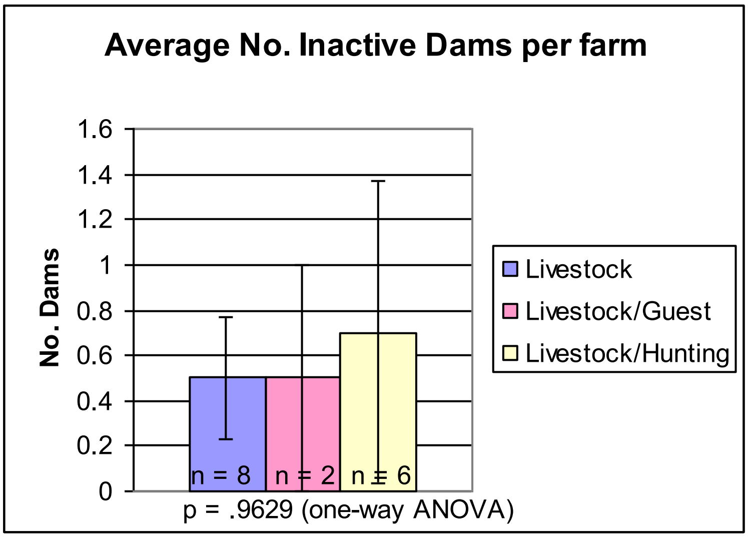


Figure D.6: Average number of inactive dams per farm for each farm type

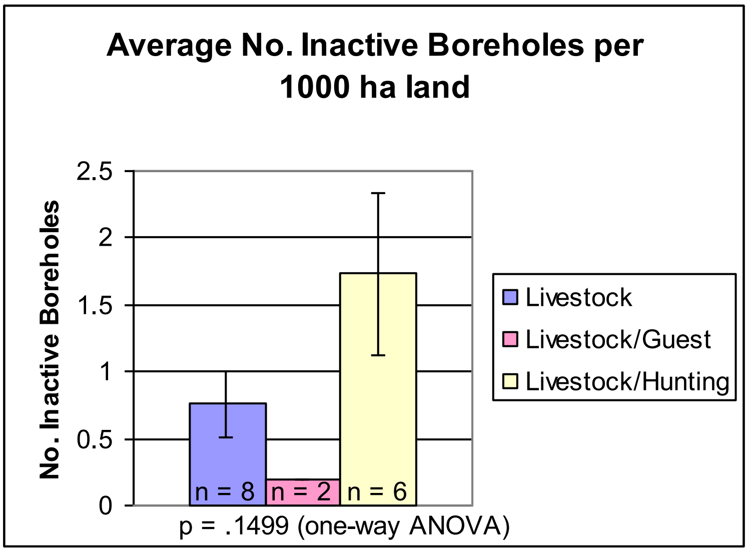


Figure D.7: Average number of inactive boreholes per 1000 ha land for each farm type

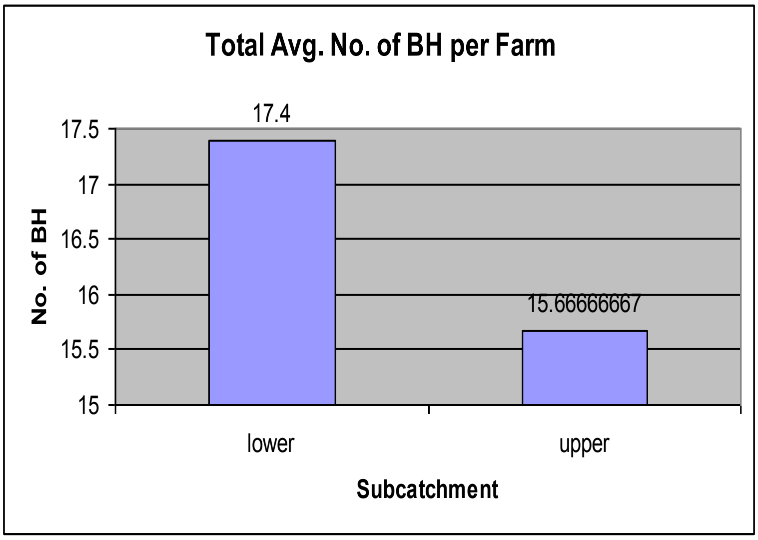


Figure D.8: Average number of boreholes (both active and inactive) per farm in each subcatchment

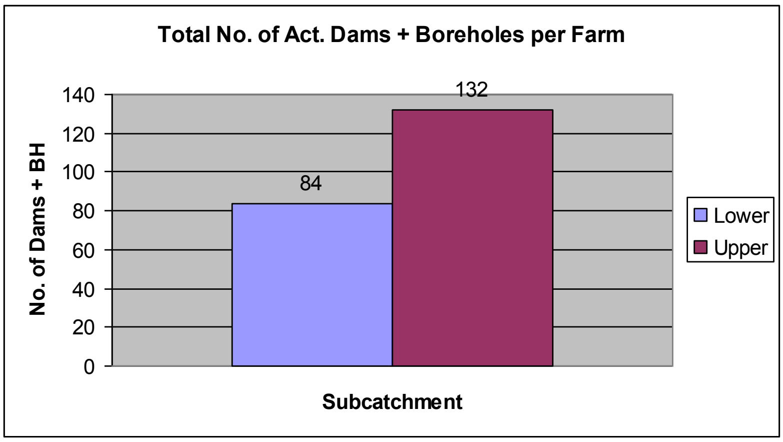


Figure D.9: Total number of active dams and boreholes per subcatchment

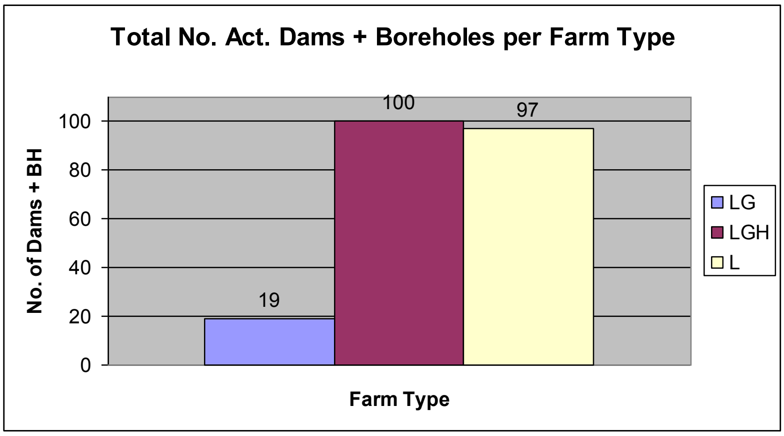


Figure D.10: Total number of active dams and boreholes per farm type

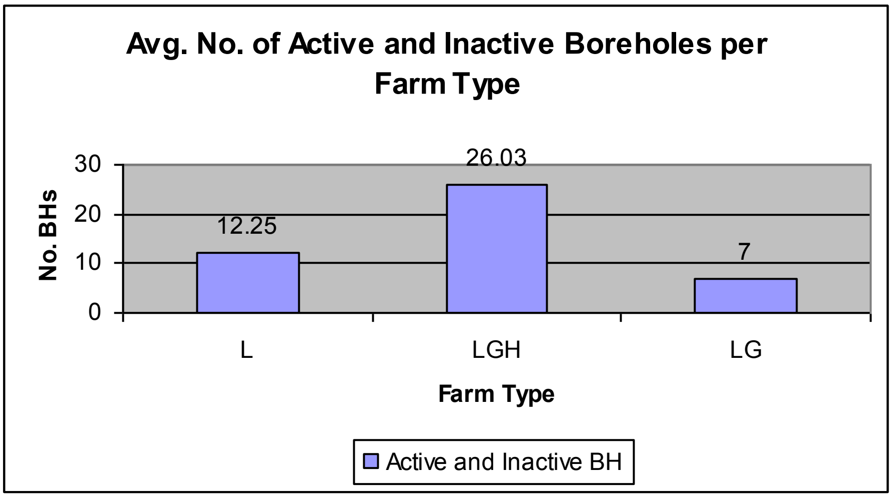


Figure D.11: Average number of boreholes (both active and inactive) per farm type

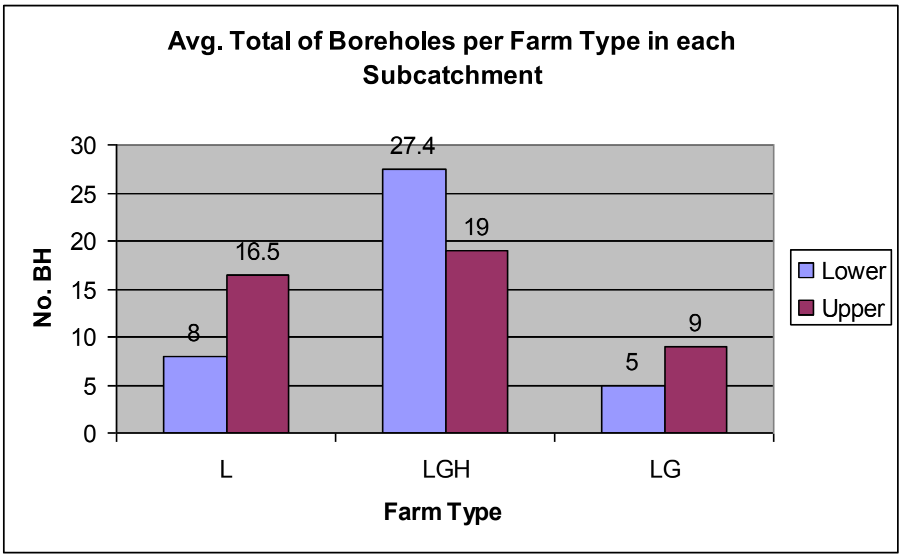


Figure D.12: Average number of boreholes (both active and inactive) per farm type in each subcatchment

Appendix E: Geographic Information System (GIS) Maps

Visual explanations of information can help to supplement literature on corresponding subjects. We enhanced our report on the Kuiseb River Basin (KRB) with the powerful GIS map production programs that were available to us at the DRFN. Both GIS programs, MapInfo™ Professional Version 5.0 and ArcView™ GIS Version 3.1, aided us in the production of numerous maps regarding certain environmental as well as logistical aspects of the KRB. We personalized the available templates of Namibia and the KRB into our own cartographic representations of which we agreed would better inform our audience on this region. To cover multiple aspects of the KRB, we created a total of twelve maps ranging from simple geographical locations to advanced geological representations, and even fog days.

GIS Maps of the KRB and Namibia

We understand the importance of visual augmentation to our writing and we hope that it will be helpful to all those who are interested in our work.

GIS Programs

ArcView GIS Version 3.1

Product ID: 825861103826

MapInfo Professional Version 4.1

Product ID: wps500000536

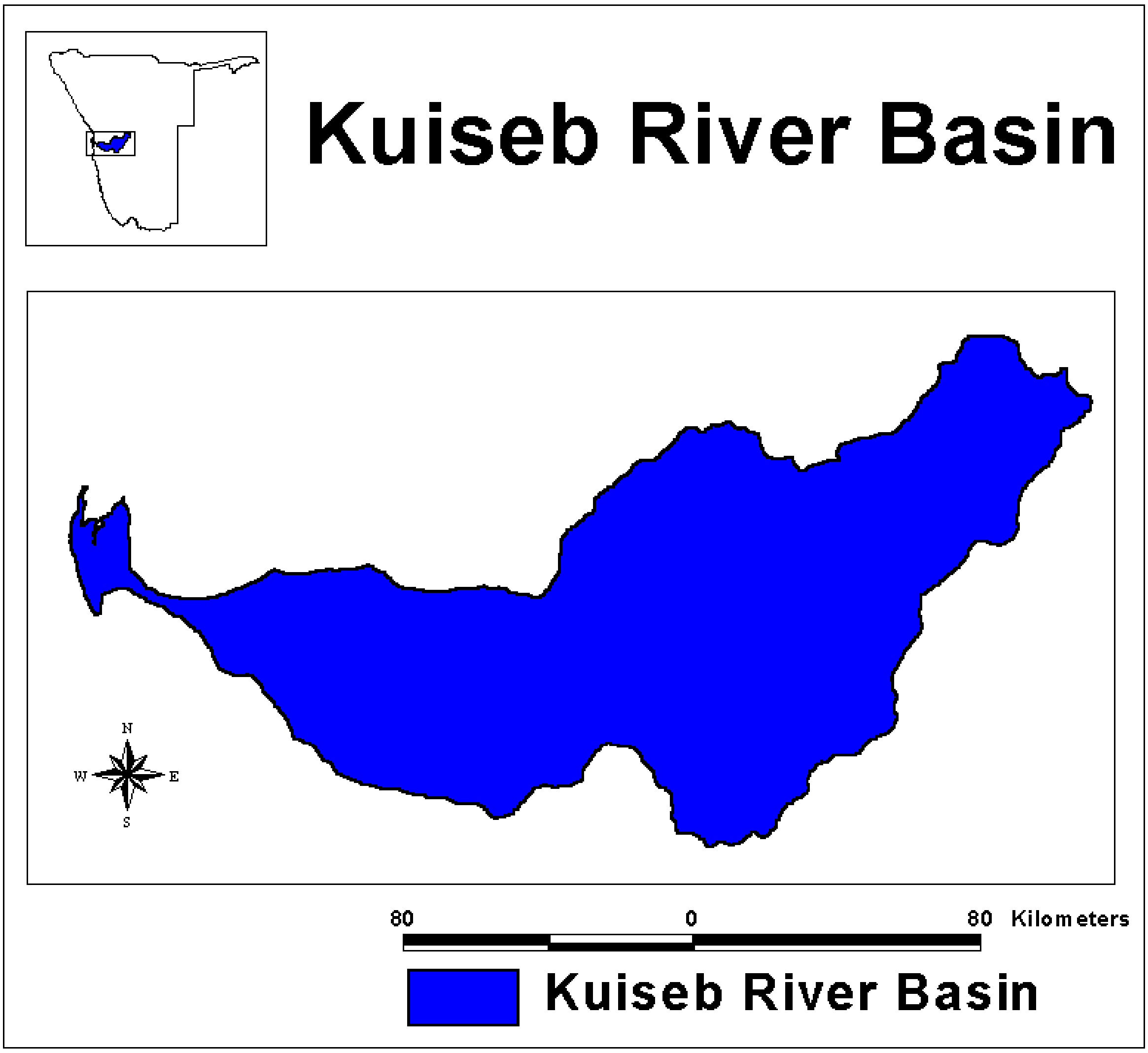


Figure E.1: Kuiseb River Basin Catchment Area

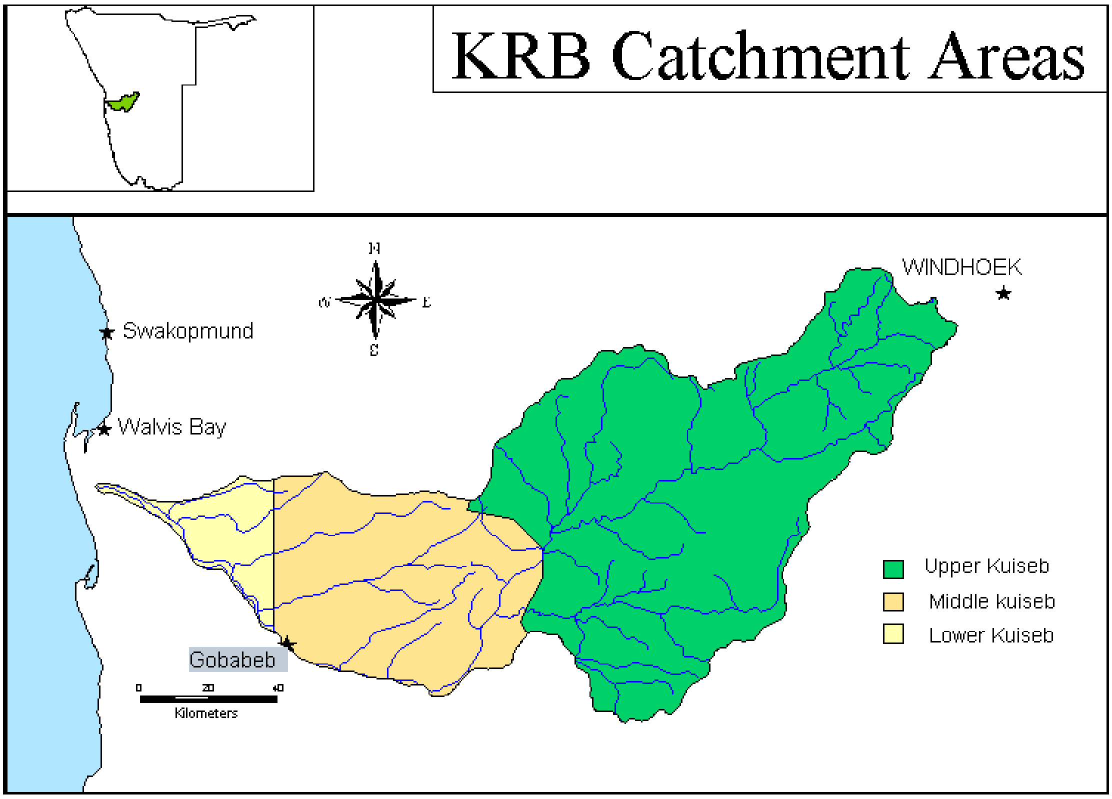


Figure E.2: KRB Catchment Areas – Upper, Middle, Lower

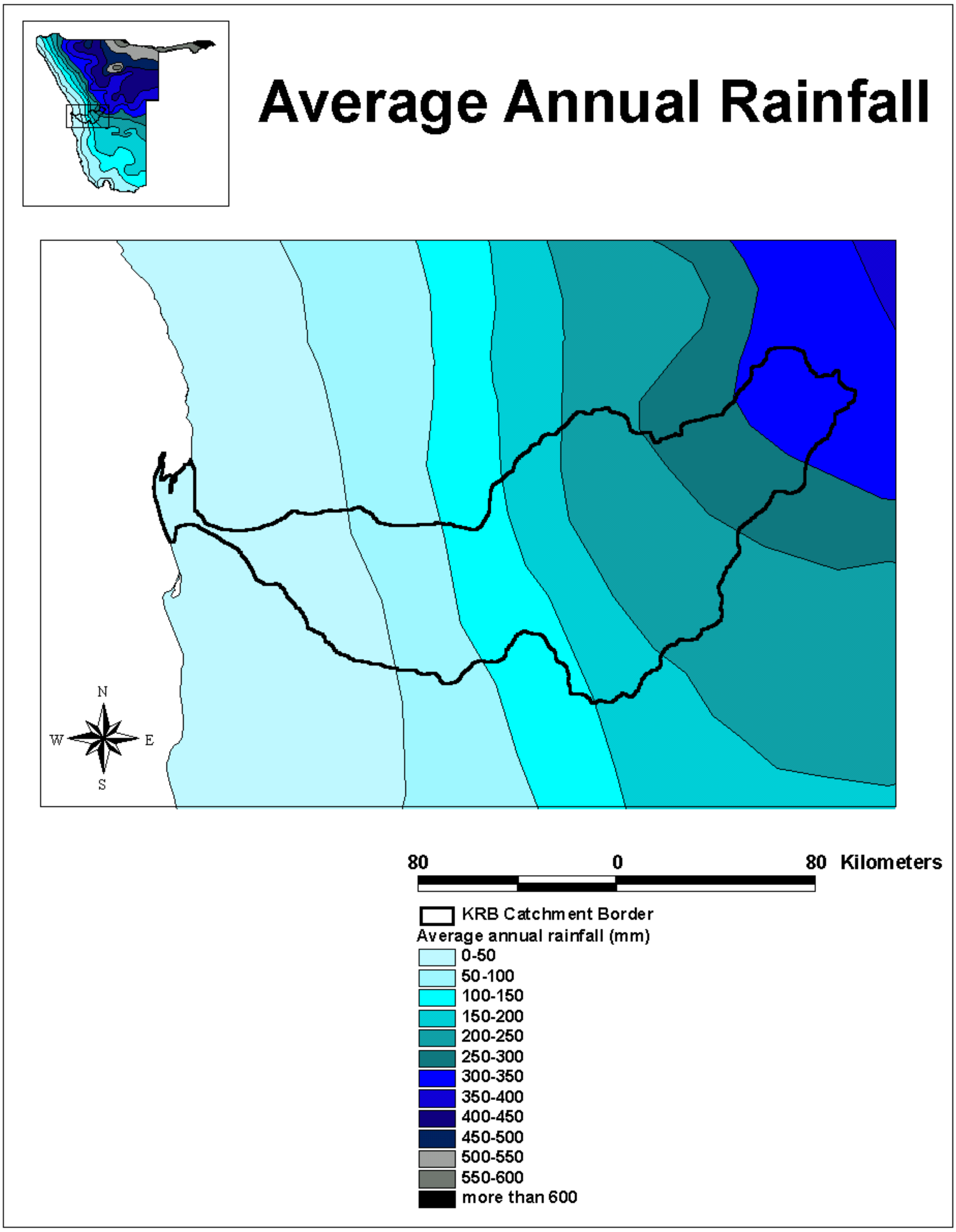


Figure E.3: Average Annual Rainfall

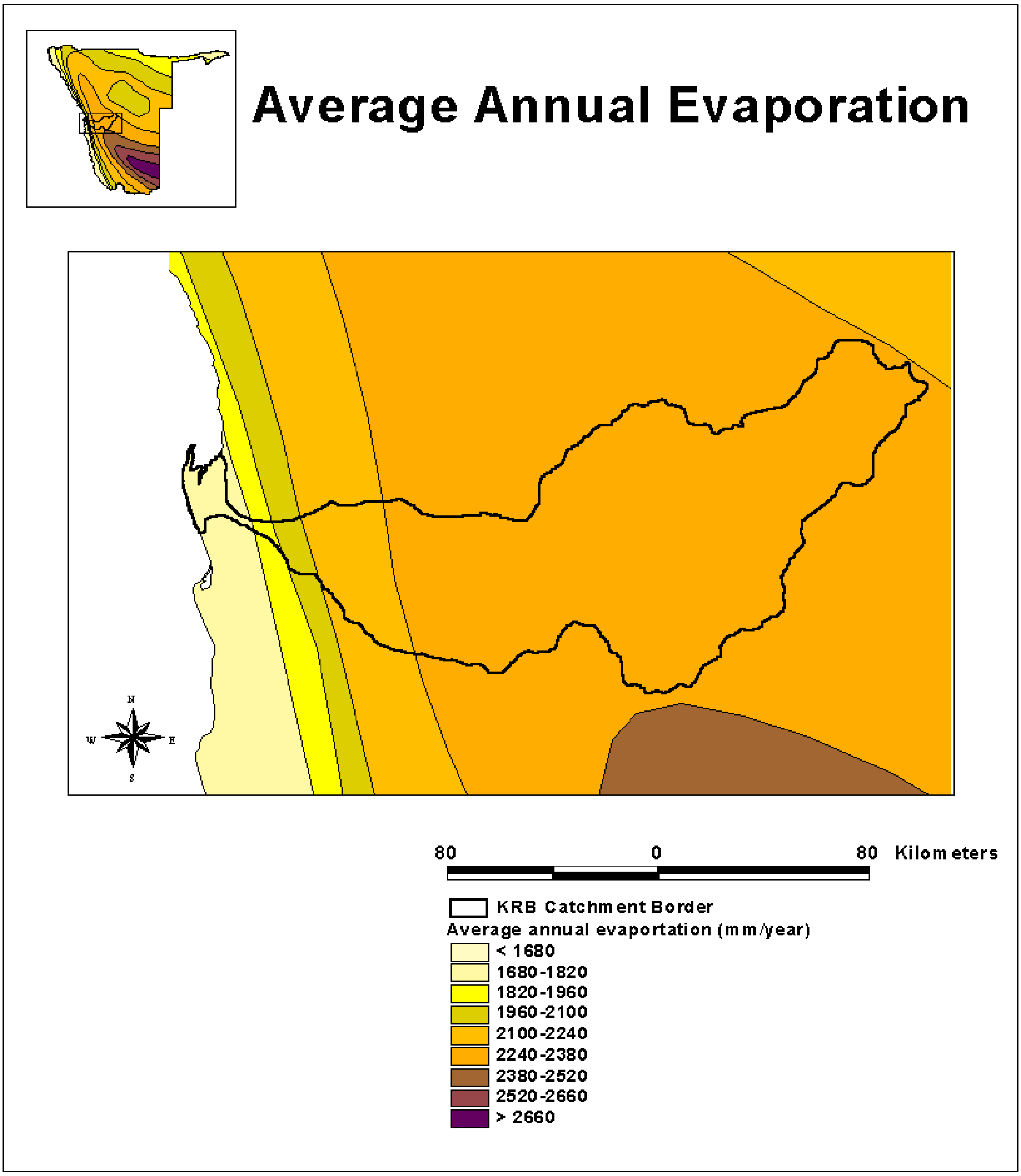


Figure E.4: Average annual evaporation

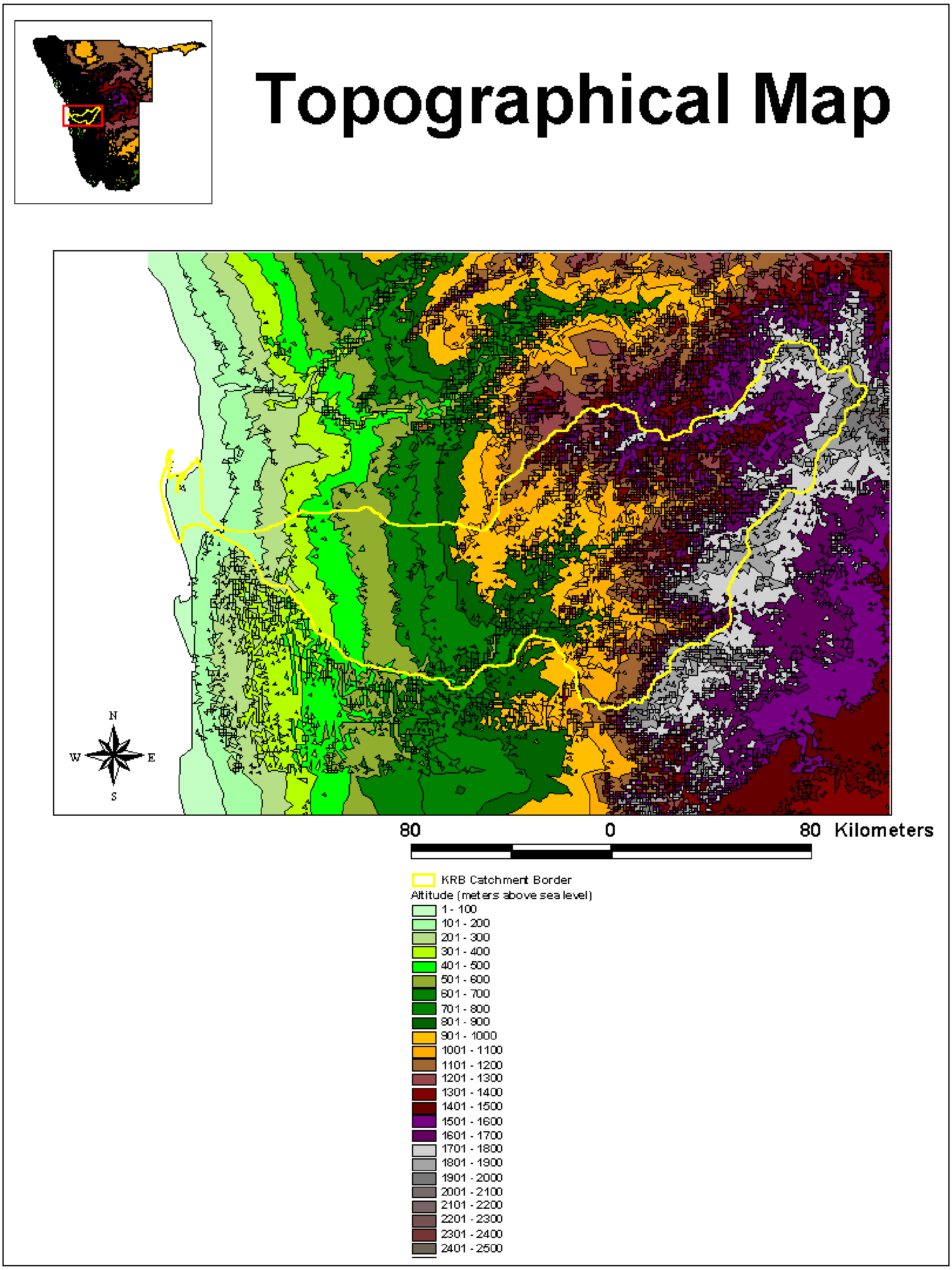


Figure E.5: Topographical Map

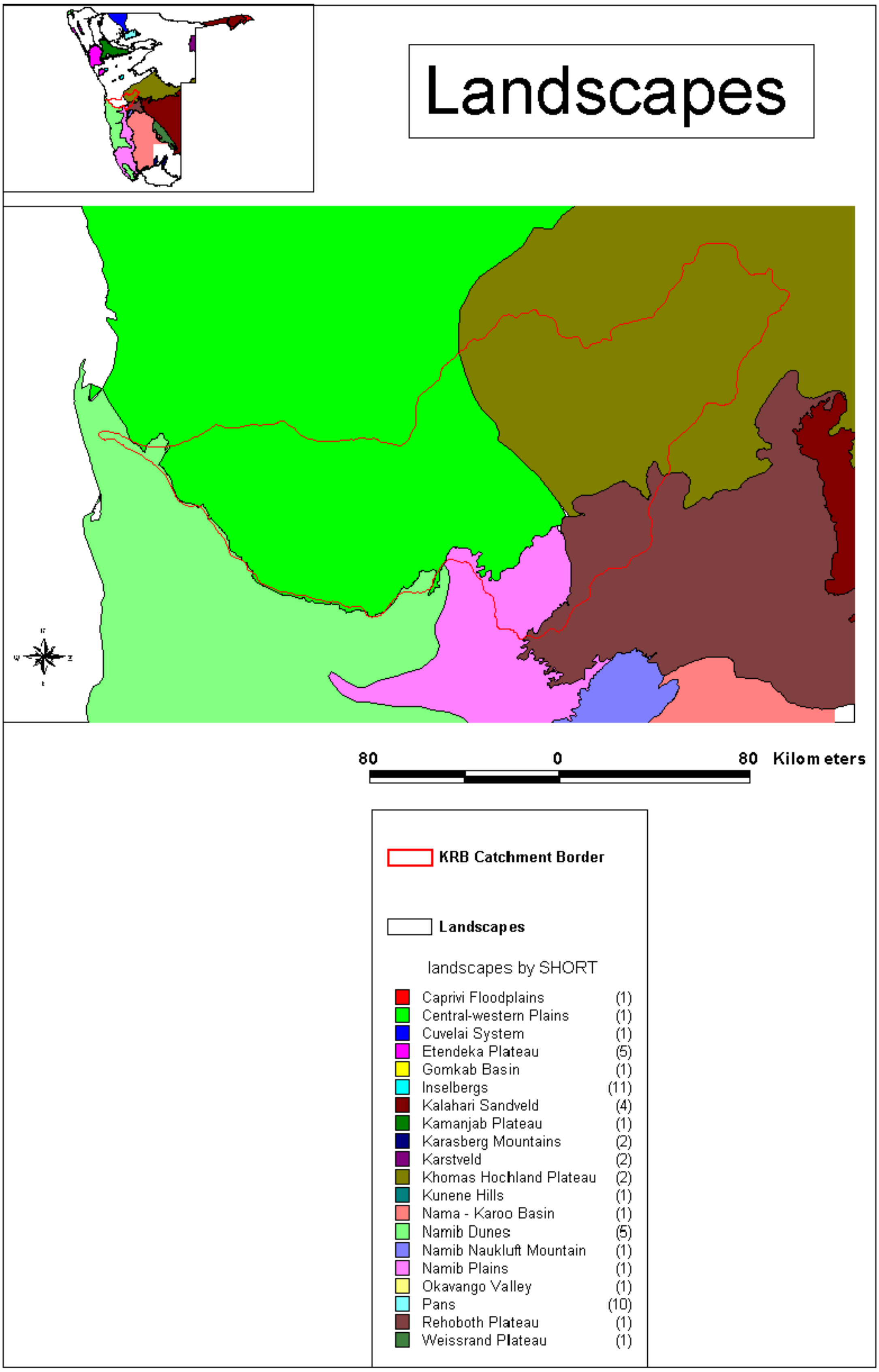


Figure E.6: Landscapes

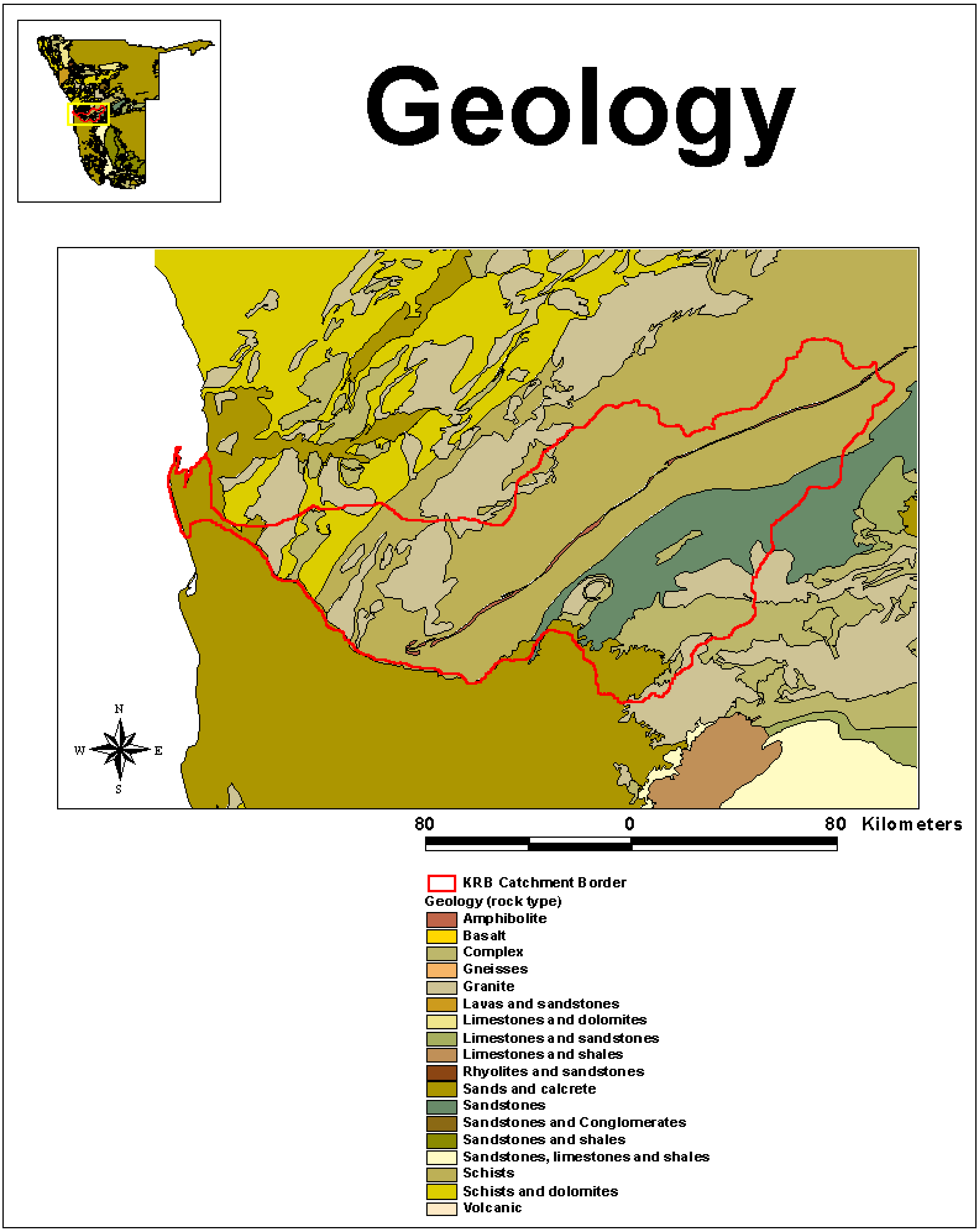


Figure E.7: Geological Map

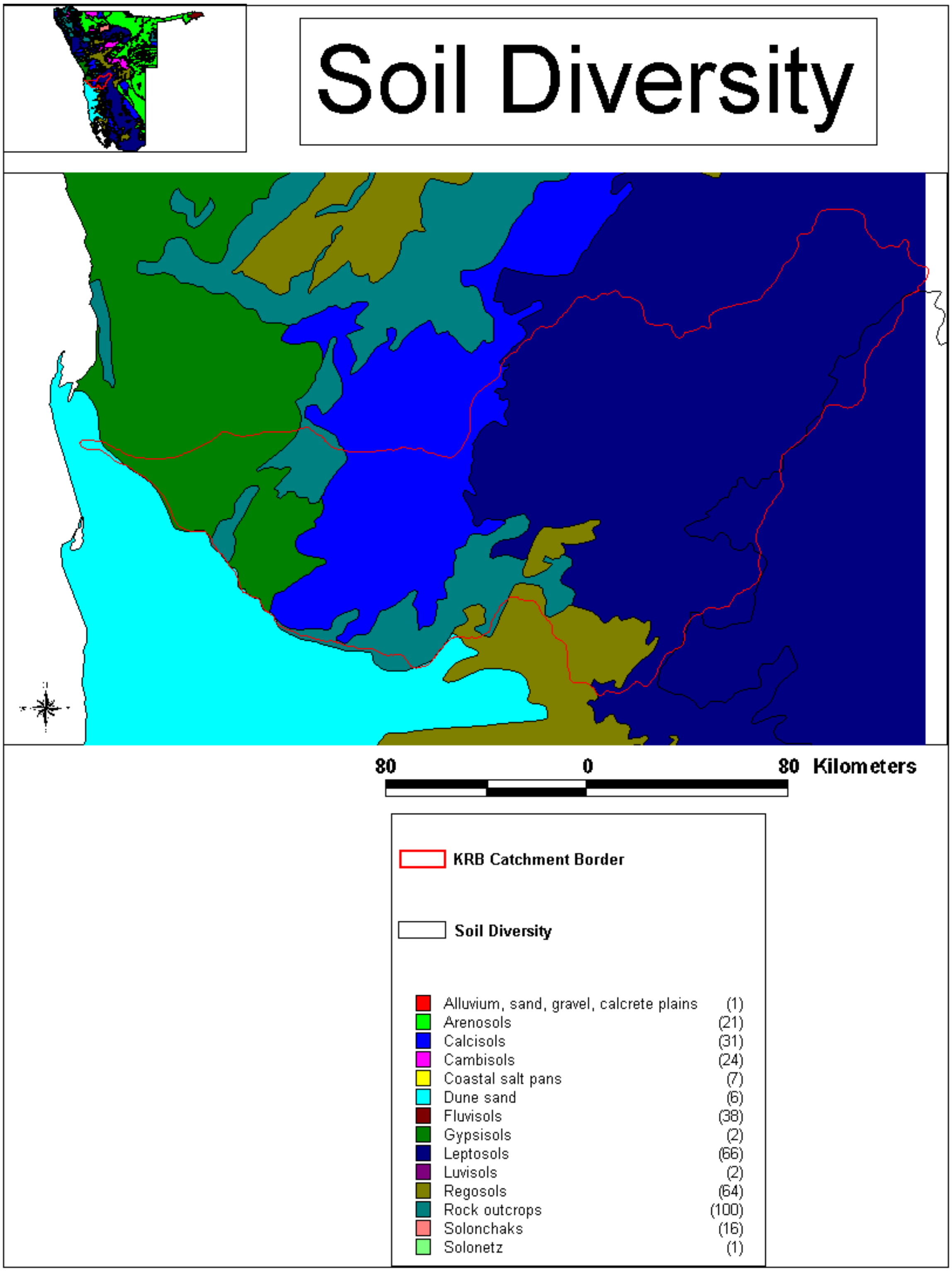
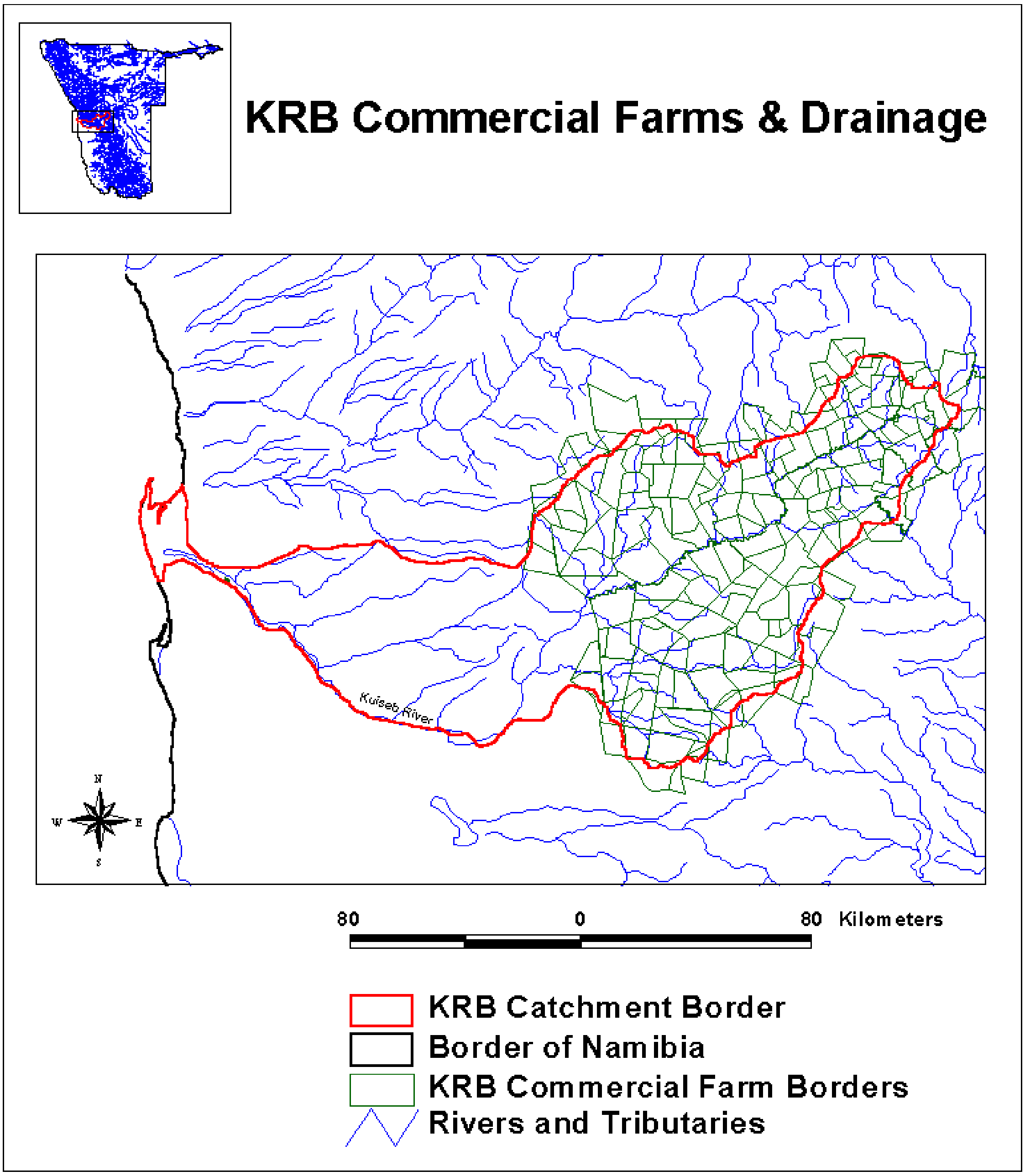


Figure E.7: Soil Diversity in the KRB

Figure E.9: Kuiseb River Basin commercial farm borders, Kuiseb River, and



tributaries

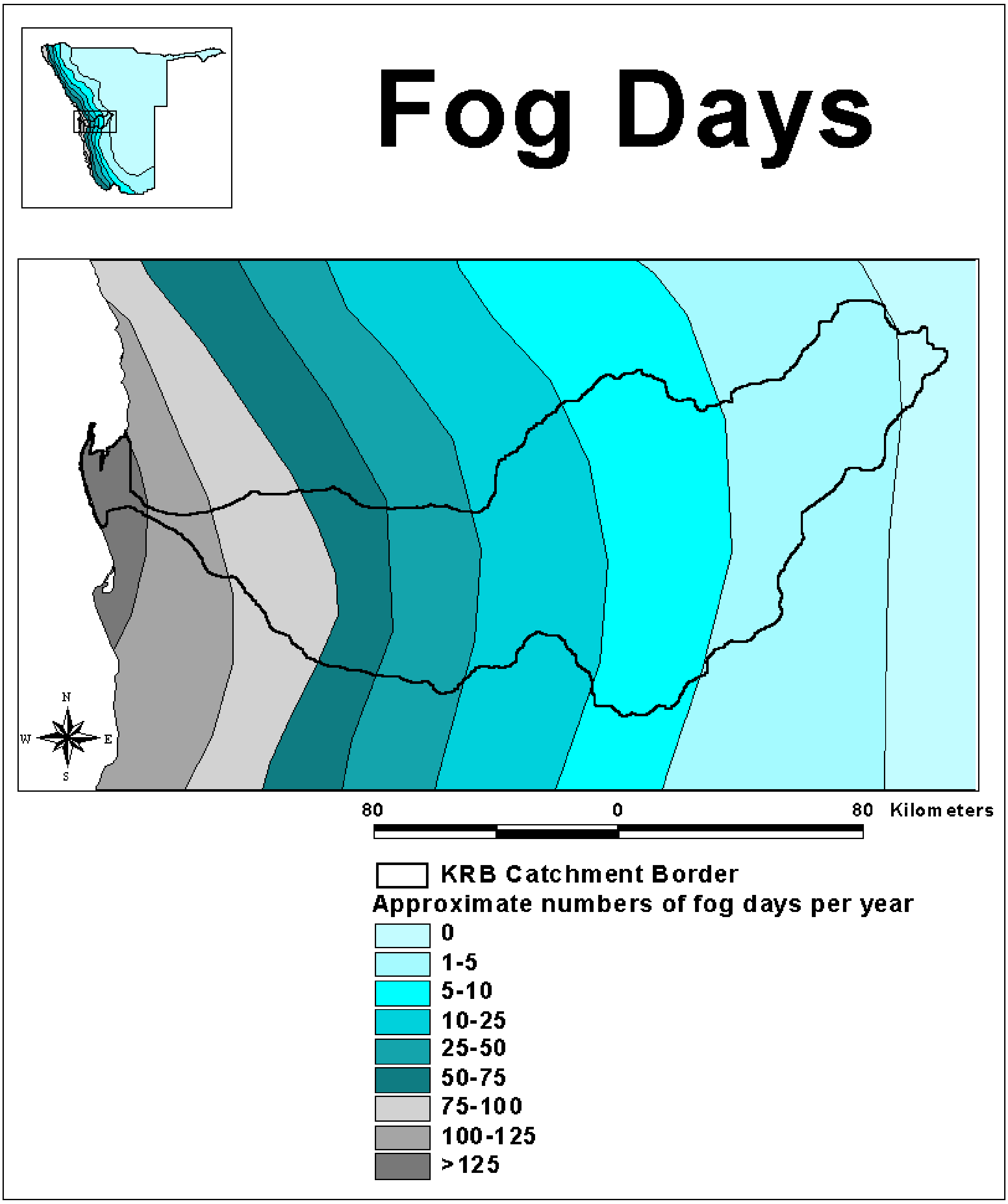


Figure E.10: Approximate numbers of fog days per year

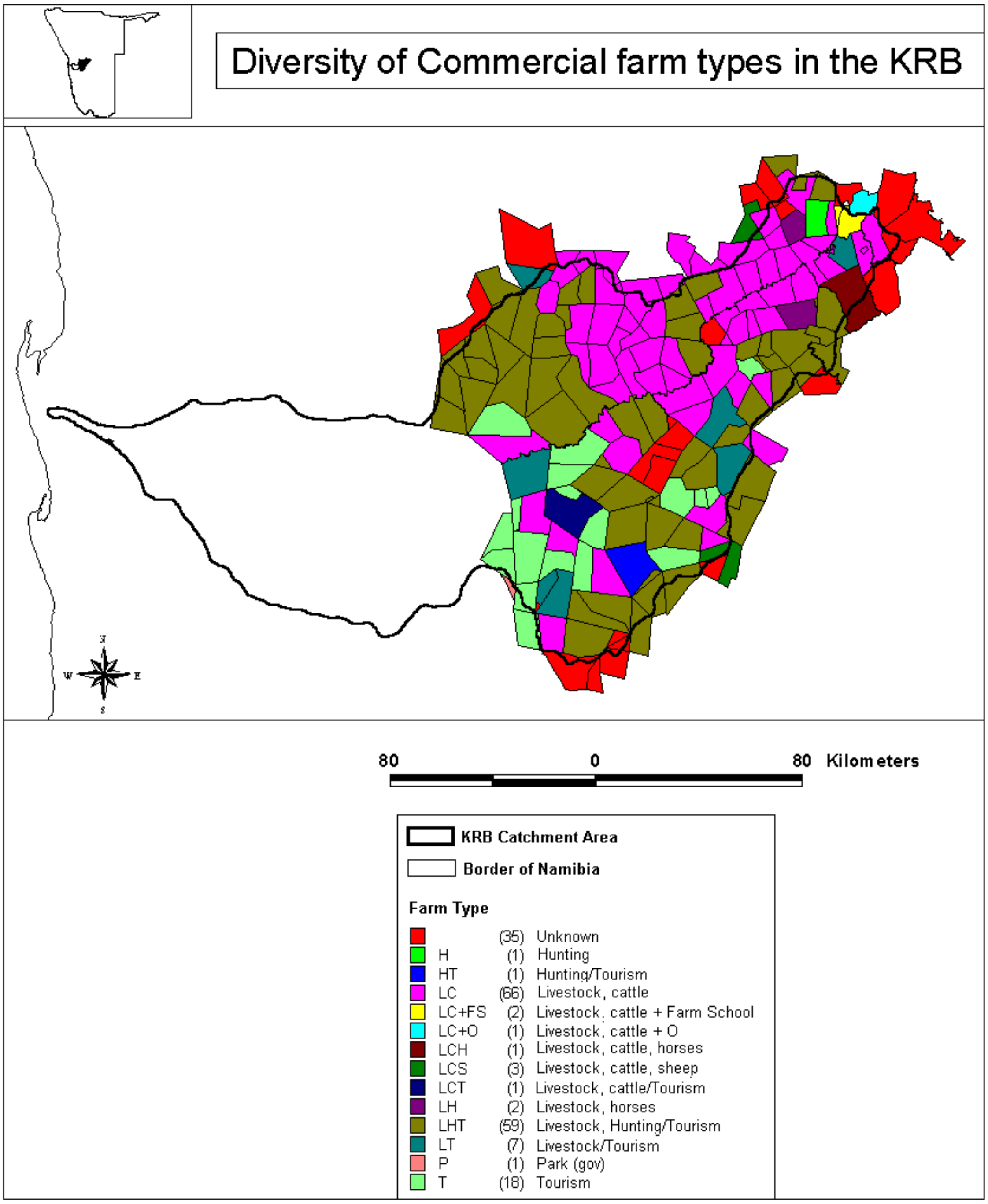


Figure E.11: Diversity of Commercial farm types in the KRB

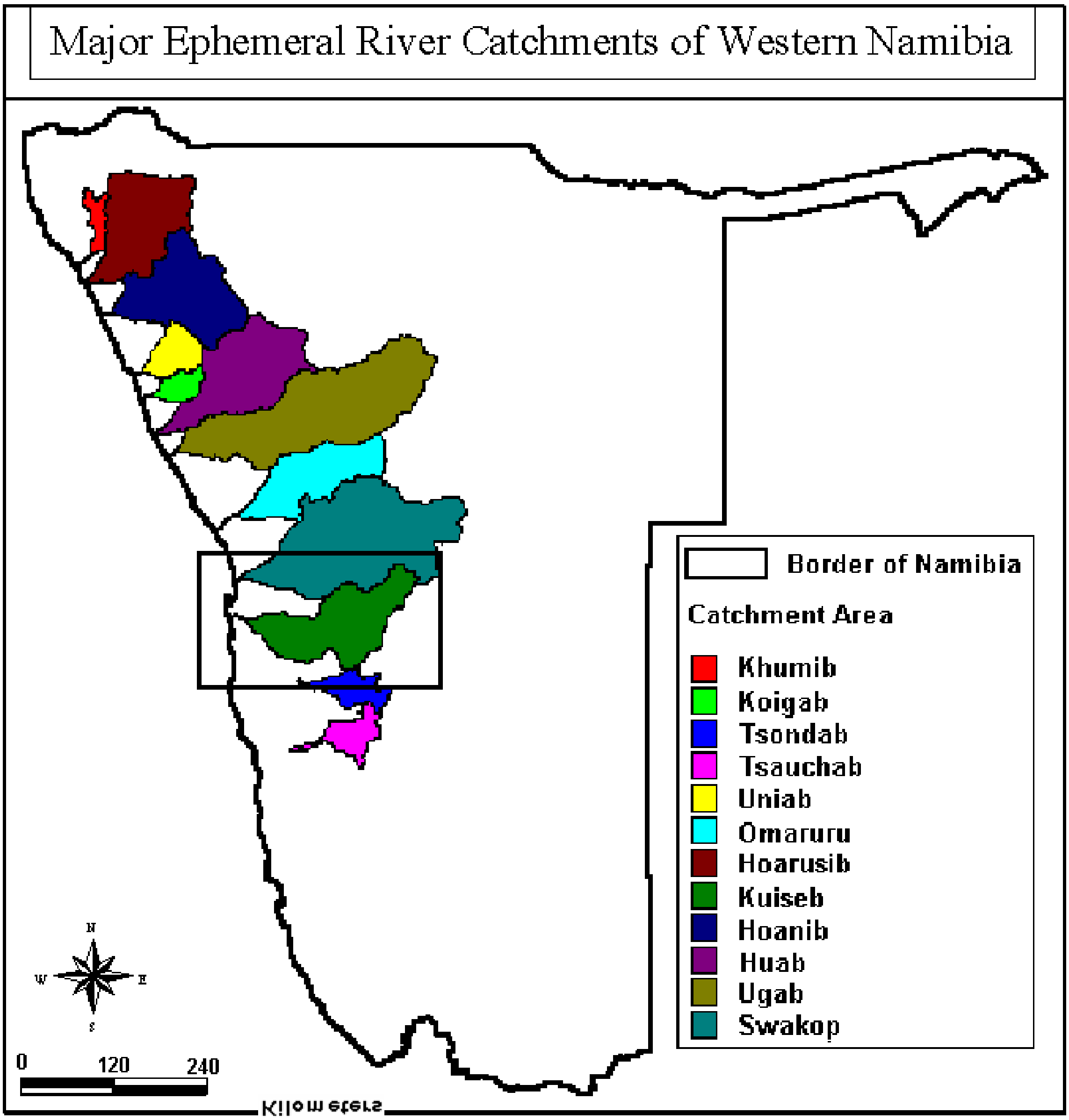


Figure E.12: Major Ephemeral River Catchments of Western Namibia

Appendix F: Rainfall Data for Selected Farms

The following charts display annual rainfall amounts for five farms in the upper catchment. All information was provided by the Weather Bureau.

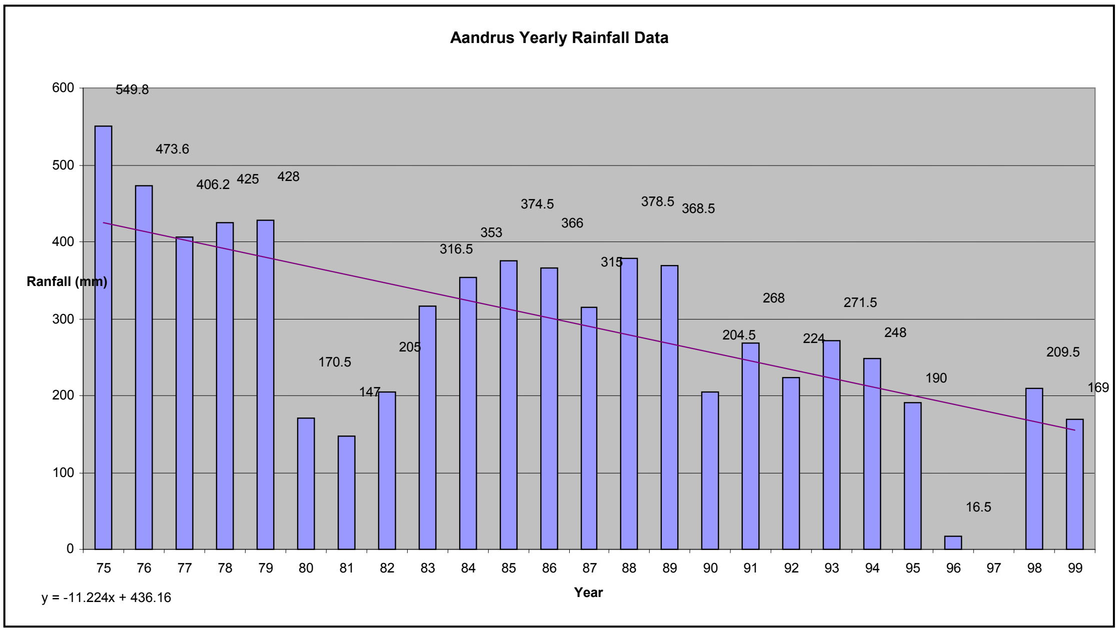


Figure F.1: Aaundrus annual rainfall data from 1975-1999

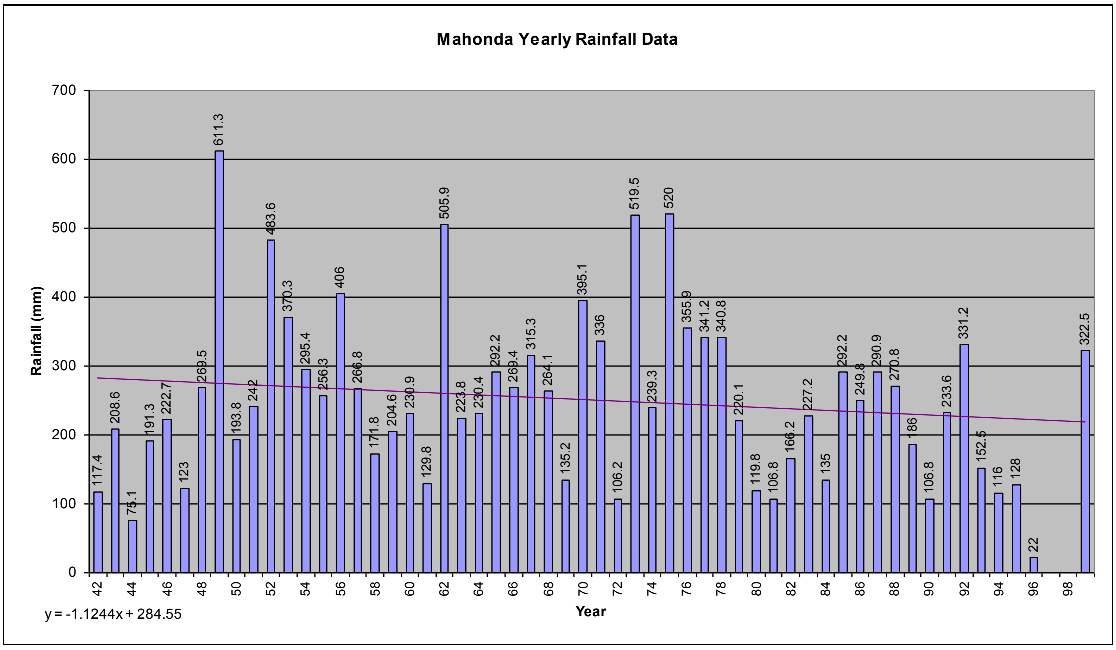


Figure F.2: Mahonda annual rainfall data from 1942-1998

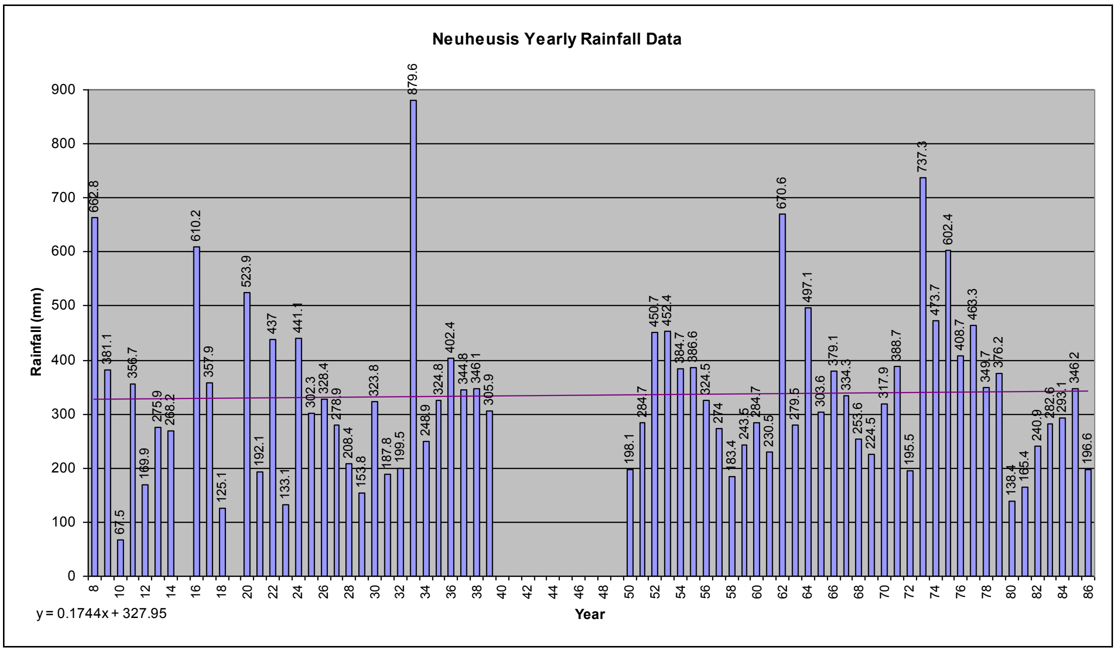


Figure F.3: Neuheusis annual rainfall data from 1908-1986

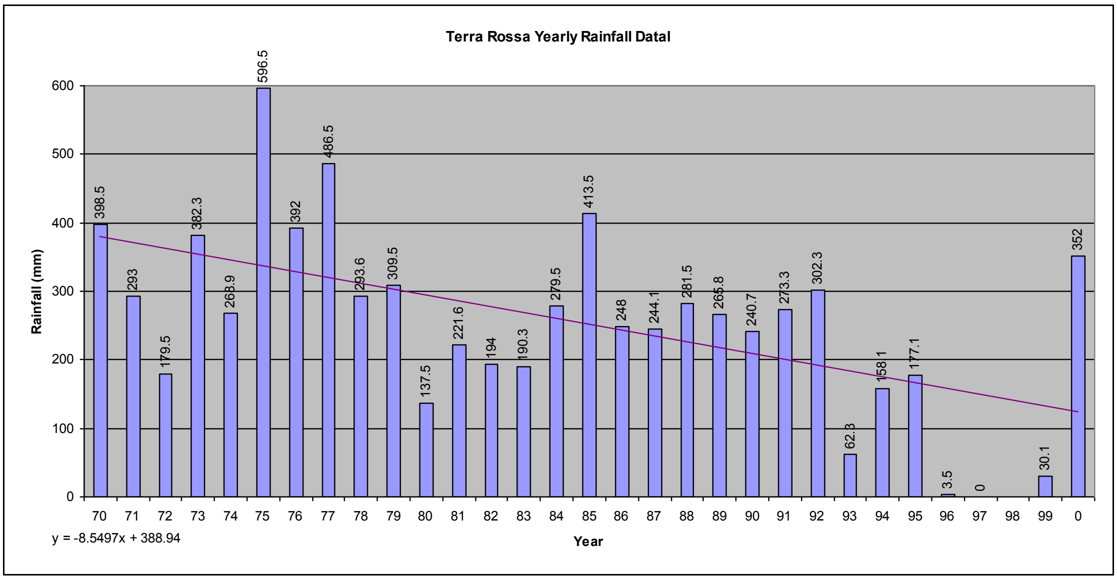


Figure F.4: Terra Rossa annual rainfall data from 1970-2000

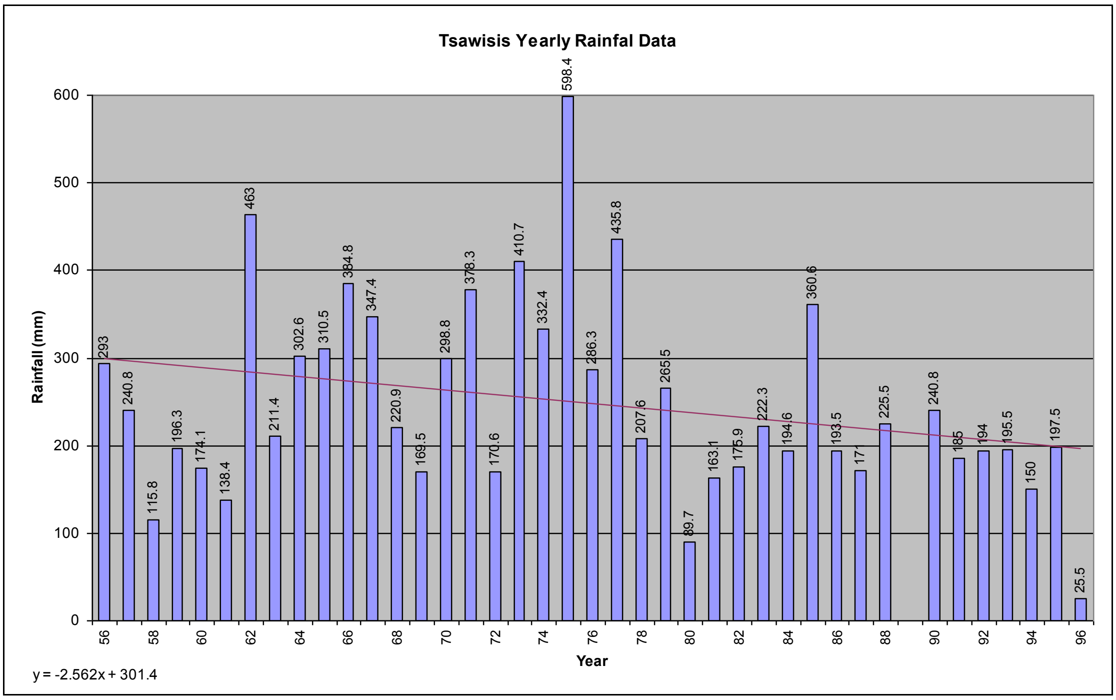


Figure F.5: Tsawisis annual rainfall data from 1956-1996

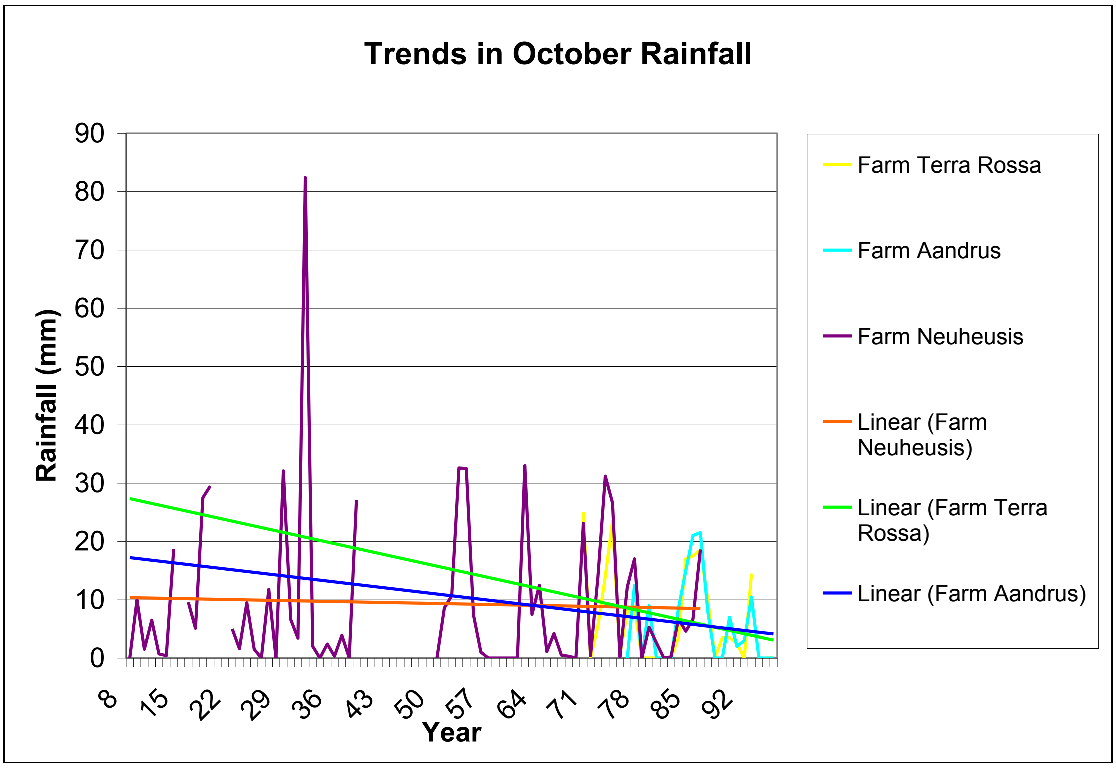


Figure F.6: October rainfall data for three farms in the upper catchment

Appendix G: Brochure of Findings

Recommendations to Stakeholders

After a thorough analysis of our findings, we have developed a set of recommendations for the KRB stakeholders. These recommendations include topics that should receive additional study through the ELAK project and suggestions for commercial farmers to improve water management practices throughout the KRB.

We urge ELAK to further research these farms. Obtaining information on water use measurements, complete records on water infrastructure changes, factors affecting surface water runoff, and the influence of farm diversification on water management would strengthen recommendations for the entire river basin.

Every farmer with active dams cited evaporation as the main source of water loss on his/her farm. We suggest investigating the following two techniques to reduce evaporation in dams and reservoirs:

*Pump water directly from the dam catchment area into covered reservoirs and/or closed tanks for use or even boreholes.

*Use mesh shade covers for reservoirs and dams to reduce evaporation while allowing rainfall and fresh air to enter the reservoir.

Furthermore, if farmers exchange knowledge about innovative water management practices, it could improve conditions on these farms and lower water-related costs as well. Continued communication through farm unions is good place to start.

We also found that farm dams require service *at least* every 8-10 years to improve dam capacity and recharge capability. We encourage farmers to continue excavating their dams regularly.

To the other stakeholder groups we recommend that they look into alternative water sources and water management practices such as desalination and fog water utilization. Making use of alternative water sources may reduce inter-stakeholder group tensions as well as relieve stress on the aquifer in the lower KRB.

Take-home Message

The KRB faces a variety of water management and supply problems but no single stakeholde can be held responsible. Issues surrounding water availability and sustainability in the KRB are the responsibility of stakholders and they must work together to understand and control these challenges.

This project was completed as an Interactive Qualifying Project (IQP) for Worcester Polytechnic Institute in Worcester, Massachusetts, USA.

This brochure is a sample of our findings and recommendations. A detailed report is available at the DRFN.

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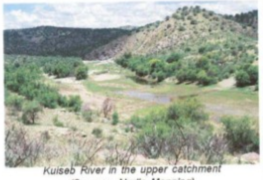
Kuiseb River Basin Management Study

Conducted
March-April 2003
by Erin Hicks, JR Johnson & Mike Torilli



Kuiseb River in the upper catchment (Source: Nadia Manning)

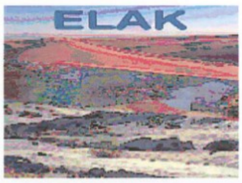
Project Summary:
An assessment of water management practices on the commercial farmer in the upper Kuiseb River Basin (KRB) and recommendations to improve water management and conduct additional research for all stakeholders of the KRB, sponsored by the Desert Research Foundation of Namibia.

Introduction to Our Project

The Kuiseb River is one of the most heavily used ephemeral rivers in the country. It provides all the water used in Walvis Bay and Swakopmund's Hansa Brewery. In addition, it supports the farming activities of the indigenous Topnaar people along the lower watercourse, and the activities on 109 commercial farms in the upper reaches of its catchment area.

Commercial farmers in the upper KRB utilize dams as a supplemental water source to boreholes. However, some stakeholders believe that commercial farm dams in the upper Kuiseb retain flood waters, which hinders the recharge of aquifers in the lower catchment.

The goal of this project was to develop recommendations for the commercial farms. The Enivironmental Learning and Action in the Kuiseb Project (ELAK) can these recommendations to further debate resolution amongst the stakeholders concerning integrated water management in the Kuiseb River Basin (KRB). We hope that our recommendations will contribute to a better understanding of the water management practices in the upper catchment amongst all user groups.



Quantitative Research Results

Open water reservoir (Source: Justin Johnson)

Our findings were based on 13 interviews with farmers, for a total sample size of 16 farms. In summary, we found:

* Factors influencing their water infrastructure: location within the upper catchment and farm type appeared to influence the number of boreholes per farm, but not dams.

* Water conservation and recharge efforts: farmers are limited by costs, and most do not use technologies to reduce water consumption. Dams recharge groundwater supplies, and several farmers have records to substantiate this claim.

* Effects of water infrastructure on downstream users: boreholes only affect local groundwater dynamics and do not influence the aquifer in the lower catchment. The amount of water that farm dams withhold appears to be negligible and is not responsible for groundwater shortages in the lower catchment.

* Communication: farmers are not communicating enough about the success of their water management practices.

These 4 points are discussed further in this brochure.

Qualitative Research Results

All of the farmers surveyed believe that their dams have no effect on any downstream users. Four reasons justify this claim:

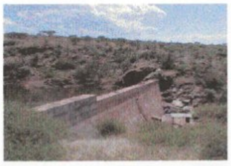
* The Department of Water Affairs (DWA) stated that dams have no significant effect on other stakeholders downstream.

* The Hydrogeological Association of Namibia has found that late flood waters (which are respon sible for recharging the lower catchment's aquifer) can overrun dam walls and flow to downstream users.

* Existing dams continue to gradually gather silt and sediment, which reduces their capacity and increases water runoff.

* Rain in the river basin is highly localized, and all farmers surveyed believed that even without their dams in place, this rain water would not reach downstream users.

Other factors contribute to the groundwater shortage in the lower catchment. Improved land management practices have reduced overgrazing and runoff. Annual rainfall in the upper catchment has been decreasing over the last several decades. An increase in population water abstraction in the coastal regions furthers problem. For these reasons, no single party or stakeholder group can be accounted for the reduction in water availability.

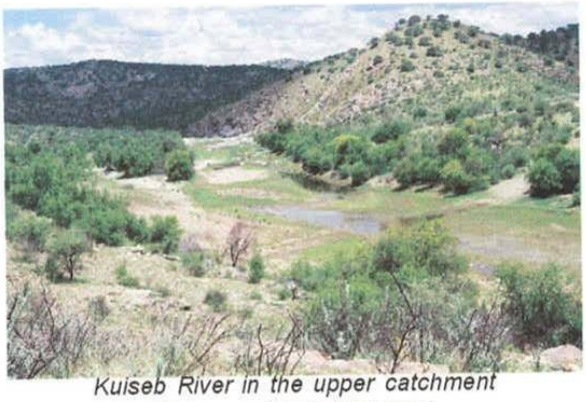


Storage dam on a farm (Source: Justin Johnson)

Kuiseb River Basin Management Study

Conducted March-April 2003

by Erin Hicks, JR Johnson & Mike Torilli



Kuiseb River in the upper catchment (Source: Nadia Manning)

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DRFN

Page 1 of Brochure

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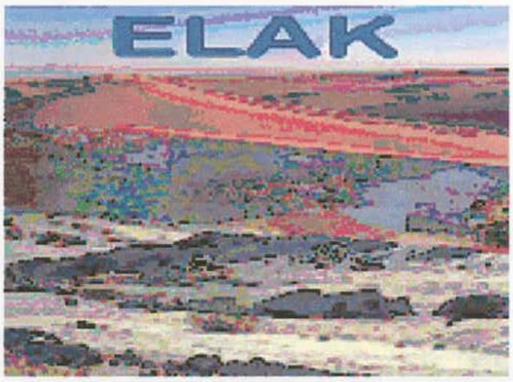
Commercial farmers in the upper KRB utilize dams as a supplemental water source to boreholes. However, some stakeholders believe that commercial farm dams in the upper Kuiseb retain flood waters, which hinders the recharge of aquifers in the lower catchment.

The goal of this project was to develop recommendations for the commercial farms. The Enivironmental Learning and Action in the Kuiseb Project (ELAK) can these recommendations to further debate resolution amongst the stakeholders concerning integrated water management in the Kuiseb River Basin (KRB). We hope that our recommendations will contribute to a better understanding of the water management practices in the upper catchment amongst all user groups.



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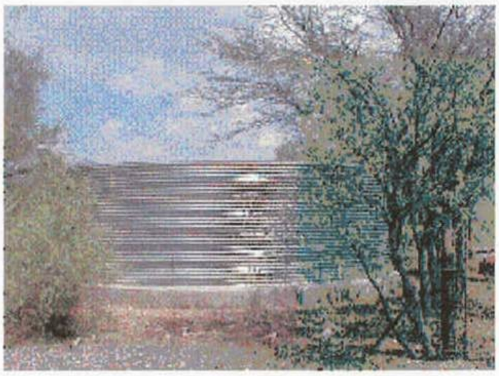
Quantitative Research Results



Open water reservoir (Source: Justin Johnson)

Our findings were based on 13 interviews with farmers, for a total sample size of 16 farms. In summary, we found:

* Factors influencing their water infrastructure: location within the upper catchment and farm type appeared to influence the number of boreholes per farm, but not dams.
* Water conservation and recharge efforts: farmers are limited by costs, and most do not use technologies to reduce water consumption. Dams recharge groundwater supplies, and several farmers have records to substantiate this claim.

* Effects of water infrastructure on downstream users: boreholes only affect local groundwater dynamics and do not influence the aquifer in the lower catchment. The amount of water that farm dams withhold appears to be negligible and is not responsible for groundwater shortages in the lower catchment.

* Communication: farmers are not communicating enough about the success of their water management practices.

These 4 points are discussed further in this brochure.

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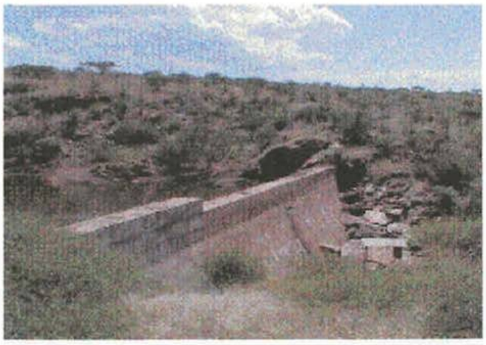
Qualitative Research Results

All of the farmers surveyed believe that their dams have no effect on any downstream users. Four reasons justify this claim:

* The Department of Water Affairs (DWA) stated that dams have no significant effect on other stakeholders downstream.
* The Hydrogeological Association of Namibia has found that late flood waters (which are respon sible for recharging the lower catchment's aquifer) can overrun dam walls and flow to downstream users.
* Existing dams continue to gradually gather silt and sediment, which reduces their capacity and increases water runoff.
* Rain in the river basin is highly localized, and all farmers surveyed believed that even without their dams in place, this rain water would not reach downstream users.

Other factors contribute to the groundwater shortage in the lower catchment. Improved land management practices have reduced overgrazing and runoff. Annual rainfall in the upper catchment has been decreasing over the last several decades. An increase in population water abstraction in the coastal regions furthers problem. For these reasons, no single party or stakeholder group can be accounted for the reduction in water availability.



Storage dam on a farm (Source: Justin Johnson)

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Recommendations to Stakeholders

After a thorough analysis of our findings, we have developed a set of recommendations for the KRB stakeholders. These recommendations include topics that should receive additional study through the ELAK project and suggestions for commercial farmers to improve water management practices throughout the KRB.

We urge ELAK to further research these farms. Obtaining information on water use measurements, complete records on water infrastructure changes, factors affecting surface water runoff, and the influence of farm diversification on water management would strengthen recommendations for the entire river basin.

Every farmer with active dams cited evaporation as the main source of water loss on his/her farm. We suggest investigating the following two techniques to reduce evaporation in dams and reservoirs:

*Pump water directly from the dam catchment area into covered reservoirs and/or closed tanks for use or even boreholes.

*Use mesh shade covers for reservoirs and dams to reduce evaporation while allowing rainfall and fresh air to enter the reservoir.

Furthermore, if farmers exchange knowledge about innovative water management practices, it could improve conditions on these farms and lower water-related costs as well. Continued communication through farm unions is good place to start.

We also found that farm dams require service *at least* every 8-10 years to improve dam capacity and recharge capability. We encourage farmers to continue excavating their dams regularly.

To the other stakeholder groups we recommend that they look into alternative water sources and water management practices such as desalination and fog water utilization. Making use of alternative water sources may reduce inter-stakeholder group tensions as well as relieve stress on the aquifer in the lower KRB.

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Take-home Message

The KRB faces a variety of water management and supply problems but no single stakeholde can be held responsible. Issues surrounding water availability and sustainability in the KRB are the responsibility of stakholders and they must work together to understand and control these challenges.

This project was completed as an Interactive Qualifying Project (IQP) for Worcester Polytechnic Institute in Worcester, Massachusetts, USA.

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This brochure is a sample of our findings and recommendations. A detailed report is available at the DRFN.

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