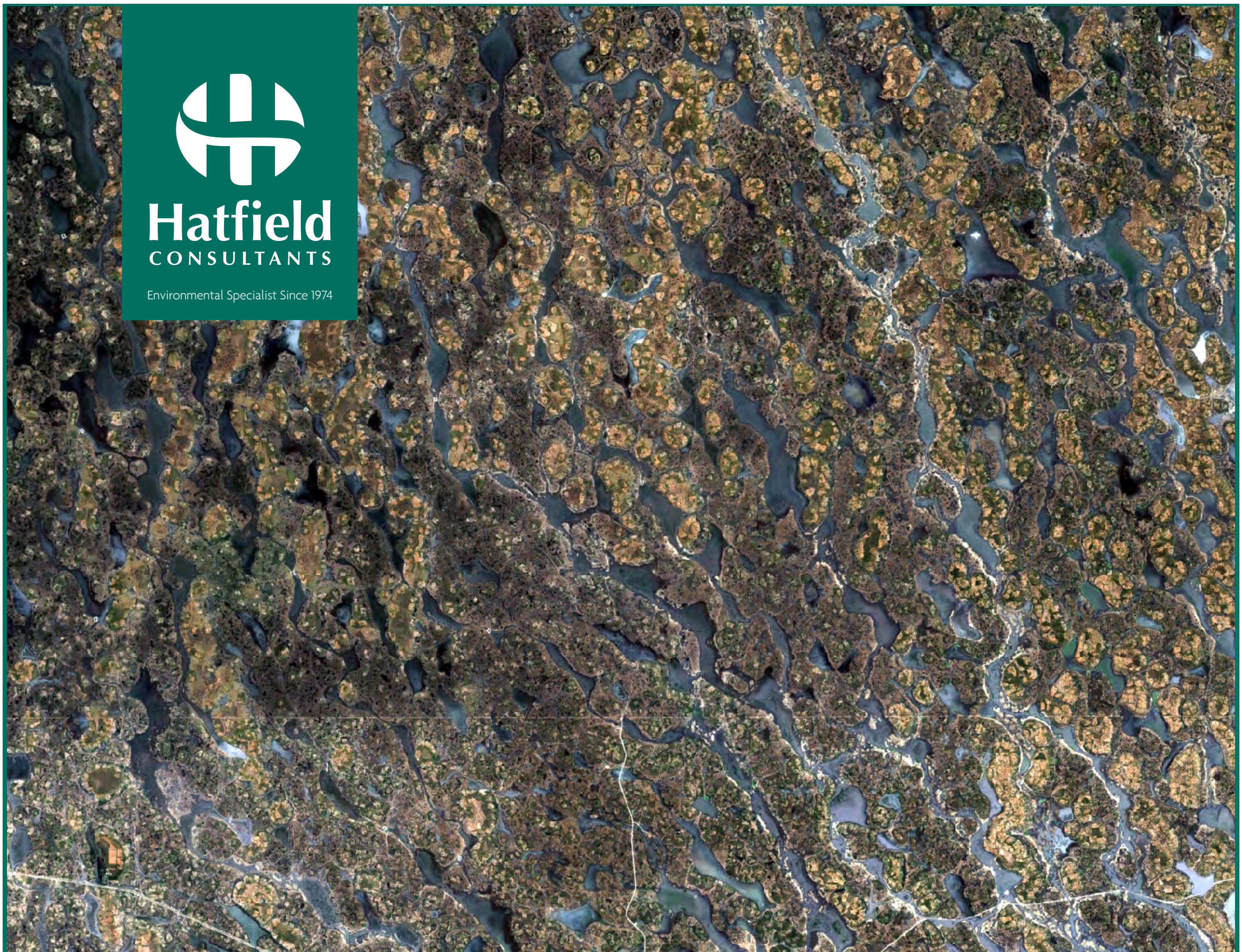

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Environmental Specialist Since 1974

CUVECOM Consultancy
Scoping Study for Enhancement of Transboundary Water Management in the Cuvelai River Basin
Report 2: Rapid Assessment

May 2017 **Version 2.0**

Prepared for:

GIZ Transboundary Water Management in SADC Programme
Gaborone, Botswana

implemented by: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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CUVECOM CONSULTANCY SCOPING REPORT FOR ENHANCEMENT OF TRANSBOUNDARY WATER MANAGEMENT IN THE CUVELAI RIVER BASIN

REPORT 2: RAPID ASSESSMENT

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VERSION 2

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AfDB	African Development Bank
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BMA	Basin Management Approach
CBD	Convention on Biological Diversity
CEDAW	Convention on the Elimination of all Forms of Discrimination against Women
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CPTC	Commissao Permanente da Bacio do Rio Cunen
CREST	Coupled Routing and Excess Storage hydrological model
CRU	Climatic Research Unit
DEM	Digital elevation model
DRFN	Desert Research Foundation of Namibia
DRWS	Directorate of Rural Water Supply
DWA	Department of Water Affairs (Namibia)
ECCAS	Economic Community of Central African States
EDF	European Development Fund
EIA	Environmental Impact Assessment
EO-1	Earth Observing-1
ESA	European Space Agency
ET	Evapotranspiration
FRM	flood risk management
GABHIC	Gabinete para a Administracao da Bacia Hidrográfica do Rio Cunene
GCM	Global Climate Model
GDACS	Global Disaster Alert and Coordination System
GDEM	Global Digital Elevation Model V2
GEF	Global Environment Facility
GFDS	Global Flood Detection System
GFMS	Global Flood Monitoring System
GHCN	Global Historical Climatology Network
GHG	Greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GPCC	Global Precipitation Climatology Centre
GWP	Global Water Partnership
HDI	Human Development Index
HYCOS	Hydrological Cycle Observation System
ICT	Information and Communications Technologies
INRH	National Institute for Water Resources (Angola)
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ITCZ	Intertropical Convergence Zone
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
JRC	Joint Research Centre (European Commission)
KNMI	Koninklijk Nederlands Meteorologisch Instituut
MAP	Mean annual precipitation
masl	Metres above sea level
MAWF	Ministry of Agriculture, Water and Forestry
MINAMB	Ministry of Environment (Angola)

MODIS	Moderate Resolution Imaging Spectroradiometer
NamWater	Namibian Water Corporation
NASA	National Aeronautics and Space Administration
NBI	Nile Basin Initiative
NCEP/NCAR	National Centers for Environmental Prediction/National Center for Atmospheric Research
NHS	Namibia Hydrological Services
NMS	Namibia Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NORAD	Norwegian Agency for Development Cooperation
NRT	Near-real-time
NWC	Namibia Water Corporation
PET	Potential Evapotranspiration
PPP	Purchasing power parity
QAQC	Quality Assurance / Quality Control
RBMP	River Basin Management Plan
RBO	River Basin Organisation
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RMF	Regional Maximum Flood
RSAP	Regional Strategic Action Plan
RWP	Regional Water Policy
SADC	Southern Africa Development Community
SAP	Strategic Action Plan
SASSCAL	Southern Africa Science Service Centre for Climate Change and Adaptive Land-Use
SPEI	Standardised Precipitation-Evapotranspiration Index
SRES	Special Report Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
TDA	Transboundary Diagnostic Analysis
TRMM	Tropical Rainfall Measuring Mission
UNCAC	United Nations Convention against Corruption
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNITAR	United Nations Institute for Training and Research
UNOSAT	United Nations Operational Satellite Applications Programme
WB	The World Bank
WMO	World Meteorological Organisation
WOIS	Water Observation Information System

ACKNOWLEDGEMENTS

The consultant would like to thank the co-chairs and delegations of CUVECOM, stakeholders from the Basin who attended stakeholder consultations during this project, SADC Water Division (specifically Mr Phera Ramoeli), GIZ Transboundary Water Management Programme, and our language consultant, Rui Correia. Special thanks go to John Mendelsohn and Development Workshop, for their support in terms of data and the excellent publication series on the Cuvelai River Basin. The decades of work that have gone into these volumes is testament to their commitment to social and environmental upliftment of the Cuvelai River Basin.

EXECUTIVE SUMMARY

The Cuvelai River Basin is a transboundary river basin, shared between the countries of Angola and Namibia. The Cuvelai River is endorheic – draining inland, rather than to the ocean – and on its journey from its source in the Angolan Highlands, it exhibits unique drainage patterns seen nowhere else on Earth. Except for the drainage channels in the Cuvelai and Mui sub-basins in Angola, the Cuvelai River is ephemeral – flowing only in response to rainfall events – and the western portion of the basin is characterised by a broad landscape of interconnected channels known as iishana (singular – oshana). This broad, almost level landscape is also prone to extensive flooding, following high intensity or prolonged rainfall events. These rainfall events are contrasted with long periods of low or absent rainfall, resulting in drought conditions. Northern Namibia and Southern Angola are home to large populations, with settlements spread across the entire region, concentrated in the iishana region, and in villages around the border region. Significant formal and informal cross-border trade in goods and services contribute to livelihoods of many basin dwellers, and transboundary grazing by livestock and other migratory practices are widespread as cultural and social ties across the political boundary are strong. The national business languages are English (Namibia) and Portuguese (Angola), but most basin dwellers share dialects of a common language – Oshikwanyama.

To ease water scarcity and improve water supply in the Cuvelai River Basin, the governments of Angola and Namibia have cooperated on the development of the Kunene Transboundary Water Supply Project, which sees abstraction of water from the Cunene River in Angola at Calueque Dam, which is then transferred over the border into Namibia via a canal, and into the Cuvelai River Basin, and on to Oshakati, where it is treated to augment existing supplies, and redistributed across the region to various towns and villages. Water from this system is also transferred back over the border to Ondjiva in Southern Angola. This project supplements vulnerable water supplies in both countries, and is the basis for an already cooperative environment between the countries of Angola and Namibia.

The agreement to establish the Cuvelai Watercourse Commission (CUVECOM) was signed by the Government of the Republic of Angola and the Government of the Republic of Namibia, in Windhoek, Namibia, in September 2014. The Agreement establishes, the definitions, the scope of the agreement, and the objectives and functions, structure and powers of the Commission. Following the signing of the agreement, small steps have been taken to move forward, but the current project is intended to catalyse action, and support concrete, tangible steps toward the development and implementation of the Commission.

This document is a Rapid Basin Assessment of the Cuvelai River Basin, forming Report 2 of the Scoping Report for Enhancement of Transboundary Water Management in the Cuvelai River Basin. Report 1 includes, a summary of stakeholder consultations undertaken with key basin stakeholders, and provides a series of recommendations based upon information gaps identified during the Rapid Assessment and priorities identified by the stakeholders. The Rapid Assessment was based upon publically available literature and data, sourced from the two delegations and other open sources, and is aimed at identifying management challenges that will impact CUVECOM.

The Rapid Assessment provides profiles of the biophysical, hydroclimate, climate change, water utilisation, disaster risk management, governance and institutional situation in the Cuvelai River Basin, and then discusses institutional arrangements for CUVECOM, and possible sustainable financing mechanisms.

The Cuvelai River Basin is a relatively flat river basin, resulting in the unique iishana drainage in the west of the basin, flowing inland to Etosha Pan, should flows be high enough. The basin extent is the subject of discussion, and should be finalised in early stages of CUVECOM technical programmes. Each of the sub-basins – Cuvelai, Mui, Calemo-Caundo, Cuvelai Delta, Shana, Central Drainage, Central Pans, Eastern Sand, and Saline Pans – have individual characteristics, most notable of which are the Cuvelai and Mui sub-basins, which include the only perennial waters in the basin.

Soils in the basin are moderately fertile, dominated by weathered, leached, and sandy arenosols, especially in the east and north of the basin, and soil fertility and distribution has significant role to play in the distribution of the human population, with settlement aligning with the presence of more fertile soil for cultivation. Evaporation of flood water creates saline soils throughout the southern portion of the basin (Section 2.1.4), which hinders plant growth (Mendelsohn and Weber 2011).

While not widely described, the ecology of the Cuvelai River Basin comprises desert shrubland, tropical and sub-tropical grasslands, shrublands and savanna, with flood grasslands/savanna around the southern pans. Biodiversity records are not widely available, except for around the Etosha National Park, which is home to a wide variety of mammals, reptiles, fish and birds. Future basin assessments will need to characterise the biodiversity of the Cuvelai River Basin in some detail in order to fully understand and cater for environmental flows, and biodiversity requirements.

The Cuvelai Basin is located in a sedimentary basin known as the Owambo Basin, part of the much larger Kalahari Basin. The Owambo is over 8,000 meters thick and consists of three main super groups overlying a crystalline basement: Kalahari group, Karoo group, and Congo Craton. It is bordered to the east and south by the Damara Belt to the east and to the west by a rift complex.

The Cuvelai River rises in the Angolan highlands flowing from north to south, inland; forming a network of ‘iishana’ in the west, mostly ephemeral and anastomosing river channels. The iishana network extends from the northwest of the catchment near the Cunene River to the Etosha Pan, and is about 270 km long, and about 150 km wide at its widest point.

Ephemeral flow during *efundja* floods quickly evaporates, leaving salt deposits, the largest of which is the Etosha Pan, which is about 110 km east to west and 45 km north to south. Unconsolidated sediments are mostly fluvial, and are hundreds of metres deep. Aeolian sediments are present in the eastern catchment; these sediments are particularly porous, and promote infiltration of rain and flood water (Mendelsohn and Weber 2011).

The land-cover of the Cuvelai River Basin closely matches the topography and eco-regions, but with marked changes in land use and land cover south of the border. Landcover maps show sparse forest and woodland cover across the eastern portion of the basin, with some agriculture and barren land across most the western basin.

Average annual air temperature is coolest in the higher elevation headwaters (~21^{o}C), and warmest in the lower-elevation south (~23^{o}C). Winter air temperatures are similar, but summer air temperatures are up to 3.7^{o}C warmer in the south. Rainfall distribution, intensity, and duration are finely balanced in the Cuvelai Basin; too little rainfall can easily lead to drought conditions and too much can lead to flooding. The severity of floods is determined by the location, intensity, and duration of rainfall. Most flood waters cross the border as surface water discharge in the iishana region, spreading south through the shallow oshana channels, and main Cuvelai River channel. Potential Evapotranspiration is more than three times annual average precipitation: highest in the warmest months (about 160 mm/month in

September and October), and lowest in the coolest months (about 90-100 mm/month in May to July). Droughts are common, often lasting multiple seasons, replaced more often by flood conditions.

The Cuvelai Basin covers an area of about 159,620 km^2 (Mendelsohn and Weber 2011), of which 67% is in Namibia, and 33% is in Angola (Filali-Meknassi et al. 2014). The basin is quite flat, with a nominal drop in elevation - 1,500 metres above sea level in the north to 1,050 in the south, over approximately 400 km (Mendelsohn and Weber 2011). The level nature of the basin landscape, and the seasonality of precipitation promote flooding.

Existing cooperation between Angola and Namibia facilitates the provision of water from the neighbouring Cuene River Basin at Calueque Dam, into the Cuvelai River Basin. Water is pumped into Olushandja Dam, and then on to Oshakati, then back into Angola to Ondjiva, to augment supplies there.

Two main groundwater flow systems are identified in the Cuvelai River Basin: groundwater recharge from the southern and western edges of the basin flows north and east through the Damara Sequence dolomites, recharging the overlying Karoo and Kalahari sequences, and the deep multi-layered Kalahari Aquifer is recharged from the north in Angola and flows south toward the Etosha Pan and the Okavango River. Due to fluctuating rainfall patters, the importance of groundwater to sustaining life in the Cuvelai River Basin cannot be overstated. However, most shallow aquifers are of varying, usually poor, quality. Deeper aquifers are yielding significantly better quality water, but further work is required to properly quantify the resources across the entire basin.

The Cuvelai River Basin is extremely dry, prone to floods and drought, and supports a large rural population dependant on agriculture and water availability. These characteristics make the basin sensitive and vulnerable to climate change, making the assessment of likely changes and uncertainties essential for mitigation and planning (Zeidler et al. 2010), and underline the need for comprehensive monitoring of hydro-climatic parameters, and the sharing of such information between the member states. Furthermore, as the basin is prone to floods and droughts, there is an urgent need for a sustainable disaster management system, which monitors key biophysical and hydroclimatic parameters, and provides early warning of climate-related disasters.

Angola and Namibia share the Cuvelai Basin, and any attempt to sustainably manage a resource must acknowledge the system's interlinkages with the socio-political context and varied social and economic perceptions and processes. Population density is concentrated in the centre of the basin and roughly correlates with higher soil fertility zones (RAISON 2013). Access to water is a key limiting factor to population growth. There are 45 towns and villages in the basin, 25 in Namibia and 20 in Angola (RAISON 2013). The population of urban areas in Northern Namibia (still within the Cuvelai Basin) increases by as much as 300% during public holidays (Zimmermann 2013), which has implications for water management. Ethnicity in the basin, at least historically, is almost entirely Owambo (RAISON 2013), and poorer households are often situated in areas more susceptible to flooding and constructed from materials less resistant to flooding (RAISON 2013), which can contribute to a higher likelihood for loss of assets.

Cross-cutting issues of Poverty and Gender have been identified through this consultancy, but due to significant lack of information in both areas, future research and data gathering will be required to fully comprehend the nature and extent of poverty and water-related gender issues.

Finally, an assessment was made of flood monitoring and forecasting, evaluating the applicability of the SADC Flood Atlas and it's methodologies, and possible data and information gaps. The assessment revealed that climatic monitoring in the Cuvelai basin is inadequate and monitored hydrologic data are sparse, making calibration and validation of flood forecasting models and dissemination of timely flood alerts difficult, and digital elevation models available for the Cuvelai River Basin are relatively low resolution, making accurate modelling difficult given the low relief of the catchment.

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AMENDMENT RECORD

This report has been issued and amended as follows:

Issue	Description	Date	Approved by	
1	First version of the CUVECOM Consultancy Report	2017-04-19	Grant Bruce Project Director	Simon Hughes Project Manager
1	Second version of the CUVECOM Consultancy Report: Rapid Assessment	2017-05-31	Grant Bruce Project Director	Simon Hughes Project Manager

1.0 INTRODUCTION

The Cuvelai River Basin is a transboundary river basin, shared between the countries of Angola and Namibia. The Cuvelai River is endorheic – draining inland, rather than to the ocean – and on its journey from its source in the Angolan Highlands, it exhibits unique drainage patterns seen nowhere else on Earth. Except for the drainage channels in the Cuvelai and Mui sub-basins in Angola, the Cuvelai River is ephemeral – flowing only in response to rainfall events – and the western portion of the basin is characterised by a broad landscape of interconnected channels known as iishana (singular – oshana). This broad, almost level landscape is also prone to extensive flooding, following high intensity or prolonged rainfall events. These rainfall events are contrasted with long periods of low or absent rainfall, resulting in drought conditions. Northern Namibia and Southern Angola are home to large populations, with settlements spread across the entire region, concentrated in the iishana region, and in villages around the border region. Significant formal and informal cross-border trade in goods and services contribute to livelihoods of many basin dwellers, and transboundary grazing by livestock and other migratory practices are widespread as cultural and social ties across the political boundary are strong. The national business languages are English (Namibia) and Portuguese (Angola), but most basin dwellers share dialects of a common language – Oshikwanyama.

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The agreement to establish the Cuvelai Watercourse Commission (CUVECOM) was signed by the Government of the Republic of Angola and the Government of the Republic of Namibia, in Windhoek, Namibia, in September 2014, hereafter referred to as the Agreement. The Agreement establishes, among other things, the definitions, the scope of the agreement, and the objectives and functions, structure and powers of the Commission. Following the signing of the agreement, small steps have been taken to move forward, but the current project is intended to catalyse action, and support concrete, tangible steps toward the development and implementation of the Commission.

This **Rapid Assessment** is part of the '**CUVECOM Consultancy'** project co-funded by GIZ and UKAid on behalf of the CUVECOM; forming **Report 2** of the **Scoping Report for Enhancement of Transboundary Water Management in the Cuvelai River Basin**.

It is intended as an initial scoping-level assessment of data and information availability for the Cuvelai River Basin, with the intention of identifying management challenges moving forward. It also includes a review of the SADC Flood Atlas, and its applicability for the Cuvelai River Basin.

Report 2: Rapid Assessment includes the following sections:

- A Rapid Assessment of the Cuvelai River Basin, including the following aspects:
  - Physiographic profile;

  - Hydro-climatic profile;
  - Climate change considerations;
  - Water utilisation and demand;
  - Disaster risk management;
  - Social and economic profile;
  - Governance and institutional considerations;
  - Cross-cutting themes
- Summary of Information Gaps Identified;
- Management Challenges Moving Forward
- SADC Flood Atlas Assessment
- Literature cited and data sources.

1.1 REPORT 1

Report 1 summarised outcomes from the parallel stakeholder engagement process, identifying priorities from the stakeholder-level, lessons learned from other river basins, guidance on institutional arrangements and sustainable financing for the further operationalisation of CUVECOM, and a series of recommendations for technical and institutional programmes for the Commission moving forward. Recommendations for operationalisation of CUVECOM identified during the stakeholder consultation process are broken down into institutional and technical issues, as listed below, and discussed in more detail in Report 1:

- **Institutional**
  - CUVECOM structure and physical location;
  - Technical Coordination;
  - Capacity Development;
  - Stakeholder Engagement;
  - Research;
  - Naming conventions; and
  - Knowledge Management and Information Sharing.
- **Technical**
  - Monitoring infrastructure;
  - Physical Infrastructure;
  - Groundwater; and

- Disaster Risk Management.

2.0 METHODOLOGY

A Rapid Assessment provides an inexpensive approach for quickly setting priorities, which can provide direction for future development. From the outset, the purpose of this process was to identify requirements for establishing and continued development of an effective river basin organisation (RBO). Recommendations included as a part of this assessment are preliminary only, and meant to be adapted as ecological conditions, water utilisation patterns, and needs identified by stakeholder groups change.

The Rapid Assessment was guided by **available** literature, sourced from the consultant's collection, GIZ, internet sources, and the delegations from Angola and Namibia. It should be noted that much of the reviewed literature focused on outputs from completed projects, which generally addressed one portion of the basin, either Angolan or Namibian.

The primary focus of this Rapid Assessment was the **identification of information gaps**, which was integrated with stakeholder meeting outputs identified in Report 1, were carried forward into a series of the recommendations for formalisation and future development of CUVECOM, also contained in Report 1.

It is **not** the intention of the Rapid Assessment to rewrite, replicate or compete with the substantial body of work that has been completed by authors including Development Workshop in Angola, John Mendelsohn and Jaro Consulting in Namibia, who have produced respected and well-received basin-wide, or country-specific summaries and atlases of the Cuvelai River Basin. These publications are detailed and were developed over many years, building upon a growing pool of data, information, knowledge and understanding of the basin and its people.

Each section of the Rapid Assessment also includes a brief assessment of information and data gaps, which are in turn summarised in Section 11.0; which is followed by a presentation of the key opportunities and management challenges facing CUVECOM and the people of the Cuvelai River Basin.

A full list of literature and data used in the development of the Profile of the Cuvelai River Basin is provided in Section 15.0.

2.1 ASSUMPTIONS

All assumptions made in this assessment are based only on available information. Conclusions are limited due to a lack of information and data in both countries; however, in general sufficient data and information sources were accessed to conclude the study. It is the opinion of the consultant that the limitations of documentation, data and information is a combination of **existence** – whether data exists at all – and **access/availability** – whether it is possible to obtain the required sources. Therefore, it is assumed that all documentation, data and information identified and accessed is everything that is available, considering clear requests were issued to both delegations for all relevant sources to be provided to the consultant.

This situation points directly to the urgent need for the establishment of a multi-lingual knowledge sharing platform, which is discussed in more detail in Report 1, and a need for consistency in data collection methods and efforts across administrative boundaries.

Please note that the river basin adjacent to the Cuvelai River Basin to the west is spelled 'Cunene' in Angola and 'Kunene' in Namibia. Throughout this document, attempts are made to use the correct reference when referring to the river in different countries. When referring to the basin it is referred to as **Cunene**.

3.0 RAPID ASSESSMENT OF THE CUVELAI RIVER BASIN

To date, several studies and profiles have been developed for the Cuvelai River Basin, but primarily on a country-basins basis - with maps, data, analysis and commentary ceasing at the border of the studied country.

It is important to note that this profile of the Cuvelai River Basin **is not** intended to replicate earlier studies or literature on the basin; and is also not intended to be a new study, collecting and analysing new data; but rather to provide a rapid desktop overview of the basin, setting the scene for the rapid assessment.

The profile includes the following components:

- Physiographic profile;
- Hydro-climate profile;
- Climate Change considerations;
- Water supply and utilisation;
- Disaster risk management;
- Social and economic profile; and
- Governance and institutional aspects.

Each section includes a summary of key available data sources, and data and information gaps.

4.0 BIOPHYSICAL PROFILE

The biophysical environment of the Cuvelai River Basin is distinct and unique, in that they extremely level landscape, shaped largely by the equally exceptional hydrological regime, and the influence of the human population. This profile includes a review of the topography of the Cuvelai River Basin, the basin extent, the soils, flora and fauna, geology, geomorphology and land cover.

4.1 TOPOGRAPHY

There is an approximately 450 m elevation difference between the source of the Cuvelai River in the highlands of southern Angola, and Etosha Pan in northern Namibia, a distance of over 380 km (Mendelsohn, Jarvis, & Robertson, 2013). This is considered to be an extremely flat river basin, especially when compared to the relief of other rivers in the region, for example:

- Limpopo – 2,238 m;
- Cunene – 2,000 m; and
- Orange-Senqu - 3,482 m

The northern portion of the Cuvelai River Basin in Angola, at 1,100 metres above mean sea level is where the source of the Cuvelai River is found. While the flow in the Cuvelai and Mui sub-basins is restricted to river channels, the largest are perennial, fed by annual rainfall of 900 mm (Mendelsohn & Weber 2011; Mendelsohn et al 2013). The central area of the Angolan portion of the Cuvelai River Basin, including the Cuvelai Delta, the Central Drainage, and Central Pans, features largely non-perennial flow, with flooding following high intensity rainfall events, except during drought periods. The Iishana region, which extends approximately 140 km from the southwestern-most area of the Angola portion Cuvelai River Basin, into Namibia, with non-perennial flow usually restricted to the iishana themselves, which are less prone to flooding compared to the central drainage area.

The Central Pans zone is formed by thousands of small pans, which fill with water during localised precipitation events. The pans are mostly isolated from adjacent pans and channels, and flooding in this area is generally not significant, as water is contained in the pans and evaporates or seeps into the sub-surface during dry periods (Mendelsohn & Weber 2011).

The Saline Pans Zone is characterised by large salt pans, including the world famous Etosha Pan, formed as salts transported over millions of years from the upper basin to the South, encrusting the pan surfaces through repeated evaporations. This build-up of saline materials has been transported from the southern reaches of the Iishana and deposited through both alluvial and Aeolian processes in these pans. Agriculture in this area is limited to cattle farming due to the saline soils, meaning that few people live in this Zone. The water that fills these pans during localised rain events is mostly evaporated because the pans are mostly impermeable due to the build-up of a salt crust. During the annual dry season, winds scour the surface of the pans, and removes fine materials, which maintains the depression features of the pans.

4.1.1 Basin Extent

During literature searches, it became clear that there are several accepted basin boundaries in-use. An urgent item for a basin-wide assessment will be to establish an agreed basin boundary, which can be ratified and accepted by CUVECOM. Much of the difficulty in delineating an agreed basin boundary is associated with the extremely flat, and in some cases shifting, topography of the southern half of the basin. Furthermore, it is also noted that there are some channels in the far south west that used to flow to the Cuvelai that now flow to the Kunene.

For the purposes of this Rapid Assessment, the United States Geological Survey (USGS) HydroSHEDS basin boundary is used, until an official boundary is accepted by CUVECOM. This boundary is applicable at a regional scale, as it was developed using consistent elevation data, captured during from Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM), and developed as part of a suite of geo-referenced vector and raster data sets at a range of scales, including river networks, watershed boundaries, drainage directions, and flow accumulations (USGS, 2010).

Topographic data sources include:

- Shapefiles from the Directorate of Environmental Affairs (2002). Coverage is for the Namibian portion of the Study Area;
- Very high resolution LiDAR datasets (Persendt and Gomez 2016);
- A global 30 m resolution digital elevation model (DEM) from National Aeronautics and Space Administration’s (NASA) Shuttle Radar Topography Mission (SRTM)(JPL 2017); and

- A global 20 m resolution DEM from ASTER Global Digital Elevation Model V2 (GDEM) (Gesch et al. 2012).

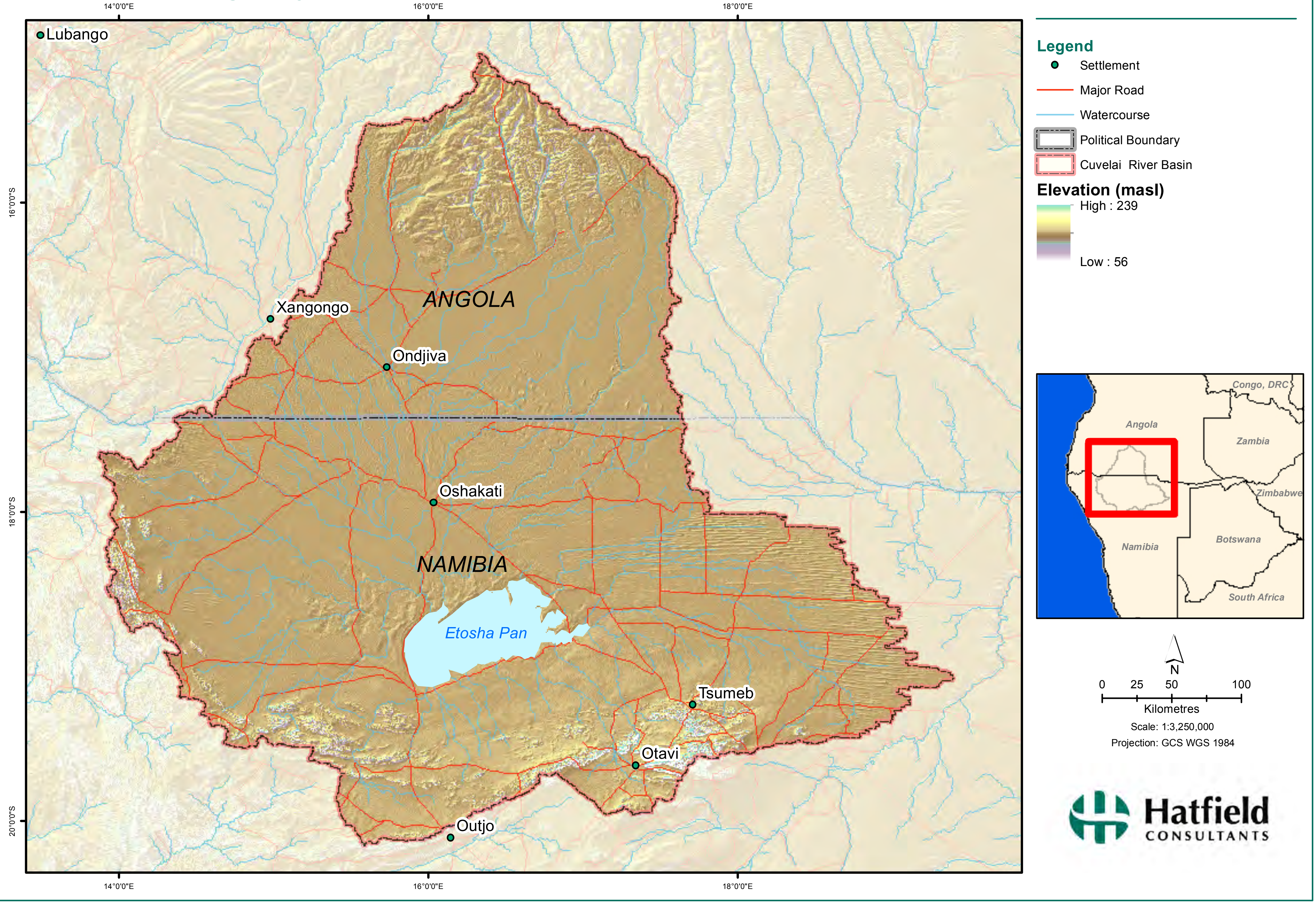
The last two data sets listed here cover the entire basin; however, in both cases, require validation in the Cuvelai River Basin, and due to their resolution, may not be detailed enough for determining hydrological regimes, and river basin and sub-basin boundaries.

4.2 SOILS

Overall, soils are relatively fertile in the Cuvelai (Mendelsohn and Weber 2011). Soils are primarily weathered, leached, and sandy arenosols, especially in the east and north of the basin. Weakly defined cambisols are found in the west of the catchment, especially the saline Shana Zone. Lime-rich calcisols are in the Central Zone, Cuvelai Delta zones (Mendelsohn and Weber 2011).

Due to the limited rainfall, agriculture is largely rain-fed; therefore, the distribution of soils within the basin generally determines the distribution of the population in the basin, as the productivity of soils have, to a large extent, determine where people have settled across the region (Mendelsohn, Jarvis, & Robertson, 2013). The relatedly fertile soils of the iishana, or chana zone, combined with access to shallow groundwater, which are in places fresh (non-saline), and can be accessed from the surface with hand-dug wells, have attracted people from across the region for hundreds of years.

FIGURE 1 - Topography of the Cuvelai River Basin.



4.2.1 Climate Smart Agriculture

Climate Smart Agriculture (CSA) is an integrated approach to agricultural practices that recognises the need to review and transform current farming practices in the face of changes in climatic patterns (FAO, 2017), within the current context of existing soils and farming practices, access to market, and other critical factors. CSA has three objectives:

- Increase sustainable agricultural yields and productivity;
- Develop realistic climate adaptation and resilience mechanisms; and
- Where possible minimise greenhouse gas emissions.

(FAO, 2017)

As the whole of southern Africa is already experiencing the effects of climate variability, CSA is becoming increasingly necessary in the Cuvelai River Basin, as a means of building resilience in agricultural systems. Specifically, it is critically important that farmers address the specific mix of crops and/or livestock that they grow/rear, as current practices may not be, or may become, unsustainable moving forward.

In simple terms, farmers dependent on crop systems are utilising seed varieties which are becoming progressively unsustainable in the light of increasing temperatures, and changes in moisture patterns. While it is easy to assume that this only true of crop-based (arable) agriculture, it can be true for livestock too, as cattle, goats and other livestock are dependent on grazing vegetation and access to water to remain alive and healthy enough to be viable livestock (CCAFS, 2017). Therefore, whilst mobile, and inherently more resilient, livestock too are fundamentally at risk from climate change.

While it may prove challenging to achieve with limited water storage facilities, a migration away from all rain-fed agriculture will increase resilience of farmers in the Cuvelai River Basin; plus, crop diversification, utilising more stress-tolerant varieties, will also increase resilience of farmers across the basin.

It is important to recognise that CSA is not a universally applicable practice that can be applied ‘out of the box’; rather localised strategies and approaches must be developed to ensure that adaptations to agricultural practices are locally appropriate, responding to the specific needs of a region (FAO, 2017).

The Namibia Country Climate Smart Agriculture Programme, under the CGIAR Climate Change, Agriculture and Food Security (CCAFS) programme is working to increase resilience in agricultural practices across the country, through a programme of programmatic result areas:

- Improved Productivity and incomes
- Building social and environmental resilience and associated mitigation co-benefits
- Value Chain Integration
- Research for Development and Innovations for scaling up CSA
- Improving and sustaining agricultural Extension Services
- Improved policy and Institutional Coordination

(MET & MAWF, 2015)

Regardless of climate, and in the face of variable levels of production in crop, livestock and fisheries sectors, data presented in MET and MAWF (2015) indicates that demands for food will increase in line with growing population.

Lessons learned and success stories from the Namibia programme, and other regions in Africa could be shared and applied in the Angolan portion of the Cuvelai River Basin to adapt to changing climatic conditions, and develop resilience. Furthermore, it must be noted that CSA was raised during stakeholder consultation processes for this project, as priority areas for CUVECOM to address, specifically in Angola.

4.2.2 Land Degradation

While there are some concerns with respect to land degradation, and the impact of land use management practices on biodiversity and ecosystems, these ecosystems are rich, presenting an opportunity in terms of ecological tourism (eco-tourism), which could be combined with a work-stay/cultural tourism in the area to substantially contribute to the regional/basin economy. Such activities could also provide a revenue stream that could contribute to CUVECOM through levees.

The challenges behind this opportunity relate to the way that tourism is currently organised in Namibia – largely through a select group of local and/or international operators. However, given the right support from government, tourism could contribute to the region, and indirectly, to CUVECOM.

4.3 ECOLOGY

Biomes are globally similar bio-climatic areas, defining major habitat types, like ecological communities of plants and animals, soil organisms and climatic conditions (PJTC Kunene, 2011), and are a useful guide for characterising a landscape and its intrinsic biodiversity in general terms. Biomes are characterised by plant spacing (forest, woodlands, savanna) or plant types (trees, shrubs, and grasses), and the climatic factors that influence the distribution of biomes are latitude and humidity (PJTC Kunene, 2011). The terrestrial biomes present in the Cuvelai River Basin, as defined by the WWF are as follows:

- Deserts and Xeric Shrublands;
- Tropical and sub-tropical grasslands, savannas and shrublands; and
- Flooded grasslands and savannas.

The distribution of these biomes across the basin is illustrated in Figure 2[1]. Most the basin is covered by tropical and subtropical grasslands, savannas, and shrublands., with desert and xeric shrublands present in the south, and flooded grasslands and savannas cover the Etosha Pan area.

4.3.1 Terrestrial Eco-Regions

Terrestrial eco-regions are region and ecosystem-specific characterisations of defined by WWF (2017) as "*large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions*". The eco-regions intersecting with the Cuvelai River Basin are listed in Appendix A2, and illustrated in Figure 3. This map illustrates a landscape dominated by

[1] Full descriptions of these biomes can be found on the WWF website: https://www.worldwildlife.org/biomes

Angolan Mopane Woodlands, and Zambezian Baikiaea Woodlands, with small portions of Angolan Miombo Woodlands, Kalahari Acacia-Baikiaea Woodlands, Namibian savanna woodlands, and Etosha Pan Halophytes.

4.3.2 Fauna

During periods of good rain, the iishana and pans fill with water and the area is abundant in various species of birds, fish, frogs, and many other small animals. Large mammals and other species are mostly limited to fenced boundaries of Ethosha National Park. The Omadhiya lakes, the Cuvelai iishana and Ethosha Pan are regarded as wetlands of national and global importance and these areas were designated as a Ramsar site in 1995 (Mendelsohn, El Obeid, & Roberts, 2000).

4.3.3 Avifauna

The Cuvelai Basin is an especially important bird nesting location with over 400 species recorded in Etosha National Park. The largest number of birds are found in the summer period (October to April) as the Etosha Pan is full of water and many nesting birds migrate to hatch their young, adding to the already significant number of birds that inhabit the Pan throughout the year. Birds such as the pelicans and flamingos (Greater and Lessor) migrate from all over Southern Africa to the pan to feed and breed (Mendelsohn, El Obeid, & Roberts, 2000).

Etosha Pan is home to the only breeding site of the Blue crane outside of South Africa, the numbers of which have plummeted over the last 40 years. In 1976, 138 individual Blue cranes were identified, whereas counts in 2012 only yielded 18 adults and 2 chicks. This decline is not limited to Blue cranes, as nesting flamingo counts have also declined from one million individuals recorded in the past, to recent years where only 20,000 individuals could be accounted for (Mendelsohn, El Obeid, & Roberts, 2000).

Like the pans, the iishana system sees its highest levels of bird life during high flows periods, which can be separated by months or years. Thus, extended high flow periods result in the highest and greatest concentration of avifauna activity.

The northern areas of the Cuvelai Basin are considered degraded of bird species, as human encroachment has drastically affected habitat (Mendelsohn, El Obeid, & Roberts, 2000).

FIGURE 2 - Terrestrial Biomes.

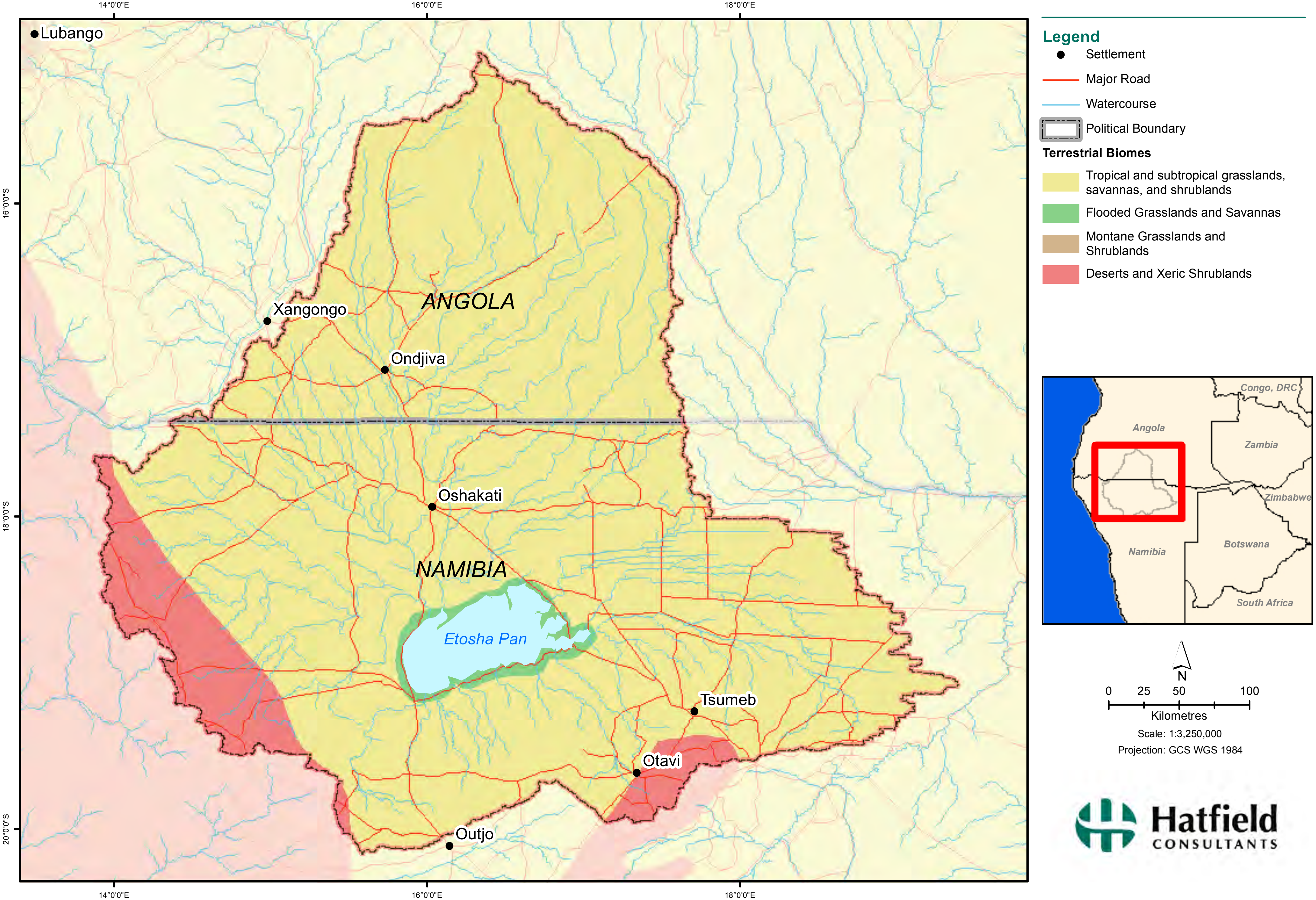
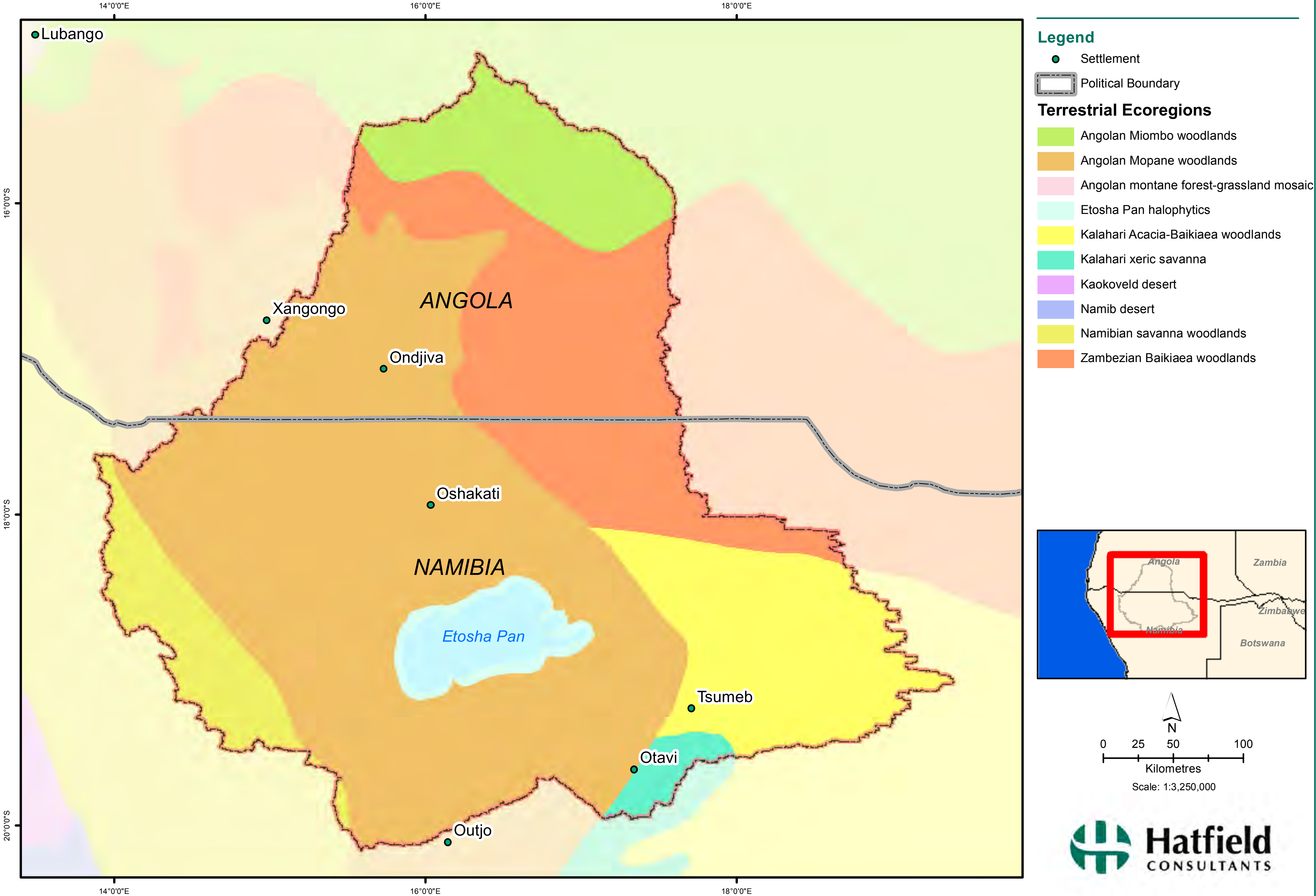


FIGURE 3 - Terrestrial eco-regions of the Cuvelai River Basin



4.3.4 Invertebrates

When flooded the Etosha Pan, and other pans in the area, represent lakes or ponds that feed on invertebrates that have evolved to survive long dormant periods and spawn during wet periods. These invertebrates have adapted to long periods of heat through shorten lifespans and laying eggs that can withstand extended dry periods. Many of these species hatch, mature and lay eggs within a few hours of the wet season. Additionally, adults of some species of invertebrates slow their metabolism to become dormant and hibernate during dry periods, emerging from this hibernation as soon as the wet season begins (Mendelsohn, El Obeid, & Roberts, 2000).

There are sixteen endemic invertebrate species to Namibia which are vital in the food chain of birds, fish, and frogs.

4.3.5 Mammals

The Cuvelai Basin serves as important habitat for species including carnivores, bats, antelope and rodents. In the past, the Cuvelai provided rich habitats for buffalo, reedbuck and other wetland mammals, but these species no longer occur there. Migratory routes have been blocked by fencing all around the basin and the Etosha National Park, and as a result, most large mammals can only be found within the Park (Mendelsohn, El Obeid, & Roberts, 2000).

Within Etosha National Park, there are over 50,000 large herbivores including zebras, blue wildebeest, and springbok. Elephants, giraffe, black rhinoceros, gemsbok, eland, kudu, steenbok, dik-dik and black faced impala are also common in the Park boundaries. Predators are also found within the Park include leopards, cheetah, hyena, jackals, fox and lions. The Park includes 86 watering-holes, which are become hives of activity during dry periods, while during the wet season populations tend to dissipate as water is less scarce.

4.3.6 Amphibians

There are fifteen separate species of frogs found in the Cuvelai Basin though none of these species are endemic. Frogs serves as an important link in the local food chain, as birds, fish, small mammals and other predators include frogs in their diets. Some species of these frogs have evolved to complete a reproductive lifecycle in as short as 22 days, allowing for these species to take advantage of high flow periods (Mendelsohn, El Obeid, & Roberts, 2000).

4.3.7 Reptiles

There are approximately 50 species of reptile in the northern sections of the Cuvelai Basin with approximately 70 species found in the southern areas of the Basin. This difference is based on more diverse habitat for reptiles in the southern area of the basin compared to the north. One small lizard species, the Etosha Agama is endemic to the Basin (Mendelsohn, El Obeid, & Roberts, 2000).

4.3.8 Fish

The Cuvelai Basin is also home to many different species of fish with 12 species known to inhabit the iishana, and another 35 species that have entered the system through linkages between the Cuvelai and Kunene river systems. Many of these species only move into the Basins channels during periods of flooding, while some species remain dormant in the substrate only emerging when the iishana or pans are inundated. Species found in the southern reaches of the Basin also tend to be more resilient to higher saline concentrations than species found outside this region.

4.4 GEOLOGY

The Cuvelai Basin is located in a sedimentary basin known as the Owambo Basin, part of the much larger Kalahari Basin. The Owambo is over 8,000 meters thick and consists of three main super groups overlying a crystalline basement. It is bordered to the east and south by the Damara Belt to the east and to the west by a rift complex. A brief description of the units is provided below.

- **Kalahari** – consolidated and unconsolidated sediments including silt, sand, gravel, sandstone, limestone and mudstone. The sediments within this unit were deposited by continental processes that primarily include Aeolian and fluvial deposition processes. This unit is composed of Quaternary, Tertiary and Cretaceous sediments and is up to 600 meters thick;
- **Karoo** – basalt, siltstone, sandstone, shale, coal, and tillite. This unit is composed of Jurassic to lower Permian sediments and is up to 360 meters thick. This unit includes volcanics (basalt) and intrusions, Aeolian deposits (sandstone), and glaciofluvial ice sheet deposits (tillite) that form the lower most units of the Karoo;
- **Damara** – Sandstone, siltstone, dolomite, limestone, shale, and phyllite. This sequence contains four known disconformities, is up to 8,000 meters thick, and is composed of Neoproterozoic sediments. This unit contains karstified carbonates that are generally located near faults. The unit has been folded and uplifted and is located in the southern and western edges of the Owambo basin; and
- **Congo Craton** – Meso Proterozoic to Paleo Proterozoic rocks consisting of granite, gneiss, schist, and gabbro.

Except for the Congo Craton, the above sequences each contain between six and 13 formations. Notable formations that will be referred to in the aquifer section of this report include:

- Kalahari formations - Andoni, Lower Andoni, Olukonda, Beiseb, Ombalantu;
- Karoo formations – Etjo; and
- Damara formations – Otavi Group including the Huttenberg, Elandshoek and upper Maieberg

Historic drilling and subsurface investigations have taken place near the Study Area as part of mineral exploration activities and the Tsumeb mine. Data from exploration activities assists in understanding the regional geology of the area.

The Study Area has recently been investigated to define its potential hydrocarbon reserves, with attention to the Damara super-group. The Kalahari super-group has been studied for its groundwater supply potential particularly within and near the Cubango Megafan.

4.5 GEOMORPHOLOGY

The Cuvelai basin headwaters are in the Angolan highlands (‘planalto’). Water flows from north to south, and forms a network of ‘iishana’: mostly ephemeral and anastomosing river channels. The iishana network extends from the northwest of the catchment near the Cunene River to the Etosha Pan, and is about 270 km long, and about 150 km wide at its widest point (Mendelsohn and Weber 2011). The basin is endoreic: a closed basin with no outflow.

Ephemeral flow during floods (‘efundjas’) quickly evaporates and leaves salt deposits. The largest salt deposit is the Etosha pan, which is about 110 km by 45 km. The pan was once a lake, and salts have been accumulating there for millions of years. The Etosha is the largest and lowest pan in the basin, but many smaller pans exist. Evaporation of flood water creates saline soils throughout the southern portion of the basin (Section 4.2), which hinders plant growth (Mendelsohn and Weber 2011).

Unconsolidated sediments are mostly fluvial, and are hundreds of metres deep. Aeolian sediments are present in the eastern catchment; these sediments are particularly porous, and promote infiltration of rain and flood water (Mendelsohn and Weber 2011).

4.6 LAND COVER

The land-cover of the Cuvelai River Basin closely matches the topography and eco-regions, but with marked changes in land use and land cover south of the border. Figure 5 is a generalised, continental-scale landcover map, showing broad land cover classes for the basin. The map shows sparse forest and woodland cover across the eastern portion of the basin, with some agriculture and barren land across most the western basin. A detailed landcover map, is needed for the Cuvelai River Basin.

FIGURE 4 - Geology of the Cuvelai River Basin.

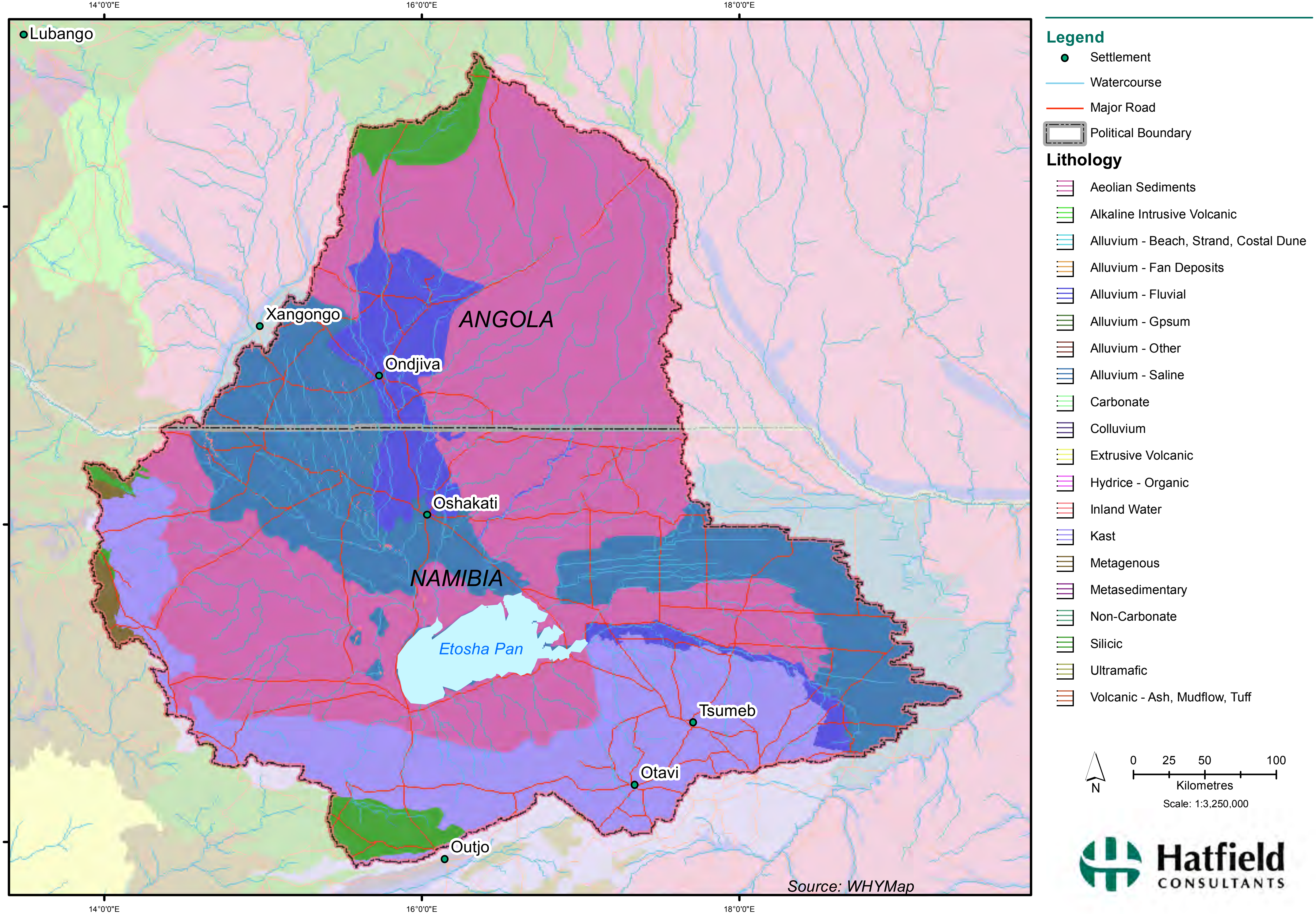


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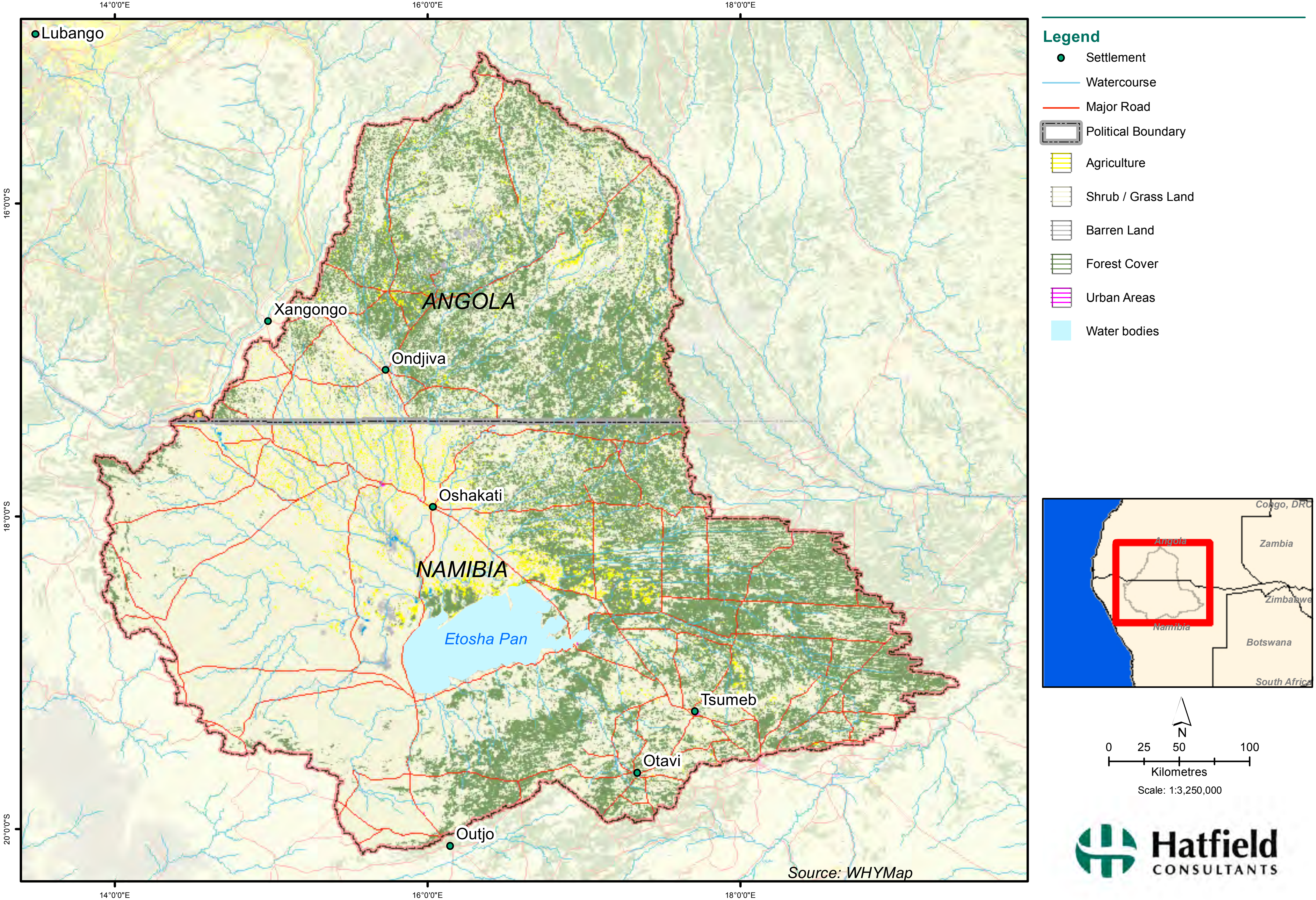
FIGURE 5 - Landcover in the Cuvelai River Basin.



4.7 BIOPHYSICAL INFORMATION GAPS

In general terms, management is an activity that requires information and analysis to inform decisions. Transboundary Water Resources Management is no different; requiring at minimum basic biophysical baseline data and information to inform hydrological and management decisions. Overall, there is a general lack of consistent, detailed biophysical data available for the Cuvelai River Basin; a situation that needs to be improved to support future studies. While an effort has been made to collect as much publicly available data as possible for this project, a dedicated inventory project would yield a helpful combination of regional, national, and basin-specific data. Prior to the initiation of a basin assessment, such a preliminary database could be developed through collaborative technical work between government departments, academic research institutions, and activities of NGOs.

The primary information gap from a topographic perspective is an agreed basin extent. This will require agreement on the physical extent of the river basin, and by extension, a standardised set of river elevation data and channels. This fundamental dataset will need to be determined by a team of hydrologists, from Angola and Namibia, reviewing all available technical data. This could be achieved through a consultancy, but would require technical steering contributions from both parties.

Soils in the Cuvelai River Basin are described in general terms in Mendelsohn and Weber 2011, and Ministry of Agriculture, Water and Forestry (MAWF) 2006, and maps and shapefiles of soil and soil suitability for cultivation in Namibia, are presented in Directorate of Environmental Affairs (2002). However, detailed soil information for the Cuvelai River Basin is lacking, and to provide detailed guidance for land management, agricultural, and social issues it will be important for a detailed soil distribution map to be developed for the basin.

If Angola and Namibia are to take advantage of CSA, and secure sustainable agricultural yields moving forward, a holistic CSA programme should be explored in the Cuvelai River Basin, which could advise communities on appropriate strategies for CSA, ensure agricultural sustainability, and contribute to food security in the basin. This could be based upon lessons learned from Namibia, with attention paid to variations in agricultural processes and practices in Angola, and would also need to be translated into Portuguese and Oshikwanyama.

5.0 HYDROCLIMATIC PROFILE

This section provides a hydrological and climatological (hydro-climate) profile of the Cuvelai River Basin, based up on available data, information and literature. In the section below, the hydrology, climate, and hydrogeology of the Cuvelai Basin are briefly described. Assembled data sets are assessed and summarized in Appendix A2, along with selected examples from these data sets.

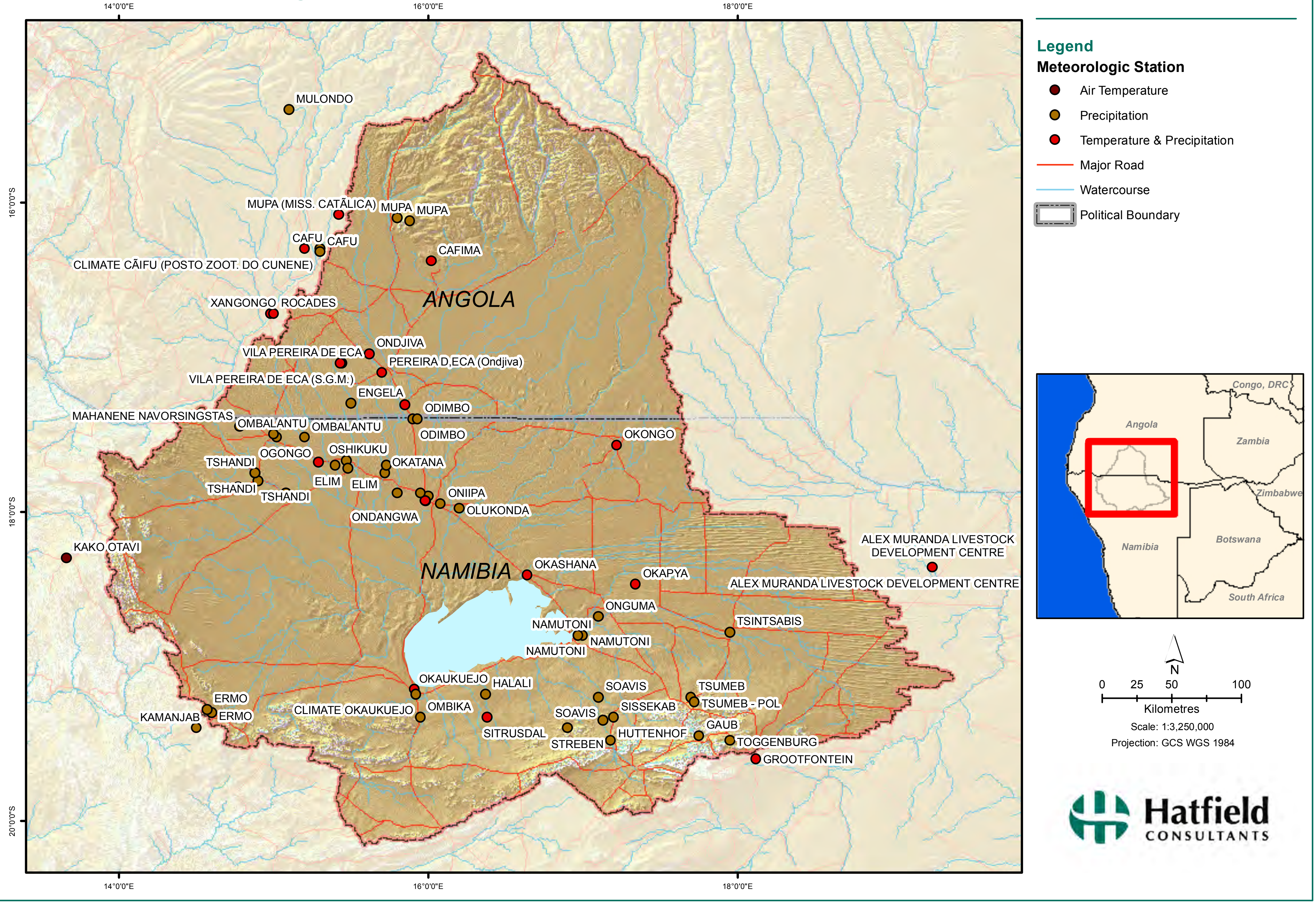
5.1 CLIMATE

5.1.1 Air Temperature

Average annual air temperature is coolest in the higher elevation headwaters (~21^{o}C), and warmest in the lower-elevation south (~23^{o}C). Monthly air temperatures vary by about 8^{o}C, with the coolest months being June and July, and the warmest being October and November. Isopleth maps of air temperature in Namibia, Angola, and the Cuvelai Basin are available from several sources (República de Angola 2016a, Mendelsohn et al 2013). Stations where air temperature records are available are summarized in Appendix A2.2.

Gridded datasets have the potential to provide data in the basin with high spatial and temporal data availability; however, their accuracy should first be assessed relative to station data. In Angola, the Climatic Research Unit (CRU) TS gridded air temperature time series was evaluated, and found to be in good agreement with station data, while providing high spatial and temporal data availability (Jones and Harris 2008; Harris et al. 2014; República de Angola 2016a). In Appendix A2.2, the air temperature record from the CRU TS grid cell closest to Ondangwa, NM was extracted, and data from 1900-2015 are presented. Results show that air temperatures have been warmer than normal since the early 1980's. Prior to this time, multi-decadal periods of relatively warm and cool periods occurred. Total range between warm and cool years since 1900 has been about 1.2^{o}C.

FIGURE 6 - Meteorological stations within and near the Cuvelai River Basin.



5.1.2 Precipitation

Rainfall distribution, intensity, and duration are finely balanced in the Cuvelai Basin; too little rainfall can easily lead to drought conditions (Section 8.1), and too much can lead to flooding (Section 8.2). Spatial and temporal rainfall patterns significantly contribute to moisture availability for rain-fed agricultural practices in the basin, and also discharge in the river channels and iishana. The severity of floods is determined by the location, intensity, and duration of rainfall. Most flood waters cross the border as surface water discharge in the iishana region, spreading south through the shallow oshana channels, and main Cuvelai channel.

Precipitation in the Cuvelai Basin is controlled by the Intertropical Convergence Zone (ITCZ), and its migration throughout the year. The ITCZ is a band of low pressure circling the globe near the equator caused by solar heating. It brings moisture to the Study Area by drawing moisture from the Indian Ocean, and upwelling air releases moisture as it cools. In the wet season, the ITCZ is located over the Study Area, but in the dry season, the ITCZ migrates northward out of the Study Area. Precipitation events in Southern Africa are also controlled by the occurrence of mid-tropospheric low pressure systems ('closed lows', Engelbrecht et al 2012).

Spatial variability in mean annual precipitation (MAP) is large in the Study Area, and precipitation totals increase from southwest to northeast (Figure 7). MAP is 300 to 400 mm in the southwest, and 800-900 mm in the northeast. Isohyet maps of the Cuvelai basin are available from several sources including Mendelsohn et al 2013, Mendelsohn and Weber 2011, Governo Provincial do Cunene 2014, Harris et al. 2014, Persendt et al. 2015, República de Angola 2016a-c, and Weber 2011. Rainfall is more inter-annually consistent in the wetter northeast, and less consistent in the southwest.

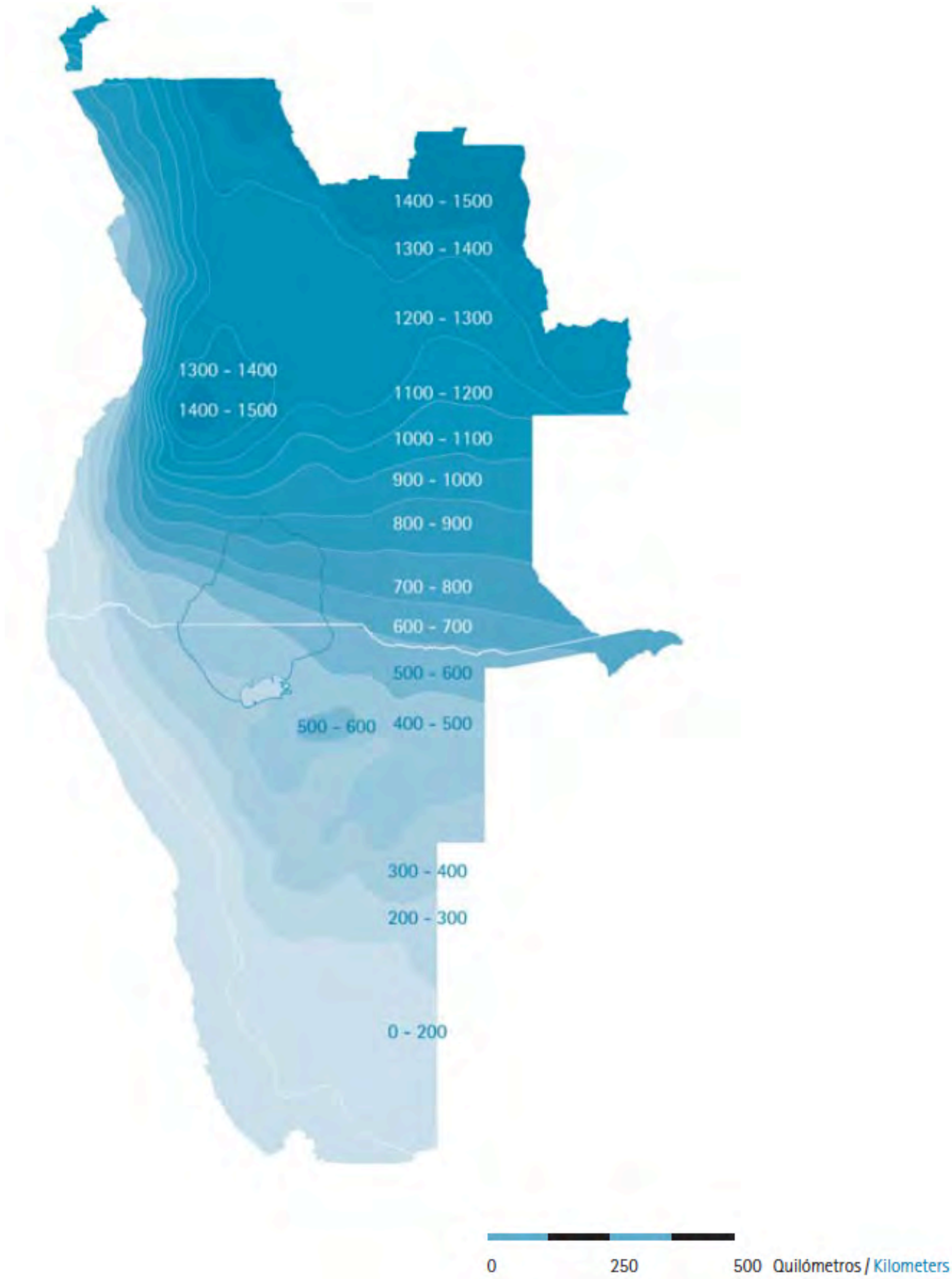
The wet season lasts from roughly December to March, when about 38% of the annual precipitation falls, and the dry season lasts from roughly April to October, when only 9% of the annual precipitation falls. However, significant variability in duration, intensity, and distribution occurs.

Precipitation indices relating to trends, and wet and dry extremes, were analysed using the 1917-2003 record of precipitation from Grootfontein, Namibia and the 1901 to 2013 CRU TS time series (Persendt et al. 2015). Grootfontein is just outside of the Cuvelai-Etosha basin, near its southeast boundary (Figure 6). No significant trends in extremes were found (annual maximum 1-day precipitation, annual maximum consecutive 5-day precipitation, and heavy precipitation days). An increase in average dry spell length, and decrease in annual precipitation and number of wet days was found in the Grootfontein record.

Precipitation extremes on the Angolan side of the Cuvelai have been calculated and mapped (República de Angola 2016a). For example, the 10-year, 24-hour precipitation event is about 60-90 mm, and the 50-year 24-hour event is about 90-130 mm. Lower values would be expected on the Namibian side.

Records tend to be discontinuous and short in Angola. Gridded precipitation data sets provide increased spatial and temporal resolution compared with station data. Gridded CRU TS and Global Precipitation Climatology Centre (GPCC) precipitation data in Angola have been systematically evaluated (República de Angola 2016a). Generally, station data agree well with results from gridded data sets. GPCC data set provided less biased results compared to station data, with higher correlation coefficients (República de Angola 2016a).

Figure 7 Rainfall distribution.



Source: (Mendelsohn & Weber, 2011)

To explore the performance of gridded precipitation datasets in Namibia, gridded precipitation data were extracted from the CRU TS time series for the grid cell closest to Ondangwa, NM, in the central portion of the catchment (Appendix A2.3). Station data were compared to CRU TS data, and show a high correlation (r^2=0.86), with a slight negative bias (i.e. the CRU TS data slightly underestimate annual precipitation at Ondangwa). The long and continuous gridded dataset allows for identification of trends that are not apparent in shorter more discontinuous records. For example, notable periods of drought occurred from about 1925 to 1935 (average annual precipitation anomaly = -142 mm), and 1980 to 1999 (average annual precipitation anomaly = -131 mm). While multi-annual to decadal periods of sustained meteorological drought and flood are characteristic of the area in the long-term, these extremes are not evident in the most recent portion of the data set. For example, the period from about 2000-2015 was a period of neither sustained wetness nor dryness when compared to the overall record (Note that flooding experienced in 2017 is not part of the record presented in Appendix A2.3).

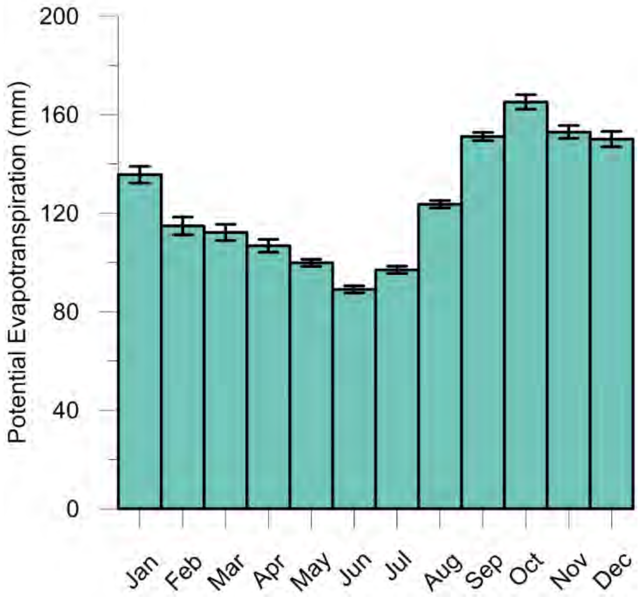
5.1.2.1 Evapotranspiration

Evapotranspiration (ET) data are available for the Cuvelai Basin as pan evaporation and potential evapotranspiration (PET). Pan evaporation is directly measured from open water pans at weather stations, and is useful for estimating evaporation from an open body of water, such as the reservoir of a dam, after applying a reduction coefficient and correcting for precipitation (IWRM Plan Join Venture Namibia 2010). PET is calculated using hydrometeorological data (for example with the Penman-Monteith equation; Dingman 2015) and is useful for water balance studies and estimates of water availability. ET data are available from several data sources in the Study Area, including:

- Pan evaporation at weather stations. In Namibia, these are water-tight pans with an area of about one metre squared, where changes in pan level are measured;
- PET data from Angola. Seventeen stations with monthly PET data in Angola are presented in República de Angola (2016a). Most data are historic, and available from about 1955 to the early 1980's.
- Gridded CRU TS PET, calculated using the Penman-Montieth approach, using air temperature, vapour pressure, and cloudiness; and
- Gridded National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) PET, available at 2^{o} resolution (Kalnay et al 1996). These are modelled data.

Evaporation is higher in the southern Cuvelai basin compared to the north (Mendelsohn and Weber 2011). For example, PET from for Ondangwa, NM using CRU TS averages 1,500 mm per year (Figure 8). Annual PET variability is low, with a standard deviation of 12 mm. PET is more than three times annual average precipitation (Section 5.1.2). PET is highest in the warmest months (about 160 mm/month in September and October), and lowest in the coolest months (about 90-100 mm/month in May to July). As expected, pan evaporation recorded at weather stations consistently exceeded PET.

Figure 8 Monthly Potential Evapotranspiration (PET) for the grid cell nearest Ondangwa, NM (CRU TS 1901-2015).



5.1.3 Drought

The timing and magnitude of drought affects vegetation, human health and livelihood, wildlife, and wildfires. Droughts in the study area are partially controlled by large-scale ocean-atmosphere teleconnections, especially El Niño (Chishakwe 2010). Droughts in the context of disaster risk management are discussed in Section 8.1.

Several drought indicators are available, including:

- The Standardised Precipitation-Evapotranspiration Index (SPEI), a standardised drought index using air temperature, precipitation, and evapotranspiration from CRU TS v.3.24 (Beguería et al. 2010; Vicente-Serrano, Beguería, and López-Moreno 2010; Vicente-Serrano, Beguería, López-Moreno, et al. 2010) As an example, the SPEI 1900-2014 time series for Ondangwa, NM is presented in Figure 9. The average SPEI is zero, and the standard deviation is one. Periods of drought are identified for the periods roughly between 1925 and 1935, and 1980 to 2000;

- The African Flood and Drought Monitor, which provides time series, point data, monitoring data, and forecasts of drought, including hydrometeorological indicators, other drought indices, and remotely sensed vegetation data (AFDM 2017); and

- The Blended Drought Index (BDI), a gridded drought index that has been applied to the Cuvelai Basin (Stein, Luetkemeier, Liehr, & Drees 2015; please refer to Section 9.1.4 for additional information). Mean annual drought conditions as represented by BDI are presented in Figure 10.

Figure 9 The Standardised Precipitation-Evapotranspiration Index of drought for the grid cell nearest Ondangwa, NM.

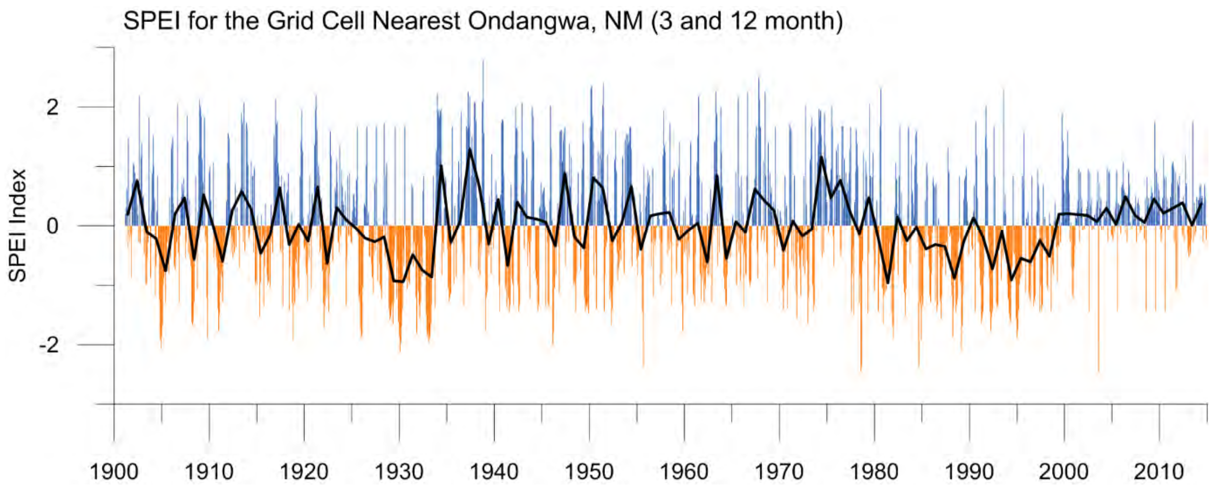
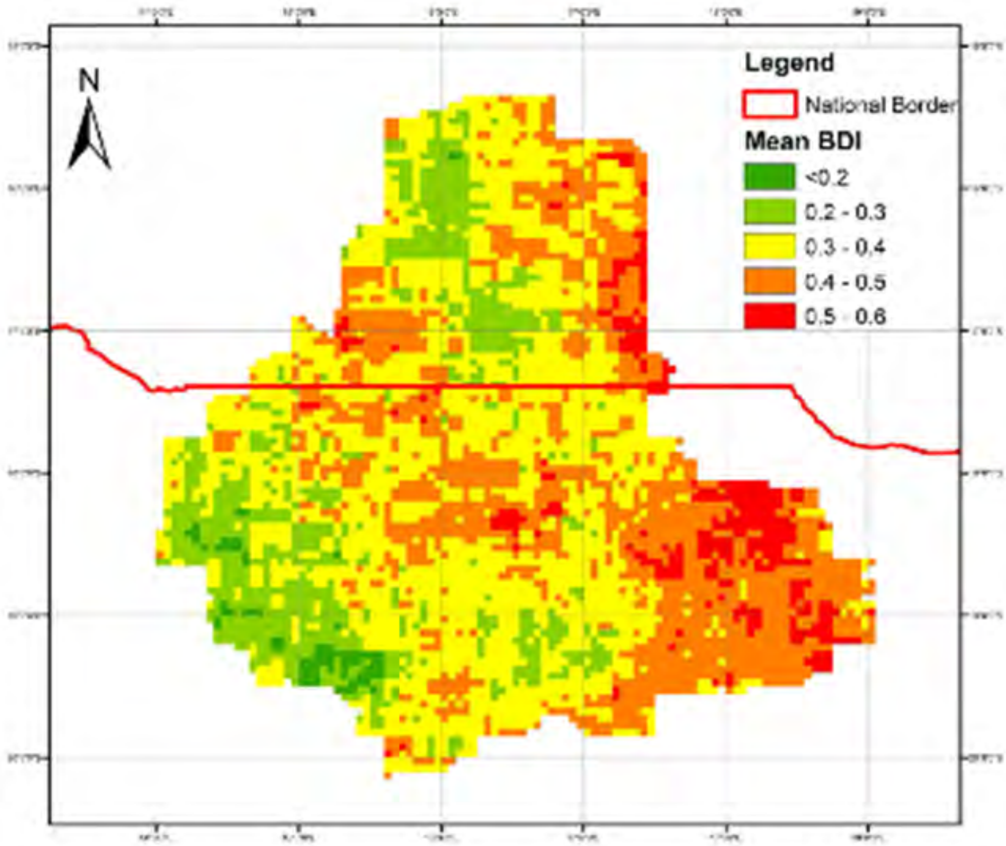


Figure 10 Mean annual Blended Drought Index (BDI) – drought exposure map



5.1.4 Climate Data Availability

Climate datasets are summarised in Appendix A2.4. Monitoring data were assessed from three major sources:

- The Global Historical Climatology Network (GHCN v.3.3.0). The GHCN is a global database of monthly and daily air temperature and precipitation time series. Data are tagged by level of Quality Assurance / Quality Control (QA/QC). The dataset is maintained by NOAA (US National

Oceanic and Atmospheric Administration), is peer-reviewed, high-quality, and is widely used (Klein Tank et al. 2002; Menne et al. 2012);

- Koninklijk Nederlands Meteorologisch Instituut (KNMI, the Royal Netherlands Meteorological Institute) Climate Explorer (KNMI 2017). The KNMI tool contains global daily, monthly, and annual climate-related time series. It also contains paleoclimatic data and climate change projections. It is peer-reviewed and widely used (Trouet and Van Oldenborgh 2013);
- The Southern Africa Science Service Centre for Climate Change and Adaptive Land-Use (SASSCAL) (Kaspar et al. 2015). SASSCAL provides near-real-time (NRT) data from a large network of weather stations in Namibia and Angola. Data are freely available, and datasets have been well documented. Data in the NRT 'WeatherNet' network are relatively recent; datasets begin as early as 2010. SASSCAL also provides archived hydroclimatic data for stations throughout Namibia and Angola, which begin as early as 1960. Some datasets contain large gaps, and data quality appears to be variable. SASSCAL contains a large repository of weather data from Angola.

Evaluated global gridded data include:

- The Climatic Research Unit, University of East Anglia dataset (Jones and Harris 2008; Harris et al. 2014);
- The Global Precipitation Climatology Centre's (GPCC) "full data reanalysis" (Schneider et al 2015); and
- The Standardised Precipitation Evapotranspiration Index (SPEI; Section 5.1.3).

These gridded datasets are freely available, peer-reviewed, have been used in the Study Area, and have high spatial and temporal resolutions. Dataset characteristics are briefly summarised in Table 1 and more completely in Appendix A2.4. All gridded data products described above contain data interpolated from nearby monitoring stations; therefore, data are potentially inaccurate when and where instrumental data are sparse.

Table 1 Summary of evaluated gridded data.

Data Product	Time step	Spatial resolution	Available datasets	Examples of use near the Study Area
CRU TS v.3.24.01	Daily for air temperature, monthly for other variables	0.5°*	Air temperature, precipitation, wet-day frequency, potential evapotranspiration, cloud cover, and vapour pressure	Hulme et al. 2001; Small et al. 2003; Persendt et al. 2015, República de Angola. 2016a
GPCC full data reanalysis V7	Monthly	0.5°, 1.0°, 2.5°*	Precipitation	República de Angola. 2016a
SPEI	Monthly	0.5°*	Drought index using CRU TS time series	AFDM 2017

Note: Over the Cuvelai Basin, a 0.5 degree grid cell is about 50 km x 50 km

5.2 HYDROLOGY

5.2.1 Hydrologic Regime

The Cuvelai Basin covers an area of about 159,620 km^2 (Mendelsohn and Weber 2011), of which 67% is in Namibia, and 33% is in Angola (Filali-Meknassi et al. 2014). The Cuvelai is an 'iishana' system: a collection of ephemeral rivers, shallow pans, and wetlands. The basin is quite flat, with a nominal drop in elevation: about 450 metres over 400 kilometres (Mendelsohn and Weber 2011). The lack of relief, the seasonality of precipitation, and relatively impermeable soils promote episodic flooding. During floods, water flows for hundreds of kilometres from the north in Angola into the Etosha Pan, where it evaporates. Iishana are dry most of the time, especially in the east of the basin. Flow is more regular over the northern and western portions of the catchment, especially the Mui and Cuvelai rivers, and the Shana zone (Mendelsohn and Weber 2011). The Shana is particularly saline, since the channels are broad, and evaporation occurs efficiently. Water in the northern Cuvelai and Mui tends to be fresher, since precipitation is greatest in the northern portion of the catchment, and runoff occurs rapidly. The natural hydrologic regime has been highly modified by large-scale water diversions, extensive land use, and small-scale collection and storage of flood water.

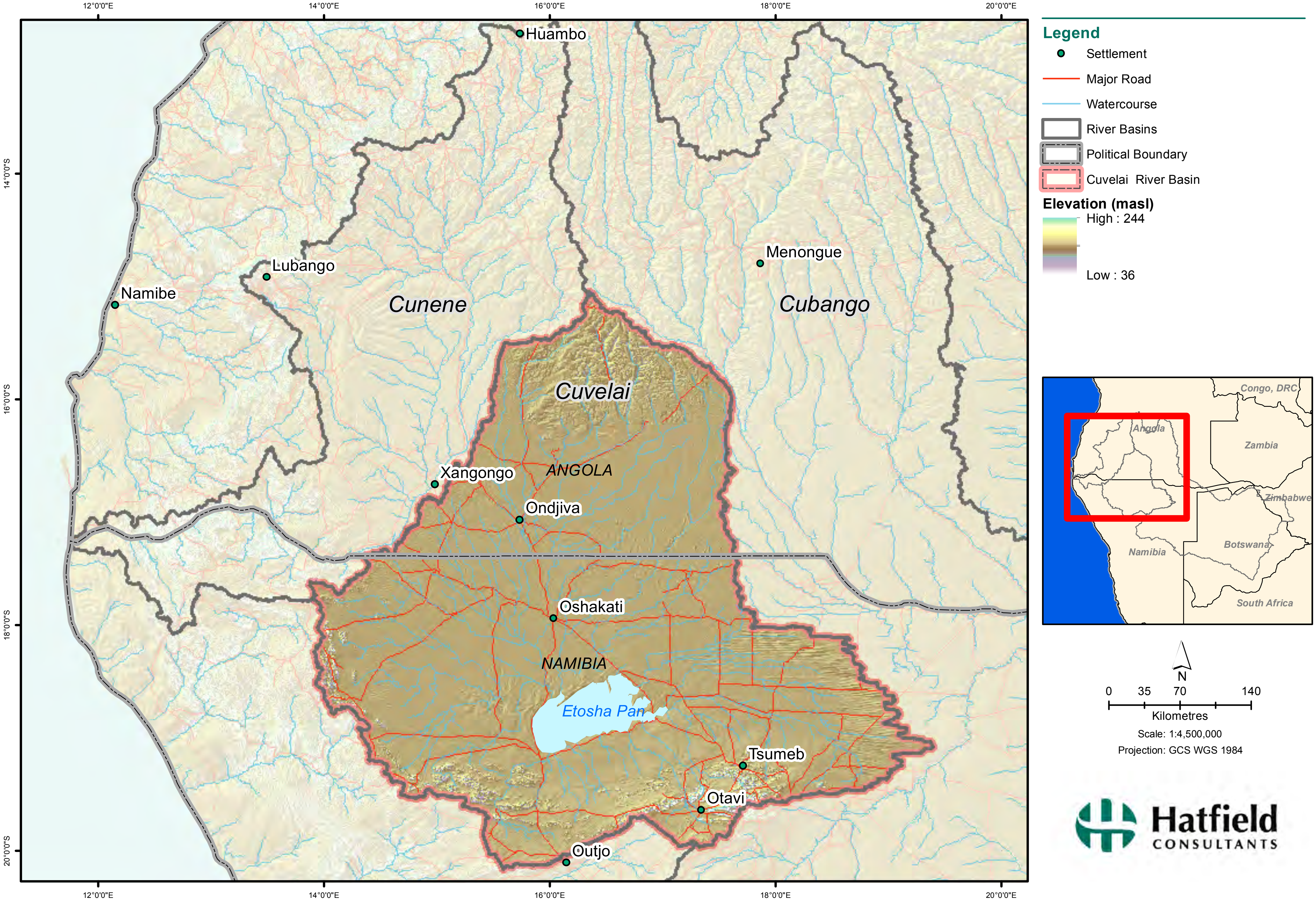
The hydrologic regime of the Cuvelai Basin is highly variable within and between years because of varying precipitation patterns, geology, and soil. Active flow is limited to the north and west of the catchment (Shana Zone, Cuvelai River, Mui, Cuvelai Delta, and Central Drainage Zones) (Mendelsohn and Weber 2011). Elsewhere, flow rapidly infiltrates or evaporates.

5.2.2 Estimates of Runoff

Runoff data should be interpreted with caution because the monitoring network is extremely sparse, drainage and drainage patterns are highly influenced by human activity, and spatial and temporal flow variability are high. Available runoff estimates are insufficient to characterise this variability. In a system where rivers are typically ephemeral, annual average runoff may be a misleading statistic. Some studies that have quantified runoff in Namibia have declined to estimate runoff in the Cuvelai basin, likely due to the low magnitude of runoff, and the lack of data (IWRM Plan Joint Venture Namibia 2010). With the above caveats in mind, estimates of runoff come from:

- Estimates of annual volumetric outflow in the Cuvelai, e.g. Amakali 2003; IWRM Plan Joint Venture Namibia 2010; DRFN and Heyns Consultancy 2013. Estimates place outflow between 100 x 10^6 to 150 x10^6 m^3/year. With a catchment area of 159,620 km^2 (Mendelsohn and Weber 2011), this equates to between 0.6 and 0.9 mm/year of runoff;
- Estimates of runoff from hydrologic models. Model results most pertinent to estimates of runoff include (and are discussed in more detail Section 5.2.4.2);:
  - Gridded global runoff data available from the Global Runoff Data Centre (GRDC; 0.5^o grid resolution; Fekete et al. 1999, Fekete et al. 2002). GRDC data predict annual runoff is <1 mm per year in most of the catchment, and about 50-150 mm Angolan highlands.
  - Estimates of runoff in Angola produced using gridded precipitation, evapotranspiration, and the Turc-Pike equation (República de Angola 2016a). This dataset predicts near-zero runoff on the Angolan side of the Cuvelai Basin. Runoff in the northern Cuvelai Basin in the Angolan Highlands appears to be broadly similar to GRDC estimates provided above.

FIGURE 11 - The Cuvelai River Basin,and adjacent Cunene/Kunene and Cubango basins



5.2.3 Dams, Diversions, and Transfers

Hydrology of the Cuvelai is highly influenced by dams, diversion, transfers, and other human modifications (Section 7.0). Water from the Kunene River is pumped from Calueque Dam in Angola into the Olushandja Dam in Namibia, and into the Cuvelai catchment. The Olushandja Dam has a reservoir volume of 42.3 x 10^6 m^3 (IWRM Plan Joint Venture Namibia 2010). Records of water abstraction from 2013 to 2016 at the Calueque Dam are presented in Figure 12. Annual abstractions have ranged from 56 x 10^6 m^3 per year to 84.7 x 10^6 m^3 per year, and have generally increased over time. Monthly abstraction volumes tend to be highest in the dry season. The Kunene Transboundary Water Supply Project allows for 180 x 10^6 m^3 of withdrawal into Namibia per year. These annual volumes are large fractions of the annual Cuvelai water balance (see 'Estimates of Runoff' above). From the dam, water is distributed through Namibia and then back into Angola through the Etaka and Ogongo-Oshakati Canals (Figure 13). The history and evolution of this transboundary Project is described in Varis et al (2008), and project infrastructure is described in República de Angola (2016b).

Figure 12 Records of water abstraction at the Calueque Dam.

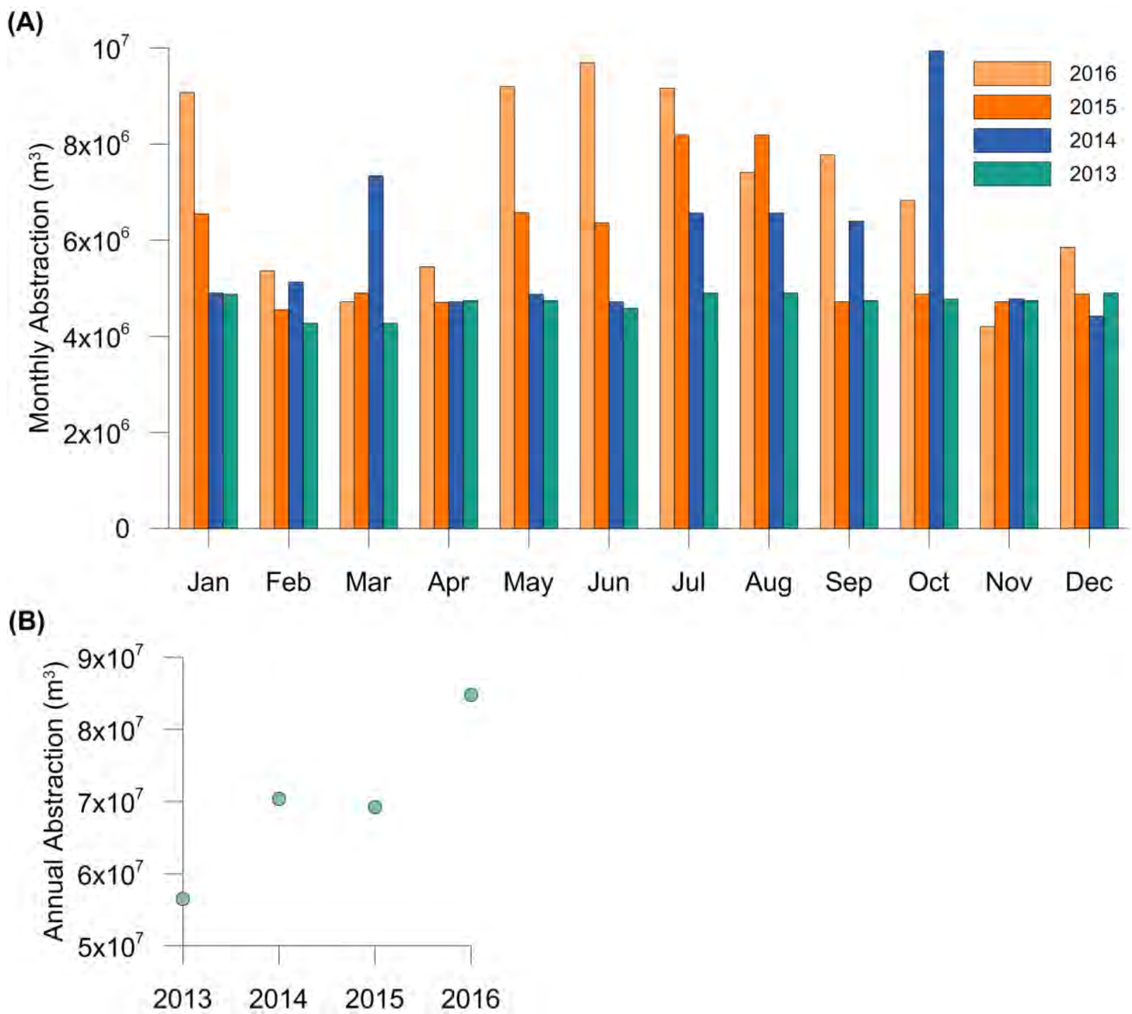
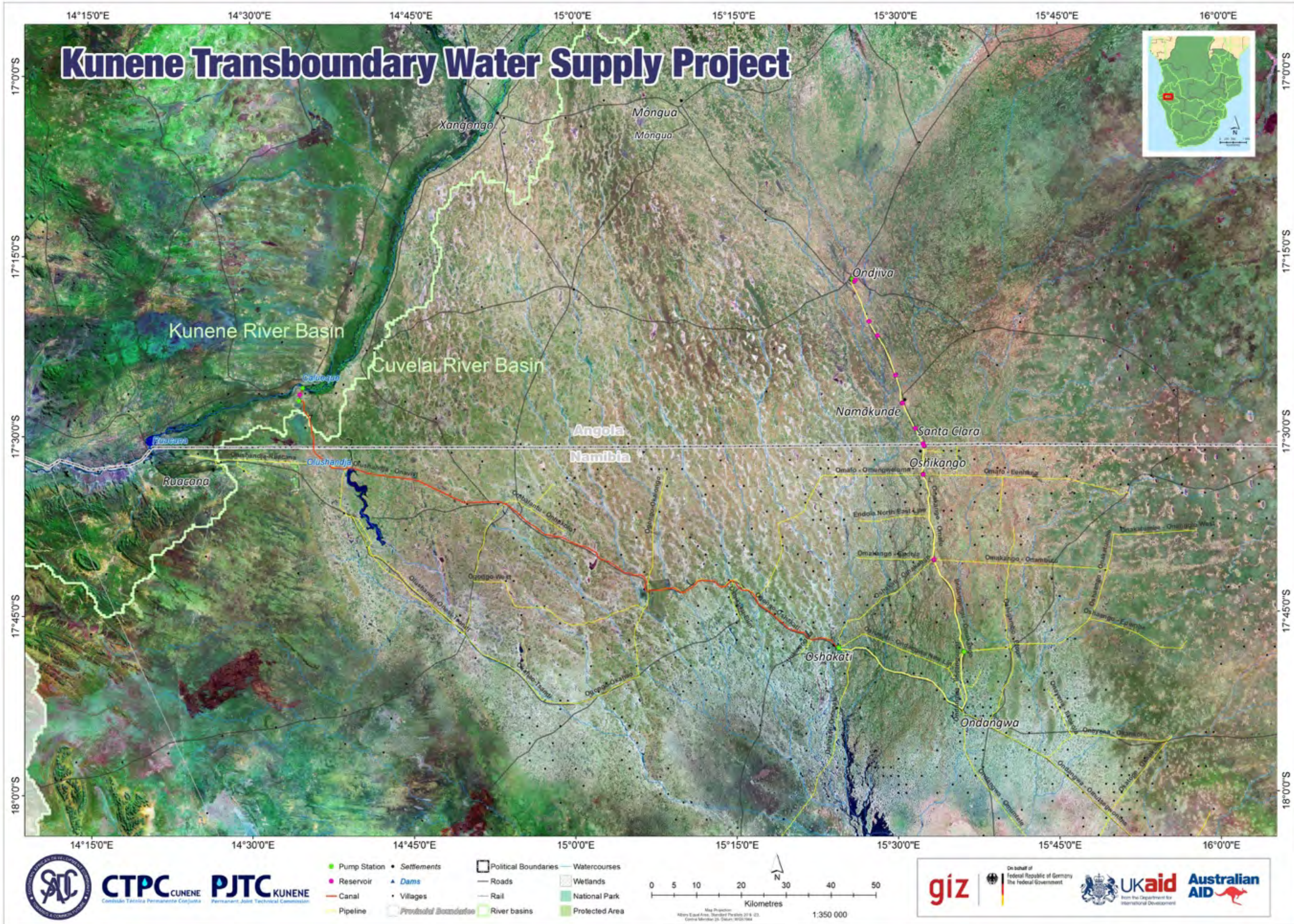


Figure 13 The Kunene Transboundary Water Supply Project.



While McDonald and Ruiters (2005) identify approximately 40 dams present in the Cuvelai River Basin, in Angola and Namibia, it is assumed that most of these are very small.

5.2.4 Hydrologic Data Availability

5.2.4.1 Monitoring

The hydrometric monitoring network in the Cuvelai is sparse. The purpose of much of the hydrometric monitoring in Namibia is to assess water availability and the potential for dams, and the potential for dams in the Cuvelai basin is low (IWRM Plan Joint Venture Namibia 2010). River flow in the Cuvelai is typically ephemeral, and flow is distributed over through numerous iishana. Therefore, the relationship between water level and flow is not consistent, and flow is extremely difficult to calculate. Finally, access to rivers during times of flood is difficult.

As of 2013, no known functional hydrometric gauges existed on the Angolan side of the basin (GEF 2013; Filali-Meknassi et al. 2014), and at the time of this report, no documentation could be found indicating that any Angolan gauges exist in the basin.

The following hydrometric monitoring data are available:

- **Datalogged water levels.** As of 2013, Namibia Hydrological Services (NHS) operated approximately 24 telemetric level gauges on the Namibian side of the Cuvelai Basin, but no long-term data (>5 years) were available for these gauges and the condition of the stations was uncertain (Filali-Meknassi et al. 2014). Near-real-time data do not appear to be available online;
- **Manually-measured water level measurements** at numerous stations, conducted during flooding (e.g., Hydrological Services Namibia 2016). Monitoring locations include Engela, Shanalumono, Shahaingu, Shakambebe, Shakamwa, Shanaheke, Okalongo, Shanaimbwengendje, Shanelago, Onembaba, Shapoko, Ogongo, Oshikuku, Otamanzi, Shashuuli, Ombwana, Endola, Okatana, and Ompundja. Water level data are provided in flood bulletins, but long delays between measurements and online data presentation occur;
- **Hydrological Cycle Observation System** (HYCOS) Station 68007 for Oshakati is cited in the SADC Baseline Discovery Portal. However, no data from this site could be found;
- **A transect of discharge measurements** that spans at least 100 km and follows the D3608 road in northern Namibia during the 2008 flood event (IWRM 2008). These data are supplemented with data from the 2008 flood event from water level monitoring stations, and extensive remotely-sensed imagery during flooding. This is a highly valuable record of discharge during an exceptional flood event;
- **Qualitative records of water levels** during flooding in 2010 at Evale, Ondjiba (Angola), and Engela and Oshakati (Namibia) (Mendelsohn and Weber 2011); and
- **Discharge at Oshakai, Namibia** (Amakali 2003). Records exist from 1941 and 1967, and are based partly on diaries from missionaries. These data have been summarised to an annual time step. Monthly records also exist from 1975 to 1979. The record is likely useful an indicator of flooding frequency and magnitude, rather than water availability. In addition, the period of record may not be representative of typical conditions in the catchment (Amakali 2003).

5.2.4.2 Modelling

Hydrologic modelling of the Cuvelai is difficult for several reasons. First, as described above, the monitoring network is sparse and inadequate, making model calibration and validation problematic. Second, the hydrologic response to rainfall is variable within the catchment, difficult to predict, and depends on land management practices. Rainfall following long dry periods can produce more runoff than rainfall following a wet period, so knowledge of antecedent conditions is essential. During periods of drought, vegetation growth is low and overgrazing occurs, leading to compaction, low infiltration, and high runoff ratios when overland flow occurs. Sediment particles and sediment grain size may also play a role partitioning surface runoff and recharge. Silt particles are thought to fill pores in river beds, increasing surface runoff (Mabande 2011).

Despite these difficulties, several hydrologic models have been applied to the Cuvelai basin, including:

- A model to simulate and predict flooding, using remotely sensed flood maps from 2009 for calibration (Mabande 2011; Mufeti et al. 2013). The authors conclude that modelling of extreme events in the Cuvelai using remotely sensed data is possible;

- Runoff data from a global water balance model published by the GRDC, with a 0.5 degree grid resolution (Fekete et al. 1999; Fekete et al. 2002). Data from the model generally agree with spatial patterns of precipitation and observations of perennial and ephemeral rivers in the catchment (Mendelsohn and Weber 2011). It is assumed that the runoff model is driven entirely by climate data and a water balance model; therefore, results should be interpreted with caution;

- Estimates of runoff in Angola produced using gridded precipitation, evapotranspiration, and the Turc-Pike equation (República de Angola 2016a). Again, the unique physiography of the Cuvelai may not have been fully incorporated, so within-watershed runoff variability may not be well characterised;

- A hydrologic and hydraulic model constructed to assess hydrologic responses and impacts from the potential construction of a flood diversion channel to protect the town of Oshakai (Muir 2012). The local nature of this model limits its applicability; and

- The flood monitoring and forecasting section of this document describes other modelling efforts aimed at flood forecasting in the Cuvelai Basin (Section 11.0).

Given the unique and variable hydrology of the Cuvelai, these modelling datasets should only be used if they are thoroughly assessed. Unfortunately, few flow records are available for validation.

5.3 GROUNDWATER

There are six main aquifers defined within the Study Area. Five of the aquifers are located within the Kalahari sequence, and one is located within the Damara sequence. The Karoo sequence is mostly inferred to act as an aquitard between the Damara and Kalahari units; however, in isolated areas groundwater can be extracted from this unit. Many of the aquifers are multi-layered including the Otavi Dolomite Aquifer located in the Damara sequences and the six main aquifers are known as:

- Otavi Dolomite Aquifer;
- Etosha Limestone Aquifer;
- Oshivelo multi-layered aquifer;
- Ohangwena multi layered aquifer;
- Oshana multi layered aquifer; and
- Omusati multi layered aquifer.

A recently introduced aquifer naming/abbreviation system has been utilised in recent studies and publications. The naming system consists of three letters and a number. The first letter represents the sequence (ie. 'K' for Kalahari) and the second and third layer represent the aquifer name and a number represents formations can be distinguished within the larger aquifer group. Table 2 provides a summary of the aquifers, associated geological units, water quality, and water yield (after Bittner 2006 and República de Angola. 2016b).

Table 2 Summary of Aquifers within the Cuvelai River Basin

Name of Aquifer	Abbreviated Term	Sequence	Group	Formation	Rock Type	Depth (m)	Water Quality	Yield (m^3/h)
Discontinuous Perched Aquifer	KDP	Kalahari	n/a	Recent	n/d	n/d	n/d	n/d
Etosha Limestone Aquifer	KEL			Andoni (Etosha Limestone)	Dolocrete, calcrete, sand	10-100	Fresh, locally high nitrates	3-100
Oshivelo Multi-layered Aquifer (undifferentiated)	KOV			Ombalantu, Beiseb, Olukonda, Andoni	Conglomerate, sandstone, sand, dolocrete, calcrete	30-150	Fresh to brackish	25-200
	KOV1			Andoni				
	KOV2			Andoni, Olukonda				
Oshana Multi-layered Aquifer (undifferentiated)	KOS			Ombalantu, Beiseb, Olukonda, Andoni	Sand, calcrete/ limestone	60-180	Saline to hypersaline	1-30
	KOS1			Andoni				
Ohangwena Multi-layered Aquifer (undifferentiated)	KOH			Andoni, Olukonda	Sand, sandstone	60-180	Fresh to brackish	25-200
	KOH1			Andoni, Olukonda				
	KOH2			Olukonda				

Table 2 Cont'd.)

Name of Aquifer	Abbreviated Term	Sequence	Group	Formation	Rock Type	Depth (m)	Water Quality	Yield (m^3/h)
Omusati Multi-zoned Aquifer (undifferentiated)	KOM	Kalahari	n/a	Ombalantu, Beiseb, Olukonda, Andoni	Sand, clay and calcrete, dolocrete	20-100	Brackish, fresh in places	1-30
Karoo Sequence Aquifer/Aquitard (undifferentiated	KR	Karoo	Ecca	Dwyka, Omingonde, Prince Albert, Kalkrand, Etjo	n/d	n/d	n/d	n/d
Mulden Group Aquifer/Aquitard (undifferentiated)	DM	Damara	Mulden	Owambo, Kombat, Tschudi	n/d	n/d	n/d	n/d
Otavi Dolomite Aquifer (undifferentiated)	DO		Otavi	Huettenberg, Elandshoek, Maieberg, Ghaub, Auros, Gauss, Berg Aukas, Varianto, Nabis	n/d	n/d	n/d	n/d
Otavi Dolomite Aquifer	DOT		Otavi (Tsumeb)	Tsumeb Subgroup	Dolomite	20-150	Fresh	>50
	DOT1			Huettenberg				
	DOT2			Elandshoek				
	DOT3			Maieberg				
	DOT4			Ghaub				
	DOA		Otavi (Abenab)	Abenab Subgroup				
	DOA1			Auros,				
	DOA2			Gauss				
	DOA3			Berg Aukas				
Nosib Group Aquifer/Aquitard (undifferentiated)	DN		Nosib	Varianto, Nabis	n/d	n/d	n/d	n/d

n/d=no data; n/a=not applicable

The Kalahari sequence sediments include several complex and interconnected groundwater systems (Christelis et al 2001; MAWF 2006). This sequence is primarily unconsolidated sands and clays, with occurrences of limestone lenses, calcrete, and semi-consolidated sandstone and sandstone fragments. A brief description of the sediments in the Kalahari aquifer formations is provided below:

- Andoni – Light green to white sand, calcrete and clayey sand to sandy clay;
- Olukanda – Red clay and sand, clayey sand to sandy clay;
- Beiseb – Light green to white sand, red semi-consolidated sand, locally clayey; and
- Ombalantu Formation – Red shale and conglomerate with sand and clay and local sandstone and limestone lenses.

The Damara sequence contains the Otavi Dolomite Aquifer that consists of nine aquifer formations within two subgroups. Five aquifer formations have been identified in the Tsumeb group, and four are located within the Abenab group. The Otavi group is primality consolidated carbonates (dolomite and limestone), with varying degrees of karstification.

The continental Groundwater Resources of Africa Map (Struckmeier & Richts, 2008) identifies the following main categories of groundwater resources for the Cuvelai River Basin, which are then illustrated in Figure 14:

- Major groundwater basin, 20 to 100 mm per annum recharge;
- Major groundwater basin, 100 to 300 mm per annum recharge; and
- Area with complex hydrogeological structure, with less than 20 mm per annum recharge.

5.3.1 Wells

Numerous boreholes for water extraction are located throughout the Study Area, and a map of these locations is provided by Mendelson et al., 2013 (p.144). Water well records and borehole logs are not available for most the wells. A national groundwater database is in the process of being developed for Namibia that will include information related to borehole lithology, water levels and chemistry data (Greenwood and Bolliger 2016).

5.3.2 Groundwater Flow

The Cuvelai River Basin exhibits an elevation difference of approximately 450 meters from the north to the south axis, and 100 to 200 meters in the east-west axis. The groundwater flow mimics the topography, and flows towards the centre of this basin towards the Etosha Pan. The Damara sequence sub-crops and outcrops along the southern and western edges of the Study Area, and gently dips towards downward towards the north. The sub-cropping and outcropping Damara sequences provide areas of potential groundwater recharge.

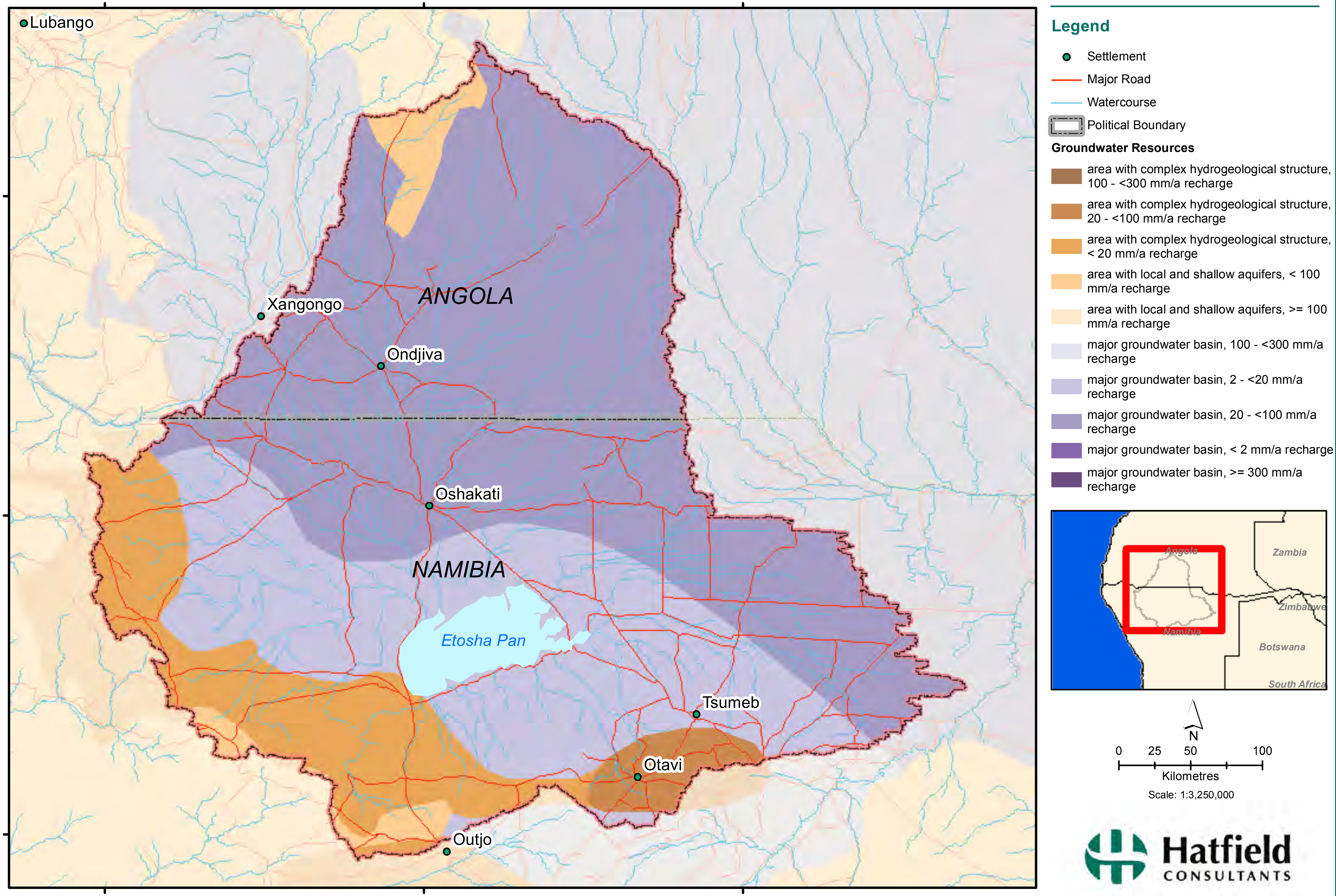
Two main groundwater flow systems are identified with the Study Area, and a summary of these two flow systems is provided below (MAWF 2006):

1. Groundwater recharge from the southern and western edges of the basin flows north and east through the Damara Sequence dolomites, and recharges the overlying Karoo and Kalahari sequences, much of this water discharges as springs and is evaporated; and
2. The deep multi-layered Kalahari Aquifer is recharged from the north in Angola and flows south toward the Etosha Pan and the Okavango River.

5.3.3 Groundwater Data Availability

A summary of the regional groundwater flow systems is provided in MAWF 2006, and a summary of the available hydraulic conductivities within the Kalahari formation is provided in Lindenmaier *et al*, 2014. Numerous other data sources are available, including Christelis et al 2001, Struckmeier & Richts, 2008, Bittner 2006, República de Angola. 2016b, and Greenwood and Bolliger 2016.

FIGURE 14 - Groundwater Resources of the Cuvelai River Basin.



5.4 HYDROCLIMATIC INFORMATION GAPS AND RECOMMENDATIONS

5.4.1 Climate

A continuous and spatially extensive climate monitoring network is crucial for assessments of water availability, detection of trends and anomalies, and for flood and drought assessment. Station records of air temperature, precipitation, and evapotranspiration in the Cuvelai Basin tend to be relatively short-term, and contain data gaps, especially in Angola. The spatial network of stations that monitor precipitation throughout the catchment is more extensive than stations that measure air temperature (Appendix A2.1).

In Angola, the climate station network is sparse. The number of operating weather stations declined in the 1970's, and has remained low. A total of 16 Angolan station records are available from KNMI and SASSCAL in the Cuvelai Basin; however, some of these may be redundant, and large data gaps exist in some records. At the time of writing there were only two near-real time weather stations on the Angolan side of the Cuvelai Basin: Ondjiva and Namacunde (Appendix A2.1). Both stations are within 50 km of the Namibian border. Therefore, datasets from the catchment headwaters in the Angolan highlands are sparse, where precipitation is highest, where the only perennially flowing rivers are found, and where floodwaters originate. Over time, it will become increasingly important to establish a more holistic climatic monitoring network, accompanied by time-series data available to all parties.

To some extent, gridded datasets can be used to fill spatial and temporal gaps. In particular, the CRU TS and GPCC gridded data sets are useful, accurate, and have been vetted for use in Africa and the Cuvelai. Gridded data are useful for examining spatial and temporal changes in the Cuvelai catchment. However, these data are not suitable for near-real-time applications, and require site-specific verification before use. Data are averaged over a grid cell, rather than representative of a point. Data may need to be downscaled where climate changes over short distances. Gridded data are potentially inaccurate when and where instrumental data are sparse.

5.4.2 Hydrology

Assessments of the hydrologic monitoring network in the Cuvelai have concluded that the current monitoring network is inadequate, and more gauging stations are needed, especially during times of flood (IWRM Plan Joint Venture Namibia 2010; Filali-Meknassi et al. 2014). Hydrometric stations have less than five years of data, and the current condition of the stations is 'under question', and 'all measurements have gaps in the time series' (Filali-Meknassi et al. 2014). Modelling and gridded datasets are generally inadequate to fill gaps in the hydrologic monitoring dataset. It is recommended that real-time data and staff gauge measurements be disseminated quickly to the public, the scientific community, and to decision makers. Remotely sensed datasets of flood area and magnitude, and flood forecasting systems are currently publicly available and are potentially extremely useful (e.g. GDACS 2017; Section 11.0).

5.4.3 Groundwater

Groundwater monitoring data are sparse, and a centralised source of groundwater information for the region or country is not available. Limited continuous time series data are available from five monitoring wells (Bittner 2006). Manual water level data are sparse and are available from a limited number of wells, and an extensive regional groundwater monitoring network has not yet been established in the region.

The groundwater flow regime and aquifer interconnectivity in the Study Area are not well understood, and pertinent data could not be found during the data collection exercise. Data pertaining to the following areas of interest would provide a more thorough understanding of the groundwater flow regime:

- Groundwater recharge from both meteoric and surface water sources and the relative contributions of each were not well defined in the reviewed reports, and only very basic conceptual models could be found;
- Aquifer mapping is limited and conceptual cross sections or groundwater models displaying the hydrographic sequences within the Study Area could not be found;
- Data pertaining to the hydraulic properties (e.g., transmissivity, storativity, and permeability) were available for a few select aquifers; however, the data are spatially and temporally limited; and
- Groundwater/Surface water interaction potential or data pertaining to the local processes related to the interactions were not available. This includes vertical gradients.

Recent published geological and hydrogeological data pertaining to the Cubango Megefan and the associated Ohangwena II aquifer (KOH-2) contains some of the relevant data required to fill the data gaps identified above and provides an adequate model for future investigations in the region (Lindenmaier et al. 2014).

6.0 CLIMATE CHANGE CONSIDERATIONS

Climate change will have direct effects on climatic variables such as air temperature, precipitation, evapotranspiration, and soil moisture. Average conditions will change, but extremes will also change. For example, it is possible for mean annual precipitation to decrease, but for extreme precipitation events to increase, resulting in increased runoff. Climate change will also have a series of secondary effects, for example on water availability, human health (e.g., climatic suitability water-borne diseases, food and water availability, temperature-related health impacts), economic activity (e.g., agriculture and tourism), and ecosystem activity (e.g., suitable range for animals) (Republic of Namibia Ministry of Environment and Tourism 2011).

The Cuvelai River basin is extremely dry, prone to floods and drought, and supports a large rural population dependant on agriculture and water availability. These characteristics make the basin sensitive and vulnerable to climate change, making the assessment of likely changes and uncertainties essential for mitigation and planning (Zeidler et al. 2010). Climate change adaptation and mitigation strategies are described in Chisakwe (2010) and SADC (2011).

6.1 CLIMATE CHANGE MODELS AND SCENARIOS

Climate change projections are derived from computer models fed with varying greenhouse gas (GHG) scenarios. Model extent is either global (Global Climate Models, GCM) or regional (Regional Climate Models, RCM). Uncertainty in model output stems from unrealistic simulation of climatic processes, and uncertainty due to the timing and magnitude of future GHG forcing. Uncertainty is assessed by intercomparing results from a suite of models, and by running models with a suite of GHG forcing. It is generally not useful to use results from a single model without an assessment of how that model fits into results from a community of models.

Results from multiple GCMs and GHG forcing scenarios have recently been inter-compared and thoroughly reviewed by the Intergovernmental Panel on Climate Change (IPCC) (Pachauri et al. 2014; Stocker et al. 2014). Results are summarised in the sections below, along with an assessment of uncertainty and inter-model variability.

GCMs typically have relevantly coarse grid cells (about 1.25-2.5^{o}), and may not accurately simulate climate in the relatively small Study Area. GCMs can be used to feed into RCMs, to increase model resolution and improve the accuracy of the simulation of climatic processes. Results from RCM that cover the Study Area are summarised below, where available.

Scenarios are defined by the IPCC as ‘representative concentration pathways’ (RCP). RCP vary by GHG emissions and land use (e.g., deforestation vs. reforestation). RCP range from ‘2.6’, where global warming is kept at less than 2°C above pre-industrial temperatures by 2100, to ‘8.5’ where global warming is about 3.7°C above pre-industrial temperatures by 2100. RCP replace emissions scenarios used in previous IPCC reports known as ‘Special Report Emissions Scenarios’ (SRES).

6.2 AIR TEMPERATURE

For a given GHG scenario, inter-model variability in air temperature in the Study Area is low, and confidence in results is high (Pachauri et al. 2014; Stocker et al. 2014). By the last two decades of the 21st Century, annual air temperatures are expected to increase by 1-1.5^{o}C (RCP2.6) to 5-7^{o}C (RCP8.5). The largest uncertainty for future air temperatures is therefore the GHG emissions that occur, rather than between-model uncertainty. Warm temperature extremes are expected to increase by similar magnitudes. Air temperatures in southern Africa are expected to increase more in summer months compared to winter months (Tadross et al. 2005).

6.3 PRECIPITATION

Annual precipitation is expected to decrease in the Study Area by 2100 by up to about 10% for RCP85, and between-model confidence is high. For RCP with lower GHG emissions, lower annual precipitation is also expected, but between-model variability is higher.

Predicted changes in precipitation vary seasonally, and there is more between-model variability in results. Some studies predict that the dry season will become increasingly dry, and the wet season will become increasingly wet (Solomon et al. 2009). Other studies predict significant decreases in rainfall in the wet season (Tadross et al. 2005).

Globally, precipitation and drought extremes are expected to increase, and this is also the case in the Study Area (Pachauri et al. 2014; Stocker et al. 2014). Both the maximum 5-day precipitation total, and consecutive dry days are expected to increase, and between-model confidence in these changes is high. Return periods for extreme precipitation events are expected to decrease.

Grid size plays a role in the accuracy and precision of modelled precipitation, particularly at lower than annual timescales. By coupling RCM with GCM, climatic processes can be more accurately simulated. For example, a coupled RCM-GCM for southern Africa showed a decrease in low pressure systems that bring moisture and most floods to the Study Area (Engelbrecht et al. 2013). However, an increase in extreme rainfall events was found by the same study, which was attributed to an increase in convective rainfall events. In a review of GCM and RCM covering the Cuvelai, it was concluded that the Study Area is expected to become drier in the future (Zeidler et al. 2010).

6.3.1 Evapotranspiration

Under RCP that predict relatively small increases in GHG, models disagree on the sign and magnitude of changes in evapotranspiration. Under more aggressive RCP, evaporation is expected to decrease by about 0 to 0.4 mm per day in the Study Area. This decrease corresponds to a decrease in precipitation and water availability for evapotranspiration (Pachauri et al. 2014; Stocker et al. 2014). Some uncertainty in estimates of evapotranspiration stem from feedbacks between air temperature, precipitation, and transpiration from vegetation, the latter of which is poorly modelled and uncertain.

6.4 RUNOFF, DROUGHTS, AND FLOODS

The Study Area is vulnerable to changes in runoff, drought, and floods (Chishakwe 2010). GCM predict slightly decreased runoff by 2100 in the Study Area; however, between-model variability is large, and confidence in the direction and magnitude of change is low (Pachauri et al. 2014; Stocker et al. 2014). Some hydrologic models incorporating climate change in Africa have generally predicted increases in runoff (Faramarzi et al. 2013). An examination of different methodologies of running climate change hydrologic models in southern Africa revealed large differences in results depending on the model, model initialisation, and model forcings (Arnell 2003). This is not surprising given the between-model differences in precipitation and evapotranspiration described above.

Overall, there is little quantitative information on the future frequency and magnitude of hydrometeorological extremes in the Cuvelai; however, the consensus is that both will increase (Zeidler et al. 2010).

It has been recommended that the hydrometeorological monitoring system be improved in the SADC region, since monitoring can detect, and warn of extreme hydrometeorological conditions (SADC 2011). Flood protection structures are being constructed and considered to reduce climate change-related risks from flooding (SADC 2011; Muir 2012).

Floods and droughts are discussed in more detail in Section 8.0.

6.5 GROUNDWATER

Groundwater is not directly modelled by GCM or RCM. Given that knowledge of modern and future runoff and recharge is low in the Study Area, predictions of future groundwater conditions are also uncertain. However, a very useful management support tool called GRiMMS has recently been developed in the SADC region (Villholth et al. 2013). GRiMMS is a GIS-based tool that incorporates layers relating to human and physical influences on groundwater. Its outputs include groundwater drought risk under current conditions, and under climate change scenarios. Current groundwater drought risk in the Study Area is 'low' to 'moderate'. Under the SRES A1B scenario, groundwater drought risk is 'moderate' to 'high'. The A1B scenario is a 'middle of the road' scenario that predicts GHG emissions will begin dropping by mid-century. Overall, a 30-70% reduction in groundwater can be expected in the 21st Century in Namibia (Republic of Namibia Ministry of Environment and Tourism 2011). Groundwater is viewed as a key resource for providing a water supply in the Study Area in the future (SADC 2011).

6.6 AGRICULTURE AND LIVESTOCK

Since models disagree over the magnitude and intra-annual timing of precipitation changes, the effects on agriculture and livestock are also uncertain. Crops that are particularly sensitive to climate change include grains and dryland crops. Livestock will be influenced by changes in rangeland capacity. Climate change will directly influence agriculture and livestock through changes in rainfall temperature, and evapotranspiration, but also indirectly through changes in soil quality, pests, and pathogens (Zeidler et al. 2010).

6.7 CLIMATE SCENARIOS SUMMARY

Expected climate change direction and confidence in predictions are summarized in Table 3. Overall, in the Study Area, air temperatures are expected to increase, annual precipitation totals are expected to decrease, and evapotranspiration is expected to decrease. Confidence in these directions of change is high. Runoff is expected to decrease, and droughts and floods are expected to increase. Uncertainty is moderate for these responses in the Study Area. Groundwater vulnerability is expected to increase, and confidence is high based on the GRiMMS study (Villholth et al. 2013). Agriculture and livestock are expected to be negatively impacted by climate change, but no quantitative studies were found.

Table 3 Summary of assessed climate change data.

Variable	Prediction	Uncertainty	Data Availability	Assessed Data Sources
Air Temperature				
Global	🟢	🟢	🟢	
Namibia	🟢	🟢	🟢	Pachauri et al. 2014; Stocker et al. 2014
Angola	🟢	🟢	🟢	
Annual Precipitation Totals				
Global	🔴	🟢	🟢	
Namibia	🔴	🟢	🟢	Pachauri et al. 2014; Stocker et al. 2014
Angola	🔴	🟢	🟢	
Evapotranspiration				
Global	🟡	🟢	🟢	Pachauri et al. 2014; Stocker et al. 2014
Namibia	🔴	🟢	🟢	Solomon et al. 2009, Engelbrecht et al. 2013, Zeidler et al. 2010
Angola	🔴	🟢	🟢	
Runoff				
Global	🟡	🔴	🟢	Pachauri et al. 2014; Stocker et al. 2014
Namibia	🔴	🔴	🟡	Chishakwe 2010, Faramarzi et al. 2013, Arnell 2003
Angola	🔴	🔴	🟡	
Drought				
Global	🟢	🟢	🟢	Pachauri et al. 2014; Stocker et al. 2014
Namibia	🟢	🟡	🟡	Zeidler et al. 2010
Angola	🟢	🟡	🟡	
Floods				
Global	🟢	🟢	🟢	Pachauri et al. 2014; Stocker et al. 2014
Namibia	🟢	🟡	🟡	Zeidler et al. 2010
Angola	🟢	🟡	🟡	
Groundwater Vulnerability				
Global	🟢	🟢	🟡	n/a
Namibia	🟢	🟢	🟢	Villholth et al. 2013
Angola	🟢	🟢	🟢	
Agriculture and Livestock Vulnerability				
Global	🟢	🔴	🟢	n/a
Namibia	🟢	🔴	🔴	Zeidler et al. 2010
Angola	🟢	🔴	🔴	

Legend

Predicted increases, low uncertainty, or high data availability 🟢

Predictions variabile, uncertainty moderate, data availability moderate 🟡

Predicted decreases, high uncertainty, or low data availability 🔴

6.8 CLIMATE CHANGE INFORMATION GAPS

Regional climate change data are more complete in Namibia compared to Angola. In 2010, it was assessed that GCM models from IPCC are “the most robust available” (Zeidler et al. 2010). However data from the Angolan side of the Cuvelai has improved since 2010, with the introduction of several new high-resolution regional datasets (Tadross et al. 2005; Solomon et al. 2009; Zeidler et al. 2010; Engelbrecht et al. 2013; Villholth et al. 2013). Regional assessments of mitigation and adaptation strategies have also been completed (e.g., SADC 2011).

7.0 WATER UTILISATION AND DEMAND

Water collection is mainly achieved through two methods: by a network of NamWater and Directorate of Rural Water Supply (DRWS) pipelines from the Angolan Kunene River Reservoirs; and by boreholes to retrieve water from aquifers (Dragnich, Dungca, Pendleton, & Tracy 2007). Water from the Calueque Dam reservoir is transported using canals and pipelines through northern Namibia and back into some of Angola. Rainwater collection and floodwater collection are also important sources of water (IWRM Joint Venture Consultants n.d.). Small-scale excavations and earthen dams are used locally for harvesting flood waters from oshanas.

7.1 DOMESTIC

Domestic water sources in the Cuvelai Basin include wells that withdraw water from shallow aquifers that require rainwater to recharge (Mendelsohn J. 2015a). In large areas of the Namibian portion of the basin and Ondjiva in Angola, water supply is highly dependent upon NamWater pipeline system that collects water from the Calueque reservoir, particularly during dry periods (Dragnich, Dungca, Pendleton, & Tracy 2007). The Xangongo Dam on the Kunene River, 75 km upstream from the Calueque dam is an important source of water for much of the Angolan portion of the basin (Marley Pipesystems 2017).

A survey conducted in the Angolan portion of the Basin reported that traditional wells were the most utilised source of water, followed by rainwater, earth dams, rivers, ponds and chanas, lakes and seasonal channels, hand pumps and taps (Calunga 2015). Most people reported using multiple sources of water. Only 28% of respondents reported treating water, despite 98% using open sources of water (considered unsafe due to the potential for contamination) (Calunga 2015). Roughly 53% of households were found to be within 2 km of a water source.

7.2 SANITATION

Effective sanitation can help to prevent disease and infection. It is unknown how much water in the Cuvelai Basin is utilised for sanitation purposes. It is also unknown if other options for effective sanitation (e.g., composting) can, or are, being used in the Basin. The level of collaboration between line agencies that deal with water supply, health, sanitation (which are all linked in this case) is also unknown. CuveWaters reports approximately 40% of the Namibian portion of the Basin’s urban population lacks access to improved sanitation facilities and less access in rural areas (2015). Earth dams in the oshanas are mainly used to harvest water for livestock (IWRM Joint Venture Consultants n.d.).

7.3 AGRICULTURE

Crops planted across the region are primarily dryland or rain-fed, with very little irrigated agriculture present. Pearl millet, known locally as mahangu, is heavily relied upon as a subsistence cereal crop in the region due to its ability to be grown in dry and sandy soils (Mendelsohn J. 2015a). The limited amount of irrigated agriculture that does exist, is located close to the Kunene Transboundary Water Transfer Scheme canal, between Olushandja Dam and Oshakati, where water can be pumped easily with small petrol or diesel powered generators and pumps, from the canal, into the fields (Mendelsohn J. 2015a). The only large irrigated agriculture facility is the Etunda Agricultural Project, which is located near Ruacana, approximately 150 km west of Oshakati (MAWF, n.d). The project is divided between 10 large-scale farming service providers, utilising centre-pivot irrigation, and 82 small-scale farmers, utilising piped irrigation. Produce is sold in Oshakati and nearby villages.

Over 100,000 cattle withdraw water as they overwinter in the Oshimolo floodplain grassland areas north of the Angola-Namibia border (Mendelsohn J. 2015b). The numbers of cattle and other livestock in the basin have increased significantly over the last 25-years, due to life expectancy increasing associated with disease control, and the subsequent increase of cattle being a viable asset for resident and non-resident investors (Mendelsohn J. 2015b). However, while life-expectancy and viability of livestock have increased, livestock holdings can be vulnerable to drought conditions, making feeding and watering such large numbers of animals problematic.

7.4 FISHERIES AND AQUACULTURE

Based upon information gathered during the stakeholder consultation process for this, and publicly available literature sources, aquaculture is viewed as an important contributing sector for food security in Namibia, which also applies to the Cuvelai River Basin. The Ministry of Fisheries and Marine Resources is committed to maintaining a position as a leading fishing nation, with a well-developed aquaculture industry, and has implemented several pilot aquaculture projects across Namibia (FAO, 2017), including those listed in Table 4. Critical to note are the projects in the Omusati and Oshana regions – understood to be community-based fish farming facilities - both of which are in the Cuvelai River Basin (MFMR, 2017).

Table 4 Aquaculture projects across Namibia.

No.	Name	Type of Facility	Location
1	Mpungu Fish Farm	Community based fish production farm	Nkurenkuru, Kavango Region
2	Karovo Fish Farm	Community based fish production farm	Rundu, Kavango Region
3	Kamutjonga Inland Fisheries Institute (KIFI)	Fingerling & fish production, Research, Training; Information center	Divundu, Kavango Region
4	Likunganelo Fish Farm	Community based fish production farm	Lisikili, Caprivi Region
5	Kalimbeza Fish Farm	Community based fish production farm	Kalimbeza, Caprivi Region
6	Epalela Fish Farm	Government fish grow out farm	Omusati Region
7	Onavivi Inland Aquaculture Center	Fingerling & fish production, Research, Training;	Omusati Region

No.	Name	Type of Facility	Location
8	Onavivi Fish Feed plant	Fish feed production facility	Omusati Region
9	Ongwediva IAC	Fingerling and fish production facility	Oshana Region
10	Hardap IAC	Fingerling & fish production, Research, Training;	Hardap Region
11	Fonteintjie FF Project	Community based grow out project	Karas Region
12	Leonardville IAC (NEW)	Under construction: Fingerling & fish production, training	Omaheke Region
13	Noordoewer IAC (New)	Feasibility study stage	Karas Region

Source: (MFMR, 2017)

If these aquaculture projects prove to be sustainable – financially, and logistically – the could contribute significantly to the food security equation in the north of Namibia, and by extension, into southern Angola through trade, as fish provide a good source of protein.

Limited remarks, on fish biota in the Cuvelai River Basin are presented in Section 4.3.8.

7.5 ENVIRONMENTAL WATER DEMAND

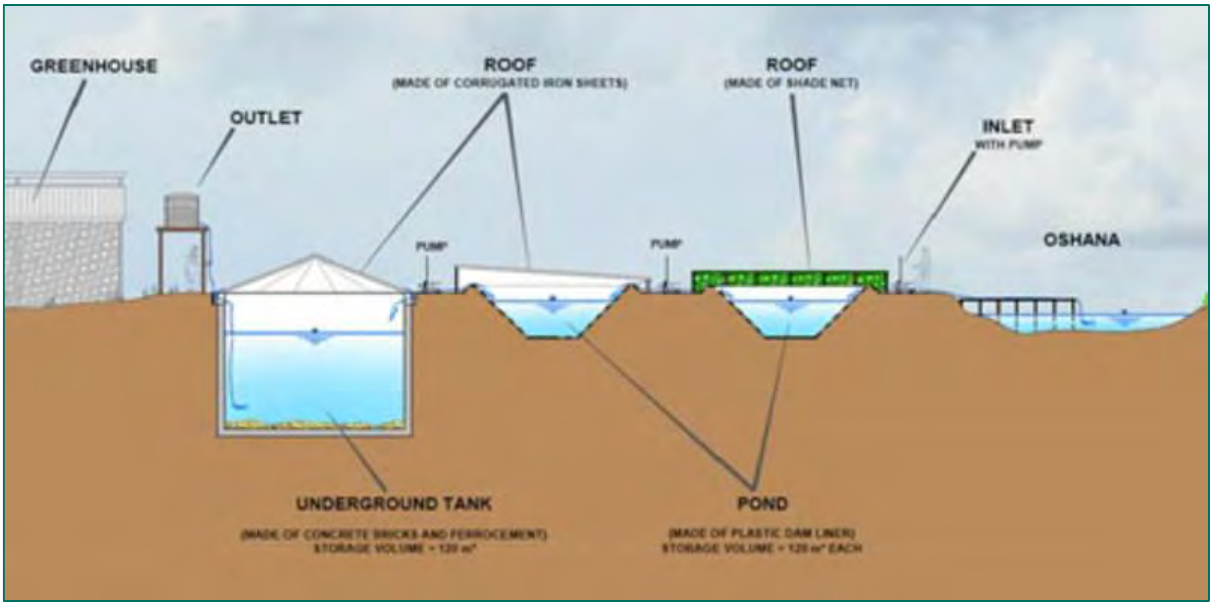
Environmental flows are the amount of water flow, the timing of water flow and the quality of water required for environmental purposes (including the support of ecosystems, species and livelihoods). No data or information was found on the water requirements for environmental purposes. Environmental Flow Assessments for various ecosystems and livelihood systems will help to inform minimal flows required.

7.6 FLOOD AND RAINWATER HARVESTING

Among its other achievements, the CuveWaters project, which ended in 2015, implemented a series of innovative pilot water reuse, harvesting and desalinisation facilities across northern Namibia. One critical element of this project was the development and implementation of flood and rainwater harvesting facilities. In 2011 and 2012, the pilot plant was established in Lipopo, a remote village in the southern Oshana region of northern Namibia. Water is pumped from flooded iishana, and stored in underground storage tanks, and covered ponds.

These facilities were intended to provide water for irrigation of gardens for subsistence agriculture and market production, using stored water gathered from rainfall events and flooded iishana. One pond has a shade-net roof and one is covered with corrugated iron, with a total storage capacity of 400 m^3. These storage facilities are located next to greenhouses, providing facilities for growing market-ready vegetables protected from direct sunlight, wind, and pests; and open gardens that use drip-irrigation. Figure 15 shows a cross-section of the facilities, and Figure 16 shows the plant next to a flooded Oshana during the floods of 2011.

Figure 15 Example rainwater harvesting facility.



Source: CUVEWaters

Figure 16 The Oshana in lipopo during the flood of 2011, in the background the floodwater harvesting plant.

Source: CUVEWaters

Constructed over 5 years ago, the facilities are still operational, as are rainwater harvesting facilities at this and other locations. Following is a summary of lessons learned provided by the CuveWaters team (Jokisch, pers comms, 2017):

- Good quality floodwater was collected in two out of three seasons during the project, and the facilities are still in operation.
- It was concluded that construction and operation of floodwater harvesting facilities in Namibia is a viable option.
- Income generation from the first growing season was N$ 4,700 from selling market produce from the greenhouse, over and above subsistence crop production.
- The diet and health status of families involved with the project improved throughout the project lifetime, and ten permanent jobs were created.
- The floodwaters of the Cuvelai River Basin vary greatly from year to year in volume and spatial distribution. These variations present challenges for consistent water supply, even though substantial quantities are stored.
- The team recommended that only locations north of the Oshakati to Okahao road should be considered to maximise potential for harvesting flood waters. The secondary benefit of this zone is that soils are better in this area, meaning that facilities would be more productive.
- Floodwater harvesting should also be combined with rainwater harvesting, to maximise rainwater capture and storage, especially in lower flood years.
- Facilities should be located no more than 20 km from markets within urban centres, such as Okahao, Outapi, Oshakati or Oshikuku.
- All rainwater and flood-water harvesting and gardening facilities development should be supported by capacity development initiatives, to increase the understanding of construction, management and farming techniques, making the projects more sustainable.
- Based on experiences, the CuveWaters team recommended that groups developing and utilising these facilities should be small private businesses or maximum 5 families working together as a cooperative venture.

7.7 DESALINISATION

While groundwater across the southern portion of the basin is relatively shallow (10 to 100 m; Mendelsohn, et al 2013) salinity is frequently high (Mendelsohn et al. 2000), meaning that if communities wish to utilise readily available groundwater resources for livestock watering, irrigation or consumption, it needs to be desalinated. Desalinisation is widely known to be an energy intensive process, often pushing the costs up to the point that the solution is unsustainable. However, the CuveWaters Project piloted four facilities – in the villages of Amarika and AKutsima - to determine the feasibility of developing and implementing desalinisation as an option for providing clean drinking water. Each facility managed to create 5 m^3 of clean drinking water per day from highly saline groundwater sources, using a mixture of desalinisation technologies, most successful of which were heat exchange and reverse osmosis (CuveWaters, 2015).

Figure 17 Solar powered desalinisation facility in Akutsima.

Source: ISOE Wikom 2014

7.8 WATER QUALITY AND WASTE MANAGEMENT

While not a currently overwhelming issue, waste management is a growing concern in the Cuvelai River Basin, with some rural communities, utilising the iishana as dumping areas for solid waste, as shown in Figure 18.

Figure 18 Waste dump outside Ondjiva.

Source: Mendelsohn 2017

As the iishana are depressions, they are natural dumping sites, as the dump is out of sight; however, the same depression is also a watercourse. During the rainy season, water flowing in the iishana network will move waste downstream, along with any contaminants accumulating in the dump. Furthermore, the waste dump can dam the watercourse, impounding water, and causing flooding, as can be seen in Figure 18; and these sites should also be considered a health-hazard to the local population and livestock, as shown in Figure 19.

While solid waste management is currently not a pressing issue in the Cuvelai River Basin, provision of suitable, managed solid waste disposal sites in major towns and villages in Angola and Namibia would avoid this situation deteriorating in future.

Figure 19 Cattle grazing in a waste dump.

Source: Mendelsohn 2017

7.9 WATER UTILISATION AND DEMAND DATA AND INFORMATION GAPS

The general uses of water in the Cuvelai Basin are understood; however, detailed data on water extraction and the amount of water used per purpose were not readily available. A basin-wide assessment of water demand would help to inform management of water balance decision making. Such a study would also help to inform where water conservation efforts are required and where conservation efforts might be most efficient. One significant gap in knowledge with respect to groundwater is the extent and sustainable yield potential of the Ohangwena II Aquifer.

8.0 DISASTER RISK MANAGEMENT

While the Cuvelai River Basin is prone to many types of typical disasters, such as fire, earthquakes, floods and droughts, the two main priorities, especially from a transboundary water management perspective, are **drought and floods**. These two issues are discussed briefly below, followed by an assessment of the SADC Flood Atlas, and its application in the Cuvelai River Basin as a Flood Forecasting and Management tool (Section 11.0). Drought is mentioned briefly in Section 5.1.3 and again with Flooding in Section 6.4.

8.1 DROUGHT

Floods are often thought of as causing the greatest impacts to the landscape, infrastructure and livelihoods, because of the rapid nature of their onset, and immediately observable physical destruction; however, droughts can have greater impacts, with longer term effects on households, due to prolonged food insecurity, and water scarcity (Mendelsohn J. , Pers Comms, 2017). The timing and magnitude of drought affects vegetation, human health and livelihood, wildlife, and wildfires. Droughts in the study area are partially controlled by large-scale ocean-atmosphere teleconnections, especially El Niño (Chishakwe 2010). Drought indicators available in the Cuvelai are described in Section 5.1.3.

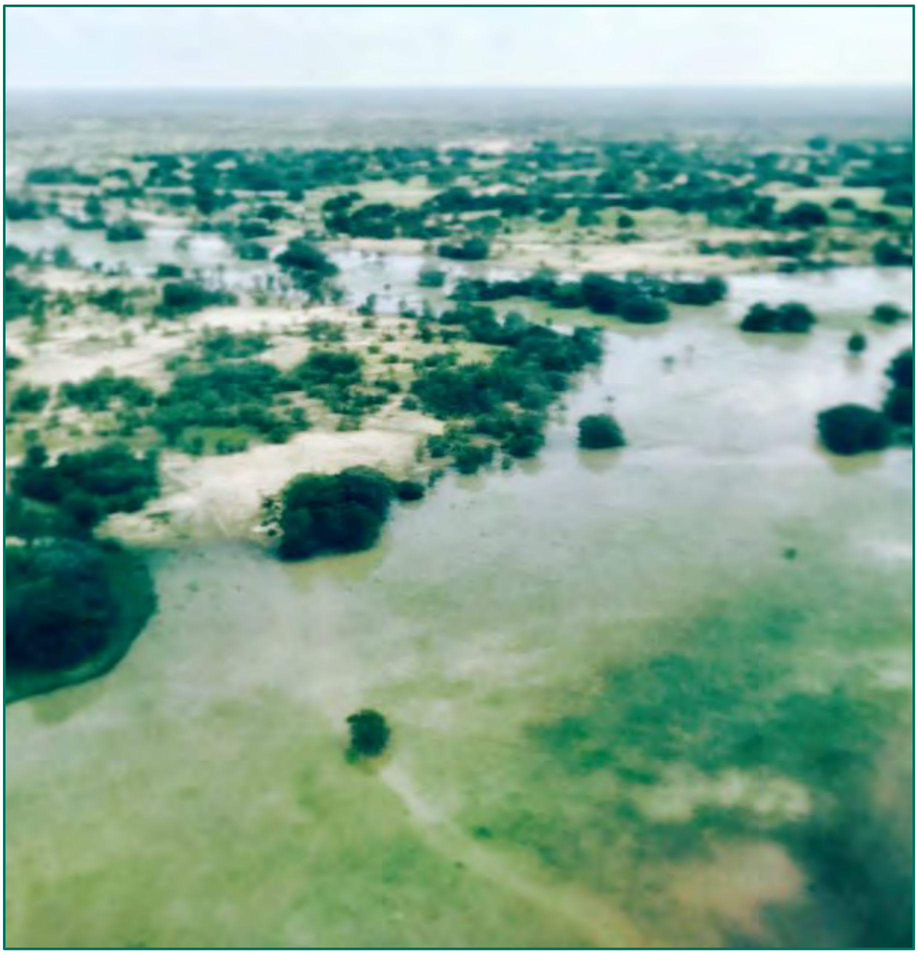
The people of the Cuvelai Basin are no strangers to drought conditions. In 2013 for example, the government of Namibia declared a state of emergency due to drought. About one third of the population in Namibia and another 1.5 million people in Angola were classified as food insecure as a result of drought (United Nations Office forthe Coordination of Humanitarian Affairs 2013). With an annual PET of 1,500 mm and a mean annual precipitation of between 300 to 400 in the south and 800 to 900 in the north (Mendelsohn & Weber 2011), PET is greater than three times the precipitation. Using remote sensing and data for three parameters (precipitation, soil moisture and potential evapotranspiration) Stein *et al.* showed that drought exposure is highest in eastern and central areas of the Cuvelai (see Figure 10; Stein, Luetkemeier, Liehr, & Drees 2015).

A temperature increase of between 1 and 7^{o}C is projected by the end of the 21st Century, as is an increase in temperature extremes, which can be expected to contribute further to an increase in evapotranspiration (Section 6.0). These changes would influence crop survival, in a region of high dependence on agriculture. Temperature change is expected to be more drastic the further inland from the coast.

8.2 FLOODS

Available flood indices are described in Section 5.1.3. Exceptionally high flows are known as 'efundjas', since 1941, floods have occurred in 1950, 1954, 1957, 1971, 1976, 1977, 1995, 2004, and 2008-2011 (Mendelsohn and Weber 2011; DRFN and Heyns Consultancy 2013); with substantial flood waters experienced across the central basin in March 2017. (Al Jazeera 2017 Mar 17). Receding flood waters from the March 2017 floods can be seen in Figure 20.

Figure 20 Remnants of flooding, late March 2017.



Source: Hughes 2017

Flood waters can take weeks or months to pass, owing to the level nature of the landscape and limited variability in topography in the catchment. Flooding is particularly difficult to predict, since flood waters take different paths through iishana at different times, in response to rainfall distribution and intensity (Section 6.3).

Flood waters in at least one example, take approximately 19 days to travel from Evale in the northern portion of the basin to Oshakati, south of the border (RAISON 2013).

Figure 21 Evale town adjacent to the Cuvelai River, in flood.

Source: Mendelsohn 2017

Figure 22 and Figure 23 show flood waters receding in late March 2017, following the flooding events of earlier in the month.

Figure 22 Receding flood waters, southern Angola on 2017-03-29.

Source: Hughes 2017

Figure 23 Receding flood waters close to Oshakati in Namibia on 2017-03-31.

Source: Hughes 2017

8.2.1 Impacts of Floods

The Cuvelai River basin has recorded several significant seasonal floods since 2008, causing numerous impacts on rural livelihoods, some positive, most negative; with the greatest impact being felt by vulnerable communities with limited means to prepare for, respond to, and survive these events (Shifidi, 2016). Apart from the security risks posed by the actual floods to the basin inhabitants, their livelihoods are threatened in the following ways:

- **Property** – damage to assets such as homes and property lead to reduced livelihood capacities as do any damage to infrastructure such as roads (e.g., reduced access to markets);
- **Human health** – increased incidences of illness and fatalities due to drowning, disease and parasites, and potentially exacerbated by reduced access to healthcare when roads are blocks;
- **Plant and crop communities** – damage to crops through reduction of soil oxygen levels, clogging of soil pores, change in soil pH balance, etc; and
- **Livestock** – reduction in productivity due to food shortages and fatalities and illness brought on by drowning, disease and parasite outbreaks.

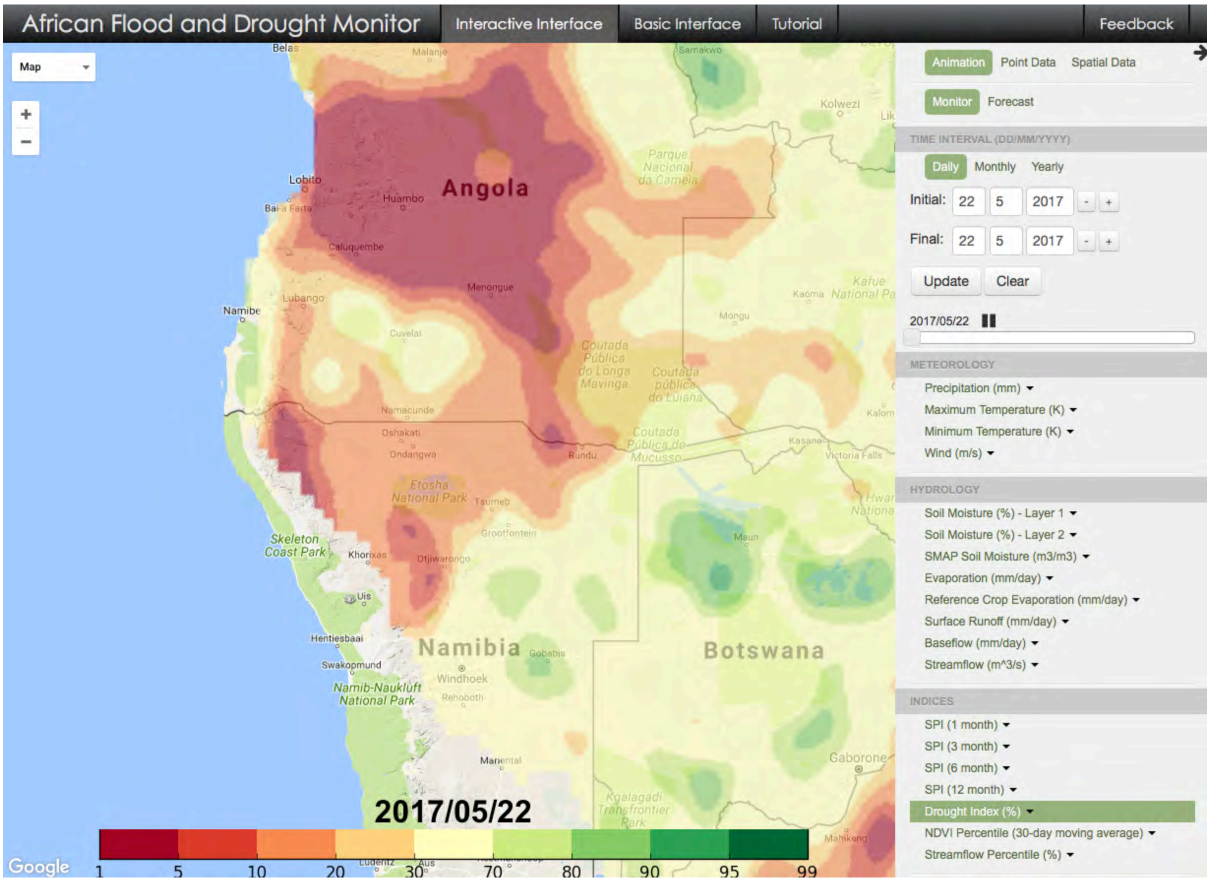
These, and other, negative impacts accumulated over the years preceding 2016 created damage estimated to cost USD 136.4 million in direct losses, and USD 78.2 million in indirect losses (Shifidi, 2016).

While floods are, often for good reason, viewed as purely negative events, communities across the region, although negatively impacted, largely believe the short-term negative impacts of floods are greatly outweighed by long-term benefits (Shifidi, 2016). Benefits of floods include increased harvest and livestock productivity in drier areas, and recharge of riparian and other aquifers, as well as the replenishment of fish stocks.

8.3 DISASTER RISK MANAGEMENT DATA AND INFORMATION GAPS

Data and information gaps for disaster risk management are largely addressed in the Section 11.4 Flood Monitoring and Forecasting Data and Information Gaps, as most disasters in the Cuvelai River Basin are associated with flooding; however, droughts are not covered in Section 11. As droughts are the result of large-scale climatic patterns, it is possible to obtain regional-scale data on drought conditions, and indicators, such as vegetation and food security indices from sources such as the Famine Early Warning Systems Network (FEWS-Net)[2], and the African Flood and Drought Monitor[3], as shown in Figure 24. While these data contribute to a regional picture, they will be augmented by local hydro-climatic data discussed in data and information gap discussions elsewhere in this document.

Figure 24 African Flood and Drought Monitor.



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[2] https://www.fews.net/

[3] http://stream.princeton.edu/AWCM/WEBPAGE/interface.php?locale=en

9.0 SOCIAL AND ECONOMIC PROFILE

Namibia and Angola share the Cuvelai Basin. Any attempt to sustainably manage a resource must acknowledge the system's interlinkages with the socio-political context and varied perceptions and processes.

The Cuvelai Basin is characterised by ephemeral rivers, high rates of evaporation, densely populated rural communities, a growing population, limited water resources and high demand for water. Subsistence livelihoods are prevalent, with heavy reliance on cattle, a limited number of crop species, and food gathering to some degree. There is a high level of reliance on groundwater aquifers for domestic water supply and for agriculture.

9.1 POPULATION

Accurate population statistics that are basin-specific are difficult to obtain. Population statistics sourced from census bureaus from 2011 (Namibia) and from 2014 (Angola) indicate that there are between 1.35 million and 2.4 million people living in, and/or near to, the Cuvelai Basin. A population of 1.35 million assumes that the boundaries of the basin include the Namibian regions of Omusati, Oshana, Oshikoto, and Ohangwena as well as the Angolan province of Cunene. A population of 2.4 million assumes that the boundaries include portions of the Namibian regions of Kunene and Otjozondjupa, and the Angolan province of Cuando Cubango. High resolution satellite imagery was used to identify a total of 14,234 urban homes and 43,865 rural homes in the Basin (Calunga P, Haludilu T, Mendelsohn J, Soares N, and Weber B 2015).

Population densities in both countries are relatively high when compared with similar regions of southern Africa, and are rising. Density is concentrated in the centre of the basin and roughly correlates with higher soil fertility (RAISON 2013). Access to water is likely a key limiting factor to population growth. There are 45 towns and villages in the basin, 25 in Namibia and 20 in Angola (RAISON 2013). The population of urban areas in Northern Namibia (still within the Cuvelai Basin) increases by as much as 300% during public holidays (Zimmermann 2013), which has implications for water management. Ethnicity in the basin, at least historically, is almost entirely Owambo (RAISON 2013).

9.1.1 Namibia

Namibia ranks 125 on the Human Development Index (HDI) (United Nations Development Programme 2016). The country has an infant mortality rate of 32.8 per 1,000 births and a life expectancy of 65.1 years. Namibia receives a medium score on the inequality-adjusted HDI (based on life expectancy, education and income gaps) at 0.415. Finally, Namibia obtains medium score of 0.986 on the gender development index.

Table 5 Demographics of the Cuvelai regions in Namibia (Namibia Statistics Agency, 2011).

Region	Population			Density	Growth Rate	Age Distribution (%)				Rural
	Female	Male	Total	People per km^2	%	Under 5	5-14	15-59	60+	%
Omusati	133,621	109,545	243,166	9.1	0.6	14	26	49	11	94
Oshana	96,559	80,115	176,674	20.4	0.9	12	21	59	8	54
Oshikoto	94,907	87,066	181,973	4.7	1.2	14	26	52	9	87
Ohangwena	133,316	112,130	245,446	23.0	0.7	15	29	47	9	90
TOTAL	**458,403**	**388,856**	**847,259**							

Numbers presented as they appear in the Namibia 2011 Population and Housing Census. 2011. Retrieved from http://cms.my.na/assets/documents/p19dmn58guram30ttun89rdrp1.pdf on February 24, 2017

Note that although a small portion of the Regions of Kunee and Otjozondjupa are inside the far south of the Cuvelai River basin, population statistics for the two Regions are excluded from the table above, as they would skew the overall population statistic for the Namibian portion of the basin

There is some indication that population estimates require updates. In official census statistics for 2011 for example, the city of Oshakati has a population of 35,600 but the mayor estimates it has grown to approximately 45,000 (Zimmermann 2013). There is a trend towards urbanisation reported by census data in all of Namibia's Cuvelai regions however over 77% of the population continue to live in rural areas. Of note, there are more than 65,000 fewer males than females in the Namibian portion of the basin. In some administrative regions, there are more women head-of-households then men, which can at least partially be attributed to migrant labour (Cecilski, Makhabane, Ndevashiya, & Hasheela 2001).

Table 6 Head of households by gender (Namibia Statistics Agency, 2011).

Region	Head of Household (%)	
	Female	Male
Omusati	55	45
Oshana	54	46
Oshikoto	49	51
Ohangwena	57	44

There are reported to be at least 127 health facilities in the Namibian portion of the basin, and 85% of the population have access to (or are within 10km of) one of these facilities (RAISON 2013).

9.1.2 Angola

Angola ranks 150 on the Human Development Index (HDI) (United Nations Development Programme 2016). The country has the highest infant mortality rate in the world (96 of every 1,000 births) and one of the world's shortest life expectancies (at 52.7 years). Angola scores low on the inequality-adjusted HDI, based on life expectancy, education and income gaps, at 0.336. Finally, no HDI data exists for the gender development index.

Table 7 Demographics of the Cuvelai regions in Angola (Instituto Nacional de Estatica, 2016).

Province	Municipalities	Population			Density	Rural
		Female	Male	Total	People per km^2	%
Cunene	All	514,474	450,814	965,288	12.5	79
Cuando Cubango	Cuchi	22,665	20,234	42,899	3.6	43
	Menongue	157,792	148,830	306,622	13.0	
	Cuangar	13,919	13,416	27,335	1.4	
TOTAL		**708,850**	**633,294**	**1,342,144**		

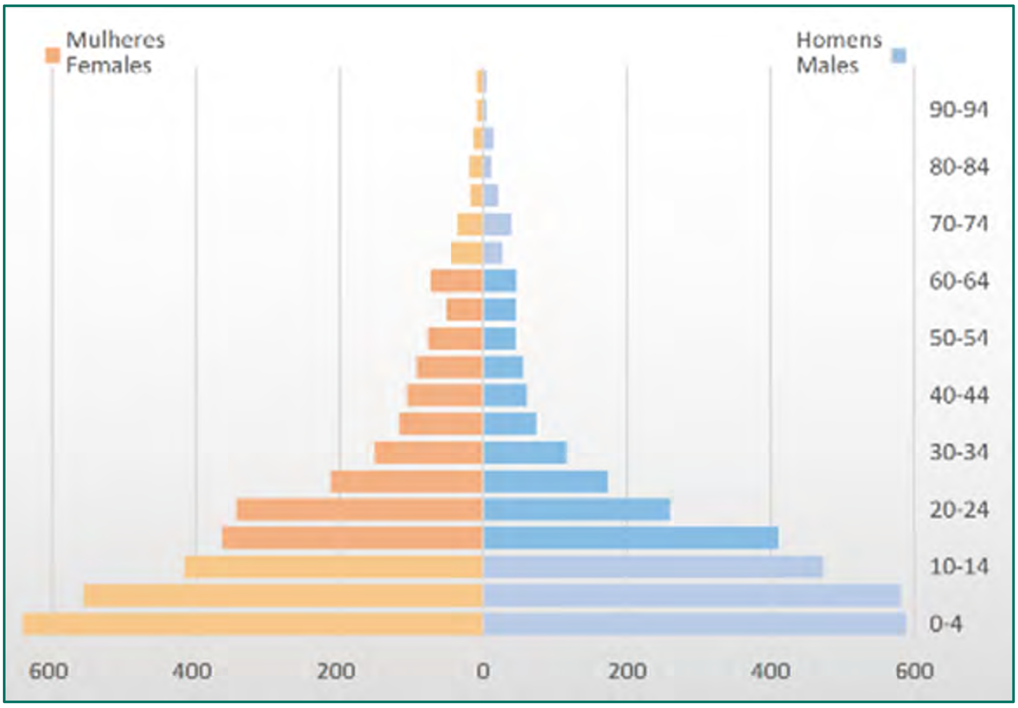
Numbers presented as they appear in Angola's 2014 Census.

Note that although a small portion of Huila Province is inside the far north of the Cuvelai River basin, population statistics for Huila Province are excluded from the table above, as they would skew the overall population statistic for the Angolan portion of the basin.

Most of the northern half of the basin is in Cunene Province, with a small area of the upper basin reaching into Cuando Cubango. and Huila Provinces.

Calunga P. et al. found that only 33% of people in interviewed households in rural areas were between the ages of 20 and 64 (2015). This leaves the population with a very high rate of dependency. They also found only 86 males to every 100 females in rural households and 92 males per 100 females in urban households. The care of dependents is therefore most often entrusted to working age women.

Figure 25 Age pyramid of rural homes in the Angolan portion of the Cuvelai Basin.



Source: (Calunga et al. 2015).

9.1.3 Economy

Angola

Angola has a gross national income of 6,211 per capita (2011 PPP$). The percentage of Angola's working aged population (15 years or older) that is employed is 68.4 (UNDP 2016). Data on the workforce in different sectors are unknown however; unemployment is reported at 7.6%. The country has a high reliance on oil followed by services. Agriculture, energy and public service sectors are experiencing growth (Fews.net 2012). The country plans to mitigate potential declines in oil with agriculture, investments in infrastructure, gradual reduction of imports, financial reform, skills development and improvement of business environment (Gallardo & Muzima 2016). Rural livelihoods rely heavily on agriculture, including livestock, and on fishing and hunting. Nomadic pastoralism is prevalent (Few.net 2012). Results of a household survey indicated income earners in urban areas had jobs in public service, in informal businesses and as labourers in urban households; and in rural areas, very little to no income is generated aside from selling homemade liquor (Calunga et al. 2015).

Namibia

Namibia is classified as an upper middle income country; however, it is also one of the world's most unequal in income distribution. Namibia has a gross national income of 9,770 per capita (2011 purchasing power parity [PPP]). The percentage of Namibia's working age population (15 years or older) that is employed is 59.4 (UNDP 2016). The percentage of the workforce working in agriculture is 31.4% and in services is 54.2%. Unemployment rates in the Namibian portion of the basin are reported to range between 13 and 20% (Namibia Statistics Agency 2011) and 25.5% by the United Nations Development Programme (UNDP) HDI data (2016).

In rural areas subsistence economy is prevalent (Zimmermann 2013). Other economic activities include agriculture and mining (diamonds, uranium, zinc and other minerals) (CIA 2017). Tourism is increasing, particularly in the Etosha National Park, but also to the south and east of the park (RAISON 2013). Locally sourced products are traded and sold in Namibian shops and in some cases exported. Marula fruits for example are used in skin and haircare products (RAISON 2013).

Table 8 Income sources in Namibia (Namibia Statistics Agency 2011).

	Population	Farming (%)	Wages (%)	Remittance (%)	Business (%)	Pension (%)
Omusati	228,842	46	16	6	8	22
Oshana	161,916	36	32	5	13	12
Oshikoto	161,007	56	20	3	6	11
Ohangwena	228,384	52	13	5	8	20

Numbers presented as they appear in the Namibia 2001 Population and Housing Census. 2001. Retrieved from https://web.archive.org/web/20120111224420/http://www.npc.gov.na/census/index.htm on February 24, 2017

9.1.4 Water Vulnerabilities

Vulnerability can be understood by understanding the likelihood of exposure to a potentially harmful change, the severity of potential harm, and the capacity to respond to changes. Potentially harmful changes can include flood, drought, crop failures and crop disease, pollution, disease, decreased access to safe water, decreased access to health care, to economic participation, among others. The ability to respond to changes is influenced by factors that include socio-economic position, education, assets, capacities for alternative livelihoods, governance capacities and disaster risk reduction systems. Vulnerabilities can be exacerbated for certain groups (e.g., women, elderly, youth, disabled) over others due to social, economic, institutional or regulatory limitations (e.g., laws that restrict women from owning property), that limit their ability to cope with change.

Using downscaled regional climate models, the Desert Research Foundation of Namibia (DRFN) projects an increase in precipitation due to climate change, a later start to the rainy season and an earlier cessation of the rainy season (Dirkx, Hager, Tadross, Bethune, & Curtis 2008). More intense rain events may therefore be expected. The shallow topography of the basin, combined with concentrated periods of precipitation (up to 96% of rainfall occurs between October and April) can mean severe floods (Zimmermann 2013), particularly in the central drainage zone (RAISON 2013). The road network connects communities, facilitates market participation and social interaction, allows for access to health care and is essential to disaster risk reduction efforts. It is largely unusable during flood situations.

Poorer households are often situated in areas more susceptible to flooding and constructed from materials less resistant to flooding (RAISON 2013), which can contribute to a higher likelihood for loss of assets. In March 2017, potentially record breaking floods occurred, triggering disaster relief mechanisms, In Namibia 1,092 people were moved to relocation camps (International Federation of Red Cross and Red Crescent Societies 2017) and 255 families in Cunene Province, Angola were displaced (DW 2017). Several sections of roads were washed away, impacting access to basic services and interconnectivity between communities (NewEra 2017).

Post-disaster assessment of damage and losses due to the 2009 floods, in six of Namibia's regions (including the four Regions in the Cuvelai Basin) are summarised in Table 9.

Table 9 Summary of damage and losses from 2009 floods in northern Namibia (Government of the Republic of Namibia 2009)

Sector	Damage (US$ million)	Losses (US$ million)
Infrastructure	34.3	4.9
Water Supply Sanitation	5.9	3.4
Transport	27.4	0.4
Energy	1.1	0.2
Production	49.7	71.7
Agriculture	4.7	14.8
Industry	17.6	19.9
Commerce	25.7	35.5
Tourism	1.6	1.4
Social	51.1	2.4
Housing	47.3	1.7
Health	0.1	0.7
Education	3.7	0.0
Cross-sectoral	1.2	0.1
Environment	1.2	0.1
TOTAL	**136.4**	**78.2**

Groundwater quality is influenced by chloride, sodium, fluoride and sulphate (Bittner Water Consult 2006). Salinity, fluoride and sulphate concentration increases towards the basin centre and elevated levels of nitrates are found in the southeast portion of the basin (RAISON 2013). Salinity of groundwater has been measured above 5,000 milligrams per litre, leading to deeper drilling to reach cleaner water (Mendelsohn, El Obeid, & Roberts 2000). Groundwater is discussed in more detail in Section 5.3. Research at four boreholes indicate that groundwater use between 1990 and 2010 exceeded replenishment (RAISON 2013). Demand can be expected to increase with an increasing population.

Other water related issues can include increases in vector-borne and water-borne diseases and an increase of crop infestations and disease during or after flooding. Calunga et al. for example, found that over 72% of households in the Angolan portion of the Basin reported a loss of livestock due to drought within the previous two years (2015). The same survey showed that the impacts of drought were reported to be less severe (e.g., fewer deaths of people and livestock and fewer people moving away) in the northern region of the Basin.

Resource conflicts over water in the basin include: South Africa troops occupying the Ruacana hydropower complex in 1975; and Angolans attacking the Calueque Dam in 1988 (Pacific Institute 2016). Namibia and Angola have experienced six other water-related conflicts (in other basins) between 1904 and 2000. Protests unrelated to water in late 2015 resulted in the destruction of water meters in Oshakati (Armed Conflict Location & Event Data Project 2016). Household surveys, conducted in the Angolan portion of the Cuvelai Basin assessed the vulnerabilities of livelihoods (Calunga P et al. 2015).

SADC reports that 40% of the Namibian population in the Cuvelai Basin are food insecure (SADC 2016). The locations of fish refugia (where small populations of fish survive through dry periods) are unknown, making conservation of these areas difficult. During wet years, fish are an important source of food, and in some cases fisheries support local economic activities (Mendelsohn J. 2015d). Marula (*Sclerocarya birrea*), bird plum (*Berchemia discolor*) and jackal berry (*Diospyros mespiliformis*) are culturally important food-source trees (Mendelsohn J. 2015c). Although not a proven linkage, increasing mortality in recent years of these trees may be an indicator of increasing water vulnerability that would be of interest to water managers. Vast areas that were traditionally used for cattle grazing are increasingly fenced in for farming, and cattle excluded (Mendelsohn J. 2015e). Lands rights are customary at best for most of the rural population in the Namibian portion of the basin (RAISON 2013). Soil fertility is in decline due to population pressure, land management practices, deforestation and unsustainable land use by individuals who lack land rights (Dahlberg & Wingqvist 2008). In Angola, remnant land mines may still be of concern in agricultural areas (República de Angola 2009). Access to safe drinking water continues to be widely accepted as a critical issue. Only 25% of households in Cunene Province, Angola, have access to potable water (Fews.net 2012). Solar powered desalinisation is practiced in at least two locations (RAISON 2013).

In Angola, the population living below the poverty line, defined as $1.90 per day (PPP) is 30.1% and in Namibia, it is 22.6% (United Nations Development Programme 2016). A household survey conducted in Angola's Cuvelai Basin in 2014 showed that between 78 and 98% of the 693 rural households interviewed grow beans, maize, sorghum and/or millet (Mendelsohn, 2015e). Over 66% of households rate millet as the single most important crop. The crop is reported to contribute to some households' income, but appears to have more importance in supporting livestock and food reserves. Ownership of cattle, goats, pigs and chicken were reported by over 50% of the households, and 17% owned donkeys. Cattle and goats appear to hold the most importance in supporting livelihoods through livestock. Fishing is particularly important for supporting livelihoods in the Western shana zone. Hunting was reported by

27% of the households. Income generation comes from a variety of sources and appears to rely sporadically on the selling of home grown and homemade products. Most households reported at least one member with income from working as a public servant or labourer.

A diversity of livelihoods can be used as an indicator for capacity to adapt to changes in climate or deal with shocks. Another indicator is the diversity of material possessions. The same household survey conducted by Mendelsohn in 2014 reveals that an overwhelming majority of households lack vehicles (96%), solar panels (94%), television receivers (97%) or vehicle tracks/roads (79%) (2015e). Materials used most often to build houses include grass thatch roof (69%), mud and stick walls (74%) and brush fencing (41%). Urban areas on the other hand use primarily corrugated iron roofing materials, bricks/blocks for walls, and have no fencing.

Poverty is associated with inadequate access to: transportation, communication, health services, education, food and clean water – all of which contribute to a lowered capacity for managing risks associated with water supply or water-related disasters. Informal settlements, for example, required evacuation during flooding in 2008, 2009 and 2011 (RAISON 2013), and other communities evacuated in 2017 (Al Jazeera 2017). Despite the potential hazards associated with floods, surveys conducted in the Namibian Cuvelai show that rural households in the central basin prefer flood events due to the increased food production (Tuwilika, 2016).

The level of education completed by adults in the Angolan portion of the Basin is low. Nearly half (49%) of the rural population aged 20 or more have never attended school (Calunga 2015). In Angola's Cuvelai Basin, between 57 and 72% of rural households lack language skills in both English and Portuguese (Mendelsohn, 2015e).In the Namibian portion of the Basin, between 8 and 23% of the population over the age of 15 have never attended school (National Planning Commission 2011). A low level of education is a limiting factor for participating in economic activities and for alternative livelihoods in times of scarcity.

Another potential issue impacting the ability to respond to climate shocks may include crop disease. In March 2017 for example, African army-worm was reported to have been impacting maize crops in Omusati for months. The worm thrives in humid weather. Maize is often milled into flour, sold to the Office of the Prime Minister and distributed as drought relief (The Namibian 2017).

Community level participation in water governance in Namibia, despite decentralisation having been mandated, remains minimal. Dragnich et al. found that perceptions at the community level are a factor in slow uptake of participatory processes, indicating a need for improved awareness and capacity (2007).

Other factors contributing to capacity gaps include limited access to health care (particularly for populations experiencing high rates of disease such as malaria or HIV/AIDS), few options for income/livelihood diversification, limited access to schooling in some rural areas, low household income, limited access to adaptable agricultural technologies and practices, among others. Calunga et al. found that only 16% of survey respondents had at least some secondary school education and attribute this to factors such as a lack of schools and teachers and a reluctance to send children to school (2015). They also mapped the locations of health care facilities and found that over 47% of residents in the Angolan portion of the basin are further than 5km from one of these facilities.

Vulnerability Data and Information Gaps

Basin-specific data on the following is required:

- It is widely suggested that increasing siltation due to agriculture (ploughing, over grazing and land clearing for crops) in the already shallow topography may be contributing to more extensive and longer lasting floods (Mendelsohn J. 2015f). However, data is required to prove this and to support management.
- Detailed information about the transportation network (roads, railways, etc.).
- Location and capacity of desalinisation efforts.
- Impacts of industry on water quality (e.g., copper smelter in Tsumeb).
- Information of the impacts from previous climate extremes (floods and drought) on loss of livelihoods, loss of life, loss of assets, etc.
- A household survey conducted in the Agnolan Basin collected data on household assets (Calunga 2015). Generally, though, food insecurity and climate change vulnerability data is needed for the entire basin (e.g., assets, livelihood alternatives, etc.).
- Traditional knowledge of ecological systems can help to improve adaptive capacity (e.g., Niipele et al. 2015). The extent of involving or understanding of traditional knowledge is incorporated into decision-making processes.
- Distance at which water is available for households.
- Cost of water to households.
- Distance between sanitation and users' houses.
- Numbers of people trained in the development and maintenance of water supply systems and sanitation systems. Information is also needed about the number of people in governance structures with training and responsibility for investigating sources of vulnerability.
- Wherever possible, all data requires gender disaggregation.
- Location of fish refugia (and other resources important for subsistence).
- Land ownership vs. informal settlements.
- Budget allocations to water sectors and to addressing climate change.
- High resolution remote sensing data can be used to identify locations (homes, communities, roads, sewage, and other infrastructure) at risk of flooding during efundjas.
- With the ever-present potential for transboundary water conflicts, it is important to understand the systems in place for negotiations, for managing conflict, the utilisation of those systems and effectiveness/amount of training provided to those who would be required to administer such systems.

9.1.5 Land Use

Subsistence economy is prevalent in the region. Most of the region is rural and is used for subsistence agriculture (livestock and some crops). There is an increasing trend towards private land ownership, which excludes the use of the land for traditional subsistence purposes (Mendelsohn J. 2015e). There are two parks in the Basin: Mupa in Angola and Etosha in Namibia. Over time, a decrease in woodland extent is observed, followed by an expansion of arable land, driven by subsistence agriculture and urban infrastructure expansion (Wingate VR, Phinn R., Kuhn N, Bloemertz L, and Dhanjal-Adams KL 2016). Changes in land use were noted to be most prominent nearer to towns, villages, rivers and roads.

9.2 SOCIO-ECONOMIC DATA AND INFORMATION GAPS

9.2.1 Population

The Cuvelai Basin crosses administrative boundaries in both Angola and Namibia. Basin-specific and current population and demographic data is lacking from each country's statistics. Statistics could also benefit from more refined delineation of age groups.

Information on population and density from different sources sometimes conflict. The methodologies for collecting population and demographics data may need to be standardised and quality assurance, or validation mechanisms reviewed. Additional information needed to better understand the social context of the Basin include: access to health care, distance from water sources and from sewage, level of education, and literacy. Gender disaggregated data is needed on all population indicators.

9.2.2 Economy

The extent of the hprivate sector's interest or investment into socially responsible water management in either Angola or Namibia is unknown. Information like this can help to inform the planning and implementation of effective awareness raising campaigns for corporate water extractors.

Data collected on many economic indicators are required. Examples can be found on the World Bank website (The World Bank 2016). Data on the economic activities that require water withdrawal is largely unknown. This type of information might include crop zones, livestock density, mine locations, etc.

9.3 CROSS-CUTTING ISSUES

9.3.1 Poverty

While poverty is a critical aspect of understanding the socio-economic setting in the Cuvelai River Basin, it is just one aspect of vulnerability, which provides a deeper understanding of living conditions. Vulnerability comprises seven key characteristics, which when strengthened, provide opportunities to develop resilience, security and confidence (Calunga, Haludilu, Mendelsohn, Soares, & Weber, 2015):

- Access to water;
- Access to healthcare;
- Access to educational;
- Labour/work opportunities;
- Food security;

- Income; and
- Access to transportation options.

Limited access to quality water and water services (e.g., sanitation) is often a contributing factor to continued poverty and effective water management plays a critical role in poverty reduction. Similarly, water investments, plans and policies impact the poor in ways that need to be accounted for. Poverty-reducing water strategies would ideally include targeted intervention (e.g., provision of safe water and sanitation to poor communities) and broad interventions (e.g., Basin-wide infrastructure). Water interventions that affect poverty include (WB 2003):

- Broad scale:
    - Resource development and management: Basin-wide water resource interventions that can include major infrastructure, inter-basin transfers, etc.
    - Service delivery: Basin-wide service delivery interventions that might include multi-purpose and multi-sectoral basin management plans or improvements to water supply utilities.
- Poverty targeted:
    - Resource development and management: Targeted water resource interventions to improve local access to safe water and sanitation (e.g. restoration of degraded habitat utilised by poor communities).
    - Service delivery: Targeted water services for poor communities, which can include community water and sanitation supply projects to previously unsupplied areas.

Finally, stakeholder engagement is critical for planning all effective interventions.

9.3.2 Gender

Gender inequity can exacerbate vulnerabilities and can hinder economic development. Water-related inequities can arise from unequal access to or control over water, or from unequal distribution of benefits from its use. Based on the literature survey conducted with this project, no recent basin-wide or country-specific gender studies have been conducted. According to the OECD however, Angola scores a medium and Namibia scores a low, on the Social Institutions and Gender Index (2014). Three main categories of data are required:

- **Livelihoods**: The roles of women and men in accessing water, and in maintaining households and livelihoods, particularly in rural areas.
- **Benefits**: The distribution of water and benefits from the use of water amongst men and women.
- **Governance**: The roles of women and men in water management, water-related policy and planning, and water-related decision making.

A gender expert can design investigations in a way that is unbiased. A better understanding of gender dynamics and the gendered aspects of water management can help to inform mainstreaming of gender into decision making, inform capacity development efforts, and improve gender equity. However, such work needs to be informed by detailed gender-disaggregated socio-economic data and information, currently lacking in the Cuvelai River Basin.

9.3.3 Gender and Poverty Data and Information Gaps

Based on the available information for the Cuvelai River Basin, very little information is gender-disaggregated, making it difficult to develop a clear picture of gender issues in the basin at this stage. Socio-economic data has been collected for portions of the basin, and available information has been aggregated to an extent, largely by John Mendelsohn of RAISON consulting in Namibia; however, there is a clear need for a basin-wide socio-economic study in the Cuvelai River Basin, to elaborate a clear household-level understanding of poverty and gender dynamics in terms of livelihoods and water resources management.

Data gaps described under Section 9.1.5 (Water Vulnerabilities) are also relevant here. Basin-specific data on the following is required (disaggregated by gender wherever possible):

- Detailed information about the transportation network (roads, railways, etc.).
- Location and capacity of desalinisation efforts.
- Impacts of industry on water quality (e.g., copper smelter in Tsumeb).
- Impacts from previous climate extremes (floods and drought) on livelihoods, life, assets, etc.
- Food insecurity and climate change vulnerability.
- The extent of traditional knowledge integration into water management decision-making processes.
- Distance at which water is available for households.
- Cost of water to households.
- Distance between sanitation and users' houses.
- Number of people trained in the development and maintenance of water supply systems and sanitation systems.
- Number of people in governance structures with training and responsibility for investigating sources of vulnerability.
- Location of fish refugia (and other resources important for subsistence).
- Land ownership vs. informal settlements.
- Budget allocations to water sectors and to addressing climate change.
- The systems in place for negotiations, for managing conflict, the utilisation of those systems and effectiveness/amount of training provided to those who would be required to administer such systems.

10.0 GOVERNANCE AND INSTITUTIONAL PROFILE

This section of the basin profile includes the following aspects:

- Southern African Development Community (SADC);
- SADC guidance on gender mainstreaming;
- The regulatory framework in Cuvelai River Basin countries;
- Institutional framework; and
- Civil society.

10.1 SOUTHERN AFRICAN DEVELOPMENT COMMUNITY (SADC)

SADC was established as the Southern African Development Coordinating Conference (SADCC) in 1980 and became SADC in 1992. The 15 member countries include Namibia and Angola. The institutional framework is determined by Article 9 and is illustrated below.

Figure 26 Summary of SADC governance units and functions.

Source: (SADC, 2017)

SADC's objectives include development, peace and security, economic growth, alleviation of poverty, enhanced standards and quality of life, support for the socially disadvantaged through regional integration, to build on democratic principles and equality, and sustainable development.

10.1.1 SADC Protocol on Shared Watercourses

The SADC Protocol on Shared Watercourses states the following objects for RBOs:

- To develop a **monitoring policy** for shared watercourse systems;
- To **promote the equitable utilisation** of shared watercourse systems;
- To formulate **strategies for the development** of shared water course systems; and
- To **monitor the execution** of integrated water resource development plans in shared watercourse systems.

The Protocol states that the purpose and function of RBOs shall be as follows:

- *With regard to National Water Resources Policies and Legislation:*
  - *Harmonisation of national water resources policies and legislation; and*
  - *Monitoring compliance with water resource legislation and, where necessary, recommending amendments thereto and the introduction of new legislation.*
- *With regard to Research, Information and Data Handling:*
  - *Collecting, analysing, storing, retrieving, disseminating, exchanging and utilising data relevant to the integrated development of the resources within shared watercourse systems and assisting member States in the collection and analysis of data in their respective States;*
  - *Reviewing the provisions of National Development Plans relating to the water course systems;*
  - *Designing and conducting studies, research and surveys relating to the environmentally sound development and management plans for shared watercourse systems;*
  - *Stimulating public awareness and participation in the sound management and development of the environment including human resources development; and*
  - *Promoting in accordance with the national development plans of the Basin States, the formulation of integrated master plans for shared watercourse systems.*
- *With regard to Water Control and Utilisation in shared watercourse systems:*
  - *Recommending regulation of the flow and drainage;*
  - *Promoting measures aimed at flood and drought mitigation;*
  - *Recommending and promoting measures to control desertification, soil Erosion and sedimentation;*
  - *Monitoring the utilisation of water for agriculture, domestic, industrial and navigational purposes;*

    - *Monitoring the establishment of hydro-electric power installations;*
    - *Monitoring the generation of hydro-electric power; and*
    - *With regard to Environmental Protection.*
- *Promoting measures for the protection of the environment and the prevention of all forms of environmental degradation arising from the utilisation of the resources of the shared watercourse systems:*
    - *Assisting in the establishment of a list of substances whose introduction into the waters of a shared watercourse system is to be banned or controlled;*
    - *Promoting environmental impact assessments of development projects within the shared water-course systems; and*
    - *Monitoring the effects on the environment and on water quality arising from navigational activities.*
- *With regard to Hydro-meteorological Monitoring Programme:*
    - *Promoting a hydro-meteorological monitoring programme in consultation with other SADC sectors.*

Essentially, the SADC Protocol on Shared Water Courses guides Member States to equitably share transboundary water resources through the application of IWRM principles, supported by the establishment of RBOs and sharing of information.

10.1.2 SADC Regional Water Policy

The Southern African Development Community (SADC) Regional Strategic Action Plan (RSAP) is a framework to support sustainable water resource development and management. The fourth iteration of the plan (2016-2020) seeks to address various issues that include; human rights to water; water quality; research for development; gender mainstreaming and youth engagement; UN Groundwater Articles; climate change; and indigenous knowledge and citizen science (Global Water Partnership 2013).

10.1.3 Implementation of the SADC Regional Water Policy

In 2015, the Global Water Partnership (GWP) assessed SADC member countries on their progress towards implementing the SADC Regional Water Policy (RWP). The RWP for the SADC region is aimed at providing a framework for sustainable, integrated and coordinated development, utilisation, protection and control of national and transboundary water resources.

Following is a summary of the GWP assessment for both Angola and Namibia.

10.1.3.1 Angola

The Water Sector Development Strategy in Angola provides the main legislative framework for integrating the RWP. Numerous instruments are in place and facilitate the implementation of the Regional Water Policy. Challenges that remain include: updating baseline data on water resources;

improving inter-sectoral cooperation and coordination; an infrastructure maintenance backlog; updating and implementing up to date legislation and regulations; and financial constraints.

Key water-related issues in Angola include the following:

- Climate change;
- Water scarcity;
- Desertification;
- Deforestation of tropical rain forest;
- Soil erosion; and
- Pollution.

Improved capacity is required in the areas of: data collection infrastructure; sanitation infrastructure; Integrated Water Resources Management; implementation of policies and regulations; cross-sectoral harmonisation; and climate adaptation and mitigation, disaster risk reduction and gender mainstreaming.

10.1.3.2 Namibia

In Namibia, the Water Resources Management Act, the National Water Policy and the Water Supply and Sanitation Policy provide the main legislative framework for integrating the GWP. The Department of Water Affairs and Forestry within the Ministry of Agriculture, Water and Forestry is responsible for all water and sanitation management. The Environmental Management Act requires Environmental Impact Assessments for projects which may have a significant effect on the environment or the use of natural resources. The legislative and institutional framework for Strategic Environmental Assessment (SEA) is currently under review.

Key water-related issues in Namibia include the following:

- Water scarcity and erratic precipitation patterns;
- Insufficient sanitation;
- A dedicated water law is yet to be finalised; and
- Insufficient implementation of policy and plans.

Improved capacity in the areas of policy analysis, planning and management, pollution control, sanitation and related element and basin management committees is required.

10.2 SADC GUIDANCE ON GENDER MAINSTREAMING

The SADC Declaration on Gender and Development (1997) reaffirms SADC's commitment to eliminating gender discrimination and mainstreaming gender issues. Guidance on gender mainstreaming in the SADC water sector (SADC n.d) recognise the different roles men and women play in water utilisation and water management. It also recognises that men and women are impacted differently when changes occur to social, environment, political, cultural and water availability contexts. Participatory processes are recognised as a method strengthening sustainable water management efforts. To support the State-level efforts for mainstreaming gender in the water sector, SADC has identified four strategic interventions:

- **Supporting the creation of an enabling regulatory environment**: States are advised to improve political will and reflect gender mainstreaming in appropriate legal, institutional and administrative frameworks and budgets (all that account for continental, international, SADC, and country-specific regulations and policy);
- **Capacity building and awareness raising**: States and organisations are advised to improve awareness and commitment of staff to remove gender inequality (including vertical and horizontal learning exchanges, providing a foundational knowledge with respect to gender concepts and definitions, benefits of gender mainstreaming, tools/systems for gender mainstreaming, etc.);
- **Providing conducive institutional arrangements**: States are advised to improve systems that guide, plan, monitor and evaluate gender mainstreaming (including disaggregated data collection and analysis, gender responsive budgeting, dedicated staff, and systems for transparency); and
- **Gender sensitive management instruments for all stages of the policy cycle**: States are advised to improve the implementation of gender policy.

The entire project cycle (from problem formulation to project implementation and monitoring to project closure evaluations) is to utilise gender mainstreaming tools.

The SADC **Protocol on Gender Development** guides the operations of the Gender Unit and has the following priorities:

- Policy Development and Harmonisation;
- Gender Mainstreaming;
- Institutional Strengthening and Capacity Building;
- Women's Empowerment Programmes;
- Communication, Information Sharing and Networking; and
- Research, Monitoring and Evaluation.

10.3 REGULATORY FRAMEWORK

10.3.1 International Conventions

The following international conventions contain provisions directly or indirectly relevant to sustainable water management in the Cuvelai Basin (this list is not exhaustive):

- **Convention on Biological Diversity (CBD) 1992**, Contains provisions for the biodiversity associated with inland waters. Both Angola and Namibia are signatory to the CBD.
- **Economic Community of Central African States (ECCAS):** Angola became a signatory to this economic community in 1999. The Protocol on Cooperation in Natural resources between

member states of the ECCAS requires that participating countries harmonise natural resource policies and activities, the sharing of research results, and development of joint capacity development programs. Angola is a member of this economic community.

- **Convention on the Conservation of Migratory Species of Wild Animals (CMS):** Angola is party to this convention.
- **Dar-es-Salaam Declaration on Agriculture and Food Security in the SADC Region (2004)**: Member states are expected to allocate substantial portions of their agricultural budgets to water management. The declaration contains provisions for trans-basin water transfers and sustainable use of living aquatic resources/ecosystems. Private sector investment is expected to play a big part in transboundary water resource development and management policies and programs. Angola and Namibia are both member states.
- **Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia** (**Raptors MOU**): This MOU falls under the CMS and is legally non-binding. Angola is a signatory and Namibia contains species relevant to the MOU.
- **United Nations Convention against Corruption** (**UNCAC**): This convention requires parties to implement anti-corruption measures focussing on: prevention, law enforcement, international cooperation, asset recover and technical assistance and information exchange. Both Angola and Namibia are signatories to this convention.
- **The Cotonou Agreement (2000):** The agreement is essentially a way to prioritise good governance strategies. It provides for state autonomy in social and economic development, participatory governance (e.g., civil society, local governments, private sector), political dialogue and mutual obligations, and considering country-specific and regional contexts (e.g., least developed countries or vulnerable regions). Both Angola and Namibia have signed the agreement.
- **United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa (UNCCD) (1994):** The convention aims to combat desertification and combat the effects of drought. Both Angola and Namibia are signatories.
- **International Renewable Energy Agency** (**IRENA) (2009)**: The organisation seeks to improve member country regulatory processes and capacities for renewable energies. Both Angola and Namibia are member countries.
- **The Convention on the Elimination of all Forms of Discrimination against Women (CEDAW) (1979)**: CEDAW requires participating nations to work towards non-discrimination and women's rights to equal political, economic and social participation.
- **The Protocol to the African Charter on Human and Peoples' Rights on the Rights of Women in Africa (Maputo Protocol) (2005):** Signatories of this protocol ensure the rights of women, including the right to participate in political and decision-making processes, the right to sustainable development, and the right to a healthy and sustainable environment, among others. Both Angola and Namibia are party to the charter.

- **The Convention on the Law of Non-Navigational Uses of International Watercourses:** The convention governs the shared use of waterways that cross international boundaries. This convention requires each riparian state to ensure, in an ongoing manner, that its use is equitable and reasonable visà-vis other riparian states. What is equitable and reasonable in any given case may be determined only by considering all relevant factors and circumstances—both natural (e.g., climate, hydrography) and human-related (e.g., social and economic needs of the riparian states, effects of uses in one state on co-riparians, existing and potential uses). States are to take "all appropriate measures" to prevent causing "significant harm" to co-riparian states and "consult" with the other international watercourse states and provide prior, "timely notification" about any new use or change in an existing use of an international watercourse that could have significant adverse effects on co-riparian states, along with relevant technical information. The convention entered into force in 2014.
- **The Ramsar Convention**: The Etosha Pan, Lake Oponono and Cuvelai drainage in Namibia constitutes a Ramsar wetland (wetland of international importance).
- **World Meteorological Organisation** (**WMO**): The WMO is an intergovernmental organisation. Angola's implementing institution is the Instituto Nacional de Hidrometeorología e Geofísica. Namibia's implementing institution is the Namibia Meteorological Service in the Ministry of Works and Transport.

In addition to the above, the international community contains many examples of best practices that can help guide effective water resources management, including:

- IFC Performance Standards;
- Millennium Development Goals; and
- The Climate Investment Fund's Phase 2 Gender Action Plan (pillar three focuses on green growth and sustainable livelihood, including water and food security).

Many international agreements contain wording on involvement of women in the management of water and other resources. These include, but are not limited to:

- Dublin Principles (1992);
- Agenda 21 (1992);
- World Water Forums;
- Bonn Conferences on Fresh Water (2001);
- Pan-African Implementation and Partnership Conference on Water (2003);
- African Union Gender Policy (2009);
- AMCOW Policy and Strategy for Mainstreaming Gender in the Water Sector in Africa (2011);
- African Charter on Human and People's Rights of Women in Africa (2011);
- African Water Vision 2025; and
- Rio+20.

10.3.2 Laws

The following provides a summary of water governance laws relevant to the Cuvelai River Basin. The summaries are not extensive legal reviews.

10.3.2.1 Angola

The Constitution of the Republic of Angola (2010) establishes public ownership of inland waters, lakes, lagoons and watercourses (including their beds). Responsibilities for managing water are applied to local authorities.

The National Water Law (2002) forms the core of the legal framework for the water sector. It establishes the water basin as the basic unit for water resources management, recognises water as a social and economic good, and decentralises water management to the Provinces.

The National Environment Law (1998) requires Environmental Impact Assessments (EIAs) and Social Impact Assessments (SIAs) be conducted for all activities that have potential impact to communities or to natural resources. The law also requires public consultation for EIAs and SIAs.

The Law of Local State Administrative Units (2007) and the Decentralisation Law (1999) extend responsibilities for executing sector plans and policies to provincial and municipal governments.

10.3.2.2 Namibia

In Namibia, water resources are 'owned' by the state (as per the Water Resources Management Act). Namibia has legislated participatory and decentralised resource management both in general terms (Namibian Decentralisation Policy 1998) and more specifically with respect to water resources (Water Resources Management Act No. 24 of 2004). This makes participatory decision-making at a local level a priority in water resource management. It also means that the capacity of regional councils and local authorities to facilitate and participate in decision making relevant to effective management.

The Local Authorities Act (1992) outlines the development and authorities of local government. Parts VI and VII of the Act outlines the authorities of local government to construct water works, supply water to persons other than residents, limit supply of water or use of water during drought or other emergencies, and issue penalties associated with offences. Part VII outlines the authorities of local government to construct, maintain and operate sewage and draining systems. It also describes the duties associated with stoppages or defects of sewage systems, and the issuance of penalties associated with offences.

The Namibia Water Corporation Act of 1997 establishes NamWater as a public company with the State as sole shareholder. The act outlines the objectives and activities of the Corporation and includes a duty to supply water, to conserve and protect water resources and the environment, to maintain records, to maintain and publish service standards and the provision of subsidies. Section 6(c) of the act establishes the legal basis for sharing water across international boundaries subject to Section 7 which prevents the supply of water to customers outside of Namibia without ministerial approval. Notably, Section 6(g) also requires the Corporation to develop and deliver training – an important point for when RBOs are planning capacity development. Cost recovery tariffs, borrowing, selling and renting of assets is provided for in Section 7 of the Act.

The Water Resources Management Act of 2013 incorporates the 2004 version of the Act, which replaced the Water Act of 1956. The objectives of the Act are to "to ensure that the water resources of

Namibia are managed, developed, used, conserved and protected in a manner consistent with" fundamental principles which are in line with Integrated Resources Management principles. The Act establishes governing bodies (including responsibilities and authorities) such as water advisor council and Basin Management Committees. It contains the legal framework for: internal watercourses; management of rural water supply; an integrated water resources management plan; water supply, abstraction and use; water service suppliers and licensing; groundwater access and protection; pollution control; water protection areas; water related emergency or pollution threats; management of dams; management of wetlands and water quality; fees for service; land occupancy; and tribunals and appeals.

Rights to gender equality are established by the **Constitution**. The Communal Land reform Bill treats men and women equally in terms of rights to customary land and the treatment of widows/widowers. It is unknown how extensively customary practice (which favors male land ownership) overrides law.

10.3.3 Regulations and Plans

10.3.3.1 Angola

The Strategy for Water Sector Development (2003) and The Water Sector Development Program (2004) allowed for sanitation master planning and assessments of rural water and sanitation sectors. Principles that guide implementation include users and polluters pay, collected wastewater should be treated, and management occurs at the smallest possible scales.

The National Development Plan (2013-2017) recognises gender inequity as an issue for rural development and promotes gender equality (República de Angola, 2012). The ultimate goal of the **Strategic National Programme for Water (2013-2017)** is to guide multi-sectoral water management investments.

The Water for all Program (2007) aimed to install or upgrade 7,000 wells and boreholes with hand pumps, install or rehabilitate 265 piped systems and benefit more than 5 million people in rural areas by 2012. Activities mandated by the program included development of operation and maintenance systems and training for public and privates sector professionals and entrepreneurs.

A National Policy on Environmental Sanitation was drafted in 2011 with the help of international donors.

10.3.3.2 Namibia

The **National Water Policy White Paper (2000)** and the **Water Supply and Sanitation Policy (2008)** establish legislative provisions for implementing agencies.

The Basin Management Approach (BMA) guides implementation of water management and contains provisions to enhance stakeholders' capacity to participate in water management. It also promotes inter-sectoral collaboration on all natural resource management (Dragnich, Dungca, Pendleton, & Tracy 2007). The BMA provides an entry point for establishing an international basin organisation in Namibia.

Namibia's Vision 2030 focuses the country's development policy around five major themes which include sustainable agriculture and gender equality. Poverty reduction activities are also prevalent.

The National Gender Policy (2010-2020) was drafted by the Ministry of Gender Equality and Child Welfare. The Policy provides guidance and mechanisms for the planning, implementation of and monitoring of gender equality strategies

10.3.4 Monitoring and Enforcement

National parks within the basin include the Etosha National Park in Namibia and Mupa National Park in Angola. The parks would have some responsibility for enforcement within the boundaries of the parks.

10.4 INSTITUTIONAL FRAMEWORK

The institutional frameworks of Angola and Namibia, with respect to water management, are discussed below; however, a critical aspect of water resources management at a local scale in Angola is the responsibility of provincial governments and Municipos, with input from GABHIC, whereas in Namibia management of water has been devolved to Sub-basin or catchment level, guided by the Ministry of Agriculture, Water and Forestry and the Department of Water Affairs.

10.4.1 Angola

The Ministry of Energy and Water and the Ministry of Finance are responsible for managing water resources, including setting tariffs. The National Water Directorate is responsible for sector planning. Additional agencies have been created recently that are likely to have relevance to water management. These include: the Ministry of Environment (MINAMB), created in 2008; the position of Secretary of State for Water Affairs, created in 2007; and the National Institute for Water Resources (INRH), established in 2012.

The Office for the Management of the Cunene River Basin (Gabinete para a Administracao da Bacia Hidrograpfica do Rio Cunene [GABHIC]) is part of the Permanent Commission of the Cunene River Basin (Commissao Permanente da Bacio do Rio Cunen [CPTC]). Initially established specifically to address the management of the Cunene River, the remit of GABHIC was recently expanded to also include the Cubango and Cuvelai rivers.

The World Bank (WB) is working with the Government of Angola (Water Sector Institutional Development Project) to develop new administrative units, including; autonomous provincial water and sanitation utilities, a regulatory agency for urban water supply and sanitation, and a national institute for Water Resources (Water and Sanitation Program - Africa 2011).

The National Gender Commission is mandated to monitor implementation of national gender policy and CEDAW.

The Instituto Nacional de Hidrometeorología e Geofísica is the implementing agency for WMO.

10.4.2 Namibia

MAWF oversees water management at the national level and is responsible for water-related infrastructure, organises water-related data collection and management. MAWF and the Department of Water Affairs implement water resource management through the BMA - see Section 10.3.3 – devolving management of water resources within catchments to Basin Management Committees (BMCs) with direct input from a range of stakeholder groups, as listed in Table 10. NamWater is the corporation responsible for water supply. A Governor is elected to each of the four Regions in the Basin, which are sub-divided into constituencies represented by elected councillors (Bittner Water Consult 2006). Traditional authorities (headmen, kings or queens) govern roughly 8 tribes and the main language is Oshiwambo, with other languages spoken by minority groups (Mendelsohn, El Obeid, & Roberts 2000).

Water supply and sanitation are the responsibilities of the Namibian Water Corporation (NamWater), as legislated in the Namibia Water Corporation Act of 1997.

Practically, there are indications that the implementation of decentralised decision making has been challenged, mainly due to a lack of resources and possibly also to resistance to participation. Dragnich et.al (2007) researched perceptions regarding water management held by key stakeholders. The research was interested in the implementation of community participation in decision making processes. They found that due to limited funds, the large distances separating communities and a lack of time available to officers, the structure of water governance in the Namibian portion of the basin varied from the planned structure laid out by the BMA. Water management information was disseminated by DRWS Extension Officers and Chief Extension Officers to local water user committees, but not to the communities. The Basin Management Committee is meant to promote community participation and monitor sustainable management of water resources. Local Water Associations and Water Point Associations coordinate water supply management at a local level.

Table 10 Community involvement management of water in Namibia.

Institution	Representing	Roles	Reporting to	Supported by
Water Point Users Association (WPA)	Comprised of all households using a water point	Use water efficiently for domestic and livestock needs	Themselves	Rural Water Supply Extension Officers (RWS-EO) & WPC
Water Point Committee (WPC)	Water Point Users Association	Take care of water point, collect fees & pay to LWC	WPA	WPA & RWS-EO
Local Water Committee (LWC)	Water Point Committees on branch line or groundwater area	Manage branchline, ensure payment to bulk water supplier	WPCs	RWS-EO & WPCs
Regional Water Committee (RWC)	Local Water Committees	Contribute to planning of water supply	LWCs and Rural Water Supply	RWS-EO & LWC & RWS- Regional Office
Basin Management Committee	Line ministries, NGOs, regional institutions; all stakeholders	Contribute to management & planning of water supply	All stakeholders	Department of Water Affairs, Division of Hydrology

Source: Zijlma, 2004; Amakali and Shixwameni, 2003; in Seely, Peet and Manning.

Directorate of Disaster Risk Management coordinates disaster response alongside Regional Councils through Regional Emergency Management Units. The National Planning Commission helps to coordinate disaster response with the international community.

The Namibia Meteorological Service in the Ministry of Works and Transport is the implementing agency for WMO. The organisation reports an annual budget of 42 Million N$ and, out of 52 staff, 14 are women (WMO 2017).

10.5 CIVIL SOCIETY

10.5.1 Civil Society Data and Information Needs

Awareness levels among civil society with respect to water management roles, responsibilities, participatory processes, etc. are unknown.

Most Angola's portion of the basin falls within Cunene province, with only a very small portion of the basin reaching into Cuando Cubango and Huila provinces. The southern, Namibian, portion of the basin spreads across four administrative regions of Oshikoto, Omusati, Ohangwena and Oshana, with a small area of the lower basin reaching into Kunene and Otjozondjupa administrative regions (RAISON 2013).

10.5.2 Governance Information and Data Gaps

A better understanding is needed of the roles communities (men and women) hold with regards to barriers to participation in decision-making. Additionally, the percentage of women who are members of decision-making structures, important for understanding gender equity, is unknown (e.g., local councils, regional councils, parliament, and administrative structures). Other issues related to governance data and information gaps are as follows:

- Indicators used to measure water management performance are unknown;
- Revenue from tariffs are unknown, as is the revenue sharing/allocation structure;
- Systems of enforcement are unknown; and
- Methods used to collect information on and understand social and environmental conditions in the Basin are unknown. Also, unknown if these methods are standardised.

11.0 Flood Monitoring and Forecasting

The following section presents an assessment of the approaches to flood monitoring and forecasting that are currently in use in the Cuvelai Basin and the surrounding region. The intent of this assessment is to provide a high-level overview; as such, it is limited to a desktop-based review of existing documentation and resources for flood forecasting in the Cuvelai Basin. It is not intended to be a comprehensive evaluation or detailed gap analysis.

11.1 BACKGROUND

The Cuvelai Basin has a high degree of hydrological and climatic variability (Section 5.1). Climate change and climate variability have exacerbated both dry and wet conditions in the region in recent years, with the past decade containing historically severe droughts and floods (particularly the floods in 2008, 2009, 2011; (Mendelsohn and Weber 2011). Flood monitoring and forecasting in the basin is particularly challenging due to the complexity of its topography and drainage networks (Filali-Meknassi et al. 2014).

In response to the most recent flooding, national and international partners initiated broad-scale re-evaluation of the flood management system in the region. Two projects are of high relevance to the Cuvelai Basin, and were used as the primary information sources for the development of this assessment:

- A review project, with the objectives of evaluating the flood forecasting system for Namibia (including an assessment of existing data) and making recommendations for flood forecasting and disaster response methods, was initiated by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) in 2011. The final report for this project, titled "Data Access, Availability and Quality Assessment for the Development of a Flood Forecasting Model for Namibia" was published in 2014 (Filali-Meknassi et al. 2014).

- A flood risk management (FRM) program led by the SADC HYCOS, referred to as the SADC HYCOS FRM, began in early 2014 and continued through 2015. The four-volume final report, "Integrating SADC HYCOS into Flood Risk Management Strategies that Support Regional Disaster Risk Reduction" was published in November 2015 (Atkins 2015). A major component of this program was the development of a Regional Flood Atlas consisting of maps showing flood-prone areas and the relative severity of the flood hazard.

11.2 EVALUATION CRITERIA

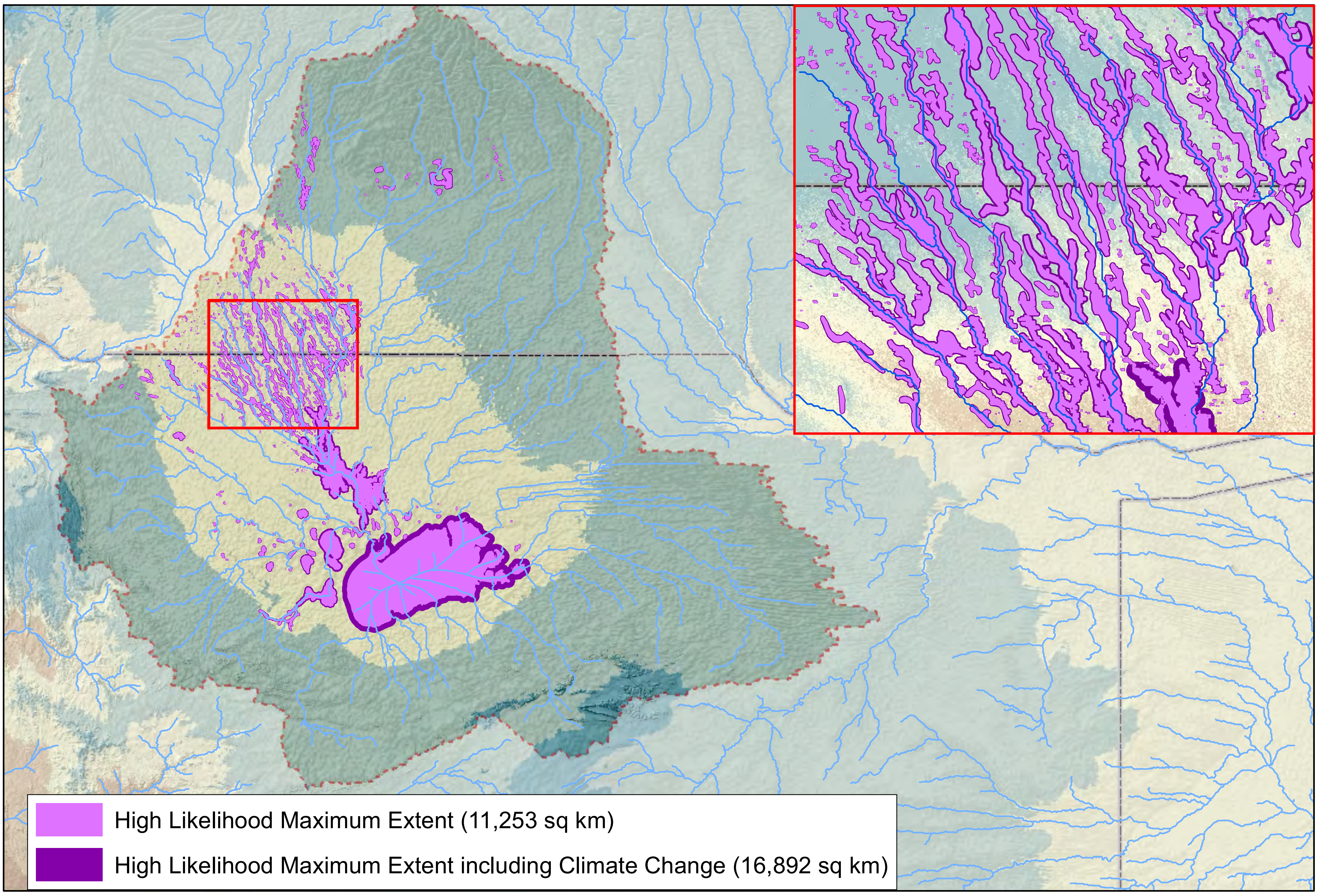
The flood forecasting system was evaluated based on the following three criteria:

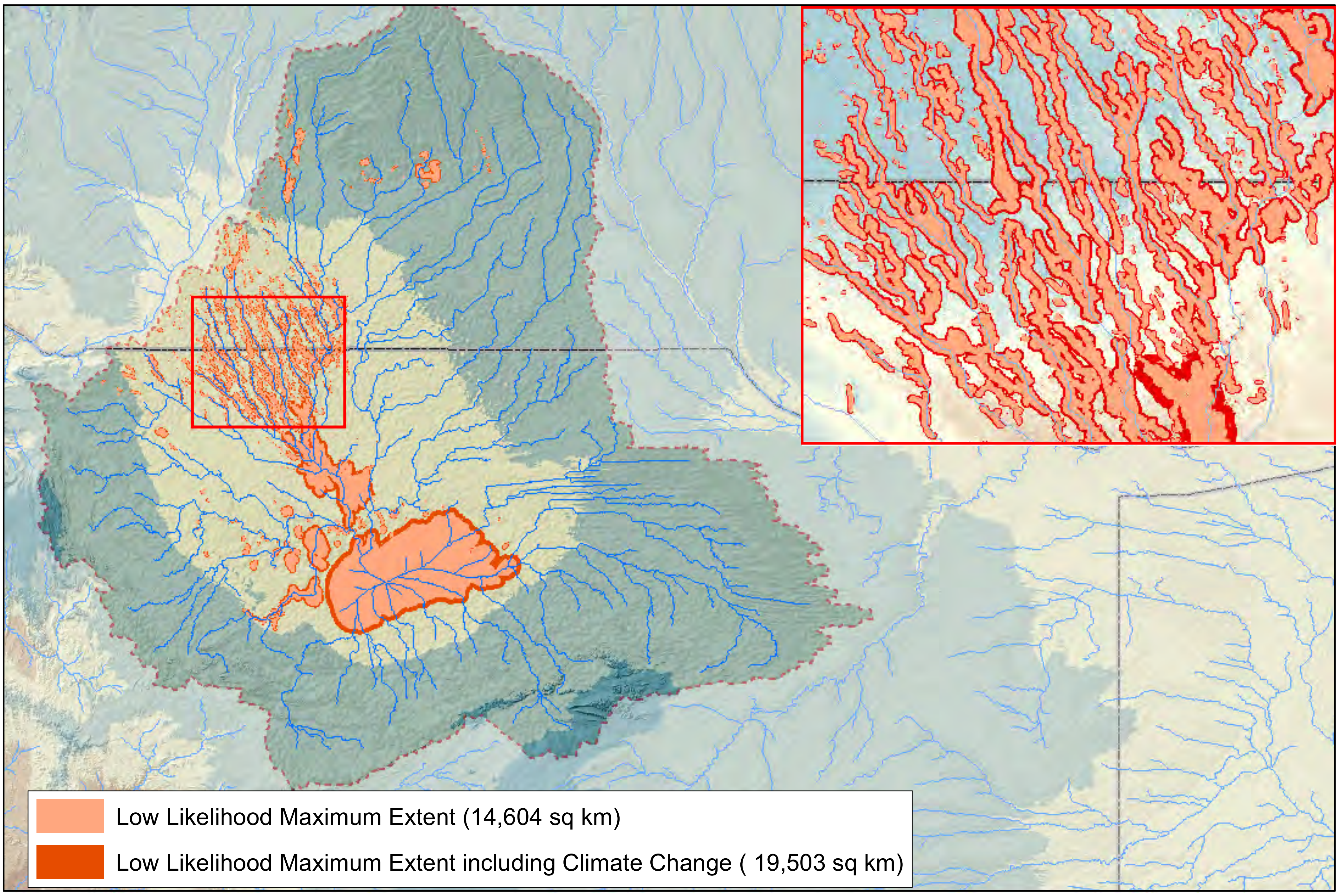
1. Is the existing flood forecasting methodology appropriate for application in the Cuvelai Basin, given the basin's unique hydroclimate and topography?

2. Are available data sufficient to support a robust flood forecasting system in the Cuvelai Basin using the current methodology (i.e., period of record, data quality, and spatial coverage)?

3. Are collaboration, data sharing, and communication systems sufficient to support the flood forecasting system in the Cuvelai Basin?

FIGURE 27 - SADC - mapped flood extent in the Cuvelai





Notes: Watercourses were delineated in ArcHydro based on a flow direction and flow accumulation grid, which defines the number of cells which flow into each down-slope cell; the watercourse network is then derived by applying a threshold on the number of flow accumulation points to theflow accumulation data set, with each flow accumulation threshold giving a different number and length of river reach. Atkins 2015.

11.3 EVALUATION RESULTS

The current activities related to flood monitoring and forecasting in the Cuvelai Basin fall into three broad categories, summarised in Table 11, and described in greater detail below.

Table 11 Summary of flood forecasting-related activities and products in the Cuvelai Basin.

Activity or Product	Key Agencies	Description
Data		
Hydrometric monitoring (HYCOS)	SADC, Namibia Hydrological Services (NHS)	Approximately 24 telemetric level gauges on the Namibian side of the Cuvelai Basin; however, little long-term (>5 years) data available for these gauges, and their condition is uncertain. No known functional hydrometric gauges on the Angolan side of the basin.
Meteorological monitoring	NMS	Possibly one staffed meteorological station and at least seven automatic meteorological stations on the Namibian side of the Cuvelai Basin; no known meteorological stations on the Angolan side of the basin
Remote sensing data (rainfall, water levels, topography)	e.g., NASA (TRMM, SRTM), UNITAR/UNOSAT Flood Portal, GDACS	Remote sensing data are available from various sources for studies of the Cuvelai Basin (e.g., Atkins 2015; Awadallah and Tabet 2015; GDACS 2017)
OpenStreetMap	NHS	Open-source, collaborative map used by the NHS to store water level data obtained from public contributors (e.g., locations of water recorded by handheld GPS), which are used in conjunction with historical satellite data to relate modelled streamflows and/or satellite rainfall data to the spatial extent of floods.
Data analysis and modelling tools		
TIGER-NET	ESA, NHS	Open-source software that provides flood forecasting capabilities using water level data and satellite RADAR imaging
HEC-RAS	NHS	Open-source hydraulic modelling software used by the NHS in flood studies
CREST	NHS	Grid-based hydrological modelling program used by the NHS to predict flood magnitude and timing using satellite-derived digital elevation data, rainfall data, evapotranspiration data, and information about soil properties, land use, and land cover
Data synthesis and dissemination		
Namibia Flood Dashboard and Flood Early Warning Project	NASA	River flow records, basin maps, infrastructure maps, TRMM rainfall forecasts, and other satellite overlays combined in an interactive, user-driven format
HYCOS Flood Atlas	SADC	Maps of flood hazards and flood-prone areas in 14 major transboundary river basins in the SADC region including the Cuvelai
Daily flood bulletins	NHS	Bulletins containing flood gauge data, rain gauge data, satellite maps of potential rainfall, and observations from flood zones

CREST: Coupled Routing and Excess Storage; ESA: European Space Agency; GDACS: Global Flood Detection System; HYCOS: Hydrological Cycle Observation System; NASA: National Aeronautics and Space Administration (United States); NHS: Namibia Hydrological Services; NMS: Namibia Meteorological Service; SADC: Southern Africa Development Community;

SRTM: Shuttle Radar Topography Mission; TRMM: Tropical Rainfall Measuring Mission; UNITAR/UNOSAT: United Nations Institute for Training and Research/UNITAR's Operational Satellite Applications Programme.

11.3.1 Data

- Hydrometerologic monitoring data available in the Cuvelai Basin are described in Section 5.0;
- Remote sensing data (topography, rainfall, water levels) are available from various sources, most notably NASA (e.g., TRMM and SRTM data), the United Nations (e.g., UNITAR/UNOSAT Flood Portal), and the European Commission Joint Research Centre (JRC) Global Flood Detection System (GDACS) for studies of the Cuvelai Basin (e.g., Atkins 2015; Awadallah and Tabet 2015). GDACS methodologies are based on analysis of passive microwave remote sensing imagery (De Groeve et al. 2006; Brakenridge et al. 2007; Kugler and De Groeve 2007; De Groeve and Riva 2009a; De Groeve and Riva 2009b);
- NHS uses OpenStreetMap (2017), an open-source, collaborative project to create a free editable map of the world, to store and organize water level data obtained from public contributors (e.g., locations of water recorded by handheld GPS). These data are used in conjunction with historical satellite data (MODIS, Radarsat, and EO-1) to relate modelled streamflows and/or satellite rainfall data to the spatial extent of floods and calibrate hydrological models (Filali-Meknassi et al. 2014; Mandl n.d.).

11.3.2 Data Analysis and Modelling Tools

- TIGER-NET (2017g), an open-source software program, is part of the European Space Agency (ESA)'s TIGER initiative to improve Integrated Water Resources Management (IWRM) in Africa (2017). It is used by the NHS for streamflow forecasting, flood monitoring, and flood vulnerability assessment (Filali-Meknassi et al. 2014). The TIGER-NET Water Observation Information System (WOIS) provides forecasting capabilities seven days in advance using recorded water level data and satellite radar imaging.
- HEC-RAS, a widely used open-source hydraulic modelling software program developed by the United States Corps of Engineers, has been used by the NHS in flood studies (Filali-Meknassi et al. 2014). It was also a key tool in developing the maps for the SADC HYCOS Regional Flood Atlas (Atkins 2015), discussed in more detail below.
- CREST, the Coupled Routing and Excess Storage hydrological model (2017), is a collaborative project between Oklahoma University and NASA (Wang et al. 2011) that is used by the NHS (Filali-Meknassi et al. 2014). CREST is raster-based (i.e., grid-based) and can be used to predict flood magnitude and timing using satellite-derived digital elevation data, rainfall data, evapotranspiration data, and information about soil properties, land use, and land cover.

11.3.3 Data Synthesis and Dissemination

- The Namibia Flood Dashboard and Flood Early Warning Project (2017) combines river flow records, basin maps, infrastructure maps, TRMM rainfall forecasts, and other satellite overlays in an interactive format that allows the user to select different layers. According to the Flood Dashboard website, its flood potential maps are based on a meso-scale hydrological model, which is assumed to be the University of Maryland Global Flood Monitoring System (GFMS), described on the TRMM Global Flood and Landslide Monitoring website (Wu et al. 2014;

2017b). The GFMS is a NASA-funded experimental system that uses TRMM data as input to a hydrological runoff and routing model. Streamflow, surface water storage, and inundation are calculated at 1 km resolution.

- The SADC HYCOS FRM project produced a Regional Flood Atlas for Southern Africa, showing flood hazards and flood-prone areas in 14 major transboundary river basins in the SADC region, including the Cuvelai Basin (Atkins 2015). The atlas is intended to be used as a tool for high level planning. Results for the Cuvelai Basin are presented in Figure 27.

    - To develop the Flood Atlas, the Regional Maximum Flood (RMF) approach (Kovacs 1988) was first used to estimate the upper limit of flood peak flows for a given upstream watershed area (estimated by Kovacs to be a >200 year recurrence interval). The Kovacs method is based on an earlier approach developed by Francou and Rodier (Francou and Rodier 1967) who plotted global maximum flood peaks against corresponding upstream watershed areas to derive envelope curves for maximum flows, described by the equation:

        - $Q = 10^6 \times (\frac{A}{10^8})^{1-0.1k}$

      where *Q* is the maximum flow (m^3/s), *A* is the corresponding upstream watershed area (km^2), and *k* is a regional dimensionless factor which accounts for variations in rainfall, geology, topography, and vegetation. Kovacs refined the *k*-values for Southern Africa by back-calculating *k*-values for locations where flood peaks and upstream watershed areas were known, and then grouping regions of Southern Africa into RMF envelopes, or “zones”. Using the Kovacs approach, RMF can be calculated using the following equation:

      $$Q = c \times A^x$$

      where *c* and *x* are regional constants defined by (Kovacs 1988). The Flood Atlas uses approximate RMF return periods of >200 years and 50 years (using scaling factors), and incorporates a climate change allowance into both return period scenarios (Atkins 2015).

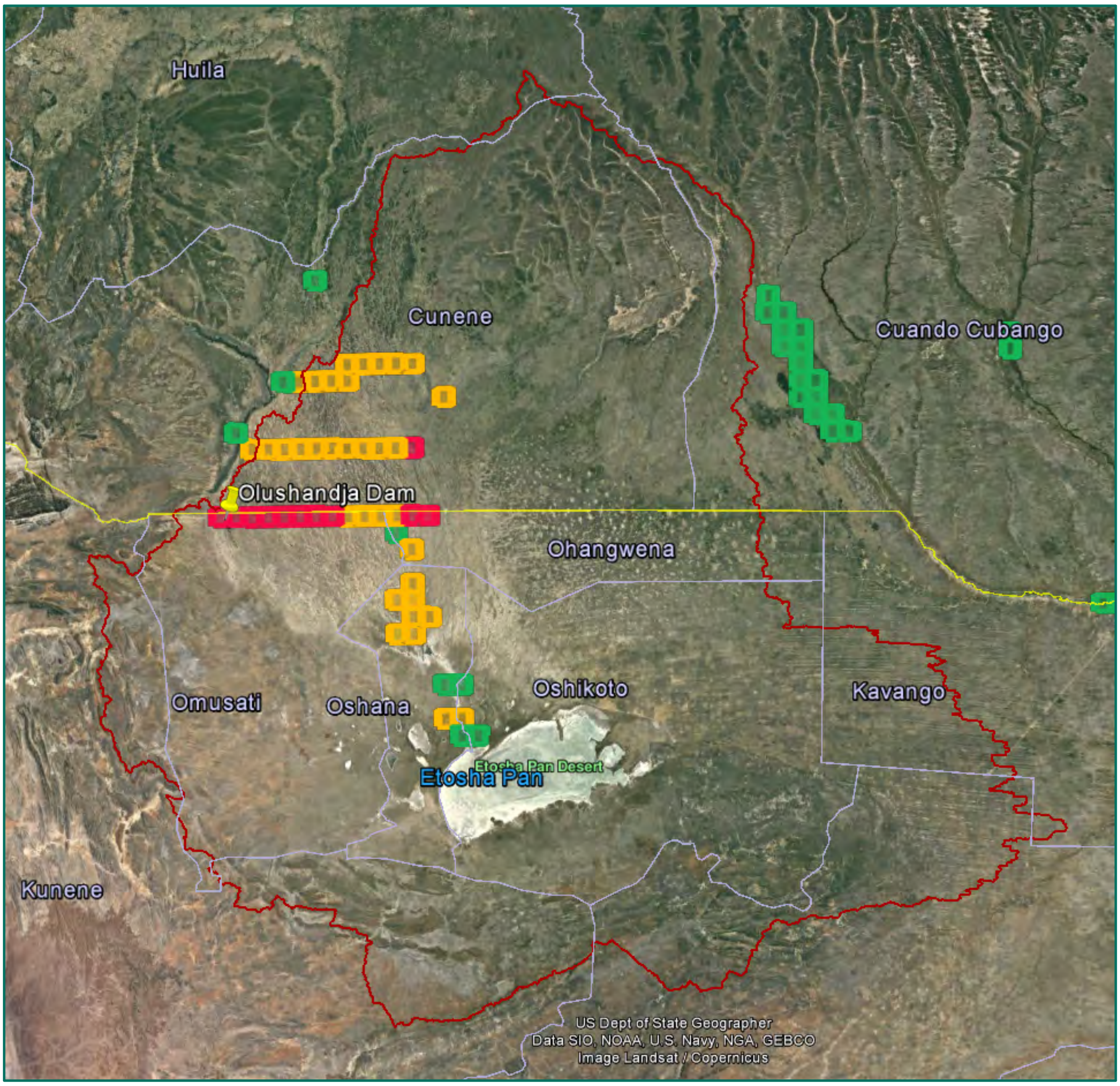
    - Floodplain delineations for the Flood Atlas were derived using HEC-RAS 1D hydraulic modelling. For most of the basins in the study area, the HEC-RAS models used 30 m resolution SRTM data for topographic inputs and streamflow data derived from the RMF approach. However, the 30 m resolution of the SRTM data is insufficient to define watercourses in the predominantly flat topography of the Cuvelai Basin. Therefore, flood outlines obtained from NASA Near Real Time Global Flood Mapping (“NASA NRT Global Flood Mapping,” 2015), the Dartmouth Flood Observatory (2017f), and UNITAR/UNOSAT (2017) were used in conjunction with SRTM data to define the flood event outlines for the Cuvelai.

    - Results for the Cuvelai Basin are presented in Figure 27. As noted below, the accuracy of results in the Cuvelai Basin could be improved by using high-resolution DEMs derived from LiDAR (Persendt and Gomez 2016). The Flood Atlas is a relatively new product, and it is unclear to what extent it is currently being implemented.

- Daily flood bulletins are posted on the Namibia Flood Dashboard and the NHS website, and are disseminated via email by request (Filali-Meknassi et al. 2014). The bulletins contain flood gauge data, rain gauge data, satellite maps of potential rainfall, and observations from flood zones.

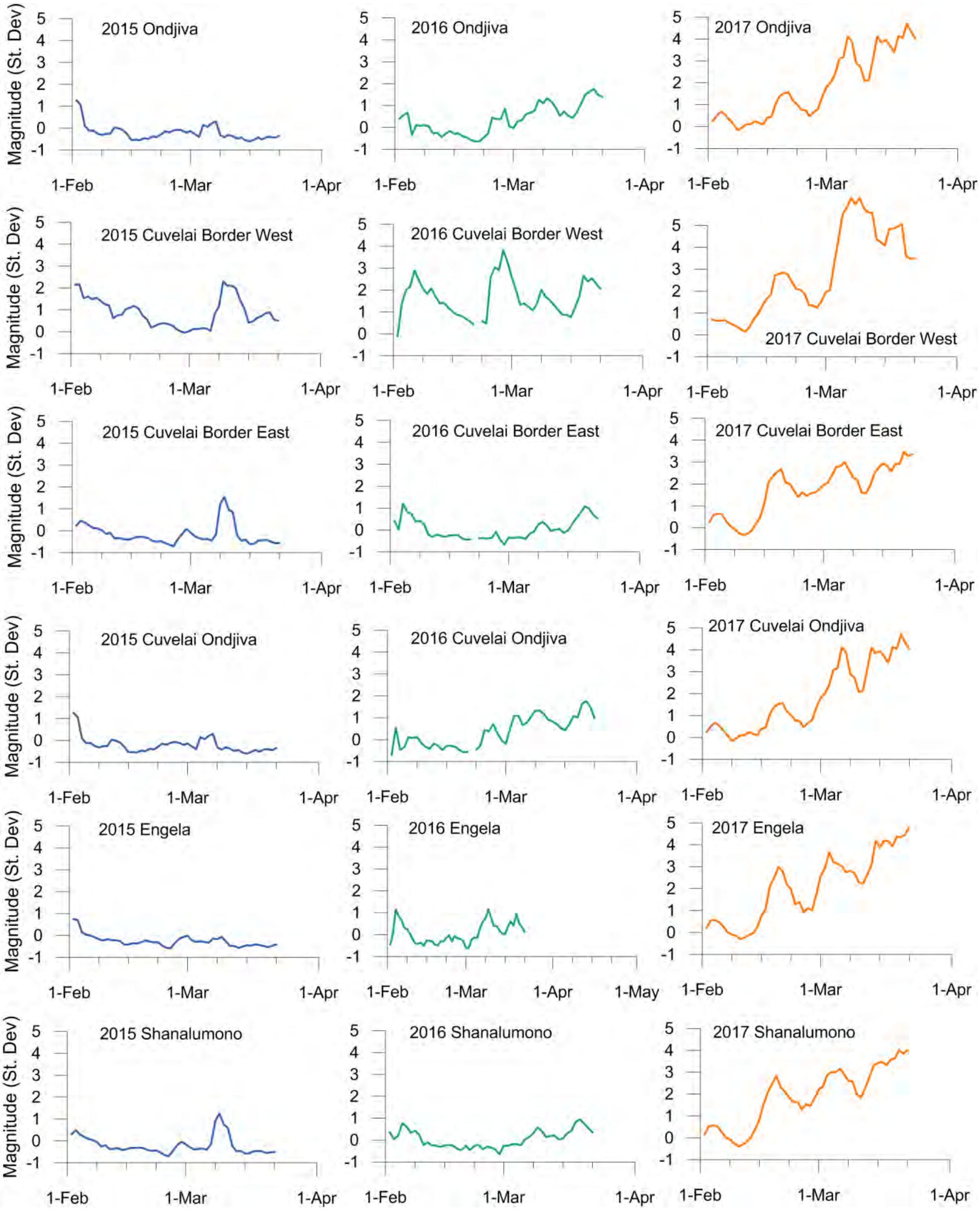
- GDACS disseminates remotely sensed estimates of water surface area and flood magnitude at key flood-prone areas in the Cuvelai (GDACS 2017). A snapshot of the near-real-time flood assessment for the Cuvelai Basin was retrieved on March 22, 2017 (Figure 28). Data were retrieved during a period of 'the worst flood in memory' in Northern Namibia (Al Jazeera 2017 Mar 17). Remotely sensed flood assessments have also been archived for six regions in the Cuvelai since 2015. Data are presented in Figure 29, and clearly show flood waters at all locations exceeding recorded variability beginning in early March 2017.

Figure 28 Near-real-time GDACS flood assessment for the Cuvelai Basin, March 22, 2017.



Note: green = no flood, orange = magnitude > 2 (small potential flood), red = magnitude > 4 (potential flood with high return period)

Figure 29 Archived assessment of flood magnitude for the Cuvelai Basin, 2015 to 2017.



The results of the flood forecasting system assessment are discussed below with respect to each of the evaluation criteria (Section 11.2).

1. Is the existing flood forecasting methodology appropriate for application in the Cuvelai Basin, given the basin's unique hydroclimate and topography?

The Namibian Flood Dashboard appears to be the primary resource for flood forecasting in the Cuvelai Basin. The TIGER-NET, HEC-RAS, and CREST models are currently in use by the NHS (Filali-Meknassi et al. 2014), but the *extent* of their use is unclear, as is the degree to which their results are integrated with the Namibian Flood Dashboard.

The use of remote sensing information to characterise flooding events is an extensively used approach, and can be particularly important in areas with limited data from sensors on the ground (e.g., Hossain et al. 2014; Awadallah and Tabet, 2015). Numerous sources of satellite data are available for the Cuvelai Basin area.

However, a key uncertainty in the application of satellite data-based models to the Cuvelai Basin is the topographic definition of the basin (Filali-Meknassi et al. 2014; Atkins 2015). The accuracy of the models is limited by the relatively coarse resolution of the available topographic data. This uncertainty has not been explicitly quantified across the basin, but it is noted by (Filali-Meknassi et al. 2014) that a vertical difference of less than half a meter may determine whether an area will be submerged in floodwaters or not.

The use of LiDAR data for assessing drainage networks in a portion of the Cuvelai Basin near Oshakati has been assessed in Persendt and Gomez (2016). Results show that high-resolution DEMs derived from LiDAR data, when checked and corrected using field-mapped channels, have the potential to accurately map the channel network in the Cuvelai Basin, despite the very low gradient, and hydrologic alterations by humans. Application of these high-resolution DEMs to a larger portion of the Cuvelai Basin, and using these data in the hydraulic modelling approach used by the SADC Flood Atlas (Atkins 2015), has the potential to improve the accuracy of flood extent mapping.

Although the extent of its current use is unclear, the Flood Atlas is a promising approach for assessment of flood risk. It is however a static tool, intended to be used for planning rather than near-real-time forecasting. Its purpose is therefore different from that of the Flood Dashboard.

The Flood Atlas, like the Flood Dashboard, has uncertainty related to satellite data resolution. Its methodology was adjusted to account for the flat topography of the Cuvelai Basin, but (Atkins 2015) notes that this adjustment may result in lower confidence in the Flood Atlas for the basin.

The Kovacs regional method used by (Atkins 2015) for the Flood Atlas is supported by a detailed review (Pegram and Parak 2004) and a recent Namibia-specific study (Cloete et al. 2014). It has the advantage of providing a consistent and readily applied methodology across a broad geographical area, which makes well-suited for application in large-scale regional mapping. However, there are several limitations to the Kovacs approach with implications for interpretation and use of the Flood Atlas results.

The Kovacs approach assumes the same rainfall and catchment characteristics for large regions. This is a disadvantage of generalised equations. Although RMF results derived from Kovacs can provide useful coarse-scale estimates, the Flood Atlas should be used with the caveat that there may be substantial, unaccounted local variability. An additional limitation is that the Kovacs approach does not account for antecedent conditions, which are often an important influence on the runoff response to rain events. Finally, while the basis of the Flood Atlas in the Kovacs approach makes it useful for long-term planning for high-magnitude, low-frequency flood events, it was not designed (and cannot be used) as a tool for predicting flood potential in response to a given precipitation event.

In summary, for both the Flood Dashboard and the Flood Atlas, the existing methodologies are generally suitable for the region; however, the quality and availability of data inputs may be a major limitation, as discussed below.

2. Are available data sufficient to support a robust flood forecasting system in the Cuvelai Basin using the current methodology (i.e., period of record, data quality, and spatial coverage)?

Lack of historical ground-based hydrological and meteorological data in the Cuvelai Basin is a major impediment to modelling and calibration (Filali-Meknassi et al. 2014). The Kovacs regional values for Namibia are tentative due to the relatively small database (Kovacs 1988). Quality of available current data is also a major limitation in near-real-time forecasting in the region (Atkins 2015).

The density and configuration of the monitoring network are additional obstacles for accurate flood forecasting for the Cuvelai Basin. Most rain falls in the Angolan (northern) portion of the basin, where there are no hydrological or meteorological stations (the hydro-meteorological monitoring network is sparse across Angola in general, as noted above). However, the flooding risk in Angola is relatively minor (Mendelsohn and Weber 2011), with little incentive or capacity to invest in a monitoring network or forecasting efforts. In Namibia the risk of flooding is greater, but hydro-climatic monitoring is limited or absent in the Angolan headwaters (Hossain et al. 2014).

Overall, limitations in the quantity and quality of available ground-based data (both historical and current) are a substantial source of uncertainty in Cuvelai Basin flood forecasts (Filali-Meknassi et al. 2014; Atkins 2015). However, satellite data (e.g., TRMM, GDACS) are readily available from numerous providers, often as free products, and are already frequently used by the NHS.

3. Are collaboration, data sharing, and communication systems sufficient to support the flood forecasting system in the Cuvelai Basin?

Data management and data sharing were noted by (Filali-Meknassi et al. 2014) as a key issue in flood forecasting in Namibia. The lack of a unified approach to data management among different agencies has generated problems in data use. Similar issues exist in Angola (GEF 2013), and cross-border data sharing presents additional difficulties. As noted above, as a “downstream” country Namibia often does not receive adequate notice of floodwaters originating in Angola (Hossain et al. 2014). The establishment of effective cross-border data sharing protocols would require substantial investment in terms of both time and cost (Filali-Meknassi et al. 2014).

Data dissemination to the public is limited. Although the Flood Dashboard provides a simple, easily accessible platform for data dissemination, the website does not appear to be regularly updated. At the time of this assessment (March 2017), the most recent daily bulletin on the dashboard was dated April 17, 2015, and the most recent daily flood report for Cuvelai was dated April 19, 2011, although a more recent flood bulletin was obtained by request via email.

Organisational capacity in both Namibia and Angola is another limitation. Multiple agencies have identified the need for proper training of staff in both field and data analysis/modelling techniques (Filali-Meknassi et al. 2014; Atkins 2015).

Collaboration, data sharing, and communication are lacking in the Cuvelai Basin region, which in turn creates an impediment to effective flood forecasting.

11.4 DATA GAPS AND RECOMMENDATIONS

The following data gaps have been identified:

- The climatic monitoring network in the Cuvelai basin is relatively sparse, and monitored hydrologic data are very sparse, making calibration and validation of flood forecasting models and dissemination of timely flood alerts difficult (Section 5.0); and
- Use of digital elevation models with relatively low resolution make accurate modelling difficult given the low relief of the catchment;

It would be beneficial to:

- Move towards a more unified, collaborative approach to flood forecasting by improving data management and data sharing. The Namibia Flood Dashboard is a useful tool that could be substantially expanded and/or linked to other data portals to include more information related to hydrology and flood forecasting. The use of OpenStreetMap could also be expanded to integrate more local knowledge into flood modelling efforts. Consideration should be given to improving management and dissemination of near-real-time data;
- Continue and expand the current emphasis on satellite-based information sources. Focusing on satellite-based sources would be a relatively low-cost, efficient approach to improving the data used in flood forecasting. TIGER-NET has been identified as a promising current initiative (Filali-Meknassi et al. 2014);
- Increase human capacity through training programs and enhancement of partnerships between government agencies and academic institutions. These training programs should cover both field protocols and data analysis/modelling methods; and
- Use high-resolution DEMs for flood extent mapping wherever possible (e.g. Persendt and Gomez 2016).

12.0 SUMMARY OF INFORMATION GAPS IDENTIFIED

Table 12 below provides a full summary of the data and information gaps identified the development of this Rapid Assessment.

Table 12 Summary of data and information gaps.

Thematic area	Data/Information Gap	What is required	Comments
Physiographic	Overall lack of consistent biophysical data outside Etosha	▪ Further studies of the complete basin with consistent methodologies and studies.	A better understanding composition of the Basin is necessary.
Climate Data	Datasets from the catchment headwaters in the Angolan highlands are sparse	▪ Climate monitoring infrastructure and data for the catchment headwaters in the Angolan highlands.	This area is where precipitation is highest in the Basin and understanding this data will be important.
Hydrological Data	Hydrometric monitoring network is sparse across the Cuvelai Basin.	▪ Establish hydrological monitoring stations throughout the Cuvelai Basin	This data tends to be collected for dam impoundments but should be collected in the Cuvelai Basin to develop consistent data.
	Flow Data is incomplete.	▪ Benchmarking studies of other low flow data collection methodologies. ▪ Agreed methodologies for studying flow across the Basin. ▪ Regular, consistent data collection.	Flow data is difficult to assess because of the ephemeral nature of the streams, especially the iishana.
Groundwater Data	No centralised source for groundwater data	▪ Centralised data collection centre for groundwater data for the Basin.	CUVECOM can serve this purpose and promote ground water data sharing across the region.
	Groundwater flow system is not well understood.	▪ Groundwater recharge studies from both meteoric and surface water sources. ▪ Aquifer mapping and cross sections showing the hydrographic sequences ▪ Updated and consistent hydraulic property data. ▪ Groundwater/surface water interaction studies.	Understanding the nature of groundwater and regeneration is important to monitor impacts of developments in the Basin.
Climate Change	Runoff Data	▪ Stronger runoff data is required as existing data is limited.	Data availability is limited in Angola and Namibia.
	Drought Data	▪ Stronger drought data is required as existing data is limited.	Data availability is limited in Angola and Namibia.
	Flood Data	▪ Stronger flood data is required as existing data is limited.	Data availability is limited in Angola and Namibia.
	Agriculture, aquaculture, fisheries and livestock vulnerability	▪ Stronger agriculture, aquaculture, fisheries and livestock vulnerability is required as there is virtually no data available.	This information will be important for socio-economic data as well as inform climate mitigation programmes and investment.

Table 12 (Cont'd.)

Thematic area	Data/Information Gap	What is required	Comments
Water Utilisation and Demand	Knowledge of groundwater and sustainable yield potential of Ohangwena II aquifer	▪ Detailed studies of the Ohangwena II aquifer.	This information will contribute to understanding the current status of the aquifer and provide a baseline for further studies.
	Knowledge of water demand	▪ Detailed study the amount of water used for each purpose (e.g., sanitation, domestic, environmental flows, etc.).	This information will help to inform an understanding of the water balance for the Basin and water management decision-making.
	Knowledge of the quality of water used for drinking and sanitation	▪ Stronger water quality data is required.	The information is important for informing water-related vulnerabilities.
Disaster Risk Management	Lack of centralised flood forecasting data availability.	▪ Establish a unified/collaborative approach to flood forecasting by improving data management/sharing.	Standardised data collection methodologies are important to provide comparisons geographically and temporally.
	Satellite based-information system	▪ Satellite based information gathering rather than ground-based data gathering.	Satellite information is low-cost, efficient compared to ground-based data.
Flood-Related	High resolution digital elevation Data	▪ High resolution elevation model covering the entire basin, ideally LiDAR.	The approach of Persendt and Gomez 2016 is very promising.
	Monitored hydroclimatic data	▪ See hydroclimatic entry above.	
Socio-economic (all data to be disaggregated by gender)	Lack of Basin-specific current population and demographic data	▪ Angola and Namibian governments provide up to data census data for the Basin and refine age group data.	Up-to-date data is important for any decision-making process.
	Conflicting data from different sources	▪ Standardised data collection methodologies and analysis.	Standardised data collection methodologies are important to provide comparisons across groups and time.
	Data gaps include information on access to health care, distance from water sources/sewerage, level of education and literacy rates.	▪ More in depth census studies to collect relevant data.	Expanded census indicators will provide a better understanding of livelihood data for the Basin.

Table 12 (Cont'd.)

Thematic area	Data/Information Gap	What is required	Comments
Socio-economic Cont'd	Economic data is regarding private sector investment in socially responsible water management is lacking.	▪ Review programmes being implemented that are being implemented or promote responsible water management.	This information will provide an overview of which programmes, if any are in the Basin and can be supported.
	Data should be collected on expanded economic indicators.	▪ Collection of census uniform census data in both countries.	Expanded indicators can be found on the World Bank website.
	Water withdrawal data for economic activities is unknown.	▪ A detailed study looking at water withdrawal in both countries.	This information will likely include crop zones, livestock densities and mine locations, etc.
	Data on the impact of remittances is widely unknown.	▪ Remittances should be included in income categories in census collection.	Remittances can be a significant income for many households.
	Basin-specific and basin-wide data on food security is unknown.	▪ Detailed study of food-security indicators (e.g., food reserves).	This information will help to understand water-related vulnerabilities.
Institutional considerations (wherever possible, institutional participation in water governance requires gender disaggregated data)	Civil society involvement in water management roles, responsibilities, participatory processes are unknown.	▪ Review of organisations operating in the Basin.	This information will provide an overview of which programmes, if any are in the Basin and can be supported.
	Information on community participation in decision-making is needed, including gender disaggregated data.	▪ Review of community structures and social structures that exist in the Basin.	This information will help understand how to engage with communities and engage with vulnerable community members.
	Indicators for measuring water management performance is unknown.	▪ Review national indicators for measuring water management performance.	Understanding these measures will help compare water management strategies, if they exist and influence further development.
	Revenue from tariffs are unknown.	▪ Review national tariff schemes for water use.	Understanding these tariff schemes will establish means for accessing funding and mechanisms for funding.

Table 12 (Cont'd.)

Thematic area	Data/Information Gap	What is required	Comments
Institutional considerations **Cont'd**	Enforcement measures are unknown.	▪ Review national enforcement measures.	This information will contribute to monitoring overdraws.
	Methods used to collect information on understanding social and environmental conditions in the Basin.	▪ Compare data collection methods in both countries and promote standardised data collections methods.	Standardised data collection methodologies are important to provide comparisons across groups and time.
	The level of cross-sectoral collaboration on water management is unknown.	▪ Assess institutional collaboration infrastructure and processes.	This information will help to inform the development of capacity development activities.
	Information on employment legislation in both countries	▪ Analysis of labour law in Angola and Namibia, to ensure future contracts are compliant.	To be used in the development of Interim Secretariat contracts.
Financial Sustainability	Compiled financial information for projects conducted to date	▪ Inventory of all single-state and transboundary projects conducted in the Cuvelai River Basin to date, including project value.	This information will be used to estimate project values for proposed technical work.
	Compiled financial information for meetings conducted to date, including all in-kind contributions.	▪ Financial information for all CUVECOM and Task-Force Calueque meetings in the past five years.	This information will be used in the estimation of costs for running CUVECOM meetings, and overall budgeting.
	Information on salaries and remuneration packages from across other RBOs.	▪ Survey of salaries and remuneration packages across other RBOs in SADC.	This will be used to determine fair compensation for proposed Executive Secretariat staff.
Cross-Cutting Issues	A gender/water assessment for the Cuvelai River Basin.	▪ A detailed socio-economic assessment, designed to include collection of gender-disaggregated water data, based on WWAP guidelines.	
	A comprehensive poverty and vulnerability assessment for the entire Cuvelai River Basin.	▪ A detailed socio-economic assessment, designed to include collection of representative household livelihood and income data.	

13.0 MANAGEMENT CHALLENGES AND OPPORTUNITIES

This Rapid Assessment presents a high-level overview of some of the key issues facing the Cuvelai River Basin, and summarises critical information gaps across each of these sectors. This section presents a selection of critical management challenges that need to be addressed by CUVECOM through collaborative work between the Angolan and Namibian governments, to ensure that these above information gaps are bridged. Each challenge is contextualised by identifying opportunities, potential benefits, and the role-players necessary to rise to the challenge.

Challenge 1	Need for coordinating institution to support co-management of the Cuvelai River Basin – CUVECOM
Opportunity	Operationalise the CUVECOM Agreement (2014), through the establishment of a formal transboundary river basin management organisation, with an interim secretariat, interim secretary, support staff, technical commission, technical task teams, and regular meeting schedule.
Benefits	▪ CUVECOM will provide an institutional focal point for transboundary management dialogue and decision making. ▪ It will also provide a platform for technical coordination of projects and programmes. ▪ Finally, it will provide a focal. ▪ Donor coordination. ▪ Knowledge and information sharing and dissemination.
Requirements	▪ Agreement from CUVECOM on decision to operationalise. ▪ Interim Secretariat – location and building. ▪ Interim Secretary, with IWRM expertise, institutional knowledge and the ability to communicate in English, Portuguese and Oshikwanyama. ▪ Support staff. ▪ Basin Assessment. ▪ Basin Strategic Action Plan. ▪ Financial Sustainability Plan.
Role-Players	**National and local government**: Commission endorsement, and commitment. **Donors**: funds to support operationalisation and facilities. **Universities/technical colleges**: participation in research agenda development and coordination to ensure CUVECOM knows what research is being undertaken in the basin.

Challenge 2	There is an urgent need for an enhanced hydrological and climatological monitoring network in the Cuvelai River Basin.
Opportunity	Develop an integrated, basin-wide hydrological and climatological monitoring network, gathering data to agreed standards, providing access to essential data for several water resource management applications. Addressing this challenge has the potential to contribute significantly to the co-management of the Cuvelai River Basin, and the well-being of the basin population.
Benefits	▪ Access to improved data and information for collaborative decision-making at a national and basin-scale. ▪ Critical contribution to Early Warning Systems development, through the provision of monitoring data. ▪ Contributions to basin management.
Requirements	▪ Physical infrastructure. ▪ Communications infrastructure. ▪ Data management infrastructure. ▪ Data dissemination platform. ▪ Training and capacity development. ▪ Systems integration with decision-making tools.
Role-Players	**CUVECOM:** Facilitation and coordination of activities, plus platform hosting, and focal point for technical standards and guidance/steering. **National and local government**: GABHIC, and Ministry of Agriculture, Water, and Forestry - Installation and management of infrastructure. **Donors**: technical supporting, funding, lessons learned from other basins. **Universities/technical colleges**: sustainable training and capacity development in hydrological and climatological monitoring, data management, dissemination and analysis.

Challenge 3	An integrated flood and drought early warning system is required, to provide warning of flood and drought onset for preparedness, mitigation and management during such events.
Opportunity	Utilise data from CUVECOM, regional and international data sources to establish an integrated early warning system for the Cuvelai River Basin, providing tangible benefits for national and local governments, basin-dwellers, farmers and business-owners.
Benefits	▪ Warning of droughts, utilising national, basin-wide and regional/international data sources. ▪ Warning of floods, including conducive conditions (risk), and flows during events (management). ▪ Data to support planning to reduce vulnerability ▪ Information to support management during events

Challenge 3	**An integrated flood and drought early warning system is required, to provide warning of flood and drought onset for preparedness, mitigation and management during such events.**
Requirements	▪ Early warning system or platform, integrating data from a range of sources. ▪ Trained staff, who can interpret data, and provide relevant warnings ▪ Data and information analysis workflows ▪ Communication tools and platforms for dissemination of warnings ▪ Feedback and review mechanisms to assist with improving systems.
Role-Players	**CUVECOM:** Technical coordination and steering, focal point for training and capacity development **National and local government**: provision of data from hydro/climatological system, technical staff to interpret and analyse data, institutional conduits for stakeholder communication and early warning through relevant channels. **Donors**: technical assistance, funding, steering.

Challenge 4	**Enhanced understanding of Groundwater Resources in the Cuvelai River Basin**
Opportunity	Through a comprehensive and holistic understanding of groundwater resources in the Cuvelai River Basin, including groundwater quantity, quality, sustainable yield, and recharge, sub-surface water resources could realise potential to contribute to water resources management and supply in the basin.
Benefits	▪ Holistic understanding of groundwater at a transboundary scale ▪ Understand the potential contribution groundwater can make to water supply at the basin scale, supporting current limited internal supply, and the existing transboundary water transfer scheme from the Cunene, and proposed transfers from the Cubango River Basin. ▪ Such a study could also provide insights into how to protect the above resources.
Requirements	▪ Groundwater study in Angola, to complement the studies currently being completed in Namibia ▪ Groundwater task force or Technical Task Team
Role-Players	**CUVECOM:** technical and institutional coordination **National and local government**: technical expertise, access to data, technical staff **Donors**: technical assistance, funding **Universities/technical colleges**: research and technical contributions to groundwater study

Challenge 5	Bridging the gap between water demands and supply in the Cuvelai River Basin.
Opportunity	Explore feasibility of enhancing and increasing sustainability of water supplies in the Cuvelai River Basin, through an integrated water supply and harvesting programme.
Benefits	▪ Ensuring that water demands are met with a multi-source solution, reducing dependence on a single source or system ▪ Reduction of the vulnerability of the basin population ▪ Potential integration with groundwater sources, once quantified
Requirements	▪ Finalisation of feasibility studies for further transboundary transfer schemes from adjacent basins ▪ Completion of the quantification of groundwater resources (see Challenge 4) ▪ Feasibility study to explore scalable options for flood and rainwater harvesting, water capture and management.
Role-Players	**CUVECOM:** technical and institutional coordination, stakeholder coordination **National and local government**: technical staff, and resources, technical data and inputs to feasibility studies, stakeholder communication and dialogue **Donors**: technical assistance (CUVEWaters project), funding **Universities/technical colleges**: research and development of methodologies

Challenge 6	There is a need to understand the socio-economic landscape within the Cuvelai River Basin
Opportunity	Undertake a comprehensive socio-economic survey of the Cuvelai River Basin, building upon past work completed by John Mendelsohn, Development Workshop and others, to realise a holistic and gender-disaggregated understanding of the basin population, including livelihoods and agricultural practices.
Benefits	▪ A resource base for basin-wide water resource planning and management ▪ Establishment of a baseline of socio-economic data to monitor parameters within the context of poverty, and sustainable livelihoods ▪ Opportunities to provide data and information to establish impact in gender mainstreaming ▪ Potential opportunities to develop a base for quantifying impact at sub-basin or household level
Requirements	▪ Exercise to gather and collate existing data ▪ Survey design and methodologies ▪ Survey tools, and survey data gathering, management and dissemination platform ▪ Basin-wide survey ▪ Data analysis and synthesis ▪ Stakeholder feedback

Challenge 6	There is a need to understand the socio-economic landscape within the Cuvelai River Basin
Role-Players	**CUVECOM:** technical and institutional coordination **National and local government**: technical staff and contributions to technical steering, access to data **Donors**: technical assistance and funding **Universities/technical colleges**: technical socio-economic leadership in the programme, associated research and analysis, synthesis and dissemination

14.0 CONCLUSIONS

This document has provided a rapid assessment-based overview of the key issues in the Cuvelai River Basin, including biophysical, hydro-climatic, climate change, water utilisation and demand, disaster risk management, socio-economics, and governance and institutional considerations. It also includes an assessment of the potential for applying the tools provided within the SADC Flood Atlas in the Cuvelai River Basin, a summary of data and information gaps identified throughout the rapid assessment and presents a series of management challenges for CUVECOM to consider moving forward.

Next steps for CUVECOM, following full operationalisation of the commission, include development of a comprehensive basin assessment that will hopefully close the gaps identified within this assessment report.

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APPENDICES

Appendix A1

Rapid Assessment Reference Materials: Ecology

A1.0 RAPID ASSESSMENT REFERENCE MATERIAL

A1.1 TERRESTRIAL ECO-REGIONS OF THE CUVELAI RIVER BASIN (ADAPTED FROM WWF 2017).

Eco-region	Description
Namibian Savanna Woodland	The Namibian Savanna Woodland ecoregion covers the Great Escarpment that delimits the interior of southern Africa from the Kaokoveld and Namib Deserts. This broken and deeply dissected escarpment is an area of high endemism for plants, invertebrates, amphibians, reptiles, mammals and birds. The northern area of the escarpment, the Kaoko escarpment, is an endemism "hotspot" (an area of extremely high species richness and endemism). This northern area is poorly protected and is under threat from poaching, off-road driving, and to a lesser extent from farming. The formal conservation status of the southern portion of the ecoregion is poor. Other forms of protection, such as conservancies, private nature reserves and game farms do, however, promote conservation of the area. If these areas can be effectively managed through collaboration with local communities, they may solve the conservation crisis in the area.
Etosha Pan Halophytes	The Etosha Pan Halophytics ecoregion is the remnant of a large, inland Pliocene lake. Today, the Etosha Pan is a dry, saline desert. Normally, the cracked, whitish clay is split into hexagonal salt-encrusted fragments, and wildlife is sustained only by surrounding freshwater springs. These springs attract a diverse array of large mammals, especially during the dry season, making it a popular tourist destination. In wet years, when the Ekuma, Oshigambo and Omuramba Ovambo rivers receive sufficient rainfall, the pan is transformed into a shallow lake.
Angolan Mopane Woodland	The Angolan Mopane Woodlands are located in Namibia and Angola, completely surrounding the Etosha Pan, which is considered a separate ecoregion. Mopane trees (Colophospermum mopane) dominate the vegetation, and are an essential resource for both the people and wildlife of the region. Elephants (Loxodonta africana) utilize almost every part of the mopane tree, and the region supports other large herbivores, including the critically endangered black rhino (Diceros bicornis). Species richness in this ecoregion is high, especially in comparison with the arid deserts to the west. Conservation potential is high in Namibia, due to the well-established Etosha National Park, and increasing community involvement and ownership of natural resources. Conservation in Angola has been severely compromised by the lengthy civil war, and many large mammal populations are near local extinction.
Kalahari Xeric Savanna	The Kalahari Xeric Savanna is characterised by a harsh climate, where temperatures may increase by 45°C from night to day, and rainfall is infrequent. Rain only falls on the reddish-brown Kalahari sands during the summer, pelting the savanna with violent, localised storms. Although this area is semi-arid, there is an impressive diversity of migratory birds and large mammals, both herbivorous and carnivorous. A considerable amount (approximately 18 percent) of this ecoregion is protected. Where it is not protected, heavy grazing has degraded the habitat. Fences are a serious problem because they obstruct the migratory routes of ungulates, and they pose significant threats to biodiversity in unprotected areas.

Eco-region	Description
Kalahari Acacia Baikiaea Woodland	Semi-arid Kalahari Acacia-Baikiaea Woodland stretches across the center of southern Africa, from northern Namibia through Botswana and just into the Tuli Block of South Africa. Surface water is scarce here and droughts occur roughly once every seven years. As a result, the human population is fairly low, especially on the sandveld that covers most of the ecoregion. The area supports a rich and diverse fauna, including a variety of ungulates and a number of threatened large animals such as white (Ceratotherium simum) and black rhinoceroses (Diceros bicornis), wild dogs (Lycaon pictus), and elephants (Loxodonta africana). However, human populations are increasing and the growing cattle industry has far-reaching effects on the environment and wildlife. The migrations of large herbivores which used to occur in the ecoregion are now hindered by veterinary control fences, resulting in mass die-offs in times of drought.
Zambezian Baikiaea woodlands	Deep Kalahari sands occur in a wide belt along the Angolan-Namibian border across to Zimbabwe, supporting dry deciduous forest dominated by Baikiaea plurijuga. The hot, semi-arid climate and nutrient-poor soils mean that this region is not suitable for farming, and thus it has retained some of its natural vegetation. Over 160 mammal species are found here, including ungulates and large predators. However, settlements occur along

Eco-region	Description
	rivers, and the valuable Baikiaea plurijuga is sought after for the timber trade. The civil war in Angola and hostilities between Angola and Namibia in the Caprivi Strip further threaten the future of this ecoregion.
Angolan Miombo Woodlands	Covering all of central Angola and extending into the Democratic Republic of Congo, the extensive Angolan Miombo Woodlands are part of an even larger miombo ecosystem that covers much of eastern and southern Africa. The miombo is characterised by several unique ecological factors, including its propensity to burn, the importance of termites, and the unusual browsing conditions found here. While only poor-quality browsing is available, this ecoregion hosts a rich assortment of large mammals, some bulk feeders like the African elephant (Loxodonta africana), some specialised feeders such as the sable antelope (Hippotragus niger), and some, such as the tsessebe (Damaliscus lunatus), that utilize the wetlands scattered throughout this ecoregion. However, large mammal populations and all conservation activities have been severely affected by the decades-long civil war in Angola since 1974.

Source: (WWF, 2017)

Appendix A2

Rapid Assessment Reference Materials: Hydroclimatology

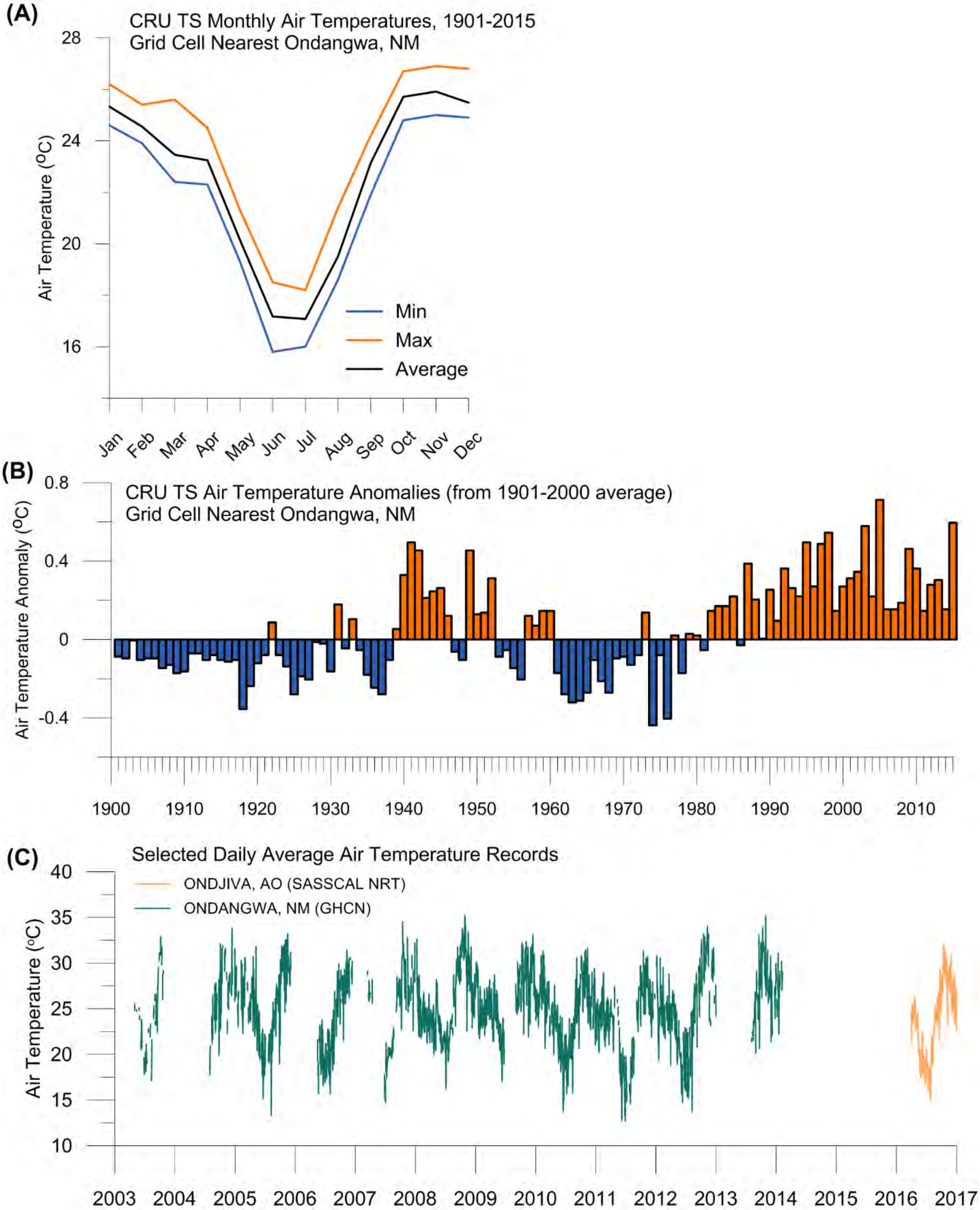
A2.0 SUMMARY OF HYDROCLIMATOLOGIC DATASETS

A2.1 SUMMARY OF AIR TEMPERATURE AND PRECIPITATION RECORDS WITHIN AND NEAR THE CUVELAI BASIN.

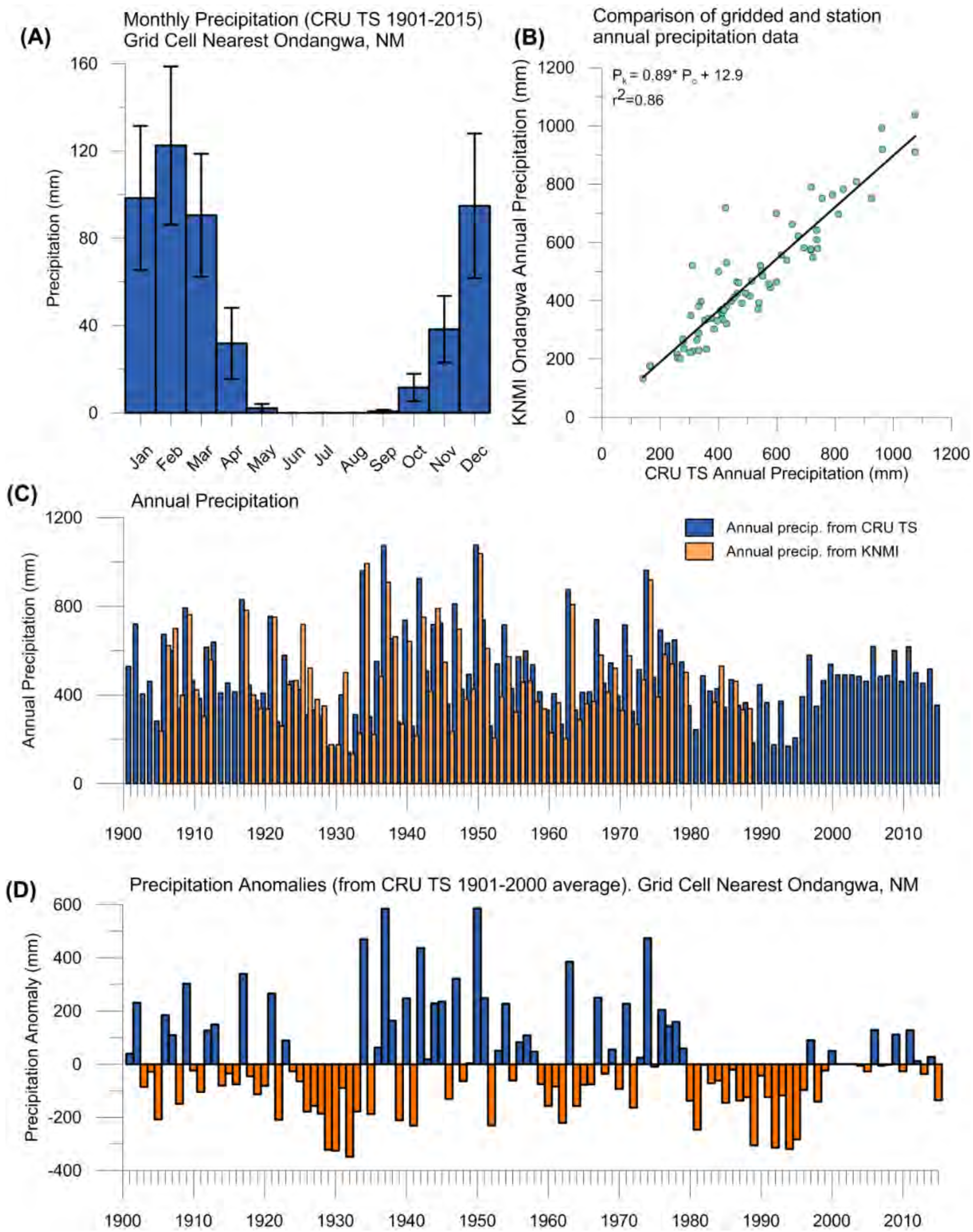
Station Name	Country	Latitude	Longitude	Elevation (masl)	Data Source	GHCN ID	WMO Station ID	GHCN Daily Average Air		GHCN Daily Precipitation		KNMI Monthly Average Air		KNMI Monthly Precipitation		SASSCAL Air Temperature		SASSCAL Precipitatio	
								From	To	From	To	From	To	From	To	From	To	From	To
CAFU	AO	-16.30	15.30	1,160	KNMI	-	-	-	-	-	-	-	-	1942	1969	-	-	-	-
MULONDO	AO	-15.40	15.10	-	KNMI	-	-	-	-	-	-	-	-	1954	1975	-	-	-	-
MUPA	AO	-16.10	15.80	1,170	KNMI	-	-	-	-	-	-	-	-	1932	1975	-	-	-	-
PEREIRA D,ECA (Ondjiva)	AO	-17.10	15.70	1,150	KNMI	-	66460	-	-	-	-	1941	1960	1928	1975	-	-	-	-
CAFIMA	AO	-16.38	16.02	1,130	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1961	1970	1961	19
CAFU	AO	-16.32	15.30	1,112	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
CLIMATE CÃIFU (POSTO ZOOT. DO CUNENE)	AO	-16.30	15.20	1,110	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1961	1972	1961	19
MUPA	AO	-16.12	15.88	1,234	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
MUPA (MISS. CATÃLICA)	AO	-16.08	15.42	-	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1961	1974	1961	19
PEREIRA D,ECA -DAILY	AO	-17.70	15.73	1,088	SASSCAL Info. System	-	664600	-	-	-	-	-	-	-	-	1974	2013	1974	20
PEREIRA D,ECA -MONTHLY	AO	-17.70	15.73	1,088	SASSCAL Info. System	-	664600	-	-	-	-	-	-	-	-	-	-	1960	19
ROCADES	AO	-16.72	15.00	1,099	SASSCAL Info. System	-	664850	-	-	-	-	-	-	-	-	1961	1974	1961	19
VILA PEREIRA DE ECA	AO	-17.04	15.44	1,110	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1965	1971	1965	19
VILA PEREIRA DE ECA (S.G.M.)	AO	-17.04	15.43	1,150	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1961	1974	1961	19
NAMACUNDE	AO	-17.31	15.85	1,112	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2015	2017	2015	20
ONDJIVA	AO	-16.98	15.62	1,119	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2015	2017	2015	20
GAUB	NM	-19.45	17.75	1,400	GHCN	WA010554470	-	-	-	1968	1985	-	-	-	-	-	-	-	-
HALALI	NM	-19.18	16.37	1,050	GHCN	WA010526410	-	-	-	1967	1986	-	-	-	-	-	-	-	-
HUTTENHOF	NM	-19.48	17.18	1,300	GHCN	WA010543290	-	-	-	1968	1986	-	-	-	-	-	-	-	-
MAHANENE NAVORSINGSTAS	NM	-17.45	14.78	1,105	GHCN	WA012505070	-	-	-	1971	1986	-	-	-	-	-	-	-	-
NAMUTONI	NM	-18.80	16.97	1,100	GHCN	WA011018280	-	-	-	1968	1986	-	-	-	-	-	-	-	-
OKATANA	NM	-17.75	15.72	1,050	GHCN	WA012003750	-	-	-	1968	1986	-	-	-	-	-	-	-	-
OKAUKUEJO	NM	-19.15	15.91	1,100	GHCN	WA010517310	68010	1975	2017	1968	2017	-	-	1900	2000	-	-	-	-
OMBALANTU	NM	-17.52	15.02	1,000	GHCN	WA011990010	-	-	-	1968	1986	-	-	-	-	-	-	-	-
OMBIKA	NM	-19.33	15.95	1,050	GHCN	WA010518000	-	-	-	1968	1986	-	-	-	-	-	-	-	-
ONDANGWA	NM	-17.93	15.98	1,100	GHCN	WAM00068006	68006	1973	2014	1977	2014	-	-	1902	1988	-	-	-	-
ONGUMA	NM	-18.68	17.10	1,100	GHCN	WA011021610	-	-	-	1968	1985	-	-	-	-	-	-	-	-
ONIIPA	NM	-17.95	16.08	1,100	GHCN	WA012011470	-	-	-	1968	1986	-	-	-	-	-	-	-	-
OSHIKUKU	NM	-17.67	15.47	1,050	GHCN	WA011998200	-	-	-	1968	1986	-	-	-	-	-	-	-	-
REHOBOTH	NM	-17.88	15.08	1,030	GHCN	WA011991430	-	-	-	1968	1986	-	-	-	-	-	-	-	-
SISSEKAB	NM	-19.33	17.20	1,250	GHCN	WA010543500	-	-	-	1968	1986	-	-	-	-	-	-	-	-
SOAVIS	NM	-19.35	17.13	1,200	GHCN	WA010542310	-	-	-	1968	1986	-	-	-	-	-	-	-	-
TOGGENBURG	NM	-19.48	17.95	1,450	GHCN	WA010558090	-	-	-	1968	1986	-	-	-	-	-	-	-	-
TSHANDI	NM	-17.75	14.88	1,000	GHCN	WA011986750	-	-	-	1968	1982	-	-	-	-	-	-	-	-
TSINTSABIS	NM	-18.78	17.95	1,100	GHCN	WA011037970	-	-	-	1968	1985	-	-	-	-	-	-	-	-
TSUMEB - POL	NM	-19.23	17.72	1,311	GHCN	WA010553740	-	-	-	1913	1985	-	-	-	-	-	-	-	-
GROOTFONTEIN	NM	-19.60	18.12	1,400	GHCN	WA010101860	68014	1974	2017	1917	2003	1974	2017	1917	2003	-	-	-	-
ELIM	NM	-17.70	15.40	1,030	KNMI	-	-	-	-	-	-	-	-	1913	1983	-	-	-	-
ENGELA	NM	-17.30	15.50	-	KNMI	-	-	-	-	-	-	-	-	1952	1981	-	-	-	-
ERMO	NM	-19.30	14.60	1,600	KNMI	-	-	-	-	-	-	-	-	1954	1984	-	-	-	-
KAMANJAB	NM	-19.40	14.50	-	KNMI	-	-	-	-	-	-	-	-	1940	1976	-	-	-	-

Station Name	Country	Latitude	Longitude	Elevation (masl)	Data Source	GHCN ID	WMO Station ID	GHCN Daily Average Air		GHCN Daily Precipitation		KNMI Monthly Average Air		KNMI Monthly Preciptation		SASSCAL Air Temperature		SASSCAL Precipitatio	
								From	To	From	To	From	To	From	To	From	To	From	To
NAMUTONI	NM	-18.80	17.00	1,100	KNMI	-	-	-	-	-	-	-	-	1902	1996	-	-	-	-
ODIMBO	NM	-17.40	15.90	1,130	KNMI	-	-	-	-	-	-	-	-	1927	1973	-	-	-	-
OLUKONDA	NM	-17.90	16.00	1,110	KNMI	-	-	-	-	-	-	-	-	1886	1964	-	-	-	-
OMBALANTU	NM	-17.50	15.00	1,100	KNMI	-	-	-	-	-	-	-	-	1933	1996	-	-	-	-
REHOBOTH	NM	-17.90	15.10	1,030	KNMI	-	-	-	-	-	-	-	-	1922	1991	-	-	-	-
SOAVIS	NM	-19.20	17.10	-	KNMI	-	-	-	-	-	-	-	-	1940	1976	-	-	-	-
STREBEN	NM	-19.40	16.90	1,200	KNMI	-	-	-	-	-	-	-	-	1950	1969	-	-	-	-
TSHANDI	NM	-17.80	14.90	1,000	KNMI	-	-	-	-	-	-	-	-	1921	1982	-	-	-	-
TSUMEB	NM	-19.20	17.70	1,311	KNMI	-	-	-	-	-	-	-	-	1907	1996	-	-	-	-
CLIMATE OKAUKUEJO	NM	-19.18	15.92	1,103	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1975	2013	1975	20
ELIM	NM	-17.72	15.48	1,092	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
ERMO	NM	-19.28	14.57	1,245	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
NAMUTONI	NM	-18.80	16.97	1,076	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
ODIMBO	NM	-17.40	15.93	1,097	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
OKONGO	NM	-17.57	17.22	1,152	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	2008	2012	2008	20
OLUKONDA	NM	-17.98	16.20	1,077	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
OMBALANTU	NM	-17.52	15.20	1,094	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
ONDANGWA	NM	-17.93	15.98	1,081	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
ONDANGWA 1	NM	-17.93	15.98	1,100	SASSCAL Info. System	-	680060	-	-	-	-	-	-	-	-	1973	2013	1973	20
ONDANGWA 2	NM	-17.88	15.95	1,097	SASSCAL Info. System	-	680130	-	-	-	-	-	-	-	-	n/d	n/d	n/d	n/(
PRECIPITATION OKUAUKUEJO	NM	-19.18	15.92	1,103	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-			1960	19
REHOBOTH 1	NM	-17.88	15.80	1,073	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
SITRUSDAL	NM	-19.33	16.38	1,341	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	1993	2012	1993	20
TSHANDI	NM	-17.75	14.88	1,109	SASSCAL Info. System	-	-	-	-	-	-	-	-	-	-	-	-	1960	19
ALEX MURANDA LIVESTOCK DEVELOPLEMTN CENTRE	NM	-18.36	19.26	1,166	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2010	2017	2010	20
KAKO OTAVI	NM	-18.30	13.66	1,427	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2016	2017	-	-
OGONGO	NM	-17.68	15.29	1,111	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2012	2017	2012	20
OKAPYA	NM	-18.47	17.34	1,138	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2012	2016	2012	20
OKASHANA	NM	-18.41	16.64	1,106	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2012	2017	2012	20
OSHAAMBELO	NM	-17.84	14.77	1,114	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2012	2017	2012	20
XANGONGO	NM	-16.72	14.98	1,123	SASSCAL WeatherNet	-	-	-	-	-	-	-	-	-	-	2015	2016	2015	20

A2.2 SELECTED AIR TEMPERATURE RECORDS IN THE CUVELAI BASIN.



A2.3 SELECTED PRECIPITATION RECORDS IN THE CUVELAI RIVER BASIN.



Note: Station data sometimes had months of missing precipitation data. In panels 'B' and 'C', years were excluded if the missing months would account for 10% or more of the annual precipitation in an average year.

A2.4 SUMMARY OF ASSESSED WEATHER AND CLIMATE DATA.

Dataset	Custodian	Components	Time series?	Gridded?	Geographic coverage	QA/QC Level	Completeness	Assessment	Comments	URL
CRU TS	Climatic Research Unit, University of East Anglia	Mean, maximum, minimum air temperatures, precipitation, wet-day frequency, vapour pressure, cloud cover, frost day frequency, and potential evapotranspiration.	✓	✓	Global	High	Complete	Excellent	0.5° grid resolution. Daily and monthly data from 1901 to 2015. Accuracy of gridded datasets should be assessed relative to monitoring stations before using. Vetted and frequently used by climatologists, and history of use in Africa and Cuvelai. For precipitation, GPCC data may better match station data.	https://crudata.uea.ac.uk/cru/data/hrg/
GHCN	Global Historical Climatology Network; National Centers for Environmental Information	A full suite of climate data; availability varies by station	✓	x	Global	High	Variable data gaps where monitoring data are not available.	Excellent	Monthly and daily dataset from meteorologic stations worldwide. Air temperature and precipitation data available in the Cuvelai.	https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn
GPCC	Global Precipitation Climatology Centre	Precipitation	✓	✓	Global	High	Complete	Excellent	Lowest resolution is 0.5°. Monthly data from 1901 to 2013. Accuracy of gridded datasets should be assessed relative to monitoring stations before using. Vetted and frequently used by climatologists, and history of use in Africa and Cuvelai.	http://www.dwd.de/EN/ourservices/gpcc/gpcc.html
KNMI	Koninklijk Nederlands Meteorologisch Instituut (KNMI, the Royal Netherlands Meteorological Institute	A full suite of climate data; availability varies by station	✓	x	Global	High	Variable data gaps where monitoring data are not available.	Excellent	Monthly and daily dataset from meteorologic stations worldwide. Air temperature and precipitation data available in the Cuvelai.	https://climexp.knmi.nl/selectdailyseries.cgi?id=someone@somewhere
SASSCAL Information System	Southern Africa Science Service Centre for Climate Change and Adaptive Land-Use	Air temperature and precipitation	✓	x	Southern Africa	Low	Variable data gaps where monitoring data are not available.	Good	Data from a large network of meteorologic stations in the Cuvelai, both in NM and AO. Well documented station data, and data are readily downloadable. Discharge and level data are available in Southern Africa, but not in Cuvelai.	http://leutra.geogr.uni-jena.de/sasscalRBIS/metadata/overview.php?view=ts_timeseries
SASSCAL WeatherNet	Southern Africa Science Service Centre for Climate Change and Adaptive Land-Use	Air temperature and precipitation	✓	x	Southern Africa	Low	Relatively short records. Variable data gaps where monitoring data are not available.	Good	Near-real-time data from a large network of meteorologic stations in the Cuvelai, both in NM and AO. Well documented station data, and data are readily downloadable.	http://www.sasscalweathernet.org/index.php
SPEI	Standardised Precipitation-Evapotranspiration Index	Drought index	✓	✓	Global	High	Complete	Excellent	SPEIbase provides drought conditions at the global scale, with a 0.5 degrees spatial resolution and a monthly time resolution. SPEI time-scales between 1 and 48 months. 1901 to 2014.	http://spei.csic.es/database.html

A2.5 SUMMARY OF ASSESSED HYDROLOGIC DATA.

Custodian	Theme	Components	Time series?	Gridded?	Geographic coverage	QA/QC Level	Completeness	Assessment	Comments	URL
Global Flood Detection System (GFDS) - Version 2	Hydrology	Remotely sensed water level in iisahana	✓	✓	Key flood-prone locations in Cuvelai Basin	Unknown	High	Excellent	Continuous daily time series available since 2015	http://www.gdacs.org/flooddetection/overview.aspx
Global Runoff Data Centre	Hydrology	Discharge, runoff, watersheds	✓	✓	Global; however, **no stations within the Cuvelai catchment**	High	High	Good	Long-term runoff and discharge.	http://www.bafg.de/GRDC/EN/Home/homepage_node.html
Hydrological Services Namibia	Hydrology	Manually measured water level in iisahana in Namibia	x	x	Key flood-prone locations in Namibian portion of Cuvelai Basin	Unknown	Low	Adequate	Data appear to be sporadically measured and made available.	http://www.mesasadc.org/namibia-hydrological-services
n/a	Hydrology	Long-term record of flood events	✓	x	Oshakia, NM	Unknown	Moderate	Adequate	Flow measurement methodology is unknown. Data are not time series per-se. Rather, flood events are binned by size.	n/a. Data available in Amakali 2003.
Southern Africa Science Service Centre for Climate Change and Adaptive Land-Use (SASSCAL)	Hydrology	Air temperature and precipitation	✓	x	Southern Africa; however, **no stations within the Cuvelai catchment**	Low	High	Good	Data from a large network of meteorologic stations in the Cuvelai, both in NM and AO. Variable data gaps where monitoring data are not available. Well documented station data, and data are readily downloadable. Discharge and level data are available in Southern Africa, but not in Cuvelai.	http://leutra.geogr.uni-jena.de/sasscalRBIS/metadata/overview.php?view=ts_timeseries
University of New Hampshire and Global Runoff Data Centre	Hydrology	Runoff	✓	x	Global; however, **no stations within the Cuvelai catchment**	High	High	Adequate	Global database of runoff data from stations.	http://www.grdc.sr.unh.edu/