AN INVESTIGATION INTO THE PERFORMANCE OF SMALLHOLDER IRRIGATION SCHEMES IN LIMPOPO PROVINCE, SOUTH AFRICA: SUCCESS FACTORS, TYPOLOGIES AND IMPLICATIONS FOR DEVELOPMENT

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ABSTRACT

The research aimed to determine the factors that contribute to the success or failure of smallholder irrigation schemes in the Limpopo Province. It focussed on public-schemes where farmers share the water system. Limpopo Province has more than half of the smallholder irrigation schemes in the country with an equipped area of approximately 28 000 ha. The main aims of the research were to identify key factors that explain performance and to develop a contemporary irrigation scheme typology. The research intended to provide a better perspective on how to focus investments across the multiple thematic areas that are associated with sustained and profitable irrigation farming activity.

A survey of 102 irrigation schemes was conducted, comprising 82% of the population of schemes greater than 20 ha in Limpopo Province. The quantitative survey complemented prior in-depth qualitative research undertaken on Limpopo schemes. Data was consolidated into five performance indicators and 13 characteristic factors that impact performance. Schemes were viewed as technical and socio-biological systems where performance was determined by the dynamic interaction of multiple factors. The analysis was done in a complex systems framework using correlation, cluster and principle component analysis. It was postulated that over-arching concepts of productivity, profitability and manageability would explain why schemes succeed or fail.

The schemes were found to be relatively very small in size with three quarters (74.8%) of them falling in the 50 to 250 ha size range, and only 11 schemes larger than 250 ha. Average plot sizes were 1.34 ha with a wide range between 0.18 and 16.25 ha. There were 65 operational schemes (equivalent to 63.7%), and 37 had failed (equivalent to 36.3%). Using a criterion for success of greater than 50% cropping intensity (to align with other studies and below which schemes can be considered to have failed), the success rate of the Limpopo schemes was 58%. The result was similar to the rest of South Africa and the same as the average rate for SADC identified in other studies using the same criterion. The schemes exhibited a mixed production purpose on average, with a significant market emphasis indicating these schemes have largely evolved from 'food schemes' to partly market-farming. Main crops grown were summer-maize and winter fresh-vegetables and cropping intensities on operational schemes ranged widely from 10% to 175%, with an average of 94%.

Failure was associated with three dominant factors: energy type; infrastructure condition; and water resource constraints. The first two factors showed that manageability of technology was important. There is strong empirical evidence that pumped smallholder schemes are vulnerable in their physical form, prone to functional and financial failure, live much shorter lives, and perform no better than gravity-canal schemes. Out of the 37 schemes that failed, 34 (91.8%) were pumped. Pumped schemes tend to collapse suddenly while young and

exhibit lower cut-off thresholds in productivity that, when crossed, trigger collapse. They also have much lower resilience to factors such as water stress or low farm-profitability. Pumped schemes need higher levels farm sophistication, market-oriented farming, and operational capability to keep the pumping pressure up. Water resource constraints were widespread, considerably more so on gravity schemes. Commercialising farmers were inhibited by lack of access to knowledge.

Success was associated with numerous factors, but two findings stand out; the performance of gravity systems and the prevalence of land-exchange activity; the latter enabled by institutional flexibility and reflecting a process of ‘bricolage’ at play. Increased plot size was associated with increased commercialisation and, when larger than 1.8 ha, only commercialised farming was pursued. Market proximity seemed to play a role in increased longevity and to market access in commercialisation. These findings highlighted the importance of productivity and profitability in explaining success.

Gravity schemes performed much more strongly in terms of longevity (nearly four times longer-lived) and similarly to pumped schemes in terms of cropping intensity. This was achieved under much greater water stress and with considerably worse infrastructure condition. Water efficiency was determined to be high on half of the schemes that were using short-furrow irrigation; equivalent, in a basin perspective, to drip irrigation. Two of the three top performing schemes (>150% intensity) were old gravity schemes.

Farmers on approximately 75% of Limpopo smallholder schemes are currently engaging in land exchange transactions in a highly insecure and un-formalised institutional setup. Land-exchange prevalence longer than two years was moderately associated with cropping intensity and strongly associated with commercialisation. This result has three important implications. First, it suggests that more land is utilised on the schemes when there is vibrant land-leasing activity. Secondly, schemes with a higher prevalence of long-term leasing seem to have a strong tendency to be more commercialised. Thirdly, the duration of the lease is significant, as neither single-season, nor annual leases yielded any positive associations, while those exchanges that were two years or longer, were associated with increased performance. These findings highlight the potential for longer-term land-exchange interventions to address the widespread low land utilisation on smallholder schemes, and to catalyse more commercially-oriented farming.

An irrigation scheme typology was derived from the cluster analysis and was aligned to a contemporary irrigation farming typology. The key descriptors included technology type, purpose of farming and scheme management type. By matching scheme type to the farmer typology (or typologies), strategic decisions regarding technology choices for infrastructure, land, and water institutional interventions can be better informed.

All schemes demand attention to the multiple factors required to achieve performance, not least water-tenure security, irrigation management organisational development, and infrastructure modernisation. Complexity was demonstrated by the finding that multiple factors contribute to success, and that there are many dimensions that change independently and have a cascading effect through the system in ways that are difficult to predict. Agricultural systems support to achieve productivity and profitability are essential for success. The research findings lead to the recommendation that, in addition, strategic planners must also consider the implications of the dominant factors of water-technology choices so that these are manageable, and the dynamics of farm-size change based on land exchange processes, in order to harness new opportunities to maximise irrigation scheme performance in future.

“If you’re walking down the wrong road,
take another one”

Quote attributed to the Akan Tribe of Ghana

“Smallholder irrigation is a highly case-specific, potentially complex, dynamic socio-biophysical entity influenced by a considerable number of internal characteristics and external driving forces and factors, and is a driver of considerable change on downstream sectors and users. Have we recognised this special nature of irrigation within livelihoods, food and cash production, river basins and the environment?”

Lankford & Gillingham (2001:1).

“If its not broken, Jonathan, don’t fix it”

Nicolas Abdo: family-elder, master-craftsman, toolmaker

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ACRONYMS

CPA	Communal Property Association
DAFF	Department of Agriculture Forestry and Fisheries
DBSA	Development Bank of South Africa
DFID	Department for International Development of the United Kingdom
DWAF	Department of Water Affairs and Forestry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
FAO	Food and Agriculture Organisation of the United Nations
IB	Irrigation Board
ICID	International Commission on Irrigation and Drainage
IMT	Irrigation Management Transfer
JVs	Joint-Ventures
MOM	Management, operations and maintenance
PCA	Principle component analysis
PIM	Participatory Irrigation Management
PTO	Permission to Occupy
RESIS	Revitalization of Smallholder Irrigation Schemes
RSA	Republic of South Africa
SADC	Southern Africa Development Community
SGVP	Standardized Gross Value of Production
TA	Traditional Authority (TA).
WUA	Water User Association
WUO	Water User Organisation
NDP	National Development Plan
NWRS	National Water Resources Strategy
DA	Discriminant analysis

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1 INTRODUCTION

1.1 Overview

Irrigation is increasingly important in debates around resource-use and rural development. Around the world and in South Africa, irrigation uses more water than any other sector globally, and makes a critical contribution to food security and rural livelihoods (Molden, 2007; RSA, 2013a). As water stress escalates due to a combination of population growth, urban expansion, catchment degradation, climate-change and cross-sectoral competition, agricultural water allocations are under the spotlight (Lankford et al., 2016). There is a new imperative attached to water-efficiency and water-productivity gains in irrigation farming and more is demanded from irrigated agriculture with less water.

This conundrum is no better reflected than in South Africa where irrigation water use nationally was capped at 60% of the quantity of the renewable resource as at 2013 (RSA, 2013a). The limit of 60% contrasts sharply with the envisaged role of 500,000 ha of new irrigation expansion in transforming rural-development and smallholder farming by 2030 (RSA, 2011) involving mainly Black South Africans (van Averbeke et al., 2011). The target is under review and will likely be reduced to 140,000 ha (Backeberg, 2018), but even so raises questions as to how this would be possible given the limited water resources that are available. The scarcity of water and the intentions for irrigation expansion also need to be viewed in the context of poor performance and underutilisation of resource potential on existing smallholder schemes (Bembridge, 2000; Perret, 2002; Van Averbeke & Denison, 2013). A better understanding of irrigation performance is therefore necessary for smallholder irrigated farming to contribute to rural and economic development as planned, in a context of national water stress.

This introductory chapter describes the global and South African irrigation scene and highlights the main drivers of irrigation expansion. The challenges facing the smallholder sector in South Africa are outlined. This leads to the central questions around irrigation performance that the research aims to answer.

1.2 World food demand and water stress

1.2.1 More people need more food

Global population growth and rapidly increasing competition for water means that, in future, more food will have to be produced using less water. Population growth is the main driver of food demand and the world's population is expected to rise to 9.7 billion by 2050, and tail-off to 11.2 billion by 2100 (FAO, 2017). While there is sufficient food on a global scale, regional differences in access to food have resulted in 800 million of the 7.5 billion people in the world being currently assessed as chronically hungry (FAO, 2017). Food systems are changing rapidly, influenced by climate change impacts and by market-shifts due to urbanization, corporate-driven vertical integration, and supermarket dominance of sales (FAO, 2016a; Sender, 2015). In addition, global trends of rising incomes have led to changing food preferences with higher consumption of meat, fruit and vegetables relative to cereals. These foods require more water than grains and this shift in diet is expected to continue in future (Molden et al., 2007a; FAO, 2017). Beef production in particular has an exceptionally high water use which is estimated at 11 times that of other animal groups (dairy, poultry, pork and eggs), and of grain crops with an equivalent calorific value (Eshel et al., 2014). The implication of more people, shifting preferences and greater demand for food means that, by 2050, crop production will have to increase by an average of 60-70% across the world relative to the production level in 2009, and will have to double in developing countries (FAO, 2011; FAO 2017). The predicted food and fodder demands mean that the water evaporated in all types of crop production (ie. rainfed and irrigation) would increase from 7,130 cubic kilometres in 2007 to 12,000–13,500 cubic kilometers by 2050 (FAO, 2015).

Transpiration through rainfed farming comprises approximately 80% of the total global agricultural evaporative demand in 2007, with the balance of 20% resulting mainly from irrigated farming (Molden, 2007). There are a wide range of agricultural water management practices that includes: irrigation, supplementary-irrigation; flood-recession farming; and water harvesting and conservation practices. These are increasingly viewed to exist on a continuum of agricultural water management practices (Savva, 2002; Rockstrom et al., 2010) that aim to reduce or eliminate water deficits needed for plant growth and contribute to increased crop production (Molden et al., 2007a; Annandale et al., 2011). On this theme, Molden et al. (2007a) differentiate between 'blue water,' which is water in rivers, dams or aquifers (and can be transported to fields for irrigation), and 'green water,' defined as rainfall that can be managed in the field to increase infiltration and is then held as soil-water and within plants. Water harvesting interventions, which divert and trap rainfall runoff to maximize infiltration into the root-zone, increase the availability of green water to the plant (Rockstrom, 2010). Irrigation, then, is about transporting blue water from a source, either continuously or opportunistically, and applying this water to agricultural land to enhance plant growth.

Global agricultural water withdrawal in 2010 was 2,769 cubic kilometres (FAO, 2016b), with a projected increase to 2,900 cubic kilometers per year by 2050 (FAO, 2015). This projected irrigation demand is in a context of increasing global water stress and highlights the need for intensification and water-productivity in all forms of farming (Molden et al., 2007a; You et al., 2011).

1.2.2 Global irrigation overview

Irrigation allows crops to be grown in areas that are otherwise too dry and reduces the water stress experienced by plants thereby increasing yields. By removing the risk of yield reductions from water deficits, irrigation enables intensification. Typically, irrigation increases both yields and quality, generates more income, and allows for multiple cropping cycles during a single year where the temperature regime is favourable (van Averbeke et al., 2011). A multiple cropping cycle increases the labour requirement per unit area and spreads it more evenly over the year. Due to intensification, increased irrigation costs and complexity necessitate a greater investment of time, equipment, fertilisers, attention to variety selection, and additional labour and market transactions (van Averbeke & Denison, 2013). Irrigation is thus always associated with blue water and with intensive farming.

Irrigated production is responsible for approximately 40% of global crop production from 20% of the cultivated land. The balance of 60% of production is produced under rainfed conditions (Faures *et al.*, 2007; FAO, 2017). The gross value of food produced under irrigation is however higher, estimated at 55% of global production (Molden, 2007), In terms of sectoral use, agricultural water withdrawals currently dominate global water use. Data from 2015 shows the sector is responsible for 69% of total global withdrawals, though with large regional variations of between 25% (Europe) and 81% (Africa and Asia) (FAO, 2016b). Industrial use accounts for 19% of global withdrawals, and the balance of 12% is for municipal use (FAO, 2016b). Just less than 40% of the total global agricultural withdrawals are supplied from groundwater (Rockstrom et al., 2007; Siebert et al., 2010). The most recent estimate from 2013 is that the total global irrigation-equipped area is 325.2 million ha (FAO, 2016b). Table 1.1 shows a disaggregation of the total global irrigation-equipped area and the relative importance of irrigation in the different world regions.

Table 1.1: Irrigation equipped areas and percentage of cultivated area by world region

World Region	Equipped Area (million ha)	% of total equipped global area	% of total cultivated area in each region
Africa	15.6	4.8%	5.8%
Americas	52.2	16.1%	11.8%
Asia	232.7	71.6%	40.9%
Europe	21.4	6.6%	7.3%
Oceania	3.3	1.0%	6.8%
TOTAL	**325.2**	**100.0%**	**20.3%**

Data source: FAO Aquastat database (2013 data set)

The dominance of Asian irrigation, accounting for 71.6% of the global equipped area, is notable. The balance of the irrigation equipped area is divided approximately equally between the Americas and the remaining regions combined. The data also shows that irrigation in Asia, at 40.9% of total cultivated area, plays a much more important role in agriculture than elsewhere, and is twice the global average of 20.3%. In the Americas (11.8%), Europe (7.3%), Oceania (6.8%) and Africa (5.8%), the irrigation sector is relatively small by comparison to the rainfed sector.

While regional variations are large, irrigation growth in the last half century has been key to meeting global demand for agricultural commodities. Over the period 1961 to 2009, total agricultural production increased by a factor of 2.5 to 3 but the world's cultivated area grew only 12%, from 1.37 to 1.53 billion ha (FAO, 2011). Irrigation more than doubled in area from 139 to 301 million ha in that time and was responsible for all of the growth in cultivated area, and contributed 40% to the rise in crop production. Globally, the total rainfed farming area declined fractionally by 0.2% in that same period, but contributed 60% to the rise in crop production, mainly derived from agricultural intensification (FAO, 2011). The green revolution, with increased productivity from agronomic gains in the form of fertilisers, improved seed and plant protection methods, saw a reduction in the average area needed to feed one person from 0.45 ha in 1960 to 0.22 ha in 2009 (FAO, 2011). The net change in total rainfed area masks regional variations and simplifies the dynamics of shifting farming practices. Rainfed farming using slash-and-burn methods has the characteristic of expansion into new lands and abandonment of degraded land associated with deforestation. The slightly negative net growth of rainfed farming does not then fully reflect the rainfed farming footprint, because vacated degraded land is impacted, but is not accounted for in the total (FAO, 2011).

1.2.3 Irrigation in Africa

In Africa, and Sub-Saharan Africa (SSA) in particular, rapid population growth, high incidence of poverty and low-levels of agricultural production result in the food sufficiency challenge to be more acute than elsewhere in the world. Africa is the only world region where population growth is expected to continue into the next century, albeit with a declining growth rate. The population is set to expand to 2.2 billion by 2050, and to more than 4 billion by 2100 (FAO, 2017). Whilst global poverty has declined significantly during the last 20 to 25 years, less progress has been made in Africa, particularly SSA. The region is the poorest in the world with poverty rates (% of population in poverty) of nearly four times the global average (World Bank, 2016). Compounding poverty, agricultural productivity in SSA is the lowest in the world. Rice and wheat yields are typically half that of high-income countries, and maize yields less than a quarter. The yield gap (actual versus achievable) is estimated to be 76% in SSA, the largest in the world, and much higher than the average of 50% in most low-income countries and the average of 11% in Asia (FAO, 2017).

Per-capita water poverty is also widespread in Africa. In 2015, the African per capita renewable internal water resource was 3,319 m^3 $annum^{-1}$ which is 57% of the global average (FAO, 2016b). The per capita withdrawals were less than half the global average (187 m^3 $annum^{-1}$ versus 486 m^3 $annum^{-1}$) (FAO, 2016b).

Whilst irrigation resource potential is nearly fully exploited in the rest of the world, the opportunity to expand irrigation in Africa is substantial as only 15.6 of the 42.5 million ha with irrigation potential have been developed. Most of that land is located in SSA, because North African countries have extensively developed irrigation sectors and limited water availability (FAO, 2016b; You et al., 2011). The data on irrigation areas in Africa, and SSA in particular, is thought to be underestimated. This is due to: first, informal or independent irrigators are a prominent growth sector in SSA in the last two decades but are under-documented; secondly, irrigation estimates vary substantially (by more than 25%), because definitions that are used are not consistent (Woodhouse et al., 2017). Irrigation-equipped land is different from actually-irrigated land and overlaps with other water-managed practices, such as flood-recession and water-harvesting farming (Siebert et al., 2010; Woodhouse et al., 2017). The rapid growth of the informal private smallholder sector has been observed across SSA but is also not well quantified. Estimates seem confined to Ghana, Burkina Faso and in selected provincial nodes in Tanzania and Mozambique. Indications suggest the contribution of this subsector would be in the order of 10-20% (Lankford, 2009; Namara et al., 2011; Burney et al., 2013; de Fraiture et al., 2014; Beekman & Veldwisch, 2016; Woodhouse et al., 2017). Analysis of data on irrigable areas in Africa, and particularly SSA, needs to consider these uncertainties.

1.2.4 Climate change and drought-proofing

Climate-change is a major factor in the future of irrigation and the impacts thereof need attention. This is due to the irrigation sector's important role in mitigating climate-change impacts. Multiple and unprecedented effects of climate change on precipitation, glacial melt, drought frequency, temperature regimes and hydrological cycles are expected to impact heavily on agriculture, particularly in the lower-latitude countries (van Ittersum et al., 2016). Climate change will impact the total evaporative demand due to increased temperatures, and the net amount of water that is available for crop farming due to hydrological shifts and catchment degradation. Negative impacts are expected to be felt the most by rainfed farmers in low- and middle-income countries, who will face significant yield reductions. These will mainly result from temperature increases and higher risk of crop failure due to increased drought frequency and intensity (van Ittersum et al., 2016; FAO, 2016). Optimistic projections of the impact of climate change on African agriculture are that yields of the five major rainfed grain crops could be reduced by between 10 and 20% (Beddington et al., 2011; Schlenker & Lobell, 2010).

In SSA, 99% of the production of main cereals, such as maize, millet and sorghum, takes place on the 94-96% of cultivated land that is rainfed (Wani, et al., 2009). This production plays a dominant role in rural livelihoods. Eighty-five percent of Africa's poor live in rural areas (You et al, 2011) and an estimated 75 per cent of the population in SSA are involved in farming, either directly or through employment (Schlenker & Lobell, 2010; Moyo, 2016). SSA economies have varied but significant reliance on agriculture, which contributes an average of 17% to the GDP across the sub-region. When these considerations of rainfed grain-dependency, agriculturally-dependent livelihoods for the majority, and the agricultural contribution to the economy are combined with the projected population growth, there are potentially dire consequences at a regional scale from climate-induced grain-yield reductions.

There are three main approaches to the mitigation of the negative effects of climate change and which are captured under the concept of 'climate-smart agriculture' (CSA). CSA aims to: increase productivity; build resilience through adaptation; and reduce greenhouse emissions. CSA includes a wide range of measures such as: watershed-scale remediation works; seed-improvement; agro-ecology; crop diversification; conservation agriculture; agro-forestry; cover-crops; full and supplementary irrigation, and water-harvesting practices among other

(FAO, 2016). But ultimately it is irrigation, where it is practicable, that remains the most robust mitigation measure that is available (Rockstrom et al., 2007). The projected doubling of food and fodder demands by 2050 due to population growth in a context of substantially under-utilised natural resources places irrigation expansion squarely on the African and on the Sub-Saharan development agenda in particular.

1.3 Irrigation performance

1.3.1 Irrigation as a poverty-alleviation and economic development strategy

There are both obvious and hidden benefits derived from irrigation investments. Initial local benefits arise in the form of construction jobs and services, but primarily, investments are justified by the gains for individual farmers and by the wider economic returns. These individual and economic benefits depend on the actual increase in farm production made possible by providing farmers with access to water for cropping.

The consensus emanating from several studies is that at the farm level, the increase in farm income brought about by irrigation was sufficient to lift poor households out of poverty (Dillon, 2011; Hussain, 2007; Lipton et al., 2003; Castillo et al., 2007). Hussain (2007) showed that poverty in 5400 households within 21 irrigation systems in six Asian countries was half that of poverty outside of irrigation systems. Castillo et al. (2007) concluded that irrigation significantly increased farmer incomes in nine developing countries. In China, Huang et al. (2006) found that the revenue from irrigated land was on average 1.79 times higher than that from neighbouring dryland farms based on a comparative farm size of 1 ha. In Ethiopia, Gebregziabher et al. (2009) compared crop income, farm income and total income of irrigation farmer households with those of dryland farmers in a rural population where agriculture contributed an average of 72% to total household income. They found that crop income of irrigation farmers was 1.9 times higher than that of dryland farmers; total farm income was 2.7 times higher, and total household income 1.8 times higher. Reasons for the positive effect of irrigation on revenue per unit of land were that irrigation increased yields of certain crops; increased cropping intensity by enabling the production of more than one crop per year; and broadened choice of crop, making it possible for farmers to select crops with superior value (Huang et al., 2006; Castillo, 2007; Gebregziabher et al., 2009; Dillon, 2011).

At an economic level, the economic performance of irrigation schemes globally has been positive. A review of 208 World Bank projects between 1950 and 1993 showed a competitive average Economic Internal Rate of Return (EIRR) of 15% (Jones, 1995). A follow up review of 131 projects between 1994 and 2004 found average EIRRs of 22% (World Bank, 2006). Several global studies also show a positive ripple effect, with economic multipliers in the range of 2.5 to 4 (Faures et al., 2007). While average outcomes were positive, irrigation investments, particularly from the 50s to the 80s, were marred by underperformance and irrigation developments are considered to have fallen short of their design potential (Jones, 1995; Shah et al., 2002; World Bank, 2006; Inocentio et al., 2007; Turral et al., 2010; You et al., 2011). The extent of underperformance is illustrated by the failure to achieve economic objectives of 33-45% of the 208 and 314 schemes, respectively (Jones, 1995; Inocentio et al., 2007). The underperformance and risk of failure of irrigation investments contributed to the slowing of irrigation development after the high growth rates of 1.6-2.2% per annum of the 1950-1980s era to rates of less than 0.2% in the decades that followed (Faures et al., 2007). Other important reasons were that: the optimal sites and available area for irrigation expansion were nearly fully developed causing the infrastructure development costs per unit irrigated land to rise; the green revolution in Asia, of which irrigation development had been an integral part, had reduced food prices, easing demand for new irrigation investments; and rising development costs and declining food prices squeezed the economic returns on irrigation development, making it less attractive. These trends combined to reduce the willingness on the part of funding agencies and governments to invest in irrigation (Chambers, 1988; Merrey, 1997; Faures et al., 2007). In the last decade, the climate change and food security issues, particularly in developing countries, have highlighted irrigation as the prime mitigation practice and have led to renewed investment interest (Lankford, 2009).

1.3.2 Irrigation scheme performance

Irrigation activity takes place in different ways and farmers can either irrigate independently or share an irrigation system with others. Schemes can be defined as an agricultural project involving multiple farm units that depend on a shared water supply and irrigation system (Reinders et al., 2010). The scheme is determined by the hydraulic command area of the land portions allocated for inclusion in the boundary. There are three elements to the water systems on schemes: the water source (dam or river), bulk conveyance system (diversion and supply canal), and the farms (Reinders et al., 2010). The scheme boundary usually includes the bulk conveyance system but excludes the source (dams or rivers).

The overarching finding from performance reviews of schemes is that there was, in the past, an overly techno-centric focus with inadequate attention to institutional, organisational, agricultural production and marketing aspects. Other reasons for underperformance included inappropriate design at a technical level, lack of participation by farmers, institutional challenges, competing water needs, weak market linkages, inadequate skills, and difficulty in accessing finance (ODI, 1985; Merrey, 1997; Jones, 1995; Faures et al., 2007; Inocencio et al, 2007; van Averbeke et al., 2011; Meinzen-Dick, 2014; Mutiro & Lautze, 2015; Lankford et al., 2016).

Awareness of the multiple factors involved in successful schemes evolved in stages over 50 years. The initial expansion phase of infrastructure expansion was characterized by an engineering construction focus (Jones, 1995; Chambers, 1988). Agricultural extension and production support were included in the late 1980s and 1990s (Jones, 1995) in response to weak smallholder production levels. The next evolution was the inclusion of participatory methods which rose to prominence in the 90s as a way to address the inadequacies of top-down operational and maintenance modalities (Ostrom, 1992; Yoder, 1994). In response to increasing water stress and competition and climate change uncertainty, irrigation modernization, water-use efficiency, affordability, land and water institutions, and reliability of water-supply have become prominent factors affecting performance (Prieto, 2006; Lankford, 2009; Woodhouse et al., 2017). Lankford and Gillingham (2001) emphasised the complex nature of irrigation systems, and the extended multi-sectoral linkages at different scales. They pose a challenge to further enquiry and reflection on complexity: *"Smallholder irrigation is a highly case-specific, potentially complex, dynamic socio-biophysical entity influenced by a considerable number of internal characteristics and external driving forces and factors, and is a driver of considerable change on downstream sectors and users. Have we recognised this special nature of irrigation within livelihoods, food and cash production, river basins and the environment?"* (Lankford & Gillingham; 2001:1).

In South African literature, the multi-factoral nature of irrigation performance is also widely appreciated (Backeberg & Groenewald, 1995; Van Rooyen & Nene, 1996; Bembridge, 2000; Van Averbeke et al, 2011; Cousins, 2013; Sender, 2015; Van Rooyen et al, 2017). The factors that impact on irrigation scheme performance are thus numerous, and these factors are inter-related within the scheme boundary and also beyond.

While the many factors impacting on the irrigation scheme system, and the farming systems that are located on schemes, are well established (expanded in Chapter 3), the relative contribution of these factors has not been quantified. This is important because the high-cost of irrigation infrastructure has historically dominated investment allocations, and while water supply is clearly central to irrigation success, equally it is clearly insufficient to achieve the intended positive outcomes on its own. This raises questions as to how much investment should be allocated to other factors beyond water supply if these are also key to performance?

And, what range of skills and expertise is needed to ensure sufficient attention to other critical factors, both in the planning and in the operation of irrigation schemes? The overall importance of irrigation in food production and water use, coupled with positive economic benefits, means that irrigation development is central to most countries agricultural and rural development agenda. In South Africa, this is very much the case but performance on smallholder schemes is low and needs to be better understood.

1.4 Smallholder irrigation in South Africa

In South Africa, irrigation is seen as a solution to rural poverty, because it can address the key socio-economic problems of food insecurity and unemployment (RSA, 2011). This is not a new political view. For at least a century, irrigation has been associated with significantly improved livelihoods and a higher asset base (RSA, 1955; Backeberg & Groenewald, 1995). The latter authors highlight the use of irrigation-development to resettle poor-whites in the 1930s and 40s, including soldiers returning from WW II, on schemes such as Vaalharts located in the arid Northern Cape Province. In the Apartheid era (1948-1994), separate development policies targeted the ‘homeland’ areas comprising mainly black South Africans. These included irrigation scheme construction which was pursued as an employment, livelihoods-support and economic development strategy (van Averbeke & Denison, 2013). While irrigation schemes for white farmers, such as Vaalharts, were based on 10 ha farm sizes (Van Vuuren, 2012), schemes for black farmers were typically developed on 1.5 ha farm sizes (Van Averbeke et al., 2011), the latter falling into the category of smallholders. The term smallholders is explored next and this is followed by quantification of the smallholder sector relative to the larger-scale, highly commercialised sector that dominates irrigation production in South Africa.

1.4.1 Smallholders in South Africa

Smallholder farming is characterized by its small scale and low turnover, with relatively weaker links to markets, relative to the dominant larger-scale corporatized agricultural sector in South Africa. Vink and Van Rooyen (2009) use 20 ha as the upper limit of small-scale crop farming, noting however that the farming context influences scale. Turnover from 1 ha of a high-value irrigated cropping enterprise, for example, theoretically has higher returns than 500 ha of low-quality grazing land in the Karoo. Size must thus consider both area and turnover (Kirsten & Van Zyl, 1998). Kirsten later, in a popular article, suggests that any farmer with a turnover of less than R500 000 per annum would be defined as a smallholder (Kirsten, 2011). Greenberg

(2013) combines these considerations to arrive at a size of 60-80 ha depending on the nature of the operation.

In South Africa there are also Black and White smallholders with various common elements (Kirsten & van Zyl, 1998) but the term mainly relates to black farmers (van Averbeke et al., 2011). Cousins (2014:34) defines smallholders *as "…small-scale farmers who use farm produce for home consumption to a significant degree, and use family labour within the farming operation to a significant degree."* Based on his typology, smallholders are defined as a separate group from small-scale capitalist farmers, whose purpose of farming is primarily as a business operation. Cousins argues that there are considerable differences amongst small farms, and that the terms small-scale farmer and smallholder are "somewhat imprecise" (Cousins, 2014:117); he thus cautions against assuming that this group has widely common interests in development planning. The diversity of smallholder farmer characteristics, interests and needs is also echoed internationally (Prieto, 2006; Molden et al., 2007a). They argue that on-scheme diversity of farming purpose and agricultural methods is a reality that must inform efforts to increase productivity and profitability of irrigation schemes. Aliber and Hall (2012), and in more simplified form, Vink and van Rooyen (2009) and Kirsten and Van Zyl (1998), assert that the term smallholder in South Africa is value-laden and often equated with primitive, non-productive, subsistence-agriculture associated with the former homelands in South Africa – one legacy of separate development under the Apartheid era. They contend that profitable and efficient farming is commonly but incorrectly linked to large-scale commercial agriculture, and highlight that care is needed when applying the terms small-farmer (or smallholder).

Despite the varied perspectives on defining smallholders, there is agreement that smallholders are characterized by a partially-developed link with the larger economic system, with input and output markets that are localized and not fully formed (Ellis, 1998). They operate more often within loose value chains than tight ones, the latter being characterized by vertical integration, strong formalized linkages with supermarkets, and agro-industrial processing entities (Christen & Anderson, 2013; Cousins, 2014). Smallholders also suffer systemic exclusion and higher transaction costs, a factor which further distinguishes them from (larger-scale) commercial enterprises which have access to fully-formed external markets (Cousins, 2013; Sender, 2015). It is evident that a small number of White farmers will fall into this general categorization due to their relatively small farm size and/or turnover. However, in South Africa and in this thesis, the term "smallholder" is used to refer to producers who are Black Africans (after van Averbeke et al., 2011).

The smallholder group of farmers has access to the following areas of land in the country (both rainfed and irrigation):

- farming on small plots as part of agricultural development projects such as irrigation schemes, estimated at 100 000 ha (Van Averbeke et al., 2011);
- homestead gardening, estimated at 200 000 ha (Botha & de Lange, 2005); and
- rainfed fields, totalling 2 000 000 ha (Backeberg & Sanewe, 2010).

1.4.2 Irrigation coverage in South Africa

The national Water Use and Registration Management System database (WARMS) of the Department Water and Sanitation in 2014 includes 1.441 million ha of registered irrigation land across all farming sectors in South Africa. Of this, 1.253 million ha was irrigated (Van der Stoep & Tylcoat, 2014). The national irrigation activity used an estimated 60-62% of water abstracted from the national surface and ground-water resource (RSA, 2013a; Annandale et al., 2011 respectively). Smallholder irrigators farm on irrigation schemes, on their own independently irrigated plots, or in backyard gardens. The data on the coverage of schemes is reasonably well defined in terms of design area, but not in terms of the irrigated area. This is due to the extensive dilapidation of systems and the underutilisation that prevails (van Averbeke, 2011). The area covered by the other two groups, independent and backyard irrigators, are based on rough estimates (Botha & de Lange, 2005) combined with more recent work. Cai et al. (2007) used remote sensing data from the winter of 2015 and identified 97 471 ha of irrigation located in areas occupied by smallholders in Limpopo (ie. three former homelands from the Apartheid era). This estimate included smallholder irrigation schemes. When the schemes were deducted in their full extent for Limpopo, the total area of informal irrigation in Limpopo was found to be approximately 70 000 ha, though the figure is uncertain. Only very rough approximations can be made at provincial and at national level due to a lack of definitive data. It is clear, however, that the informal sector is important given the relatively large area they seem to cover.

Based on the information referenced above, South African smallholder irrigator populations can be grouped and quantified as follows:

- Farmers on plots as part of irrigation schemes are estimated to cover approximately 48 000 ha.
- Independent irrigators are estimated to cover 80 000 – 100 000 ha.
- Irrigated gardens (each of very small total size) are estimated to cover 10 000 - 20 000 ha.

Smallholder irrigation, estimated at approximately 150 000 ha (noting the substantial uncertainty), thus comprises approximately 10 % of the national irrigated area, which is relatively small. The number of Black African irrigation farmers is estimated at 200 000-300 000 individuals based on the updated information. This group includes those who farm under irrigation on schemes, independently, or in home and community gardens.

1.4.3 A focus on smallholder irrigation schemes

Irrigation as a practice varies widely in its technical sophistication, from hand-watering to computer-controlled sub-surface systems, and in the scale of farming where it used, from corporate estates farming tens of thousands of hectares to smallholders on one or two hectares, or less. Where irrigation farming takes place on schemes, farmers share the hydraulic system. On independent farms, a single farmer operates the system by him or herself.

The nature of irrigation *schemes* is very different from independent or private irrigation farms because the hydraulic system is shared. This requires high levels of social, technical and organisational collaboration to ensure equitable delivery of water, collection of operation, maintenance and management (OMM) revenue, and ongoing and periodic maintenance of infrastructure, and enforcement of water allocations. Schemes are most typically funded by public funds with resultant Government ownership of assets. They have inherently more complicated and wider sets of relationships, with concomitant risks, than individual irrigation farms. Yet schemes are necessary when land-resources are geographically distant from the water source requiring bulk-supply and distribution infrastructure.

While independent irrigation has seen high levels of growth over the last two decades globally, in Africa (Lankford, 2009) and in South Africa (Denison et al., 2016; Cai et al., 2017), irrigation schemes represent a major historical investment (Backeberg & Groenewald, 1995). They are often located on well-suited soils close to major water resources with entrenched land-use rights and attached social systems. Public irrigation schemes, as opposed to private irrigation systems, cover about half of the irrigation area in Africa (World Bank, 2010). Public irrigation schemes are expected to be an important feature of new irrigation development in SSA in parallel with independent irrigator development (de Fraiture et al., 2007; Lankford, 2009; World Bank, 2010; You et al., 2011).

In South Africa, irrigation potential is almost fully developed at 1.441 million ha (Van der Stoep & Tylcoat, 2014) with expansion potential of only 82 000 ha (RSA, 2013a), so the expansion agenda is relatively limited at national scale. In terms of smallholders, however, the expansion agenda is relatively significant. Policy intends for benefits to accrue to previously disadvantaged individuals (RSA, 2008; RSA, 2011; RSA, 2015) currently occupying approximately 48 000 ha on irrigation schemes. The possible expansion area, in terms of water availability, is thus 1.7 times the current smallholder scheme area.

There are thus three reasons for the focus on smallholder irrigation schemes in this thesis:

- Firstly, they represent substantial sunk infrastructure costs and are shown to be the most cost-effective location for irrigation development interventions to improve food production, employment and rural livelihoods (Backeberg & Groenewald, 1995; Prieto, 2006; Inocencio et al., 2007; Molden et al., 2007a).

- Secondly, where schemes function as they should, they provide a more secure location for farmers to engage in irrigation farming. The scheme exists for the sole reason of providing access to land and water for farming. It also results in a defined collective of farmers with common interest who can benefit from collaboration on other important agricultural functions, such as marketing and knowledge exchange.

- Finally, schemes are significantly under-utilized in terms of the available land and water resources, reflected by vacant and unused plots, low intensity and low productivity (Bembridge, 2000; Perret, 2002; Van Averbeke & Denison, 2013).

1.5 Research objective

The research is focused on smallholder irrigation schemes in South Africa. It aims to quantify and provide a weighting that reflects the relative importance of the multiple factors that contribute to success or to failure of scheme operations. The outcomes will provide a better perspective on how to balance investments in irrigation across the multiple thematic areas that lead to successful and sustained irrigation farming activity. It was postulated that over-arching concepts of productivity, profitability and manageability would explain why schemes succeed or fail.

The general objective of the research was to identify empirically critical factors that are associated with smallholder irrigation scheme failure, and with scheme success. The specific objectives of the study were:

1. To collect empirical data on factors linked to smallholder irrigation performance and assess which factors contribute to scheme failure.
2. To identify the contribution of factors to successful performance on operating schemes as measured by a set of performance indicators. These performance indicators include: scheme longevity; extent of land utilization (intensity); and degree of commercialisation.
3. To develop a contemporary scheme typology that captures irrigation scheme diversity to inform irrigation development interventions in South Africa. This will allow reference to smallholder farming typologies that can thrive on different kinds of schemes.
4. Interpret the findings from a policy, investment and physical planning, and design perspective.

1.6 Structure of the thesis

Chapter 2 provides an overview of irrigation development history and the eras of development which have had an impact on technology choices, smallholder farmer support strategies, and scheme management arrangements. Emphasis is given to the South African history and experiences which are foundational to the research as the history is embodied in the physical and social arrangements found on schemes today.

Chapter 3 covers the theoretical basis for the research and defines the factors of interest in the irrigation system. The factors are viewed as being part of a dynamic socio-biological-technical system which conforms to contemporary dynamic-systems theory. Concepts of functional thresholds, feedback loops and regime changes in the system operation are highlighted.

Chapter 4 describes the methods and materials deployed in the census survey of the identified smallholder irrigation schemes in Limpopo Province of South Africa. The quantitative survey complemented prior in-depth qualitative research undertaken by the author on Limpopo schemes. The research instrument and data-entry protocols are described. A statistical analysis approach was adopted involving correlation, regression and principle component analysis. These required the development of proxy or consolidated variables to achieve meaningful results and the rationale behind each proxy indicator is explained.

Chapter 5 presents the summary statistical results. The summary data captures the full extent of the survey including both the primary dataset and the consolidated meta-data (proxy indicators) derived from the dataset.

Chapter 6 presents the statistical analysis results including the correlation, regression and cluster analysis outcomes. The multi-factoral nature of irrigation system functioning is clear in the results, though a number of dominant factors emerge in relation to failure and success.

Chapter 7 is the discussion where the meaning of the results is analysed in the light of other literature. Policy, planning, and design implications are described. The chapter includes reflection on the limits of the findings given the high diversity of scheme characteristics.

Chapter 8 summarises the approach, conclusions and recommendations emerging from the research.

2 HISTORICAL AND POLICY PERSPECTIVE

This chapter provides an overview of global and South African irrigation development history and describes the social-development paradigms that underpinned irrigation expansion. The chapter concludes with a brief review of relevant South African policy.

History is important because of path dependency. This is the tendency of a past practice, preference or technological choice to continue, even if better alternatives are available (Berman, 1998). North (1990), in his seminal work, expounded on path-dependency in the relationship between institutions and development. He identified the trait of persistence in institutions and explained this as resulting from a process of increasing returns that reinforced organisational behaviour, thus perpetuating itself and narrowing future options of change. This could be attributed to an initial, deterministic, institutional characteristic that generated persistence or rigidity. Institutions and technology are also closely interlinked where technical decisions have a direct impact on how the technology must be managed, and what human-capacity, systems and rules are needed to do so (Ostrom, 2000; Prieto, 2006).

Scheme infrastructure includes bulk water supply pipelines, canals, pumps, hydraulic structures, access roads, fencing, and agricultural and administration buildings. This infrastructure, and decisions on plot sizes and landholding mechanisms, are necessarily defined during scheme planning and inform irrigation layout and design. At the same time, organisational modalities for water management and distribution are also instituted and operationalised. When organisational and technical re-design is necessary due to age or changing circumstances, the pre-existence of engineering components and embedded social and institutional structures determine future avenues of development. Historical facts and factors thus persist for many decades after their establishment, regardless of the operational status of the scheme. Due to this, an appreciation of development history is important for understanding the future of smallholder irrigation practice.

2.1 Irrigation development over time

2.1.1 Early civilizations to the industrial revolution

Debate around the role of agricultural water management seven to nine millennia ago centres on whether organized rangeland, political settlements or wetland agriculture was the driver of civilization. For some, political centralization is first associated with early village life in the hills centred around animal watering points, rangeland territoriality and tribal affiliations (Hassan, 2003). Others show that the first writing and organized political systems arose alongside permanent wetland agricultural systems along the Tigris, Euphrates, Indus, Yellow and Yangtze rivers (Millon, 1954; Diamond, 1998; Pournelle, 2003; Oweis et al., 2004). In either case, what is important for this work is that politically organized complex societies, and their associated institutional systems and capabilities, permitted the construction of complex irrigation systems and facilitated their management. The corollary is that without structured institutional systems (civilized society), irrigation collaboration is difficult or impossible.

2.1.2 The modernisation era

Modernisation theory arose after the second World War and underpinned the subsequent Japanese economic reconstruction effort. The theory projects the industrialized development path of the United States as the best model for the transformation of traditional societies which are limited by a range of challenges (Lerner, 1958). The concept pertains to the social evolution of a traditional agricultural economy and related aspects of society, such as its politics and culture, as it evolves into a modern society. It stresses the process of change and the intended positive responses to change (Bernstein, 1971). The emphasis of modernisation was on the following main themes: i) industrialisation and urbanization were the drivers of economic growth; ii) educational transformation, alongside systemic institutional reform, to inhibit archaic organisational structures (re-organization of chiefdoms etc.); iii) adaptation and use of new capital-intensive technologies; and iv) economically and financially-centred planning processes to prioritize and justify development investment decisions (Kendall, 2007). Despite prominent critiques regarding the patriarchal and simplistic character of the theory, including those by Lerner himself (Wilkins, 2010), the themes live on and became known as the 'Dominant Paradigm' (Akhahenda, 2004).

Irrigated farming increased rapidly in the last century driven by food and agricultural commodity demands and supported by modernisation and technology (Molden et al., 2007). Global irrigated areas increased from 63 million ha in 1900, to 111 million ha in 1950, reaching 306 million ha in 2005 (Siebert et al., 2015). The most recent estimate from 2013 is that the total global irrigation-equipped is 325.2 million ha (FAO, 2016b). Most of the world's large irrigation schemes were developed during the modernisation era from 1950 to 1980. This usually involved the construction of large dams and large-scale water distribution systems typically covering tens of thousands of hectares in a single scheme (Molden et al., 2007).

Irrigation growth rates peaked in the 1970s at 2.2% per annum, and from about 1985 onwards the rate of expansion fell steadily, before dropping sharply to 0.1% after 2000 (Faures et.al., 2007). Factors that contributed to the rapid decline in irrigation expansion were: the lower-than-expected benefits derived from the capital-intensive irrigation schemes established during the boom era (Inocentio et al., 2007); corruption associated with large irrigation development (Turral et al., 2010); rapidly declining food prices with profitability implications for farmers; and a growing lack of water and land available for the extension of irrigation (excepting in Sub-Saharan Africa) (Molden et al., 2007). The total estimated global irrigation area of 325.2 million ha used 69% of the world's consumptive freshwater (FAO, 2016b). This use is in a context of increasing competition with mining, industrial, environmental and domestic sectors (FAO, 2017; Faures et al., 2007).

Against this backdrop of competition for water, the term 'irrigation modernisation' is now more widely used in reference to ongoing innovative technical and organisational interventions to improve irrigation efficiencies and increase water-use productivity. The FAO defines (irrigation) modernisation as *"a process of technical and managerial upgrading of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization and water delivery service to farms"* (FAO, 2003:49). Irrigation modernisation is by nature an ongoing, dynamic, evolutionary process, which includes the concepts of service orientation, operational decentralization, demand management, water productivity and water markets (Renault, 1999). These can theoretically include high-tech and low-tech solutions, high-cost and low-cost investments and foreign as well as endogenous innovations. Modernisation practice on irrigation schemes, however, is often patriarchal and viewed by some as inappropriately dominated by external experts. Prieto (2006) argues the case that modernisation in irrigation has maintained some of the problematic paternalistic elements of the dominant paradigm. He points to the imposition of inappropriate and even destructive interventions on schemes by international development banks and foreign experts. Yet the increased global demand on finite water resources and the priority use for irrigation means that modernisation is unavoidable (Wahaj & Renault, 2011). Developmentally-sensitive irrigation modernisation needs to adopt a responsive and adaptive approach, rather than a prescriptive set of standards that ignores local experiences and concepts (Prieto, 2006). This critique is in line with a shift to more people-centred interventions prompted by key contributors to the rural and irrigation development discourse, such as Chambers (1983) and Ostrom (1992).

2.1.3 The shift to people-centred development approaches

Even though irrigation development proceeded into the 1980s driven by the dominant paradigm, by the late 1960s it was already apparent that the fading of the traditional society, which Lerner had predicted, with massive social and economic transitions on a linear path from traditional peasantry to modernized prosperity, was not to be. Melkote (1991) lists a number of reasons for this: i) modernisation theory measured development in terms of quantifiable economic growth indicators, but ignored poverty, income distribution and unemployment; ii) labor-intensive technologies were ignored; iii) internal constraints were the main considerations for analysis, while external, more global factors were not considered; and iv) the top-down and centralized planning approach failed to recognize the need for local self-reliance and the value of participation. Rogers (1978) suggested several alternatives, arguing that attention needed to shift from economic growth to equality of distribution; planning and implementation needed to move from centralized systems to ones encouraging popular participation; emphasis should be placed on integrating existing traditional and modern systems instead of a high reliance on expensive, imported, capital-intensive technology; and self-reliance needed to be prioritized. These shifts in development philosophy saw the rise of participatory development methods, originating in the mid-50s (Scoones, 2009), but achieving global influence with Chambers' 'Putting the Last First' (Chambers, 1983). This new way of working in rural development has spawned participatory rural appraisal techniques, rural-livelihoods frameworks and participatory research tools, and other people-centred ways of working (Scoones, 2009). The integrative character of participative approaches generally contrasts with earlier modernisation thinking, where 'mono-disciplinary perspectives ruled the roost' (Scoones, 2009:175). Earlier, professional economists, natural, medical and engineering sciences dominated while rural development generalists and sociologists were pushed to the side.

2.1.4 The era of participatory irrigation management and irrigation management transfer

Irrigation reforms since the mid-1980s emphasized a shift from centralized irrigation scheme control to one where irrigators were involved in decision-making in more fundamental ways. Irrigation Management Transfer (IMT) was central to this reform agenda and entailed a radical shift in the farmers' participation in irrigation water-service provision, operational responsibility and fee collection (Merrey, 1997; Merrey *et al.*, 2007). In the IMT process, large, capital-intensive irrigation schemes initially managed by a centralized government agency were handed over to irrigators, motivated by decentralization, efficiency improvements and reduction in State expenditure (Vermillion, 1997). While these had varied outcomes, often resulting in operational and financial difficulties, they also contributed to the more cautious approach to irrigation investment of that time. IMT as a fundamentally participative reform intervention has had mixed results, tending to be successful where plot sizes are substantial, where there is an individual business-farming orientation, where input-output market linkages are strong, and where the gross value of the product greatly exceeds the management costs (Shah et.al., 2002). High-cost systems, particularly highly modernized ones (with pumps and complex technical components), were found to be the most financially-vulnerable after transfer, as farmers had to carry the energy costs, which had typically been subsidized by the State prior to IMT (Vermillion, 1997; Laker, 2004). On modernized schemes where farmers were obliged to carry pumping costs, the whole farming system has to be elevated to a more productive and profitable level to enable the higher costs to be recovered and profits made (Merrey, 1997; Denison & Manona, 2007).

From the IMT experiences it can be seen that technical determinism resulting from design decisions made in the modernisation era (such as high-tech pumps and related costs) present a particular set of challenges when contemporary, people-centred philosophies are superimposed on existing schemes. The nature of the technical elements, particularly the water control and management technology and farm sizes, has strong bearing on what must and can be done. These socio-technical implications of irrigation design decisions must then be at the forefront of considerations when looking at schemes from the modernisation era functioning in this later, people-centred era (Prieto, 2006)

2.2 Water stress as a driver of irrigation change

Water stress from rapid industrial, agricultural and urban development is a widespread and increasingly high-profile issue. Globally, there is still sufficient water and land to produce enough food for the projected world population by 2050, but this belies the reality of regional disparity and local extremes. An estimated 2.8 billion people live in a situation of water scarcity (Molden et al., 2007b). Poverty statistics of the WHO and FAO in 2004 showed that more than 1.1 billion people had no access to clean water, 2.5 billion people lived on less than USD 2/day, and nearly 1 billion people were undernourished (Molden et al., 2007b).

Cross-sectoral competition for water is ubiquitous, so the economic value of water keeps increasing in free-market economies. Nieuwoudt and Backeberg (2011) argue that industrial and domestic markets place a high value on assurance of supply while the agricultural sector emphasizes large volumes of water to meet food market demands. The average value product of water is much higher for industrial and urban use than for agricultural use. This, they argue, will drive a shift in allocation from agriculture to industry and a related increase in the value of agricultural water. Farmers are thus under increasing pressure to assume responsibility for payment of agricultural water tariffs, and at the same time face increased water uncertainty and declining profitability margins (de Fraiture et al., 2007; Nieuwoudt & Backeberg, 2011).

Given that the irrigation sector is the largest user of 'blue' water in the world (69%) and in South Africa (60-62%) (RSA, 2013a; Annandale et al., 2011 respectively), the sector is a high priority for more efficient water-use technology and practice. The drivers of increased water-use productivity originate from within the irrigation sector, to increase farming profitability, and, from a national perspective, to increase allocations to higher value sectors to achieve better economic returns from the limited available water. Modernisation, with a much wider socio-technical scope than in the time of the modernisation-era, now including technology as well as production and water-management systems, is an important factor in irrigation practice for the future.

2.3 Irrigation Development in South Africa

Irrigation development in South Africa can be directly linked to the social policies of economic and racial segregation which dominated the irrigation development period (Backeberg & Groenewald, 1995), and technical choices made during this period have geographic, social and technical consequences on the present situation. The following three consequences are of particular interest. Firstly, the lion's share of scheme development was for settlement by white farmers (Backeberg & Groenewald, 1995; Bruwer & Van Heerden, 1995). Secondly, irrigation schemes developed for black farmers typically had much smaller plots than those for whites (Van Averbeke, 2008). Thirdly, technical choices and modernisation resulted in significantly different kinds of systems being implemented, in different eras (Van Averbeke & Denison, 2013). These and other historical factors still influence the future trajectory of smallholder irrigation development.

2.3.1 Pre-colonial irrigation and water management systems

Tempelhoff (2008) has written extensively of early indigenous southern African agricultural water management practices, both for supply to village settlements and for irrigation during the iron-age period from 800-1500 AD. These hydraulic capabilities, he highlights, were an essential part of survival for isolated Bantu people in the Southern African region, supporting powerful centres, such as Mapungubwe and Great Zimbabwe between 1200 and 1500 AD.
He argues that these early mixed-purpose water systems were as important then as high-tech, intensive irrigated farming is for food security in our society today. He makes a case that these indigenous practices are under-emphasized and were eclipsed by the introduction of the plough and modern Western farming traditions in the nineteenth century. These effectively obliterated ancient furrow systems and dominated subsequent historical narratives (Tempelhoff, 2008). While the importance of engineered water systems seems to be the case for early larger settlements, others argue that early agricultural water-technology development

in Southern Africa was comparatively limited. Some indigenous technologies were found to exist in southern Africa but these were significantly less prevalent and less-sophisticated than in east and North-African societies of the time (Denison & Wotshela, 2012). The point of interest that emerges is that while water-systems played a key role in supporting early settlements, southern African farmers did not have the long-historical connection with irrigation farming and water-harvesting that is evident elsewhere in many other places in the world.

2.3.2 Multiple use and early European settler development

There is no question however about the centrality of irrigation farming in the earliest colonial settlements in South Africa. In 1654, two years after van Riebeeck arrived at the Cape, irrigation gardens of 18 ha were established ('The Gardens' next to Parliament today), fed by the Oranjezicht and Platteklip streams. These supported the production of cabbage, carrots and greens for the Dutch East India Company (VOC) provisioning station (Van Vuuren, 2012). Over the next 100 years irrigated farming expanded very slowly further afield around Table Mountain to Constantia Wine Estate (established by Simon Van der Stel), and across the Cape Flats to the Great Winterhoek Mountains. These were all supplied by streams and springs and were farmed by the first Vryburghers (free citizens) who were released from the Dutch East India Company to farm and increase food supplies (Van Vuuren, 2012). In the late 17th century irrigation expanded inland with missionary settlements and small-town development, often as part of the domestic water supply systems (van Averbeke *et al.*, 1998). Wuppertal in the Cedarberg Mountains, and Prince Albert at the foot of the Swartberg Mountains, both in the Western Cape, are typical of towns designed with mixed-purpose supply. In these irrigation settlements, each home received a water allocation for domestic and agricultural use and is an example of the multiple-use services (MUS) approach (van Koppen et al, 2009). When the British took control of the Cape they brought engineering and hydrological specialists to secure domestic water, but did not finance dams or invest in irrigation as such. Farming had moved into the dryer hinterland due to land pressure and was centred around stock, mainly sheep on rangeland (Van Vuuren, 2012).

In the mid-1800s, the flood-spate irrigation technique called 'saaidamme' was established and proliferated. Saaidamme are essentially large, flat irrigation basins 1-100 ha in size, which capture seasonal flash-floods that occur in dry areas. The water is then stored in the basin (up to 0.6m depth of water) for a few days to allow deep infiltration (Denison & Wotshela, 2012). Saaidamme were mainly used to produce fodder and grains. Van Vuuren quotes the district Engineer's report from 1922 commenting on the "…enormous tracts of land covered with glorious grains and one realizes what an asset to the country the farmers are who have developed this principle of irrigation, the only one possible under the circumstances" (Van Vuuren, 2012:31) Saaidamme remain an exceptionally successful innovation, with potential sites where it could be replicated for small-scale and large-scale applications in similar semi-arid areas (Denison & Wotshela, 2012).

2.3.3 Government-driven expansion through large dam investments

Social policies of economic and racial segregation dominated the subsequent period of major irrigation expansion in South Africa (Backeberg & Groenewald, 1995). From the beginning of the 20th century there was a progressive shift from privately-initiated and funded irrigation schemes to projects which were driven and financed by the government, including large-scale settlement and poverty-relief projects that aimed to benefit the white population (Backeberg & Groenewald, 1995). The major schemes with regional impact, primarily for white farmer expansion, continued from 1930 through to the 1970s and were linked to large dam construction (van Vuuren, 2012). Smallholder schemes for black farmers were well-established in a missionary mode but accelerated after the 1950s following the findings of the Tomlinson Commission (RSA, 1955).

2.3.4 Tomlinson Commission and the gravity-canal schemes

In 1950 Professor FR Tomlinson was charged with the task of defining how Apartheid, as a somewhat vague political philosophy that launched the Nationalist Government into power in 1948, could be put into practice (Houghton, 1957). The Commission set out to evaluate options for the future development of the Bantu people in the Reserves of South Africa. Five years' worth of research and deliberation was recorded in extensive detail in 18 volumes containing data, analysis, and maps that still have some relevance today. The Commission tackled all spheres of life, including agriculture, settlement, infrastructure, the economy, culture, education and religion. It was then summarized into a more accessible 200-page report (RSA, 1955). The main task of the Commission was to explore two alternatives: a path of planned racial and social integration, deemed inevitable if nothing was done to prevent integration; or structured segregation of the Bantu and European people of South Africa. As with the current National Development Plan (RSA, 2011), agriculture and irrigated agriculture were key to rural development. Early in the process, the Commission adopted the belief that, given the reality of equal resolve for European self-determination and Bantu demands for equality, integration would "only intensify racial friction and animosities, and recommended that the only alternative was separate racial communities in separate areas, where each will have the fullest opportunity of self-expression and development" (Houghton, 1957).

The 200-page summary report (RSA, 1955) describes a context of highly under-utilized farming resources, deeply entrenched cultural values, and the dominant responsibility placed on women for all crop and grain production for home food. The recommendation was to create self-sustaining, independent farm units which would fully support a Bantu family to undertake full-time farming, through the development of irrigated holdings wherever possible, and with support given to rainfed cropping and livestock farming on rangelands. The Commission documented in extensive detail indigenous farming practices with challenges not dissimilar from today. They observed the success of simple flood irrigation schemes, the importance of high quality extension, of input and output value-chain links to urban centres, of cattle-cropping synergies, and the need for sufficiently large plots to allow full-time farming. Houghton (1957) also highlights that instead of basing their program on a subsistence economy, western technology and scientific advancement were a central tenet. This was underpinned by the intent to plan for economically-sustainable mixed-farming enterprises that would feed into the 'European' (ie. White South African) fresh produce and commodity value-chains, and lead to the establishment of a Black middle-class farmer group. All non-farming 'Bantu' were to be settled in betterment villages, with employment-based livelihoods through migrant labor.

Tomlinson's commissioners made a set of well-substantiated recommendations, many of which resonate with irrigation development literature today:

- Future schemes should have simple diversion works and gravity-canal schemes.
- Each scheme should be coordinated by a skilled European Technical officer to support water management and crop production activities.
- Land should be demarcated with reduced survey accuracy to facilitate speedy administration regularisation, and administration should be done locally by establishment of a land committee comprising five local Bantu leaders and scheme members and the Government technical officer.
- Land should be held in title, not customary or quitrent tenure, and should include conditions on effective resource use (thereby establishing clear institutions in relation to use, access, control and exchange rights).
- Typical land holding sizes should be between 1.3 ha and 1.7 ha (considered economically viable units at the time) combined with off-scheme cattle-rearing in a mixed farming system.
- Full technical and agricultural support services should be provided to farmers (i.e. they adopted a systems view of the farming enterprise);
- Irrigation schemes should be regarded as an integral part of rehabilitation programs, covering grazing, veld and erosion activities, and must embrace the preservation of

water sources and 'sponges' (i.e. and appreciation of the importance of wider ecological stability, with an emphasis on wetlands).

It is remarkable that, with the exception of the recommendation for 'European' technical officers rather than simply 'skilled technical officers', these recommendations closely align with contemporary work on irrigation revitalisation and development. The point on simple technology can be observed in successful Sub-Saharan schemes (Inocencio, et al., 2007) and in South Africa (Reinders, 2011; Van Averbeke & Denison, 2013). The types of schemes promoted by the Tomlinson Commission (simple, gravity-fed canals and furrow or flood-irrigation in the fields) were documented to have survived the longest in Vhembe District of Limpopo, and still have the greatest chance of being in operation today (van Averbeke, 2012). The recommendation for agricultural-systems support aligns with current agricultural systems thinking (Bembridge, 2000; Backeberg & Sanewe, 2013). The emphasis on extension and knowledge remains an elusive contemporary challenge (Stevens et al., 2012). Land titling, and local land registration and management systems are now a highly topical theme in transformative agricultural programs in Africa (Deininger & Fang, 2016). These types of land solutions are also recommended in South Africa (Denison & Manona; 2007a; Manona & Baiphethi; 2008; Denison et al., 2016).

The above review throws light on the dominant strategies that informed the establishment of many smallholder schemes in South Africa. Somewhat surprisingly perhaps, it exposes the reality that many of the contemporary challenges and proposed solutions are remarkably similar now to what they were then. Part of the reason may be that many of the recommendations were never effectively put in place (Van Rooyen & Nene, 1996). The alignment of Tomlinson's documented and contemporary issues, and the failure of Government to implement the Commission's recommendations at the time, suggests these may still have value in relation to the current discourse.

2.3.5 High-tech schemes of the homeland era

The second phase of smallholder irrigation development took place in the 1970s and 80s when a series of irrigation schemes was developed by the then homeland governments, now incorporated into the Eastern Cape, Limpopo, Kwazulu-Natal and Mpumalanga provinces. These high-tech schemes were classic products of the modernisation era and the dominant paradigm, typified by large dams, pump stations, centre-pivots and sprinkler systems. These were developed in a top-down fashion. The consultants favoured sophisticated capital-intensive technology, manifested in the type of infrastructure found at schemes such as

Thyefu, Ncora, Keiskammahoek, Zanyokwe (Eastern Cape), Makuleke in Limpopo, and Taung in North-West Province (Denison & Manona, 2007b). This was intended to increase production and provide local people with two main opportunities: small irrigated food plots (0.16 to 0.25 ha in size) for growing food and generating some cash; and individual commercial farms (4 to 10 ha) demarcated for small-scale commercial farmers. A central, commercially-operated corporate entity (a few hundred hectares in size) in some cases anchored the development by providing agricultural services and markets (van Averbeke et al., 1998). Control over farming was heavily enforced, with books kept by central management and farmers receiving a stipend and a yield-linked payment after harvest. Production on the small food-plots was observed to be a reasonably successful part of these developments. This outcome pertained to both the relatively large numbers of poverty-stricken people who benefitted (van Averbeke et al., 1998) and their continued operation and use when field-based production on other parts of the scheme had seriously declined (Denison & Manona, 2007b). In general, the vision of integrated, intensive agricultural development projects striving for social and economic objectives and underpinned by a corporate-style estate did not succeed. These schemes caused substantial social upheaval due to their top-down approach, land re-allocation, and high investment costs (Bembridge, 2000; van Averbeke & Denison, 2013).

Ncora Irrigation Scheme, planned for 2830 ha in the Eastern Cape, is one striking example of this era. The scheme characterizes both the modernisation dream and its unfortunate and unintended outcomes. Ncora was built with its own major dam and reservoir, large-diameter pipelines, gravity sprinklers throughout, and a central agri-industrial complex and commercial farm of 1542 ha. The final 1000 ha of the planned scheme was not developed. The development included a central agro-industrial commercial estate including a dairy and cannery (100 ha) which supported multiple surrounding irrigated smallholdings with agricultural services. To justify the expense of constructing schemes, the Government prioritized economic objectives which included high production, high employment and high gross margins. The original holders of the land on which the scheme was established were required to give up part of their dryland allotments to make land available for the central agro-industrial unit. In return they received access to a smaller-sized irrigation plot of either a 0.9 ha plot, or a 0.3 ha plot with a share in the central estate farm enterprise. These options were to enable them to produce crops for their own consumption and for sale, thus taking care of the social objective (van Averbeke & Denison, 2013).

The Ncora Project was never able to finance itself, let alone pay back its capital investments, and at its peak in 1984, just 2 years after it was completed, required Government to cover a shortfall of 12% of total operating expenditure (van Averbeke & Denison, 2013). Rising financial deficits, a decline in quality of service provision to farmers, and a lack of profits from the group farm led to a sense of distrust as farmers were shareholders. People started to call for the return of the land they had transferred to the group farm. At the end of 1996, two years after the new dispensation in South Africa, the Eastern Cape Department of Agriculture discontinued financing the parastatal projects it had inherited. All project staff were retrenched, and the scheme was transferred to its landholders, who were not skilled or able to take over management. Being a gravity-fed scheme, irrigation at Ncora has continued to limp along with ad-hoc Provincial Government revitalisation and planting efforts, but production is restricted to small portions of the scheme. Ageing pipework and vandalism have affected the functionality of the irrigation system and impressive fountains from high-pressure water leaks were recorded to be a common sight (van Averbeke & Denison, 2013).

Ncora was the ultimate plan for an integrated and industrial approach to farming, with a complete farm-production support system and with processing facilities on site. Despite the apparent responsiveness to the whole agricultural complex of challenges, the Ncora experience appears to have been little more than an expensive mistake. The reorganization of the original land holdings to accommodate irrigated farms and food-plots has resulted in ongoing contestation over land-use rights. As on many schemes, the condition of the water-supply system continues to decline, with a pervasive sense of hopelessness. Recent activity at Ncora has been driven by various Provincial and District Government initiatives, including the establishment of centre-pivots on part of the scheme. These are now farmed under a large-scale joint-venture dairy initiative. No financially or technically sustainable model for smallholder agriculture has yet been developed for the scheme (Joubert, 2018).

2.3.6 Revitalisation and irrigation management transfer in the democratic era

The third phase of irrigation development in post-apartheid South Africa has been a process of irrigation management transfer (IMT) accompanied by revitalisation programs. Most schemes were previously administered centrally and subsidized through homeland parastatals such as Tracor, Ulimocor and the ARDC in the Transkei, Ciskei and Limpopo respectively. Post-1994, the State moved to cut costs of involvement (Perret, 2002) and, in 1996, State subsidies were withdrawn. Almost instantaneously there was a widespread collapse of scheme operations. Large schemes from the 1970s and 80s were affected most, due to the termination of funding to their central management entity which kept the complex systems, usually involving pumps, operating. High running costs, large scheme size, technical complexity and the absence of local involvement meant that participant farmers could not manage or finance the schemes themselves (Bembridge, 2000; Shah, 2002).

From 1997, policy shifted to an emphasis on IMT, which was promoted widely by international agencies at the time (Vermillion, 1997). Besides a few exceptions, such as the Limpopo WaterCare Program 1998-2004 which focused on 37 schemes, modernism in its technical or commercial agri-business form has dominated irrigation revitalisation efforts (Denison & Manona, 2007a).

One prominent example was the 2004 Revitalising Smallholder Irrigation Schemes (RESIS) program that included 126 schemes in Limpopo Province. This intervention was originally based on the relatively successful experiences of the earlier WaterCare program and pursued an integrated irrigation development approach. The approach combined infrastructure rehabilitation, organisational and farmer skills development, and market brokering. It was in line with international trends promoting farmer participation and people-based approaches, rather than relying primarily on modernist technical solutions. In 2005, before any real progress was made, the participative elements which had promoted diversity of farming were replaced. RESIS-Recharge was introduced, and promoted a top-down development approach, pinned on high-tech pumped floppy and drip irrigation systems. The schemes were then to be farmed by large-scale commercial entities in strategic joint-venture partnerships, with farmers as (non-farming) shareholders (van Koppen et al, 2018). The RESIS-Recharge approach ignored the significant evidence of the resilience and efficiency of existing canal-furrow schemes using short furrow irrigation (van Averbeke & Khosa, 2011; Reinders, 2011). Many of the older canal-furrow schemes were demolished and converted to high-tech systems, with design similarities to Ncora in their dominant feature of technical-modernisation (Denison & Manona, 2007b). Subsequent failure of most of the RESIS-Recharge schemes was largely ascribed to undefined 'social' issues or the lack of a strategic partner (Tapela, 2008; Schreiner et al., 2010; van Koppen et al., 2018). The failure was easy to predict. An assessment was made by the author at the initiation of the RESIS-Recharge program based on an assessment of international success factors. This showed RESIS-Recharge to score a very low 5/50 for the whole approach, versus the earlier WaterCare program which scored 28/50, the original RESIS approach which scored 36/50, and the Eastern Cape Ten Schemes Project which scored 40/50 (Denison & Manona, 2007b). RESIS-Recharge confirmed the weakness of the modernisation paradigm, and highlighted its persistence, in the minds of contemporary decision-makers, of the industrialised agricultural model as the solution to all problems.

This part of the review is relevant to the thesis because it illuminates the deep-seated belief in the modernisation paradigm and the lack of awareness of other important factors. RESIS-Recharge was the largest irrigation investment program in South Africa in the last 20 years, underpinned by the modernisation paradigm and failed in implementation (van Koppen et al, 2018). This was despite local published evidence and international guidelines on best practice to the contrary (Denison & Manona, 2007b).

2.4 South African Agricultural Policy & Smallholder Irrigation Development

2.4.1 The National Development Plan

The National Development Plan (NDP) (RSA, 2011), developed by the National Planning Commission (NPC), is the overarching planning strategy for South Africa and complements other sectoral strategies. A detailed review of smallholder farming policy over time is set out in Denison et al. (2015). This shows a philosophical alignment between numerous Departmental policies across health, agriculture, social-development, land and water sectors. There is general agreement on the importance of smallholder farmers and their central role in rural development. But there is a notable disjuncture regarding smallholder irrigation expansion between the NDP, the National Water Resources Strategy 2 (RSA, 2013a) and the National Irrigation Strategy (RSA, 2015). The latter document is relatively vague compared to the NDP but apart from potential expansion area, presents no other significant contradictions. Relevant sections of the NDP are discussed next in the thesis, and key differences with the NWRS 2 and the National Irrigation Strategy are highlighted. Together these documents frame the thesis within the national policy context.

The vision of the agricultural section of the NDP is that more opportunities must be realized for rural communities to participate in economic, social and political activities. The NDP envisages the expansion of smallholder agricultural development and the integration of smallholder farmers with the dominant, highly-commercialized, large-scale agricultural economy. Such integration is seen as critical for improved livelihoods. The rural development vision rests heavily on 500,000 ha of new smallholder irrigation, and the belief that smallholder irrigated agriculture will be the driving force of growth and change in the country's rural areas to achieve job creation and poverty alleviation: "*To achieve this (job creation and poverty reduction impact), irrigated agriculture and dry-land production should be expanded, with emphasis on smallholder farmers where possible. The 1.5 million hectares under irrigation (which produce virtually all South Africa's horticultural harvest and some field crops) can be expanded by at least 500 000 hectares through the better use of existing water resources and developing new water schemes"* (RSA, 2011:218).

The NDP presents a wide-ranging analysis of the water-agricultural complex and of factors to consider in smallholder irrigation farming. It highlights critical elements for promoting smallholder irrigation and agricultural development, including the multi-factor, holistic perspective of the agricultural system. It identifies and emphasizes several strategic elements that must be addressed to take national rural development and agrarian reform forward, and which are summarized below.

Smallholder links with large-scale agri-business: While the NDP focus of rural development is on smallholders, strong links with commercial partners and the commercial sector are central to the plan: “Some under-used land in communal areas and land-reform projects might need to be used for commercial production and established agricultural industries must be enabling partners” (RSA, 2011). The plan emphasizes new entrants, value chains, and the development of women’s skills and capabilities. Specific interventions to achieve these are not provided, but the NDP notes that creative combinations of opportunities need to be found.

Empowerment of women: Black empowerment and gender economic empowerment have been identified as a priority in the formation and expansion of new businesses, including agri-business, with an emphasis on value-adding. Gender discrimination is reported to be a continuing problem despite efforts that are being made to address the issue. Weaknesses are reported within the institutions responsible for promoting gender equity, including inequitable land and water allocation.

Extension – calling for a new cadre: Skills development in the agricultural sector, including entrepreneurship training, is highlighted as critical. This would include the training of a new cadre of extension officers to respond to the needs of smallholder farmers and assist with their integration into the food value chain.

Land and tenure: Tenure security is acknowledged as being vital to secure an income for existing farmers and new entrants. The National Planning Commission emphasizes the need for tenure security, particularly within communal systems. *“Failing to adequately address tenure security for black farmers in the communal areas and under the land reform program would pose a major risk to agricultural expansion. As long as these farmers (especially women farmers) do not have secure tenure they will not invest in the land and agricultural production will not grow at the rate and pattern required for growth in employment”* (RSA, 2011:25). A thriving land market is widely thought to be key to increased land-utilisation by facilitating the exit of some farmers and to allow the entry of new ones (i.e. securing rights of use through formal lease or sale) (de Soto, 2000; Deininger & Fang, 2015). In addition, without tenure reform in areas under traditional tenure, it is not possible to secure loans for agricultural production. While highlighting the key issues of tenure security generally, the NDP gives a clear pointer to the value of local administration solutions. *"The focus should be on cooperating with traditional leaders to secure tenured irrigable land supported by fully defined property rights. This will allow for development and give prospective financiers and investors the security they require"* (RSA, 2011:220). The NDP thus implies local land administration interventions, and cooperation with traditional leaders in order for investors (at any scale) to secure traditionally-administered land with better-defined rights.

Growth markets and employment: The potential for smallholder agriculture to expand (and irrigated agriculture in particular) is linked to high-return crops such as macadamia nuts, pecan nuts, rooibos tea, olives, figs, cherries and berries, although the development impact is limited by climatic suitability. Irrigated vegetables are a high-value but also volatile market which could expand by 25% through better linkages to local rural markets, and more distant Southern Africa Development Community (SADC) markets (RSA, 2011). Also positive are the grain, oilseed and livestock industries, with strong upstream and downstream linkages. The downstream linkages, agro-processing and other support services that are available to create sustainable jobs in these markets are significant.

Value chain interventions and market linkages: The NDP explains that the traditional approach to rural development and improving agricultural income in poor countries is to help farmers move up the value chain by supporting agro-processing (RSA, 2011), but notes that in South Africa most value chains tend to exclude small, new or black farmers. The potential role of supermarket chains as a key point of entry into a higher-return market is highlighted, which concurs with international experience (Green, 2008; Sender, 2015), but it requires sophistication to achieve quality and reliability of food supply to outlets. Establishing market linkages must therefore go hand-in-hand with considerations of consistency of quality and supply at farm level.

Cooperatives: Given the dominating presence of existing agro-industries, only niche opportunities for agro-processing exist in the value chain. Importantly, the Commission notes that these "cannot sustain group projects or cooperatives" (i.e. production cooperatives) due to their size and given the need for quick market responsiveness, which is not facilitated by group decision-making. The Plan identifies some cooperatives (e.g. bulk purchasing) that can be key organizations in helping to achieve collective market bargaining power with other commercial players in the value chain (RSA, 2011).

Multi-faceted strategic interventions: The Plan recommends connective infrastructure and emphasizes the need to support agricultural enterprises. Government investments, it notes, should support investment in water and irrigation infrastructure, markets for small-scale farmers, sustainable agriculture, land transfers, and skills transfer. It is clear that more investment should be directed toward providing innovative market linkages for new entrants and small-scale farmers in communal and land reform areas. This list of priorities and considerations provides clear direction on how the numerous challenges to smallholder agriculture must be addressed to achieve successful growth of the smallholder sector.

The NDP aligns well with the varied smallholder farming practices being operated at different scales in South Africa and articulates broad support strategies for sustainable agriculture. Improving or conserving agricultural water is highlighted as a priority. The wide reach of strategic responses also addresses some of the key concerns raised by Kemerink et al. (2011) identified as limiting reform, including: institutional chaos in the former homelands in particular; the tendency of government to force people to work in groups, often acting as a disincentive; the disconnected reform programs at policy and implementation levels; and the fact that many people with land and water resources are not farmers nor interested in farming. Among the priority target groups of the NDP are rural people in general, and women and youth in particular. Skills development of young people to expand opportunities and unlock potential for economic growth, increased employment, better health, and food security are of vital importance. The Commission observed the high prevalence of poor land-use practices in communal areas, and the need to reverse this to improve the livelihoods of rural communities. One aim has been to curb the high migration from rural to urban areas. If rural people engage in agriculture as an economic activity, there is potential to increase the number of real jobs created by the sector, from production through to processing.

2.4.2 Strategic direction and the development challenge at hand

The agricultural section of the NDP, as it pertains to smallholders, is closely aligned to various sectoral policies and strategies which aim to address the national crisis of rural unemployment and hunger. While critical institutional gaps systemically entrench the status quo of a struggling smallholder sector (Cousins, 2014; Sender, 2015), the NDP provides a coherent vision of a much-expanded irrigation sub-sector. One critical disjuncture, however, is the political target for the development of 500 000 ha of smallholder irrigation, which contrasts sharply with the National Water Resources Strategy 2 (DWA, 2013a) and the National Irrigation Strategy (RSA, 2015). The appendices of the NWRS 2 detail the available water for smallholder expansion as being between 80 000-82 000 ha nationally, which is less than 17%

of the water needed for the 500 000 ha irrigation expansion target set in the NDP. The National Irrigation Strategy defines a much smaller area of 34 863 ha for potential expansion, though this is qualified as being data provided by each of the provinces and the document itself suggests uncertainty as to the data. The NDP target is under review and may be reduced to 140 000 ha (Backeberg, 2018) but no formal revision has been made.

In either case, there is a difference of an order or magnitude in projected smallholder irrigation expansion target. This is a significant misalignment of intentions between the Department of Water and Sanitation, the Department of Agriculture Forestry and Fisheries, and the National Planning Commission. The disjuncture is more pertinent when funding implications are considered, let alone implementation capacity in both the private sector and Government. The National Irrigation Strategy estimates new irrigation development to cost R200 000 ha^{-1} (RSA, 2015) which means that the funding required for the reduced NDP target of 140 000 ha would be R28 billion (over 15 years from the envisaged start), an unlikely allocation in the present constrained fiscal climate.

The NDP target, according to the NDP Agricultural Commissioner, needs to be seen as a political vision of an expanded irrigated smallholder sector, and an important anchor to agrarian revitalisation (Karaan, 2015). While water is one dominant limiting factor, and budget availability for expansion another, the NDP presents a challenge to the development community to find ways of supporting intensive smallholder agricultural expansion.

National development policy, as it pertains to smallholder irrigation development, provides a clear statement of the importance of the smallholder sector in achieving rural development in South Africa. The reality of water-scarcity, reflected in the aforementioned documents, places emphasis on maximizing returns from all available irrigation resources including existing infrastructure, available water, land and people, to achieve rural progress. The policy review demonstrates a high degree of social relevance of the research focus of this thesis.

2.5 Closing note

This chapter summarised the history of irrigation development globally and provided insight into the three distinct phases of irrigation history in South Africa. The early phases up to the 1960s comprised more robust, gravity-canal schemes and many remain operational today. The modernisation paradigm dominated development in the 1970s and 80s, with high-tech mostly pumped systems, with generally higher operational costs and technical complexity. The second era was followed by an attempt at irrigation management transfer of smallholder schemes around 2000. That however failed to hand over operational responsibility to smallholder-scheme farmers due to capability limitations and the poor condition of infrastructure. These different eras of development are associated with distinct water-supply, technology, institutional, layout and land-tenure issues. These continue to have impact on their operations (or failure), and through path dependency, on their possible evolution in future.

The lack of attention to scheme-level irrigation management institutions is reflected in the National Irrigation Policy, where ‘water user association’ (WUA) is mentioned only once. Legal provisions for WUAs were established in the National Water Act (NWA) (RSA, 1998) for the inclusive and integrated water resources management of demarcated ‘areas of operation’, including irrigation scheme management. Prior the act, irrigation operations were managed by Irrigation Boards (IBs) that originated from the Irrigation and Conversation of Water Act (Act 8 of 1912) (Schreiner et al., 2017). The Irrigation Boards, up until 1998, had the primary function of maintaining water resources and supporting the white commercial farming sector. Since the NWA came into effect, the IBs have undergone a transformation process into WUAs. These were intended to have a development focus supporting, among other, emerging Black farmers. One of the persistent challenges has been the slow pace of transformation (RSA, 2013b) with 99 of the original 278 IBs having been transformed. This process included consolidation of smaller IBs, thus leaving 100 IBs to be transformed as at 2017 (RSA, 2017).

While detailed legal mechanisms for WUAs are provided for in the NWA (RSA, 1998), and are active and effective on many of the large-scale, predominantly white-owned commercial irrigation schemes (Benade, 2011), they are markedly absent from the smallholder scheme landscape (ARCUS GIBB, 2002; Pegasys, 2013). This apparent gap in the policy and of smallholder-scheme institutional development, contrasts with the origins of successful irrigation development described in the review. Early civilisations and irrigation settlements were established in a symbiotic relationship with institutional and social order that underpinned effective irrigation system functions. The institutional gap on smallholder schemes, and the link with limited water-services functionality is pursued further in the review of performance factors, and in the fieldwork and analysis.

The next chapter addresses the theoretical aspects of irrigation system functions and performance. A complex systems framework is used to describe scheme operational dynamics and relationships and the factors that are part of the complex system are identified and explained. The focus of the research that follows is on the specific factors that contribute to outright scheme failure (‘kill factors’), and those that contribute to the irrigation scheme performance.

3 IRRIGATION SCHEMES: TYPOLOGIES, FACTORS AND A SYSTEMS VIEW ON PERFORMANCE

Chapter 3 presents the theoretical foundations of the thesis. The themes that are covered include scheme typologies, farmer typologies, factors in irrigation, and irrigation schemes as complex systems. One aim of the research is to develop a statistically-substantiated scheme typology to inform irrigation development interventions in South Africa. A review of six existing scheme typologies identifies important descriptors and highlights their contemporary relevance. Identified typological shortfalls are addressed later through the research findings in Chapter 6. The research also aims to answer questions on the relative contribution of factors in relation to scheme performance. The key factors of interest are presented here. Their relationships are then explained from a systems point of view, providing the basis for the analysis of scheme success and failure factors in the chapters that follow.

In addition to reviewing selected literature, the chapter consolidates prior work of the author and collaborators. The author has previously been the lead author responsible for several research reports on smallholder farming and irrigation in South Africa which were peer reviewed. Consolidation of that knowledge is relevant to the thesis and is integrated with, and linked to, the published work of others.

3.1 Irrigation scheme typologies

Typologies are an important way of organizing complex cause-effect relationships, thereby providing key reference points to the development of strategies (Fiss, 2011). The value of a typology is that certain similar responses or interventions can be formulated and applied to all members of a grouping. The basis for establishing typologies is varied and depends on the need. In the case of irrigation, there are various ways to group schemes according to key characteristics in order to aid analysis, planning and intervention. Six relevant typologies are summarised next.

Inocencio et al. (2007) analysed the costs and performance of 314 irrigation schemes constructed between 1964 and 2003 in 50 developing countries and identified six scheme types. They highlight that some developments are for irrigation alone, while others are multi-purpose. These projects include irrigation, hydropower, urban supply and other sectoral interests. In their pursuit of understanding the relative performance of African schemes

compared to international schemes, they selected mainly technical and water-source descriptors.
These were:

- river-diversion systems without major storage;
- systems which use river water with dams and major storage capacity;
- tanks (i.e. to supply small irrigation systems such as hand-watering);
- pump irrigation systems from rivers or dams (i.e. surface water);
- pump irrigation systems using groundwater;
- drainage or flood control systems.

This categorisation emphasises descriptors of scale, type of infrastructure, water source, and, to some extent, the wider economic purpose. It does not include any reference to the kind of farming that takes place on the irrigation scheme.

Moving to an African perspective, the World Bank Africa Action Plan (World Bank, 2010) defined a set of groupings to give direction to strategic investment planning. This is not an irrigation scheme categorisation *per se*, as it includes independent irrigators who by definition are not located on schemes, and a rainfed group with managed agricultural water. It does, however, provide useful insight into how the categorisation was approached. Their grouping was:

- Market-oriented irrigation schemes with a Public Private Partnership (PPP) in place;
- Small-scale community-managed irrigation schemes focussed on local markets;
- Large-scale irrigation schemes;
- Individual smallholder irrigation for high-value crops (i.e. independent irrigators);
- Rainfed water control interventions and watershed management (including water-harvesting).

The above categories share a descriptor of scale as did the prior one, and in addition there are mixed descriptors including agricultural purpose, and the scheme management arrangement (community management or PPP). The Africa Action Plan also includes agricultural water development through water-harvesting interventions, not irrigation as such, but in line with key authors who propose a continuum of agricultural water practices (Molden, 2007; Rockstrom et al., 2010). Molden explains that the *"…continuum of water management practices starts with fields or grazing land entirely dependent on rainwater. On-farm conservation practices focus on storing water in the soil. Moving along the continuum, more surface water or groundwater is added to enhance crop production. This additional freshwater* *provides opportunities for multiple uses, including aquaculture and livestock production within the production system"* (Molden, 2007:18). The idea of a continuum opens the door to a wider categorisation of schemes, because there are certain water-management interventions using water-harvesting and conservation techniques that are, in fact, constructed as 'schemes'. One example is the opportunistic rice-growing 'sawah' technique in West Africa. This method combines on-farm practices of levelling and bunding the perimeter of fields with the diversion of flood-water (Nwite et al., 2012). It fits the classification of (spate-) irrigation (Oweis et al., 2004) and of 'scheme' as defined in the thesis. In South Africa, a closely similar agricultural water management practice is the extensive 'saaidam'[1] flood-water-harvesting systems found around Calvinia (Denison & Wotshela, 2012). These flood-spate schemes support lucerne production that underpins livestock farming, which is the main agricultural enterprise in the extremely arid region. Saaidamme (*plural of saaidam*) were estimated to cover 35,000 ha in area though the full extent was uncertain (Denison & Wotshela, 2012). This sub-group of agricultural water schemes is important for policy, planning and implementation (World Bank, 2010), but were not included in the study. While the 'sawah' are a smallholder spate-irrigation system, the South African saaidam systems do not include smallholder farmers. It is however interesting that these are schemes and sit on the transition between irrigation and water-harvesting in the agricultural-water continuum.

Lankford et al. (2016) offer a critique of the idea of the agricultural water continuum in the context of scale, which is a prominent descriptor in the prior two typologies. They posit that management complexity has a geometric rather than a linear relationship with the size of irrigation schemes. They argue that a continuum concept is thus potentially misleading from a policy perspective because the nonlinear effect of scheme size leads to an inflexion point where completely different kinds of schemes exist on either side that point. A key determinant of the inflection point is when schemes are sufficiently large that they cannot be operated by a farmer-managed arrangement that would typically involve a Water User Association (WUA). Schemes are classified as 'large' when operational management is carried out by an operator or a government irrigation and drainage (I&D) agency. These large-scale schemes are associated with a very different set of operational and institutional phenomena due to their hierarchical nature (Lankford et al., 2016). Water control is difficult to achieve with high levels of accuracy, infrastructure ownership is complex, and physical distances and communications have significant logistical challenges regarding management, operation and maintenance (MOM). Small schemes, on the other hand, have much simpler organisational and institutional

[1] An Afrikaans language word literally translated to mean 'sowing dam', as in seed-sowing.

challenges to overcome to achieve operational functionality and exhibit strong social bonds (Lankford et al., 2016). Policy therefore needs to address a bipolar reality in terms of irrigation scheme management and institutions, rather than a spectral one. This perspective on scale and management, operations and maintenance (MOM) institutions has implications for the findings of this research and is pursued further in the analysis.

A third set of scheme categorisations was used by Backeberg & Groenewald (1996), who primarily considered the bulk water supply arrangement and whether these were individual or collectively managed. They defined three main categories: a) individual diversion schemes, b) co-operative flood diversion schemes, and c) public storage schemes (these involved the settlement of new farmers which was typical of the mid-1900s irrigation development era). Perret (2002) provided a grouping based on historical eras, including: Private Schemes (from 1650), Irrigation Board Schemes (1912 onwards), White Settlement Schemes (1930s–1940s), Bantustan Schemes (1950s–1980s), and more recent food plots and community gardens.

These latter two typologies are useful in identifying characteristic themes but are generalised in their categorisation. These were intended to describe historical phases of irrigation development, not to inform strategy or policy. Bembridge (2000) expanded on the historical theme. He added organisational-management characteristics and scale descriptors as follows:

- ‘Top-down’ bureaucratically managed smallholder schemes. Practically all farming operations are carried out by management on behalf of farmers. The larger schemes from the former homelands fall into this category (e.g. Mid-Letaba in Limpopo; Ncora in the Eastern Cape; and Taung in North-West Province).
- Jointly-managed schemes in which some functions are performed by farmers themselves.
- Community schemes, usually small in size and operated by water-users.
- State- or corporation-financed schemes such as sugar cane, where farmer participants are selected on entrepreneurial and farming ability and on their financial and other resources.
- Large estate schemes that are managed by agents. These aim for maximum use of resources through the production of high-return cash crops such as tea and coffee. Farmer participation in both scheme MOM and in farming decision-making is minimal, usually limited to involvement as labourers. This group was called ‘equity-labourers’ by Denison & Manona (2007).

This typology brings additional detail and makes a useful distinction based on management type and scheme size but is outdated. All four of the above categorisations were informed by the purpose at the time, though they differ somewhat in the characterising elements. Scale and management type are prevalent as descriptors.

It is striking that none of the typologies consider plot size (i.e. smallholders or larger-scale farms) or technical complexity of the irrigation method (flood, sprinkler, drip etc.) in the factors informing the typology. It is also evident that none capture the current character of smallholder schemes in South Africa, as they are outdated. Much has changed since their development, notably the closure of provincial agricultural management parastatals in the mid-90s, and various efforts towards revitalisation and re-organisation of schemes undertaken between 1998 and 2010 (ARCUS GIBB, 2002; Shah, 2002; Pegasys, 2013). Major legislative changes, particularly the effects of implementation of the National Water Act (RSA, 1998) that provided the basis for the establishment of Water User Associations (WUAs), as well as the Irrigation Management Transfer (IMT) efforts discussed in Chapter 2, have also changed the irrigation typological landscape.

The fifth, and most recent, typology was proposed by the author in a prior publication developed from observation of schemes during a three-year study in Limpopo (Denison & Manona, 2007). The classification of schemes considered purpose, predominant plot size, and the technical character of the scheme (including irrigation method and operational complexity). This was subsequently amended by van Averbeke et al. (2011) as shown in Table 3.1. The word ‘peasant’ replaced the originally ambiguous ‘smallholder’, and ‘commercial’ replaced ‘business’, but with the same essential descriptors.

The term ‘peasant’ is used in an agricultural-development, rather than a political-history context. Van der Ploeg (2008), writing on three studies conducted over 30 years in Italy, the Netherlands, and Peru, presents a positive view of the concept of a peasant. He argues that the peasant condition is characterised by a struggle for autonomy and sustainable development. Peasant farming is associated with the establishment of a self-governed resource base and differs in fundamental ways from two other identified modes of farming; capitalist-entrepreneurial and corporate arrangements. Furthermore, rather than being associated with a negative connotation of poverty, disenfranchisement, and lower social status, he argues that peasantries in both industrialized and developing countries are re-establishing through rich and complex processes. In this sense, the concept of ‘peasant’ is positive and empowered. It is associated with the preservation of resources, lifestyle, and cultural values, through a sustainable mode of farming. Peasant is used in this sense in the typology in Table 3.1.

Table 3.1: Typology of South African smallholder irrigation schemes *Source: van Averbeke, Denison & Mnkeni, (2011)*

Scheme type	**Typical plot size**	**Typical irrigation system**	**Purpose of farming and farming system**
Food plot	<0.5 ha	Canal irrigation or immoveable sprinklers	Mainly for own consumption with local marketing. Low external input approaches to production.
Peasant	1-2 ha	Canal irrigation	Different purposes in line with diversified livelihoods of plot-holders, and different production approaches reflecting risk appetite. Local (urban) markets dominate, but with assistance, distant city markets could be accessed.
Commercial		Simple overhead sprinklers or micro-irrigation	Full-time, commercial farming that includes engagement with distant markets. Highly productive farming systems are necessary and access to finance could be a requirement.
Equity-labourer	Consolidated landholding	Complex overhead sprinklers or micro-irrigation	Commercial farming with strategic partner who manages the enterprise, whilst plot-holders are farm workers who also receive a share in the profits in return for providing the land.

This last typology still resonates with observed realities at the time of writing this thesis but has a limitation in that it was developed by simple observation from extensive fieldwork during 2003-2006 (Denison & Manona, 2007). It has no quantitative basis for its formulation. All of the reviewed typologies have value in that they highlight different criteria for scheme groupings in response to diverse contexts, and for different purposes. At present though, there are no scheme typologies based on substantiated quantitative evidence that are relevant for South Africa's strategic planning for smallholder irrigation development. The development of such a typology is one of the objectives of the thesis and would help guide more responsive strategies for smallholder irrigation revitalisation in South Africa.

3.2 Smallholder farmer categorisations

The previous section examined irrigation scheme typologies. This section on smallholder farmer typologies links the typology of schemes to the kind of smallholder farmers that they can support. The rationale is that certain kinds of schemes are suitable only for certain typologies of farmers and conversely, are not suitable for others. The relationship between the scheme-type and the farming-type will impact recommendations that emerge from the thesis in relation to schemes, as farmers and their livelihoods are the a-priori reason for investment in smallholder irrigation schemes.

The relationship between scheme and farmer-type can be illustrated with a simplistic example. A pumped-irrigation scheme that has high monthly energy costs for operations would require farmers on that scheme to be geared to farming for profit, enough to pay the energy bills. This calls for a level of technical, financial and market sophistication. A business-farming approach is thus necessary to generate sufficient cash to cover relatively high energy costs (related technical aspects are discussed later in this chapter). The type of farming, crop choices, irrigation methods and risk profile would be significantly different from, for example, a small gravity-canal scheme that has secure water from a spring or mountain stream and would be associated with much lower operational costs. The latter scheme could reasonably support farmers interested more in low-external-input, low-risk farming methods for the purpose of home-food provisioning while the former (pumped-scheme) could not. Farmer typologies that capture such characteristics are well-established in South Africa and are addressed next.

3.2.1 Livelihoods and farmer groupings

There is good evidence that smallholders should be studied and understood within a livelihoods context as there is substantial diversity in the role that farming plays within peoples' livelihoods (van Averbeke & Mohamed, 2006). Scoones, (2009) places a heavy emphasis on livelihoods diversity and explains that high diversity is linked to resource availability, different interests and aspirations, varied capacity to absorb shocks, and practical alternatives for survival. Where farmers rely on irrigated agriculture, a thorough understanding of the farming system is required in order to appreciate their motivations and choices. It follows logically that where farming is a small part of people's livelihoods, there are a much wider mix of survival strategies outside of the farming system that must be considered.

There is extensive literature on livelihoods, all of which aim to understand *"the means of gaining a living"* in a holistic way (Scoones, 2009:171). Scoones attributes this inclusive view of people's survival strategies to Chambers and Swaminathan (1986), who outlined this way of understanding the realities of the rural poor in order to promote change more effectively. A descriptive analysis of livelihoods portrays the complex web of activities and interactions that describe the different ways people make a living; these have various starting points of interest, and different foci, when viewed subjectively (Scoones, 2009). Among the various livelihoods approaches, the Sustainable Livelihoods Framework (SLF) (DFID, 1999) is widely used, comprising five capitals: human, social, physical, financial and natural. Importantly, the framework facilitates the analysis of timelines and evolutionary change that take place over time. Change over time can show movement between different livelihoods typologies, with positive or negative implications (Scoones, 2009). This movement over time can be viewed as a development pathway. The reality of a dynamic transitioning in livelihoods priorities can manifest in similarly dynamic transitions across farmer typologies. The livelihoods perspective highlights the importance of the wide diversity in how people (irrigation farmers) survive and thrive. It also points to the reality of changing livelihoods over time. The technical aspects of irrigation scheme design, and of rehabilitation or revitalisation choices, influence both social behaviour (Prieto, 2006) and the kind of farming that can thrive on schemes. Scheme technological factors can thus constrain livelihoods evolutions (shifts from one to another farming type), or act as triggers and force shifts in farming typology, with an impact on people's livelihoods strategies, bounded by the five capitals to which they have access.

3.2.2 Farmer typologies

Most typically, references to farmer groupings are characterised as subsistence, semi-commercial and commercial farmers (Kirsten & Van Zyl, 1998; Vink & Van Rooyen, 2009). While this is adequate for some applications, there has since been work that is more nuanced (van Averbeke et al., 2011; Cousins, 2014). These authors identify details that may be important for linking scheme typologies with the types of farmers who can operate and survive on different scheme types. It was highlighted earlier that the scheme typology of van Averbeke et al. (2011) contained food-plot, peasant, business, and equity-labourer farmers. This shows similarities to international perspectives on farming-based livelihoods (Green, 2008; van Der Ploeg, 2008; Scoones, 2009; van Hofwegen, 2010) by their emphasis on some or all the same characteristics of peasant, entrepreneurial and corporate farming. These concepts are briefly explained below, drawing mainly on van der Ploeg (2008):

1. Peasant farming was outlined earlier and is characterised as farming with the primary intention of strengthening the agricultural resource base. Income is only one of several motivations for farming, others including producing food for own consumption, investment in social linkages, resource reproduction in the long term, and livelihoods resilience more broadly. Peasant farmers tend to have a limited appetite for risk and try to reduce their dependence on external markets. Risk and independence are important factors in making farming decisions. The peasant mode of farming does not mean that there is a disconnect from markets, particularly output markets, but rather that such farmers tend to seek out

and develop relationships with markets which do not threaten their autonomy (van der Ploeg, 2008).

2. Entrepreneurial farming as termed by van der Ploeg (2008) is characterised by full market engagement (input, including labour, and output) with the primary purpose of generating profits. As a result, farming is subject to the volatility of markets, which represents risk. This kind of farming is the same as what van Averbeke et al. (2011) called business farming.

3. Corporate farming has the same orientation as entrepreneurial farming, but as the name states, is undertaken by corporate entities and not individuals. The type of farming is larger in scale and is financed by venture capital, often within a web of interlinked agri-enterprises. Vertical integration across the value-chain, including on-farm production, agro-processing, industrial packhouses and transport fleets for national and international distribution, is a feature. Corporate farming is not of primary interest in this study, other than this group has a major impact on market competition due to their economies of scale, competitive pricing and high degree of sophistication.

The other relevant South Africa typology was developed by Cousins (2014) and modified by Manderson (2015), reproduced in Table 3.2. This captures the important characteristics identified above and provides more detail than van Averbeke et al. (2011).

There are two aspects that not explicit in any of these farmer typologies: i) the degree of capital investment by the farmer and his/her indebtedness (financial capital) and ii) the degree of risk that is acceptable to farmers. Chipfupa & Wale (2018) developed a farmer typology including financial descriptors and a sixth livelihood capital of psychological capital. They highlighted the heterogeneity of smallholder farmers in terms of characteristics that included education, age, cautiousness, social-grant dependency, and psychological endowment, along with other livelihoods capitals and farming attributes. They confirmed the importance of access to finance and education, training, and market-access as critical to entrepreneurial development which was the main focus of their study. These perspectives are useful and can be aligned to and enrich the understanding of the market-oriented typologies above.

Table 3.2: Typology of smallholders in South Africa *(Reproduced from Manderson, (2015:8), based on Cousins, 2014)*

Attribute	**Smallholder categories**			
	Subsistence-oriented smallholders	Market-oriented smallholders in loose value chains	Market-oriented smallholders in tight value chains	Small-scale capitalist farmers
Objective of production	Home consumption	Home consumption + cash income	Cash income + home consumption	Profit
Proportion of marketed output	None or insignificant	50% or >	75% or >	100%
Contribution to household income	Reduces expenditure	Variable, from small to significant	Significant	Very significant
Labour	Family	Family + some hired	Family + significant numbers hired	Hired
Mechanisation	Very low	Low	Medium to high	High
Capital intensity	Very low	Low	Medium to high	High
Access to finance	Absent	Some	Significant	Very significant
Households in SA	2-2.5 million	200-250 000	?	?

Alignment between Chipfupa and Wale (2018) and Manderson (2015) can be achieved through developing a common understanding of entrepreneurship. Schumpeter (1934) underlines key factors to the concept of entrepreneurship in psychological terms, with elements of innovation, creativity, or discovery. This is supported by the work of Peterson (1985) who describes entrepreneurship as the opportunity-seeking style of management that sparks innovation. The definition of Nieman et al. (2004) is particularly useful in bringing the psychological concepts embedded in the concept of 'entrepreneurial' with the commercialisation concepts of 'market-oriented'. They posit that an entrepreneur can be defined as "a person who sees an opportunity in the market, gathers resources, establishes and grows a business towards the satisfaction of the needs of the market" (Nieman et al., 2004:4). The above typology of Manderson (2015), is therefore readily aligned with the more recent work of Chipfupa and Wale (2018); the latter adding depth and value to the understanding of farm-level dynamics in regard to entrepreneurship and market-based farming activity.

The terminology of Manderson (2015) was assessed to be the most relevant for this study and was adopted. The discussion of the drivers of farmers' livelihoods, and of farm-enterprise types, is inseparable from the analysis of scheme performance. The thesis does not engage in more detail with farmer typologies but links these to scheme types in the light of the results. The intention is develop the scheme typology so that it is coherent with contemporary farmer typologies given the importance of scheme type in determining, or accommodating, different farming types. Scheme performance, which is the focus of this study, includes a wider set of factors beyond the farm, and these are discussed next.

3.3 Factors and the performance of smallholder irrigation schemes

3.3.1 Factors and farming

Many studies on agricultural and irrigation development over the last 60 years have highlighted the multiple factors that must be considered to achieve agricultural success (RSA, 1955; Van Rooyen & Nene, 1996; Bembridge, 2000; Perret, 2002; Bolding 2004; Prieto, 2006; Ostrom, 2009; van Averbeke, et al., 2011; RSA, 2011; Sender, 2015; Lankford et al., 2016; Van Rooyen et al., 2017). Factors that impact on farming are interrelated and dynamic and are widely viewed to comprise complex socio-ecological systems (Lankford et al., 2016). There are discrete factors as well as relationships between factors; the latter, within a complex systems paradigm, are viewed as the drivers of the system. Performance of irrigation schemes is discussed first, followed by the elaboration of the factors that impact on performance. This is followed in the next section of the chapter by a discussion of the inter-relationship between factors (ie. of complex-systems), and of their defining features and dynamic characteristics.

The performance of irrigation schemes has been the subject of extensive enquiry given the irrigation sector's importance in global food production, status as a dominant user of water, economic importance as described in Chapter 2. Performance is increasingly important in a context of water-stress and closing river basins (Faures et al., 2007). There is substantial information and knowledge on the factors that impact irrigation performance, such as irrigation system design, field-application methods, institutions, land-tenure, value-chains etc., but studies covering the full range, and interaction, of these factors are scarce (van Averbeke, 2012; Mutiro & Lautze, 2015). Before moving to a discussion of the factors impacting performance, reasons for performance assessments are first discussed.

Small and Svendsen (1992) provide a useful overview of the reasons for undertaking performance assessments as follows:

1. Operational enquiry: relates to daily and seasonal monitoring and evaluation of scheme operations.

2. Accountability enquiry: involves the performance assessment of those responsible for managing a scheme.
3. Intervention enquiry: is the study the performance of the scheme in preparation for a specific intervention.
4. Sustainability enquiry: identifies longer term resource use and impacts of irrigation schemes.
5. Diagnostic enquiry: is a study of performance to identify the cause, or causes, of (under) performance in order that improvements can be made or performance levels sustained.

This research aims to identify what factors influence the performance of smallholder irrigation schemes in Limpopo province and the motivations are mainly in line with categories three and four (sustainability and diagnostic enquiry). In defining how performance can be measured with these reasons in mind, it is necessary to consider the practical realities of what can be achieved given the scope, time and finances available for the undertaking.

Measures of performance vary widely and follow from the reason for undertaking the performance investigation. The World Bank and other international finance organisations have been interested mainly in financial and economic internal rate of returns (EIRR) on investment (Jones, 1995; World Bank, 2006). Operational performance is focused mostly on water-delivery performance of the hydraulic and management system and operational finances. Indicators are quantitatively defined, service-oriented parameters such as adequacy, reliability, equity and irrigation service payment ratios, among other (Bos et al., 2005). These kinds of indicators require detailed hydraulic measurements and financial assessments and are geared more to scheme operational diagnosis and optimization rather than comparative assessment across many schemes. More relevant to the comparative nature of the thesis, Molden et al. (1998) established nine indicators for irrigation scheme performance. These included agricultural production, water productivity (in terms of the tonnage of crop produced per cubic metre of water, and the financial value of crop, per cubic metre of water) and financial returns. Obtaining the detailed information across many schemes requires extensive, in-depth enquiry at field and farm-level, including yield, water and financial measurements, with associated time and financial resource demands.

Mutiro and Lautze (2015) studied performance in a meta-study of 107 published papers in the Southern African Development Community (SADC). They emphasised the idea of ‘success’, and on the related influence of factors, but were limited to measuring performance by data that was available in the publications they reviewed. They took a compromising approach, assessing what data they could extract in terms of the EIRR, crop gross margins, crop yield, net farm income and cropping intensity. The latter indicator, cropping intensity, is a particularly useful measure because it is tangible, visible and readily-measured. Cropping intensity is the total area cropped in one year divided by the area of land that can be irrigated (Renu, 2016) and was used as a key indicator by Svendsen et al. (2009) in an Africa-wide performance assessment of schemes. van Averbeke (2013), assessing the performance of schemes in Vhembe District in Limpopo, noted that in South Africa, detailed data on many of the criteria listed above are rarely available. He identified that most investigations use operational status, condition of the irrigation system, observations of cropping intensity, and farm income (in selected cases) for assessments. The performance indicators that were selected for the purposes of the comparison in the thesis were based on prior survey and experience (Denison & Manona, 2007), in-depth research experience on Limpopo schemes (Denison et al., 2016), informed by the literature discussed above. A pragmatic view on the level of detail that could be obtained across the schemes with the time available led to the selection of the following indicators of performance: operational status; scheme longevity; summer cropping intensity; winter cropping intensity and level of commercialisation. The detailed description of how these were defined and measured is provided in Chapter 4.

The next part of the discussion explores the factors of importance that are identified as having an impact on scheme performance. The description is framed by works with a South African focus on factors in smallholder irrigation, namely: van Averbeke et al. (1998); Bembridge (2000); Backeberg (2002); van Averbeke (2012); van Averbeke and Denison (2013) and Mutiro and Lautze (2015). International references are used extensively to complement these more local studies that provide a useful boundary to the review.

A holistic perspective of factors that need to be considered for successful irrigation development is provided by Backeberg (2002) in an internal Water Research Commission (WRC) report and this has been adopted as a practical framework. The framework was used in subsequent published work (Denison & Manona, 2007; van Averbeke & Denison, 2013).

Backeberg (2002) identified eight groups of factors that influence irrigation schemes across the domains of farm, scheme and the external world. Slightly modified, these are:

- natural resources;
- technology and infrastructure;
- location in relation to markets;
- policy, institutional arrangements and social resources;
- human resources (knowledge and skills of smallholders);
- financial services;

- farming system feasibility;
- agricultural support services.

This framework includes all the important themes that describe the irrigation scheme complex system and are expanded next.

3.3.2 Natural resources

Physical factors are routinely considered in irrigated agriculture and mainly relate to climate, soil, and water. Climate is the long-term characteristic regime of weather and includes solar radiation, temperature, rainfall and air movement. Solar radiation and temperature are key considerations in crop selection while rainfall directly influences the amount of irrigation water needed for cropping. Air movement can cause physical damage to crops and also affects the rate of evapotranspiration (van Averbeke et al., 1998).

Rainfall is a primary parameter in irrigation design as the irrigation system is intended to supply the deficit needed for crop growth. Where sufficient irrigation water is available, rainfall will not have much influence on crop production outcomes, other than in relation to related effects such as storm erosion and drainage. However, irrigation water is not always available when it is needed, and aspects of water quality, quantity, and reliability of supply are of high importance in appreciating the effect of water supplies on scheme functioning (van Averbeke et al., 1998). A positive correlation between rainfall and scheme performance has been identified in a study of 314 irrigation schemes (Inocencio et al., 2007) and less directly in terms of agro-ecological zones (thus including rainfall as a key parameter) by Mutiro and Lautze (2015). The finding is intuitive in that the higher the rainfall, the less important is the functionality (in terms of adequacy and timeliness of supply) of the irrigation system in ensuring cropping success. Scheme survival depends on farmers' active contribution in kind or cash to ongoing functioning and that, in turn, depends on cropping success. In higher rainfall areas it stands to reason that a functionally weak irrigation system providing only supplementary irrigation, in broad terms, could still support successful cropping enough for farmers to continue efforts to keep the scheme going, while such a scheme in an arid area would not.

Soils include considerations of slope, general morphology in relation to flooding and drainage, and the structure, chemical and organic composition of the soils. Soil is a complex mass of mineral and organic particles arranged in a structure comprising air, water and soluble material, all which impact the growth of plants, and the physical properties of soils are central parameters in the technical design of irrigation schemes (Withers & Vipond, 1974). The physical structure, depth, chemical and organic characteristics also impact on crop selection and crop-production planning, where consideration must be given, in scheme and farm-planning processes, to effective rooting depth, infiltration, alkalinity, phosphorous deficiency and soil compaction (van Averbeke, et al., 1998). Soil quality is highly variable and complex to define. Many definitions of the term ‘soil quality’ have been proposed (Seybold et al., 1997; Schoenholtz et al., 2000). In the past, soil quality was defined in terms of the suitability or limitations of the soil for a particular use (Seybold et al., 1998). With the recent emphasis on the role of soil for production and environmental quality, soil quality is more broadly defined as the capacity of the soil for water retention, carbon sequestration, plant productivity, waste remediation, and other functions (Schoenholtz et al., 2000). A widely accepted definition was proposed by Karlen et al. (1997). They defined soil quality as the “capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation” Karlen et al. (1997:6). They further make the point that the level of detail of soils description must be suitable to the task and define five levels, from detailed descriptions needed for crop- and location-specific soil-treatments, to broad-brush descriptions appropriate for national-level policy. Bembridge (2000) provides similar direction and argues that a simple classification is acceptable for feasibility level detail and, by extension, for this research that is focused on the wider system in a development context, rather than on detailed technical design of irrigation schemes. He simplifies climatic as well as soils factors simply into three categories of good, fair and poor (Bembridge, 2000).

Water resource availability for crop production under irrigation is a combination of rainfall and the irrigation supply. Bos et al. (2005) note that water-related factors are the main business of irrigation and have primary importance in relation to the performance of irrigation schemes. Irrigation water can be obtained from surface sources such as rivers and dams, or from groundwater sources. The source is critical from two perspectives, that of water supply adequacy and of reliability. Other factors, such as infrastructure type, condition and operational management thereof also have a major bearing on adequacy and reliability at the farmer’s field edge but are discussed separately later. Water resource availability is concerned with the source of water. Other factors address the distribution system and operational practices. Adequacy is mainly concerned with the degree to which water supply availability at source meets the crop irrigation requirements, while reliability is concerned with the timely supply of water over the growing season (Bos et al., 2005). There are numerous other water-related performance indicators that are used for high-resolution diagnosis and planning, such as depletion fractions, field application ratio, drainage ratio, outflow-inflow ratios etc. (Bos et al., 2005). These require in-depth measurements and analysis and it is not necessary for the thesis study objectives, nor would it be practicable to attempt obtain these, as the thesis aims to cover a much-wider range of factors than water-services provision. Adequacy and reliability have therefore been identified as key parameters to consider in terms of the water source.

Water quality: In relation to water quality, salinity is most important as it affects the soil's long-term ability to support crops (Bembridge, 2000). Chemical pollution and temperature are further factors of interest for detailed operational performance, or design-level applications (Bos et al, 2005). Turbidity, or the amount of suspended solids, is well-established in engineering practice to be important for the wear and lifetime of pump impellors, and in causing siltation in canals. Sedimentation is a seasonal reality and was viewed to fall more practically under operations and maintenance (desilting), identified under organisational aspects. Water quality with a focus on salinity was thus identified as the key factor to consider.

3.3.3 Technology and infrastructure

Backeberg (2002) sets out a number of areas for attention in relation to technology and infrastructure: the infrastructure related to the storage and bulk water supply system; the infrastructure of the irrigation distribution system; and the transport infrastructure (i.e. roads) to and on the scheme. The type of water distribution system and irrigation technology that is in place has an important bearing on management institutions, organisational arrangements and operational costs (Ostrom, 1992; Chambers, 1988; Bolding, 2004; Prieto, 2006). The inter-relationship between infrastructure (technology type) and water- and land-institutions has been given greater emphasis in the description of factors than others. These are thematic areas of high importance that were identified in the international literature and have similarly been identified to be of high-importance in detailed studies on irrigation schemes in Limpopo (Perret, 2002; Shah, 2002; Machete et al, 2004; Denison & Manona, 2007; Manona et al., 2010; van Averbeke et al., 2011; Denison et al., 2016). The technical-institutional theme emerges later in the thesis as key to understanding why schemes fail.

The bulk water infrastructure mainly involves supply canals and/or primary pump stations that transport water from the source to the irrigation scheme boundary. Within the boundary of the scheme, it is well-established that distributory-infrastructure can take the form of pipelines or canals and the latter can be lined or unlined. The functionality of the water transport system is dependent on appropriate design, and on the hydraulic infrastructure condition. In this study, the suitability of design in terms of ability to transfer required capacities was not subject to review, and it is assumed that competent hydraulic and irrigation engineers were involved in the original scheme implementation. The emphasis in relation to bulk-infrastructure was on the factor of condition. While hydraulic designs were assumed to have been undertaken by competent engineers, the issue of technology choices is completely different as this impacts institutions and farming styles as highlighted earlier. This aspect is discussed in detail next as the technology-institutional interaction is a central theme of the thesis.

Energy type (pumping or gravity) and on-farm irrigation technology combine to provide an indication of technical complexity and are two key factors. Pumping occurs from both groundwater and surface water sources depending on the local geography (water vs. land levels) and choice of irrigation technology. Upgrading of a gravity-canal scheme to sprinkler or drip systems, for example, always requires pumping to provide the additional pressure needed for the different technology choice. Newtonian physics determine that the energy required for pumping (and related financial costs) increases proportionately with pressure requirements and volume of water supplied. Pressure requirements are a function of static lift (height) and the dynamic hydraulic pressure requirements of the system. While the MOM of flood-irrigation schemes, including distribution and canal maintenance, should not be technically over-simplified or financially underestimated, it is a general rule that irrigation operational costs and technical complexity on pumped schemes are higher for a scheme of a given size (Bembridge, 2000; Mutiro and Lautze, 2015). The implications of technical characteristics regarding investment decisions is further complicated by the reality that pressurised systems for irrigation schemes tend to have lower initial development costs (Crosby et al., 2000). They also tend to have higher rates of economic return (ARCUS GIBB, 2004) because of the discount effect on the deferred energy cost (the time value of money).

Yet pumped schemes have also been observed to have higher failure rates. While *individually-owned* pumped irrigation is a prominent and fast-growing phenomenon in smallholder irrigation in Asia and Africa (Lankford, 2009; de Fraiture et al., 2014; Shah, 2014; Woodhouse et al., 2017), *collectively-managed* pumped schemes have the opposite track record (Merrey, 1997). In sub-Saharan Africa, a number of more recent studies have identified pumping on schemes as a high priority issue. Mutiro & Lautze (2015), in a meta-study of 107 schemes in the Southern Africa Development Community (SADC), highlighted the high costs, operational challenges and high failure rates of pumped irrigation schemes. Similar findings were documented in Northern Ghana in the Small-Scale Irrigation Development Project (SSIDP), where all 26 pumped small-scale group schemes (covering 2,170 ha) faced critical issues around high energy and operational costs, a lack of technical operational support, and weak water-management organizations (Nyamadi, 2018). The author also has direct experience in Mozambique of the failed pumped-schemes (author's notes, 2017) that were developed under the World Bank-funded PROIRRI program that unfolded in the Zambezi River corridor (World

Bank, 2011). The same failure-trend was observed in Malawi on small shared pumped-schemes (Kamwamba-Mtethiwa, 2018). In South African smallholder schemes this was observed, though not quantitatively assessed, by Bembridge (2000).

The introduction of pumping can also result in changes to the nature of the farming system. Denison and Manona (2007b) documented findings from a set of engineering feasibility studies in the Eastern Cape where the choice of sprinklers, centre-pivots or drip irrigation, to replace gravity canal schemes, had the effect of forcing a shift to higher-yield and higher-risk farming approaches. This was needed to generate additional income to cover the significantly increased energy costs associated with pumping. It also necessitated land consolidation into larger farming enterprises to allow for economies of scale in production (ARCUS GIBB, 2004).

A further technical consideration is the ‘hydraulic unit’. The hydraulic unit is the block of irrigation land that is supplied by (or encompassed by) a dominant hydraulic component such as a canal-outlet gate, or a control-valve on a piped system, or a pump-station (Prieto, 2006). A hydraulic unit can also be ‘created’ by the on-farm irrigation technology choice, such as when a large centre-pivot is imposed on many smallholdings previously supplied by surface irrigation, in which case the boundary of the hydraulic unit is altered in significant ways. In irrigation management terms, the boundary of a hydraulic unit forces a group of farmers to coordinate around the operation of that shared infrastructure. In this sense, a hydraulic unit, created by a technical design choice of the hydraulic component itself, and the boundary effect this has on hydraulic management or use of water, is a deterministic factor in the institutional arrangements that result (Bolding, 2004). This has major implications on how land can be farmed by multiple smallholders when systems of one hydraulic unit, such as large centre-pivots, or drip-systems supplied by a single pump-station, are super-imposed on multiple small (individually-held) plots (Prieto, 2006). In the example of a centre-pivot, farming of a uniform crop under the entire block is required and this directly affects the whole farming system, and the land and water institutional arrangements. Such implications are prominent in the irreversible Joint-Venture interventions under the RESIS-Recharge program described by van Koppen et al. (2018) and discussed in Chapter 7.

A summary of the above technical considerations concurs with Bembridge (2000) who notes that gravity-fed schemes have lower running costs than pumped schemes and highlights the importance of site-appropriate technology selection. Prieto (2006) asserts the importance of the socio-technical and institutional interplay and how technology choices in irrigation systems have determinism over human behaviour, organisational structure and irrigation institutions. In this way technology choices, such as pumping or gravity, on-farm irrigation technology, and hydraulic units, steer schemes and farmers down different farming and operational pathways. It can be concluded then that the following factors are important aspects of infrastructure to consider in any analysis of schemes: a) the *technical system type* in relation to the bulk water supply system; b) *gravity or pumped* supply; c) the *level of complexity* of the irrigation distribution technology; and d) the *characteristics and size of hydraulic units*.

Transport facilities include roads, railways, airports, seaports and related vehicles, trucks, trains and ships, as well as animal and human transport. Arnon (1987) notes that an efficient marketing system for commercial farming is not possible without a good transport system. Poor roads, inadequate access to suitable vehicles for long-haul distances and a lack of railway access, for example, can result in very high costs and also significant delivery losses, particularly for perishable products. It is also evident that transport costs increase with distance and this is discussed in more detail next.

3.3.4 Location in relation to markets

Rodrigue et al. (2017) expand on the history of transport geography and point out that modelling of the relationships between transport and agricultural markets was first undertaken almost 200 years ago. This was pioneered by Von Thunen early in the 19th Century, around 1826. Von Thunen was the first to develop a basic model that analysed land-use and market processes based on the agricultural landscape. Key to this was the relative cost of transporting agricultural products based on factors of production cost, market price and transport cost (Rodrigue et al., 2017). This relationship determined how land was used for different agricultural purposes in the surrounding areas. Transport routes essentially provided access to competing centres when viewed from the perspective of a single node of interest, and when viewed at a more macro-scale, gave rise to changed land-use and farming practices along the route at the same time.

Proximity to a sizeable urban centre is thought to be important in different ways in regard to purpose of farming in a South African smallholder context as well. Where the purpose of farming is mainly for own-provisioning, schemes are typified by small plots with ad-hoc surpluses (van Averbeke & Denison, 2013). Schemes of this character have fewer risk-taking farmers, and farmers tend to have a diversified livelihood mix, where farming plays a small role in their livelihoods mix. Farming services and supply stores that are located close-by, provides farmers with the opportunity to fund small (input) purchases with limited financial reserves. Being close to town also facilitates ad-hoc and relatively inconsistent marketing activities, often through 'bakkie' (*colloquial term* for pickup) traders and micro-traders who bring produce from the scheme to town daily using public transportation (micro-bus taxis). These farmers tend to purchase small quantities of inputs and their production is relatively small and diverse. Commercial farmer schemes, on the other hand, that are producing a non-perishable or commodity crop are not as dependent on proximity to urban centers because the size of their production makes bulk transportation logistically possible and more affordable per unit of produce (van Averbeke & Denison, 2013; Denison et al, 2016). The key determinant in improving transport linkages is efficiency of movement and the elements of importance in efficiency are capacity, cost, time and environmental impacts (Rodrigue et al., 2017). In evaluating market linkages in the thesis, these elements were combined to two more-easily measured determinants, that of distance and road condition.

3.3.5 Institutions: a definition

The most important institutions at scheme level are those impacting on land, water and markets (Ostrom, 1992; Merrey et al., 2007). In discussing institutions, the definitions of the institutional economist and Nobel Laurette, Douglass North (1990), are adopted. These are based on a sports analogy. Institutions are defined as the rules of the game and provide the basis for the expected behaviour, and for enforcement of deviant behaviour. Organisations, on the other hand, are the analogous teams, comprising organisations of formal or informal groups, including individuals, Government entities, farmer collectives and companies that play the farming ‘game’. North (1990) argues that three behavioural choices are available to organisations: one is to maximise favourable outcomes in compliance with the rules; the second is to allocate resources to changing the rules to increase benefits; and the third is to ignore the rules and to cheat. These alternatives are not mutually exclusive, and they comprise an important framework for understanding institutions and institutional change.

3.3.6 Land tenure systems and related institutions

Land tenure institutions are an important factor in irrigation farming. Tenure is understood as a land holding arrangement in which the land holder enjoys a set of rights. These are user rights, enforcement rights, exclusion rights and transfer rights (Adams et al., 1999; FAO, 2002). Land tenure has different dimension and can be viewed as a bundle of rights including breadth, duration and assurance (Moor & Nieuwoudt, 1995). Breadth refers to the quantity and quality of rights enjoyed by the land holder. Duration concerns itself with the length of period in which the land holder enjoys such rights. Assurance is about the presence of certainty that the prevailing land administration order will enforce the rights and has links to enforcement rights (Moor & Nieuwoudt, 1995).

Tenure arrangements impact on tenure security and agricultural productivity. Where tenure is not deemed to be secure for a sufficient timeline this acts as a disincentive for farming investment (Arokoyo & Chikwendu, 1993; de Soto, 2000; Cotula, et al., 2004; IFAD, 2008; Boudreaux & Sacks, 2009). When farmers are unsure about the breadth, duration and assurance of their rights, they are hesitant to invest in hard assets such as fencing, irrigation infrastructure, agricultural equipment and resources (mechanisation, storage, etc.) (Denison et al., 2016), as well as in soil-quality management. Soil quality management raises the nutrient status and soil organic matter content, increasing fertility. For example, it was estimated that the perceived risk of losing land alone reduced productivity in Mozambique by up to 12% (Deininger & Fang, 2016).

There are different forms of tenure in South Africa that have evolved under the influence of both traditional tenure systems and imported colonial arrangements. These evolutions have resulted in a complicated mix of individual, family and communal rights of access, use and control of land. In the rural areas of South Africa located in the former Bantustans, including self-governing territories[2] and independent states[3], arable lands are predominantly classified as *communal.* The propriety connotations of this term have attracted criticism from revisionist scholars of agrarian studies, particularly in the last two decades (Okoth-Ogedo, 2008; Cousins, 2008; Peters, 2009; Peters, 2013). The conceptual propriety of the term is problematic. Cousins summarises the issue and explains that the terms customary, communal, and traditional are widely and incorrectly used as if they were synonymous. He asserts that it is important that these terms be understood to mean different things. A custom is something that is commonly practiced and widely agreed as the norm, while a tradition is something derived from ancestral roots. Customary tenure can thus cut across multiple traditional groups in an area and can include both communal rights (such as grazing) and individual rights (such as to arable land) (after Cousins, 2008).

The problems of what is commonly called communal-tenure arrangements emanate from the reality that the administrative model is highly fragmented and varies greatly in how it is interpreted and applied across the country. In South Africa the communal land tenure system does not denote a single, unified regime of land administration in the same way that the individual tenure system does. The legislative and administrative history of South Africa is characterised by repeated State efforts to engineer and modify property relations, resulting in the communal land tenure system being an umbrella concept that covers diverse forms of

[2] Lebowa, Kangwane, Gazankulu, QwaQwa, KwaZulu and KwaNdebele

[3] Vhenda, Bophuthatswana, Transkei and Ciskei

tenure. The main forms of tenure that affect landholdings in the former homeland areas are customary, Trust, Permission to Occupy (PTO) and Quitrent tenure forms (van Averbeke, 2013) expanded below:

- Customary tenure is normally not based on statutory sources but on customary traditions and norms. When the South Africa courts have to rule on customary tenure matters, interpretation cannot be based on normal rules. The court has to draw from evidence of traditional values of land use to determine the rules connected to land tenure (Cousins et al., 2008; Lahiff, undated)
- Trust tenure was created by the 1936 Land and Trust Act, which provided that land be held in trust for blacks by the South African Bantu Trust, which later became the South African Development Trust (SADT) under Government control (van Averbeke, 2013).
- PTO tenure was established when the State went on to use the Black Administration Act 38 of 1927 to create other forms of land control on SADT land, including PTO, deed of grant, and lease hold. The PTO system is also regulated by Proclamation R.5 of 1963, called the Regulations for the Control of Irrigation Schemes in Bantu Areas (van Averbeke, 2013).
- Quitrent tenure is a conditional individual title that originated from the Glen Grey Act (No. 25 of 1894). This was an attempt to tie African people to the land in order to levy taxes more effectively. The title holder had to comply with a set of conditions established by the colonial administration including: title-holders could not mortgage their land; transfer of lots required approval of the Governor; and inheritance was determined by the Magistrate with the proviso that the widow of the male title-holder could use the land for her lifetime or until re-married (Williams-Wynn, 2015).

Edward Lahiff (undated) gives a brief historical account of how the State used a series of legislative instruments that have led to confusion. In many villages, customary and PTO tenure systems overlap, causing confusion over land rights among landholders. After three decades of continuous amendments to property relations and administrative modalities, the State promulgated the Bantu Areas Land Regulations, Proclamation No.R.188 of 1969, which subsequently became the dominant legislative mechanism of communal land administration, at least until 1994. The State found it necessary to pass this proclamation because, even though the 1913 and 1936 Land Acts created designated spaces for black farmers, they did not specify the tenure systems under which land in the affected areas had to be used (du Plessis & Pienaar, 2010). The R188 (1969) proclamation is widely credited for attempting to bring order and uniformity to the domain of communal land administration across the homelands. It provided that quitrent tenure would be issued on surveyed land, and Permission to Occupy (PTO) on un-surveyed land.

The historical fragmentation in communal land administration was then exacerbated by the State's passing of the Constitution of Self-Governing Territories Act 21 of 1971. This provided self-governing territories (i.e. homeland governments) with legislative powers to oversee and institute their own land administration orders. This Act, in combination with the Black Administration Act 38 of 1927, empowered self-governing territories to determine the nature of land rights and gave them the power to pass proclamations. The PTO system then became the dominant mechanism of land allocation and rights in the former homelands. The issuing process involved the local chief, district magistrate and the Department of Agriculture. *"It was a system of lesser rights to land, where land is rented for life and rent is paid to the government via homeland authorities (e.g. magistrates)"* (Lahiff, undated; 296). PTO, Trust and Quitrent systems often coincided, and overlapped with customary tenure land rights, whereby land was issued by exclusive direct involvement of local traditional leadership according to tribal customs observed by the community.

In an effort to project a non-racial face in matters of land administration, the State passed the Abolition of Racially Based Land Measures Act in 1991, which repealed the 1913 and 1936 Land Acts, but left Proclamations passed according to these Acts intact, including the R188 which sanctioned the PTO system (du Plessis & Pienaar, 2010). This created an administrative vacuum and costly confusion in matters of land administration and tenure security. The issuing of PTO certificates has continued to the present day, but land held under this system lacks legitimacy of tenure, and there is no assurance of enforceability of rights by rights holders. In other areas, PTO certificates are no longer used, and procedures for issuing land vary considerably from place to place (Cousins, 2007). The PTO tenure system originally offered use-rights, but emphatically prohibited the transfer of land rights. Following the State's abolition of racially-based land measures in 1991, the PTO system has lost the legal basis for enforcement and the assurance rights, despite the Proclamation R188 (which sanctioned PTOs) remaining intact. The status of PTOs in regard to exclusion rights is equally problematic, as there is no legal order to resort to where contestations arise.

In summary, land tenure on smallholder irrigation schemes comprises a confusing overlay of different interpretations of existing and repealed laws, in a context of legislative gaps. Tenure mechanisms under customary law, Trust tenure and PTO arrangements provide no formal basis for land-leasing or alienation (sale) should land-rights holders want to exit farming, or the scheme altogether. This limits the ability of scheme farmers to securely expanded their irrigated holdings, and the ability of new entrants to enter the schemes other than through insecure tenure forms. The reality of confusing, variously interpreted and insecure tenure undermines investment in irrigated farming.

3.3.7 Water institutions

Water institutions are self-evidently a major factor in irrigation scheme functions and performance. These cover two scales: first national-level water laws and their local application in water management arrangements as they impact smallholder irrigation in particular; and secondly water-management organisations at scheme level, notably Water User Associations (WUAs) provided for in the National Water Act (RSA, 1998).

National level water institutions: The need to balance the tension between the social and economic benefits of water is long-established and highlighted in the White Paper of 1997 (RSA, 1997) and the National Water Act (RSA, 1998). The DWS has mitigated the financial impact on Historically Disadvantaged Individuals (HDI) who are smallholder irrigators and continues subsidized support through the Resource Poor Farmers Subsidy (RSA, 2004). These policies aim to support HDIs who are prioritized in the National Water Allocation Reform Strategy (RSA, 2008).

At a national level, the National Water Resources Strategy (NWRS-2) (RSA, 2013**a**) identifies that, with the sustainability of fresh water resources having reached a critical point, South Africa is facing serious water challenges. Primary concerns include security of supply, environmental degradation, and resource pollution. Related to this, the associated management of water is also facing a crisis, a situation defined as having a negative impact on economic, political, societal or environmental goals. These crises are occurring in a context where agricultural water is the largest category of use, accounting for 60%[4] of the national available surface and groundwater resource (RSA, 2013**a**).

The NWRS-2 further notes that agriculture has enormous potential for making a socio-economic impact in rural communities, but expansion potential due to water constraints is less than 17% of the expansion target defined in the National Development Plan (NDP) (discussed in Chapter 2). The vision of agrarian reform underpinned by smallholder irrigation seems unrealistic, compounded by the well-documented reality that smallholder schemes in South Africa perform well below their potential (van Averbeke et al., 2011). Challenges include: water-insecurity; weak market linkages; a lack of agricultural financing; inadequate production knowledge; and severe institutional deficiencies in land and water organisational domains (NPC, 2011; Sender, 2015; Cousins, 2013, Hollingworth & Matsetela, 2012; Denison et al., 2016).

[4] Van der Stoep and Tylcoat (2014) assesses agricultural water use similarly but slightly higher at 62%.

The potential burden on struggling smallholder irrigation farmers is accentuated by the National Water Policy Review Position Paper (RSA, 2013**b**). This echoes the NWRS-2 imperative to obtain economic returns on water, given increasing water stress. It also clearly prioritizes social redress considerations in relation to future water-use authorizations. Following the principle of "the user pays", all users including smallholder farmers should be paying for water use, adding further financial stress to an already-struggling sector. This presents a development conundrum, where initiatives for redress and reform, which are linked mainly to agricultural water-use, have higher risk and de-facto lower economic returns, given the underperformance of smallholder irrigation nationally.

There is thus strong intent that water and water benefits which largely accrue to White South Africans be radically transformed. While policy is patently clear, smallholders in Limpopo, for example, face major challenges obtaining formalized allocations in a generally stressed water environment. In two Limpopo Local Municipalities with high numbers of smallholder irrigation schemes it was found that very few smallholders have water-use licenses, leading to water-supply uncertainty and farmers' perceptions that they were exposed to high and unacceptable risks (Denison et al., 2016). While the policy intentions are strident, it is apparent that the administrative mechanisms to provide secure water-use entitlements to smallholder schemes are lacking or absent. As a result, smallholder farmers farm with high levels of insecurity and uncertainty and exposure to unacceptable levels of risk.

Scheme level water institutions and organisations: The second domain of water institutions relates to irrigation system management, operations and maintenance and at the level of the scheme. Water User Organizations (WUOs) are found all around the world and provide services to irrigators and other water users, including domestic supplies, to fisher-people and to stock-farmers (Renault et al., 2013). Functional and efficient water institutions and organisations are critical to ensure water is provided in sufficient quantity, quality and at the right time etc., and that the irrigation water distribution system is maintained over time to ensure water provision into the long-term (Lankford et al., 2016). This requires competencies in technical administration (operations and water distribution), financial administration (fee collection, reporting and enforcement), and water infrastructure maintenance and replacement.

The National Water Act (1998) made provision for Water User Associations (WUAs) that is one of a wider group of WUOs (Hodgson, 2003; Pegram & Mazibuko, 2003) . These include variations of legal form and function including Irrigation Organizations (IOs), Irrigation Boards, and irrigation committees. Some WUOs operate on the basis of informal local arrangements, others use customary law, or more commonly are established using formal laws, acts and regulations (Hodgson, 2003). WUAs were institutionalised in South Africa to take responsibility for all MOM of irrigation schemes in South Africa. This includes large commercial schemes under Irrigation Boards, Government Water Schemes, and smallholder schemes. While WUAs in the large-scale commercial irrigation sector have been effective (Benade, 2011), the development of smallholder WUAs has not been so successful (RSA, 2013**b**). This combined with the failure to give effect to Water Allocation Reform (WAR) in a substantive manner over the last 15 years has led to a reform initiative outlined in the DWA Water Review Position Paper (RSA, 2013**b**). The positions paper calls for radical reform including the disestablishment of all WUAs and a move to centralize water management. While policy decisions on WUAs remain undecided since the 2013 positions paper, and WUA de-gazetting seems like an impracticable course of action given no reasonable alternatives, the reality of weak or absent WUAs on most smallholder schemes persists (Pegasys, 2013, Denison et al, 2015; Denison et al., 2016). The presence and functionality of local water management institutions on smallholder schemes are thus key factors to consider in the analysis.

International experiences in regard to irrigation institutions are extensive and important to consider. Legal forms of WUOs include those established under country-specific legislation for WUOs, associations, trusts, co-operatives and companies. It is noted, with some emphasis, that these latter legal forms are viewed to be inadequate for the unique task of collective irrigation water provisioning (Hodgson, 2003). Hodgson advocates strongly for WUO-specific legislation to fully enable and empower irrigators and their water-service organizations, as is the case in South Africa. This is due, among other to: the unusual nature of the supplier-user relationship (wholly inter-dependent on each other); the individual use of public assets that demands legal clarity; the reality that full cost recovery for MOM is often not viable; and the potentially conflicting legal linkages between land, scheme (hydraulic) boundaries demanding compulsory membership (Hodgson, 2003). Notwithstanding legal variations, sustainable and effective WUOs share the following main characteristics (after Hodgson, 2003):

- They provide a specific water management service in terms of irrigation/drainage, and in cases, water to other users such as villages and towns, fish-farmers, etc.;
- They operate within a defined land area with a boundary linked to the hydraulic command area of the system and that all users agree on (called the ‘Service Area’ or in South Africa it is called the ‘Area of Operation’ (RSA, 1998));
- They are ‘non-profit’ entities where any surplus of income over expenditure is retained within the WUO and not transferred to beneficiaries or shareholders; and

- They are self-governing with decisions being democratically made by the WUO participants who benefit from, and pay for, the services that the WUO provides. Compulsory membership of WUOs, Hodgson argues, is critical to ensure involvement and compliance, and South African legislation is deficient on this point, not explicitly requiring compulsory membership (RSA, 1998).

Meinzen-Dick (2007) provides a succinct overview of WUO history and the various institutional ‘panacea’ for poor performing large-scale irrigation schemes in Africa and Asia. Poor performance has been a high-profile irrigation issue since the 1970s and has remained so since (Lankford et al., 2016). Meinzen-Dick (2007) highlights the many cases of successful indigenous irrigation management organizations at a small scale that prompted new ways of viewing irrigation management, and catalysed irrigation management transfer (IMT) globally. She explains that these indigenous successes were documented mostly in Nepal, Philippines, Indonesia, Sri Lanka and India. Scheme size was generally relatively small, up to a few hundred hectares. There were also local solutions to water management on larger schemes, that covered up to 3,000 ha, though this was unusual. Farmers collaborated without any external involvement in scheme construction in difficult mountainous terrain, and in MOM. Sustainable, rules-based, water-service delivery over long timelines was achieved (Meinzen-Dick, 2007). In the Philippines, similarly endogenous but complex multi-layered WUOS evolved. These *Zanjeras* were named after the Spanish derivative of *zanjera* meaning ditch or canal. *Zanjeras* demonstrated indigenous competency at even higher levels of the basin system, extending to integrated catchment management functions. Multiple Zanjeras operating successfully at scheme level coordinated into federation structures for the management of shared and competing water sources (Tang, 1992). These marked achievements showed then, and now, what can be achieved when farmers are central to irrigation institutional arrangements. This phenomenon of endogenous water management inspired Participatory Irrigation Management (PIM) approaches that became part of the Irrigation Management Transfer (IMT) initiatives in the 1990s (Meinzen-Dick, 2007).

It is notable, on observation, that these endogenous successes have mostly occurred in cultures with centuries, if not millennia, of irrigated farming culture. The famers, therefore, have long-evolved technical experience with irrigation, locally-developed irrigation technologies, related rules, and social mechanisms in regard to water management. Such WUO achievements, while important, are not easily replicated elsewhere where social norms, knowledge, and historical livelihoods strategies are very different (Shah, 2018). This diversity of context explains to some extent the varied outcomes where simplistic replication was attempted (Suhardiman & Giordano, 2014). The successes that were observed in indigenous and community-managed systems described above, coupled with the fiscal crisis of the 90s, prompted a move to Irrigation Management Transfer (IMT) globally from the 1990s onwards (Merrey, 1997). More than 70 countries have undertaken IMT programs providing for the establishment of WUOs and the transfer to them of public irrigation schemes or parts thereof (Suhardiman & Giordano, 2014). The idea was that by devolving MOM responsibility at the lower levels of large schemes, typically tertiary and sometimes secondary levels, the successes of endogenous community-managed arrangements could be repeated. This was expected to lead to reduced MOM costs and better performance, but unfortunately outcomes were variable (Meinzen-Dick, 2007; Lankford et al., 2016). Failures were linked to multiple challenges, including: a lack of clear legal arrangements for asset use and control; fee retention for MOM; poor institutional design and implementation; and a governance capability gap of farmers who were shouldered with the heavy transaction costs of a new management role. The lack of appreciation of the power-disparity between the WUO's responsibilities (at tertiary or secondary level), and the state agency role at bulk-water supply level, was a further factor (Suhardiman & Giordano, 2014; Lankford et al., 2016).

While the management of public irrigation schemes, and large-scale schemes in particular, remains a vexing problem (Lankford et al., 2016), formally structured WUOs based on structured legal arrangements have been highly effective in developed countries. This is also the case on large, mainly commercial schemes in South Africa (Benade, 2011). These WUAs were 'transformed' from the original apartheid-era Irrigation Boards (IBs). They have a broader mandate than the IBs in terms of responsibilities to multiple users, not just irrigators, including domestic supply, and in supporting the emerging farmer sector (RSA, 2013**a**). The implementation of measures to strengthen WUOs (or WUAs in South Africa) with an emphasis on both their legal form and on their functional roles, remains an important way of regularizing chaotic and moribund schemes. As Hodgson (2003) emphasises, attention to enabling laws and regulations, especially for fee-retention, compulsory membership, and use-right or ownership of assets, remains key to IMT and WUO establishment success on all kinds and sizes of schemes.

3.3.8 Farmer organisations

Collective action for the management, operations and maintenance of water functions was addressed in the above discussion. This section is focussed on the agricultural aspects of farmer collaboration through farmers' organisations (FOs). Farmers' organisations play an important role in improving the outcomes from farming and are a prominent feature in developed and developing countries alike. Farmer organisations allow farmers to do things collectively, such as: purchase in bulk at discounted rates; coordinate with each other to get crop-production information; aggregate their produce for packing and transport; lobby Government or other agencies; and engage with markets (Swanson et al., 1998). In the smallholder sector, there is a significant and positive effect on small-scale farmers' income from being members of farmers' organizations. In Uganda, Mwaura (2014) found that membership of farmers organizations had the positive effect of increasing farmer's technology uptake, yields and their financial returns from farming. In Nigeria, Oyeyinka et al. (2009), showed that involvement in FOs had positive farm-related economic benefits and improved farmers' sense of well-being. Tolno et al. (2015), studying smallholder potato farmers in Guinea, reported on how they tend to organise themselves at a grassroots level with the intention of increasing their on-farm production and the benefits they derive from post-production activities. They form primary agricultural groups of various institutional forms including community-based, and commodity-based organizations and associations. Their results showed that farmer groups play an important role in improving farmer's livelihoods by increasing productivity and incomes, thereby reducing poverty in the process (Tolno et al., 2015).

Swanson et al. (1998) explain that there are two main forms of farmers' organisations: community-based, resource-oriented organisations, and commodity-based organisations. The first form is the classic village cooperative or association, where farmers collaborate to get access to inputs and information in order to increase the productivity of their farming systems. Their focus is mainly on resource access and use. Farming systems are wide ranging, include cropping, animal and irrigation systems as sole enterprises or in integrated farming arrangements. They are characterised by their focus on inputs, are highly centralised geographically, and include widely diverse crops and commodities in their membership group (Swanson et al., 1998).

The second type of FO are commodity-based with a market-orientation rather an input-supply and knowledge-exchange focus. These FOs are specialised, usually involving one commodity where value is added through aggregation, and/or processing, with bulk linkages to onward markets. They extend beyond the boundaries of schemes or communities, and their collective interest is that of the single commodity that they produce. Commodity-based FOs often employ professional managers and include processing plants and facilities, with a complete range of services for their members. These could include functions of research, input supply, extension, credit, collection of produce, processing, and marketing in an integrated package (Swanson et al., 1998).

The productivity and sustainability of farmer organisations depends on their resourcefulness and commitment, and on a clearly-defined organisational mandate (Legoupil, 1990). Membership of FOs is associated with increased access to knowledge, technology uptake, input supply, post-processing and value-adding elements of the farming system. The absence or presence (and vitality) of farmer organisations on schemes is thus an important factor to consider regarding scheme performance and functioning.

3.3.9 Social resources

Social resources are understood as material or symbolic goods that are considered important for safeguarding and improving an individual's interests and position in society (Lin, 1982). They can be accessed and used in social actions and extend beyond ownership of the assets: they include assets that can be borrowed, loaned, or, such as political support, mobilised in pursuit of livelihoods outcomes (Lin, 1982). Social resources thus include religious, educational, housing, political, health and administration resources, across infrastructure, institutional and cultural domains. Irrigation infrastructure is an obviously important social resource within irrigation communities. The issue of social resources in an irrigation context has received extensive attention from multiple disciplines (Chambers, 1988; Ostrom, 1992; Ostrom, 2009; Obertreis et al., 2016). Most prominently perhaps, was Wittfogel's anthropological manifesto on the 'hydraulic hypothesis' (Wittfogel, 1957). He posited that large-scale irrigation, with a requirement for centralised management and coordination, leads to the inevitable and extreme centralisation of political power. This led to what Wittfogel called hydraulic despotism, that enabled and empowered autocratic political regimes.

Wittfogel's perspective on the relationship between irrigation systems and governance has parallels with Diamond (1998). Diamond, however, views the social-irrigation relationship more from a synergistic perspective, where irrigation and civilisation development drove each other forward, rather than where large-scale irrigation schemes are a driver of autocratic institutions. Wittfogel's hypothesis is probably the best-known irrigation theory in non-irrigation sociological circles (Tang, 1992) and has been widely debated, admonished and contested (Obertries et al., 2016). The hypothesis spawned a stream of counter arguments that sought to explain the relationship between society, technology and nature (Obertreis et al., 2016). Among the many examples arguing against determinism of the 'hydraulic hypothesis', farmers have shown capability to self-organize for construction and MOM of irrigation systems, though at scales of several hundreds of hectares rather than many thousands of hectares (Tang, 1992; Meinzen-Dick, 2007). Access to the social resource in these systems is more equitable and inclusive.

Lin (2001) identifies two important social resource hypotheses. First, those with access to, and use of, better social resources can take more successful actions; and second, people with higher levels of position in society have greater access to other, more-influential people, thus acquiring greater access to social resources. These two are interlinked, the second being an accelerator of the first. Individual social capital (as per the livelihoods framework) is the key to the attainment of higher status, and thereby the means by which greater access and use of social resources can be achieved (Pena-López & Sanchez-Sántos, 2017). Perspectives on the meaning of social capital differ widely but four main aspects of social capital can be identified (Pretty and Ward; 2001). These aspects are: relations of trust; reciprocity and exchanges; common rules, norms and sanctions; and the connectedness, networks and groups. Some of these relate to the institutional domain (connectedness, rules, norms and sanctions) that are covered more directly under the factors of water and farmer organisations. The element of trust emerges as a key driver of increased co-operation, reducing transaction costs and increasing access to networks and social resources. Pretty and Ward (2001) make a separation between having trust in people that are known, and those who are not known, but are trusted (to whatever degree) because of the strength of the social structure. They also point out that trust takes time to establish but erodes quickly. Highly applicable to an irrigation setting (centred around access to social resources) they also note that collaborative arrangements are likely to be absent or difficult to achieve in social contexts where trust is weak or absent (Pretty and Ward, 2001). Accessing social resources in terms of irrigation, including land, water, use of infrastructure, knowledge and collaboration in farming and irrigation activities needs to be understood in the above context. Trust and strong institutions are key factors to be considered in understanding cohesion and collaborative action in relation to access, and use, of social resources.

3.3.10 Human resources

It is common knowledge that human resources, in a conventional business paradigm, relates to the hiring and training of employees and managing their benefits. That view is not particularly useful to the focus of the thesis where a broader view is justified. Human resources are treated as conceptually equivalent to human capital, based on the livelihood's framework (Ellis, 2000). Human resources (capital) then pertain to skills, knowledge, ability to work, educational level and health status of people more broadly (Scoones, 1998; Ellis, 2000). The concept includes elements that apply to both individuals and to the wider population (Ellis, 2000) and there are qualitative and quantitative dimensions (Lewis, 1984). When viewed from a household perspective, the quantitative dimension is reflected by the amount of labour that a household can mobilise, which is associated with its size and composition. When viewed from a farm perspective, and where household labour is insufficient, this necessarily includes employed labour. Health, skills and knowledge represent the qualitative dimension of human capital (Lewis, 1984), with the latter two (skills and knowledge) closely tied to education (Winters, 2011). Successful farming requires knowledge and competencies across multiple domains and calls for a wide-ranging set of capabilities. These include: financial planning; land preparation; mechanisation; crop selection; labour-management; irrigation; fertilisation; plant protection; harvesting; post-harvesting; and marketing among other. These skills can be obtained formally or informally (Winters, 2011). In considering human capital as a factor in irrigation scheme performance, this can be defined as the skills, knowledge and health status of the people that are involved in the scheme.

At a farm level, historically, and somewhat traditionally, farming (and irrigation management) skills were transferred from parents to children while working on the farm in an informal learning process. Innovation through experimentation and adaptation contributed to advances and improvements in the farming system. When shifting from rainfed to irrigation farming, or from one irrigated crop to another, the existing knowledge- and skills-base of farmers needs to expand and new learning is essential. In a family farming context this knowledge is returned and retained back into the family unit and available for future benefit (van Averbeke & Mohamed, 2006). This requires external support in all stages of the process which, if absent, leaves farmers without the necessary skills and knowledge to produce and market successfully (van Averbeke & Denison, 2013). While health is an important aspect of human resources (capital) at an individual and household level, it is difficult to define and capture in a higher-level study of schemes. Access to knowledge and labour availability then emerge as important factors in relation to human resources, and in understanding irrigation scheme performance as far as this research is concerned.

3.3.11 Financial Services

Financial needs are dependent upon the scale at which production occurs, although some economies of scale will occur (van Averbeke & Denison, 2013). It is evident that smallholders on the smaller side of the spectrum are often able to finance production from their own resources. Fay (2013) found that the provision of child grants and pensions played an important role in vibrant and increased home-garden production in Hobeni in the Eastern Cape. A similar situation was found in a detailed study of 30 home-food gardeners in the Eastern Cape (Denison et al., 2015). In a study of irrigators in Limpopo Province, both home-food gardeners and smallholder irrigators, farming on small plots (typically <1.5 ha), were able to draw on their own resources to finance production costs, albeit with difficulty. While own-financing is possible at the level of small-scale farming, access to financial services is critical for those farming at larger scales, and with a full business outlook. Farmers rarely have the financial reserves to pay all production expenses at the start of the season, making access to production loans important, along with the need for crop insurance to protect the loan amount in the event of disease, insect or weather-related calamity (van Averbeke & Denison, 2013). Here, the focus is on short-term credit to cover seasonal production costs. The issue of medium-term credit to allow farmers to pay back investments in scheme rehabilitation, as suggested by Bembridge (2000), is not contemplated here, as it is highly unlikely to ever be required by Government, or to be financially feasible from a smallholder farmer's perspective, given the financial marginality that prevails.

3.3.12 Farming system financial feasibility

The financial feasibility of the farming system is evaluated from the difference between the total cost of production and the total income received from crop sales. In assessing financial feasibility there are some highly sensitive factors, notably the yield obtained (relative to the target yield) and the market price. Both are estimated at the time of financial investment in the crop, but are subject to numerous influences over time, some controlled by the farmer (e.g. infield production) and some not (e.g. global price fluctuations, local market price response to produce inflows, weather). On schemes supporting farmers with a food production orientation (rather than a full business orientation) there are ways to replace capital with labour (often with family labour, which has little or no opportunity cost). In addition, input resources, such as compost and manure, can be produced on-farm instead of the purchase of fertiliser. Low external input practises are well suited for small-scale operations but become less feasible on larger enterprises due to the volumes (of manure, compost etc.) that are required when farming at scale. Measurement of farm-level financial feasibility is beyond the scope of this study, which has an emphasis of scheme level performance. Financial feasibility is indirectly reflected through other performance indicators, such as cropping intensity and commercialisation, albeit not without exception. Mohamed (2006), studying livelihoods and motivations for farming at Dzindi Scheme in Limpopo, identified a group of farmers called 'employers' who, in full awareness, continued farming with family labour at a net financial loss. They were themselves largely employed migrants in distant centres and were motivated to keep home-based family members active and employed, rather than be left idle and without purpose residing at the family home located near the scheme. While that might explain a small proportion of cropped area (translated into intensity as a performance indicator), it would the exception rather than the rule.

3.3.13 Agricultural support services

Agricultural support services include all knowledge domains associated with farming, along with practical access to all inputs, mechanisation, packaging and marketing facets of the enterprise. In South Africa, Stevens and Van Heerden (2016) have emphasised the critical shortage of extension competency for smallholder farmers, and the need for them get access to production knowledge, and for more effective integration into the value-chain. They document that the weak status of the extension service (to smallholders) is widely acknowledged in both farmer and Government circles. Extension officers working with smallholders were reportedly de-motivated and poorly capacitated and a call was made for an urgent response to address the issue (Stevens & Van Heerden, 2016). The effectiveness and efficiency of extension is a direct function of the competency level of the extension staff who need to have a set of professional skills. These include: interpersonal and communication skills; crop and irrigation production knowledge; farm planning and evaluation; and ethical competence (Stevens et al., 2012).

Access to, and knowledge about markets in particular, has been identified by irrigation farmers' themselves as a high priority and a constraint to increased profitability. In the void of extension services that prevail, farmers rely on knowledge from each other and from commercial seed, fertiliser and pesticide suppliers (Van Averbeke, 1998; Denison et al., 2016). The issue of agricultural support services overlaps with extension, though as noted, extension services can be, and are de-facto provided directly by the private sector in the absence of effective extension services in place. In this context of knowledge deficit, the potential for farmer's organisations to increase access to production and marketing knowledge is of increased important.

3.4 Irrigation schemes viewed as complex systems with multiple factors

A multi-factor view of irrigation systems is the main theoretical basis of the thesis. The many factors addressed above combine and interact in a dynamic manner to make up a complex system. The outcomes that result from these interactions, such as productivity and profitability, cannot be simply explained by any single factor. Irrigation schemes are best understood when viewed as true systems that comprise complex and hierarchical systems, with multiple technological, social and biological factors that impact on performance (Lankford & Gillingham, 2001; Lankford et al., 2016). Others assert more forcefully that systems in general can neither be understood nor managed without a complex-systems approach (Jasanoff et al., 1997; cited in Berkes et al., 2003). Systems are multi-level, with sub-systems nested within higher-level systems, and there is a longitudinal dimension of dynamic change-over-time

(Gatrell, 2005). Adoption of a complex systems view is essential in understanding irrigation performance because the alternative of pursuing a narrower disciplinary approach, focused on a single or limited set of factors, runs the risk of being undermined by other factors of importance (Berkes et al, 2003).

3.4.1 Systems and complexity theory in overview

Systems theory has its roots in a philosophy which was first applied to natural systems. Laszlo (1972) explains that Von Bertalanffy, who was a biologist, presented the first coherent theoretical framework in his seminal work 'General Systems Theory: Foundations, Development, Applications' (Von Bertalanffy, 1968). The concept of holistic systems, however, goes back even further. Pollard et al. (2011) note that Van Bertanlaffy credits Smuts (1926) with the familiar concept that 'the whole is more than the sum of its parts', although the original holistic perspective is more widely credited to Aristotle (around 350 BC) (Pollard et al., 2011).

Systems theory developed quickly in the 20th century, around the same time that Newtonian physics and the related deterministic laws were being radically re-defined by Einstein and his theory of relativity (Laszlo, 1972). Where Newtonian physics was deterministic and reductionist, based on principles of cause and effect, systems theory recognised an additional overarching character of the 'whole', such that it is impossible to *'compute the behavior of the whole from the behavior of its parts'* (Laszlo, 1972:8). Laszlo also predicted, quite correctly, that systems theory would find use across many disciplines. This perspective is validated by subsequent wide application in philosophy, political and socio-ecological sciences, management, knowledge and organisational theory, economics, education, aid and development (Pollard et al., 2011).

Complexity theory is, however, more than systems theory and the contemporary understanding of complexity emerged out of many contributions to both systems and chaos theories since the 1960s (Lichtman, 2011; Bloom, 2000). Key elements of chaos theory are summarized from Dooley et al. (1995):

- Seemingly random behaviour may be the result of feedback-coupled linear systems and observed randomness may not be randomness at all.
- Simple deterministic systems can have limited predictability, and systems can move from equilibrium to chaos through parameter changes as well as structural changes.
- Chaotic systems can be discovered by topological mapping (fractal topology), revealing patterns which are repeated at different scales (eg. cloud formations, structure of fern leaves, shape of coastlines).

- Non-linear systems can be subject to sensitive dependence on initial conditions (Lorenz's 'butterfly effect'), where a positive feedback loop in non-linear systems evolves very differently with minuscule changes in starting values. Here Dooley et al. (1995) note this raises the importance of understanding causality which is multi-level and multi-determinate. Also importantly for this thesis, sensitive dependency and robustness can be reflected by the same system, but depends on the point of evolution that the system has reached at that juncture in time.
- Systems that are pushed far from equilibrium (at the edge of chaos) can self-organise into new structures.
- Changes in the essential nature of the system, also called regime changes by Pollard et al. (2011), take place when a critical parameter passes a critical threshold.

Many of these chaos theory precepts are embedded firmly in complex systems theory. Bloom (2000) throws light on the theoretical distinctions between chaos theory and complex systems theory. She explains that the focus of chaos theory is on the manner in which "*systems give rise to very complicated behavior*, while *complexity theory focuses on how systems consisting of many elements can lead to well-organized and predictable behavior"* (Bloom, 2000:2). Dooley et al. (1995) add perspective, noting that the concepts of chaos and self-organisation evolved from the physical sciences, while the notion of complex adaptive systems had their roots in the biological sciences. Systems theory explains the interdependencies of system elements and how feedback loops drive the self-adjusting dynamic nature of the system. The development of complex systems theory has thus evolved from both chaos theory and systems theory over the last 40 years.

3.4.2 Properties of complex systems in the irrigation scheme context

There are numerous contemporary descriptions of the key properties of complex systems in the literature and with varied emphasis, but these are largely congruent. A number of works were used to develop a summary description of the characteristics of complexity theory (Lichtman, 2011; Pollard & du Toit, 2008; Pollard et al., 2011; Rihani & Geyer, 2001; Dooley et al., 1995; Walonick, 1993; Gatrell, 2005). These are contextualised within or applied to the irrigation scheme context where possible.

Emergence: First is the property of *emergence* or, in systems thinking, the observation that the system itself has a completely distinct character from its component parts. Pollard et al. (2011) drawing on Heylighen et al. (2007), present a simple example of emergence. This is illustrated by a description of table salt comprising sodium (a soft metal) and chlorine (a poisonous gas). When combined in a molecular structure they form table salt (NaCl), a compound which is neither metallic nor poisonous. When applied to an irrigation scheme, emergence refers to the composite 'life' of the scheme to form what Lankford and Gillingham (2001) term a socio-technical-biological entity. This involves the people that the scheme supports in symbiosis with all the social, technical, biological, human and economic elements of the scheme, interacting dynamically over time. The emergent property of irrigation schemes is most easily visualised in satellite photography, particularly in arid areas. The scheme then stands out as a vibrant entity, bright green in contrast to brown surrounds; a single but composite entity connected to larger systems beyond. Within the scheme, nested and interdependent sub-systems can also be clearly seen in the mosaic of farm-systems, fields, roads, canals, centre-pivots and villages. Schemes, viewed like this, quite clearly have a life of their own.

Open systems and boundaries: A second property is that of 'open systems', which applies to all living systems. Energy and matter flow freely within the system, as well as between the system and its environment. In other words, open systems maintain themselves through constant interaction and exchange with their environment. Input to the system comes from the environment and output returns to it, with the boundary of the system (or sub-system) defining the border between the system and the environment, and the system's processes turning the inputs into outputs (Walonick, 1993). Boundaries can be set at different scales of interest for the purpose of understanding a system with the sub-systems and adjacent systems then being defined accordingly. Experimentalists such as those documented by Gleick (1987), who were grounded in the topology of chaos and searched for deep and complex patterns in seemingly random systems, included a major emphasis on scale (Dooley et al., 1995).

In complex systems the same patterns are reflected at different scales, so observing a pattern at one scale informs what might happen at other scales not so easily observed. One application in the irrigation context, for example, is to set boundaries at the scale of the household, the field, the scheme and more distant input-output markets. Household livelihoods depend on a web of interactions extending from the household to the farm, and from the farm to the scheme, onto more distant domains of input and output markets. It is of interest here that in developing a typology of smallholder irrigation schemes (Denison & Manona, 2007a), the authors inferred from a set of detailed case studies that the topology at farm level (food-grower, smallholder, business and equity-labourer) was similarly applicable to describing the scheme type, suggesting that the delimitation at scheme scale (system) and farm scale (sub-system) will have similar system dynamics (patterns). The form and character at farm level are then repeated and describe the form and character at scheme level and viceversa. This returns to the theme of the earlier discussion on the link between deterministic technology at scheme level rippling down and having the effect of determining farm-level typologies.

Adaptation and feedback loops: Development and change in all complex systems is viewed as an evolutionary process, where the emergent structures are not only outcomes, but also in turn, influence future events through feedback loops (Lichtman, 2011; Pollard et al., 2011; Rihani & Geyer, 2001). On irrigation schemes, for example, farm-level production (as a sub-system) influences ability to pay for irrigation service charges, which influences operation and maintenance, and thus water supply reliability and quality, in an obvious feedback loop impacting on farm-level production. Irrigation-water supply is thus both a key driver within the system, and an outcome of the emergent-system level of functioning. The payment or irrigation-service fees is a feedback process, dependent on adequate service provision of water (plus profitability and willingness to pay). Adaptation follows from this cyclical process between the farm subsystem and the scheme-level system over time in response to changing input dynamics, leading to different output consequences. This explains the fundamentally evolutionary nature of complex adaptive systems, where cycles of evolution lead to self-organisation of the system (Dooley et al., 1995), always in flux, and in the case of most smallholder schemes, often in cyclic decline. It also explains simply but correctly, why farm productivity is critical to scheme vibrancy, an obvious relationship, but one often ignored when there is a dominant focus on, and faith in, water-technology solutions that do not address other critical feedback loops needed to keep the system vibrant (Obertreiss et al., 2016).

Drivers, thresholds and regime change: Complexity theory views change as being initiated by various drivers or control parameters; these can be both factors and relationships between factors, which are often non-linear and operate at different scales (Gatrell, 2005; Dooley et al., 1995). Drivers vary in strength over space and time, producing different outcomes in the systems; those that are structurally stable are resilient in their emergent nature when responding to changes in inputs (Lichtman, 2011). Rihani and Geyer (2001) explain that while stable systems maintain this observable global pattern (i.e. stability), they are in a state of *'organized complexity'* and are still cycling through many similar, though not identical states that return close to the *'global pattern'*. In complexity theory, this is called the effect of the strange-attractor (Gleick, 1987). This view of a pulsing, self-correcting entity, hovering around an average but fundamentally unstable state, helps to understand the fragility of some schemes, or the resilience of others, and provides insight into identifying those factors that have inherent potential instability on their own, triggering a cascading cycle of system collapse.

In unstable systems, or systems near to 'the edge of chaos', a minor change in inputs can result in dramatic change in the nature of the system itself, which is called a regime change or phase change, leading to a completely different system state (associated with ongoing oscillations of closely similarly system states around a new attractor, maintaining a new global pattern for the system). Where specific factors or relationships can be identified to trigger regime change, this is known as the critical threshold of the factor (Dooley et al., 1995). The result of regime change is that step-wise (as opposed to linear) evolution of the system takes place in ways that are natural, and derive from orderly principles, which can be explained by the dynamic system and the interactions of its component parts.

Declining infrastructure, particularly water supply infrastructure such as pump failure, would be a classic transition through a threshold, causing regime change. Application of the concept of sub-threshold factors linked to scheme dysfunctionality is central to this thesis. Where factors within a system can be identified as sub-threshold, identifying these sub-threshold factors would logically lead to regime change (i.e. from a dysfunctional irrigation system to a functional one). If there were only one sub-threshold factor, this would be a 'silver-bullet' solution to getting the scheme system to function adequately. However, from the emphasis in the literature on multiple factors, it is highly unlikely that only one factor would be in this condition, and multiple factors would likely require attention. The importance of the concept of thresholds is that *not* all factors have to be addressed to ensure the system can function adequately, but only those that are essentially limiting, or below critical thresholds. Similarly, success in addressing most sub-threshold factors will not result in scheme success if even one sub-threshold factor is inadequately responded to. Regime changes (such as pump-failure) can be reversed, but the scheme system can also decline quickly due to subsequent processes triggered by the initial regime change (cables being stolen, schemes being stripped of irrigation equipment in a non-operational status for example), all requiring consideration in how responses to low performance, or collapse, need to be formulated.

Maximum performance at the edge of chaos: The point of equilibrium for systems is one where systems are *'at their most adaptive and creative"* (Kauffman, 1993 in Dooley et al., 1995:13), and this is when systems are functioning at the edge of chaos. The edge of chaos is the point where the maximum combined benefit is derived from systematic efficiency in routine, linear tasks, and dynamic innovation through reflexivity. Applying complexity theory to the broad challenges of development, Rihani and Geyer (2001) argue that too few interactions between the agents (comprising individuals or groups) results in a state of stultifying order, while too many could lead to chaos. There is therefore either chaos, brought about by constantly shifting, unclear and often conflicting rules, or stifling order, created by arbitrary and rigid rules that prevent healthy interactions. Optimum system performance must therefore strive to find a balance between rigid efficiency and dynamic reflexivity, in a constant oscillation at the 'edge of chaos'.

3.4.3 Farming systems within an irrigation context

Farming systems theory is briefly discussed to provide context in relation to global systems theory. Farming systems theory also originated early in the 20th century but unlike global systems theory, it was reductionist and deterministic. It was mainly applied to feed requirements for meat and milk production to optimize product yields (Baldwin & Hanigan, 1990). The farming systems approach expanded quickly and became directed at the wider biological and physiological systems underpinning the agricultural enterprise. This included application of a systems approach to field crop production, plant-animal interactions, and the design of the optimum enterprise mix at the farm level (Jones & Street, 1990). The household, its resources, and the resource flows and interactions at an individual farm level are together referred to as a *farm system* (Dixon et al., 2001). South African work on the application of farming systems was pioneered by Bembridge (1982), who in the late stage of his career applied his experience to the smallholder irrigation challenge (Bembridge, 2000). He highlights that problem-solving in agriculture, particularly irrigated agriculture, requires a holistic approach that integrates the full range of factors that apply to circumstances. In this sense, in the application to irrigation schemes, the global systems theory is most appropriate.

3.5 Methodological perspective

The thesis study was based on a quantitative approach that followed and built on prior qualitative studies of smallholder irrigation in Limpopo Province. A set of guidelines for the revitalisation of smallholder irrigation schemes (Denison & Manona, 2007) was developed previously using a multi-stakeholder interview and selected case-study approach. This earlier study included an evaluation of South African and international approaches to irrigation development with a focus on success and failure factors that were drawn from the literature and from stakeholder interviews. A subsequent in-depth case study of two Limpopo irrigation schemes, Dzindi in Vhembe District and Julesburg in Greater Tzaneen District, focussed on entrepreneurship, farmer-livelihoods and farmer-development pathways (Denison et al., 2016).

The case study approach used in these prior works is understood as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used" (Oosthuizen et al., 2005: 71). Constraints and opportunities were documented based on multiple participant interviews using a systems perspective. These and other qualitative and mixed-method works provided rich insights but did not cover the diversity of irrigation schemes in Limpopo and did not provide a statistically robust data set for analysing success and failure of smallholder irrigation schemes across the province. A quantitative approach covering a substantial number of smallholder schemes across the province was therefore considered to be most suitable to complement prior existing published work. The findings would then enable the formulation of robust policy and strategy interventions.

3.6 Summary of key points

3.6.1 Scheme typologies

Scheme classification typologies are important to provide reference points for analysis and for the development of strategies that can address the poor performance of smallholder irrigation schemes in South Africa. Two international and four South African irrigation scheme typologies were reviewed. These were found to include descriptors of scale, type of infrastructure, water source, wider economic purpose, era-of-development, management type, farming purpose, and scale of farming. The two international typologies were of interest in the descriptive characteristics they used, but do not adequately capture the diversity and type of smallholder schemes in South Africa. Two of the South African typologies had generalised groupings and were developed with a descriptive and historical overview and were not useful for analysis and operational planning. The more detailed typology of Bembridge (2000) was of interest in its emphasis on management type, scheme size, purpose, and scale of farming, but was outdated due to the major institutional changes in Government around the time of his publication. The agricultural parastatals that were previously responsible for scheme MOM withdrew from scheme MOM in the late 1990s along with a policy changes that terminated full operational subsidisation (Shah et al. 2002). The sixth typology, developed by the author and modified later (van Averbeke et al., 2011), appears to still have relevance to the South African context, but was based on observation without quantitative substantiation and requires either verification or replacement. The development of a contemporary typology would help guide more responsive strategies for smallholder irrigation revitalisation in South Africa and is one of the aims of the thesis. The results of the statistical cluster analysis, used to inform an updated typology are discussed in Chapter 6, and the analysis and implications are presented in Chapter 7.

3.6.2 Farmer typologies

The characteristics of the irrigation scheme, such as technical type, operational cost, complexity, plot size, distance to market etc., all have a bearing on the kind of farming that can be supported on the scheme. This in turn determines the type of farmer(s) who can be sustained. Scheme typologies are therefore linked to farmer typologies. The review of farmer typology was contextualised by the livelihoods framework with an emphasis on the dynamic nature of livelihoods. The importance of socio-technical factors was highlighted; notably irrigation cost and the push towards market-farming that results; technical determinism from choices regarding the size of hydraulic units and on-farm irrigation systems – these force collective action and limit individual choice on farming type and purpose; and, the land and water-institutions that exist, or result from technical changes. Decisions on technology choice, are shown to impact on the options for farmers in how they collaborate, or not, and how they choose to farm. In the thesis, the nuanced farming typology of Manderson (2015), based on the work of Cousins (2014) is adopted for the discussion of farming typology and scheme typology interactions.

3.6.3 Summary of factors affecting irrigation scheme performance

The research aims to identify what factors influence the performance of smallholder irrigation schemes in Limpopo province. The thesis is interested in what Small and Svendsen (1992) called sustainability and diagnostic enquiry. Overarching concepts that are expected to explain performance are profitability and scheme manageability. Indicators of performance vary greatly in their level of detail, their specificity, and their thematic range, including water-services, water-productivity, financial and economic performance, agricultural output, and governance and institutional performance. Selection of the type of assessment is based on the reason for enquiry and on pragmatism regarding what data can be obtained. Scheme performance indicators in thesis were established to be operational status, scheme longevity, summer cropping intensity, winter cropping intensity and level of commercialisation. The latter combines several considerations and reflects complexity and sophistication of the farming enterprise, as explained in Chapter 4.

The review of factors that affect irrigation farming and irrigation scheme performance was based on Backeberg's framework for irrigation scheme assessment (Backeberg, 2002) and is summarised below:

- Natural resource factors that have a bearing on scheme performance were identified to include: rainfall, soils (in a simplified categorisation of good, fair and poor); water resource adequacy and reliability, and water quality in terms of salinity.

- Technology and infrastructure factors were shown to have high importance regarding socio-technical dynamics. Technology impacts manageability and land- and water-institutions, and influences the farming types that can be accommodated. Technology choices have a deterministic effect, in cases forcing market-orientation, and/or shifts from individual farming to group farming when large and indivisible hydraulic boundaries are created. Technology factors of importance included: type and condition of bulk water infrastructure, and infield irrigation technology; energy type, either gravity or pumped; size of the hydraulic unit; transport availability, reflected in roads condition and type.
- Location relative to markets is based on the proximity to the urban centres where markets are located. Markets directly impact on both productivity (input markets) and profitability (output markets).
- The inter-relationship between infrastructure (technology type) and water- and land-institutions has been given substantial emphasis as these have high importance in the international and South African literature regarding farming and irrigation performance. The type of land-tenure institutions, and the ability to consolidate or expand the farm size, through land-exchange, are important land-related factors. Water institutions at national level were identified to be important from the perspective of water-tenure security (water-use licenses), and at scheme level in terms of the type of institutions (WUAs or other) that are responsible for water-related MOM. Irrigation costs, and related service-fees for irrigation, linked to technology type and energy source, were another factor that has bearing on performance.
- Farmer organisations play an important role in improving access to knowledge and inputs, and outcomes from farming, particularly in the context of a weak extension service. Factors of interest include: institutional type; ability to access to production inputs; and farm production and marketing knowledge. Organisational structure and design affects manageability.
- Social resources were understood to overlap with the institutional domain, in that scheme-level institutions impact on access to individuals with power, and on their ability to have direct or indirect access to the shared irrigation resources. Trust and conflict were identified to be important as these act to undermine collaborative action and affect manageability.
- Human resources were understood in terms of human capital from a livelihood's framework perspective. This included mainly factors of knowledge, overlapping with farmers' organisations in terms of how knowledge is accessed, and labour availability.
- Financial services and farming system financial feasibility are determinants of high importance in relation to profitability. The specific farm-level and detailed enquiry required for elaboration of availability of financial resources for farming requires a focus at farm

level rather than scheme level. This means that collection of data of this type requires in-depth study, not suitable to the broad assessment of many schemes that was intended. Prior detailed work of the author and collaborators, involving in-depth livelihood studies on smallholder schemes in Limpopo (Denison et al., 2016), provides coverage of this factor for contextual discussions.

- Factors in relation to agricultural support services were identified to include access to inputs (seed, fertiliser, mechanisation etc.), crop and irrigation production knowledge, and knowledge in relation to access to markets and marketing knowledge. Agricultural support impacts on productivity and profitability.

3.6.4 Irrigation schemes as complex systems

Factors that impact on farming are viewed in this thesis to comprise complex socio-ecological systems, inspired by, and following the socio-biophysical-technical theme that Lankford and Gillingham (2001) proposed. This dynamic, multi-faceted approach seems well-aligned to the usually chaotic reality that the author has observed through research and practice on smallholder irrigation schemes. The factors described above are discrete, but the relationship between the factors can be understood within the complex systems paradigm. Various key factors interact in dynamic ways, and schemes exhibit classic systems properties including: i) emergence, which is the existence of a systemic form which is different from and more than its constituent parts comprising canals, fields, farms, buildings, technology and people; ii) feedback loops where system-outputs are in turn inputs, thus accelerating dynamic change, such as water-provision as an output which is linked to fee-payment in a return flow into the system; iii) open systems, which maintain themselves through constant interaction and exchange with their environment or sub-systems, such as farm to scheme level dynamics; and iv) are subject to regime-change which may or may not be reversible. This is the total change of their operational mode when combinations of, or individual factors rise above or fall below critical thresholds in terms of their effect on the system.

The next chapter describes the field methods and materials used in data collection. A quantitative approach was adopted to complement the substantial existing published qualitative data on Limpopo smallholder schemes. Chapter 4 describes the data entry process and the development of consolidated proxy indicators. These were necessary to reduce the number of variables (factors) in relation to the total number of schemes that were surveyed to facilitate statistically valid and meaningful analysis. This leads into the two chapters describing the survey findings, Chapters 5 and 6, followed by the discussion in Chapter 7.

4 METHODS AND MATERIALS

This chapter describes how the irrigation schemes were identified and surveyed, and the field methods, data entry and management that lead up to the analysis. The population under study was the smallholder irrigation schemes in Limpopo Province. Limpopo was the location of most of the smallholder schemes in South Africa and these had similar characteristics to smallholder schemes in the rest of the country. The unit of analysis was 'the scheme'. The chapter also explains how proxy variables were consolidated and describes the statistical methods used.

4.1 Focus on Limpopo

The subject of the research will be smallholder irrigation schemes in Limpopo for the reasons set out below. A map of the project area and typical climatic data are given in Appendix 1. A national database of 317 smallholder irrigation schemes in South Africa was compiled in 2017, of which 183 smallholder schemes are listed in Limpopo Province (Denison & Manona, 2007b). Limpopo thus has more schemes than the rest of the country combined. Summary data extracted from this national database of schemes is shown in Table 4.1, and Figures 4.1 and 4.2. The database shows that most smallholder schemes (93%) were located in three provinces: Limpopo (183), the Eastern Cape (75), and KwaZulu-Natal (36). The clustering in these provinces is explained by their geographic overlap with most of the former homelands where landholdings were small and under various forms of communal tenure. The Limpopo section of the database was updated during 2009 and 2010 (van Averbeke et al., 2011), and while accuracy was improved, the general picture from the earlier survey changed very little. It was estimated that smallholder schemes cover 47 667 ha, equivalent to 3.4% of the national total irrigated area.

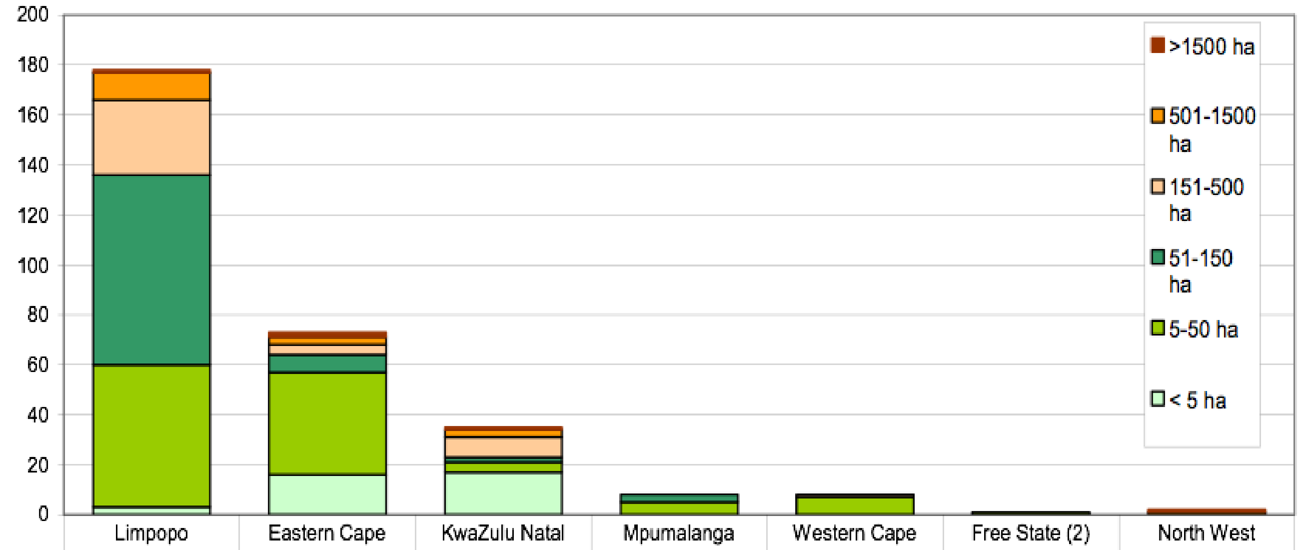
A summary analysis of the updated national database provided useful context for the Limpopo research. Operational status was found to be associated with technology choice, with pumped schemes more likely to have failed (Table 4.2). From the total of 296 schemes with operational data, 17% of gravity schemes (81 in total) are no longer functioning, while 35% of the pumped schemes (215 in total) were no longer functioning. The total number of people with land rights on smallholder schemes were estimated to be 34 158, but the schemes had a direct impact on some 200 000 to 250 000 people through family and kin (Perret, 2002). Most of the schemes (96.7%, totalling 46 114 ha) obtained water from rivers, either pumped directly, diverted by weirs, or through storage in dams.

Table 4.1: Summary data on smallholder irrigation schemes in South Africa *(Source: Denison & Manona, 2007b)*

Province	No. of schemes	Irrigation command area	No. of farmers	Average plot size [1]	Number of schemes by size category							Scheme activity [3]				Area under irrigation by type (ha)				
	Number	Ha	Number		<5 ha	5-50 ha	51-150 ha	151-500 ha	501-1500 ha	>1500 ha	Missing data	No. Active	No. Active %	Active Area (ha)	Active / Total Area %	Flood	Overhead Sprinklers	Centre Pivot	Drip / Micro	Missing (Ha)
Limpopo	183	28283	17785	2.2	3	57	76	30	11	1	5	105	57%	17452	62%	10834	10214	471	3070	3694
Eastern Cape	75	9641	7871	1.3	16	41	7	4	3	2	2	51	68%	3869	40%	2340	5533	1235	110	423
Kwa-Zulu Natal	36	6621	6174	1.4	17	4	2	8	3	1	1	35	97%	3097	47%	1730	4891			0
Mpumalanga	8	990	125	9.1	0	5	3	0	0		0	8	100%	556	56%	189	641	160		0
Western Cape	9	425	737	1.0	0	7	0	1	0	0	1	8	89%	386	91%	367	58			0
Free State[2]	3	20	2	10.0	0	1	0	0	0	0	2	0	0%	0	0%	20				0
North West	3	3524	423	5.3	0	1	0	0	0	1	1	2	67%	2816	80%		3524			0
TOTAL RSA	**317**	**49504**	**33117**	**1.49**	**36**	**116**	**88**	**43**	**17**	**5**		**209**		**28176**						

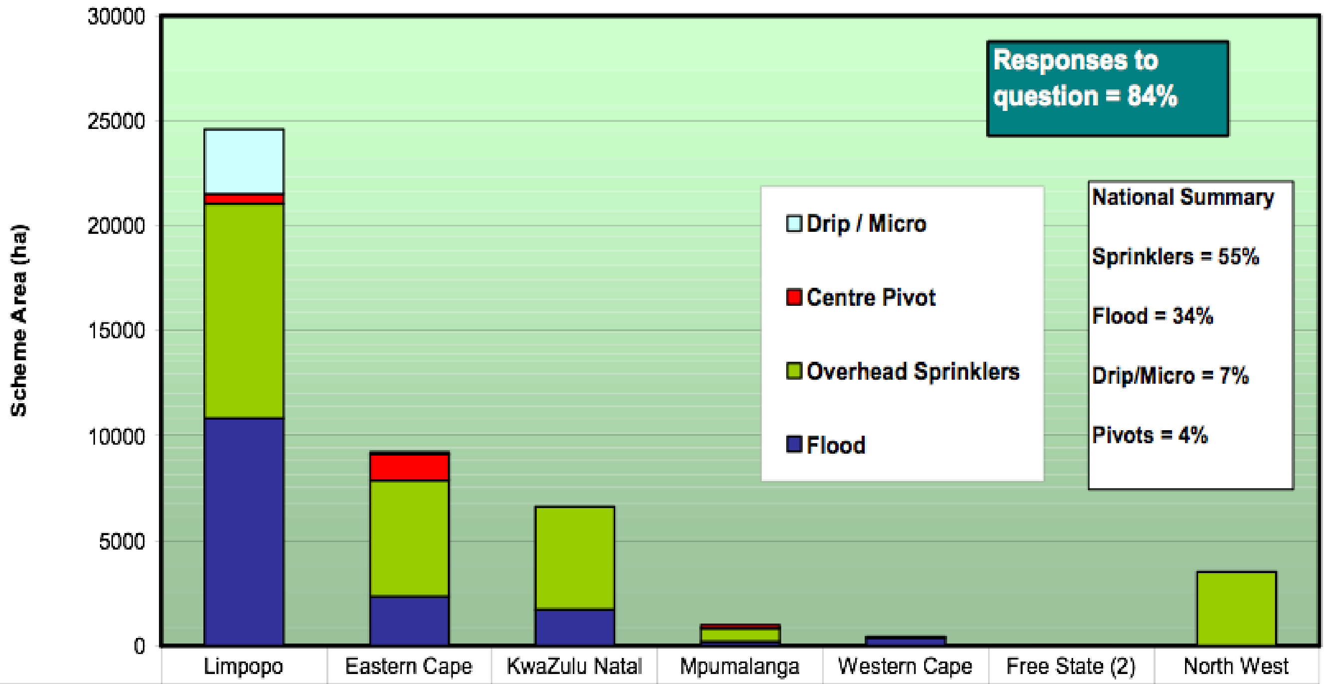
Notes:

1. Average plot size does not reflect the important distribution of plot sizes on many schemes, particularly the modernised 1970s and 1980s schemes of the former homelands, where many schemes comprised a mix of small food plots (0.05 ha), subsistence plots (1 ha) and commercial farms (4 ha) or variations thereof.
2. Free State scheme data is incomplete
3. Activity is the estimated area that is cropped in one year. The secondary nature of the information sources did not allow for verification
4. Information obtained from existing Provincial Databases, published information and questionnaire surveys filled out by Department of Agriculture officials in the Provinces



	Limpopo	Eastern Cape	KwaZulu Natal	Mpumalanga	Western Cape	Free State (2)	North West
>1500 ha	1	2	1		0	0	1
501-1500 ha	11	3	3	0	0	0	0
151-500 ha	30	4	8	0	1	0	0
51-150 ha	76	7	2	3	0	0	0
5-50 ha	57	41	4	5	7	1	1
< 5 ha	3	16	17	0	0	0	0

Figure 4.1: Number of smallholder schemes and size distribution by province



	Limpopo	Eastern Cape	KwaZulu Natal	Mpumalanga	Western Cape	Free State (2)	North West
Drip / Micro	3070	110					
Centre Pivot	471	1235		160			
Overhead Sprinklers	10214	5533	4891	641	58		3524
Flood	10834	2340	1730	189	367	20	

Figure 4.2: Infield irrigation technology and irrigated area by province

(Source: Denison & Manona, 2007b)

Table 4.2: Operational status of smallholder irrigation schemes (*Source: Van Averbeke et al, 2011)*

	Number of operational schemes				Number of non-operational schemes				
Province	Gravity surface	Pumped surface	Pumped Overhead	Pumped Micro	Gravity surface	Pumped surface	Pumped Overhead	Pumped Micro	TOTAL
Limpopo	49	9	30	13	12	5	41	11	**170**
Mpumalanga	3	0	4	0	1	0	11	0	**9**
North West	0	2	0	0	0	0	0	0	**2**
KwaZulu-Natal	5	0	30	0	0	0	0	0	**35**
Free State	0	1	0	0	1	0	0	0	**2**
Northern Cape	0	2	0	0	0	1	0	0	**3**
Eastern Cape	4	0	46	1	0	0	16	0	**67**
Western Cape	6	0	1	0	0	0	1	0	**8**
TOTAL	**67**	**14**	**111**	**14**	**14**	**6**	**59**	**11**	**296**

Note: the operational status of six schemes – five in the Eastern Cape and one in Kwa-Zulu Natal – was unknown, bringing the total to 302 schemes.

Groundwater only supplied 1 405.5 ha (3.0%) and municipal water 110 ha (0.2%), with spring water being used to irrigate 37.6 ha (0.1%). Water was pumped on 23 111.8 ha (48.5%), gravitated on 16 497.2 ha (34.6%), and on the remaining 8 058.5 ha (16.9%) pumping and gravity supply occurred in combination (either pumping from the river into canals, or pumping from gravity-supplied canals into the fields). The schemes in Limpopo have a similar history, and a similar range of technical, agricultural and social characteristics to those in other provinces (van Averbeke et al., 2011; Bembridge, 2000). This provides grounds for generalising from Limpopo to the other provinces. The high number of Limpopo schemes, the similar development histories nationally, and the need for pragmatism regarding fieldwork scale and costs led to a focus on Limpopo smallholder schemes for this thesis.

The irrigation systems on all smallholder schemes listed in the updated 2010 database were constructed after 1950, even though scheme development in South Africa has a much longer history. While some schemes were built before 1950, these no longer exist in their original form, and the details recorded are those of the reconstructed schemes.

4.2 Census survey of Limpopo schemes

4.2.1 Census or sample survey

The term 'survey' is used in a variety of ways, but generally refers to the selection of a relatively large sample of people from a pre-determined population of interest followed by the collection of data from the population or a sample thereof (Kelley et al., 2003). Pinsonneault and Kraemer (1993) define survey research as a means of gathering information about the characteristics, actions or opinions of the population. It is used to investigate the phenomena occurring at a point in time of an ongoing activity (Leedy & Omrod, 2001; Kelley et al., 2003). Survey research is used to answer questions that have been raised, to solve problems that have been posed or observed, to assess needs and set goals, to determine whether specific objectives have been met, to establish baselines against which future comparisons can be made, to analyse trends across time, and generally to describe what exists, in what amount and in what context (Isaac & Michael, 1997).

A census survey aims to collect information on every element of the population. This approach is recommended when the population is small, or when unusually detailed information is required. Cost and time are major factors to be offset against accuracy and reliability when comparing a census approach with a sample survey approach (Babbie & Mouton, 2007). In this case, given the knowledge that there is significant diversity in scheme history, technology and other factors, and that the population of Limpopo schemes is relatively small, a census survey was pursued.

4.2.2 Defining the scheme population

The number and details of irrigation schemes were found to be different across the three main datasets that were available. These included:

- The author's national database of 183 smallholder schemes from 2007, updated in 2010 to a total of 170 schemes in Limpopo.
- Government project lists obtained in different levels of detail from regional Department of Water and Sanitation, and the Limpopo Department of Agriculture in 2009-2010.
- The Revitalization of Smallholder Irrigation Schemes (RESIS) program list of 125 irrigation schemes (Denison & Manona, 2007b).

Finalising a complete list of schemes required a revisit of the definition of 'scheme' adopted for the study. A data-screening and alignment process of the multiple databases was also needed to identify and address anomalies and differences, which can arise for several reasons. Firstly, schemes often have two names, typically one in Afrikaans and one in a local language, so to compare the data sets the names had to be systematised. This required line-by-line checking of the databases for name similarity, plotting of location coordinates, and corroboration with locality names from maps.

Secondly, many schemes exist as historical (arti)facts, with decades passing since their last operation. While there is little or nothing remaining of these schemes in the field, they were found to be on some databases, but not on others. Where these were known to be non-existent, they were removed from the database.

Thirdly, the dynamic period of the 1990s, with the new dispensation in South Africa, led to numerous transfers of agricultural development responsibilities from past parastatal entities to new government bodies. The Agricultural and Rural Development Corporation (ARDC) was established in 1996 to take over operations of former-homeland projects in Limpopo and Mpumalanga (Matlala & Shaker, 2003). These were mainly larger orchard estate farms, including orange, mango and coffee plantations. The implementation of land reform projects, mainly under the Land and Rural Development Program (LRAD), complicated database alignment further by not conforming with the definition of irrigation schemes. The LRAD, ARDC-run and independent irrigation farms are more correctly collectives undertaking a single farming venture, with landholding rights established through a Communal Property Association (CPA). These do not conform to the definition of schemes used in this thesis, because there are no individual landholding rights, and the irrigation infrastructure system is not shared.

The scheme databases obtained were screened, using the following criteria:

- **All smallholder schemes in Limpopo in 2010 were included.** The boundary of Mpumalanga and Limpopo changed during demarcation adjustments in 2003, particularly in Bohlabela Local Municipality, resulting in some schemes being transferred to the Mpumalanga Department of Agriculture; these schemes were thus removed from the Limpopo data sets.
- **Only smallholder schemes were included.** Schemes are defined as the hydraulic boundary of the shared irrigation infrastructure of a number of individual smallholders. Irrigation projects and irrigation farms under the LRAD program, held collectively by Communal Property Associations, were thus excluded.
- **Independent irrigators were excluded** as they do not fit the definition of schemes.

- **Schemes smaller than 20 ha were excluded.** The size of 20 ha is an arbitrary cut-off for pragmatic reasons; these schemes are few and are not significant in their contribution to the total irrigated area.

The final list of Limpopo smallholder schemes at 2010 is thus one sub-group of the irrigation sector, which also includes: large-scale farms on irrigation schemes (commercially operated); LRAD irrigation farming collectives; and independent irrigators, who comprise both smallholders and large-scale commercial irrigation farmers. The smallholder-scheme subgroup, finally consolidated into the research project database, thus defines the population of the census survey that was undertaken. A summary of the screening outcome is shown in Table 4.3.

Table 4.3: Summary of consolidated Limpopo irrigation scheme database as at 2009

	Irrigation 'projects' (no.)	LRAD projects and independent irrigators	Size <20 ha	Defined as project-relevant 'schemes'
Scheme Database	167	16	9	142

The final research project database comprised 167 irrigation projects (i.e. including LRAD projects and independent irrigators). Of these, a total of 142 projects conformed to the definition of smallholder schemes and thus represent the population of interest. Scheme inactivity was not considered a reason for exclusion from the field survey, as it was anticipated that lessons would be learned from both active and inactive schemes. The consolidated database of these schemes is shown in Appendix 2.

Available data on the population of schemes was consolidated for the field survey and included: name, size (ha), number of farmers, activity status, location, type of irrigation system and main crop(s). It is noted that there were differences in the data sets, and data was not complete for all schemes in all databases. This is not surprising, as the databases were established at different times, and elements such as total irrigated area and the operational status of schemes (particularly those with pumps) can change in within weeks if critical maintenance issues are not addressed timeously. The field survey and data collection activity thus targeted all 142 schemes, with the intention of achieving a census survey of smallholder irrigation schemes in Limpopo.

4.3 Materials

4.3.1 Questionnaire development

The questionnaire for the survey is shown in Appendix 3 and facilitated data collection on the key factors influencing the performance of the irrigation system. The factors and related issues are described in Chapter 3 and lead logically to the main sections of the questionnaire. Four different questionnaires and prior surveys were reviewed and used to inform the final questionnaire structure and content, listed next.

- **ICID Smallholder Irrigation Checklist:** The International Commission on Irrigation and Drainage (ICID) in collaboration with the Food and Agricultural Organization of the United Nations (FAO) and the then Department for International Development of the United Kingdom (DFID) have developed a detailed checklist to assist preparation of small-scale irrigation projects. This has been extensively tested and is promoted by ICID and FAO for use globally. The checklist includes itemised factors that impact on scheme success and must be considered in an evaluation. The checklist, it is noted in the document, while primarily drawn up for evaluation of new developments, can, with minor adaptation, be applied for the purposes of reviewing existing schemes (Field & Collier, 1998).

- **ICID Socio-Economic and Institutional Questionnaire:** The ICID Working Group on Socio-Economic Impacts and Policy Issues developed a questionnaire with useful elements regarding institutions and organisations at scheme level (ICID, 2007).

- **RSA National Smallholder Irrigation Survey Questionnaire:** In 2006, the author conducted a national survey of smallholder schemes (Denison & Manona, 2007b). This involved the collection of secondary data from Government officials at a low level of resolution. Nontheless, the questionnaire was used to guide the preparation of the more detailed questionnaire required for the study.

- **Costs and performance of irrigation projects in Sub-Saharan Africa and other developing regions**: In 2007, the International Water Management Institute (IWMI), with support from the World Bank, conducted an extensive survey of irrigation schemes (Inocencio et al., 2007). This focused on costs and performance, and highlighted topics of importance for inclusion in the questionnaire.

4.3.2 Questionnaire structure

The questionnaire, shown in Appendix 3, was developed and structured with statistical analysis in mind. It was intended to gather mainly quantitative data but open boxes for hand-written narrative descriptions and organisational annotations were also included. The questionnaire had six parts. The coding was based on sequential numbers that started at the next one-hundred for each part of the questionairre as shown in Table 4.4:

Table 4.4: Questionairre structure and coding system

Section of Questionairre	Coding
PART 1 – Scheme descriptive data	101 - 127
PART 2 – Size and soils	201 - 220
PART 3 – Water infrastructure	301 - 355
PART 4 – Water quality and availability at scheme level	401 - 416
PART 5 – Institutions	501 - 582
PART 6 – Farming system	601 - 656
PART 7 – Transect walk?	701 - 713

4.4 Piloting of the Research Instrument

4.4.1 Field planning

The aim was to conduct the survey over a period of 9-12 months, targeting as many of the 142 identified schemes as could be located in the field. The scheme location was identified on Google Earth using the available coordinate data from the consolidated database. Satellite images were studied to identify schemes, using visual cues such as centre-pivot circles or the herringbone layout that is typical of flood schemes. Using this aerial imagery, 1:100 000 maps depicting the schemes were generated.

Not unexpectedly, the scheme coordinate data was found to have many inaccuracies and data gaps. Approximately one-third of the schemes had incorrect coordinates and could not be properly positioned on the satellite images. Two schemes contained gross location errors, being incorrectly positioned outside of the country. To improve information on scheme location and facilitate fieldwork planning, a series of workshops was held with Government extension officers from each district. In Vhembe District, this work was done in collaboration with Prof. van Averbeke, who conducted the location and planning exercise. In the other four Limpopo Districts, the author facilitated discussions. The outcomes led to refinements of the thesis database comprising the study population (shown in Appendix 2). Not all of the schemes were in fact located and surveyed and a detailed account of this is included later in this chapter.

4.4.2 Pilot survey

Field visits were made to three schemes to pilot the questionnaire. The aim was to test the questions and ensure they were intelligible to respondents, and that the information obtained was adequate in scope and captured in a form that enabled analysis.

A basis for grouping schemes was developed by the author in a prior research project, mainly around the purpose of production (Denison & Manona, 2007a; refined later in van Averbeke et al., 2011). These are: food-producers (primarily for home consumption); peasant farmers (with diversified livelihoods portfolios and mixed farming purpose); business farmers (mainly farming for sale); and a fourth group which includes schemes where land has been consolidated and leased to commercial agri-business entities in a joint venture arrangement. The pilot schemes represented three of the four scheme groupings, purposefully selected based on technical and historical factors available in the existing database at the time. These are outlined below.

Dzindi Scheme (total 128 ha; plot size 1.28 ha). Dzindi is located 8 km from Thohoyandou, and is a classic example of a low-cost flood irrigation system, with smallholders who largely adopt a low-risk approach to farming, mostly on small plots of 1.3 ha. The scheme was operational with a very high level of wet-season activity and productivity but faced water shortages in the dry season. Dzindi scheme, while in the second grouping, had many of the characteristics of the first group (food producing schemes), including gravity-canals, small plot sizes (<1.5ha), and extended age (being built in the 1960s).

Mwanedi Scheme (total 2000 ha; plot size >5 ha). This scheme was from the third grouping: business farmers. Mwanedi, located 70 km from Musina, was a cluster of commercially-oriented, individually-held, larger irrigation farms of 5 to 20 ha. Farmers were mainly growing tomatoes, maize and fresh vegetables. These farmers had adopted a higher-risk commercial model, with high external dependency. The cluster of schemes was operational but was facing significant challenges pertaining to chemical-resistant diseases, with a lack of information to address these challenges.

Makuleke Scheme (total 342 ha; plot size 3.2 ha). Makuleke was operating under a JV arrangement. It is located near Punda Maria in the far north-east of Limpopo, on the border of the Kruger Park. This is a Joint Venture (JV), where potatoes were grown based on an arrangement between the group of irrigators and a commercial farmer. A marketing contract with Simba Chips is in place. Production was high-tech under centre-pivots, and practically all decision-making was done by the commercial partner, with little say from the plot-holders themselves. The scheme was operational, and the plot-holders were getting cash return for their involvement, but were challenging various contractual aspects of the JV.

Outcomes of the piloting process

The questionnaire was administered through a focus group representing each scheme, usually comprising the the scheme committee. The process was found to be practical and took approximately ninety minutes to administer. It was found that the interview approach needed to be flexible in an open discussion format, rather than adopting a strictly sequential approach from beginning to end. Minor changes to layout and wording were then made. The main issue arising from the process related to the level of soil survey detail, and the time implications thereof. The initial inclusion of a preliminary field soil survey to identify soil colour and depth would have taken substantially more time than was available for the study. It was realised that a full reconnaissance survey was unrealistic and subsequently decided that the soils colour information would be obtained through a combination of local knowledge and a review of satellite imagery. This was informed by Bembridge (2000), who advises that for planning purposes, a simple categorisation of poor, moderate and good is adequate. Rather than conduct physical investigations in the field (i.e. soil profiling using augers), soil depth, colour, waterlogging and salinization information was obtained from respondents and a visual cross-check undertaken during each transect walk.

Given the wide spread of schemes across Limpopo it was initially estimated that two schemes could be surveyed per day. The pilot survey suggested this was possible but would depend on the availability and timeliness of the local extension officer to facilitate quick access to local stakeholders. Attention was also paid to the need for accurate GPS locations of the scheme headquarters, extension officer’s office or residence, or scheme main gate.

4.5 Survey process and data collection

4.5.1 Field survey process

The field survey was conducted over the period of June 2009 to September 2010, when multiple trips of 3-4 weeks were made. The average survey rate was only one scheme per day, which was half the estimated rate. In some cases, extension officers and/or schemes could not be located timeously, or at all. Distances were extensive and schemes were often located in relative outposts where local officials did not follow official working hours. In just a few cases two or three schemes were surveyed in one day, but equally often, days would pass without any successful interview. Approximately 12,500 km were traversed during the field survey.

The interviews were conducted in focus group sessions, typically with the scheme committee and the extension officer in attendance. Meetings were arranged in advance; the party was met, and a brief introduction regarding the interview purpose was made. This was followed by a short field tour of the scheme, conducted in vehicles and on foot. Typically, the field tours lasted 1-2 hours and included visits to the fields, diversion weirs, headworks, main canals, pump stations, stores, and infield irrigation systems. The main elements of the scheme were observed while an informal discussion was held on scheme history and context. The group was then seated and the questionnaire survey conducted, followed by a final transect walk along a line selected to facilitate the verification of cropping intensity estimates made by the group.

4.5.2 Extent and challenges of the census survey

Despite the extensive field effort, a full census survey of 142 schemes was not achieved, due to logistical limitations in the field and a lack of local knowledge about schemes that were on the list. In total, 117 schemes were surveyed, with 25 not being covered. In some of the missing cases, it was apparent that schemes had ceased to exist decades before but remained on the provincial lists. In other cases, schemes were not known by local officials or were difficult to locate by the name and positional information available. These were not pursued further due to time and cost limitations.

Summary data on the schemes that were surveyed was compared with the population of 'smallholder' schemes, presented in Table 4.5. The final survey covered 82% of the population (117 of 142 in number). An analysis of key characteristics of those surveyed and those not surveyed showed that average scheme sizes were similar (116 ha and 95 ha). The surveyed schemes also included a wider range of scheme sizes than those missed (5-1433 ha versus 23-253 ha). Both groups contained a significant proportion of inactive schemes (58% and 32%), and pumped-overhead schemes (67% and 41%).

Table 4.5: Summary data on surveyed and un-surveyed schemes based on the scheme population database compiled for the study

	Surveyed	Not surveyed	Surveyed as % of population
No. of schemes	117	25	82%
Size (ha)			
Average	116	95	
Max	1 433	253	
Min	5	23	
Operational status	**(no.)**	**(no.)**	**(%)**
Active	73	10	51%
Not active	35	14	25%
Missing data	9	1	6%
Total	117	25	82%
Type	**(no.)**	**(no.)**	**(%)**
Canal & flood	48	3	34%
Pumped overhead	43	16	30%
Other	15	5	11%
Missing data	11	1	8%
Total	117	25	82%

Source: Consolidated Limpopo database of schemes compiled by the author from van Averbeke et al. (2011), updated with the then Department of Water Affairs and Forestry (DWAF) and LDA information as at 2010 (see Appendix 2 for these scheme lists).

The outcome of the field survey was that data was obtained for 82% of the defined study population. The implication of this was that instead of a census survey, a large sample survey was conducted – a field outcome that required consideration of sampling implications. Hill (1997) argues that sample size is often as much a budgetary consideration as a statistical one, and advocates application of the 'rules of thumb' proposed by Roscoe (1975). The rules are as follows:

1. Use of statistical analyses on samples smaller than 10 is discouraged.
2. Large samples are preferred over smaller ones.
3. There is seldom justification for sample sizes smaller than 30 and larger than 500.
4. The lower limit of 30 is the minimum needed for a reasonable probability of detecting treatment or group differences.

5. When a sample is broken up into groups (sub-samples), rule 4 applies to the sub-samples.
6. For descriptive research, the sample should be not less than 10% of the population.
7. For correlation research, at least 30 elements are required.
8. For experimental research (e.g. testing of group effects, as in the current study), 30 elements per group are required.

The survey of 117 schemes out of a population of 142 exceeded the requirements for a representative sample. An analysis of the main characteristics of the final sample of 117 versus the population of 142 is presented in Chapter Five and shows these to be closely similar based on the available data including size, energy source and field irrigation method.

4.5.3 Identification of surveyed irrigation projects which are not irrigation schemes

Results from the field survey showed that 15 of the 117 visited irrigation schemes did not comply with the definition of *schemes* adopted for the study (i.e. where more than one farmer has landholding rights within the hydraulic boundary and shares the irrigation system). As the nature of these 15 schemes (Table 4.6) was not evident prior to the survey, they were surveyed but excluded from the analysis.

Five of the projects were found to be individual enterprises being pursued on nominally-rented land that was either purchased under the LRAD program, or was land previously owned by the State. Two projects, marked as LRAD-TA, were small dairy projects that were operated by the Government agricultural parastatal in the former homelands. These had an irrigation component for dairy fodder, but all agricultural activity ceased in the mid-90s and the land was handed over to be administered by the relevant Tribal Authority (TA) under the land reform program in the late 1990s. The Phalaborwa dairy project lands were leased to a neighbouring commercial farmer at the time of survey, while the Modjadji dairy is non-existent as far as irrigation or cows are concerned, and was the site of a defunct chicken-rearing project in what remained of the dairy sheds.

Table 4.6: Irrigation projects that were surveyed but excluded from the analysis

	Scheme Name	District	Original Irrigation Area (ha)	Operational Status	Reason for exclusion*
1	Khuvutlu Farm	BaPhalaborwa	22	No	Individual
2	Maninaspruit	Capricon	132	Marginal	Individual
3	Phalaborwa Dairy	Mopani	30	No	LRAD-TA
4	Lekgalametse	Mopani	105	No	LRAD-JV
5	Modjadji Dairy	Mopani	30	No	LRAD-TA
6	Masalal	Mopani	50	Yes	Individual
7	Moradu	Mopani	120	Yes	Individual
8	Selwane Citrus	Mopani	76	Yes	LRAD-JV
9	Lesedi	Sekhukhune	No data	No	LRAD-JV
10	Kgotlelelo	Sekhukhune	50	Yes	LRAD-JV
11	Pretoria Farm	Sekhukhune	8	Yes	Individual
12	Maandagshoek	Sekhukhune	21	Yes	Individual
13	Ipopeng	Sekhukhune	150	Yes	LRAD-JV
14	Naphuno Farm	Tzaneen	246	Yes	LRAD-JV
15	Matlala Icheong	Sekhukhune	100	Yes	Individual

***** *explanation below*

The projects marked as LRAD-JV were all former white-owned farms purchased under the land reform program. The Government strategy was to promote joint-venture (JV) arrangements for production involving the beneficiary communities and commercial agri-business partners. Landholding rights to these farms are vested in Communal Property Associations with no provision for exclusive individual rights to portions thereof. The last project on the list, Matlala Icheong, was a project operated on land administered by Chief Matlala and his son, reportedly as a project to benefit the community through cash dividends received. Maize and potatoes (in rotation) were irrigated under two 50 ha centre pivots under a profit-share arrangement with a commercial partner. As there were no individual rights to the irrigated land and the entire area was farmed as a single enterprise, this had no characteristics associated with smallholder plots, or smallholder schemes as defined for the study. This irrigation farm was classed as an individual project.

4.5.4 The special case of Tshiombo scheme sub-sections

Tshiombo scheme was treated as a special case in the analysis. Tshiombo comprises seven hydraulically-separate sub-schemes ranging from 60.5-173.5 ha, which share a 10 km-long supply canal. Originally, the scheme was 839 ha in size with 660 plot holders, but became effectively partitioned over time. The seven sub-schemes have markedly different characteristics due to different technical interventions over time and diversity in local practices including landholding customs. Different modernisation interventions have taken place over the last 20 years in five of the seven sections, with two sections remaining in their original flood irrigation form. The five upgraded sections were subject to varied revitalisation efforts; in some cases minor repair interventions, and in others major land-tenure and technology restructuring, such as in Block 1 under the RESIS Re-charge program from 2006-2009.

This diverse development history has left the different sub-sections with distinctly different overall characters, some with newer pumped systems, and others with the original gravity systems. One section (Block 1) was subject to a land consolidation and leasing initiative with a Joint-Venture arrangement. Water supply, land-tenure arrangements and water stress also vary significantly across the sub-sections. For this reason, Tshiombo is entered into the database as seven separate sub-schemes, given that scheme performance and the associated factors are the primary points of study interest and would be blurred by assessment of the conjoined sub-sections.

4.5.5 Treatment of the RESIS-Recharge Joint Venture Schemes

Twelve of the surveyed schemes were part of the Revitalisation of Smallholder Irrigation Schemes Recharge Program (RESIS-Recharge) implemented by the Limpopo Department of Agriculture between 2006 to 2012. Four of these were operational and eight were not, listed in Table 4.7.

Table 4.7: Characteristics of RESIS-Recharge schemes included in the database

Scheme name	Operational status (2010)	Original scheme command area (ha)	Developed area (ha)	No. of plot holders	Irrigation system type
Tshiombo Block 1A	YES	100	100	86	Floppy sprinkler
Makuleke	YES	342	138	43	Centre pivots
Tswelopele	YES	410	410	84	Floppy sprinkler
Strydkraal A	YES	180	180	99	Floppy sprinkler
Mapela	No	90	70	54	Floppy sprinkler
Grootfontein B	No	92	92	67	Centre pivots
Homu	No	172	70	26	Floppy sprinkler
Metz	No	284	117	129	Floppy sprinkler
Phetwane	No	52	52	48	Floppy sprinkler
Setlaboswane	No	119	119	96	Floppy sprinkler
Mogalatsane	No	130	124	99	Floppy sprinkler
Roodewal	No	30	0	30	Floppy sprinkler
Total (12 in No.)		**2001**	**1472**	**861**	

As far as the statistical analysis is concerned, the thesis aims to understand the influence of key factors on truly characteristic smallholder schemes, defined by their individual tenure rights and the boundary of a shared hydraulic system. Operational and non-operational RESIS-Recharge schemes were treated differently in the analysis. The eight non-operational schemes complied with the definition of smallholder scheme based on their landholdings and on the shared nature of the original hydraulic irrigation systems. These were all old canal-furrow irrigation schemes in a state of transition driven by RESIS-Recharge. They had failed in the process of conversion to a collectively owned enterprise and retained key characteristics of individual land rights and a shared water system. Participants were able to demonstrate the boundaries of their plots despite partly-completed transitions and they shared the hydraulic system thus complying with the scheme definition.

The operational RESIS-Recharge schemes were evidenced by a completed land-consolidation process where all individual plots were combined as part of the Joint Venture (JV) process and handed over to a single commercial operator to farm. Thus they did not comply with the definition of 'schemes'. Van Koppen et al. (2018) explains how RESIS-Recharge was based on JVs, where the landholders on the scheme consolidated the landholding and leased the land to a large-scale commercial agricultural partner. The arrangement was facilitated by the Limpopo Department of Agriculture, which provided grant funding for a new, highly-modernised pumped irrigation systems at each scheme. Floppy sprinkler, centre-pivot or drip irrigation was developed. A JV partner (called the strategic partner) was then contracted to farm the entire scheme as a single farm enterprise with a profit-share arrangement of sorts. All these schemes had similar physical factors: high-quality and high-tech infrastructure; a reliable water supply; reasonably good soils; and consolidated landholdings (van Koppen et al., 2018).

An analysis of the RESIS Re-charge program, while of interest and discussed in Chapters 6 and 7, is not the primary focus of this work and has been documented elsewhere (Tapela, 2012; Schreiner et al., 2010; van Koppen et al., 2018).

4.6 Data entry and management

Data was entered from the hardcopy questionnaires into an MS Excel database constructed for this purpose. Decisions on data entry were made based on data type:

- quantitative data was entered directly;
- data based on yes/no questions was entered as a 1 or 0; and
- data linked to ranked categories was coded from 1 to 4, as the case required.

Detailed comments on the data entry and cleaning process are described in the sections that follow, referenced by the questionnaire 'Part' and the question code as appropriate. The full questionnaire is included in Appendix 3.

4.6.1 Data compression and the use of dummy variables

The survey process generated numerous elements of data intended to describe factors of interest. Application of Rules 4, 7 and 8 (in Section 4.5) mean that the number of subgroups and factors need to be rationalised to facilitate meaningful statistical analysis. In several cases (detailed later in the chapter), the multiple descriptors related to a theme of interest were consolidated into dummy variables. This was the case, for example, with data relating to water stress and scarcity, land-tenure modalities, and infrastructure condition. The consolidated variables, along with relevant primary data such as scheme size, technical-character etc., comprised the final data set that described each irrigation scheme (complex) system. These were then analysed in relation to parameters of scheme performance to answer the research questions.

4.6.2 Scheme descriptive statistics

Data from the questionnaires was entered into a Microsoft EXCEL spreadsheet. In addition, rainfall data was obtained from the SAPWAT 4 meteorological database (van Heerden & Walker, 2016). SAPWAT 4 is a georeferenced crop-water modelling package integrated with the Water Resources of South Africa (WR2012) model (Bailey & Pitman, 2016), formally adopted and hosted by the Department of Water and Sanitation. The rainfall dataset is derived from 350 South African Weather Service stations around the country (van Heerden & Walker, 2016).

4.6.3 Soils

Soil parameters are important in relation to scheme performance, and data was collected on depth, colour (Part 2) and salinity and waterlogging (Part 3). Soil depth was based on local knowledge, and colour was observed in the field. Salinity was identified as white encrusted soil. The manifestations of poor drainage are a high water table or the presence of grey-coloured soils, both of which lead to significantly reduced crop growth. Respondents indicated if drainage or salinity was an issue. A soils quality index was then developed based on a weighting of the different key parameters (Table 4.8) and the equation is shown in Box 4.1.

Table 4.8: Calculation of soils quality index

Code	**Description**	**Category**	**Variable**	**Weighting**
212	Soil depth % of total irrigated area	>1.5 m	a	1
213		0.75 to 1.5m	b	0.7
214		< 0.75m	c	0.4
216	Soil Colour % of total irrigated area	red soils	d	1
217		yellow or brown soils	e	1
218		black soils	f	0.7
219		grey soils	g	0.4
351	Proportion of the scheme visibly affected by salinity (percentage)		h	(% area/2)
352	Proportion of the scheme visibly affected by water logging (percentage)		i	% area

Equation for the calculation of the soil quality index (following from Table 4.8)

I_{depth} = Soil depth index = (a x 1) + (b x 0.7) + (c x 0.4)
I_{colour} = Soil colour index = ((d + e) x 1) + (f x 0.7) + (g x 0.4)
$I_{salinity}$ = Salinity index = 100 – (h)
$I_{wlogging}$ = Waterlogging index = 100 – (i)
Soil quality index = (I_{depth} x I_{colour} x $I_{salinity}$ x $I_{wlogging}$)/100

4.6.4 Water infrastructure type and condition

This section documented what was on the ground at the time of the interview. In some schemes, particularly pumped-sprinkler systems which last operated in the 1980s, numerous infrastructure elements such as sprinklers and pump-stations were no longer in existence. Evidence of these could be seen in derelict and/or empty pump-houses, exposed and often-damaged portions of bulk pipelines, and pumping ramps extending into rivers, etcetera. The status quo at the time of the survey is reflected in the data set. Irrigation schemes consist of many different technical elements, of varied types, and varied condition. The capability of the system to provide water is a function of all of these elements combined.

Condition of infrastructure

The condition of the elements was recorded in the field as shown in (Table 4.9). Where the infrastructure element was not part of the original scheme design, those were marked as N/A.

Table 4.9: Scoring for condition of the main hydraulic engineering components

Code	Technical element of the scheme	Enumeration based on condition
313	pumps	1-removed or not functional 2-operational N/A (i.e. no pumps in the original design)
314	infield sprinklers / drippers / pivots	1-don't exist (destroyed or removed) 2-leak badly 3-some leaks 4-optimum condition
315	main and secondary canals	1-completely dysfunctional 2-major leaks 3-minor leaks 4-no cracks, good condition
316	tertiary canals	1-completely dysfunctional 2-major leaks 3-minor leaks 4-no cracks, good condition
317	canal control gates	Aligned with canal condition

Each of these systems types required different logic to be used to arrive at a representative dummy variable for overall condition. The logic is set out in Table 4.10 for all permutations of technical elements and condition. The resultant dummy variable was one of the following:

1. critical (no irrigation possible at all)
2. major limitation
3. operable (sub-optimally)
4. no limitation (optimal)

This variable captures the overall scheme infrastructure condition in regard to capability to distribute water to farmers. The detail on canal control-gate function and condition was excluded from the calculation logic of dummy variable. This is because the gates played a minor role in water management, and the condition of the gates within the surveyed irrigation systems were similar to the condition of the concrete hydraulic components. The schemes with gates are all old (built in the 1950s and 60s) and the simple steel sliding gates were observed to be similarly deteriorated as the concrete-canal infrastructure. The Limpopo smallholder schemes (average = 116 ha) are all relatively small, requiring few gated structures for hydraulic control. The prevailing design choice at the time was to limit gates and rely on robust, fixed, concrete duck-bill weirs at offtakes, rather than gates for hydraulic control. Duckbill weirs are permanent, constructed of concrete, and the long overflow spillway requires no adjustment.

Table 4.10: Calculation of dummy variable for condition of hydraulic infrastructure (V_{con})

System type A: Gravity canals to surface irrigation														
pumps	---	---	---	---	---	---	---	---	---	---	---	---	---	---
pressurised in-field system	---	---	---	---	---	---	---	---	---	---	---	---	---	---
supply canals	1	1	2	2	2	2	3	3	3	3	4	4	4	4
infield canals	1	2	1	2	3	4	1	2	3	4	1	2	3	4
Variable for Condition (Vcon)	***1***	***1***	***2***	***2***	***2***	***2***	***2***	***3***	***3***	***3***	***3***	***3***	***3***	***4***
System type B: Gravity canals, booster pumps to pressurised infield														
pumps	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
pressurised in-field system	Any	1	2	2	2	3	3	3	3	4	4	4	4	
supply canals (main/secondary)	Any	1	2	3	4	1	2	3	4	1	2	3	4	
infield canals	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Variable for Condition (Vcon)	***1***	***2***	***2***	***2***	***3***	***2***	***2***	***3***	***3***	***2***	***3***	***3***	***4***	
System type C: Pumps to pressurised infield														
pumps	N	N	Y	Y	Y	Y								
pressurised in-field system	1	2	1	2	3	4								
supply canals	---	---	---	---	---	---								
infield canals	---	---	---	---	---	---								
Variable for Condition (Vcon)	***1***	***1***	***2***	***2***	***3***	***4***								
System type D: Pumps lifting to canals with surface irrigation														
pumps	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
pressurised in-field system	---	---	---	---	---	---	---	---	---	---	---	---	---	---
supply canals	1	1	2	2	2	2	3	3	3	3	4	4	4	4
infield canals	1	any	1	2	3	4	1	2	3	4	1	2	3	4
Variable for Condition (Vcon)	***1***	***1***	***2***	***2***	***2***	***2***	***3***	***3***	***3***	***3***	***3***	***3***	***3***	***4***

Scores EXCLUDING PUMPS: 1=critical (no irrigation possible at all) 2=major limitation 3=operable (sub-optimally) 4=no-limitation (optimal)
Scores for PUMPS: Either Y-operational or N-not operational

Steel gates typically played a role in releasing water from the main into the small tertiary canals, but in practice were effectively replaced with wooden boards, or sand-bags, when condition of the steel control gate was poor. When considering the need for consolidation of all variables into a single variable, inclusion of the additional variable of gate condition was deemed to add no value to the analysis.

4.6.5 Fencing infrastructure

Fencing effectiveness is a function of two factors: whether the fence surrounds the entire irrigated area, and the condition of the fence. This was reduced to a dummy variable which related to fencing effectiveness as a single factor (Table 4.11).

Table 4.11: Dummy variable for fencing

Ref	Question	Eg.1	Eg.2	Eg.3	Eg.4	Eg.5
354	Is the scheme fenced 0 = no 1 = partially 2 = fully	0	1	1	2	2
355	condition of the fence 0 = useless 1 = keeps some animals out 2 = fully effective	---	0 or 1	2	1	2
	Dummy variable 0 = no fence protection 1 = keeps some animals out 2 = fully effective	Then 0	Then 0	Then 1	Then 1	Then 2

4.6.6 Consolidated variable for all scheme infrastructure

The main on-scheme engineering components that impact on scheme performance are the hydraulic system (bulk transmission and infield) and fencing (needed to keep out domestic animals as well as wild game). A consolidated variable was developed, as shown in Table 4.12. The condition score can be understood to represent the impact on scheme production, given infrastructure condition status, all other things being equal.

Table 4.12: Weighting for infrastructure condition index

Description	Category	Condition Factor
Fencing	0= no fence protection	0.7
	1= keeps some animals out	0.85
	2= fully effective	1
Hydraulic Infrastructure	1=critical limitation	0.1
	2=major limitation	0.5
	3=operable (sub-optimal)	0.8
	4=no limitation (optimal)	1

Equation for the calculation of the infrastructure index (following from Table 4.12)
Infrastructure condition index = (hydraulic infrastructure factor) x (fencing factor)

For example, the fencing factor for no fence at all is 0.7, which means that for any scheme the complete absence of a fence would result in an estimated 30% crop damage on that scheme. This seems realistic as crop damage, particularly on maize and horticultural crops by animals (wild and domestic) was widely reported. The nature of the index for statistical purposes does not require an exact representative figure as the purpose is for correlation, not absolute assessment. The approach facilitates a reasonable and weighted spread of data for the analysis of performance in relation to overall infrastructure condition, noting issues such as water resource scarcity, and water-stress behaviours are addressed under other indicators.

4.6.7 Water quality and availability at scheme level

The data on water quality and availability was entered into the database using the following rationale:

Code 401 – Formal DWAF water allocation: This was a simple factual question as to whether farmers know about the then DWAF (now Department of Water and Sanitation (DWS)) water allocation for the scheme.

Code 402 – Volume of the allocation: Where the actual volumetric allocation (translated to m^3/annum) was known, this was entered as a numerical value.

Code 403 – Assurance of supply: If 402 was YES, 403 was either YES or NO. If 402 was NO (i.e. the DWAF allocation was unknown), then 403 was N/A.

Codes 404-414 – Questions on water supply availability and on-farm responses: Farmers' responses at the time of survey were entered as YES or NO. One set of questions focussed on water availability (Table 4.13), the second set on water-stress behaviours (Table 4.14). Each of these data sets were transformed into a consolidated score, using the logic below.

Codes 404-407 were translated to an index of the severity of water resource stress as shown in the examples in Table 4.14. Only one of questions 404, 405 and 406 could be marked as YES. Question 407 could be marked as YES or NO regardless of the entries above it.

Table 4.13: Consolidated score for water resource constraint

Code	Questions		Permutations and scores					
404	Adequacy of supply during the year Y=1 : N=0	Water is adequately available throughout the year	**1**	**1**	0	0	0	0
405		Water is available but subject to seasonal fluctuations	0	0	**1**	**1**	0	0
406		There is virtually no water during the dry season	0	0	0	0	**1**	**1**
407	Long term supply fluctuations Y=1 : N=0	Water availability is affected by whether it is a wet or dry year	0	**1**	0	**1**	0	**1**
Index for water resource constraint 1 none 2 minor 3 major 4 critical			***1***	***2***	***2***	***3***	***3***	***4***

Codes 408-414 were translated to a dummy variable to reflect water stress adaptations and behaviours by farmers. This was obtained by counting the number of affirmative behavioural responses to water stress on each scheme (Table 4.14):

Table 4.14: Index for water stress behaviours

Code	Questions		Answer
408	Farmer response to limited supply (Y=1 : N=0)	night irrigation	Y/N
409		water theft	Y/N
410		water exchanges	Y/N
411		adaptation in crop selection	Y/N
412		reduce the planted area	Y/N
413		reduce the irrigation frequency	Y/N
414		evaporation control / mulching	Y/N
		TOTAL stress-response behaviours	***Sum Y***

Equation for the calculation of water stress behaviours (following from Table 4.14) *Index for stress behaviours = sum of behaviours (Count 1 to 7)*

4.6.8 Institutions

Where schemes were completely inactive, i.e. where cropping in both wet and dry seasons was 0%, then all of Part 5 (Codes 501 to 582) was treated as N/A. Where schemes were active to some degree, YES/NO entries were transfored to 1 or 0 respectively in the database.

Dummy variables based on institutional data

Conflict on the scheme is considered to add risk and this potentially undermines productivity for smallholder farmers. The conflict index is a simple summation of conflicts that were recorded in the affirmative (Table 4.15).

Table 4.15: Index for conflict

Is there conflict (that cannot be resolved amicably) on the scheme in relation to: Y=1 : N=0	land and/or water	Y/N
	theft of equipment	Y/N
	theft of produce	Y/N
	inter-organisational or factional conflict	Y/N
Is there conflict between plot-holders and people off the scheme Y=1 : N=0		Y/N

Equation for the calculation of the conflict index (following from Table 4.15) *Conflict index = sum of positive answers (Count 1 to 5)*

The practice of, and institutional constraints to, farmers engaging in land exchange was anticipated to be a factor impacting on scheme performance. The data in relation to land exchange practices was consolidated into a land-exchange index by applying weightings to the three different elements: institutional approval; type of payment; and duration of exchange (Table 4.16). The higher the index, the more conducive is the land exchange environment.

Table 4.16: Land exchange index

Code	Question		Response	Weighting	Contributing value
573	Is there any form of land exchange on the scheme?		Y/N	If NO index=0	If NO index=0
574	Do land exchanges have to be formalised (sanctioned) by scheme management?		Y/N	Y=1 N=0.8	Max value of line 574 & 575
575	Do land exchanges have to be formalised (sanctioned) by the Tribal Authority?		Y/N	Y=1 N=0.8	
576	If a farmer uses the land of another how is this organised?	sharing of crops produced	Y/N	0.4	Max value of line 576 through line 579
577		rental through cash payment	Y/N	1	
578		based on land preparation services	Y/N	0.7	
579		Joint-Venture	Y/N	1	
580	What durations of land-exchange are found on the scheme?	single season exchange	Y/N	0.4	Max value of line 580 through 582
581		multiple seasons less than 2 years	Y/N	0.7	
582		Multiple seasons more than 2 years	Y/N	1	

Equation for the calculation of the land exchange index (following from Table 4.16)

Land exchange index = (max value of line 574 & 575) x (max value of line 576 through line 579) x (max value of line 580 through 582)

4.6.9 Farming System

The data on winter and summer crop types was recorded as an estimate of which types of crops were grown on the whole scheme. Data on institutional support aspects were either Yes or No, entered as 1 or 0. Three dummy variables were generated from the data so as to represent: market complexity (Table 4.17); the degree of commercialisation (Table 4.18); and agricultural information adequacy (Table 4.19). The way in which these was done is explained in the tables below.

Table 4.17: Market Complexity Index

Code	Question asked		Diversity score
620	Do any of the plot holders on the scheme use the following techniques to sell their produce?	Small traders or hawkers buying on the scheme	1
621		Supply to local retailers	2
622		Supply to distant retailers in major centre	3
623		Contract farming	3

Equation for the calculation of the market diversity index (following from Table 4.17)

Market diversity index = sum of diversity score (from 0 to 9)

Table 4.18: Commercialisation Index

Code	Question asked		Commercialisation Weighting
615	What is the primary use of produce (estimate % of farmers for each category)	Home use - food and animal fodder	0
616		Equal cash sale and home use	0.5
617		Mainly sale off-scheme	0.9
618		other (describe)	

Equation for the calculation of the commercialisation index (following from Table 4.18)

Commercialisation index = [(% of farmers in 616)x0.5 + (% of farmers in 617)x0.9]/100

Table 4.19: Agricultural Knowledge Index

Code	Question asked		Adequacy of information score	Selected answer
640	**Production Information:** What is the quality of advice relating to production: soil prep / seed / fertiliser / pest control etc.?	All their questions are answered satisfactorily.	3	X
641		Most of their questions are answered satisfactorily.	2	
642		Few of their questions are answered satisfactorily.	1	
643		None of their questions are answered satisfactorily.	0	
652	**Marketing information:** What is the quality of advice related to marketing?	All their questions are answered satisfactorily.	3	Y
653		Most of their questions are answered satisfactorily.	2	
654		Few of their questions are answered satisfactorily.	1	
655		None of their questions are answered satisfactorily.	0	

Equation for the calculation of agricultural knowledge index (following from Table 4.19)
Agricultural knowledge index = [average of X and Y] / 3 = fraction from 0 to 1.

4.7 Data entry for schemes that were not operational

Data on schemes which had stopped operating *less than two years* prior to the interview was recorded in the same way as on operational schemes. The reason for allowing a window of relevance between the time of non-functioning and the time of survey was because: i) valuable information could still be obtained on factors and scheme activity levels, as respondents' recall was deemed sufficiently reliable; and ii) some schemes, particularly pumped schemes, were often in good functioning condition but had failed because of a relatively simple technical issue, or because Eskom bills were not paid. The character and operational realities, and the respondents' memory thereof, were all deemed to be valid information for the analysis. In the analysis, the detail of these recently non-operational schemes (including cropping activity when last functioning) was used in the same way as for operational schemes. The operational status of the schemes at the time of the survey was, however, listed accurately (i.e. as non-operational).

Where scheme water infrastructure had not operated for an extended time (T>2 years):

- **Questionnaire Part 1 to 3:** Technical aspects were recorded as YES/NO, based on evidential facts and oral reports.
- **Questionnaire Part 4 – Water quality and availability:** These as well as operational aspects (e.g. top-end tail-end use, water availability, licensing) were recorded as NOT APPLICABLE.
- **Questionnaire Part 5 – Institutions:**

  Codes 501-508: Organisations present. The type of organisations present on the scheme at the time of survey were recorded and entered.

  Codes 509-563: Organisations involved in crop production and water management. Organisational roles and responsibilities were all recorded as N/A.

  Codes 564-581: Land exchange and land conflict. The de-facto situation regarding land exchange and land conflict at the time of survey was recorded, regardless of operational and cropping status. The tenure status of landholdings and local land administration practices (crop-share, lease etc.) is not affected by the fact that the irrigation system fails to provide water to the land, so this data was deemed current and relevant.

- **Questionnaire Part 6: Farming system:** This section covered the types of crops grown, marketing channels, and sources of knowledge. Where the scheme was not operational, these data points were N/A.

4.8 Analysis of performance indicators

4.8.1 Background to performance indicators

Globally, irrigation scheme performance has received considerable attention because of the strategic importance of irrigation, its high investment costs, and the increased competition for water across sectors (Faures et al., 2007; Inocencio et al., 2007). More recently, van Averbeke (2012) highlights that while substantial work has been done on irrigation performance, few studies have attempted to identify factors that contribute to differences between schemes.

Molden et al. (1998), in their extensive review of irrigation performance indicators for IWMI, argue that the parameters for performance measurement need to be tailored for the purpose. Performance can be measured to: improve operations; assess progress against strategic goals; measure the impact of interventions; diagnose constraints within a system; compare a system over time; or compare various systems with each other. They emphasise that much work has been done on internal processes (such as water-delivery reliability, fee collections etc.), with few studies of performance across irrigation systems (such as the one undertaken here). The performance indicators put forward by Molden et al. (1998) revolve around the Standardized Gross Value of Production (SGVP) and require detailed information on yields, market prices and water-use volumes, amongst other things. This type of information was not readily available and is costly and time-consuming to obtain. The closest indicator to these type of performance indicators that could reasonably be obtained, given the many schemes and the practicalities of research time available on each scheme, was that of cropping intensity. Bos et al. (2005) present a comprehensive description of performance indicators that can be used for the different purposes such as operational, strategic and diagnostic analysis; the purpose in this research being primarily strategic. They highlight a set of key descriptors that informed the development of the proxy (consolidated) independent variables that characterised the schemes, and the definition of dependent variables that describe 'scheme performance'. Most of the performance indicators however required detailed quantitative data involving extensive research on each scheme such as: water measurements for equity of distribution; measurement of seasonal irrigation volumes to crop yields; financial assessment of water-management organisations, among other. As in the case of the SGVP indicator, the practical and financial limits of the thesis research did not allow for such a high-level of detail, with associated extended time and costs, to be obtained from every scheme.

The characteristic or descriptive variables (independent variables), and the performance variables (dependent variables) were thus informed by Bos et al. (2005) but relied more on a set of consolidated performance indicators that were put forward by van Averbeke (2012) in a study of smallholder schemes in Vhembe District in Limpopo.

The data was finally consolidated to a data set comprising 18 factors. Five of these were dependent variables that reflected scheme performance. The remaining 13 were independent variables, either extracted directly from the original data set or consolidated as described earlier in the chapter. These independent variables characterise the schemes and were expected to explain scheme performance as defined by the five dependent variables.

4.8.2 Scheme performance indicators (dependent variables)

Following from van Averbeke (2012), and also informed by Bos et al, (2005), five performance indicators were used in the analysis as described below, with details in in Table 4.20.

- ***Operational status*:** This is a primary indicator of performance which is definitive when non-operational, but provides no insight into the degree of functionality when operational. An operational scheme is any scheme that provides some irrigation water to farmers, even if inadequately and inequitably.
- ***Number of years operational*:** This data, following simple logic of counting the operational years from scheme commencement, provides an indication of the durability of the system.
- ***Cropping intensity – wet season and dry season*:** Cropping intensity is widely used as an overarching indicator of the level of activity in agricultural systems. In an irrigation context, intensity reflects both water and land utilisation (Molden et al., 2007). Cropping intensity is the total cropped area divided by the irrigable area. It can be expressed as a ratio, but is usually expressed as a percentage. Cropping intensity can also be calculated per season, or for the entire year. When two crops are planted on the whole scheme in a year, the cropping intensity is 200%. Cropping intensity was assessed by asking respondents to estimate how much of the scheme was cropped in each season. A cross-check was then done during the transect walk. Intensity during both seasons was enumerated separately in the survey, with the dry season being particularly important as rain-fed production is possible in the wet season at many of the locations studied.
- ***Degree of commercialisation*:** Commercialisation is reflected by purpose of production and related market linkages (both formal and informal). In the smallholder irrigation discourse, commercialisation and a business orientation for smallholder farmers has been shown to increase production and result in strengthened linkages in the agricultural system (Makhura et al., 1998; Van Hofwegen, 2010).

4.8.3 Factors influencing scheme performance (independent variables)

The independent variables were based on key factors identified in the literature review and on review of the available data in the data set. A table listing the dependent and independent variables, with an explanation of each, is shown in Table 4.20.

Table 4.20: Factors used in the correlation and cluster analysis

Variable	Name	Data type	Description	Data range / example
DEPENDENT VARIABLES (Indicators of irrigation scheme performance)				
Var 1	Operational status as at 2010	Nominal	Indicates whether the scheme is operational or not-operational. depending on whether irrigation water is supplied to farmers (even nominally) or not.	0=Not operational 1=Operational
Var 2	Years operated	Ratio	Measures the 'scheme life' from the date of irrigation scheme operation commencement up to the date when irrigation activity ceased (if not operational at 2010), or up to 2010 (if operational at 2010).	Years (integers from 0 to …)
Var 3	Winter cropping intensity	Ratio	Measures the proportion of scheme land cropped during winter. The winter cropping intensity is the land area cropped in the winter season, divided by the total scheme area. A winter cropping intensity of 0.5 means that half the scheme is cropped in that season.	Any fraction from 0 to 1
Var 4	Summer cropping intensity	Ratio	As above but for the summer season.	Any fraction from 0 to 1
Var 5	Commercialisation index	Ordinal	Estimates the degree of commercialisation among farmers on the scheme. Commercialisation is measured by the fraction of produce that is grown for market purposes.	Any fraction from 0 to 1

INDEPENDENT VARIABLES (factors contributing to irrigation scheme performance)				
Var 6	Command area	Ratio	Size of the scheme as planned and constructed in hectares.	ha
Var 7	Plot size (Average)	Ratio	Size of the scheme divided by the number of plot holders on the scheme in hectares.	ha
Var 8	Rainfall	Ratio	Mean annual rainfall (mm) at the scheme location estimated to the nearest 10 mm from national datasets.	mm
Var 9	Distance to market	Ratio	Distance by road in km to main input/output markets for agro-chemicals and produce.	km
Var 10	Soil suitability index	Ordinal	The index combines scores for soil depth, soil colour, presence of soil salinity, and presence of waterlogging on an area basis, to arrive at an indicator of the overall suitability of the soils on the scheme for irrigation purposes. The higher the index, the more suitable the soils are for irrigation. A factor of 1 means that on the entire scheme there are no soil factors that limit irrigation.	Any fraction from 0 to 1 0 = totally unsuitable soils 1 = no soil limitations
Var 11	Energy source	Nominal	Indicates whether gravity or pumping is used to supply water to the scheme and plots. Pumping includes electricity and diesel sources and covers pumping for fully pressurised systems, as well as booster pumps from canals for sprinklers/micro/drip systems infield.	0 = gravity 1 = pumped

Var 12	Infrastructure condition index	Ordinal	Combines the hydraulic infrastructure and fencing condition scores on a weighted basis. The hydraulic score assesses the main elements of the irrigation system infrastructure and consolidates the status of these elements into four categories (1=critical limitation; 2=major limitation; 3=operable; 4=no limitation). This reflects the ability of the infrastructure to supply water to the field crops. A critical limitation would exist when pumps or infield systems are inoperable, stolen or broken, or canals are dysfunctional and cannot transport any meaningful volumes of water. The fencing score assesses the effectiveness of the fence(s) in protecting the standing crops. Fencing is needed to keep large and small animals which damage crops in the fields. The fencing score combines completeness of fencing (i.e. whole perimeter or not) with the effectiveness of the fence. The combined infrastructure condition index is calculated from both scores, using a set of weightings.	Fraction from 0 to 1 0 = totally defunct infrastructure 1 = optimal condition
Var 13	Water resource constraint index	Ordinal	Combines factors of normal supply, seasonal variations (over one year) and long-term water resource availability to arrive at a measure of resource constraint.	1 = no constraint; 2 = minor; 3 = major; 4 = critical constraint
Var 14	Conflict index	Ordinal	A count of the types of conflict that occur at a scheme, based on a predetermined list of possibilities. Conflict can exist over water, land, theft of crops, theft of equipment and with people off the scheme.	Ranges between 0 and 5 (integer) 1 = No conflict 5 = Conflict in all five domains

Var 15	Land exchange index	Ordinal	Reflects how conducive the land-exchange practices are to enable farmers to expand their farm enterprises. It is calculated by combining factors of organisational involvement (formalisation/enforcement); type of exchange arrangement (monetary exchange, share cropping etc.) and the maximum duration of these exchange arrangements. A value of 0 indicates a non-conducive situation while a value of 1 indicates the most conducive situation possible within the prevailing legal framework.	Ranges between 0 and 1 (any fraction in between) 0 = non-conducive 1 = most conducive
Var 16	Market complexity index	Ordinal	Assesses the extent to which scheme farmers' market produce using different channels, both local and distant. The higher the value, the more complex the marketing approaches are on the scheme, reflecting sophistication.	Ranges between 0 and 9 (integer)
Var 17	Agricultural information index	Ordinal	A consolidated variable which combines the scores for the adequacy of production and marketing information available to farmers, based on their perceptions. A value of 0 indicates that no information is available, while a value of 1 indicates that all agricultural production and marketing queries are answered fully.	Ranges between 0 and 1 (any fraction in between) 0 = no information available 1 = all information needs met
Var 18	Irrigation method	Nominal	A simple descriptor of the infield irrigation system type into three main categories linked to increasing modernisation. *Surface* irrigation included furrow, short-furrow and basin methods. *Sprinklers* included draglines, quick-coupling laterals and centre-pivots. The category of *micro* included floppy sprinklers (by virtue of their association with modernisation), micro-jets and drip irrigation systems.	Range 1-3 (integer) 1 = surface 2 = sprinkler 3 = micro

4.9 Separate analysis of 'failure' and 'success'

4.9.1 Background

The analysis focussed first on all 102 schemes to investigate which factors are linked to a scheme's failure to operate. This was followed by an analysis of operational schemes to understand why schemes are successful and thrive. The terms 'failure' and 'success' are used descriptively but are defined more exactly by the choice of performance indicators used for each. The full dataset is included in Appendix 4 and the variables used in the statistical enquiries are listed in Tables 4.21 and 4.22, with the reasoning expanded upon thereafter.

Table 4.21: Summary of statistical analysis to understand 'failure' and 'success'

Enquiry into …	Type and number of schemes	Analysis	Dependent variables (performance factors)	Independent variables
'Failure'	All schemes (n=102)	Association/correlation	Var 1: Operational status Var 2: Scheme longevity	9 used
'Success'	Operational schemes[1] (n=61) [2]	Association/correlation Cluster Principle component	Var 1: redundant Var 2: Scheme longevity Var 3: Winter intensity Var 4: Summer intensity Var 5: Commercialisation	13 used

[1] Variable 1 (operational status) was redundant in the 'success' analysis because it applied to operational schemes only.

[2] The operational schemes total 65 in number, but four schemes under the RESIS-Recharge program were excluded for reasons that are explained in Section 4.10.2.

4.9.2 Analysis of factors contributing to scheme failure (n=102)

The association and correlation analysis (including Chi-square and Spearman's Rank as appropriate to the type of data) was conducted for the full set of 102 schemes to understand the effect of factors on 'failure'. Data availability limited these to a reduced number of performance (dependent) variables and influencing (independent) variables. This was because during the fieldwork process it was not possible to obtain reliable data for many of the non-operational schemes on factors such as intensity of production, commercialisation, scheme conflict, land-exchange prevalence, the nature of production organisations, etcetera, because of elapsed time since failure. There was useful and comprehensive data on physical and technological factors such as scheme size, average plot size, key elements of the engineering design, the infield irrigation method, water availability (in cases augmented by DWAF data), soils, rainfall and location. The absence of information about certain variables on the non-operational schemes resulted in a focus on two of the five performance variables (operational status and longevity) and nine of the 13 independent variables. This analysis of failure to operate can also be understood as an enquiry into 'kill factors'. The extent of data availability and the inclusion or exclusion of variables in the failure analysis is shown in Table 4.22.

4.9.3 Analysis of factors contributing to 'success' (n=61)

The data set for the operational schemes (n=65) was almost complete as shown in Table 4.20. Only one element was missing for Variable 14 (Conflict). The four RESIS-Recharge schemes were excluded from the success analysis for the reasons explained earlier (ie. Joint Venture schemes), leaving the number of analysed schemes at 61.

4.10 Statistical tests

4.10.1 Three levels of analysis

Descriptive statistics were first generated to describe the population of smallholder irrigation schemes using one variable at a time. These are reported in Chapter 5.

The second analysis tested for associations between each of the independent variables and each of the scheme performance variables. The data type, either nominal, interval, ordinal, or ratio is shown in Table 4.23, and determined whether association tests (using Chi-square) or correlation tests (Spearman's rank) were appropriate.

In the case where one of the variables comprised nominal data (Variables 1, 11 and 18), a Chi-square test was conducted to establish the probability of an association through the derived p-value. When the other data set comprised ratio data, range-limits were defined and frequencies were calculated to convert to interval data for application of the test (Roscoe, 1975).

The strength of the association was calculated using Pearson's Phi or Cramer's V tests.

- When both data sets were binary, the strength of the Chi-square association was assessed using Pearson's Phi. Pearson's Phi is weaker when closer to the value of zero and stronger when closer to the value of one, interpreted similarly as a correlation coefficient, excepting Phi is absolute, and a correlation coefficient can be negative.

Table 4.22: Data availability and inclusion or exclusion in the statistical analysis for 'failure' and 'success'

			Data availability					Inclusion in analysis	
	Variable	Descriptor	All schemes (n=102)	Oper-ational[1](n= 65)	Non Oper-ational (n=37)	Oper-ational %	Non Oper-ational %	'Failure' (all schemes)	'Success' (operational schemes only[1])
Dependent variables (scheme performance)	Var 1	Status in 2010	102	65	37	100%	100%	Y	Y
	Var 2	Years Operated	102	65	37	100%	100%	Y	Y
	Var 3	Winter cropping intensity	73	65	8	100%	22%	N	Y
	Var 4	Summer cropping intensity	73	65	8	100%	22%	N	Y
	Var 5	Commercialisation index	83	65	18	100%	49%	N	Y
Independent variables (factors impacting on performance)	Var 6	Command Area	102	65	37	100%	100%	Y	Y
	Var 7	Plot size (average)	102	65	37	100%	100%	Y	Y
	Var 8	Rainfall	102	65	37	100%	100%	Y	Y
	Var 9	Distance to Market	102	65	37	100%	100%	Y	Y
	Var 10	Soil Suitability Index	102	65	37	100%	100%	Y	Y
	Var 11	Energy Source	102	65	37	100%	100%	Y	Y
	Var 12	Infrastructure condition index	102	65	37	100%	100%	Y	Y
	Var 13	Water resource constraint score	102	65	37	100%	100%	Y	Y
	Var 14	Conflict score	91	64	27	98%	73%	N	Y
	Var 15	Land exchange index	92	65	27	100%	73%	N	Y
	Var 16	Market diversity score	80	65	15	100%	41%	N	Y
	Var 17	Agricultural information index	79	65	14	100%	38%	N	Y
	Var 18	Main irrigation method	102	65	37	100%	100%	Y	Y

[1] The operational schemes total 65 in number, of which four, under the RESIS-Recharge program, were excluded in the 'success' analysis.

- When one of the data sets was not binary, Cramer's V test was used to establish the strength of the association. The interpretation is similar to Pearson's Phi.
- The interpretation of the strength of Chi-square association tests was discussed in four classes (where sr=strength ratio): weak (sr<0.3); moderately weak (0.3≤sr<0.49); moderately strong (0.5≤sr<0.7); and strong (sr≥0.7) (after Moore et al., 2013).

In the case where variables comprised either ordinal, interval or ratio data:

- Spearman's rank correlation was used to identify the correlation coefficient and the p-value. Correlations increase from zero to one, and the strength of the correlation coefficient (r) was interpreted as above (Moore et al., 2013).
- The p-value is the probability that the null-hypothesis (i.e. that correlation does not exist) is false given the data size and distribution. A p-value of 0.01 for example, reflects a 99% probability that the null-hypothesis is false. A 95% confidence interval was used in all cases.

The association tests, as they were applied to the variables in the failure analysis and the success analysis are shown in Table 4.23 and Table 4.24.

Table 4.23: Type of association tests conducted in relation to failure on all smallholder schemes in the data set (n=102)

Scheme Characteristic (independent variable)		**Data Type**	**Var 1: Operational Status (binary)**	**Var 2: Lifespan (ratio)**
Var 6	Command area	Ratio	Chi Square	Spearman's Rank
Var 7	Plot size (average)	Ratio		Spearman's Rank
Var 8	Rainfall	Ratio		Spearman's Rank
Var 9	Distance to market	Ratio		Spearman's Rank
Var 10	Soil suitability index	Ordinal		Spearman's Rank
Var 11	Energy source (binary)	Nominal		Chi Square
Var 12	Infrastructure condition index	Ordinal		Spearman's Rank
Var 13	Water resource constraint score	Ordinal		Spearman's Rank
Var 18	Main irrigation method (3 classes)	Nominal		Chi Square

Table 4.24: Type of association tests conducted in relation to success on operational smallholder schemes in the data set (excluding Joint-Ventures) (n=61)

Dependent variables		**Data type**		
Var 2	Years operated	Ratio	None of the dependent variables are nominal, thus the selection of the appropriate test is based on the data type of the independent variable below.	
Var 3	Winter cropping intensity	Ratio		
Var 4	Summer cropping intensity	Ratio		
Var 5	Degree of commercialisation	Ordinal		
Independent variables			**Chi Square**	**Spearman's Rank**
Var 6	Command area	Ratio		✔
Var 7	Plot size (average)	Ratio		✔
Var 8	Rainfall	Ratio		✔
Var 9	Distance to market	Ratio		✔
Var 10	Soil suitability index	Ordinal		✔
Var 11	Energy source (2 classes)	Nominal (binary)	✔	
Var 12	Infrastructure condition index	Ordinal		✔
Var 13	Water resource constraint score	Ordinal		✔
Var 14	Conflict score	Ordinal		✔
Var 15	Land exchange index	Ordinal		✔
Var 16	Market diversity score	Ordinal		✔
Var 17	Agricultural information index	Ordinal		✔
Var 18	Irrigation method (3 classes)	Nominal	✔	

The *third stage* of analysis involved undertaking a cluster analysis and a principle component analysis. Tan et al., (2013) explains that clusters are essentially classes or groups, and that a cluster analysis is a technique for automatically defining categories. Certain clustering methods have the utility function of defining cluster prototypes, where characteristics are generated to most closely represent the data in the cluster. In pursuing the cluster analysis, the characteristics used for clustering were defined based on the factors identified in the literature review.

Principle Component Analysis (PCA) is a technique used to emphasize variation and bring out strong patterns in a dataset and is often used to make data easy to visualize and explore. The method is useful for interval data but can also be used for ordinal data (e.g. Likert scales), where the variables are linearly related to each other (Rencher, 2002; Manly, 2005). PCA offers a convenient way to control the trade-off between losing information in the database (through abstraction or data compression) and having the useful result of simplifying the problem at hand (Manly, 2005). PCA generates eigenvalues, which indicate the variances of the principle components. Manly (2005) notes that it is essential that variables used as input to PCA are moderately correlated to each other or the number of principle components will be almost the same as the original variables and the analysis will serve no purpose. The output from PCA lists eigenvalues where the largest value indicates the variable with the greatest variation, ending with variables with low or zero eigenvalues. The PCA analysis highlights the relative contribution of independent variables in describing the data set, thereby their relative importance. It also provides an indicative grouping of schemes by virtue of the dominant characteristic indicators.

4.11 Closing note on Chapter 4

The field research method, data management and analytical approach described in this chapter was informed by the specific objectives of the thesis. The research aims to answer questions on the relative contribution of factors in relation to scheme performance in two modes; that of success and that of failure. The statistical analysis involving associations and correlations will provide insight by showing if there is a statistically meaningful relationship between the independent variables (that characterize the schemes) to the dependent variables (that reflect scheme performance). The principal component analysis will contribute to this understanding by giving weights to the dominant independent variables that impact on scheme success and failure.

A second aim of the research is to develop a statistically-substantiated scheme typology to inform irrigation development interventions in South Africa. The cluster analysis was the main analytical tool to empirically group schemes based on their dominant features.

The logical links between the analysis and the intended aims of the research are shown in Figure 4.3.

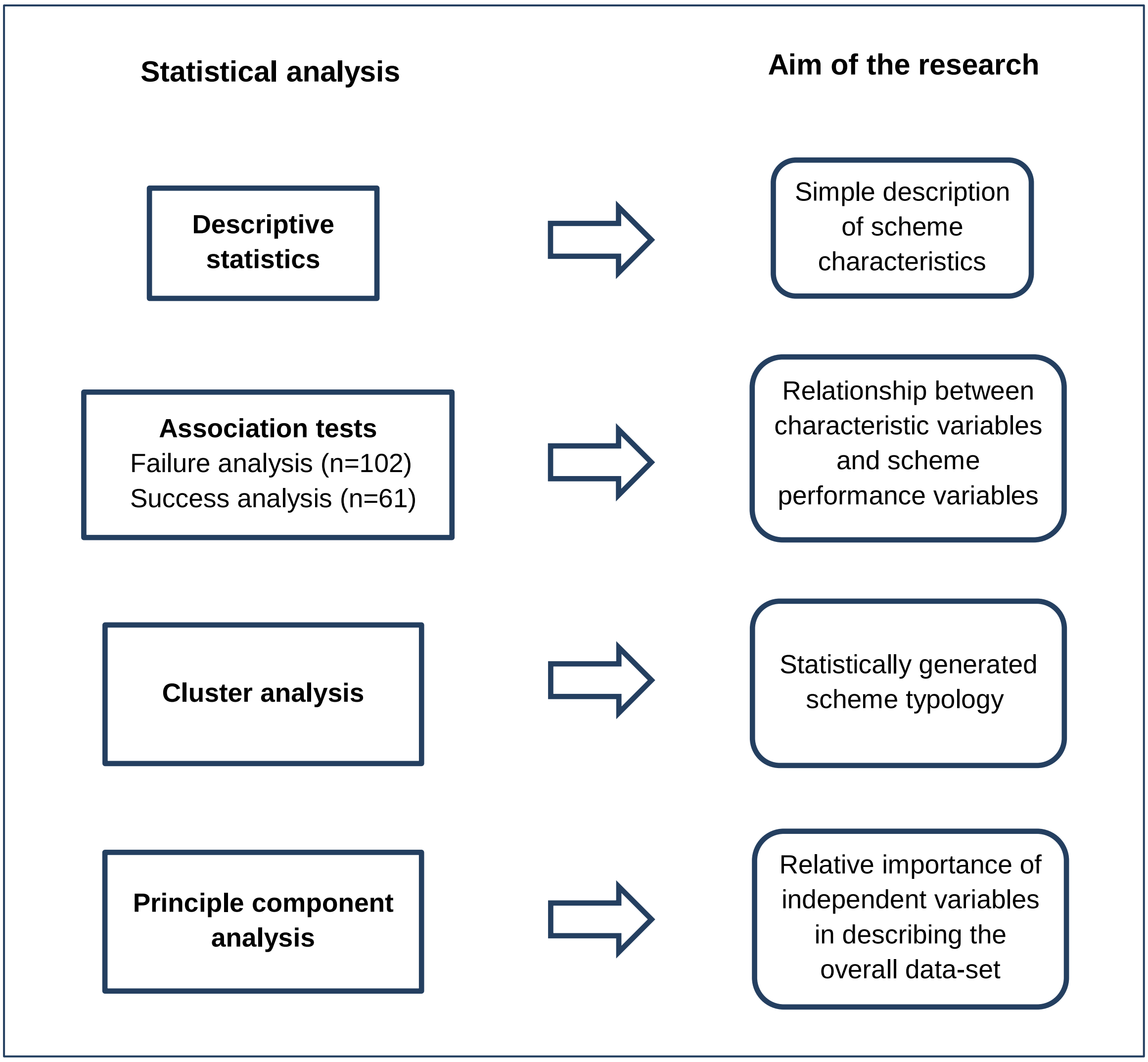


Figure 4.3: Linkage between statistical tests and the aims of the thesis

Chapter 5 that follows presents the summary statistics of the primary data-set and the meta-data derived from the consolidated proxy variables. Chapter 6 provides a detailed description of the association, cluster and principle component analysis.

5 DESCRIPTIVE STATISTICS

This chapter describes the first level of analysis and provides a summary of the characteristics of the 102 schemes finally included in the scheme database. Chapter 6 describes results of the statistical evaluation involving the correlation, cluster and principle component analysis.

In overview, the 102 schemes cover a total net command area of 12 128 ha, this being the original planned area of the schemes. A total of 65 schemes were operational, meaning some irrigation water was supplied to crops through the irrigation system at the time of survey. The command area of the 65 operational schemes amounted to 6,606 ha, though not all of this command area was serviceable by the existing irrigation infrastructure. In some cases, the quantity of water supplied, and the irrigated area was very small due to water shortages or degraded infrastructure, but these were nonetheless defined as operational. The remaining 37 schemes covering 5 522 ha were not operational at the time of the survey; these were schemes with no irrigation water supplied to the fields. The survey results, described in detail in sections 5.1 to 5.10, are summarized in section 5.11.

5.1 Plot holder populations and scheme sizes

The distribution of scheme sizes is shown in Figure 5.1. The average scheme size was 118.9 ha and the median was 81.15 ha. Most schemes are in the size range of 50 to 250 ha (n=76), with 10 schemes larger than 250 ha and nine schemes 20 ha or smaller. The combined scheme area of 12 128 ha was held by 9 060 plot holders. The defunct Mid-Letaba scheme is the largest scheme on the database (at 1 730 ha) and has the most plot holders (n=1442). The smallest scheme is Klein Tshipise, with a command area of only 9 ha, which is occupied by 30 plot holders, each holding an average of 0.29 ha. Three schemes (Sanari, Tsatane and Makhuva) have the smallest number of plot holders, with just six people each, although each of these schemes has average plot sizes which are unusually large (5 ha, 10 ha and 14.6 ha respectively).

The data set thus comprises mostly small irrigation schemes. While there is no norm, Lankford et al., (2016) note that large schemes are generally those over 3,000 ha, though in sub-Saharan Africa, schemes over 1,000 ha are considered large-scale. On this basis, only Mid-Letaba (1,730 ha) is a large scheme, the rest being small to very small schemes.

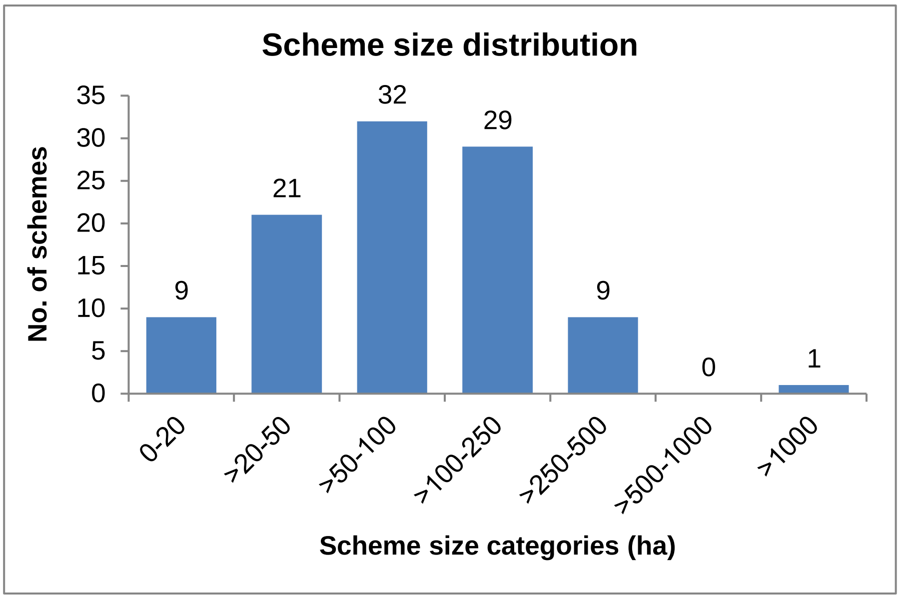


Figure 5.1: Frequency distribution of smallholder irrigation scheme size in Limpopo Province (n=102: 2010)

Average plot size per scheme for the data set are presented in Figure 5.2 and show a predominance of relatively small irrigation parcels. The average plot size across all of the schemes was 1.34 ha. The largest average plot size on a scheme, of 16.25 ha, was found at Phaswana (scheme size of 260 ha), while the smallest average plot size, of 0.178 ha, was at Nesengani B1 (scheme size of 20.6 ha). Schemes with average plot sizes of between 1-1.5 ha are most prevalent (47.1% of schemes), with 72.9% of the schemes having average plot sizes in the range of 0.51-2.0 ha.

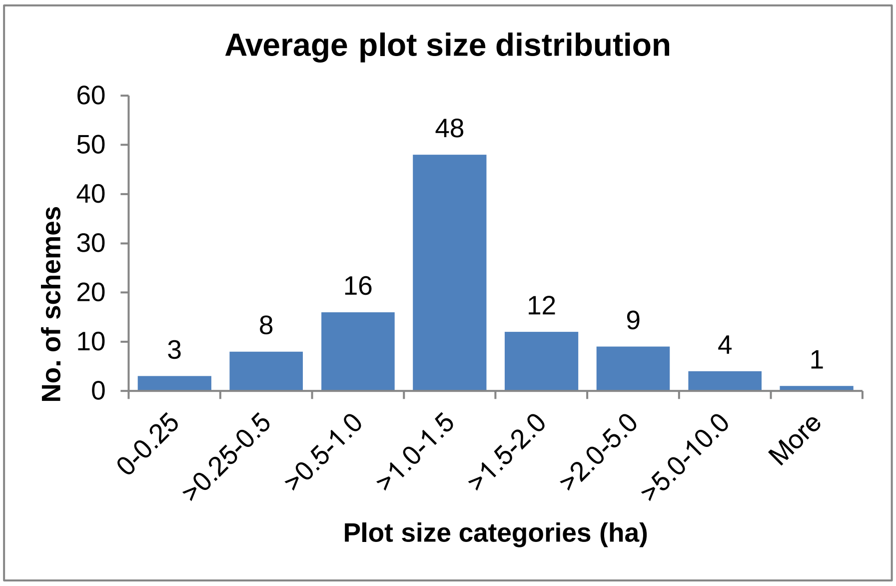


Figure 5.2: Frequency distribution of average plot size smallholder irrigation schemes in Limpopo Province (n=102; 2010)

Only 14 schemes have average plot sizes of over 2.0 ha, and the combined area of these schemes was equal to 2 669 ha (22.0% of the total smallholder scheme area surveyed). This reality of predominantly small plot sizes, mostly smaller than 2.0 ha, has implications for the discussion of commercialisation, which is associated with larger farms.

5.2 Scheme age and irrigation method

Schemes that were mostly in their original form were dated from their original commencement of irrigation activity, based on the Government records. Schemes that underwent fundamental changes in the form of their infrastructure, typically conversion from gravity canals to pumped pipeline infrastructure, were dated from the time of rehabilitation. At the time of the survey, most of the schemes were old, with the average being 30.7 years and the median 34 years. The two oldest schemes were Mecklenburg (72 years) and Thabina (61 years). Nineteen schemes were older than 50 years, 35 schemes were between 30 and 50 years old, 28 schemes between 10 and 30 years old, while 20 schemes were constructed, or underwent major re-construction in the last decade.

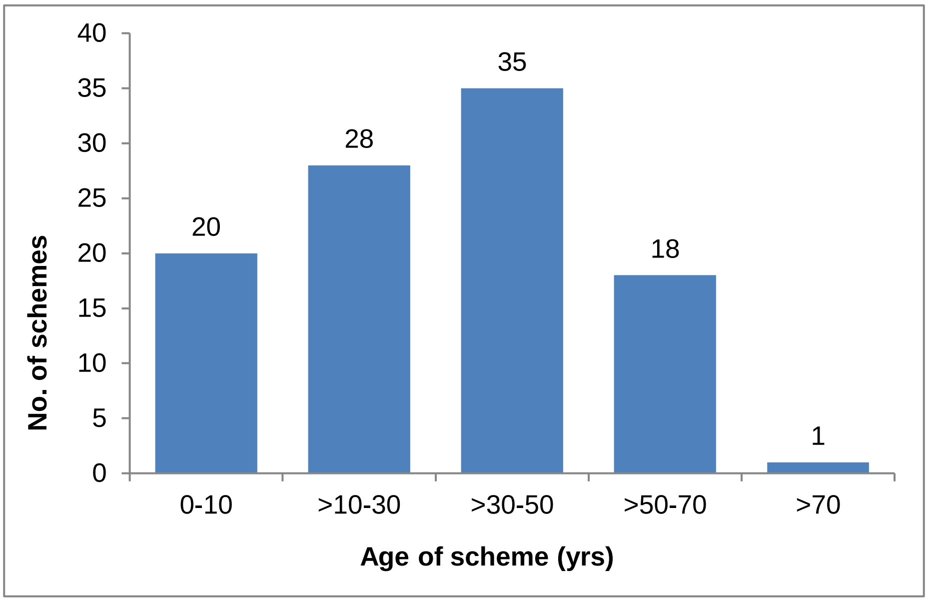


Figure 5.3: Age distribution of Limpopo smallholder irrigation schemes (n=102; 2010)

In line with the development philosophies of the different development eras discussed in Chapter 2, gravity-canal schemes were much older. These had an average establishment date of 1960 but commencement ranged from 1938 to as late as 1988. Pumped schemes were established on average 28 years later (average 1988), between 1970 and 2006.

5.3 Type of water and source and energy

The source of water and energy used for water supply are summarised in Table 5.1. Rivers were the primary source of water for 68 schemes, while dams and reservoirs supplied 28 schemes. Five schemes were supplied from springs (Platklip, Vlakspruit, Rietfontein, Klein Tshipise and Luvhada). On 37 schemes, water was diverted from rivers using weirs and two of these received supplementary water from springs (Garside and Lucerne). Only one scheme, Sekgagapeng, was totally reliant on boreholes, while Steelpoortdrift was supplied by a dam (one of the 28), but had supplementary boreholes, which only worked occasionally. Steelpoortdrift was categorised as a gravity scheme, because it relied primarily on gravity supply, even though it had three boreholes, used ad-hoc for supplementary supply to furrows.

Data on pumping energy is also shown in Table 5.1 and pertains to the situation where there is any pumping on the scheme (either lifting to field level from a river, and/or providing booster-pressure for sprinklers, pivots or micro-jets, and/or supplementary pumping to gravity schemes from boreholes). Pumping was used for irrigation on 51 schemes (including the Steelpoortdrift supplementary borehole pumps). The energy sources on the 51 pumped schemes (including Steelpoortdrift) comprised electricity (43 schemes), diesel (6 schemes), and a combination of both electricity and diesel (2 schemes). Of the 8 schemes in total that used diesel, only two were operational at the time of survey. Gravity pressure was used for sprinklers on only two schemes, at Julesburg and Sterkspruit, although the condition of both was severely dilapidated and pressurised irrigation took place in an ad-hoc manner alongside surface irrigation.

Table 5.1: Source of water and primary energy for irrigation on Limpopo smallholder irrigation schemes (n=102; 2010)

	Main source	Supplementary source[1]	Gravity	Pumps utilised
Run of river (weirs)	68	---	37	31
Dams	28	---	10	18
Springs	5	2	5	0
Boreholes	1	1	0	2[1]
	102	3	52	51

[1] The schemes were categorised on the primary source on which they were dependant for their irrigation supply, but Steelpoort scheme (a gravity supplied scheme) also had supplementary borehole pumps. This was an exception, and is double counted in the table, thus explaining why the total gravity plus pumped schemes totals 103 and not 102 schemes in the table above.

On 30 schemes pumping was used to lift water from the source and to pressurise the infield irrigation system; on 16 schemes pumps were used to boost pressure from main-supply canals; on the remaining 5, water was lifted from the source and surface irrigation was practiced (either furrow or short furrow).

5.4 Scheme operational status and energy source

A total of 65 of the 102 schemes were operational, while 37 were not. In the statistical correlation assessment (Chapter 6), the operational status is one of the five scheme performance indicators tested for associations with independent factors. In this summary assessment, some general enquiry is made and operational status is quantified in relation to energy-source (Figure 5.4) and type of irrigation (Figure 5.5). Pumping has energy-cost, complexity and maintenance considerations, while irrigation system-type has bearing on factors such as water application efficiency, production labour and operational costs. There were 52 gravity-supplied schemes, and 50 schemes where irrigation was dependant on pumping.

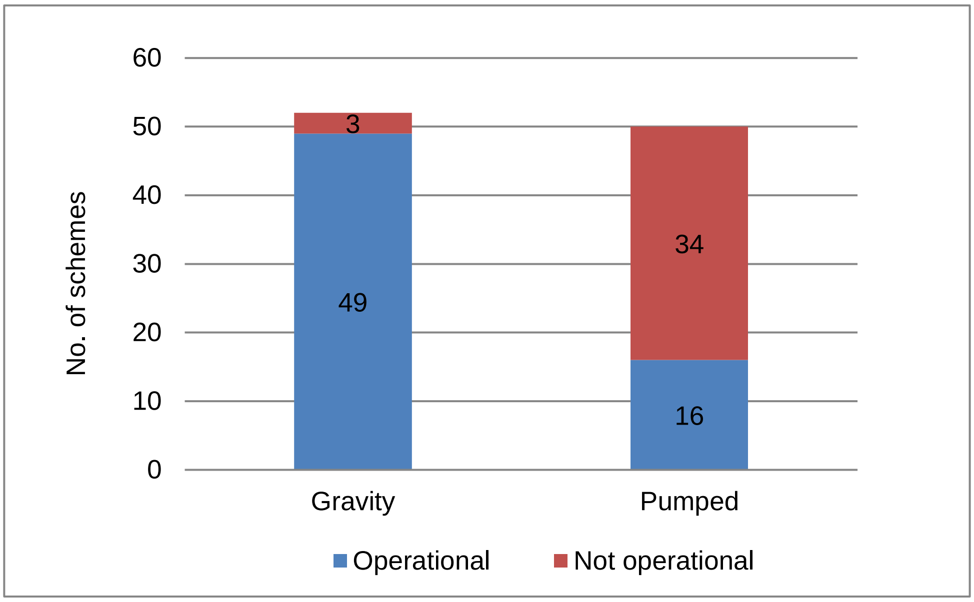


Figure 5.4: Operational status and energy source on smallholder irrigation schemes in Limpopo Province (n=102; 2010)

The operational status shows that 49 of the 52 gravity schemes were operational (96%), while only 16 of the 50 pumped schemes were still operating (32%). Of the 37 non-operational schemes it is significant that 34 were pumped schemes, while only three were gravity-supplied (Rietfontien, Koedoeskop and Lepellane). These gravity schemes that failed were dilapidated, but failure was attributed by respondents to changes in the bulk water supply regime and resultant severe water-resource stress. In the case of Lepellane, the supply dam was heavily silted plus the water was entirely re-allocated by the Department of Water and Sanitation to a mining company. The rather tragic situation on two of these schemes is reflected in the photos in Plates 5.1 and 5.2. No production takes place on these two schemes, but at Rietfontein the whole area is cropped with rainfed summer maize.

Plate 5.1 and 5.2: Koedoeskop (left) and Lepellane (right) schemes; two of the three gravity schemes in the data set that were not operational at the time of survey.

5.5 Infrastructure

The scheme irrigation system type is shown in Table 5.2 and Figure 5.5. The data reflect the scheme designed command area, not the functional irrigable area, which is smaller. Water supply shortages or infrastructure dilapidation are the main reasons for reduced operational size, elaborated after Figure 5.5.

5.5.1 Irrigation system type

Just over half of the designed irrigation area used surface irrigation with furrow, short-furrow and basin irrigation methods equal to 6,086 ha (equivalent to 50.2%). Sprinkler systems, comprising draglines, quick-coupling sprinkler lines, centre-pivots and floppy-sprinklers contributed 5,445 ha (44.9%) of the command area. Micro-jets and drip irrigation made up a very small contribution of 598 ha (4.9%) at the time of survey.

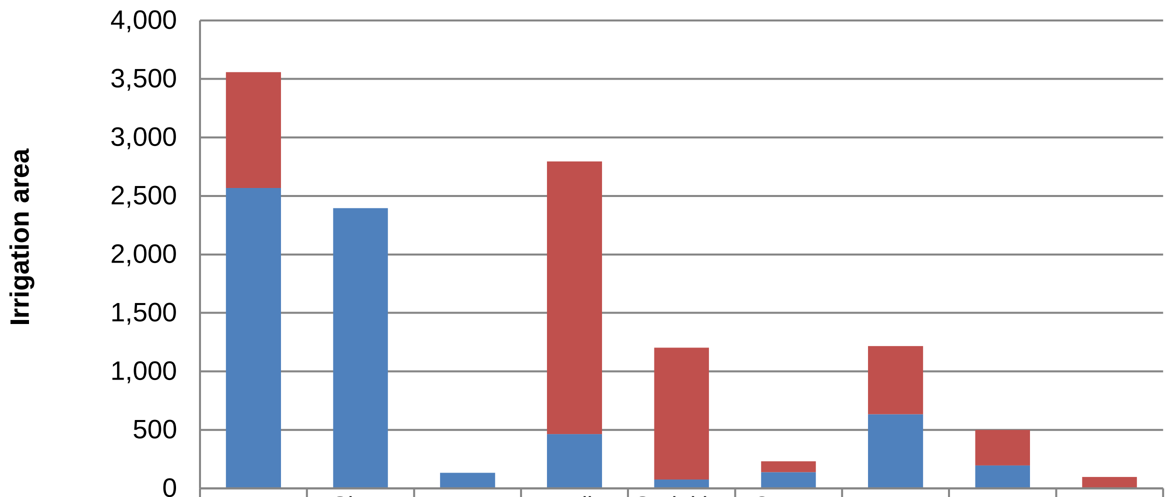
When looking at the operational schemes only, the areas under the different technologies contrast to the full data set including all schemes. Of the schemes that were operational, totalling 6,606 ha, surface irrigation dominated on at 5,097 ha (77.2%, compared with 50.2%

for all schemes). The schemes designed under sprinkler systems had only 1,313 ha which were functional (19.9%, compared with 44.9% for all schemes).

Table 5.2: Irrigation type and area for operational and non-operational smallholder schemes in Limpopo Province (n=102; 2010)

Irrigation type	Operational schemes (ha)	Non-operational schemes (ha)	Total area (ha)	% of Total schemes	% of Operational schemes
Furrow	2 569	990	3 557	29.3%	39%
Short furrow	2 396	0	2 396	19.8%	36%
Basin	133	0	133	1.1%	2%
Dragline sprinkler	464	2 332	2 795	23.0%	7%
Sprinkler line	76	1,126	1 202	9.9%	1%
Centre pivot	138	93	231	1.9%	2%
Floppy	635	582	1 217	10.0%	10%
Drip	196	305	501	4.1%	3%
Microjet	0	97	97	0.8%	0%
Sub-surface	0	0	0	0.0%	0%
Border strip	0	0	0	0.0%	0%
Wild flooding	0	0	0	0.0%	0%
Raingun sprinkler	0	0	0	0.0%	0%
TOTAL	**6 606**	**5 525**	**12 128**	**100.0%**	**100.0%**

The serviceable irrigation area, which is that portion which could physically be irrigated given the extent of the serviceable hydraulic infrastructure, is much smaller than the design command area. The serviceable irrigated area of 5 408 ha is equivalent to 81.9% of the scheme design command area of operational schemes (5 408/6 606 ha). As a percentage of the *area on all schemes,* the serviceable irrigated area equals 44.6% (5 408/12 128 ha). This does, however, slightly underestimate the serviceable area, as there is an additional 791 ha on various non-operational schemes that for most practical purposes comprise serviceable infrastructure. The only reason these were not operational was because the pump stations were not operating at the time of survey because of relatively minor technical issues (in terms of complexity and cost) or cable theft. A more realistic estimate for the serviceable area would thus be 6 199 ha, which is 51.1% of the total design command area.



	Furrow	Short furrow	Basin	Dragline sprinkler	Sprinkler line	Centre pivot	Floppy	Drip	Microjet
Not operational	990	0	0	2,332	1,126	93	582	305	97
Operational	2,569	2,396	133	464	76	138	635	196	0

Figure 5.5: Irrigation method by design command area on smallholder irrigation schemes in Limpopo Province (n=102; 2010)

The large difference between the design command area (12 128 ha) and the serviceable area (6 199 ha) can be attributed to the following:

i) Most significantly, the irrigation area is reduced because old and dilapidated infrastructure was not repaired or replaced, resulting in large parts of the original schemes being without means for water distribution.

ii) Irrigation revitalisation efforts often involved a change in irrigation technology, such as a shift from furrow irrigation to centre-pivots, drip or floppy systems, leading to unused irrigable portions. Centre-pivots, such as implemented at Makulele scheme, by virtue of their circular shape, result in a loss of approximately 20% of land between the irrigated circles. In some modernisation efforts, cost-efficiency considerations of drip or floppy systems required regularisation of the shape of lands and a focus on the most suitable soils only (e.g. at Wonderboom).

iii) The irrigated area is often reduced permanently when there are significant reductions in the availability of the bulk water resource.

5.5.2 Hydraulic infrastructure condition

Data was obtained on scheme water infrastructure and on fencing, these being two key factors enabling irrigated production. The data is shown in Table 5.3 and expressed as a percentage of schemes in Figure 5.6. The condition of the hydraulic infrastructure was recorded using a ranking of 1 to 4 (with 1 being fully operational and 4 being critically dilapidated and/or dysfunctional). The condition was recorded for the main categories of scheme hydraulic components: infield irrigation systems (if pumped); main and secondary canals; tertiary canals (infield); and canal gates and hydraulic structures. Pump stations were assessed either as operational or not-operational. The condition of the various hydraulic elements was consolidated into an infrastructure condition index, using the same four-scale rating system as detailed in Chapter 4.

Table 5.3: Operational condition of hydraulic infrastructure of smallholder irrigation schemes in Limpopo Province (n=102; 2010)

Consolidated variable for infrastructure operational condition	Whole scheme assessment (Number of schemes)[1]	Components of the hydraulic infrastructure[2]				
		Pumped components		Canal components		
		Pumps	Infield pressurised system	Main & Sec. canals	Infield canals (tertiary)	Gates & Hydr. Control
Fully operational	38	26	17	13	13	18
Operational - moderate limitation	33	---	6	30	14	17
Operational – serious limitation	13	---	9	14	7	8
Not operational – critical limitation	18	24	16	10	0	8
n =	102	50	48	67	34	51

Notes: [1] Operational condition of the whole scheme based on the consolidated dummy variable calculation of all of the hydraulic infrastructure components

[2] Schemes can comprise multiple components explaining why the components do not total to the number of the schemes.

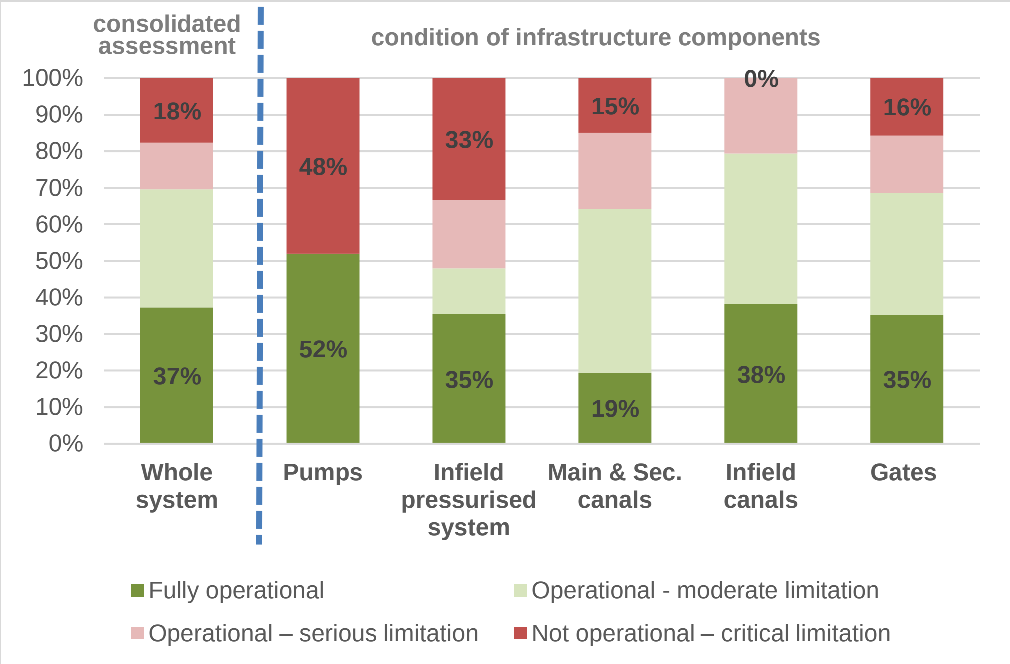


Figure 5.6: Condition of overall hydraulic infrastructure and infrastructure components of smallholder irrigation schemes in Limpopo Province (n=102; 2010)

The pumps and related pressurized systems reflected significantly worse operational status percentage-wise than the surface irrigation infrastructure (illustrated in the top 'not-operational' bar of the columns in Figure 5.6). This is the case despite the canal schemes being of a much older average age. Pumped schemes (from construction to time of survey) averaged 13.6 years (n=50), while gravity-canal schemes were on average three times as old at 46.6 years (n=52), reflecting the shifting technology focus over the eras of irrigation development in South Africa. The condition of the small infield canals was never critical because these could always be overcome with ad-hoc farmer-built ditches to transport water.

5.5.3 Fencing status

The condition of fencing on schemes is shown in Figure 5.7. On 53 schemes the fencing was completely ineffective. Partially effective fencing was recorded on 26 schemes. This fencing would keep out a significant number of large animals (cows and larger buck) but not be effective for smaller animals such as goats and small buck. Only 23 schemes had fully effective fencing. At some of the wilder locations, bush pigs and baboons were able to access fields and raid crops regardless of fencing measures. Other measures such as night-guarding and hunting were adopted, but no quantification of these tactics was attempted in the survey.

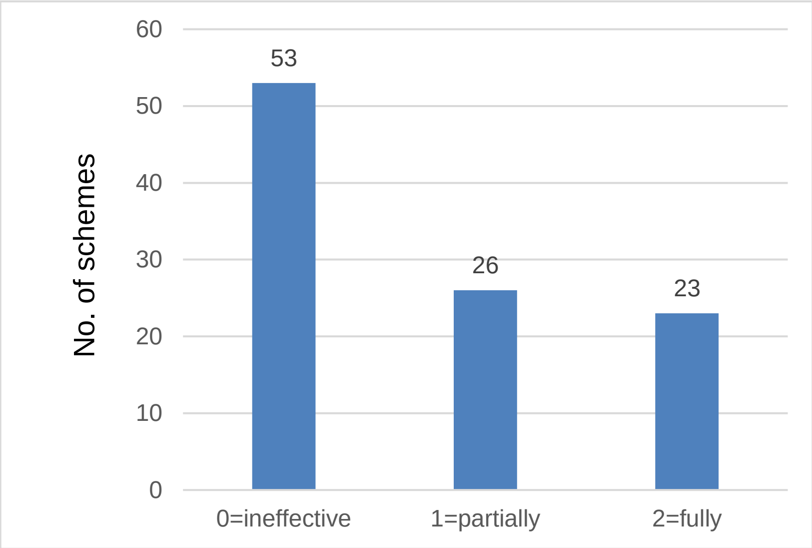


Figure 5.7: Effectiveness of fencing on smallholder irrigation schemes in Limpopo Province (n=102; 2010)

5.5.4 Combined fencing and hydraulic infrastructure condition index

In order to assess the relationship between overall infrastructure condition and performance variables, a consolidated infrastructure variable was developed. The results of the combined hydraulic and fencing condition, weighted as explained in Chapter 4, are shown in Figure 5.8. The quantification using the index provides a general classification and positions each scheme within a spectrum, from totally dilapidated (very poor) to optimal. The consolidated variable is important as it facilitates the correlation and cluster analysis. In terms of overall physical infrastructure, there were 38 schemes in very poor condition, 33 were dilapidated but functional in a limited way, 19 were in moderate condition and 12 were in good to optimal condition.

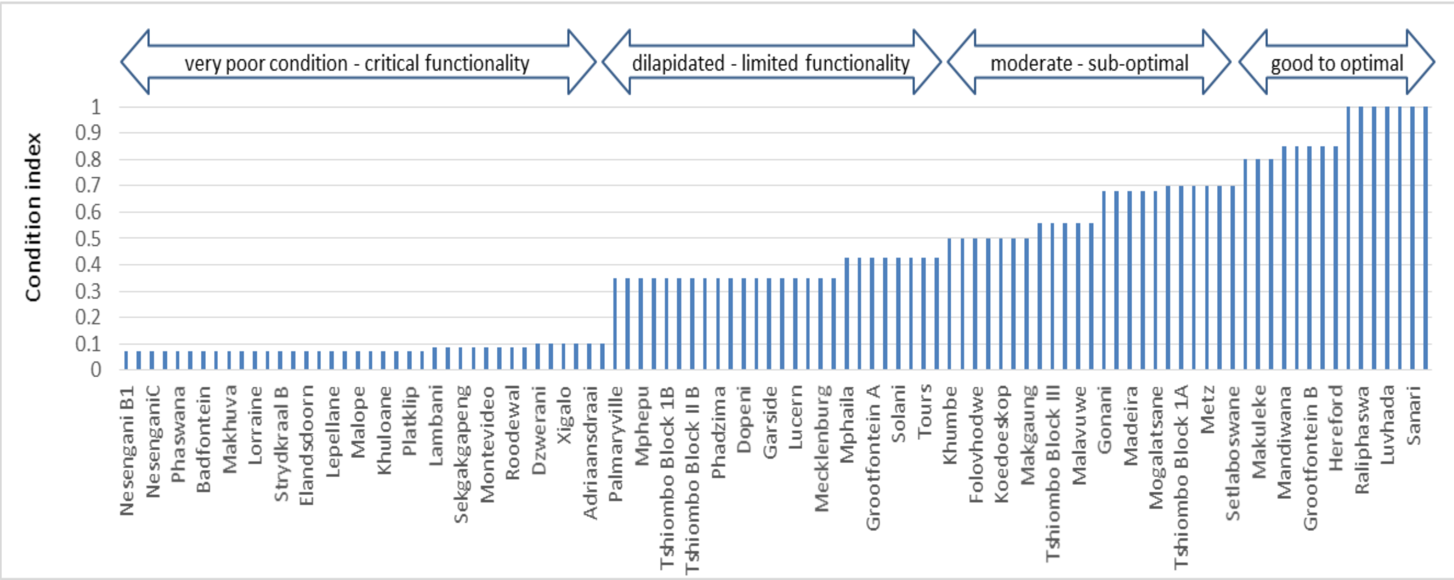


Figure 5.8: Combined hydraulic and fencing infrastructure condition index for smallholder schemes in Limpopo Province (n=102; 2010)

5.6 Adequacy of supply

Adequacy of water supply to schemes was assessed based on respondents' experiences on water availability to meet demand all-year round in normal years, with regard to seasonal fluctuations within any one normal year, and in relation to long-term fluctuations (a scheme could meet demand in normal years but suffer shortages in longer term cycles). The responses are shown in Figure 5.9, disaggregated by energy type (gravity or pumped).

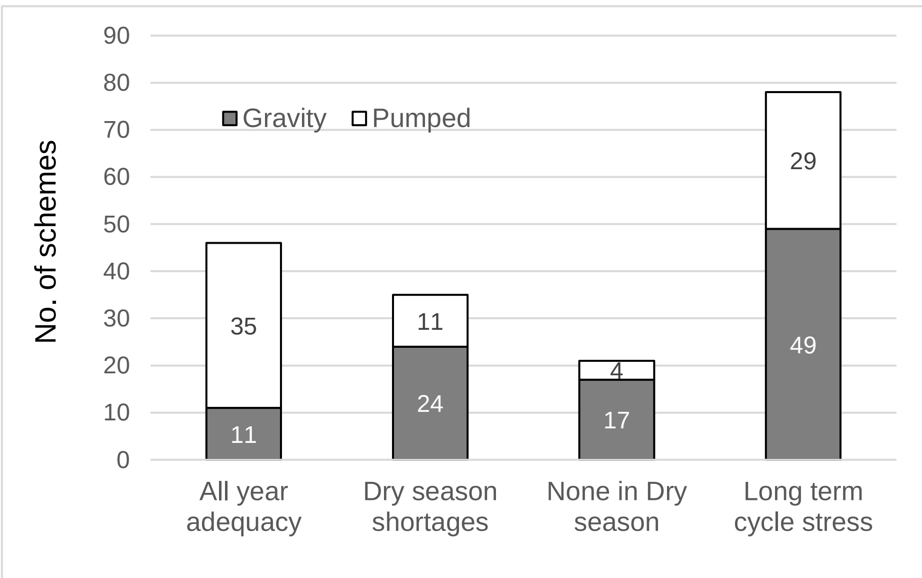


Figure 5.9: Adequacy of water resource availability on smallholder irrigation schemes in Limpopo Province (n=102; 2010)

Given reliance on respondents' memory and knowledge, it follows that a normal year is not intended to mean statistically 'normal' but is the respondents' subjective perspective on the usual situation of water availability. The data collection process allowed for only one of the first three categories to be chosen, and the fourth (long term cycle stress) was applicable to all situations.

Over the long-term cycle, 73 schemes experienced inadequate supply, but in normal years, respondents from 46 schemes reported that there was an adequate supply all year round. Shortages in the dry season were reported on 35 schemes, while 21 reported no water at all in the dry season. Gravity canal schemes suffered more water shortages than pumped schemes, with only 11 of the 46 schemes where water was adequate all year round being gravity canal schemes. The pattern of more water stress on gravity schemes is reflected in dry season shortages, and where there was no dry-season water supply. Gravity schemes accounted for 69% and 81% of these two high-stressed categories.

The indicators for adequacy of water supply were combined into a single water resource constraint index as explained in Chapter 4. Here "no constraint" was ranked as 1, and a "critical constraint" was ranked as 4. A critical constraint meant that the water resource was always in short supply and was critically constraining production on the scheme all year round, regardless of season or longer-term drought cycles. Water resource availability by scheme frequency using this proxy index is summarised in Figure 5.10.

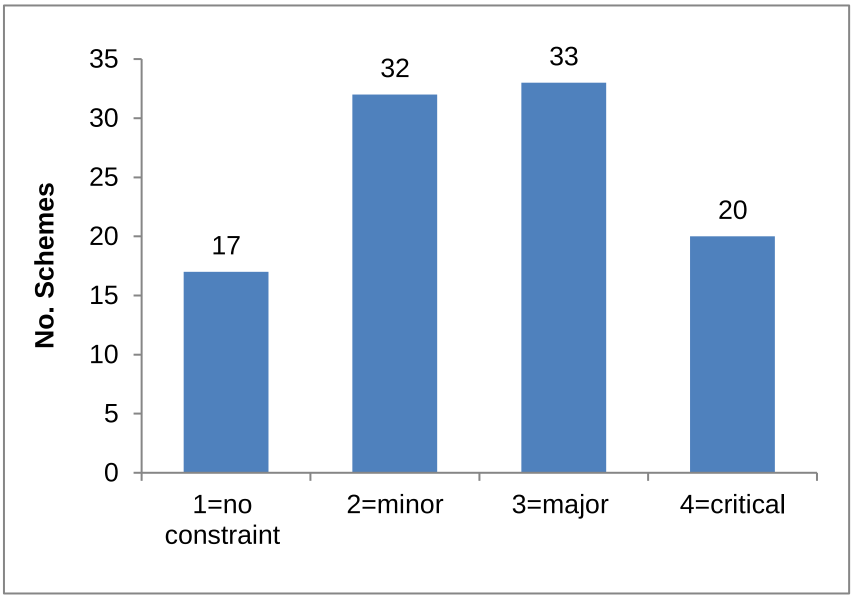


Figure 5.10: Frequency distribution of water resource constraints on smallholder irrigation schemes in Limpopo Province by scarcity proxy index (n=102; 2010)

Water resource availability presented no limitation to production on 17 of the schemes, with 32 schemes experiencing only minor water resource stress due to some shortages during the dry season, or shortages over long-term cycles. The remaining 53 schemes showed major to critical water resource inadequacy. Thirty-three schemes suffered major water stress, having either no water available in the dry season, or a combination of both shortages in the dry season plus shortages over longer cycles. In the last category, 20 schemes were critically restricted in production due to no supply in the dry season, and also suffered stress in the wet season over longer-term cycles.

A second indicator of water stress enumerated farmers' field practices in response to water stress. Seven possible stress behaviours were identified. Data was obtained from the 65 operational schemes, and an additional 11 non-operational schemes where historical memory of field practices still existed. Stress behaviours can be prompted by water resource constraints, inadequate infrastructure, or both. Behaviours include water conservation practices such as night irrigation and mulching; practical measures such as on-scheme water exchanges; the practice of shifting to more water-efficient crops; planting a reduced land area; and water theft. The number of schemes where the various behaviours are evident is shown in Figure 5.11, noting more than one stress behaviour is possible on any scheme.

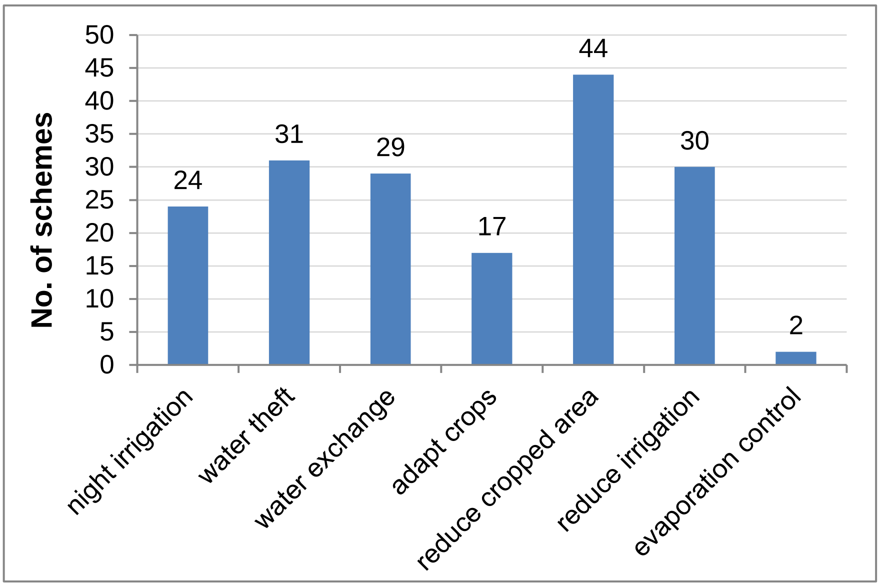


Figure 5.11: Water stress behaviours on smallholder irrigation schemes in Limpopo Province (n=76; 2010)

The most common response to stress was to reduce the cropped area. This was followed by a set of responses with nearly equal prevalence: water theft (31 schemes); reducing the amount of water applied to the same size field (30 schemes); and exchanging water with neighbours (29 schemes). Night irrigation was recorded on 24 schemes and is practiced both as a conservation measure and because there is less competition for water in the fields at night. Evaporation control (mulching) was recorded only on two schemes. It is pertinent that 52 of the 65 operational schemes were recorded as exhibiting some water stress behaviours, indicating the widespread water stress on the operational schemes.

5.7 Water user organisations, water allocations and payments

Data on water user organisations was obtained on 83 schemes. Established water user organisations were stated to exist on 58 schemes. Only two of these were formally established as Water User Associations (WUAs) as provided for in the National Water Act (1998), and 56 operated nominally under informal irrigation committees. The presence of cooperatives with water responsibilities was recorded on nine schemes. A further nine were organisationally structured to be operated by JV partners but these were absent in five cases, awaiting Government intervention to secure a JV partner. JV partners' were active on the remaining four schemes. The general picture was that water user organisations of any type where characterised by existence in name and had limited or no practical presence and tended to be weak and ineffective.

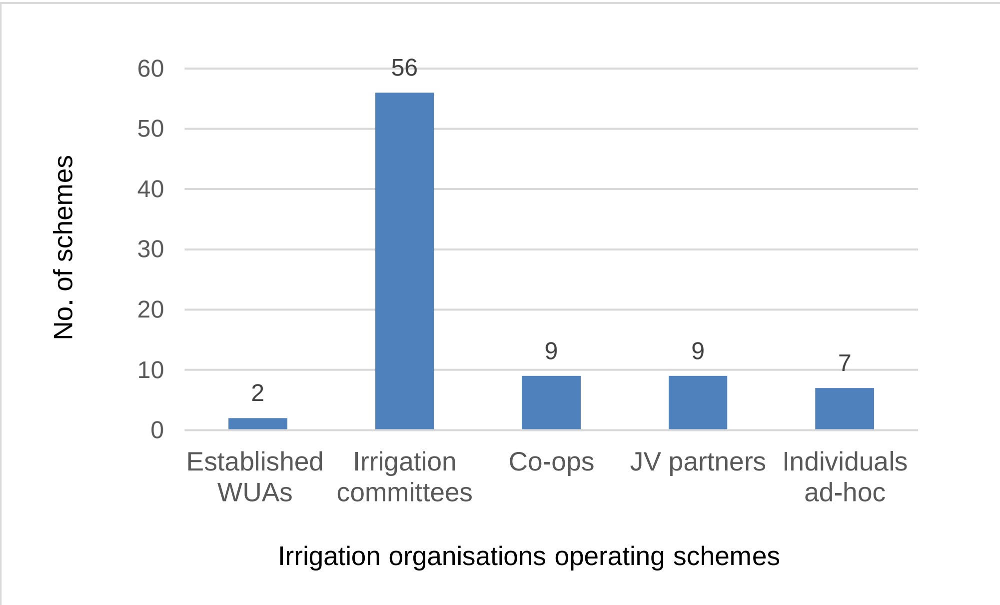


Figure 5.12: Organisations responsible for scheme operations on smallholder irrigation schemes in Limpopo Province (n=83; 2010)

Maintenance of the irrigation infrastructure followed a similar pattern to operations: 58 schemes were maintained by water committees and farmer co-ops, 15 by individuals on an ad-hoc and uncoordinated basis, 11 by government, 9 by JV partners (noting four of these were recently constructed and not yet operational), and only two by WUAs.

Rules were formally written down in the case of 53 schemes (of the 83 with data), and on one scheme they existed but were not written down. There was some measure of enforcement on 50 of these same schemes, ranging from verbal and written warnings from the water organisation, to cash fines ranging from R5– R20, to more serious measures such as reporting the transgression to the Tribal Authority for a warning to be made. Operational rules on gravity-canal schemes were typically adapted from historical arrangements established many decades earlier under the original government water-bailiff setup, with weekly rotations and durations of water access via the canal systems. Rules on pumped systems were geared to the division of payment for electricity, though the actual payment defaulted to the Limpopo Department of Agriculture in all cases except the Hereford scheme and five JV schemes that were operational (of nine in total). At Sanari (micro-irrigation) and Dovheni (sprinklers) there was no management organisation and farmers were allowed to draw water whenever they wanted.

Data on irrigation service fees was obtained on 84 schemes (one additional scheme had information on fees, but none on water organisations). While only 65 schemes were operational, it was still useful to document the historical fee-paying status from schemes that were not operational, though these were separated in the statistical analysis (Chapter 6).
Fees were due on 39 of the 84 schemes (46.4%), while 45 schemes (53.6%) had no requirement for payment at all (Figure 5.13).

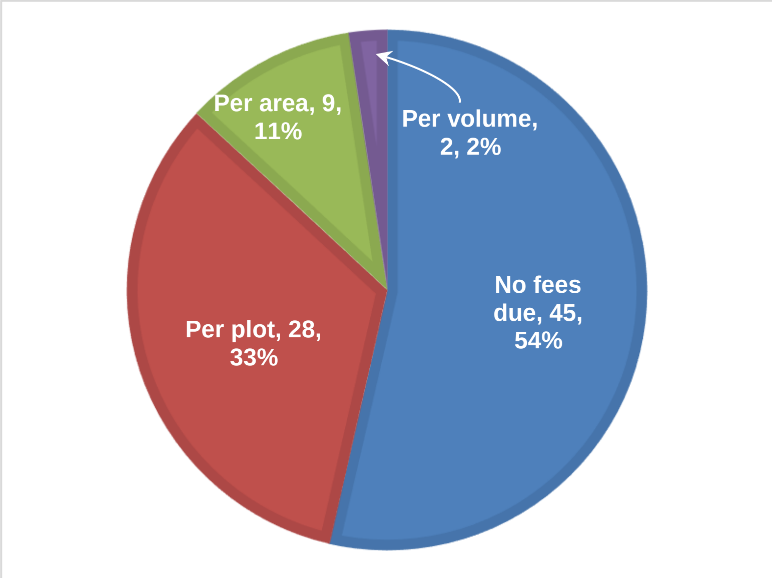


Figure 5.13: Basis for payment of irrigation service fees on smallholder irrigation schemes in Limpopo Province (n=84; 2010)

On the 39 schemes where fees were due, these were charged on the basis of: a single plot (28 schemes = 72%); plot area (9 schemes = 23%); and water volume (2 schemes = 5%). The two schemes requiring payment based on water volume were Hereford Scheme (160 ha) and Magalatsane. Hereford had a pumped sprinkler arrangement to irrigate farms of 5 ha, each equipped with a water meter. Magalatsane (130 ha) was developed as a profit-share JV arrangement and newly-equipped with floppy sprinklers but was unused at the time of survey because the commercial partner could not be mobilised, so the charge structure was theoretical.

The amounts due for irrigation services ranged widely, and only 28 of the 39 schemes where fees were due were actually paying an amount. Fees were standardised to a comparable basis of R/ha/year and this shows: an exceptionally wide range from a token fee to a meaningful amount of R6–R867/ha/year; an average of R86/ha/year; and a median value of R10/ha/year. Only four of the 28 schemes recorded more than R20/ha/year, reflecting the very nominal and token nature of irrigation service fees on these smallholder schemes.

Regarding higher-level water management arrangements, respondents from 18 schemes stated awareness of, and some involvement in, CMAs in their area, such as attending a CMA meeting or receiving information about the CMA. Active involvement in CMA activities or water forums was, however, absent.

5.8 Land tenure type and prevalence of land-exchange

Data was obtained for 98 schemes and is shown in Figure 5.14. A total of 89 of the 98 schemes (91%) held their irrigation allotments by means of a 'permission to occupy certificate', administered locally by the Traditional Authority (TA). Of these, two (Mphepu and Dopeni) had small portions allocated to groups mostly comprising women, who were farming small food plots for home consumption. Six of the 98 schemes (6.1%) had land allocated by the TA to a group as a single block; the group then apportioned the land within the block between their members.

Hereford was the only scheme (1%) held under the provisions of a Communal Property Association (CPA), implemented under the Land Reform Program in 2006. Hereford scheme is 160 ha in size and comprises larger individual farms of 5 ha which are apportioned by the CPA to each of the individual CPA members.

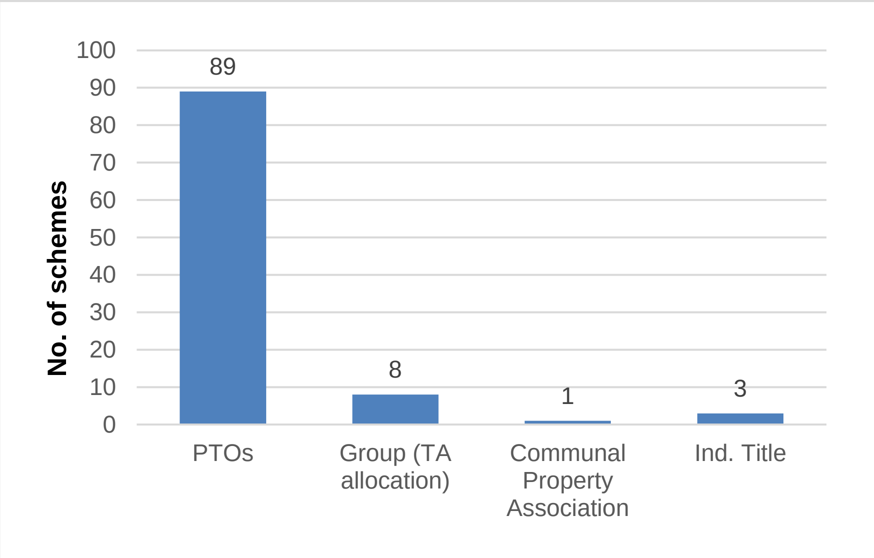


Figure 5.14: Landholding type on smallholder irrigation schemes in Limpopo Province (n=98[5]; 2010)

On three schemes, some or all irrigation plots were held under title deed. These were: i) the whole of Dzwerani scheme, which is a 124 ha pumped scheme from 1980 and no longer operational; and ii) a very small portion of Palmaryville (1.3 ha of 92 ha in total) which is an

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[5] Note that 2 of the 8 schemes included in the category 'Groups (TA allocation)' had food plots that comprised a small portion of the area, with most of these two schemes having land allocated to individuals using the PTO system. Similarly, a small portion of one scheme was under individual title, while most of the scheme was allocated using PTOs. This is why the number of schemes in the graph adds up to 101, while the total number of responses in the data set is 98.

older gravity scheme from 1951 that was still operational. Both are in Vhembe District. Sterkspruit scheme in Sekhukhune District was also reported to be held under title deed; this scheme was built in 1957, is 280 ha in size and was still operational.

Data on land-exchange prevalence and practices was obtained from 98 schemes. On 73 (74.5%) of these schemes, land exchange was found to have taken place (Figure 5.15). On 27 schemes, the land-leasing transactions were carried out privately and independently, with no involvement of scheme organisations or TAs. On 41 schemes (37%), the main scheme organisational entity (e.g. irrigation committee or irrigation-farmer cooperative) was involved in land-leasing authorisations. On 24 schemes (32.9%), the TA was required to authorise transactions, while on 18 of the 73 schemes (24.7%), authorisation took place at both TA and scheme organisation levels.

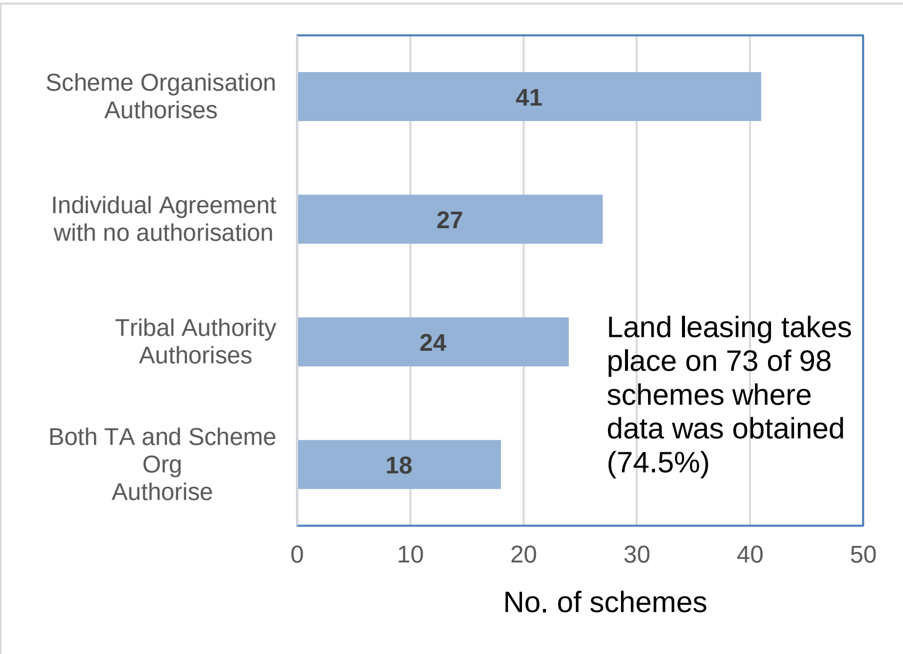

Figure 5.15: Type of authorisation for land-exchanges on smallholder schemes in Limpopo Province (n=73; 2010)

The nature of exchange included four categories: leasing to a commercial JV partner, which in all cases took the form of a block-lease arrangement facilitated by Government; cash-leasing to other individuals from on or outside of the scheme; leasing in exchange for land-preparation services; and crop-share arrangements. The incidence of each is shown in Figure 5.16, disaggregated into operational and non-operational schemes.

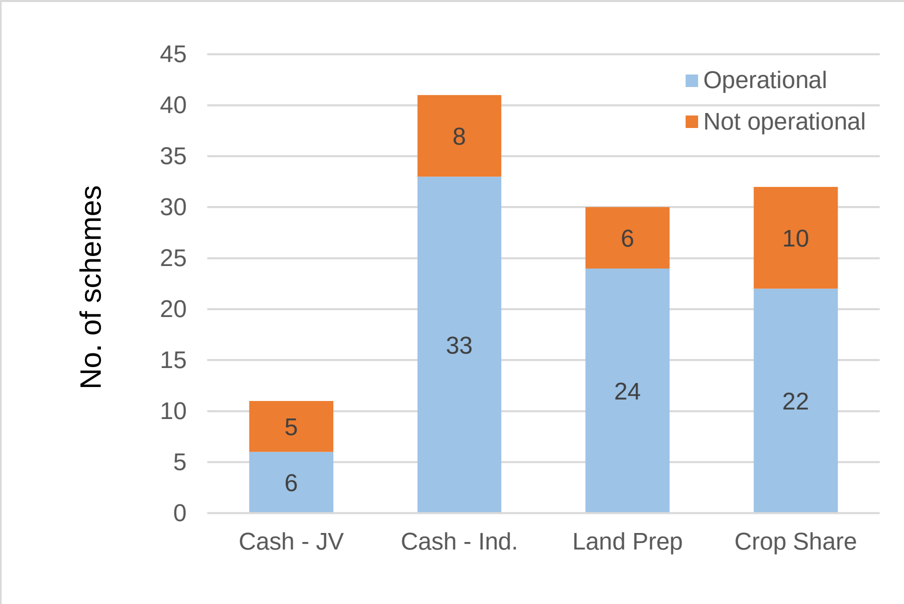

Figure 5.16: Transaction basis for land-exchanges on smallholder irrigation schemes in Limpopo Province (n=73; 2010)

The duration of leases or exchanges was fairly balanced across both short- and medium-term timelines (Figure 5.17). Single-season exchanges were found on 47 schemes. Exchanges of between 1 and 2 years were made on 40 schemes, and 51 schemes reported that exchanges of longer than 2 years were made.

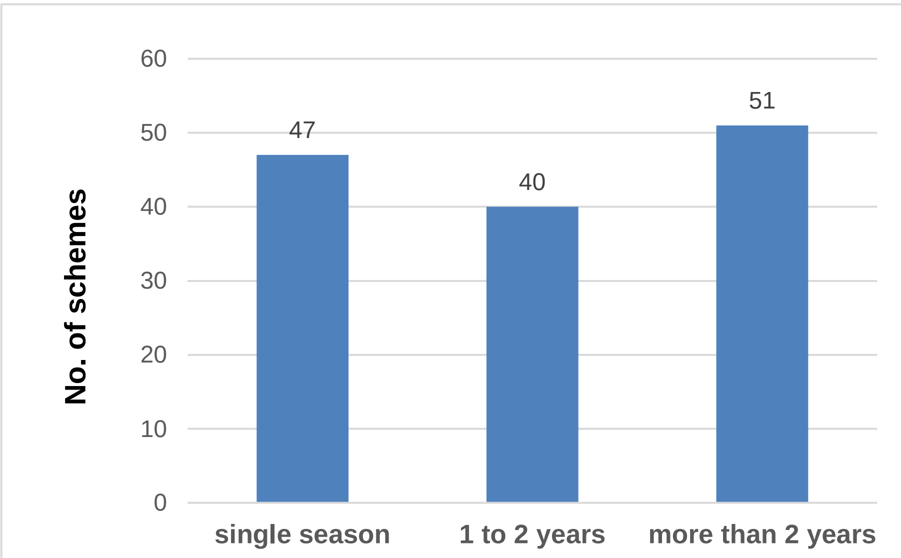

Figure 5.17: Incidence of durations of land-exchange agreements on smallholder schemes in Limpopo Province (n=73; 2010)

5.9 Conflict

Conflict was defined during the interviews as being relevant when it impacts negatively on farmers' ability to derive benefit from the scheme. Occasional petty theft or minor squabbles were thus not be deemed conflict. Conflict was queried with five yes or no questions as to the presence of conflict on the scheme in relation to: land and water; theft of equipment; theft of produce; conflict within organisations operating on the scheme; and conflict between scheme land-holders and surrounding communities. Data was obtained from 92 schemes and is shown in Figure 5.14. Theft of both equipment and produce was the most prevalent conflict issue, recorded on 32 of the 92 schemes (34.8%), while conflict between scheme farmers and people off the scheme was experienced on 31 of the 92 schemes (33.7%). Conflict around land and water, and intra-organisational conflict, was relatively low, recorded on 17 and 18 schemes respectively (18.5% and 19.6%).

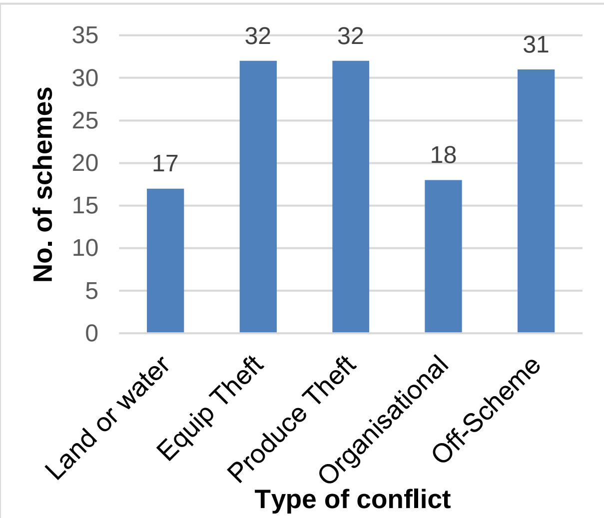

Figure 5.18: Incidence of type of conflict on smallholder irrigation schemes in Limpopo Province (n=92; 2010)

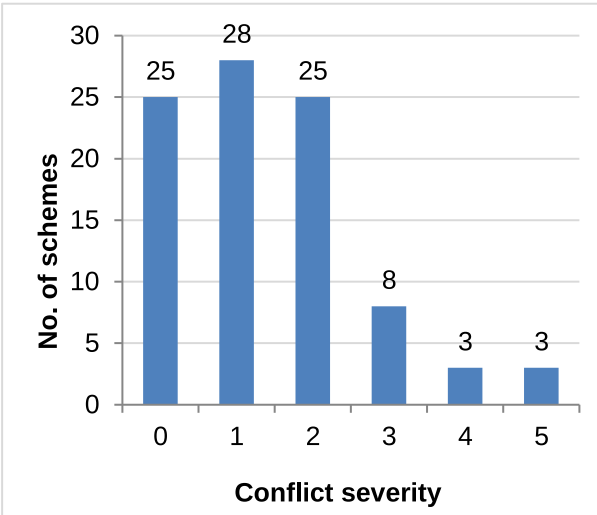

Figure 5.19: Incidence of overall conflict (expressed as a severity index) on smallholder irrigation schemes in Limpopo Province (n=92; 2010)

A simple consolidated variable, or conflict index, was enumerated to capture the overall level of conflict on each scheme. The higher the number the greater the conflict (from 0 to 5). Figure 5.19 shows more than half the schemes have no or low conflict. Zero conflict was recorded on more than a quarter of the schemes (25 = 27.2%), with a further 28 (30.4%) recording only one area of conflict. Twenty-five schemes experience two areas of conflict, with only six being in the upper two conflict brackets, experiencing severe conflict in four or five domains of engagement.

5.10 Agriculture

5.10.1 Crop choice and intensity

Summer and winter crops were assessed separately. Summer (September to March) is the wet season. Average annual rainfall for all schemes was 615 mm (range of 374mm to 985mm), and on average 510 mm (equivalent to 83%) of precipitation fell in the summer season. Summer crops were grown on all of the operational schemes, with the total planted irrigation area estimated to cover 3,900 ha. Winter crops were estimated to cover 2,330 ha. Winter production was absent in three of the operational schemes (Mecklenburg, Solani and Makgaung). These schemes all suffered critical water stress in the winter period, combined with a low average winter rainfall, explaining the absence of production. Rietfontein was unusual regarding intensity, in that it was not operational, but summer intensity under rainfed production was 100%. Given that this production was not irrigated, the scheme was excluded from the operational analysis. The most common farming system comprised the production of grain, mostly maize, and vegetables (Figure 5.20).

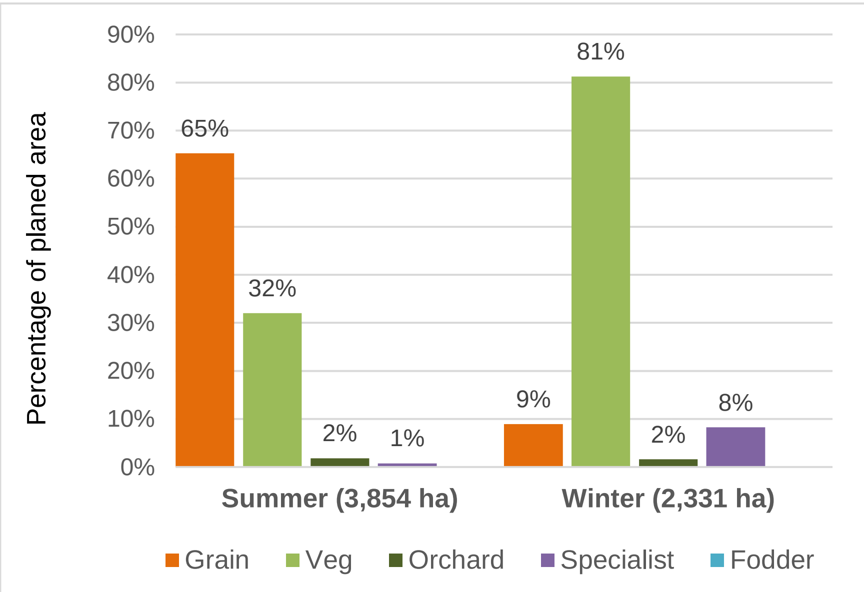

Figure 5.20: Crop type preferences by season on smallholder irrigation schemes in Limpopo Province (n=65; 2010)

In summer, 65% of the total cropped irrigation area of all operational schemes was planted to grain crops (mainly maize), 32% was under vegetables, and the balance under orchard crops (mainly mangos) and specialist crops (such as coriander and seed maize), these taking up 2% and 1% of the planted area, respectively. No fodder crops were recorded in summer. The winter cropping scenario was different, dominated by the production of fresh vegetables (81%), with winter grain (9%), and specialist crops (8%, including potatoes under JVs for factory-based potato chip production), along with the same 2% of orchard crops making up the balance. As in summer, no fodder crops were recorded in the winter period.

Out of the 65 operational schemes, a total of 46 (71%) planted more than 60% of the irrigation area with maize in summer, and 59 schemes (91%) grew some summer maize. Orchard crops were grown on 11 of the 65 operational schemes, with trees covering between 5% and 20% of the total irrigation area, making them less important overall.

Cropping intensity was assessed on the 65 operational schemes and reflects the total area planted (by season or year) divided by the total land area available on the scheme (i.e. the irrigation command area). Average seasonal and annual intensity is shown in Figure 5.21, and the frequency distribution of annual intensity is shown in Figure 5.22.

The average seasonal intensity of the operational schemes was 0.62 in summer and 0.32 in winter, totalling an average annual cropping intensity for all schemes of 0.94. This indicates that the available land resource on smallholder irrigation schemes is planted just less than once over the course of a year. This is very low for irrigation farming, where targets of 1.6 (see Chapter 4) and higher are generally required for financially feasible investments (discussed in Chapter 7).

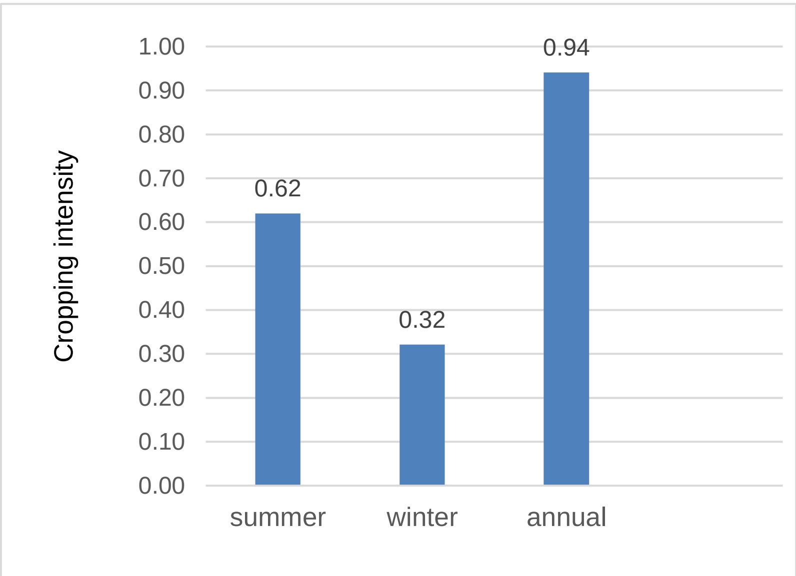

Figure 5.21: Cropping intensity for all operational smallholder schemes in Limpopo Province (n=65: 2010)

Annual cropping intensities varied considerably between operational schemes, ranging from 0.1 to 2.0. The median intensity was 0.9, with an interquartile range of 0.7-1.3 (32 schemes in this mid-range). Eighteen schemes (27.2%) had cropping intensities greater than 1.2, which is the range where schemes are reasonably active, and only six schemes (9.1%) had an intensity greater than 1.5. In this last group, schemes are operating near to their full potential as far as planted area is concerned (without accounting for yields, water-use efficiency, etc)

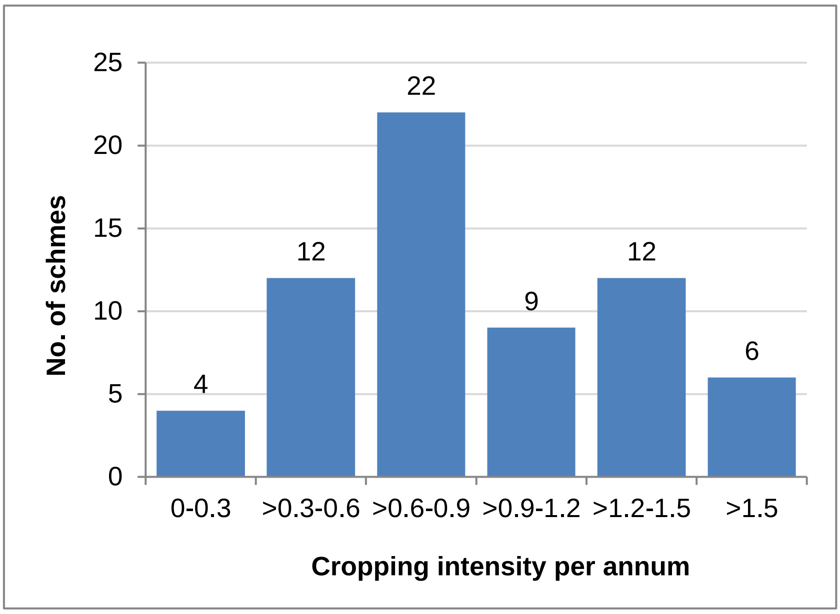

Figure 5.22: Cropping intensity frequency distribution for operational smallholder irrigation schemes in Limpopo Province (n=65; 2010)

Of the 18 schemes with an intensity greater than 1.2 (120%), 14 were gravity-canal schemes (highest intensity of 175%) and four were JV arrangements (pumped to floppy sprinklers or drip irrigation). The four JV schemes all had an intensity of 200%, reflecting the double-cropping maize-potato rotation adopted by the RESIS-Recharge commercial JV partner they shared.

5.10.2 Commercialisation and marketing

Data on purpose of production was obtained for the 65 operational irrigation schemes shown in Figure 5.23. Schemes were grouped into four categories based on their degree of commercialisation as a whole. Fifteen of the schemes are producing mainly for home-food production, with 25% or less of the produce being grown for sale, while 17 schemes are more market oriented, but still emphasise home provisioning, producing 26-50% for sale. Thirty-three of the 65 operational schemes (50.7%) grow more than half of their produce for sale. In terms of purpose of production then, the surveyed schemes reflect a diverse mix and a near equal balance between schemes emphasising markets and those emphasising home-food provisioning. In almost all scheme then, mixed farming purpose dominates.

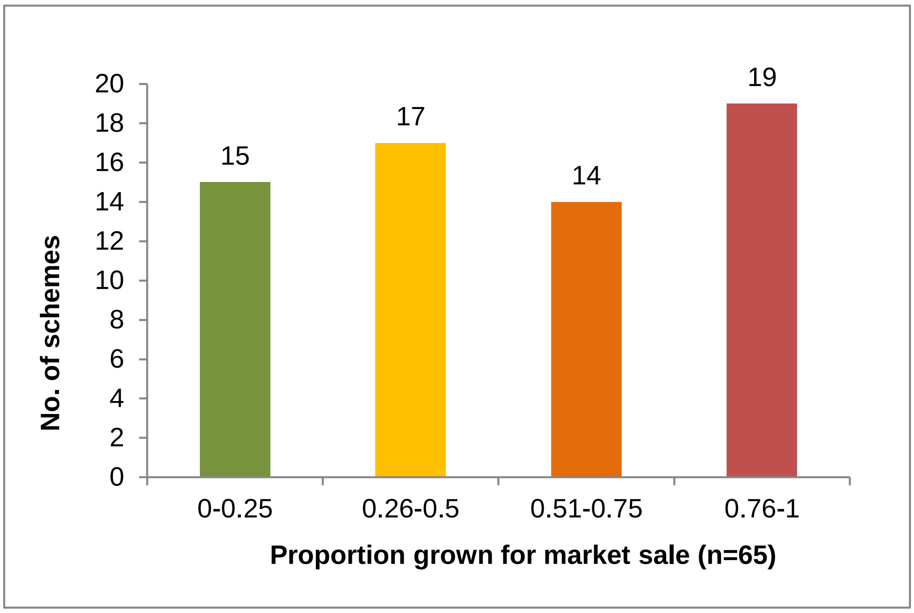

Figure 5.23: Number of schemes in categories of degree of commercialisation for smallholder irrigation schemes in Limpopo Province (n=65: 2010)

5.11 General picture emerging from the summary analysis

Size: The Limpopo smallholder schemes are comparatively small, with 74.5% falling in the size range of 50 to 250 ha (n=76), with only 10 schemes larger than 250 ha, and one larger than 500 ha. Average plot sizes were 1.34 ha with just less than half of the schemes (47.1%) in the 1-1.5 ha bracket, though ranging rather more widely between 0.18 and 16.25 ha. Nearly three quarters of the schemes (72.9%) were found to have average plot sizes in the range of 0.51-2.0 ha.

Energy: The type of energy driving the water supply (ie. gravity or pumped) emerged as an important factor with evident links to the scheme operational status (failure or not). This relationship could be seen even in the summary analysis. Irrigation activity was wholly reliant on pumping technology on 50 schemes, in addition to Steelpoortdrift scheme where gravity supply was supplemented by borehole pumps at times. Electricity was the main energy source for 86% of the pumps, the balance using diesel, with no solar or petrol pumps in use.

Operational status: The operational status data show that gravity schemes have a much greater incidence of being operational than pumped schemes; 49 of the 52 gravity schemes were operational (96%), while only 16 of the 50 pumped schemes were still operating (32%). Viewed differently but accentuating the same point, 34 of the 37 non-operational schemes were pumped schemes, while only three non-operational schemes were gravity-supplied.

Irrigation methods: In regard to irrigation methods used on the farms, just over half of the commanded irrigation area used surface irrigation with furrow, short-furrow and basin irrigation methods (6 086 ha; 50.2%). Sprinkler systems, comprising draglines, quick-coupling sprinkler lines, centre-pivots and floppy-sprinklers were similarly prevalent (5 445 ha; 44.9%). Micro-jets and drip irrigation made up the balance (598 ha; 4.9%).

Condition: In terms of overall physical infrastructure (both water and fencing), 71 schemes were in a poor to very poor condition, while 31 were in a moderate to optimal condition. A best estimate of the serviceable irrigation area (that which can be supplied with water with the existing infrastructure) was equal to 6 199 ha, which is 51.1% of the total design command area.

Source: Water was primarily supplied from surface water with 93 schemes drawing by gravity or pumps from rivers and dams. Only nine schemes relied on groundwater, mostly boreholes, but two sourced water from perennial springs.

Water availability and stress: More than half of the smallholder schemes face serious water resource shortages and nearly three-quarters practice stress-related water-savings behaviours. Water resource availability was a major to critically limiting factor on 53 of the 102 schemes, with gravity schemes more impacted by scarcity than pumped schemes, yet more resilient at the same time despite the water stress, indicated by their relative longevity. Water scarcity is further reflected in a significant level of water stress behaviours such as smaller planted areas, night irrigation, theft, etc., prevalent on 69% of the schemes with data. This constrains full utilisation of the land and would logically be more severe if higher levels of cropping intensity, which were found to be low at only 0.94 (94%) on average, were achieved.

Organisations: Water management organisations were generally very weakly instituted, with minimal operations, maintenance, or enforcement. These mostly took the form of semi-formal ‘water committees’ with only two WUAs established in line with policy and law. On pumped schemes, farmers relied almost entirely on the Government for the payment of energy costs and pump maintenance, while on gravity schemes, operations tended to follow the historical practices instituted under the homeland governments (rotations etc.), but somewhat chaotically, inequitably, and with weak enforcement. Some measure of enforcement was recorded on 60% of schemes with data (83 in no.), ranging from verbal and written warnings from the water organisation, to nominal cash fines ranging from R5– R20. Irrigation service fees were mostly nominal, with a median value or R10/ha/year but ranged widely from a token fee of R6 per year, to an outlier of R867/ha/year.

Land tenure: Landholdings were mostly under the PTO arrangement which was used on 89 of the 102 schemes (91%), administered locally by the Traditional Authority (TA). The balance of property rights were held in title or under a Communal Property Association (CPA), with individual use-rights administered by the CPA.

Land-leasing most frequently involved the TA which played some role in 58% of the cases, either directly or in conjunction with the main scheme organisational entity (typically a 'co-op'). The scheme organisation was similarly important, either on its own or in conjunction with the TA, in 56% of cases. Leasing was privately arranged with no other involvement on 37% of the cases. Approximately 2/3 of the leasing arrangements then required engagement with external parties, either the scheme organisation or the TA, with associated transaction costs.

Conflict: The findings on conflict were interesting, and showed a relatively low incidence of serious issues across key domains of water, land, equipment or produce theft, organisational and off-scheme relationships. More than half the 92 schemes with data (57.6%) had no or low conflict, with the two highest levels of conflict only found on 15% of the schemes. Here, conflict was measured by incidence of type, and did not attempt to measure the financial or social effects which could be severe even when only in one or two domains (such as water or land).

Crops and purpose: The most common farming system comprised the production of grain, mostly maize, and vegetables. The average average annual cropping intensity was only measured on the 66 operational schemes, and was equal to 0.94 (i.e. just less than 1 crop per year for all schemes). Data on the purpose of production of 65 of the operational schemes showed a clear bias to market production. An estimated 53% of the schemes produced crops mainly for sale (more than 50% were for the market), while only 23% of the schemes produced mainly for own consumption (i.e. 25% or less was for the market).

Concluding point: The summary presents a picture of relative homogeneity in terms of small scheme size, the PTO landholding type, a weak institutional setup for water management, and withdrawal from surface water sources (with some but minimal groundwater use). There is a duality in terms of technical systems (gravity or pumped) and operational status, and there is diversity in land-exchange, water stress and purpose of production. Market-oriented production tends to be more prevalent than subsistence farming though mixed purpose farming dominates across the data set. Energy source emerged as one obvious factor linked to operational status with most of failed schemes being ones where pumping was involved. These factors are further explored in the correlation and statistical analysis in Chapter 6.

6 STATISTICAL ANALYSIS RESULTS

6.1 Overview

The statistical analysis comprised a factor-on-factor analysis for correlations and associations, a cluster analysis, and a principle component analysis. The findings of these statistical tests are described in this chapter using the methods detailed in Chapter 4.. The statistical analysis was divided into two main lines of enquiry to understand firstly which factors were associated with scheme failure and, secondly, with scheme success.

The failure assessment was conducted on all 102 schemes and involved statistical tests for associations and correlations using only two of the five performance variables and nine of the 13 independent variables. The reason for analysing a reduced number of variables was that sufficient data on the excluded variables could not be obtained on the non-operational schemes due to elapsed time (more detail on this can be found in Chapter 4). The two performance indicators that were analysed in relation to failure were operational status (Variable 1) and scheme longevity (Variable 2). Results of the failure assessment are presented in Section 6.2.

The success analysis focussed on 61 of the 65 operational schemes and comprised correlation, cluster, and principle component analysis (PCA). The analysis excluded the four functioning Joint-Ventures (JVs) that were farmed as a single estate, also explained in more detail in Chapter 4. The statistical evaluation included the remaining three of the five performance variables and all 13 independent variables. The performance variable on operational status (Variable 1; operational or not operational) and scheme longevity (Variable 2: years operated) were redundant because the success analysis related only to operational schemes. Results of the success-assessment are presented in Section 6.3 onwards.

6.2 Assessment of the relationship between scheme characteristic factors and scheme ‘failure’

The analysis of failure identified variables that are associated with scheme operational status and durability (lifespan) and involved either Chi-square tests or Spearman’s rank correlation tests (see Chapter 4, Tables 4.23 and 4.24). The results of the analysis of factor relationships to Variable 1 (operational status), and Variable 2 (years operated) are shown in Table 6.1.

Table 6.1: Associations between scheme characteristic factors and performance in relation to the failure of smallholder schemes in Limpopo (n=102: 2010)

Scheme Characteristic (independent variable)		Performance Indicator Operational Status (Variable 1 - binary)			Performance Indicator Scheme longevity (Variable 2 - ratio)		
		Probability (p-value [1])	Strength [2]	Statistical Tests [3]	Probability (p-value)	Strength [2]	Statistical Tests
Var 6	Command area	0.977	0.127	χ^2 & Cramer's V	---	no correlation	Spearman's rank [4]
Var 7	Plot size (average)	0.489	0.208	χ^2 & Cramer's V	0.031	-0.214	Spearman's rank
Var 8	Rainfall	0.0013	0.481	χ^2 & Cramer's V	<0.0001	0.424	Spearman's rank
Var 9	Distance to market	0.024	0.378	χ^2 & Cramer's V	---	no correlation	Spearman's rank
Var 10	Soil suitability index	0.059	0.345	χ^2 & Cramer's V	0.026	0.221	Spearman's rank
Var 11	Energy source (binary)	0.0001	0.647	χ^2 & Pearson's Phi	<0.0001	0.845	χ^2 & Cramer's V
Var 12	Infrastructure condition index	0.0017	0.604	χ^2 & Cramer's V	---	no correlation	Spearman's rank
Var 13	Water resource constraint score	0.004	0.358	χ^2 & Cramer's V	<0.0001	0.505	Spearman's rank
Var 18	Main irrigation method	0.0001	0.642	χ^2 & Cramer's V	<0.0001	0.702	χ^2 & Cramer's V

Notes:

1. The p-value is the probability that the result was obtained when the association was in fact zero (null hypothesis).
2. 'Strength' refers to the strength of association of the Chi-square test result (Cramer's V or Person's Phi) or, in the case of the Spearman's rank correlation test, reflects the value of the correlation coefficient.
3. Refer to Chapter 4, Section 4.10 for an explanation of the tests.
4. 'Spearman's rank' means Spearman's rank correlation test.
5. The level of confidence in all cases was 95% (ie. alpha = 0.05). Where p<α, the result is statistically significant.

6.2.1 Treatment of unequal starting data in relation to Variable 2 - 'scheme longevity'

The statistical analysis and the discussion of 'scheme lifetime' or 'durability' required attention to the date of commissioning. The 52 gravity schemes were commissioned between 1938-1989 (average 1960) and were, on average, constructed 28 years earlier than the 50 pumped schemes commissioned between 1970-2006 (average 1988). At face value the longer lifetime of gravity schemes is clearly illustrated by the data:

- The average lifetime of *operational pumped schemes* was 16.1 years (n=16), and *non-operational pumped* schemes was 12.5 years (n=34), noting non-operational schemes dominated the pumped data set;
- The average lifetime of *operational gravity schemes* was 48.2 years (n=49), while the *non-operational gravity schemes* were few (n=3) with an average lifetime of 29.3 years. Operational schemes dominated the gravity scheme data set.

In evaluating 'longevity', the pumped and gravity *non-operational* schemes could be directly compared. However, in the case of *operational schemes,* given the generally later start date of the pumped schemes, these could not be directly compared. One option was to evaluate only non-operational schemes but this included only three relatively short-lived gravity schemes, when the reality was that 49 operational gravity schemes were clearly much older than most of the non-operational pumped schemes (average of 48.2 years which is equal to four times the 34 failed pumped schemes). This fact would be important in the association analysis. The decision was taken to run the association statistics on the full data set, in the knowledge that 16 pumped schemes (15.7% of 102 schemes) and 49 gravity schemes (48.0%) were still operational, and that the 16 pumped schemes were commissioned later. Given that the 16 operational pumped schemes were longer-lived on average (16.1 years) than the 34 failed pump schemes (12.5 years), and similarly so in the case of the gravity schemes, this would provide a result that seemed more representative of reality than if the operational schemes were excluded all together. While there is no doubt about the overall conclusions in regard to trends and relationships to 'longevity', the exact statistical results need to be considered with some caution due to the above.

6.2.2 Factors and failure

Command area (Var 6) has no association with operational status, nor to scheme longevity.

Plot size (Var 7) has no association with operational status and a very weak though statistically significant correlation with scheme life (r=-0.214; p=0.031). This suggests, rather weakly, that schemes with smaller plots tend to live longer. The finding is more likely linked to the reality that average plot sizes on the older flood irrigation schemes which are more resilient and longer lived, are generally smaller than the shorter-lived, later-era, pumped schemes that typically included farms of 5-10 ha, and centralized estates (van Averbeke and Denison, 2012).

Rainfall (Var 8) has a high probability of association with operational status with a moderate strength (p=0.0013; strength=0.481). There was a similarly moderate and significant correlation with scheme life (r=0.424, $p<0.0001$). This means that schemes that are located in higher rainfall areas are more likely to be operational with a tendency to have a longer life than schemes in lower rainfall areas.

Distance to market (Var 9) has a statistically significant and moderately weak association with operational status (p=0.024; strength=0.378), but no correlation to scheme life.

Soil suitability (Var 10) is not significantly associated to operational status, though has a statistically significant but very weak correlation in relation to scheme life (r=0.221; p=0.026). The result suggests a tendency for schemes with less-suitable soils to be shorter-lived. This seems logical but given that issues such as waterlogging and shallow-soils were a very limited issue on all of the schemes, the finding has little weight in explaining failure in general. Kumbe scheme was an exception however to this general finding. The infrastructure located on well-drained Hutton soil seemed to be in good condition. The infrastructure located on shallow, relatively poorly drained soils was severely dilapidated. It appeared that the physical properties of the soil had played a role in the concrete of the canals and furrows breaking up.

The energy source (Var 11) that was used for irrigation has strong and statistically highly significant associations with operational status and scheme life. Pumping is strongly associated with scheme failure (R=-0.647; $p<0.0001$) and has a strong (negative) correlation to scheme life (R=-0.802; $p<0.0001$). The findings provide strong empirical evidence that pumped schemes are highly prone to failure and have shorter lifespans.

Infrastructure condition (Var 12) is statistically significantly, and moderately strongly associated with scheme non-operation (p=0.0017; strength=0.604) as would be expected. Where water infrastructure is in poor condition, irrigation activities are more difficult to carry out, leading to a collapse of operations when condition deteriorates beyond a critical point.

Water resource constraint (Var 13) was statistically significantly, and moderately weakly associated with operational status (p=0.004; strength=0.358). This implies that irrigation and farming activity on schemes adjusts dynamically to water stress conditions but does not fail catastrophically. The correlation between water resource constraint and scheme longevity was moderately strong (R=0.505) with high statistical significance (p <0.0001). This is counter-intuitive, as one would expect that as water stress increases, so scheme life tends to decrease. The explanation for this apparent contradiction can be found in the durable, older gravity schemes that comprise a fraction over half of the data set (52 of 102). In the summary analysis in Chapter 5, it was observed that the age of these (46.6 years) was more than three times the average of the pumped schemes (13.6 years). Most of these older gravity schemes were still operational in some measure (49 of the 52), despite suffering water constraints, while most of the younger pumped schemes had failed due to pumping technology issues, regardless of water availability.

The main infield irrigation method (Var 18) captures the level of sophistication of the water-application technology (infield). The descriptor ranges from surface methods (furrows, basin), to sprinklers (draglines, pivots) and finally to high-tech micro-systems (such as micro-jet and drip). The associations between Variable 18 and operational status were highly significant and strong (p<0.0001, strength=0.642) and similarly so with longevity (p<0.0001, strength=0.702).

Energy source and type of infield irrigation system are strongly cross-correlated (p<0.00001; strength=0.846). In most cases gravity schemes used surface irrigation (50 out of 52) and, conversely, most pumped systems used pressurized infield systems (45 out of 50). The more sophisticated pumped schemes with sprinklers, micro-jets and drip infield systems, are more prone to failure with shorter lifespans. Given the strong association between energy type and infield irrigation method there seems no basis to conclude that the infield system itself is associated with failure. Further study on a greater number of gravity schemes that use a range of infield methods would be needed to reach conclusions in regard to the effect of infield method on lifespan.

6.3 Assessment of the relationship between scheme characteristic factors and scheme 'success'

The correlation analysis of factors on the 61 operational schemes is discussed in relation to the three performance indicators shown in Table 6.2. The data types excluded nominal variables so the entire analysis was done using Spearman's Rank Correlation tests. The results are shown in Table 6.2. The correlations between contributing factors and performance factors are discussed first, followed by a discussion of factor-to-factor correlations of interest between the independent variables (Var 6–18).

Table 6.2: Spearman's rank correlation coefficients in relation to success on operational smallholder schemes in Limpopo Province (n=61:2010)

	Scheme characteristic	**Performance indicator (dependent variables)**		
		Var 3	**Var 4**	**Var 5**
		Winter cropping intensity	Summer cropping intensity	Degree of commercial-isation
Dependent variables				
Var 2	Years operated	---	---	---
Var 3	Winter cropping intensity	**1**	---	---
Var 4	Summer cropping intensity	**0.719** ***(****0.0001)*	**1**	
Var 5	Degree of commercialisation	---	---	**1**
Independent variables				
Var 6	Command area	**-0.312** *(0.015)*	**-0.367** ***(****p=0.004)*	---
Var 7	Plot size (average)	---	---	**0.289** *(p=0.024)*
Var 8	Rainfall	---	---	**-0.360** *(p=0.005)*
Var 9	Distance to market	**-0.262** *(p=0.042)*	---	---
Var 10	Soil suitability index	---	---	---
Var 11	Energy source	---	---	---
Var 12	Infrastructure condition index	---	---	---
Var 13	Water resource constraint score	**-0.376** *(p=0.003)*	**-0.291** *(p=0.023)*	---
Var 14	Conflict score	---	---	---
Var 15	Land exchange index	---	---	**-0.298** *(p=0.020)*
Var 16	Market diversity score	---	---	**0.268** *(p=0.037)*
Var 17	Agricultural information index	---	---	**-0.315** *(p=0.014)*
Var 18	Main irrigation method	---	---	---

The values extracted from the results matrix and shown above are different from 0 with a significance level alpha=0.05. The related p-values are shown in brackets.

6.3.1 Factors impacting on cropping intensity

Scheme command area has a moderately weak and statistically significant negative correlation to both winter and summer cropping intensity (R=-0.312, p=0.015; and R=-0.367, p=0.004). This indicates a tendency for smaller schemes in the data set to be associated with higher productivity in both cropping seasons, than is the case with the larger schemes. The range of operational scheme sizes is however rather small; between 8.8 ha and 333 ha, with an average of 91 ha and a median size of 70 ha.

Distance to market had a weak negative correlation with winter cropping intensity which was moderately statistically significant (R=-0.262, p=0.042). No correlation with summer cropping intensity or commercialisation was found.

Water resource constraints are associated with lower cropping intensities in both seasons with high statistical significance. The winter association is slightly stronger than summer (R=-0.376, p=0.003; R=-0.291, p=0.023).

The cross-correlation between winter and summer cropping intensity is strong and highly significant (R=0.719, p<0.0001), meaning that schemes that are productive in summer tend to be productive in winter as well. The factors of scheme size, water resource constraints and distance to market are all significant, though with weak to moderately weak correlations with cropping intensity.

6.3.2 Factors impacting on the degree of commercialisation on operating schemes

The measure of the degree of commercialization was based on the percentage of crops grown for sale. As in the case of cropping intensity, the statistically significant correlations with scheme characteristics were weak. Factors of interest emerging from the results were plot-size, rainfall, land-exchange prevalence, agricultural information and market diversity.

Plot size has a positive and significant correlation with commercialization. This is important although this relationship was rather weak (R=0.289, p=0.024). It suggests that increased scale of operation is linked to commercialization. The plot of Spearman's correlation coefficient of commercialization and average plot size shows an interesting trend (Figure 6.1). A sharp point of inflection is evident at the commercialization index of approximately 0.7-0.8 and the correlating plot size is equal to approximately 1.8 to 2 ha. This shows that up to 2 ha in size, all types of farming purpose are present, but over 2 ha in size, the commercialization objective dominates. The finding implies that a commercialisation drive would be facilitated by interventions which aid the consolidation of farms larger than 2 ha.

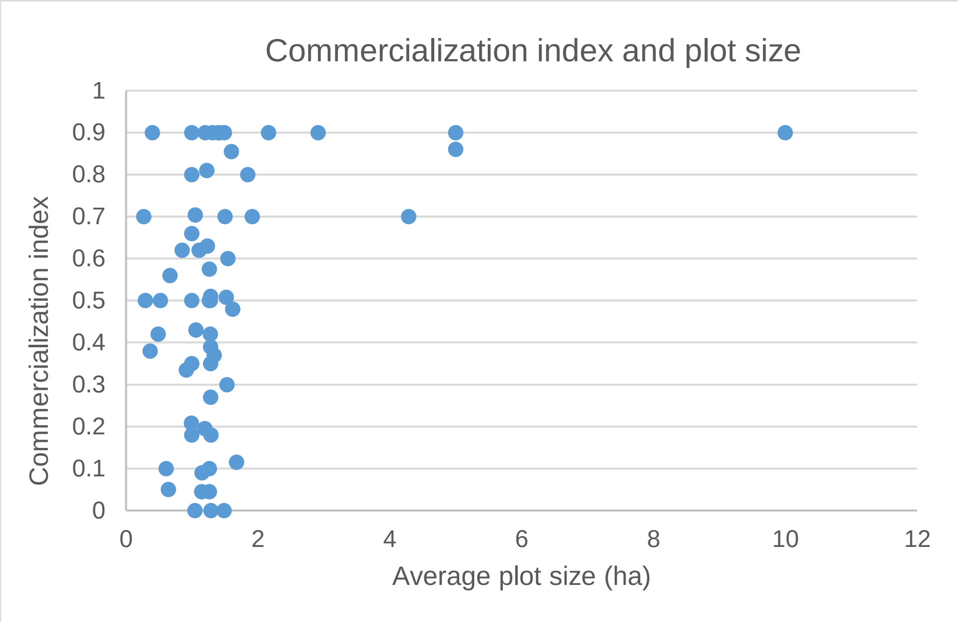

Figure 6.1: Correlation between commercialization index and plot size for operational smallholder schemes in Limpopo Province (n=61: 2010)

Rainfall had a moderately weak negative and statistically significant correlation (R=-0.360, p=0.005) with commercialization. This means that schemes that are located in relatively wetter areas tended to be more oriented to production for home-use rather than for market purposes. The reason for this may result from a home-food purpose of farming that involves rainfed summer-maize production. This practice might be replicated on the predominantly gravity-canal schemes that have lower operational costs and accommodate a home-food production orientation. Uncertain irrigation supplies, as was found to be the general case on these schemes, are thus not critical for production (given higher rainfall), and provide supplementary water.

Market diversity was measured as the sum of marketing outlets that included: sale to bakkie traders; local stores; nearby town markets; distant fresh-produce markets; and contract-growing arrangements. The level of market diversity was found to be significantly associated with commercialization, but only weakly so (R=0.268; p=0.037).

Agricultural information availability also shows a similar, moderately-weak and negative correlation with commercialization (R=-0.315, p=0.037).

Land exchange prevalence has a weak and negative correlation with commercialization (R=-0.298, p=0.020). The land exchange index was a combined measure of land-exchange activity, plus the degree to which exchange transactions had to be approved by scheme organisations and the Traditional Authority. The weak negative correlation suggests a trend that more commercialized farming took place on schemes with a weaker land-exchange environment. To further investigate this counter-intuitive tendency, a more-nuanced analysis was conducted on the operational schemes, presented next.

6.4 Detailed analysis of land exchange prevalence

The consolidated land-exchange index was developed from three different sets of data as presented in Chapter 4: i) lease type (informal; with involvement of the scheme committee; with involvement of the Traditional Authority); ii) payment basis (crop share, cash, in exchange for mechanisation); and lease duration (seasonal, 1 year, or 2 years or more). More specific association tests were conducted on the source data from which the index was compiled. Various combinations of variables were tested for associations with annual cropping intensity and commercialisation using Pearson's Chi-square test for probability, and Pearson's PHI for strength.

The only contributing variable that showed any association was when the lease duration was longer than two years. Neither the involvement of the committee or traditional authority (or both), nor the payment basis of the transaction showed any association with performance. There was also no statistically significant association for commercialisation values of less than 70%. The results are shown in Table 6.3.

Table 6.3: Association between land exchange prevalence of two years and longer, and scheme performance indicators

	Annual Cropping Intensity (>100%)		**Commercialisation (> 70% for market sale)**	
	Probability (Chi-square test)	Strength (Pearson's PHI)	Probability (Chi-square test)	Strength (Pearson's PHI)
Land-exchange duration two years and longer	0.04882	0.497	0.01837	0.712

Note: Chi-square test at 5% level of significance

The results show a statistically significant relationship between land-exchange (two years or longer) with both annual cropping intensity (p=0.0488; strength=0.497) and commercialisation (p=0.018; strength=0.712). The association with cropping intensity is moderate, and with commercialisation, the association is strong.

This result has three important implications. First, finding suggests that more land is utilised on the schemes when longer-term land-leasing takes place, indicated by the moderate association with higher cropping intensity. Secondly, schemes with higher prevalence of long-term leasing have a strong tendency to be more commercialised. Thirdly, the duration of the lease is significant, as neither single-season, nor annual leases yielded any positive associations, only those longer than two years. These findings highlight the potential for longer-term land-exchange interventions to address the widespread low land utilisation on smallholder schemes, and to catalyse more commercially-oriented farming.

6.5 Other factor to factor correlations of interest

An analysis of the full 102 schemes was also conducted where missing data, mainly in the non-operational schemes as detailed in Chapter 4, was dealt with using the nearest neighbor statistical method. This is a widely-used, robust and simple algorithm that classifies missing data using a similarity measure based on pattern recognition in the data-set of the variable that is not perfectly complete (Holmes & Adams, 2002). The missing data thus generated facilitates analysis that could otherwise not be done. The procedure enabled further insight into various factor on factor dynamics described below.

6.5.1 Land exchange and water shortages

Land exchange was weakly and positively correlated with water resource constraint (R=0.238, p=0.023) and moderately with water stress behaviours (R=0.408, p=0.0003). In the earlier analysis, these two variables that reflected water shortage were combined to reduce the number of independent variables in the assessment of performance. The correlations of the separated input data indicate that where water stress is experienced on the scheme there is a trend for increased land-exchange activity.

6.5.2 Production knowledge and cropping intensity

Agricultural knowledge was generated as a consolidated variable, based on data on production knowledge and marketing knowledge obtained from the survey. The original input data from each of the knowledge sub-sets was correlated with cropping intensity for the 102 schemes. A statistically significant but weak positive correlation was found between production knowledge and cropping intensity (winter R=0.257, p=0.025; summer R=0.277, p=0.038) at a significant probability. The weakness of the association is perhaps surprising as one might logically assume that cropping intensity is driven by a stronger knowledge set. The result indicates that other important factors are at play. A farmer may, for example, know a whole lot about farming, but if their water supply is insufficient and erratic, or their fencing inadequate, or they don't have access to financing for fertilizer or crop-protection chemicals (among many other possible contributing factors), their production could be critically limited by these other factors.

6.5.3 Gravity schemes and water resource stress

A Chi-square analysis showed that gravity schemes had a very high probability of association with water stress ($p<0.00001$, strength=0.58 at a 95% significance level). The strength of the association was moderate. There were 52 gravity schemes, and 41 of these were either suffering major or critical constraints, while in the case of the 50 pumped schemes, only 12 schemes were in the same two categories. This pattern of higher water stress on the gravity schemes was repeated in the analysis of the 61 operational schemes ($p<0.00001$; strength=0.66).

6.5.4 Conflict

In the full data set (n=102), with statistically generated pairwise data to account for data gaps, conflict had weak but significantly positive correlations with longevity (0.214, $p=0.042$) and water stress behaviours (0.273, $p=0.017$). This indicates a tendency for higher conflict on schemes the older they get, and for higher conflict where water stress is more prevalent. While these associations are weak, they suggest a deterioration of social relationships over time which is likely linked to a combination of deteriorating infrastructure plus wider water-resource competition over time, leading to a trend of increased on-scheme water stress. The relationship between conflict and water stress on the scheme is consistent with common sense, in that increased water stress understandably leads to increased conflict over access and use.

In relation to the 61 operational schemes, conflict had similar weak but significant associations with water resource constraints (0.274, $p=0.035$). The highest correlation with conflict was with scheme size though was still moderately weak but highly significant (0.391, $p=0.002$) indicating a trend of higher conflict on larger schemes.

6.6 Cluster analysis of operational schemes

6.6.1 Overview

The agglomerative hierarchical clustering method was used to assess dissimilarity, which led to the establishment of a hierarchy of groups of schemes. The analysis was run in two different ways for the 61 operational schemes (noting the four operational JVs were excluded). As explained earlier, data on many variables could not be obtained on the non-operational schemes, and the resultant extensive data gaps meant that clustering including non-operational schemes was not expected to yield meaningful results.

Analysis Run A: The first statistical clustering routine (Analysis Run A) was based on only the four performance variables (Variable 2 to 5). Variable 1 was redundant as it referred to operational status – the selected sample all being operational. Variable 2 (longevity), that was excluded from the earlier performance analysis (as it was redundant in the operational set being simply a function of when the scheme started) was included in the cluster analysis. This is because in the set of operational schemes, Variable 2 reflects the age of the schemes. Age is associated with development era and technology type as explained in Chapter 2, with gravity-canal schemes predominating in the 1950s and 1960s while pumped-sprinkler schemes predominating the in the 1970s and 1980s. The analysis yielded four clusters with associated contributing factors identified by the statistical routine.

Analysis Run B: A second statistical clustering sequence (Analysis Run B) was carried out on the same 61 schemes but using all 18 variables (with Variable 1 excluded as above). This resulted in three groupings being defined using the procedure.

Both the first and second clustering results are described with the clusters prefixed with A or B in the description. An additional cluster (class) comprising the operational RESIS Recharge schemes were added post-analysis to the summary table of clustered data that was generated statistically. The RESIS Recharge cluster was not based on statistical procedures as these were excluded from the statistical analysis for reasons explained in Chapter 4. Their distinct character, however, is clear in Table 6.4 (group A5) when compared with the four statistically generated clusters (groups A1-A4).

6.6.2 Description of the clusters (A Run)

The results from the first cluster analysis were characterized with a general description of the performance variables and given indicative names which are listed in Table 6.4. This presents the main characteristics of each cluster. Age dominated as a factor, with high diversity of values within each of the remaining statistically identified key variables. The wide range of each cluster, and the similarity across the clusters, particularly A1 and A2 made characterization less meaningful than it otherwise might have been. Energy source, which is an independent variable and not a performance indicator, played no role in the statistical process but was added to the indicative table as a descriptor. This was done to aid interpretation given the high importance identified in the correlation analysis.

Cluster A1 - Resilient old-timers: This cluster comprises 26 schemes with a narrow range in age of 38 to 49 years. Twenty-four are gravity-canal schemes and two are pumped. The annual cropping intensity is derived from the sum of winter and summer cropping intensities. The average annual cropping intensity[6] of Cluster A1 (Table 6.5) is relatively low for irrigation schemes (92%) though inspection of the data shows a wide range between the schemes in the cluster, of 40% to 150%. A cropping intensity of 92% indicates that a little less than the whole scheme area is cropped over the entire year, suggesting a more rainfed character, with irrigation playing a supplementary role.

The commercialisation average is 0.4 indicating 40% of produce is sold. Inspection of the data within the clustered schemes shows this also comprises a wide range from completely home-food oriented to four schemes that are fully commercialised (commercialisation index range from 0.0-0.9). Despite these variations, the generalized group character is one of advanced age with a home-food emphasis. All of these schemes had generally small plot sizes (average of 1.26 ha) and most suffered major or critical water resource constraints.

[6] The annual cropping intensity is calculated from the sum of summer and winter intensities. Two crops a year on the whole scheme equals a cropping intensity of 2.0 (alternatively expressed as 200%). A cropping intensity of 1.7 would equate to two season of 100% and 70% of the area cropped, or 90% and 80% in the two seasons etc..

Table 6.4: Summary of operational smallholder irrigation scheme clusters in Limpopo Province based on four performance variables (A Run) (n=61: 2010)

Class	Indicative name	No. in cluster	Age	Cropping Intensity	Purpose (Sale/Food)	Energy Source
			Var 2	Var 3 + 4	Var 5	Var 11
A1	Resilient old-timers	26	Old	Moderate	Mainly food	Gravity-canal
A2	Water-stressed old-timers	20	Very old	Low	Both	Gravity-canal
A3	Up and comers	10	New	Moderate	Mainly sale	Pumped
A4	Not meaningful	5	Middle-aged	*varied*	*varied*	Mainly gravity
A5	JV Shooting stars	4	Very new	Very high	Sale	Pumped

The data for schemes in each cluster was averaged providing a centroid value shown in Table 6.4.
The centroid data was also used to generate Figure 6.2.

Table 6.5: Characteristics of operational smallholder irrigation scheme clusters in Limpopo Province based on four performance variables (A Run) (n=61: 2010)

		Performance variables (dependent)					Independent variables						
Class		Years operated	Winter cropping intensity	Summer cropping intensity	Annual intensity	Commerc -ialisation index	Command area (ha)	Plot Size (ha)	Energy source (% schemes pumped)	Water resource constraint score	Land exchange index	Agric. Information index	Main irrigation method
		Var 2	Var 3	Var 4	Var 3+4	Var 5	Var 6	Var 7	Var 11	Var 13	Var 15	Var 17	Var 18
A1	Resilient old-timers	45.42	0.27	0.66	0.92	0.40	75	1.26	8%	2.96	0.73	0.65	1.00
A2	Stressed old-timers	55.80	0.22	0.53	0.75	0.56	120	1.16	0%	3.05	0.64	0.57	1.00
A3	Up and comers	12.3	0.39	0.66	1.04	0.64	53	2.64	90%	1.90	0.34	0.67	2.3
A4	*Not meaningful*	*32.60*	*0.32*	*0.41*	*0.73*	*0.64*	*135*	*2.01*	*20%*	*2.60*	*0.33*	*0.43*	*1.20*
A5	JV Shooting stars	2.50	1.00	1.00	2.00	0.90	258	3.95	100%	1.75	0.45	0.75	2.75

Note:

1. *Data in the table is the centroid value which is equal to the average of all schemes in each class.*
2. *Winter and summer cropping intensity (Var 3 and Var 4) did not show major distinction between the classes so were combined into an annual intensity for ease of discussion.*
3. *Shaded cells highlight interesting characteristics of substantial differentiation across the clusters by observation.*

Cluster A2 – Water stressed old-timers: The cluster comprised the 20 oldest schemes averaging 55.8 years and with a range from 50 to 72 years old. The cluster has a low annual intensity on average (0.75) and reflects a nearly equal mixed production purpose with 56% of crops being produced for sale. As in the case of Cluster A1 there was substantial variation within the cluster in relation to commercialisation in particular (between 5% and 90% grown for sale). Average plot sizes were the smallest of all clusters (1.2 ha) and most schemes suffered from significant water resource constraints. All of this cluster comprised gravity-canal schemes.

Cluster A3 – Up and comers: This group of 10 schemes was distinct in their relatively young age (12.3 years average), relatively larger average plot sizes (2.6 ha) and a commercialisation emphasis (64% crops grown for sale). Annual cropping intensity was low at 1.04, though higher than the previous clusters. As in the case of the other clusters, the data set contained a wide range of both plot size and commercialisation. All but one scheme relied on pumping, which was to sprinklers or micro irrigation system in the fields. The clustering indicates a clear tendency for pumped schemes to be more commercialised.

Cluster A4 – Not meaningful: The cluster comprised five schemes of 28 to 36 years of age with a low average annual cropping intensity (0.73), the average masks a wide range of scheme intensity data across the five schemes (0.1 to 1.55) meaning that cropping intensity was not a useful descriptor. Commercialisation was more representative of the group character but was moderately low, averaging 0.64. Of the remaining characteristics, only energy type and the co-variant, irrigation method, reflected the character of the group. Four of the schemes were pumped and one was gravity. The Cluster A4 schemes would seem better suited to be re-allocated to alternate clusters where they do not seem to share the set of representative characteristics, other than age, and related energy source by virtue of the development era the scheme was constructed in.

Cluster A5 – JV Shooting stars: This group of four schemes are the RESIS-Recharge joint ventures and have closely similar characteristics to each other, excepting for scheme size and plot size. They are all very new schemes (2 or 3 years), with high annual cropping intensity (2.0) and are fully commercialised (0.9). They are also all pumped schemes with micro-irrigation systems infield and have the lowest water-resource constraints of any other group.

6.6.3 Discriminant analysis of the clusters (A Run)

A discriminant analysis (DA) was conducted on the clustered groupings in the A Run, noting these clusters (established using four of the five performance variables). The purpose of the DA was to identify what scheme characteristics were mostly strongly represented by the A Run clusters to better understand their character. The outcome of the DA and the relative contribution of scheme characteristics to the statistically established DA factors (F1 and F2) is shown in Table 6.6 and Figure 6.2. F1 and F2 highlight the dominant variables that explain data variability (or inversely, similarity) of the clusters.

The DA shows that Factor 1 explains 92.6% of the variation in the data which is very high, and Factor 2 played a very minor role explaining only 5.2% of the variation. Observation of the values in Table 6.5 shows age (Var 2) and energy source (Var 11) largely explain similarity (or variability) across the data set. The main irrigation method (Var 18) was shown in the correlation evaluation to be covariant with energy source with a similar contribution to DA Factor 1. Water resource constraint is another contributor (0.4306). DA Factor 2, which is displayed on the vertical axis of Figure 6.2, is influenced by rainfall, cropping intensity and commercialisation.

Table 6.6: Correlations with discriminant factors for operational smallholder schemes in Limpopo Province clustered by four performance variables (Run A) (n=61: 2010)

Scheme characteristic		**F1**	**F2**
Var 2	Years operated	**0.9839**	0.0666
Var 3	Winter cropping intensity	-0.3272	-0.0106
Var 4	Summer cropping intensity	-0.1277	**0.4105**
Var 5	Commercialisation index	-0.1518	**-0.4100**
Var 6	Command area	0.2642	-0.3679
Var 7	Plot size (Average)	-0.3788	-0.1403
Var 8	Rainfall	0.3136	**0.5707**
Var 9	Distance to market	0.2290	-0.2353
Var 10	Soil suitability index	-0.0713	0.0880
Var 11	Energy source	**-0.7826**	-0.1219
Var 12	Infrastructure condition index	0.0897	0.1781
Var 13	Water resource constraint score	**0.4306**	0.1142
Var 14	Conflict score	0.0031	0.0389
Var 15	Land exchange index	0.3380	0.3791
Var 16	Market diversity score	-0.0577	-0.0568
Var 17	Agric. Information index	-0.1170	0.3568
Var 18	Main irrigation method	**-0.7774**	-0.2055

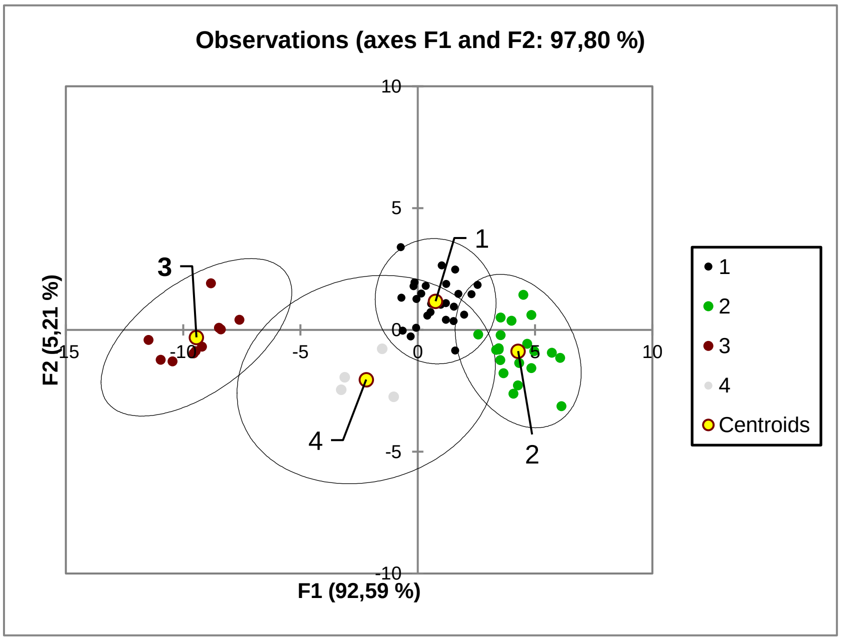

Figure 6.2: Scheme clusters based on the four performance variables for operational schemes in Limpopo Province (n=61: 2010)

The RESIS Recharge schemes were not included in the statistical clustering process as explained before, but the importance of this group being defined as a separate cluster can be seen clearly in the context of the DA findings. The DA Factor 1 is dominated by age and technology type and the RESIS Recharge schemes are, first, exceptionally young by comparison to other schemes (average 2.5 years) and, secondly, were all pumped micro-irrigation schemes. This separation into Cluster 5 is thus in alignment with the clustering logic highlighted by the DA. The water resource constraint (Var 13), a significant but weaker contributing variable in the DA, is also markedly lower on the RESIS Recharge schemes than the other clusters as shown in Table 6.5.

6.6.4 Description of clusters (B Run)

The same clustering procedure was followed using all the characteristic variables (Total of 18 less the redundant Variable 1 (operational status) = 17). This yielded three clusters and the fourth Cluster, comprising the four RESIS Recharge schemes – B4, was added for comparison.

These are first summarized in Table 6.7 and elaborated in Table 6.8. The importance of variables is confirmed by the discriminant analysis discussion that follows after the summary cluster descriptions.

Table 6.7: Summary of operational smallholder irrigation scheme clusters in Limpopo Province based on seventeen variables (B Run) (n=61: 2010)

Cluster	Indicative name	No. in cluster	Rainfall	Purpose (Var 5)	Energy Source
B1	Market schemes of many types	23	Low	Mainly sale	Both
B2	Mixed-purpose gravity schemes	32	Moderate	Mixed	Gravity
B3	Food gravity schemes	6	High	Mainly food	Gravity
B4	JV Shooting stars	4	Varied	All sale	Pumped

Cluster B1 – Market schemes of many types: This group of 23 schemes is characterized by a higher commercialisation value with an average of 63% of crops grown for sale, alongside higher average plot sizes (1.81 ha). Rainfall is also relatively lower at 527mm. The average age of schemes (32.9 years) is slightly lower than the other clusters, apart from Cluster B4 which comprises new schemes. Notwithstanding these generalisations there is a wide diversity within every other characteristic when looking at the individual scheme data. The scheme values within the cluster cover almost the entire range, excepting for rainfall and commercialisation which are more consistent.

Eleven of the schemes are pumped and use sprinklers or micro infield as the main irrigation method, the other 12 are gravity schemes. Annual cropping intensity is one example where the average (cropping intensity = 0.94) not much different from the other clusters but comprises individual scheme data which ranges widely from 0.1 to 1.75 This characteristic (intensity), therefore, is not a meaningful descriptor on its own.

Cluster B2 – Mixed-purpose gravity schemes: The cluster comprises 32 schemes that are characterized by their mixed purpose and location in moderate rainfall areas (708 mm). Importantly, all but one are gravity schemes using surface irrigation methods. An average of 49% of crops are grown for sale on typically sized smallholder irrigation plots (1.37 ha). Water resource constraints are generally major. As with all prior clustering apart from the JV Shooting Star cluster, there is substantial diversity within, with the exception of energy source and irrigation method.

Table 6.8: Characteristics of operational smallholder irrigation scheme clusters in Limpopo Province based on seventeen variables (B Run) (n=61: 2010)

Indicative Cluster Name		**Market schemes**	**Mixed purpose**	**Food schemes**	**JV shooting stars**
Scheme characteristic	**Var**	**Cluster B1**	**Cluster B2**	**Cluster B3**	**Cluster B4**
Years operated	2	32.9	48.2	47.2	2.50
Winter cropping intensity	3	0.32	0.24	0.28	1.00
Summer cropping intensity	4	0.62	0.57	0.65	1.00
Annual intensity	(3+4)	0.94	0.81	0.93	2.00
Commercialisation index	5	0.63	0.49	0.15	0.90
Command area	6	58.5	117.1	78.8	258.0
Plot size (Average)	7	1.81	1.37	1.16	---
Rainfall	8	527	708	912	555
Distance to market	9	35.7	36.0	38. 7	50.4
Soil suitability index	10	0.72	0.75	0.82	0.93
Energy source	11	0.48	0.03	0.00	1.00
Infrastructure condition index	12	0.41	0.49	0.58	0.84
Water resource constraint score	13	2.48	3.00	2.83	1.75
Conflict score	14	1.54	1.55	1.67	2.00
Land exchange index	15	0.44	0.66	0.93	0.45
Market diversity score	16	4.00	4.63	2.17	3.00
Agric. Information index	17	0.58	0.63	0.61	0.75
Main irrigation method	18	1.57	1.03	1.00	2.75
Number of schemes in Cluster		*23*	*32*	*6*	*4*

Note: Shaded cells are observed to have substantial variation from the other data and therefore provide insight into differentiation between the clusters.

Cluster B3 – Food gravity schemes: These six schemes are primarily food producers selling only 15% of their crops on average, farmed on generally smaller plots (1.16 ha). They are in higher rainfall areas (912 mm) and are all gravity schemes using surface irrigation. Land exchange on these schemes is notably high and the water resource constraint is major, if slightly lower than Cluster 2. Somewhat differently from the other clusters above, this small group has less internal variation in the data.

Cluster B4 - JV Shooting stars: The description is the same as under the previous clustering A run. The significant difference in the many shaded variables in Table 6.8 compared with the other B clusters shows the uniqueness of these schemes. These are new schemes, average age of 2.5 years compared with the other clusters which average approximately 33 to 48 years. Cropping intensity, commercialisation, energy source (all pumped), infrastructure condition and main irrigation method are all significantly higher than the other three groups. Water resource constraints are significantly lower.

6.6.5 Discriminant analysis of the clusters (B Run)

The discriminant analysis provides insight into the importance of various scheme characteristics and the influence they had on the cluster formation. The correlations between the scheme characteristic variables and the DA factors are shown in Table 6.9.

Table 6.9: Contribution of scheme characteristic variables to discriminating factors (B Run)

Scheme characteristic		F1	F2
Var 2	Years operated	**0.4454**	0.4434
Var 3	Winter cropping intensity	-0.1622	-0.2961
Var 4	Summer cropping intensity	-0.0284	-0.2547
Var 5	Commercialisation index	**-0.4650**	0.3221
Var 6	Command area	0.2654	0.5729
Var 7	Plot size (Average)	-0.1747	-0.0637
Var 8	Rainfall	**0.9557**	-0.1388
Var 9	Distance to market	0.0208	-0.0308
Var 10	Soil suitability index	0.1062	-0.1047
Var 11	Energy source	**-0.5314**	-0.4262
Var 12	Infrastructure condition index	0.2151	-0.0425
Var 13	Water resource constraint score	0.2182	0.3070
Var 14	Conflict score	0.0212	-0.0415
Var 15	Land exchange index	**0.4253**	-0.0883
Var 16	Market diversity score	-0.0838	0.5521
Var 17	Agric. Information index	0.0908	0.1256
Var 18	Main irrigation method	**-0.4302**	-0.3514

The DA Factor F1 accounts for 96.9% of the variation in the clustered data sets for Run B, while F2 accounts for only 3.1%. Observation of the data shows that rainfall plays a dominant role in clustering with a very high correlation to F1. Other variables with moderate correlation to F1 include longevity, commercialisation, energy source, land exchange index and main irrigation method (with is a covariant with energy source as explained earlier).

The clusters from Run B, shown in Figure 6.3, form distinct clusters along the F1 axis, but are more widely scattered along the F2 axis. The statistically generated lozenge around Cluster 3 (6 data points – all shown) extends beyond the graph border due to the relatively large scatter, and low number, of the points.

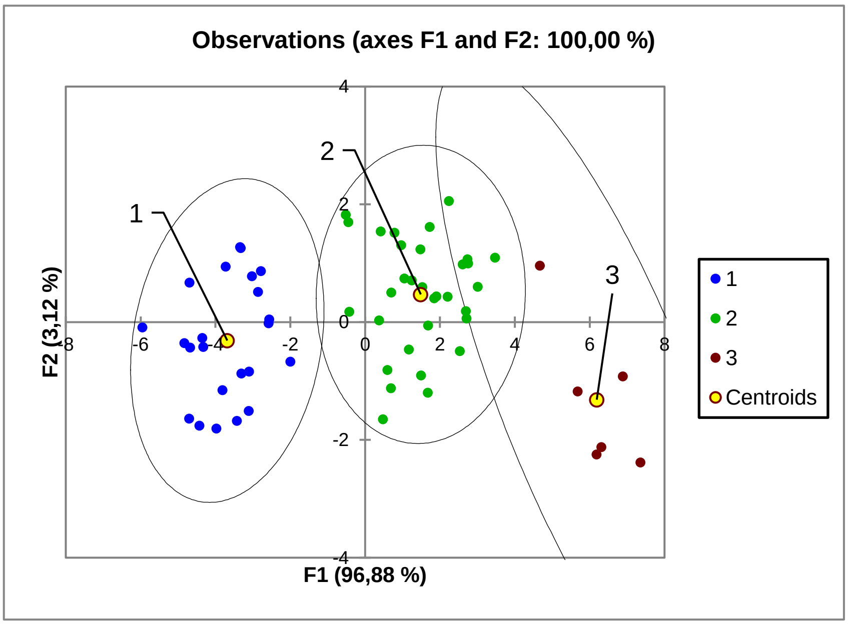

Figure 6.3: Scheme clusters from Run B based on discriminant analysis factors (F1 and F2)

6.6.6 Comparison of Cluster A and Cluster B

Scheme composition of clustered groupings: The incidence of overlap of schemes that comprised the Run A and Run B clusters (necessarily only including operational schemes as per Run B) was tested using Chi-square. The result was not significant at $p<0.05$ for all groupings, meaning that within the operational set, there was no statistically relationship between the component schemes.

Plot size and commercialisation: One of the more interesting points to emerge from the cluster analysis was a trend that all the clustered schemes (excluding A4 which seemed to lack meaning and comprised only 5 schemes) conformed to a trend of increasing commercialisation with increasing plot size. This is shown graphically in Figure 6.4.

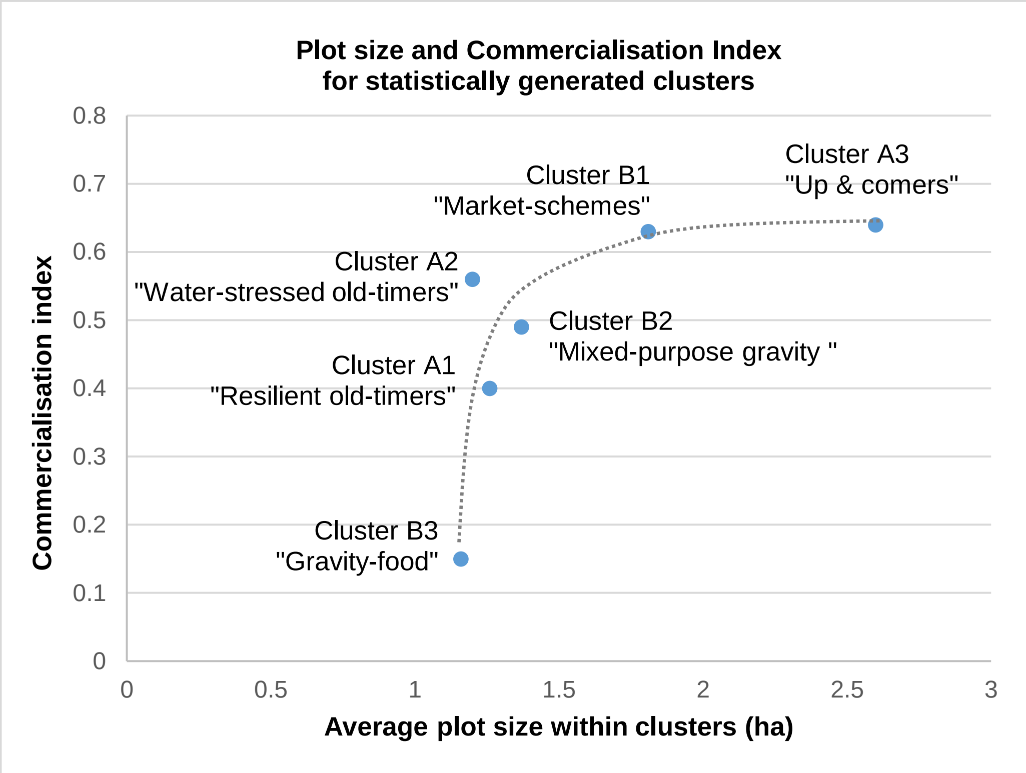

Figure 6.4: Plot size and commercialisation index of all statistically clustered schemes

The finding is interesting and complements the correlation analysis of plot size and commercialisation of all operational schemes (Figure 6.1). That analysis showed that levels of commercialisation (on each scheme) were diverse below 2 ha, but from 2 ha upwards purpose of farming was dominated entirely by commercial purposes. The cluster analysis grouped operational schemes (n=61) on their statistical similarity using a set of performance variables (Run A), and very differently, by all variables (Run B). The average characteristics of the clustered schemes are the centroidal value of the 'typical scheme' in the cluster. The trend in Figure 6.4 shows clearly that regardless of the (widely divergent) clustering approach, that for the 'typical scheme' in each cluster, increasing commercialisation is closely associated with increasing plot size. In the above graph, it is the trend, rather than the absolute value of commercialisation that is important. This confirms, by completely different statistical approaches, the existence of a relationship between increased plot size and commercialisation.

6.7 Principle Component Analysis

The principle component analysis (PCA) generated a set of 17 factors which contribute to explaining the variability in the data. The relative importance of each factor in explaining variability is indicated by the Eigen value which is the association between the components (PCA factors) and the original variables. The variability is the percentage of variability in the data that is explained by that factor. The interpretation of the PCA requires selection of a sufficient number of factors to adequately describe the variability of the data followed by discussion of the scheme characteristics (variables) that contribute to each principle component. Variables that emerge as 'strong' in describing a PCA factor indicate higher importance, and when in relation to one factor, that these are associated with each other.

The Eigen values of the principle components that were generated from the data set of 61 operational schemes is shown in Table 6.10 and graphically in a scree plot in Figure 6.5. Typically, there are a number of guidelines for selecting the number of the components that are assessed (Zwick & Velicer, 1982; O'Rourke & Hatcher, 2013) and four have been selected:

i) the Kaiser criterion of using only those Eigen values greater than 1;
ii) for descriptive purposes one would aim to explain 70-80% of the data variability;
iii) observation of the scree plot for an inflection point; and
iv) retention of factors which account for 10% or more of data variability.

Typically, most of the variability is explained in the first two or three factors, as the contribution to explaining variability both diminishes and becomes less meaningful beyond that point. Observation of the principle components in Table 6.10 show that F7 would be the last factor to assess based on criterion i) and ii) above. The Eigen value of F7 is 1.03 and the cumulative contribution of F1 to F7 explains of 74.95% of variability. While using seven or eight principle components for predictive modelling is routine, the purpose here is to expand the general understanding of scheme characteristics. In terms of criteria iii), observation of the scree plot of Eigen values shows a point of inflection at F3 - F4. While factors F4 - F8 continue to contribute to explaining variability, narrative interpretation back to scheme characteristics comprises too many diminishing levels to be practical. The discussion of contribution of scheme characteristics is therefore limited to the first three PCA factors, which corresponds to the fourth selection approach, noting F4 accounts for less than 10% of the variability so is excluded.

In combination F1 to F3 contribute only 46.5% of the data variability but interrogation of key contributing variables to the PCA factors will throw light on relative importance of these characteristic variables in describing the data.

Table 6.10: Eigen values and variability from the principle component analysis of operational smallholder irrigation schemes in Limpopo (2010: n=61)

	Eigenvalue	Variability (%)	Cumulative %
F1	3.84	22.56	22.56
F2	2.31	13.61	36.17
F3	1.75	10.32	46.49
F4	1.43	8.40	54.89
F5	1.26	7.40	62.29
F6	1.12	6.58	68.87
F7	1.03	6.08	74.95
F8	0.89	5.24	80.19
F9	0.60	3.55	83.75
F10	0.55	3.25	87.00
F11	0.51	3.00	89.99
F12	0.45	2.62	92.62
F13	0.39	2.30	94.91
F14	0.36	2.11	97.02
F15	0.23	1.34	98.37
F16	0.17	1.03	99.39
F17	0.10	0.61	100.00

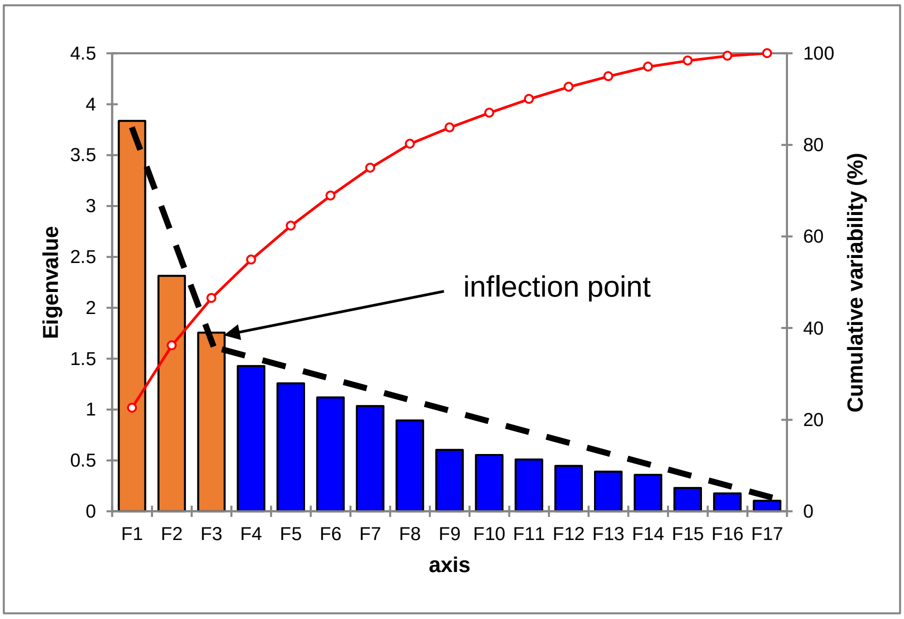

Figure 6.5: Scree plot with Eigen values of the principle components for operational schemes (n=61)

The PCA factor loadings, representing the correlations between the scheme characteristic variables and the PCA factors, indicate the influence of the variable on the PCA factor. As in all correlations, values range from -1 to 1 and the greater the magnitude the more influence the variable has on the PCA factor. The PCA factor loadings are shown in Table 6.11.

Table 6.11: Correlations between independent characteristic variables and factors in the Principle Component Analysis of smallholder irrigation schemes in Limpopo Province (2010: n=61)

	Scheme characteristics (independent variables)	**F1 (22.56%)**	**F2 (13.61%)**	**F3 (10.32%)**
Var 6	Command area	**-0.526**	0.373	**-0.515**
Var 7	Plot size (Average)	0.010	**0.475**	**-0.419**
Var 8	Rainfall	**-0.487**	**-0.451**	-0.137
Var 9	Distance to market	-0.090	0.117	**0.802**
Var 10	Soil suitability index	-0.107	0.219	0.356
Var 11	Energy source	**0.811**	0.262	0.075
Var 12	Infrastructure condition index	0.214	**-0.454**	-0.024
Var 13	Water resource constraint score	**-0.655**	0.104	0.047
Var 14	Conflict score	-0.385	0.152	**-0.483**
Var 15	Land exchange index	**-0.476**	-0.336	0.206
Var 16	Market diversity score	0.044	**0.396**	-0.056
Var 17	Agric. Information index	0.264	**-0.418**	-0.359
Var 18	Main irrigation method	**0.774**	0.249	0.042

Factor F1 explains 22.6% of the data variability which is relatively low for the first PCA factor. There are numerous scheme characteristics that contribute to this factor with the stronger correlations being in relation to energy source (Var 11) and its covariant, main irrigation method (Var 18). Moderately strong to moderate contributions to Factor 1 are made by the variables (in order of declining magnitude and ignoring polarity): water resource constraint, command area, rainfall and land-exchange index. The PCA indicates that these characteristics are the most important characteristics and are most strongly associated in explaining outcomes related to the data set.

Factor F2 contributes 13.6% to explaining variability and this factor is moderately strongly influenced by plot size, infrastructure condition, rainfall and the agricultural information index. Market diversity, with a correlation of 0.396 influences Factor F2 moderately weakly but still plays a role.

Factor F3 contributes even less (10.3%) to understanding data patterns with major influences being distance to market, command area, conflict and plot size. Soil suitability had minimal weighting in F1 and F2 and is moderately weakly associated with F3.

Combined, these three PCA factors account for 46.5% of the data variability. The main outcome of the PCA is that the most important characteristics in defining the shape (or groupings) within the set of independent variables are: energy type (and the associated method of infield irrigation which is a covariant as determined earlier), water resource constraints, command area, rainfall and the prevalence of land-exchange. Plot size, infrastructure condition and agricultural information are contributing variables of importance. However, because of the relatively small contribution of each of the PCA factors (F1 to F3), the identified most important variables only describe the data set (i.e. reflect the grouping of the principle components) somewhat weakly.

6.8 Summary of the statistical evaluation

6.8.1 Summary of failure factors (n=102)

There are moderately strong associations between the independent variables of energy source (ie. gravity or pumped), infrastructure condition and main infield irrigation method, and scheme failure. Failure to perform is defined by operational status (Variable 1) and scheme lifetime (Variable 2). Pumping and poor infrastructure condition emerged as the dominant factors associated with scheme failure. Despite having a much higher level of relative water stress and much older infrastructure, the gravity schemes defy these forces of age and degradation both in terms of operational status and longevity.

Other factors associated with scheme failure, but moderately so, are water resource constraints and rainfall. Where rainfall is higher, schemes are more likely to be operational. Finally, in regard to failure, infield irrigation method showed a strong association with operational status, but is also strongly cross-associated with energy source ($p<0.00001$; strength=0.846). A total of 50 out of 52 gravity schemes used surface irrigation, and 45 out of 50 pumped schemes used sprinklers, micro or drip irrigation, explaining the cross-association. While a conclusion is drawn on the role of pumping in failure to operate, the role of infield irrigation method itself cannot be determined due to the cross-association with, and dependence on pumping in the data set.

The discussion in Chapter 7 addresses the socio-technical and organisational dimensions of these findings, following the rationale that more complex infrastructure requires more sophisticated organisational arrangements to ensure ongoing operations.

6.8.2 Summary of success factors

The results show that explaining success is more elusive than failure, as increased performance results from the contribution of multiple factors. Associations between the scheme characteristics and performance were tested on the 61 operational schemes and were found to be multi-fold, and generally moderate to weak.

Factors that had statistically significant, albeit weak to moderately weak, correlations with cropping intensity, were: command area (smaller schemes were more intensive); distance to markets (closer schemes were more intensive) and water resource constraints (more water-stressed schemes were less intensive). Of these, the characteristic of water resource constraint yielded the strongest correlation though the result was still moderately weak ($R=0.376$, $p=0.003$).

As in the case of cropping intensity, the statistically significant associations between commercialisation and scheme characteristics were weak. Factors of interest emerging from the results were plot-size, rainfall, land-exchange prevalence, agricultural information and market diversity. Plot size was found to be important for the reason that the purpose of farming became almost entirely commercial as plot sizes approached 2 ha, and upwards.

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6.8.3 Summary of cluster analysis

The two cluster analyses aimed to understand the similarities in operational schemes from two different perspectives. Run A was a statistical procedure based only on the four performance variables: age, winter cropping intensity, summer cropping intensity and degree of commercialisation. Run B applied the same statistical clustering method but took account of 17 variables that were relevant to operational schemes. In both cases the clustering outcome relied heavily on one scheme characteristic with high diversity observed in the individual scheme data within each cluster.

Run A, which used the statistical routine to cluster the operational scheme data using only the performance variables, resulted in four clusters. The RESIS Recharge schemes were added as a fifth for comparison, which highlighted their distinctly different nature across most variables. The data, both on observation and when combined with the insights from the discriminant analysis, showed that longevity and energy source (whether pumped or gravity) provide the main explanation for scheme similarity. Commercialisation and rainfall were contributing factors. Longevity has been shown to be closely linked to scheme technology type (gravity-canal or pumped) and this is mainly due to the varied technology preferences that were prevalent during different irrigation development eras. Older schemes from the 1960s were all gravity-canal, while those from the homeland era of the 1970s and 80s were mostly pumped-sprinklers. Most recently, RESIS-Recharge was the highest tech intervention and pumped-micro solutions were used. In understanding scheme groupings and their related performance characteristics, it seems that history and the dominant development paradigm of the time, reflecting longevity and technical choice, are statistically most important.

Run B, which clustered the operational scheme data based on 17 variables resulted in three statistically generated clusters. The RESIS-Recharge schemes were added as fourth for comparison. As in the case of Run A, the latter group was distinctly different on most variables excepting scheme and plot size. The three statistically generated clusters were grouped with a strong influence from rainfall, with energy source, degree of commercialisation, longevity and land-exchange all describing the cluster character. In Run B, land exchange had a high average value on the gravity-food schemes (Cluster B3, 0.93) but trended to the lowest value on the market-oriented schemes (Cluster B1, 0.44), which would be the opposite to what is expected. The correlation analysis suggested that water-stress may be one driver of increased land-exchange prevalence, and that water stress is also linked to scheme-type. The effect of land exchange is expected to be diluted by the nature of average data that was collected on average plot-size as allocated and did not reflect the average area actually farmed on the schemes, discussed more in Chapter 7.

It is of importance that for both sets of clusters, Run A and Run B, there was a clear trend of increasing commercialisation with larger plot sizes, based on the observed average (centroidal) values. Each centroid depicts a statistically best-fit description of the characteristics of the cluster of schemes – and thus characterises each group. A graph of all of the characterised groups shows that commercialisation increases sharply from average (cluster) plot sizes of just over 1 ha, and levels off at maximum commercialisation close to 2 ha. The finding resonates with the graph of individual scheme plot sizes and commercialisation, with a similar sharp breakpoint value at 2 ha.

6.8.4 Principle component analysis

The PCA statistically demonstrates the wide diversity of the data, and that simplistic relationships between characteristic factors (independent variables) and performance outcomes (dependent variables) do not exist. This all reinforces the findings of the correlation analysis and the cluster analysis, pointing to high levels of diversity on schemes, and that multiple factors must be considered in relation to scheme performance.

The findings described in Chapter 5 and Chapter 6 are discussed in Chapter 7 in the context the wider body of literature.

7 DISCUSSION

7.1 Introduction

This penultimate chapter analyses the findings and discusses their meaning in relation to smallholder irrigation development in Limpopo. The primary aim of the research was to understand what factors affect smallholder irrigation scheme performance. Performance was considered first in terms of scheme ‘failure’ and was analysed on all 102 schemes and answered the question, ‘Why do smallholder schemes fail?’. The analysis of ‘success’ was conducted on 61 of the 65 operational schemes. Four operational Joint-Venture (JV) schemes were excluded. These were the schemes where all the smallholder plots were consolidated and farmed by a commercial partner as one large farm enterprise (van Koppen et al., 2018). They are a different phenomenon in their estate-mode of production. Inclusion of JVs would distort factor-relationships with success as they apply to smallholder schemes comprising many individual farm enterprises. A secondary aim was to develop a statistically-substantiated scheme typology that would capture the essential features of smallholder schemes in the light of the key drivers of performance. The typology would inform future development initiatives. The discussion in this chapter revolves around three themes that lead to three propositions based on the findings.

First, in the technical domain, it will be argued that modernisation efforts must prioritise the development and improvement of gravity-canal schemes to promote smallholder irrigation farming in Limpopo. The performance of gravity-canal schemes is equal or better to pumped schemes. They are more resilient despite their age and the higher water resource stress that prevails. It is shown that the destruction of gravity schemes to be replaced by pumped schemes is not justified by agricultural performance nor water efficiency considerations. Where pumped schemes are unavoidable due to topography, the higher operational complexity and operational costs need to be matched by intensified market-oriented farming, institutional and operational sophistication. The implication is that scheme type determines farming type.

The second theme is in the land domain. The findings lead to the conclusion that performance can be accelerated on schemes through land-tenure interventions that promote farm-size consolidation. This follows from the result that cropping intensity and commercialisation are moderately and strongly associated, respectively, with higher prevalence of land-exchange of duration two years or longer. That result is complemented by the finding that plot sizes over approximately 1.8 ha have a marked relationship with high levels of market-oriented farming.

The third theme is an integration of the above two in terms of the land, water-management and irrigation-system type on schemes. Different scheme types are suitable for different kinds of farmers and institutions. Gravity schemes are more accommodating of a wide range of farming typologies. Pumped schemes, however, require a highly-commercialised farming objective that is enabled by larger farm sizes. The operational complexity of collaborative pumping requires highly functional, and properly administered scheme-level water-institutions. These essential functions, technical, financial and administrative, it is argued, demand sophisticated farm-level production and marketing operations. Scheme technical characteristics thus have determinism on plot-size, farming style, and land/water institutional character. Within these boundaries, institutional and technical design choices need to include the concept of flexibility and counter institutional persistence that stifles dynamic systems. This pertains to reversible land-consolidation processes, and the incorporation of multiple hydraulic units to accommodate both estate-mode and smallholder-modes of farming on schemes. In this way, schemes can, within the boundaries of technical-determinism, evolve dynamically into one form, then back to another, driven by ever-changing internal and external opportunities and market forces.

The chapter first examines the factors that were found to have contributed in statistically significant ways to success or to failure. Their relevance in relation to literature and other findings are explained and analysed within a complex-systems view of schemes. The latter part of the chapter addresses the findings of the cluster and principle component analysis that are used to define a contemporary irrigation scheme typology. Reference is then made to the kinds of smallholder farming typologies that can be supported on smallholder schemes. Chapter 7 then concludes by consolidating the various findings into the three main arguments.

7.2 Failure – extent and reasons

7.2.1 Interpreting failure and success

Two performance indicators were used to understand failure of the 102 surveyed schemes. These were operational status and longevity. A failed scheme was one that was non-operational at the time of survey. Longevity was used to provide insight into the process and timeline of failure and, while quantified, was not defined with a baseline value as failed or successful. Longevity was use comparatively to understand characteristic differences of long-lived and short-lived schemes.

Defining failure or success is a subjective and context-specific exercise, so direct comparison with other studies is not always straightforward. 'Operational' status does not necessarily mean ‘success’. ‘Operational’ in this study was defined as when a scheme provided some irrigation water, even if that was a small percentage of what the design intended. Success in other studies is defined differently and two highly relevant studies are highlighted as these provide useful comparative data given their parallel study focus. Mutiro and Lautze (2015) conducted a meta-study of 107 schemes in the Southern Africa Development Community (SADC) with an interest in performance and factors. Limited by the depth of data that could be obtained, they categorised schemes as either successful or not, based on five types of information (EIRR, gross margin, net income, yield and cropping intensity). They used whatever information was available, relying first on EIRR; when that was not available the next indicator was used, and so on. The only common indicator with this study is annual cropping intensity, though their EIRR parameter (EIRR>10%) was the same as Inocencio et al. (2007). Mutiro and Lautze (2015) defined successful schemes as those with intensities of greater than 50%. The indicator was however only used in relation to two of the schemes they analysed. To facilitate comparison with this study, their cropping intensity threshold value (>50%) was applied to the Limpopo dataset on the assumption that their concept of ‘success’ was equally evaluated by the other four parameters they used. Based on the same assumption of parity of ‘success’ across their indicators, that would allow comparison with Inocencio et al. (2007) as well.

Van Koppen et al. (2017) conducted a study of 76 smallholder schemes in Limpopo in 2015, similar to the subject of this thesis. They used winter cropping intensity as their main indicator. They defined schemes into four categories and included five JVs, of which two were operational and three were not. Non-utilised schemes were defined as those with less than 10% winter cropping intensity. The indicator of winter cropping intensity data is also captured in the thesis but the baseline definition of failure was different. In the thesis, failure is when the scheme is non-operational. Van Koppen et al. (2017) conducted a comparative analysis of three groups of schemes based on low (10-49%), moderate (50-89%) and full (90-100%) winter cropping intensity. In the thesis, performance was evaluated across the full data spectrum using statistically more detailed association, correlation and cluster analysis methods. The previously-mentioned similar studies conducted more-simple summary and comparative analysis. The thesis data was also analysed on the same basis as these two studies to facilitate direct comparison.

7.2.2 Failure in Limpopo irrigation schemes

There were 65 operational schemes (equivalent to 63.7%) out of the 102 that were surveyed, meaning that 37 of these had failed (equivalent to 36.3%). The rate of failure was slightly higher than the 32 % for all smallholder schemes in South Africa (van Averbeke et al., 2011). By comparison, Mutiro and Lautze (2015) found that 58% of the 107 schemes in SADC were successful. They found that success in South African smallholder schemes was lower than other SADC countries, at 45%. An analysis of the study data using their criteria showed the success rate of the Limpopo schemes to be 58%, which is coincidentally identical to their SADC average success rate, and higher than their estimate for South Africa (45%). These are all comparable to the 55% found by Inocencio et al. (2007) using the EIRR parameter. Failure rates in Limpopo schemes are thus much the same as elsewhere in SADC and Sub-Saharan Africa (SSA), based on closely similar evaluation parameters.

The correlation analysis identified that the most important factors associated with failure (defined in the failure analysis as non-operational status) were: type of energy source (gravity or pumped) and poor condition of infrastructure. Water resource stress and distance from markets were weaker associated factors. These factors are discussed next.

7.2.3 Pumped schemes are short-lived

The findings provide strong empirical evidence that pumped schemes are highly prone to failure and have much shorter lives than gravity schemes. Out of the 37 schemes that failed, 34 (91.8%) were pumped. There were a total of 50 pumped schemes and 34 (68%) of these had failed. By contrast, 49 (94.2%) of the 52 gravity schemes were still operational to some degree albeit many with limited irrigation area and/or poor water delivery. Regarding longevity, the 49 operational gravity schemes had an average age of 48.1 years. This was approximately four times that of the 34 non-operational pumped schemes (14.1 years). The difference in operational status and lifetimes between gravity and pumped schemes is marked.

The statistical analysis confirmed what seems clear from the above summary data. Pumping is strongly associated with scheme failure and has a strong negative correlation to scheme durability (ie. years operating). Gravity schemes, by corollary, are much more likely to be operational at any point in time and have much longer lifespans than pumped schemes. The resilience of gravity schemes is similarly emphasized by both Mutiro and Lautze (2015) and van Averbeke (2013). The complexity and challenges of achieving success on collectively-managed pumped schemes are also highlighted with cautionary tone in a South African smallholder scheme manual (Crosby et al., 2000). The findings from this research suggest that much greater caution was probably warranted.

Wider experience regarding collective pumping confirms this is not just a South African phenomenon. De Fraiture et al. (2014) documented the absence of collective (shared pumping) and the emergence of pump owner-operators supplying individual farmers in an entrepreneurial mode in Burkina Faso. In Northern Ghana, the AfDB Small Scale Irrigation Development Project (SSIDP) based on diesel and electric pumps adjacent to major rivers, ended with the failure of all 26 group schemes (covering 2,170 ha in total) due to critical issues around high energy and operational costs, a lack of technical operational support, and weak water-management organizations (Nyamadi, 2018). Mutiro & Lautze (2015) highlighted the high failure rates and inherent weaknesses of pumped schemes in their review of 107 irrigation publications relating to smallholder irrigation in Southern Africa. In Mozambique, 3 000 ha of small-scale pumped rice schemes along the Zambezi flood plain, of 100 to 450 ha in size were developed under the PROIRRI-Sustainable Irrigation Program. Most of these failed at the time of commissioning. Failure was due to technical complexity in the highly mobile, silt-laden rivers, a lack of farmer-consultation, and serious organisational deficiencies regarding management, operations and maintenance (MOM) in general (de Moor & Veldwisch, 2016; Beekman, 2018). The same failure-trend of shared pumped-irrigation systems was observed in Malawi. These were supporting women's food-production groups, lifting water from shallow wells, and failed due to collaboration and institutional issues (Kamwamba-Mtethiwa, 2018). Collective pumping thus presents a high risk of failure and this challenge is not just a Limpopo challenge, but is widely experienced across SSA in a smallholder setting.

7.2.4 Infrastructure condition

The second important factor associated with non-operational schemes was poor condition of physical infrastructure. Dilapidated infrastructure may be a cause, or it may be a consequence of failure, or in the case of a downward-spiral to collapse, it could be both. In terms of operational condition: 18 schemes were critically limited; 13 had serious limitations; 33 were moderately functional; while 38 were fully operational. The association between operational condition and failure was moderately strong. One way of viewing the condition-failure relationship is that when water infrastructure is in poor condition this has a negative effect on irrigation-services. Crop production is then undermined, and the farm-level system fails, cascading upwards to failure of the scheme system. This reflects interdependent nested systems in a complex systems view. On a pumped scheme, pump failure is definitive – when the pump or pipeline fails there is no water in the system. On gravity schemes, failure is usually slower due to leaks and distribution issues. It's a case of sudden collapse versus slow decline.

The causal links could also be the other way around. Production failure as a result of other reasons can lead to disinterest in the scheme despite water availability on-farm, leading to neglect and infrastructure collapse. This was the situation reported at Mbekweni in the Eastern Cape (Denison et al., 2015). Gravity water was supplied from Bushmankrantz dam to a series of small schemes via a pressurised pipeline. The official water allocation for 610 ha of irrigation was secure but only fractionally used. Other farming factors in the farming system were found to be critically limiting, not irrigation water as this was available under pressure in the fields. Limiting issues including lack of fencing, inability to finance production costs, old-age of farmers, and marginal returns from farming (Denison et al., 2015). These challenges left people with little interest in taking the risks despite irrigation water being available on-farm.

This alternate explanation does not seem to apply to the Limpopo context. The Limpopo schemes are generally old and in poor condition and suffer significant water resource constraints. Yet, farming practice seems to persist wherever there is some water despite these major water supply challenges. It is interesting that such regional differences were observed in the Tomlinson Commission (1955), who observed high-levels of interest and commitment to irrigation farming in the north of the country in contrast to the Eastern Cape region. Van Koppen et al. (2017) similarly conclude that poor condition is a constraint and recommend infrastructure investments, among other responses. It seems more likely that the poor performance that is reflected by low cropping intensity (and then failure) follows from water resource and condition factors (among other), rather than the other way around in the Limpopo schemes.

7.2.5 Water resource constraints

Water resource constraints increase failure: Water resource constraints were either critically limiting, or a major factor on 53 of the 102 schemes. The association of water resource constraint to operational status (ie. failure) was moderately weak and, in the case of longevity, was moderate and negative. The direction of the second result means that as the water resource stress increases, the scheme life is shorter. This is interpreted to mean that water stress is both a contributing factor to failure and to shorter scheme life. Water stress was also observed to be an issue in the 76 Limpopo schemes surveyed by van Koppen et al. (2017).

Gravity schemes are more water stressed but more resilient than pumped schemes: This finding was not as intuitive as the water scarcity association with failure but has a logical explanation in gravity scheme resilience. They remain operational, albeit at lower levels of activity, despite greater resource stress. In the full data set of 102 schemes, 41 of the 52 gravity schemes were either suffering major or critical water resource constraints, while only

12 of the 50 pumped schemes were in the same two categories. This pattern of higher water stress on the gravity schemes was repeated in the analysis of the 61 operational schemes ($p<0.00001$; strength=0.66). The result means that gravity schemes can survive greater water stress than pumped schemes before system collapse.

7.2.6 The dynamics of pumped scheme failure

The explanation of the failure dynamics draws on complex systems theory described in Chapter 3, particularly that of ‘thresholds’ and ‘feedback loops’. In complex systems theory, when the status of a factor crosses a limiting threshold, it triggers regime changes in the system. Pumped schemes, due to their higher direct energy costs and operational complexity are dependent on profitable farming, and on functional institutions for MOM for continued operation. The authors observations from two pumped schemes in the Eastern Cape are presented in Box 7.2 that illustrates the process.

Box 7.2: “Values of generosity clash with financial realities triggering failure”

It was observed at both Kama Furrow scheme (author’s notes; 2005) and Siyazama scheme (author’s notes; 2012) both in the valleys below the Amatola Mountains in the Eastern Cape[1], that some of the farmers in the pumped system were unable or unwilling to pay the monthly energy fee. These were monthly ESKOM electricity payments at Kama Furrow, and ad-hoc diesel purchases at Siyazama. Initially, the financially stronger, or larger-scale, farmers in the irrigator-group covered the monthly costs to keep the pumps running. The fact that substantial investments were already made in crop establishment and cultivation was an incentive to continue. Social relationships came into play, where weaker farmers were often older or poorer. This made it difficult for those members of the group who were paying to run the pump, to refuse water to those who had not paid. The absence of a water user association with rules, regulations and hydraulic control to cut-off water to non-paying members was important contributing context. The financial burden on those paying increased with time, and their incremental benefit reduced as their total production costs went up disproportionately compared to the expected returns from their own irrigated crop. Even where energy loans (farmer-to-famer) were made informally, the loan repayment amount increases each month, and the farmers who paid for the pumping energy are at increasing financial risk. At Kama Furrow the experience led to a failure to commence cropping in the following season. At Siyazama, the scheme collapsed.

The system collapse can be due to financial reasons such as inadequate generation of profits from farming, or inadequate collection of fees to pay for energy, such as were observed at both Kama Furrow and Siyazama schemes (Box 7.2). It can also be for technical reasons, where a technical failure, or electricity cable theft required major and unaffordable capital re-investment to get the system operational again such as on Grootfontein scheme observed in the survey (Plate 7.1 and 7.2 below). In either case, the pumped irrigation system grinds to a halt. In a complex systems view, pumped systems have lower threshold values in relation to the critical factors of institutional functionality, profitability and MOM payments than gravity systems. When the thresholds are crossed by the changing status of a system-factor, regime change is triggered, manifested in scheme collapse.

7.2.7 Pumped schemes have vulnerable on-farm equipment

The mechanism of failure on pumped schemes goes beyond the pump station itself due to vulnerability of pipelines and on-farm irrigation equipment. There were 50 pumped schemes and 45 supplied water to pressurised on-farm irrigation systems, in the form of pipelines, sprinklers and centre-pivots. Electricity cables were used on 44 of the pumped schemes. Theft of cables and vandalism and theft of aluminium irrigation equipment is prevalent. Theft of equipment had the highest incidence that was recorded in relation to conflict, with 32 of 92 schemes recording this as an issue. On a gravity scheme it is difficult to steal components though not impossible to vandalise canals and gates. Vandalism on gravity schemes was not observed during the survey but was ubiquitous on pumped schemes. When a pumped system stops operating, even for a short time, they seem even more vulnerable to theft as there is less farming activity and presence of people. Vandalism, often due to conflict with non-irrigators who live in the area, is also a problem. This kind of conflict with non-irrigators in the vicinity was recorded in 31 of the 92 schemes where data was obtained. Van Koppen et al. (2017) identified a similar pattern where the condition of pump stations and pipelines was worse on on non-operational schemes. The missing pump and idle centre-pivot at Grootfontein irrigation scheme were one such case encountered.

Plate 7.1: Grootfontein Irrigation Scheme in Limpopo Province: Pump plinth remaining after pump was stolen from the new pumphouse.

Plate 7.2: Grootfontein Irrigation Scheme in Limpopo Province: New centre-pivot idle in the fields due to missing pump.

The vulnerability of pumped systems must therefore be understood in the context of a whole range of vulnerable elements including: the pumping technology itself; the need for profitable farming to pay for high energy payments; institutional strength for MOM activities including fee payment and enforcement; and the on-farm irrigation equipment that is vulnerable to theft and vandalism.

7.2.8 Other factors associated with a short scheme life

Rainfall mitigates the failure trend: Schemes that were in lower rainfall areas were less likely to be operational. They also tended to have a shorter operational life than schemes in higher rainfall areas. Both of these relationships were of moderate strength. The finding makes intuitive sense, as when rainfall increases, dependency on irrigation alone to ensure farming success proportionately decreases (whether pumped or by gravity supply). Farming activity can continue without crop failure for periods even when irrigation-supply is non-operational for some reason, and continued growth is supported by rainfall until the irrigation system is up and operational again. This same relationship between decreasing rainfall and lower performance was identified by Inocencio et al. (2007) in their study of 314 irrigation schemes in 50 countries. Mutiro and Lautze (2015) also found high and reliable rainfall to be important in explaining success and failure. The simple interpretation of the finding is that schemes providing supplementary irrigation are more robust than those entirely dependent on irrigation.

Plate 7.3: Vallis Irrigation Scheme in Limpopo Province: Summer maize under limited gravity irrigation (47 ha) in medium rainfall area (rainfall = 645mm; 47 ha; cropping intensity 60%; no water stress)

Plate 7.4: Mashushu Irrigation Scheme in Limpopo Province: Intercropped sweet potatoes, maize and mangoes with supplementary irrigation (rainfall = 702 mm; 40 ha; cropping intensity 115%; seriously water stressed).

Rainfall facilitates different scheme development pathways due to only partial reliance, at least for the summer crop. The above two schemes (Plate 7.3 and 7.4) are 10 km apart, and while both are old gravity-canal schemes (Vallies=49 years; Mashushu=50 years) in a similar agro-climatic, social and market context, they have a different functional character. At Vallies, the groundwater was reported to be relatively shallow in the valley-bottom. The farmers seem to have shifted from irrigation farming to a form of shallow-groundwater farming, similar to saaidamme discussed in Chapter 3, with a focus on a summer maize crop. Mashushu, just 10 km further into the mountains is more intensive, irrigation dependent, with a different set of cropping, irrigation and marketing strategies. At Mashushu, they had a dynamic extension officer, who established links with a coriander company 120 km distant, providing a low-risk, contract-based winter cash-crop. The performance at Mashushu was nearly double Vallies in cropping intensity (115% versus 60%) with a more diverse crop mix, including fruit and vegetables. The diversity on these adjacent similarly technical schemes is not only wide, it is not easily predicted. This conforms with one of the characteristics of complex systems; discernible patterns of form and behaviour can be observed, but behaviour is difficult to predict due to their highly dynamic nature with feedback loops that accelerate changes. Very small differences can lead to very different outcomes very quickly (ie. Lorenz's 'butterfly effect' described in Chapter 3).

Schemes located closer to markets seem to live longer: The relationship between market-proximity and operational status was significant, but weak-to-moderate. While the association test in relation to failure was non-directional, this finding is interpreted to mean that schemes closer to urban centres are associated with a greater likelihood of being operational. It was postulated early in the research process, based on literature and field observations, that proximity to urban centres would be a driver of performance. Van Averbeke et al. (2011) draw on a number of authors (Bembridge & Sebotja, 1992; Kamara et al., 2001; Matchete et al., 2004, and Magingxa et al., 2009) to show that the position of the scheme in relation to markets or located next a major road prompted greater degree of commercialisation. Proximity to urban centres allows for more varied marketing opportunities through farm-gate sale to 'smouse' (bakkie-traders), street vendors, and other outlets such as found at the Dzindi scheme (van Averbeke & Mohamed, 2006).

In Ghana, proximity also seems to have played a central role in driving the fastest growing informal irrigation sector, which was peri-urban, growing high-value horticultural crops. These farmers had strong linkages to the adjacent urban centres with easily accessed market. While shallow motorised pumps played a key part as they did across Sub-Saharan Africa (Shah, 2014) the Ghananian peri-urban irrigators quickly eclipsed public irrigation schemes nationally by a factor of nearly 4 (Namara et al., 2011). A peri-urban or relatively accessible link with urban centres provides transport- and transaction-cost advantages on both input and output value chains.

Given the above, it was thought that urban (market) proximity would be moderately or even strongly associated with cropping intensity and commercialisation, thus contributing to scheme longevity. The association of market proximity was however weak to moderate and with the exception of long-lived schemes located far from centres diluting the strength of the finding. Schemes such as Steelpoortdrift (38 years old), had a high intensity (150%) and were fully commercial, but were located distant from markets (65km). A multi-factor reality is another explanation for the weakness of the relationship. Market proximity was also found to have a similarly weak, but significant relationship with cropping intensity, discussed next.

7.3 Performance: factors associated with cropping intensity

7.3.1 Cropping intensity quantified

The annual cropping intensities were found to vary considerably ranging from 10% to 175% with an average of 94%. These were general low by international comparison. In Asia, much higher cropping intensities of 200% and above are common (Renu, 2016). Expectations of cropping intensity on Sub-Saharan smallholder schemes are lower, with 160% typically targeted to achieve economic returns on investment in irrigation feasibility (ArcusGIBB, 2004; WS Atkins, 2014). The result is lower than the 113% recorded on six comparable smallholder schemes in the Eastern Cape (van Averbeke et al., 1998) and nearly double the 48% recorded on Zanyokwe smallholder scheme in the Eastern Cape (Fanadzo et al, (2010). The latter figure is very low indeed. Only eighteen of the operational schemes had cropping intensities greater than 120% which is the range where schemes are moderately active (van Koppen et al., 2017). Three schemes had an intensity of 150% or more, which reflects high scheme performance.

In their study of 76 schemes in Limpopo, van Koppen et al. (2017) used winter cropping intensity as an indicator. A comparative analysis was conducted with the thesis data set using the same grouping criterion. The thesis results showed lower levels of performance: 43% vs 37% of schemes were not utilised; 53% vs 26% that were low to moderately utilised; and only 17% vs 37% were found to be fully utilised. The indicator was directly comparable, but the studies were five years apart. The thesis baseline was 2010, while the baseline of van Koppen et al. (2017) was 2015. The difference is significant though the reason for the difference could not be established. It could mean that performance is increasing over time, or that different field methods arrived at different data.

The comparison shows that performance in terms of cropping intensity (94%) is much lower than typical targets of high-performing schemes that would be in the order of 160%. They are slightly lower than cropping intensity measured by van Averbeke et al. (1998) in the Eastern Cape, and significantly lower than van Koppen et al. (2017) measured in Limpopo. While the performance is relatively low, the schemes are still cropped almost to their full extent, equivalent to once per year. Part of the reason for this are attributable to the significant disabling constraints of dilapidated infrastructure, stressed water resources, and serious institutional weaknesses in relation to land and water management.

7.3.2 Market proximity and cropping intensity

Market proximity had a weak correlation with scheme lifetime that was discussed earlier. It was also found to have a weak correlation to winter cropping intensity. The correlation with winter but not summer makes sense in the light of crop preferences from the summary analysis (described in Chapter 5). It was found that fresh vegetables dominate the winter production preference, covering 81% of the planted area. Fresh vegetable production is mainly market based, and combined with the limited shelf-life, is logically more prevalent on those schemes located closer to the urban markets. The weakness of the association of market proximity in general is vexing. One possible explanation was thought to be that perhaps the distances were all relatively small and the distance therefore insignificant, but this is not so. The range is 0.1-140 km and the data is normally distributed. Similarly, the range of commercialisation and cropping intensities were wide, facilitating, rather than inhibiting, the assessment of relationships if they existed. In their study of 76 similar schemes, van Koppen et al. (2017:15) identified that the “remoteness of irrigation schemes from markets was most often seen as the main problem” by farmers. Poor accessibility in distance and cost was the highest priority issue in 57% of the farmers that they interviewed. Market proximity is clearly an associated factor to performance but was not as statistically strong as anticipated in the thesis data.

The likely explanations are: i) mixed purpose farming is the norm on most schemes and this mutes the relationship; and ii) there are many factors that contribute to performance indicated by increased commercialisation, and this tends to dilute individual factor relationships; iii) patterns and trends emerge from the data but diversity is wide, causing these to be weaker, rather than stronger. The case of Steelpoortdrift scheme outlined below and shown in Plates 7.5 and 7.6 is one that highlights diversity.

Steelpoortdrift offers some explanation of the weak association of commercialisation and urban proximity based simply on a distance and road-type measurement, as was the case in the thesis. It is located 65 km from Burgersfort which is a major mining town in eastern

Limpopo. The gravity-canal scheme is 38 years old and is 69 ha in size. Water supply stress is rated as major in winter (rated 3 out of a possible 4). Despite this, the scheme recorded 155% cropping intensity. It is high-performing by smallholder standards. Plots were relatively small comprising 1.0 ha on average. Irrigation was by means of the short-furrow method. The tractor driver was innovative and experienced and had developed a furrow-construction technique using a plough with multiple runs, saving labour and time. Soils were good. Ad-hoc supplementary supply from two boreholes funded by the Tubatse Local Municipality provided some dry-season relief but maintenance and electricity cost were narrated to be ongoing challenges. At the time of survey (summer wet season), these were not operational due to a maintenance issue. Steelpoortdrift farmers were producing mainly fresh vegetables with a 100% market-orientation, yet markets were relatively distant with the nearest urban centre 65 km away. A primary point of sale was via a roadside stop where scores of long-haul trucks and mini-bus taxis passed through each day. Many of these loaded one or two, up to 20 or so, large sacks of produce on route. The arrangement was an informal, but systematic and structured, marketing and transport system that linked to markets in both directions from the scheme, and to an organised informal trading network in distant centres. This positive roadside effect in achieving market access was highlighted by Magingxa et al. (2009).

Plate 7.3: Steelpoortdrift Irrigation Scheme in Limpopo Province: Furrow formation - initial tractor-constructed furrows (left strip) and later conversion by hand to short furrows (right strip).

Plate 7.4: Steelpoortdrift Irrigation Scheme in Limpopo Province: Short-furrow irrigation of onion seedlings in practice.

The success at Steelpoortdrift, despite old infrastructure, water resource stress, and a relatively long distance to markets, can be attributed to a combination of factors. Not least were strong social cohesion, competent farmers, hard work and entrepreneurial drive. The farmers' highly efficient use of water in short-furrows (discussed later), innovation in mechanisation, and their conversion of the transport opportunity on the road-route seem to be key contributors to the long-life and remarkable success. The overview of the scheme highlights scheme diversity, and that distance, while important, is not necessarily a limitation to success. A measure of market access may have been a better indicator. Nonetheless, the finding that market proximity is overall associated with performance, both in terms of scheme longevity and intensity, suggests proximity is an important factor.

7.3.3 Scheme type – gravity-canal schemes perform the same or better

Comparisons were also made between cropping intensity and scheme type. The top fifteen schemes in terms of cropping intensity, comprised 10 gravity-canal and five pumped. These had cropping intensity greater or equal to 120%, with a maximum intensity[7] of 175%. The top three schemes (155-175%) comprised one that was pumped (Mangondi) and two supplied by gravity (Klein Tshipise and Steelpoortdrift). On the 61 operational schemes, the average cropping intensity on the (12) pumped schemes was 104% (range of 46-175%) while on the 49 gravity schemes was 83% (range of 10-155%). Pumped schemes have a high failure rate an only 12 were operational. The finding of higher intensity could be interpreted to mean that when pumped schemes do operate, they perform better. A closer look at the data in a systems view shows surprisingly little difference between modernised pumped schemes and gravity schemes. In the context of earlier discussion on threshold values on pumped schemes, it was shown that pumped schemes require higher levels of sophistication and profitability to cover pumping costs and technical complexity. This explains why no pumped schemes were operating at very low levels of intensity (all>45%), but nine gravity schemes below that threshold were still limping along. The reality, as noted previously, is that the pumped schemes collapse suddenly, at a higher threshold value of intensity, than the gravity schemes that just fade away. These old, low-intensity gravity schemes have the effect of lowering the average. There were 49 operational gravity schemes. The upper half of gravity schemes (n=25) had an average intensity of 111% (better than pumped scheme average), while the upper three quartiles (n=37) had an average intensity of 100%, close to the 104% average of the pumped schemes. In this more realistic comparison, there is no discernible difference in performance, measured by cropping intensity, based on technology type.

There are three additional disadvantages that characterise gravity schemes and need to be emphasised to understand relative performance. They: i) face statistically significantly higher levels of water stress, identified earlier; ii) they are much older in that the average age of the

[7] This excluded the four operational Joint-Venture schemes that had intensities of 200% with full double cropping of maize and potatoes in a constant rotation.

upper three quartiles of gravity schemes is 47.6 years, compared with the 14.1 years of the 12 pumped schemes; and iii) they are located further, on average, from input and output markets (pumped=25 km, gravity = 47 km on average) effectively doubling their transport costs on inputs and outputs. Despite these disadvantages of water stress, age (and dilapidation) and distance, they reflect near-parity in performance as far as cropping intensity is concerned. If these other elements were brought to parity, it seems highly likely from the above analysis that the technology of gravity-canal schemes would perform better than pumped schemes as measured by cropping intensity.

7.3.4 Water resource availability

Water resource constraints were weakly and negatively associated with performance as measured by cropping intensity, with stronger association in winter. This can be attributed to the lower winter rainfall and higher water resource stress. A closer look at the data reveals that water resource constraints related to *seasonal* differences in supply (ie. within a year) were more prevalent than were longer-term variations (year to year). The implication is that reduced water resource availability tends to constrain irrigators from using the full extent of their plots in the dry season. This supports the rationale for investment in more efficient irrigation technology and localised storage to address intra-annual variations.

7.3.5 Smaller schemes seem to do better

A weak to moderate association was identified between scheme size with cropping intensity meaning that smaller schemes tend to be cropped more. In contrast, van Koppen et al. (2017) and Mutiro and Lautze (2015) found no association with scheme size and performance. The finding does however concur with You et al, (2011) who identified better economic performance on small-scale schemes in Sub-Saharan Africa (EIRR=28%) compared with large scale schemes (EIRR=6%). The thesis findings also align to those of Inocencio et al. (2007). They concluded that programmes (they used the term ‘project’ throughout their report) with many small-irrigation schemes (they used the term ‘systems’ throughout their report) are more likely to be successful than those with large-scale schemes.

That finding that smaller schemes are associated with higher performance seems to have been misunderstood by Mutiro and Lautze (2015), perhaps due to the nomenclature used. In commenting on their own finding that scheme size had no association with performance, they noted that Inocencio et al. (2007) had concluded *“the larger the scheme size, the lower the unit cost and the higher the performance”* (Mutiro and Lautze, 2015:189). In fact, the conclusion was the opposite *“… the average size of irrigation systems within a project has a* *unit-hardware cost-reducing impact, it also has a performance-reducing impact. This implies that the smaller the size of irrigation systems within a project, the better the expected economic returns. These results on the impact of the sizes of project and irrigation system provide justification for developing many 'small' schemes within large projects since these options have reinforcing effects on both unit costs and project performance."* (Inocencio et al., 2007:42; author's emphasis).

The extensive study by Inocencio et al. (2007) across 50 countries and 314 schemes, complements the thesis finding that 'small is beautiful', drawing on EF Schumacher's seminal work (Schumacher, 1973). Not only do smaller schemes in Limpopo seem to perform slightly better in terms of cropping intensity, they are associated with lower conflict. The factor of conflict was not prominent in the correlation results, excepting for the association with scheme size. It was moderately weak but highly significant. The explanation is that smaller schemes are likely to have stronger social cohesion and that contributes to lower risks and costs in general (Shah, 2018). The net result is in keeping with international findings that smaller schemes are more likely to perform better. This suggests that size should be considered in the mix of factors in prioritising future investments.

7.4 Performance: factors associated with commercialisation

7.4.1 The commercialisation indicator in economic context

The indicator of commercialisation was a consolidated variable that reflected market-sophistication by counting the number of marketing avenues pursued on a scheme. This indicated performance on the premise that market-oriented farming is a necessary feature of successful irrigation due to the associated high risks and costs. Sender (2015) argues convincingly, and somewhat dismissively of small-farming successes where they exist, that the South African agricultural context makes smallholder farming unviable. He points to the fact that that agricultural markets are unprotected with large fluctuations, including due to forex exchange, resulting in high risks for farmers. Protective mechanisms for farmers in the form of subsidies and market-price control are estimated at only 3% in South Africa, versus 18% of the Organisation for Economic Co-operation and Development (OECD) countries. The sector is further dominated by a sophisticated and vertically-integrated corporate farming system with unmatchable economies of scale. This all makes it more expensive and higher risk for small-scale farmers to produce their own food than to buy food (from large-scale farms) in the shops (Sender, 2015).

This view was, to an extent, corroborated by Mohammed (2006), who identified farmers on Dzindi scheme in Limpopo who farm successfully under irrigation but do so at a financial loss (called the employers). They are motivated by social and cultural reasons that justify this cost, though one other group in that study was farming profitably and successfully (called the profit-makers). Denison et al. (2015) found similarly at Mbekweni. Sender argues that land under traditional tenure should be consolidated on mass, and farmed through leasing by corporate entities, and that benefits would accrue to land-rights holders mainly through labour (Sender, 2015). Sender's stance resonates with the JV approach of RESIS, which is documented to have failed in most cases (Schreiner et al., 2010; van Koppen et al., 2018) and suggests caution is needed regarding assumptions of social and political compatibility, despite economically convincing arguments. The development benefits of capitalist trickle-down philosophy are also challenged by Cousins (2013), who argues for massive aggregation of many smallholder contributions into households and the economy, in what he calls accumulation from below (Cousins, 2013). This is based, among other, on successful market-oriented farming recorded on Tugela Ferry smallholder irrigation scheme in KwaZulu-Natal. While Sender's proposals on how to deal with the reality of productivity and profitability are variously contested, the highly competitive, risky, and marginal nature of agricultural enterprises in South Africa is not. Commercialisation, or more precisely, a market-oriented farming objective with the intention to generate cash, is therefore seen to indicate irrigation performance.

7.4.2 Commercialisation quantified

Purpose of farming was categorised on each scheme into three groupings by the estimated area farmed for each: mainly own provisioning, approximately equal home-food and sale, and mainly-sale. This facilitated calculation of a commercialisation index for each scheme; the value of 1 meaning fully commercial, and the value of zero meaning only home food production. The results showed that the overall scheme objectives were equally balanced between own-provisioning and market-based farming (scheme was the unit of analysis). The overall scheme commercialisation index was 0.51. There were 15 schemes in the lower quartile; these had mainly home food production objectives (<25% of the scheme area was farmed for markets). The upper quartile comprised 19 schemes; these were mainly engaged in market-oriented production (>75% of the scheme area for markets). Pumped schemes showed a tendency for greater commercialisation on aggregate (index of 0.62) compared with gravity schemes (0.49). The need for greater cash-generation on pumped schemes has been explained earlier and seems to explain this difference.

7.4.3 Market-oriented farming is a core objective on Limpopo smallholder schemes

The findings in relation to purpose of farming means that market-oriented farming is at least an equal objective of irrigation farming across the Limpopo schemes. Van Koppen et al. (2017) found a higher level of commercialisation in their scoping survey on 76 schemes, as did Denison et al. (2016). Van Koppen et al. (2017) found sale to be a more important or a primary goal (ie. commercialisation index>0.5) on 72% of the schemes they surveyed. This can be compared directly with 51% of schemes in the thesis data set. The number of schemes, data collection method, and baseline date of the survey (2010 vs 2015) is different which may explain the differences. While less marked than van Koppen et al. (2017) the finding of approximately equal market-orientation is still notable because, it adds weight to their finding that "debunks any assumption that irrigation farming in the former homelands of the Limpopo Province is primarily 'subsistence'" (van Koppen et al., 2017:14).

The other detailed study, by the author and collaborators (Denison et al., 2016), included the purpose of farming at Julesburg and Dzindi scheme in Limpopo. They quantified irrigator livelihoods in depth. The study was conducted on both scheme- and independently-irrigated plots in Thulamela District in Limpopo. The results showed a high degree of commercialisation of farming, defined as the proportion of gross income that was derived as sales, around 90% on average. Ten years prior to that, at Dzindi irrigation scheme (2002/03), this value was only 48% (van Averbeke & Mohamed, 2006). Earlier work by Backeberg et al. (1996) presenting a general view of smallholder irrigation across South Africa at that time, stated that approximately 37% were commercially oriented. When these results that extend over 21 years are combined, there is a clear trend of increasing commercialisation. This gives reason to conclude that the purpose of production has progressively shifted from subsistence to market-oriented farming on smallholder schemes most-likely related to the rising cost and reduced margins of irrigated farming as indicated to the prevailing reality by Sender's analysis (2015).

7.4.4 Success with a maize-vegetable mix

It is necessary to understand what farmers were growing to understand the above commercialisation discussion in context. Mixed-purpose cropping, comprising mainly summer maize and winter vegetables, was the norm on the surveyed schemes. In summer, maize covered 65% of the cropped area, and vegetables were farmed on 32% of the cropped area. In winter, vegetables covered 81% of the area, with maize, likely green maize which has high value, comprising 9%. The choice of crop mix warrants some attention. The availability of fresh vegetables is an important deficit in the poorer areas of the country, and while maize is the stable food in South Africa, leafy green vegetables provide critically-needed nutritional food security (Wenhold & Faber, 2008). Indigenous leafy-green vegetables have high market-demand, provide high levels of Vitamin A, (30-150% of the recommended daily allows) and included varying quantities of other nutrients such as protein, elements and fibre (van Averbeke, et al., 2007). Not only are these well suited to irrigation farming, they have substantive nutritional benefit and market relevance.

The role that the predominant crop mix (maize-vegetables) plays in success is placed in interesting perspective by Mutiro and Lautze (2015). They identified in their SADC irrigation review that those schemes growing a combination of maize and vegetables showed a remarkably high success rate. This was a prominent crop mix on 76% of schemes that were found to have high rates of success. Schemes focussed on the production of field crops, such as maize and wheat alone, or of vegetables alone (10% and 45% respectively) had much lower associations with success.

The irrigated farming systems on the Limpopo smallholder schemes have evolved under a harsh agricultural-economic context (Sender, 2015). They exhibit characteristics of crop choice, mainly a maize-vegetable crop-mix, that meets market and household needs and is associated with success more widely in irrigation across SADC (Mutrio & Lautze, 2015). This crop mix is balanced in terms of nutritional food security and meets staple food needs in the form of maize. In this sense, the observed crop mix combined with the significant market-orientation, seem to be important contributing factors to overall scheme performance and resilience.

7.4.5 Market diversity

The factor of market diversity quantified how many channels of marketing were used on the scheme, from highly local to distant cities. The indicator was intended to provide insight into markets as a pull-factor and as a driver of performance. The result showed a weak correlation between market diversity and commercialisation and suggested that as (farmers on) schemes become more commercialised they tend to utilize more types and more complex market outlets. The relationship could be causal in the opposite way; where farmers are keen on expanding their commercial agenda they could be driven to search out new, more and more distant markets. While the relationship is weak, market diversity supports an increased commercial agenda. This is confirmed by other studies in Limpopo (van Averbeke, et al., 2011: Denison et al., 2016; van Koppen et al., 2017). These all highlighted market access as a top priority as expressed by farmers themselves. The relationship likely works both ways: driven by farmer interest as they seek out options, and their commercial orientation being increased through increased opportunities. Distance also plays a role in market diversity as schemes far from centres will have fewer options immediately available. Distance from markets arose as a priority challenge as perceived by farmers (van Koppen et al., 2017). These earlier studies combined with the present result suggests that access to more diverse market options stimulates commercialisation and highlights the importance of output value-chain development in driving irrigation scheme activity.

7.4.6 Plot sizes

The average plot size across all the schemes was 1.34 ha (ranging from 0.18 ha to 16.25 ha). Averages need to be analysed with caution for two reasons. First, some schemes have varied plot sizes including food plots. Secondly, land-leasing was observed on 74.8% of schemes. It is safe to assume that a significant part of leasing took place between plotholders. Leasing, albeit largely informal and insecure in general, were found to be common for seasonal, annual and longer-than-two-year durations. Thus, the size of plots farmed would be larger than the average plot size based on total size divided by number of farmers. Averages were unavoidable in the study and still provide useful insight, but the averaging process would always have the effect of reducing the strength of relationships between plot size and performance.

Schemes with average plot sizes of between 1-1.5 ha are most prevalent (47.1% of schemes). It was found that 60 schemes (59%) had average plot sizes in the range of 1.0-2.0 ha, higher than the 43% that van Averbeke et al. (2011) recorded nationally. The scheme type and history in Limpopo is comparable, as explained in Chapter 2, though the Eastern Cape had more schemes with many small-food plots, such as Ncora, Keiskammahoek, and Theyfu that could explain the difference. The average plot size of 1.34 ha is approximately half the 2.6 ha recorded by van Koppen et al. (2017). The difference may be due to their inclusion of JVs which are a single large entity though this could not be confirmed. Plot size has a significant, albeit relatively weak correlation with commercialization. The finding suggests that increased scale of farm-level operation is linked to commercialization. Of particular significance is the finding described in Chapter 5 that commercialisation is consistently high for average plot sizes of 1.8 ha and greater (Figure 7.1 reproduced from Figure 6.1). A sharp point of inflection is evident at the commercialization index of approximately 0.7-0.8 (70 to 80 % for market-sale) and a plot size approximately equal to 1.8 ha (by observation of Figure 7.1). This is interpreted to mean that up to 1.8 ha in size, all types of farming purpose are present. (index of 0=entirely own provisioning; an index of 0.9 means entirely market oriented). However, when plot sizes extend above approximately 1.8 ha in size, the commercialization objective dominates completely. This observation points to economy of scale being a factor in commercialised farming orientation. The clear vertical and then horizontal trend explains the weakness of the linear correlation test between these two variables, and the relationship as explained above, is more appropriate.

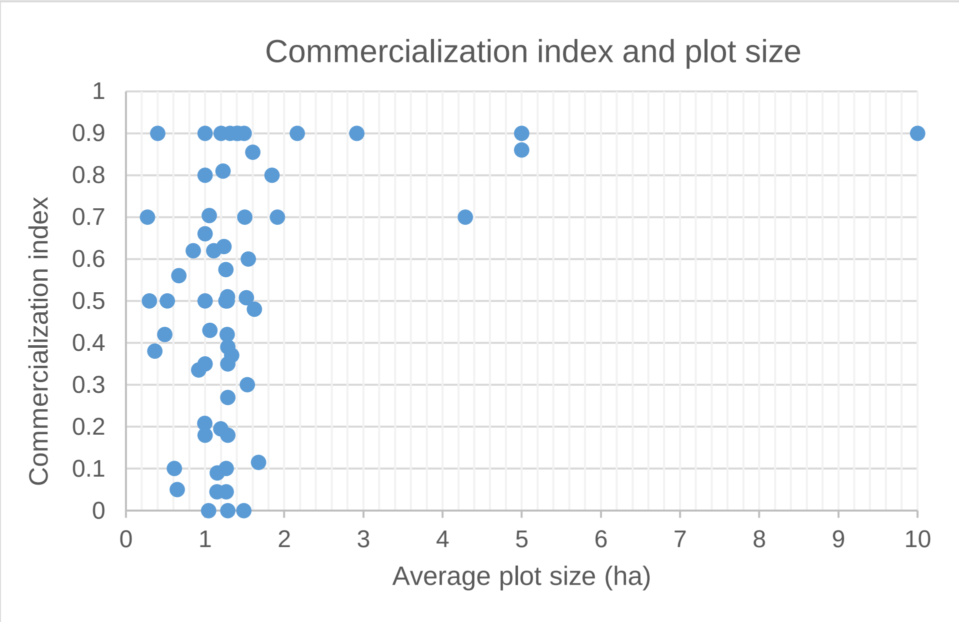

Figure 7.1: Commercialization index and plot size for operational smallholder schemes in Limpopo Province (2010: n=61)

The result suggests that a drive to support commercialisation on smallholder schemes would be facilitated by interventions which enable the consolidation of farms larger than 1.8-2 ha in size. Bembridge (2000) similarly concluded that commercialisation was mostly restricted to schemes with plots larger than 2 ha in size.

A further analysis was done on the clustered schemes that are discussed later in the chapter. The cluster analysis generates a characteristic scheme that represents the centroid values. These characteristic schemes were plotted against commercialisation and a similar trend emerges from this completely different analysis (Figure 7.2 reproduced from Figure 6.4).

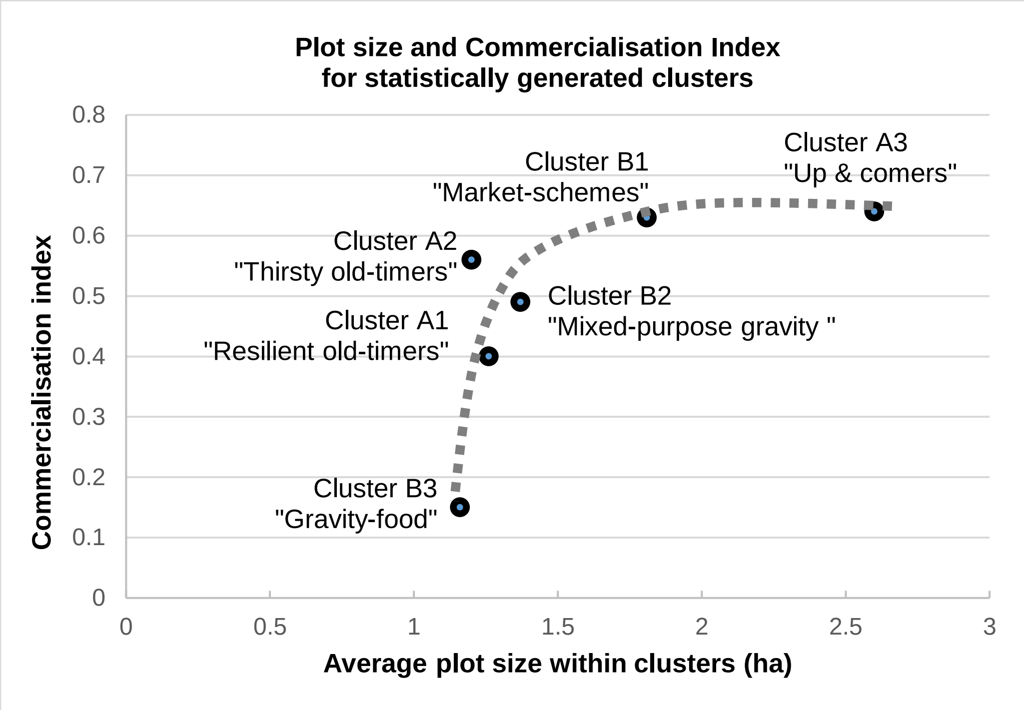

Figure 7.2: Commercialisation and plot size for statistically generated clusters for operational schemes in Limpopo Province (2010: n=61)

Commercialisation increases rapidly with increasing plot size and for plot sizes greater than 1.5 ha, the index is above 0.6 (more than 60% for sale). This seems to support the argument that increased commercialisation is related to increased plot sizes above a threshold of 1.5 to 2 ha. There are important strategic and policy implications where a commercialisation agenda is to be pursued discussed at the end of Chapter 7.

7.4.7 Commercialised farmers seek knowledge

The relationship between agricultural information and commercialization was weak and negatively correlated. How the question was asked is important to understand this finding. The question was whether the farmer was able to obtain all, most, some or none, of the information they needed in regard to crop production, plant protection and marketing etc. The negative correlation means the more commercialised they are, the less satisfied they are with their ability to access knowledge and confirms the need for agricultural knowledge to support commercialisation (Stevens et al., 2012).

7.4.8 Water constraints were not associated with commercialisation

On a side-note, farming purpose (increased commercialisation) was not associated with more reliable water resource. The absence of such an association was unexpected. It was assumed that the higher risk nature of commercial farming would be associated with a more secure water resource. Water resource constraints increase risk, reduce the ability to use land and water intensively, and undermine profitability. One possible explanation is that commercially-oriented farmers, given the higher level of sophistication, capability and resources that are associated with business farming, and the financial returns that are generated, likely have greater financial and social capital. Using this, they may be able to secure access to the social resources, such as land at the top-end of schemes where water-scarcity is less severely experienced. Given that the unit of analysis was the scheme, such internal strategies would not be identified.

7.5 Land and water institutions – the heart of the performance challenge

7.5.1 Land leasing: an institutionally irregular practice

The summary data shows that some form of exchange took place on 74.8% of the schemes in roughly equal durations based on summary data. A number of tests were conducted in regard to land-exchange prevalence, frequency, type and authorisation. Initially a land exchange index was used. This combined elements of land-exchange activity, the level of authorisation that supported transactions, and the kind of payment. This was based on the hypothesis that land exchange would be enabled and would be lower risk when: i) there were more options open to the farmer and the lessor, reflected by freedom to transact leases for one, or two or more years; and ii) there was higher-level institutional support from scheme organisations, or from traditional organisations that would have the effect of strengthening the enforceability of the transaction. Using this consolidated variable, relationships between the 'enabled' land-exchange environment and the performance indicators were tested. Weak results emerged, but the interpretation was unclear, outlined below.

Increased leasing when the water resource is stressed: Land exchange was weakly and positively correlated with water resource constraint and moderately with water stress behaviours. The correlations suggest that where water stress is experienced on the scheme there is a trend for increased land-exchange activity. This may arise from the fact that irrigation farming is more difficult when water is in short supply, and the less capable, or financially less able people have to step aside, allowing more capable people in to use the limited resources. It could also be explained by a higher-value placed on the top-end of schemes that have more secure water, and as suggested by the water-constraint association with commercialisation, that land-exchanges are stimulated by water-shortages in this way.

Land exchange transaction costs appear to constrain commercialisation: The relationship between the land-exchange index and commercialisation was significant, but weak and negative. The weak and negative correlation is contrary to expectations on both counts. At face value, the finding weakly suggests that a more limiting land-exchange environment is associated with increased commercialisation. One reason could be that having many leasing options might be a positive factor, but transaction costs of scheme-level and traditional authority approvals may involve rent-seeking behaviour as identified to be widespread on two schemes (Denison et al., 2016), thus constraining commercialisation. Further interrogation of the data, by analysis of only the institutional aspects of the land-exchange (ie. involvement of the committee and/or the Traditional Authority), and excluding the three categories of duration, showed no associations with either cropping intensity or commercialisation. The finding from the consolidated variable is therefore not attributed much weight and more attention was paid to a detailed analysis on land-exchange duration, and on institutional involvement separately, described below.

7.5.2 High land exchange prevalence is a performance factor

The original data used for the consolidated variable, quantifying leasing type and duration was then tested for associations with commercialisation and cropping intensity. The categories of agreement were: informal between farmers; with irrigation committee approval; and with traditional authority approval. No associations were found with either cropping intensity or commercialisation. Duration of agreement was also in three categories: seasonal; 1 year; and 2 years or more. The findings on duration indicated the importance of long-term land exchange.

Cropping intensity was moderately-strongly associated with long-term land-exchange: The association test showed a moderately strong and significant relationship on schemes where land-exchange was two years or longer. It is important that no association was found with the schemes that only had seasonal exchange and/or one-year exchange, independently or combined. The strong link between commercialisation and land-exchange longer than two years, rather than seasonal or annual, is thus one of the more important findings of this thesis.

The relevance of a longer timeline is explained by the view that longer-term access to the resources (land, irrigation infrastructure such as roads and fencing, and water) is an incentive for farming investment and more land on the scheme is utilised. The fact that there was no association regarding the scheme institutions implies that these provide no significant additional security of tenure and are ineffective institutions in terms of strengthening access through leasing.

Commercialisation was strongly associated with long-term land exchange: The association was tested on two categorisations of commercialisation; on a 50/50 split grouping that reflected the average level of commercialisation on schemes, and on a 70/30 grouping that correlated to the inflexion point of the commercialisation graph (Figure 7.1 and 7.2). This meant that land-exchange prevalence was tested for an association with farming purpose by comparing those schemes with 70% market orientation and above with the rest of the schemes. The association was statistically significant and strong for those schemes where land-exchange was prevalent for 2 years or more. Importantly, no association was found on with schemes that had only seasonal exchange, or up to one-year agreements for land exchange.

The finding confirmed the expectations that land-exchange was an important factor in understanding performance. Denison & Manona (2007) had motivated for and included a practical land-exchange strategy to accelerate performance on schemes. The motivation at that time was based on field observation and had no quantitative statistical underpinnings as generated now by this study. The thesis findings provide quantitative evidence that increased land exchange is related to increased performance on smallholder irrigation schemes, both in terms of the extend of land used (cropping intensity) and the purpose of production (commercialisation). This finding means that institutional interventions that contribute to easier and more enforceable land-exchange transactions on schemes can address the issue of low resource utilisation (reflected by low average cropping intensity) and promote a more commercialised purpose of production that is associated with success.

7.5.3 An absence of water institutions linked to failure

The institutional vacuum in relation to irrigation service provision (management, operations and maintenance) was a feature of the schemes. Data on water user organisations was obtained on 83 schemes. Established water user organisations were stated to exist on 58 schemes. Only two of these were formally established as Water User Associations (WUAs) as provided for in the National Water Act (1998), and 56 operated nominally under informal irrigation committees. The presence of cooperatives with water responsibilities was recorded on nine schemes. A further nine were organisationally structured to be operated by JV partners but these were absent in five cases. Maintenance of the irrigation infrastructure followed a similar pattern to operations: 58 schemes were maintained by water committees and farmer coops, 15 by individuals on an ad-hoc and uncoordinated basis, 11 by government, 9 by JV partners (noting four of these were recently constructed and not yet operational), and only two by WUAs. Formally established WUAs were only functionally effective in one case, that of Hereford scheme, a new pumped scheme with 5 ha farms. Water meters at each farm with valves for control and enforcement were an important socio-technical feature in support of administration, billing and compliance control. The attention to hydraulic units, and organisational functions, not just institutional form are indicators for future action. The risk is that WUA building initiatives focus on establishing the institutional architecture but fail to address functional detail and human capability for MOM more generally.

The absence of formal water management organisations in general has much greater consequences on pumped schemes for the reasons explained earlier. The organisational vacuum on smallholder schemes arose in the late 1990s when the homeland Governments were disbanded. The Government-subsidised operational support to smallholder schemes provided by the Government parastatals at the time was withdrawn (Perret, 2002). Schemes were ostensibly handed over to farmer groups, but with completely inadequate investments in institutions and capacity for MOM (Shah et al., 2002). There was also no farm enterprise support that is essential for generating profit to sustain irrigation operations (Shah et al., 2002).

Management of the pump stations on the Limpopo schemes is socially, organisationally and technically possible. The findings of the study show that this requires attention to uplifting the whole system to a higher ‘regime’ to achieve sustainability. The crux, as Hodgson (2003) asserts, is that organisational structure, knowledge, human and financial resources, explicit and enforceable rules all must be in place for the MOM to be carried out successfully. Organisations must have the legal power and administrative capability for fee collections and for enforcement of non-payment, or they will quickly go into the downward-spiral to collapse that characterised pumped schemes in the study.

The practicability of such pump station operation is demonstrated by successful pumping on small schemes across the Nile Delta. The author assessed the performance of 2433 small pumped schemes (average size 26.8 ha, range 3 ha to 48 ha) in the lower delta in 2018. Remarkably, these were all found to be fully operational with a formalized WUA and a trained operator in place (World Bank, 2018). The Limpopo context is a continent away from the Nile in many ways. Irrigation farming in the Nile Delta extends back thousands of years (Diamond, 1999) and the pumped units (called ‘marwa’s after the shared distributory canal) were all family-or clan-based. There are strong familial bonds that still prevail, with high social capital. Rural livelihoods and food production are dominated by irrigation with no rainfed production at all, a point that Shah (2018) highlights as central to pivotal in understanding irrigation success. Average yields were also extremely high (rice=9.2 metric tonnes/ha; wheat = 9.1 metric tons/ha) (World Bank, 2018). Further, farming in Egypt is heavily subsidised. Electricity receives a 75% subsidy along with subsidies for high-yielding, high-quality seed and fertilizer, all of this given the high strategic importance of irrigation in Egypt (World Bank, 2018). The schemes are notably small. Social cohesion was of high importance, identified to be a further positive characteristic that is associated with small schemes (Lankford et al., 2016; Shah, 2018).

The Egyptian case outlined above includes unique factors that are never likely to be replicated in South Africa so simple assumptions that operational success can be achieved on pumped schemes should be avoided. Pumped schemes have been emphasised because of their prominence in the failure analysis, but gravity-canal schemes should not be underestimated. Water user organisations are equally important to enable equitable, timely and adequate water supply (Bos et al, 2005). Canal schemes need similar sets of rules, legal power, administration, maintenance, operations and water management expertise. When considering schemes of comparable size the findings show that the operational complexity, level of capability, and the consequences of underperformance on pumped schemes are completely different.

7.6 Scheme types and farmer typologies

The purpose of the cluster analysis was to identify key descriptors for a scheme typology that is relevant to contemporary smallholder applications in South Africa. The detailed analysis of factors also informed the process. Multiple factors emerged as being statistically important in explaining failure and success, but a typology is required to be simple and capture essential defining features.

7.6.1 Statistical clustering

A hierarchy of groups of schemes was generated statistically using the agglomerative hierarchical clustering method based on the 61 operational schemes. The first grouping was clustered using the dependent performance variables, while the second was based on the full data set. The set of characteristic schemes that were generated contributed to the analysis of plot size relationships with commercialisation discussed earlier and led to a revised scheme typology presented below.

The clusters that emerged from the first analysis ('A' run of clustering) were defined by characteristics of age, cropping intensity, purpose of production and energy source. Age of schemes and market-based production seemed to trend upward together, with cropping intensity and energy source being variable across the groups. The discriminant analysis identified water resource constraint, rainfall and commercialisation to be important.

The clusters that emerged from the second analysis ('B' run of clustering), comprising all of the variables in the data set, were defined more simply by rainfall, purpose of production and energy source. The discriminant analysis indicated that age, commercialisation and land exchange index were important in characterizing the groups statistically. This second group has more practical meaning. The 'B' typology captures the most prominent features in recognizable and strategically practical categories and was used as the basis for a new typology.

The one key missing element of high importance, that did not emerge from the statistical process, but has practical implications, is scheme size. Scheme size was identified in the factor analysis to be linked to long scheme life and has a major institutional implication. Lankford et al. (2016), argue that the definition of 'large' or 'small' schemes should not be based on their physical size alone, but also on their water-management organisational setup. 'Large' schemes are those that by virtue of their size and operational complexity, cannot be operated by farmers groups on their own. Large schemes, by their definition, are where a Government irrigation agency, or a private operator is involved in the water operations. This is potentially confusing in the South African context, where all of the large commercial schemes (such as Vaalhaarts, Orange-Riet, Great-Fish etc.) are operated by professional WUAs governed by a farmer-representative board. In international literature, WUAs are more commonly associated with farmer-managed schemes, or in relation to irrigation management transfer, to those portions of schemes where responsibility is devolved to farmers at tertiary level (Meinzen-Dick, 2014). In interpreting Lankford et al. (2016) in the South African context, the crux is whether professional management is involved, versus a collective of farmers managing the scheme on a voluntary basis. Thus 'large', implies a level of complexity that demands professionals involved in water-services provision. While WUAs are neither government nor private operators in South Africa, they are clearly 'large' schemes operated by a professional team. The point emerging is that the defining feature is not size per se, but complexity of operations. This has relevance to the findings on pumped schemes, due to costs and operational complexity, and could involve schemes of small physical area. A defining feature in the typology, then, should capture the issue of operational complexity.

To avoid confusion, given that WUAs in South Africa cover both farmer-groups and professional-organisations, the descriptor has avoided the use of WUAs. WUAs would, however, be the most likely legal form of organisation on both farmer-collective, or professionally-managed schemes, excepting JVs.

The key descriptors that define the typology from the above discussion are:

- **Technology type:** This includes type of energy source, and type of infield equipment which are cross-correlated in most cases. Pumping is the definitive feature. The typology accounts for technology type as different types of schemes have an impact on MOM institutional strategy, and on farmer type that can be accommodated. It is a defining feature that influences priorities and intervention responses.

- **Purpose of farming:** increasing commercialisation in smallholder irrigation was identified to be a marked long-term trend in South Africa and an important factor in increased smallholder irrigation performance. Purpose of farming is a key descriptor in the farming typology and inclusion in the scheme typology provides a necessary basis for integration of farming type and scheme type, in terms of planning and strategic initiatives.

- **Scheme management type:** Scheme-management type is defined by the involvement of professionals in the scheme MOM. Physical extent will play a role as large schemes always have professional management due to operational complexity. Although not a feature in South Africa, smallholder schemes could well be operated by private operators where complexity demands professionalism beyond the capability of the farmers' collectives. Such an arrangement would thus demand a market-orientation to justify the costs. The management type is of high importance in defining the character of schemes and is thus a key typological descriptor.

Based on the above discussion and descriptors, the typology is presented in Table 7.1. A final category of collective estates is included to accommodate smallholder schemes that have converted their landholdings into a single estate. This group would include irrigation projects that fall under the land reform program and JVs.

Table 7.1: A modernized typology of South African smallholder irrigation schemes

Indicative name	Purpose	Technology type	Management type
Market schemes – gravity	Mainly sale	Gravity-canal	Professional
			Farmer-collective
Market schemes - pumped	Mainly sale	Pumped pressurised	Professional
			Farmer-collective
Mixed-purpose gravity schemes	Mixed	Gravity-canal	Farmer-collective
Food gravity schemes	Mainly food	Gravity-canal	Farmer-collective
Collectively owned schemes	All sale	Pumped	Operator/partner

This way of grouping schemes seems to be most relevant for use in strategic applications in South Africa given the findings of study and the factor analysis in relation to performance. The typology ends up defining all pumped schemes as primarily market-oriented. This is a necessity for scheme sustainability. The emphasis on management type as a key descriptor highlights the prime importance of irrigation institutions in addressing irrigation development challenges. The collectively owned schemes, in various legal forms, could farm using different approaches. These include: JVs with profit-share; farming the land with employed professional management under board of land-rights holders; or leasing all or part of the farm to commercial entities to engage in irrigated farming, with possible retention of portion for individual or collective use. If the existing irrigation technology did not force collaboration by imposition of a single hydraulic unit of irrigation, they could conceivably return to smallholder farming as well. A return to smallholder farming could also be facilitated by re-design of smaller units.

7.6.2 Integration of scheme and farming typology

The typology as defined in Table 7.1 is already well-aligned with the farming typology of Manderson (2015) that is presented in Chapter 3. Market orientation and the farming contribution to livelihoods are key descriptors in that typology. The resolution of the farming typology is detailed, with additional factors pertaining to key farm-level operations such as labour, mechanization, and access to finance. The scheme typology, however, does not determine the scale of the farming enterprise explicitly, but it is implied in the categories in the contribution to household income. An appropriate farm size for a full-time farming typology can be viewed to be a function of gross margins, cropping intensity and their target income. If the assumption is made that a farmer needs to generate R120,000-150,000 to justify their risk and effort in full-time farming, then the farm size can be calculated. Using a modest, mixed crop gross margin of R40,000 / ha per crop, and a cropping intensity of 150%, this would translate to an irrigated farm size of 2 ha to 2.5 ha. This calculation is only illustrative and demonstrates the kind of thinking that is needed to match farmer type and scheme type. Thriving schemes depend on thriving farm-enterprise in an interdependent cycle. The limitations and possibilities of scheme typology determine those of the farming types that can survive on the scheme.

It was shown earlier that the trend in South Africa over the last two decades reflects a steady increase in farming for markets on smallholder schemes. The finding that land-exchange is widespread on the schemes, and persists amidst a weak and chaotic institutional environment, suggests that institutional formalisation would contribute to increased land-exchange activity. This would likely lead to fewer farmers being active on larger farms on average. The reality of a high-prevalence of land-exchange and strongly associated increased market-orientation should not be interpreted as a trend to uniformity in farming typology on all types of schemes. The range of market-oriented farmers identified by Manderson (2015), includes those farming for mixed purposes as only a part of their livelihoods mix, mainly linked to markets via loose-value chains. Others would be more dependent on farming for their livelihoods, linked to markets with tighter value chains such as fresh-produce markets, organized informal produce outlets in cities, and perhaps supermarkets. The thesis results showed that high-levels of commercialisation exist on a wide range of (scheme) average plot sizes from 0.25 ha to 1.8 ha, highlighting diversity – mainly in terms of how much farming contributes to the mix of livelihoods strategies of a household. Such diversity in plot size (and the balance of part-time/full-time farming) is more likely to be found on gravity-canal schemes. These are accommodating, with practically no limit on the size of a hydraulic unit as an earth canal can always be constructed in the field. Where technical and operational cost factors are high such as on pumped schemes, this will exclude some of the farming types, and the tendency will be towards full-time farming mainly for markets. The need for sophistication, larger farm sizes, and then land-exchange to facilitate that, becomes of high importance to match farming type to scheme type. It is people that farm, and entrepreneurial traits are a key underpinning of market-oriented farming. Additional consideration needs to be given to aspects of education, age, social-grant dependency, and psychological traits, such as risk-aversion in characterising farmers (Chipfupa & Wale, 2018) to enrich the typological descriptions. Manderson's farming typologies, based on their market-orientation could be strengthened through the addition of entrepreneurial and psychological capital attributes. Such additions would complement, but do not change, the typological structure or relevance. They are valuable in their simplicity and in their meaningful description of the farm-level irrigation reality as it pertains to the scheme typologies defined in the thesis. In matching scheme type to the farmer typology (or typologies) strategic decisions in regard to technology choices for infrastructure, land, and water institutional interventions can be better informed.

7.7 Implications

The findings from the factor analysis reinforce the perspective of schemes as socio-technical-biological systems. A systems view of irrigation is well-established (Clemmens, 2006; Van Laerhoven & Ostrom, 2007; Lankford et al. 2016; Van Rooyen et al., 2017) and the many factors that impact on systems are well-known. These include the human, technical, social, natural resource, land and water institutions, financial, agricultural production and marketing elements of systems. Failure can often be ascribed to one or two factors. In Limpopo, failure was mainly due the physical, financial and operational vulnerability of pumped schemes. Poor performance, most visible in the low utilisation of irrigation areas, was found to result from stressed water resources, old and dilapidated infrastructure and institutional weaknesses regarding water organisations, with little or no MOM. Low farm-profitability in a competitive market environment for smallholders was identified from the literature to be a prevailing reality, making scheme-level success more difficult. Success, however, is never related to only a few factors; it is always multi-dimensional, complex and dynamic. The challenge is to better understand what factors can catalyse positive change beyond the well-established list of requirements for successful farm-enterprise and irrigation scheme activity. Three main implications emerged from the analysis that show promise to contribute to long-term scheme success and are discussed next.

7.7.1 Technology: go with the flow for high performance outcomes

There is strong empirical evidence that smallholder schemes that are pumped are vulnerable in their physical form, prone to functional and financial failure, live much shorter lives, and perform no better than gravity-canal schemes. Their operational lifetimes are nearly four times shorter than gravity schemes (14.1 years versus 48.1 years) and their incidence of failure is more than ten times higher (68% versus 5.8%). They collapse suddenly while young, and exhibit lower cut-off thresholds before their functionality crashes, ie. they have lower resilience. Pumped schemes need higher levels of farm profitability and operational capability to keep the pumping pressure up. Gravity schemes slide down a slow but inexorable slope of deterioration. The lowest functioning pumped scheme had a cropping intensity of 46%, while nine gravity schemes were lower, trickling along at an average 29% intensity, one at 10% that is barely alive, but not quite dead. These nine were 50.9 years on average; the oldest, Mecklenburg, 72 years old and going nowhere rather slowly.

The criterion for failure could be viewed as skewed because the low-intensity of some operational gravity schemes (ie. not completely failed) is so low. Comparative care is needed. Romantic rural-development notions of thriving agrarian reform in the smallholder sector (Sender, 2015), based on resilient appropriate technology should be avoided. Productive use of land and water resources, as set out in the NDP, is an economic and social imperative (RSA, 2013). A higher level of performance of 50% cropping intensity is another defining threshold of failure (Mutiro & Lautze, 2015). Yet, even so, when factors such as age and water stress are brought to parity, it seems that gravity schemes outperform pumped schemes: 79% of gravity schemes suffered serious or major water resource stress versus 24% of pumped schemes. Despite this markedly greater stress, if a 50% cropping intensity baseline is used to assess failure, then 19% of gravity schemes failed (10 out of 52), versus 76% of pumped schemes (38 out of 50). Based on that higher criterion for success, of all the failed schemes thus defined 48 in total (79.2%) were pumped schemes. The implications of economic returns on investment over such different lifetimes (approximately 48 years versus approximately 14 years) is substantial. This should be a key factor in decision-making where gravity schemes can be improved or sustained, rather than replaced with pumped schemes.

But what about productivity? Do they perform equally in terms of output? The measure used was cropping intensity. Though it takes no account of water productivity, yields or quality, it does tell the story of how much of the irrigable area is farmed per year. Using the same 50% ‘success’ criterion of Mutiro and Lautze (2015), the average cropping intensity of the successful gravity-canal schemes was found to be 95% while the 11 successful pumped schemes were utilised at 110% intensity. This difference needs to be viewed in context. The gravity schemes suffered much greater water resource stress. The stress index for the gravity schemes was 2.9 versus 1.7 on a Likert scale of 1 to 4 (none, minor, major, critical). This means that the nearly four-times older gravity schemes performed only slightly lower in cropping intensity while suffering water resource stress rated on average as “major” versus an average water stress for the pumped schemes rated less than ‘minor’. This remarkable performance by comparison, and with water resource being equal (let alone age and condition), there seems little doubt that gravity schemes have better productivity than pumped schemes.

Finally, what about efficiency? The question of efficiency of resource use is of high importance in national water policy and the agricultural allocation is capped (RSA, 2013) and has multiple boundaries to be considered. Only the immediately relevant elements of this expansive agricultural engineering topic are summarised. There are three issues regarding efficiency that can be related to three physical boundaries; the field, the scheme and the basin.

The issue of the field boundary pertains to the application-efficiency of infield irrigation technology. This includes short-furrow, sprinkler, micro-jet and drip on-farm methods. The short story is that short-furrow irrigation is practiced on nearly half of the Limpopo irrigation schemes (Stevens et al., 2012) and has very high distribution-efficiency (85%) (Reinders et al., 2011). This is not the same as the more-commonly compared application-efficiency, but according to Reinders et al. (2011) is the key determinant of application efficiency. Farmers' knowledge and skill, as in all but highly automated and monitored systems, is important to avoid over-irrigation. Short furrow appears to be a Limpopo innovation and is scientifically substantiated to have distribution-efficiencies and therefore when managed properly, application efficiencies equivalent to micro-jet systems (eff.=85%). This is better than sprinklers (eff.=75%), or other flood irrigation methods (eff.=60%) (Reinders, 2011; Reinders, et al., 2011). Short furrow irrigation, when practised correctly, is therefore highly efficient at field level.

Next, the issue of the scheme boundary. Gravity-canal schemes typically rely on transmission through canals, which incur losses from the head of the canal to the field edge. These losses vary on many parameters (soils, slope, lining, operational regime etc.), but are typically 10-15% (Reinders et al., 2011). Modernisation of canal systems is a global challenge and many technologies (including uPVC large-diameter pipes, lay-flat pipes etc.) are available for cost-effective engineering solutions to this challenge. Egypt, for example, has embarked on a massive canal-modernisation program (World Bank, 2018) aiming to replace 2 million hectares of canal transmission with uPVC pipelines (World Bank, 2018). Transmission losses within the boundary of the scheme then can be readily addressed with routine infrastructure modernisation using low-cost plastic-pipe, or other canal-lining technologies.

Finally, the river basin boundary. Perry, (2007), in a body of work officially adopted by the International Commission of Irrigation and Drainage (ICID) shows that even if there were heavy transmission losses, and low on-farm efficiencies discussed above, the water is not in fact 'lost'. He asserts that the catchment (or sub-catchment) level is the fundamental unit of analysis. Water is not lost through so-called inefficiencies as most of that water returns to the basin as a usable fraction via groundwater recharge and tailwater flows. This water is available in rivers and aquifers (Perry, 2007). Reinders (2011) confirmed this often-misunderstood concept in a detailed study of 12 major irrigation schemes in South Africa. He showed that gravity-flood irrigation with lined canals were 95% efficient from a basin perspective, equal to drip and higher than sprinklers that incur evaporation losses (Reinders, 2011). The challenge arising is more one of basin hydrological modelling, and administration of more complex water-interactions at basin level. There is reason therefore, to simplify the administrative task and address the efficiency issue at field and scheme level where it is practical and cost-efficient to do so. This can be done in the knowledge that any efficiency imperfections do not result in water being 'lost', but in fact it would still be available to the wider system.

The above body of evidence combined with the study findings on gravity-canal scheme resilience and performance leaves little scientific doubt that gravity-canal schemes should remain as the priority for intervention support to smallholders wherever technically possible. Gravity-canal schemes should be upgraded physically to reduce transmission losses and farmers' need to be trained in short furrow techniques where they are not already being used. Technical modernisation would need to be complemented by institutional modernisation. Water user organisation development would be essential to achieve longer-term operational and financial sustainability, discussed later. Ignoring the body of evidence and replacing gravity schemes with pumped schemes is tantamount to planning for a much greater chance of scheme failure, shorter lifetimes of investments, and lower performance, all water-supply and marketing factors being equal.

Where the simple and robust technology of gravity schemes cannot be pursued, which is particularly the case for new schemes as most gravity-opportunities are taken up already, institutional establishment of water-management organisations must be a top priority. Farm sizes need careful consideration (discussed below). There needs to be a major emphasis on water-management functions, roles and institutional mechanisms to enable fee collection and enforcement. In this way the weaknesses that were identified in the failure analysis regarding pumped schemes can be addressed, and the opportunities in the success analysis can be maximised.

7.7.2 Land-rental market can drive performance

Several researchers have reported that land tenure security on South African smallholder irrigation schemes was inadequate and is a constraint to agricultural growth. There are two reasons for this. The first was that in the absence of individual title to their plots, plot-holders were prevented from using their holding as collateral to access loans from registered financial service providers (Bembridge, 2000; Crosby et al., 2000; Machete et al., 2004; Tlou et al., 2006). The second was that the cropping intensity on many smallholder schemes was well below potential. This is borne out by the findings. Cropping intensity was below 120% on all but the top 15 schemes, a finding that confirms that land on smallholder irrigation schemes in Limpopo is significantly underutilised. Underutilisation has more than one dimension, not least water-scarcity and poor infrastructure, but also weak land institutions are identified as one key domain for engagement. Alongside the evident underutilisation, there is demand for access to irrigation land on schemes, both internally and from outsiders. This is interpreted as a failure of the land market, but as land cannot be sold, of the land-rental market.

Informal leasing was, however, found to be widespread. Farmers' on approximately 75% of Limpopo smallholder schemes are currently engaging in land exchange transactions despite the insecure and un-formalised institutional setup. The additional risks to their farming operations has been reported in other studies (Deininger & Fang, 2016; Denison et al., 2016). The two performance indicators of cropping intensity and commercialisation showed a medium and strong relationship with land-exchange prevalence longer than two years, respectively. This result has three important implications. First, it suggests that more land is utilised on the schemes when there is vibrant land-leasing activity. Secondly, schemes with a higher prevalence of long-term leasing seem to have a strong tendency to be more commercialised. Thirdly, the duration of the lease is significant, as neither single-season, nor annual leases yielded any positive associations, while those exchanges that were two years or longer, were associated with increased performance. These findings highlight the potential for longer-term land-exchange interventions to address the widespread low land utilisation on smallholder schemes, and to catalyse more commercially-oriented farming. This is obviously subject to other critical constraints in both the farm, and the scheme system.

The finding that land-exchange is associated with higher performance needs to be understood along with the findings on the relationship between plot size and commercialisation. Average plot sizes showed weak correlations to commercialisation, but the effect of plot size was diluted by the averaging process used in calculating plot sizes for each scheme. The relationship between plot size and commercialisation emerged more clearly from graphical plots and the statistical cluster analysis. When plot sizes are greater than approximately 1.6 to 1.8 ha, the purpose of production is primarily commercial, greater than 70% for market. When greater than 2 ha the purpose of production is solely for market. The co-existence of relationship between commercialisation and plot-size and commercialisation and land-exchange prevalence is also important. Land-exchange is an obvious method by which farm sizes can be increased by a single farmer extending his or her operations to multiple plots. These two findings combine to make a strong argument that land-tenure interventions that facilitate increased farm-sizes are an opportunity to accelerate scheme performance in terms of cropping intensity and commercialisation.

It is important that there is clarity in the definitions of tenure security and what can be achieved through land-tenure interventions. Alchian and Demsetz (1973) argued that land must be viewed as a resource, and that 'ownership' over a resource refers to rights of use, which are socially recognised. They defined the strength with which rights are owned as the extent to which an owner's decision about how a resource such as land will be used determines that use. This means that the bundle of property rights over a resource is divisible. They viewed land tenure systems, which stipulate and govern rights over land, as a social system which relied on techniques, rules or customs to resolve conflicts. They also include land scarcity in the definition. The bundle of rights that make up a land tenure system can be categorised into four types, namely, user rights, exclusion rights, transfer rights and enforcement rights. User rights stipulate the privileges a holder has to utilize the land for production or other purposes, make permanent improvements, harvest products and derive income from the land. Exclusion rights specify the privileges a rights holder has to exclude others from claiming use or transfer rights in relation to a piece of land. Transfer rights stipulate the privileges a holder has to transmit the rights of the land to his or her successor, or the rights to alienate rights to the land through sales, donations, mortgaging, leasing, renting or bequeath, and enforcement rights refer to the legal, institutional and administrative provisions that are available to guarantee the rights related to the land (Feder and Feeny, 1991; Adams et al., 1999; FAO, 2002; FAO, 2005).

In promoting the concept of land-exchange, it is essential to separate out these divisible rights and treat them as distinct as they involve different institutional challenges. Enabling transfer rights is a national reform process, important to mobilise the economic value of land through sale and to promote capital investment in farming, for roads, fences and irrigation equipment etc. The ability to effect transfers, through title-based ownership, enables farmers to use land as collateral in order to obtain finance for production loans and for irrigation investment. Legal mechanisms for smallholders are not in place in South Africa, and change is part of a complex political and social process that is ongoing. It is pertinent that Rwanda and Malawi have passed transformative legislation in the last 15 years enabling forms of individual and collective titling on customary land (Gillingham & Buckle, 2014; World Bank, 2017). South Africa has not. Enabling more secure use, exclusion, and enforcement rights, can be achieved, without transfer rights, through quasi-legal local-land administration mechanisms (Manona & Baipheti, 2008). The establishment of local land administration systems without national tenure reform has limitations in legal enforceability but are one immediately available mechanism to regularise the de-facto widespread practice of informal land-exchange. De Soto (2000) argues for more radical legal mechanisms to unlock the full economic potential of land through transfer rights of land under customary arrangements. He also points to the value of decentralised administrative land-management systems located at and involving local authorities. The National Development Plan (RSA, 2011) similarly motivates that *"The focus should be on cooperating with traditional leaders to secure tenured irrigable land supported by fully defined property rights. This will allow for development and give prospective financiers and investors the security they require"* (RSA, 2011:220). These kinds of initiatives fall into the institutional development approach that Cleaver (2002) calls 'bricolage'. Bricolage, as the French word implies, is the pragmatic construction of institutional solutions using whatever instruments are at hand in addition to new ones to bridge critical gaps. These 'bricolage' solutions involve a mix of modern and traditional, formal and informal institutions (Cleaver, 2002) that can be used to achieve institutional outcomes without the extended timelines associated with wholesale law reform. Such an approach of bricolage could then facilitate land-leasing for longer durations, which is the mechanism observed in this study to be linked to increased performance. Radical legal reform that assigns ownership and transfer rights and replaces the currently irregular customary tenure regime that exists on smallholder schemes would be and immediate way to liberate the land-market and catalyse increased performance. In the absence of national law reform, exclusion and enforcement rights can be facilitated through local land-administration interventions while the national land reform process continues unfold.

There is also reason to treat irrigation schemes differently from other communally-administered land areas and would justify specific attention as an exceptional case in the ongoing land-reform process. The hydraulic infrastructure is largely immovable, and the historical investments are much greater than on rainfed land. The social resource of irrigation infrastructure has a much higher value than rainfed land, and the impact on livelihoods, food production and household income is much greater, approximately a factor of two at household level, and two to four times in terms economic multiplier effect. There is thus an imperative to maximise the existing soil, water, infrastructure and human capital resource on under-utilised, irrigated schemes as a priority. Effort to develop quicker, formalised, enforceable, and lower-risk land-exchange institutions between farmers on schemes, and between potential outside investors and land-holding farmers', seems to be justified by the findings.

7.7.3 The intersection of typologies, and land and water boundaries

The third theme addresses the nexus of farmer and scheme typologies with land and hydraulic boundaries. It is argued that by integrating these dimensions in strategic planning processes, greater success can be achieved. All schemes demand attention to the multiple factors in the system to achieve performance, not least water-tenure security, irrigation management organisational development, and infrastructure modernisation. Agricultural systems support is needed everywhere farmers are farming. The question is how to go beyond these and liberate the undefined opportunities that rigid planning concepts seem to quash.

Different scheme types are suitable for different kinds of farmers and institutions. Gravity schemes in Limpopo are generally small, a few hundred hectares in size. This is a positive characteristic and is linked to easier and more practicable institutional development. The gravity-canal schemes will be more accommodating of a wide range of farming typologies as there is less need to generate the substantial cash required to cover monthly MOM costs compared with pumped schemes. Yet, as shown by schemes such as Steelpoortdrift, and Dzindi among many others, gravity-canal schemes can be fully commercialised and highly productive. They exhibit flexibility of purpose and cannot be relegated to a category of ‘food schemes’ but serve varied and primarily market-oriented farming typologies. Pumped schemes on the other hand have greater technological determinism. They require a highly-commercialised farming objective with market-oriented, capitalist farmers, enabled by farm sizes seemingly larger than 2 ha. This is larger than the current plots on most schemes. The point is not to determine plot sizes by desk-economics and design, but to establish land institutions and hydraulic systems that allow internal and external market forces to do so, dynamically and reflexively.

7.7.4 A complex systems view: success through flexibility and reflexivity

The finding that scheme diversity is wide, alongside the fact that water-technology and land-exchange are factors of high importance in understanding performance, points to the concept of flexibility as a strategic tool. North (1990), from the school of New Institutional Economics, identified institutional persistence to be an inhibitor to economic development. He showed how organisational practices from the past, and the persistence of beliefs, attitudes and informal and formal rules, explain why changes that are initiated to take development forward, often produce unexpected results that impede growth. He emphasised the concept of changes over time and strove to understand the dynamic nature of institutional responses to a changing external and internal environment. Scoones (2009) argues from a similarly dynamic perspective about farmer’s livelihoods, that these are not static but change over time.

Eleonor Ostrom was one of the more influential thinkers on irrigation reforms. Her design principles for crafting community resource management institutions also draw on New Institutional Economics (Ostrom, 2000). These principles consider the community to be isolated or nested enterprises. The principles emphasise the importance of having a clear user group with clear resource boundaries, graduated sanctions, clear use rights, and users directly involved in decision-making. However, the approach has been found to have some important shortcomings (Cox et al., 2010) and are less reflexive than the concept of "*Bricolage*", derived from French and meaning building from available pieces or concepts (Cleaver, 2002). Bricolage is a pragmatic approach of building new solutions based on the organisational and institutional elements that are readily available rather than trying to establish new rules and institutions to give effect to Ostrom's principles. Cleaver and Franks (2005) give five reasons why Ostrom's design principles alone are inadequate to craft new or improved irrigation institutions:

1. Institutions and human interactions are more complex than just individual responses to economic incentives. People behave out of cultural habits, multiple dependencies (debt-trap, patronage, etc.), and risk-taking and avoidance.

2. People have more than one identity: they are not only irrigators, they may also be rainfed farmers or fishermen, and at the same time also belong to a particular family, brotherhood, and religious, political, ethnic and age group. Their interests and drivers for action are therefore much more complex than mere responses to a set of rules or incentives.

3. The role of (irrigation) technology, bio-physical conditions, and location (e.g. upstream and downstream), are import factors which are not articulated in the rules of Ostrom.

4. In many societies it is socially important to avoid conflicts. Graduated sanctions to correct misconduct are not necessarily the most effective way to steer social behaviour, and other socially-normative mechanisms can achieve intended outcomes. Peer pressure, open negotiation, use of traditional-conflict resolution mechanisms (traditional leaders, etc.), or even shunning, are often familiar, routine and effective, and can be more relevant than graduated sanctioning.

Farming aspirations, financial resources, household priorities thus all need to be considered and, in addition, need to be viewed as dynamic. In this way people in their social and economic context can be better understood. In (dynamic) systems theory, change and reflexivity is a foundational concept, along with the perspective that 'whole is more than the sum of its parts'. The ability of a system to function dynamically 'at the edge of chaos' is when they perform best, because that is when they can respond most quickly and creatively to fleeting opportunities. Yet by remaining 'on the edge of chaos' they are able to maintain the core function of an institution which North (1990) explains is to provide stability and predictability to human behaviour. In dynamic systems terms this ensures efficiency for predictable routine functions and activities.

The findings of the thesis (ie. high diversity between and within schemes, the bearing of water-technology on management success, and evolutions and variations of land-exchange modalities) highlight the need for flexibility as elaborated by North (1990), and seem to support Cleaver's bricolage view of institution building as most relevant. Bricolage is a pragmatic strategy for building institutions, but also explains how land and water systems shift over time – through piecemeal additions and ongoing variations. This seems to be a more appropriate working concept for institutional crafting in the context of the Limpopo smallholder schemes than Ostrom's design principles alone, particularly in the absence of clarity and consistency in the application of land and water laws across schemes.

An opportunity, based on bricolage, then seems to lie in the nature of the irrigation institutions that are built to enable farm- and scheme-level land-administration processes, and how these overlap with the hydraulic boundaries of the irrigation system. These arrangements together define the possible evolutionary trajectories across different forms, captured in discrete categories by scheme typologies and within them, nested farming typologies. Decisions on land-holdings and water-technology hydraulic boundaries, when rigid and persistent, result in a lack of evolutionary capability. One such example is the one-way development path of estate-style Joint-Venture farming arrangements. Once land is consolidated and a single hydraulic boundary is imposed, these lock the collective into a single destiny of future partnerships, with no option for alternatives. Similarly so with smallholding sizes of 1.3 to 1.5 ha that were established in the 1960s to 1980s based on economic and management parameters that are long outdated. The informal land-rental arrangements do not enable these farmers to acquire additional plots easily and in a low-risk manner to increase the scale of their farm enterprise. In this way, while productivity targets may be achieved, profitability, enabled by economies of scale, is limited.

Alternative solutions, however, can facilitate multiple options for scheme and farming typologies. Flexible institutional design could include for individual farming on plots, or the partial leasing of blocks, or wholesale estate approaches such as JVs and commercial-contracting at scale. Through the planned incorporation of many small hydraulic units, matched with land-institutions that enable the land-rental market and/or consolidation into group-held portions, it is possible to accommodate variations of scheme type. These would facilitate the full range of options, from JVs to smallholder-modes of farming on schemes. In this way, schemes can, within the boundaries of technical-determinism be allowed to evolve dynamically from one type to another. These changing forms will be driven by ever-changing internal opportunities and external market forces. The institutional flexibility to farm individually on a plot, expand to more than one plot, or combine land into groups, will increase the options open for private investment. This would include investment by the scheme-farmers themselves if they choose to expand their individual enterprise, and/or private sector investments from outside of the scheme. Continuation of the same hydraulic, land-holding and land-boundary patterns that defined schemes in the 1960s and 1980s is no longer relevant to the contemporary farm-economic and water-stressed context. Strategic planners therefore need to consider the opportunities in water-technology choices that are appropriate to the farmer type, to the sizing of hydraulic units that enable individual and group enterprise, and to landholding institutions on schemes that formalise land-rental markets. These interventions build on observed trends and relationships and have the potential to catalyse increased irrigation scheme performance in future.

8 CONCLUSIONS

8.1 Introduction

The research aimed to determine the empirically critical factors that are associated with smallholder irrigation scheme failure and success. A secondary aim was to develop a contemporary scheme typology that captures irrigation scheme diversity. When combined, the findings and analysis would inform irrigation development interventions in South Africa. The focus was on smallholder irrigation schemes in Limpopo Province where more than half of the smallholder schemes in the country are located. A survey of 102 irrigation schemes was conducted using questionnaires that were administered to focus groups comprised of scheme committee members and farmers. Field inspections of infrastructure, and transect walks through the irrigation lands, corroborated interview data and provided additional information. Data was analysed using correlation, cluster and principle component analysis.

8.2 Main Findings

8.2.1 Overview

The schemes were found to be small in size with three quarters (74.8%) of them falling in the 50 to 250 ha size range, and only 11 schemes larger than 250 ha. Average plot sizes were 1.34 ha, though with a wide range, between 0.18 and 16.25 ha. There were 65 operational schemes (equivalent to 63.7%), and 37 had failed (equivalent to 36.3%).

Based on a success criterion of annual cropping intensity greater than 50%, the success rate (marginally successful being just above 50%) of the Limpopo schemes was 58%. This was similar to the average success rate for Africa (55%), SADC (58%), South Africa (45%-68%) that were identified in other studies using the same criteria (Mutiro & Lautze, 2015). The schemes were farmed mainly with mixed purpose production in mind, with market-oriented production slightly more important (51%). This indicates that schemes have largely evolved from ‘food schemes’ to a market-farming perspective, in line with the long-term business trend driving irrigation growth that is identified in the literature (Woodhouse et al, 2017; Shah, 2018). The main crops grown were a maize-vegetable mix in summer (65% and 32% respectively) and vegetables in winter (81%). Cropping intensities ranged widely from 10% to 175%, with an average of 94%, which is low for irrigation schemes (Renu, 2016), suggesting infrastructure and natural resource underutilisation.

There are three over-arching concepts that explain the performance of the complex and diverse smallholder irrigation schemes in Limpopo Province: i) scheme manageability (ie. simple technology and appropriate effective organisations); ii) productivity (reflected – albeit inadequately on its own - by cropping intensity); and iii) profitability (reflected by a commercialised purpose of farming, larger size of plots, and to an extent, market access). Where schemes are manageable, productive and profitable, the findings suggest that success will be achieved. Success was associated with multiple factors, but two findings stand out; the performance of gravity systems and the importance of land-exchange in relation to commercialisation and increased land-use. Failure was associated with two dominant factors, energy type and infrastructure condition. Water resource constraints and distance from markets played a significant but lessor role.

8.2.2 Why schemes fail

There is strong empirical evidence that smallholder schemes that are pumped are vulnerable in their physical form, prone to functional and financial failure, live much shorter lives, and perform no better than gravity-canal schemes. Out of the 37 schemes that failed, 34 (91.8%) were pumped. There were a total of 50 pumped schemes and 34 (68%) of these had failed. By contrast, 49 (94.2%) of the 52 gravity schemes were still operational to some degree albeit many with limited irrigation area and/or poor water delivery. Pumped schemes collapse suddenly while young and exhibit lower cut-off thresholds in productivity with much lower resilience to factors such as water stress or low-farm profitability. The average age of pumped schemes was 14 years, nearly a quarter of the gravity schemes that averaged 48 years. In terms of operational condition, 31 schemes were critically or seriously functionally limited, while 38 were fully operational. The association between operational condition and failure was moderately strong. Failure can be explained at a higher level by inappropriate (unmanageable) technology and related low-profitability in a high operational cost context. Water resource constraints were widespread, considerably more so on gravity schemes which on average experience major stress, while pumped schemes suffered only minor water resource stress on average.

8.2.3 Why schemes succeed

Gravity schemes performed more strongly in terms of longevity and similarly to pumped schemes in terms of cropping intensity. This was achieved under much greater water stress and with considerably worse infrastructure condition. Water efficiency was established to be high on those schemes using short-furrow irrigation; equivalent, in a basin perspective, to drip irrigation. Two of the three top performing schemes (>150% intensity) were old gravity schemes and many exhibited high levels of commercialisation. The technology exhibits flexibility of purpose and cannot be relegated to a category of ‘food schemes’ but is accommodating of a range of farming typologies. When factors such as age and water stress are brought to parity, it seems that gravity schemes outperform pumped schemes. This should be a key factor in decision-making where gravity schemes can be improved or sustained, rather than replaced with pumped schemes. Where the simple and robust technology of gravity schemes cannot be pursued, which is usually the case for new schemes, establishment of water-management organisations must be a top priority. In such cases, the determination of farm sizes needs careful consideration to enable the more-sophisticated, commercialised farming typologies to thrive, so pumping cost (linked to a need for profitability) and operational complexity (linked to manageability) can be managed.

Market proximity and market access were weakly associated with increased cropping intensity and commercialisation, and hence profitability. Small scheme sizes were also weakly associated with increased cropping intensity suggesting that the implementation of many small schemes is better than the construction of fewer larger ones.

8.2.4 The land-exchange link with performance

Farmers’ on approximately 75% of Limpopo smallholder schemes were engaging in land exchange transactions in a highly insecure and un-formalised institutional setup. At the same time, plot sizes were associated with increased commercialisation, and when larger than 1.8 ha, only commercialised farming was pursued. Land-exchange prevalence longer than two years was further, moderately associated with cropping intensity and strongly associated with commercialisation This result has three important implications: i) more land is utilised on the schemes when there is vibrant land-leasing activity; ii) schemes with a higher prevalence of long-term leasing seem to have a strong tendency to be more commercialised; and iii) the long duration of the lease (two years or longer) is significant as shorter leases showed no associations. These findings highlight the potential for longer-term land-exchange interventions to address low land utilisation on smallholder schemes, and to catalyse more commercially-oriented farming. The point here, is not that plot sizes should be determined by desk-economics or administrative design, but that land institutions and hydraulic systems should be established to allow farm-size to be determined by internal and external market forces, dynamically and reflexively.

8.2.5 Scheme and farmer typologies

An irrigation scheme typology was derived from the cluster analysis and was aligned to a contemporary irrigation farming typology. The key descriptors included technology type, purpose of farming and scheme management type. By matching scheme type to the farmer typology (or typologies), strategic decisions regarding technology choices for infrastructure, land, and water institutional interventions can be better informed.

8.2.6 System complexity, institutions and the nexus of land and water boundaries

One of the important debates in the irrigation literature is around the nature of institutional structure and the processes by which institutions should be formed and shaped. Ostrom's principles emphasise the importance of having a defined user group with clear resource boundaries, graduated sanctions, clear use rights, with users directly involved in decision-making (Ostrom, 2000). This contrasts with the more pragmatic concept of bricolage meaning building from available pieces or concepts be they formal, informal, traditional or customary (Cleaver, 2002). An important finding of this thesis was that there are inadequate and widely varying legal interpretations and practices in relation to land and water, alongside multiple technological and water-resource uncertainties that bring risk and undermine productivity and profitability. The analysis highlights the need for flexibility and reflexivity to be included in institutional design as promoted by North (1990) to address stultifying 'persistence', or inability to change and respond to dynamic shifts. When reflexivity is facilitated in institutional design, the system can operate closer to the 'the edge of chaos' which is when performance is highest. The system can respond most quickly and creatively to threats and opportunities, such as water-shortages, or the uptake of under-utilised land by willing and capable farmers. The findings suggest that the pragmatic approach to institution building of bricolage, provides the best chance of achieving higher performance outcomes.

All schemes demand attention to the multiple factors in the system to achieve performance, not least water-tenure security, irrigation management organisational development, and infrastructure modernisation. Agricultural systems support is needed everywhere farmers are farming. The question is how to go beyond these important, but routine frameworks, and enable new opportunities by addressing persistence in institutions, and determinism in technology choices. The planned incorporation of sufficiently small hydraulic units, matched with agile land-institutions that catalyse a secure land-rental market, can lead to variations of farm-production models at different scales. These would include a patchwork of smallholders on the one hand, to Joint Ventures on the other, with many varied farm-sizes in between. In this way, agricultural enterprises on schemes can, within the bounds of engineering realities, be facilitated to evolve dynamically from one type to another, and back again in response to ever-changing external and internal opportunities. The research findings lead to the final recommendation that strategic planners must consider the implications of the dominant factors of water-technology choices and the dynamics of farm-size change based on land exchange processes in order to maximise irrigation scheme performance in future.

8.3 Areas for further research

The research was limited in the depth of analysis that could be pursued on any one scheme. The nuances and diversity within schemes is therefore not reflected by the data, though the analysis has drawn on other in-depth studies. Questions that emerge from the findings that warrant further study include:

1. **On-scheme farm-consolidation details:** Land-exchange of plots was recorded to have taken place on 74.8% of the schemes, but the quantitative effect this has on farm-sizes on the schemes is not known. The farm size would be the total area farmed, including the farmers own plot, plus leased plots that they farm in addition. This raises questions as to what the actual distribution of de-facto farmed portions is on schemes, compared with average plot sizes. Further, it would useful to understand the relative performance of the different size of farms, in relation to cropping intensity and commercialisation, or indeed, other performance indicators such as crop-productivity or water-productivity.

2. **Attitudes to land-leasing and tenure formalisation:** The findings of the research identified widespread land-exchange activity but made no enquiry as to who was renting land. Was it scheme-farmers renting from other scheme-farmers, or was it outsiders? There is also high diversity in local attitudes to customary tenure. In the course of the fieldwork for this study, the Traditional Chief at Steelpoortdrift was found to welcome the concept of formalized land-leasing. At Julesburg scheme however, the Chief holds firm control. He allows only annual leases to farmers, administered by the irrigation scheme committee. Yet the Chief dictates conditions on the scheme use, such as no planting of maize on the scheme. This was reported to inhibit the individual farmers' investment on fencing and irrigation infrastructure (Denison et al., 2016). It would be valuable to gain deeper understanding into the details of demand for land, and the social and attitudinal factors that could lead to successful land-exchange systems on schemes. The gendered dimension of land-access through land-exchange mechanisms would also be important.

3. **Technical research into short-furrow irrigation:** Short furrow irrigation is an endogenously developed technology and is associated with high efficiencies (Reinders et al., 2011). Yet the technology is not well-understood and seems to be negatively received by decision-makers justifiably concerned with water resource stress. While some research has been done on short-furrow irrigation efficiencies, this could be strengthened so the scientific case is more strongly established. Research on practical and cost-efficient methods of forming furrows, such as the innovations described at Steelpoortdrift, would aid better understanding of the method and facilitate wider uptake.

4. **Water user associations:** The research identified only two irrigation schemes with registered Water User Associations, and only one of these was functional. Yet there were sixty-five irrigation committees of some form or another (including co-operatives) that were responsible for water management. There are various schools of WUA institutionalisation. Some, such as the pragmatic approach of ‘bricolage’, may be more suitable when there are insufficient resources to formalise in ways that are provided for by legislation. It would be useful to understand the level of functioning of these various ad-hoc committees. Research would need to explore how they are structured and institutionalised (formal and informal rules), to what extent they function in relation to water-management activities, fee collections, maintenance and enforcement, and what challenges they face in their water service provision role.

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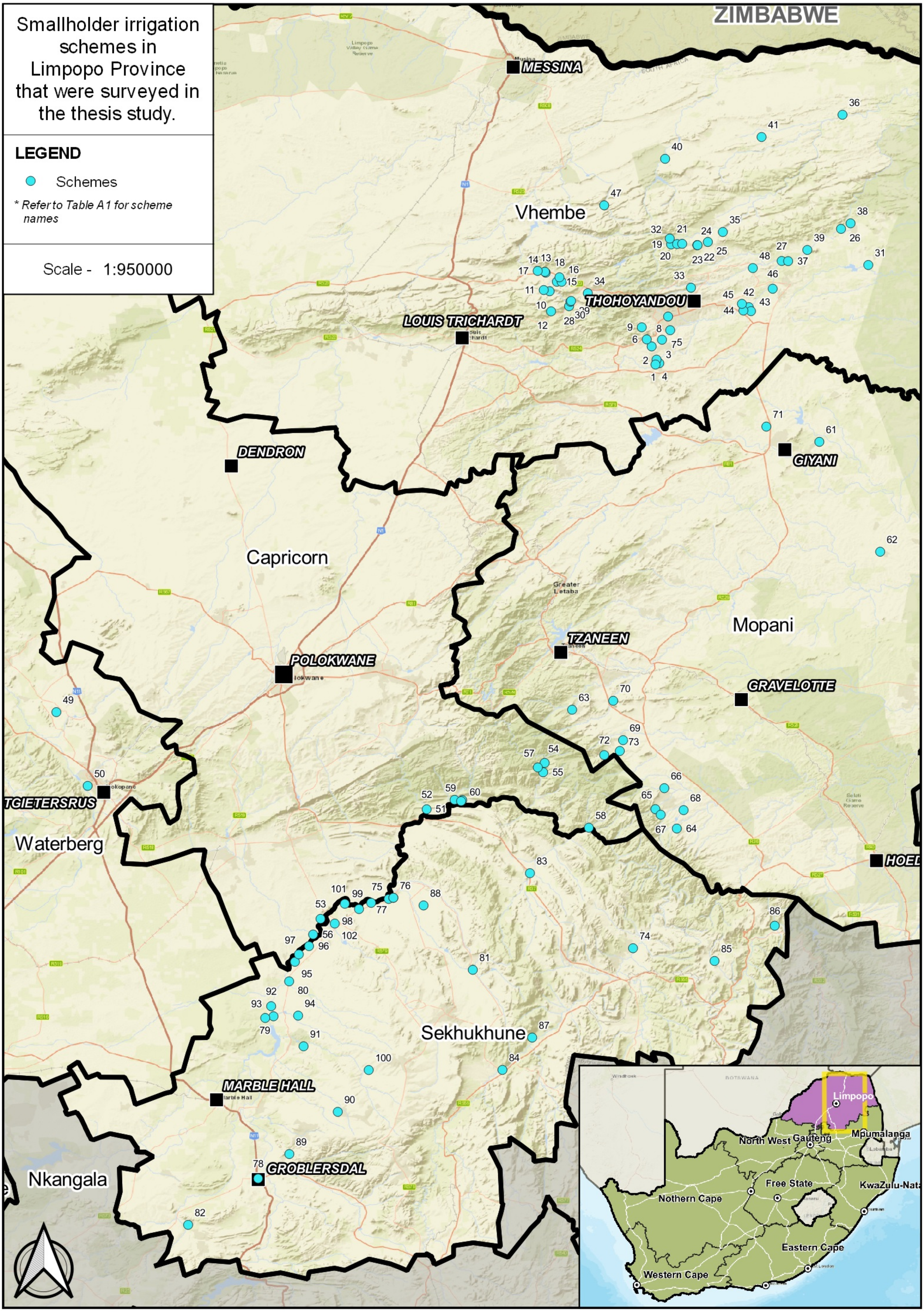
APPENDICES

APPENDIX 1

Map of the project area and summary climatic data


Smallholder irrigation schemes in Limpopo Province that were surveyed in the thesis study.
LEGEND
Schemes
* Refer to Table A1 for scheme names
Scale - 1:950000
ZIMBABWE
MESSINA
Vhembe
THOHOYANDOU
LOUIS TRICHARDT
DENDRON
GIYANI
Capricorn
Mopani
TZANEEN
POLOKWANE
GRAVELOTTE
TGIETERSRUS
Waterberg
HOED
Sekhukhune
MARBLE HALL
GROBLERSDAL
Nkangala
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Nata
Nothern Cape
Eastern Cape
Western Cape

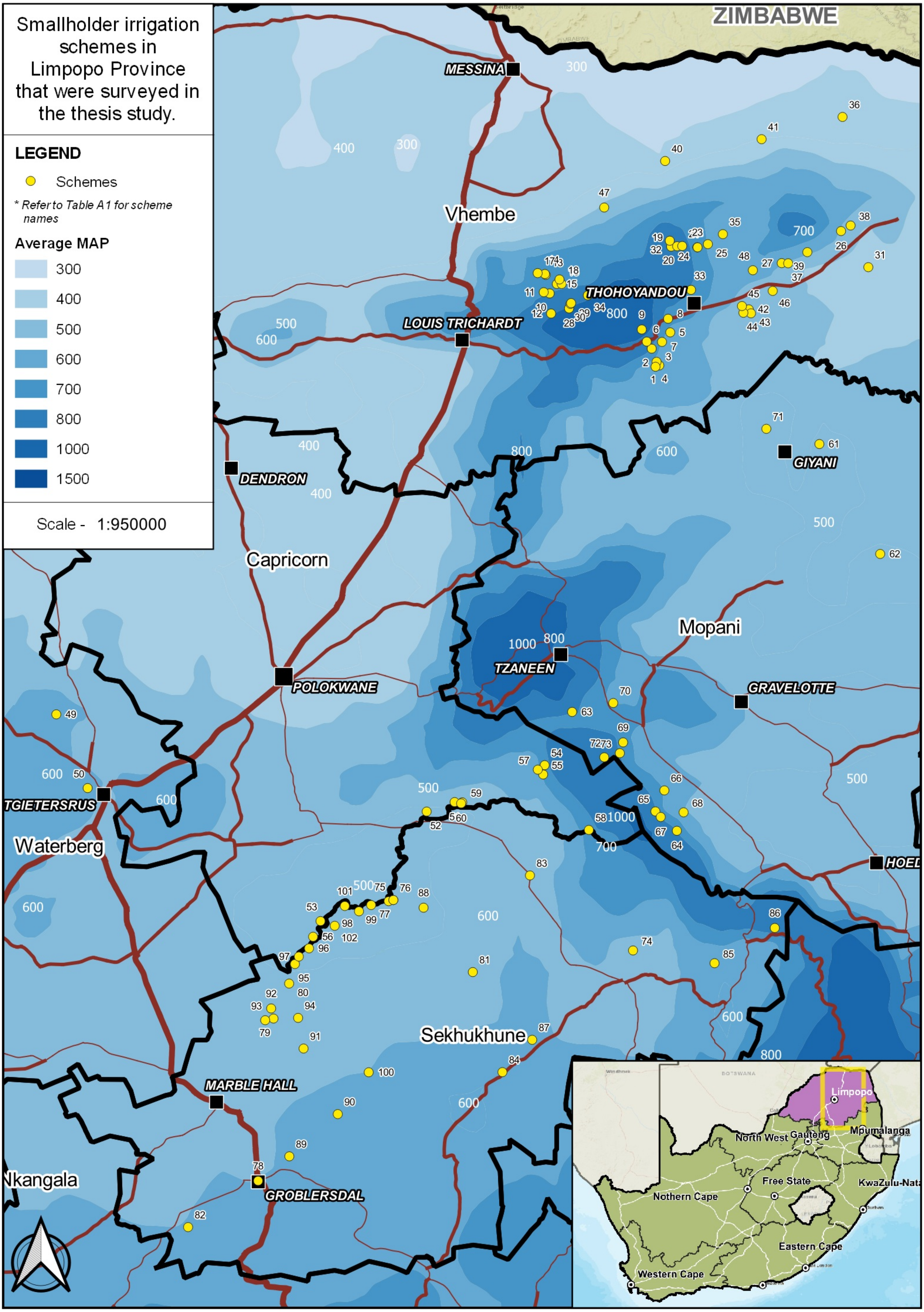

Smallholder irrigation schemes in Limpopo Province that were surveyed in the thesis study.
LEGEND
Schemes
* Refer to Table A1 for scheme names
Average MAP
300
400
500
600
700
800
1000
1500
Scale - 1:950000
ZIMBABWE
MESSINA
Vhembe
LOUIS TRICHARDT
THOHOYANDOU
DENDRON
GIYANI
Capricorn
Mopani
TZANEEN
POLOKWANE
GRAVELOTTE
TGIETERSRUS
Waterberg
HOED
Sekhukhune
MARBLE HALL
GROBLERSDAL
Nkangala
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Nata
Nothern Cape
Eastern Cape
Western Cape

Table A1: Smallholder Irrigation Schemes in Limpopo Province that were surveyed in the thesis study (refer to maps in Appendix 1)

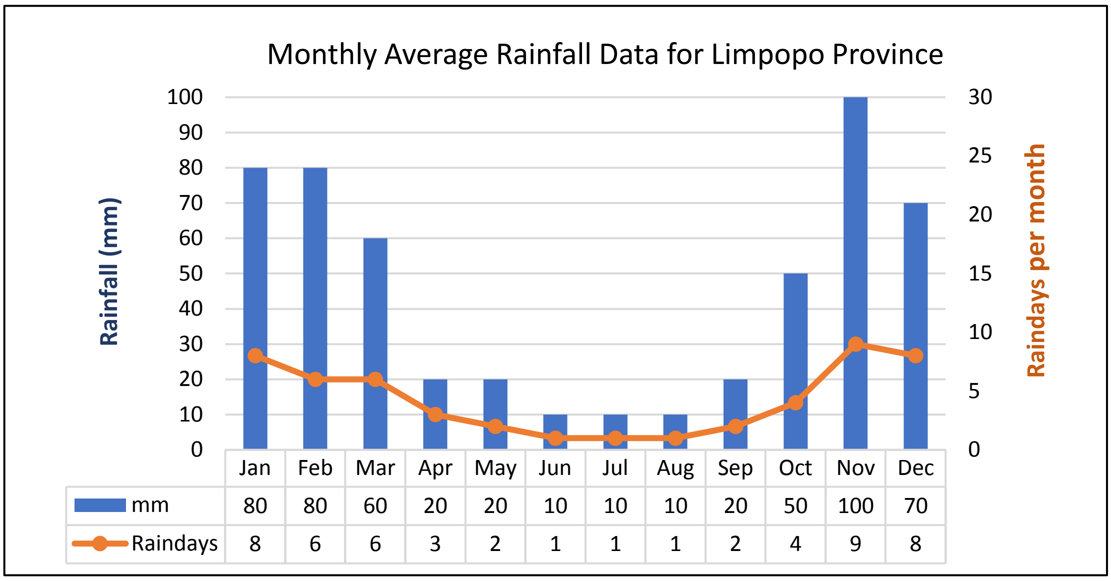
REF No.	District	Scheme Name	Latitude **South** (dec ^{0})	Longitude **East** (dec ^{0})
1	Vhembe	Nesengani	23.10558	30.40798
2	Vhembe	Nesengani B1	23.06318	30.38868
3	Vhembe	Nesengani B2	23.09652	30.40108
4	Vhembe	NesenganiC	23.10893	30.39840
5	Vhembe	Dzindi	23.02207	30.43557
6	Vhembe	Khumbe	23.04528	30.37625
7	Vhembe	Dzwerani	23.04615	30.41482
8	Vhembe	Palmaryville	22.98750	30.43020
9	Vhembe	Lwamondo	23.01468	30.36367
10	Vhembe	Mauluma	22.92348	30.13072
11	Vhembe	Mavhunga	22.92043	30.11577
12	Vhembe	Raliphaswa	22.97440	30.13432
13	Vhembe	Mandiwana	22.87657	30.12077
14	Vhembe	Mamuhohi	22.87433	30.11873
15	Vhembe	Mphaila	22.89950	30.14890
16	Vhembe	Luvhada	22.89957	30.16107
17	Vhembe	Rabali	22.87212	30.10048
18	Vhembe	Mphepu	22.88818	30.15552
19	Vhembe	Tshiombo 1	22.80507	30.43787
20	Vhembe	Tshiombo 1A	22.80410	30.45300
21	Vhembe	Tshiombo 1B	22.80348	30.46590
22	Vhembe	Tshiombo 2A	22.80675	30.50412
23	Vhembe	Tshiombo II B	22.80675	30.50412
24	Vhembe	Tshiombo III	22.80688	30.50468
25	Vhembe	Tshiombo IV	22.79878	30.53078
26	Vhembe	Lambani	22.76568	30.86750
27	Vhembe	Phaswana	22.84688	30.71742
28	Vhembe	Cordon A	22.96142	30.17983
29	Vhembe	Cordon B	22.95000	30.18333
30	Vhembe	Phadzima	22.94803	30.18493
31	Vhembe	Makuleke	22.85708	30.93643
32	Vhembe	Rambuda	22.79017	30.43443
33	Vhembe	Murara	22.91450	30.48810
34	Vhembe	Dopeni	22.92845	30.22725
35	Vhembe	Makhonde	22.77357	30.56873
36	Vhembe	Sanari	22.47694	30.87124
37	Vhembe	Tshikonelo	22.84730	30.73372
38	Vhembe	Chivirikani	22.75165	30.89165
39	Vhembe	Gonani	22.81905	30.78223
40	Vhembe	Folovhodwe	22.58845	30.42268
41	Vhembe	Klein Tshipise	22.02820	30.67720
42	Vhembe	Morgan	22.96375	30.63425
43	Vhembe	Makumeke	22.97382	30.63980
44	Vhembe	Dovheni	22.97242	30.62057
45	Vhembe	Mangondi	22.95540	30.61692
46	Vhembe	Xigalo	22.91715	30.69475
47	Vhembe	Garside	22.70608	30.26862
48	Vhembe	Malavuwe	22.86485	30.64452
49	Waterberg	Mapela	23.98847	28.88333
50	Waterberg	Sekgakgapeng	24.17495	28.96262

REF No.	District	Scheme Name	Latitude	Longitude
51	Capricon	Success	24.21037	29.89037
52	Capricon	Koedoeskop	24.23432	29.81980
53	Capricon	Badfontein	24.51145	29.55134
54	Capricon	Mashushu	24.11700	30.11813
55	Capricon	Vallies	24.14052	30.11428
56	Capricon	Adriaansdraai	24.55102	29.53260
57	Capricorn	Fertilis	24.12828	30.10080
58	Capricon	Lucern	24.28085	30.22984
59	Capricon	Grootfontein A	24.21098	29.90978
60	Capricon	Grootfontein B	24.21364	29.90682
61	Mopani	Homu	23.30453	30.81277
62	Mopani	Makhuva	23.58262	30.96647
63	Mopani	Lephaphane	23.98230	30.18755
64	Mopani	Makgaung	24.28300	30.45235
65	Mopani	Sofaya	24.23393	30.39812
66	Mopani	Lorraine	24.18083	30.42070
67	Mopani	Madeira	24.24807	30.41153
68	Mopani	Metz	24.23632	30.46943
69	Mopani	Solani	24.05935	30.31645
70	Mopani	Thabina	23.95970	30.29150
71	Mopani	Mid Letaba	23.26603	30.67862
72	Mopani	Tours	24.09709	30.26877
73	Mopani	Julesburg	24.08667	30.30815
74	Sekhukhune	Tswelopele	24.58575	30.34150
75	Sekhukhune	Strydkraal A	24.46107	29.72354
76	Sekhukhune	Strydkraal B	24.45813	29.73550
77	Sekhukhune	Mooiplaats	24.45813	29.73550
78	Sekhukhune	Hereford	25.16855	29.39358
79	Sekhukhune	Phetwane	24.75802	29.43253
80	Sekhukhune	Setlaboswane	24.66953	29.47202
81	Sekhukhune	Tsatane	24.64043	29.93640
82	Sekhukhune	Elandsdoorn	25.28570	29.21655
83	Sekhukhune	Mecklenburg	24.39597	30.08093
84	Sekhukhune	Steelportdrift	24.89360	30.01130
85	Sekhukhune	Rietfontien	24.61806	30.54761
86	Sekhukhune	Sterkspruit	24.52885	30.69992
87	Sekhukhune	Boschkloof	24.81183	30.08655
88	Sekhukhune	Lepellane	24.47752	29.81187
89	Sekhukhune	Bono Idire	25.10662	29.47250
90	Sekhukhune	Montevideo	24.99980	29.59500
91	Sekhukhune	Goedvertrouend	24.83388	29.50852
92	Sekhukhune	Mogalatsane	24.73250	29.42653
93	Sekhukhune	Roodewal	24.76223	29.41150
94	Sekhukhune	Vlakspruit	24.75633	29.49468
95	Sekhukhune	Mphane	24.62010	29.48657
96	Sekhukhune	Malope	24.58042	29.52229
97	Sekhukhune	Makgwabe	24.60123	29.49650
98	Sekhukhune	Khuloane	24.48667	29.64867
99	Sekhukhune	Tswaing	24.47090	29.67939
100	Sekhukhune	Platklip	24.89397	29.67325
101	Sekhukhune	Wonderboom	24.47327	29.61277
102	Sekhukhune	Veeplaas	24.52335	29.58728

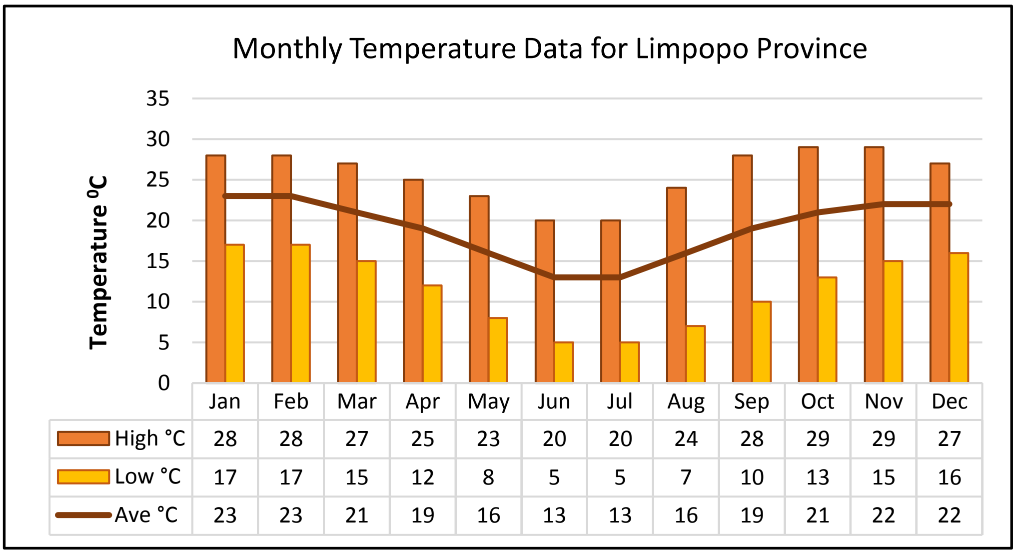
MEAN ANNUAL PRECIPITATION BY PROVINCE (SOUTH AFRICA) (mm)							
Province/Country	Mean Value	CV (%)	Maximum Value	Minimum Value	Exceedence Probability		
					20%	50%	80%
Limpopo	527	28	2031	200	616	517	411
Mpumalanga	736	24	1933	341	851	695	618
North-West	481	21	782	246	584	485	377
Northern Cape	202	43	540	20	284	185	129
Gauteng	668	38	900	556	693	670	638
Free State	532	22	1689	275	634	524	422
KwaZulu-Natal	845	20	1967	417	973	819	707
Eastern Cape	552	43	1722	96	768	528	332
Western Cape	348	72	3345	60	477	282	165
Swaziland	860	22	1690	451	997	832	705
Lesotho	701	21	1796	361	791	689	589

MEAN ANNUAL TEMPERATURE BY PROVINCE (SOUTH AFRICA) ^{0}C							
Province/Country	Mean Value	CV (%)	Maximum Value	Minimum Value	Exceedence Probability		
					20%	50%	80%
Limpopo	20	8	23.8	14.1	21.6	20.1	18.5
Mpumalanga	17.1	15	23.1	10.2	19.5	16.1	14.9
North-West	18.3	6	21.1	15.6	19.5	18.3	17.3
Northern Cape	17.4	8	22.5	10.4	18.7	17.6	16.3
Gauteng	16.5	5	19.3	15	17.2	16.2	15.7
Free State	15.8	7	17.9	3.9	16.9	15.8	14.8
KwaZulu-Natal	18.1	14	22.7	2.2	20.8	17.8	16
Eastern Cape	16.1	11	20	5.4	17.7	16.3	14.7
Western Cape	16.5	9	20.3	9.2	17.7	16.8	15.5
Swaziland	20.1	9	22.8	14.8	21.7	20.7	18.4
Lesotho	10.9	30	16.8	0.8	14	11.3	7.6

MEAN ANNUAL POTENTIAL EVAPORATION BY PROVINCE (SOUTH AFRICA) (mm)							
Province/Country	Mean Value	CV (%)	Maximum Value	Minimum Value	Exceedence Probability		
					20%	50%	80%
Limpopo	2218	6	2592	1896	2349	2205	2084
Mpumalanga	1946	6	2335	*1537	2044	1935	1856
North-West	2646	8	3058	2116	2882	2637	2424
Northern Cape	2690	6	3028	1890	2846	2702	2546
Gauteng	2178	3	2372	1960	2238	2176	2121
Free State	2233	11	2677	*1152	2474	2235	2017
KwaZulu-Natal	1770	8	2097	*1067	1882	1788	1643
Eastern Cape	1930	15	2616	1232	2262	1849	1661
Western Cape	2230	13	2714	*781	2477	2308	1943
Swaziland	1904	5	2078	1607	1977	1914	1827
Lesotho	1634	12	2107	*975	1831	1616	1475



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	80	80	60	20	20	10	10	10	20	50	100	70
Raindays	8	6	6	3	2	1	1	1	2	4	9	8



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High °C	28	28	27	25	23	20	20	24	28	29	29	27
Low °C	17	17	15	12	8	5	5	7	10	13	15	16
Ave °C	23	23	21	19	16	13	13	16	19	21	22	22

Note:
Data in tables obtained from SA Weather Service
http://planet.botany.uwc.ac.za/NISL/Invasives/Assignments/GARP/atlas/atlas.htm

Data source for illustrative graphs from: https://www.holiday-weather.com/limpopo/avera

APPENDIX 2

Pre-existing irrigation scheme databases and schemes surveyed

No	Project Name	District	Municipality	Size [ha] DWAF 2007	Size Ha JD 2007	Status JD 2006	Pumped or Gravity	Irrigation Method	Crop (1)	LATITUDE	LONGITUDE	Catchment	River	Dam / Weir	Borehole	Pipeline	Canal
1	Adriaansdraai	Capricorn	Lepelle-Nkumpi	100	80	Not Active	Pumped	Overhead	Wheat	24.55101	29.53195		Olifants/Lepelle			P/L	
2	Badfontein	Capricorn	Lepelle-Nkumpi	80	80	Not Active	Pumped	Overhead	Vegetables	24.50188	29.55702		Olifants/Lepelle			P/L	
3	Barotta	Vhembe	Makhado	175	175	Active	Pumped	Overhead	Fruits	23.0534	30.2824	A91D	Luvhungwe			P/L	
4	Beaconsfield	Vhembe	Makhado	39	35	Active	Pumped	Surface	Maize	22.9306	30.1499	A80A	Mutshedzi			P/L	canal
5	Belasting P1-3	Mopani	Baphalaborwa	115	1,169	Not Active	Pumped	Overhead	Fruit				Great Letaba			P/L	
6	Berlyn Citrus	Mopani	Greater Tzaneen	147	102	Not Active	Pumped		Fruit	23.89665	30.37692	B81E	Great Letaba		B/Hs		
7	Blyde river	Mopani	Maruleng	800		Active	Pumped	Overhead	Fruit				Blyde	Blydepoort dam		P/L	
8	Bona o dire	Sekhukhune	Elias Motswaledi	20		Active	Gravity	Overhead	Vegetables	25.11666	29.4708			Varshwater dam	B/h	P/L	
9	Boschkloof	Sekhukhune	Greater Tubatse	324	324	Active	Gravity	Surface	Vegetables	24.8102	30.0976	B41J	Steelpoort				Canal
10	Brakfontein	Sekhukhune	Greater Marble hall	16	11	Not Active	Pumped	Surface	Maize	24.95514	29.4081	B32J	Olifants/Lepelle			P/L	
11	Capesthorne	Vhembe	Makhado	99	99	Active	Both	Surface	Maize	23.0359	29687	A71H	Dorpriver	Spies dam		P/L	canal
12	Chivirikani	Vhembe	Thulamela														
13	Coombe bank	Mopani	Greater Tzaneen	135	135	Not Active	Gravity	Surface	Fruit	23.97116	30.18113	B81D	Letsitele				canal
14	Cordon A	Vhembe	Makhado	30	73	Active	Both	Surface	Vegetables	22.95764	30.18544		Tshiluvhadi/Mutshedzi			P/L	Canal
15	Cordon B	Vhembe	Makhado	50						22.95764	30.18544	A80A	Tshiluvhadi/Mutshedzi			P/L	canal
16	Cross Mango	Vhembe	Musina	12	12	Active	Pumped	Overhead	Fruit	22.47337	30.46787	A80J	Nwanedi	Cross dam		P/L	
17	De Paarl	Sekhukhune	Makhuduthamaga	64	66	Not Active	Gravity	Overhead		24.5908	29.5056	B51C	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
18	Devonia	Sekhukhune	Molemole	52	52	Active	Pumped	Overhead	Vegetables	23.33324	2911898	A72A			Borehole	P/L	
19	Dientjie	Sekhukhune	Makhuduthamaga	33	33	Not Active	Pumped	Surface	Maize	24.66421	30.80724						
20	Diepkloof	Vhembe	Makhado	40	40	Active	Both	Surface	Maize	22.91669	30.1133	A80A	Tshanzhe			P/L	canal
21	Dopeni	Vhembe	Thulamela	180	170	Active	Gravity	Surface	Maize	22.9288	30.2332	A80A	Nzhelele				Canal
22	Dovheni	Vhembe	Thulamela	56	57	Active	Pumped	Overhead	Vegetables	23.4214	30.1712		Levuvhu			P/L	
23	Dzindi	Vhembe	Thulamela	136	137	Active	Gravity	Surface	Maize	23.0216	30.4357	A91E	Dzindi				canal
24	Dzwerani	Vhembe	Thulamela	25	25	Not Active	Pumped	Overhead	Maize	23.0811	30.4386	A91F	Levuvhu			P/L	
25	Elandsdoorn	Sekhukhune	Elias Motswaledi	80	90	Active	Gravity	Overhead	Vegetables								
26	Elandskraal	Sekhukhune	Marble Hall	136	136	Active	Pumped	Overhead	Vegetables	24.73321	29.41129	B51E	Olifants/Lepelle			P/L	
27	Fertilies	Capricorn	Lepelle-Nkumpi	96	137	Active	Gravity	Surface	Maize	24.12502	30.10833	B71C	Mohlapitsi				canal
28	Folovhodwe	Vhembe	Mutale	55	55	Active	Gravity	Surface	Maize	22.58949	30.42203	A80J	Nwanedi				canal
29	Fontein Dechamp	Sekhukhune		10	10	Active	Pumped	Overhead	Vegetables	22.53112	28.5012				Borehple	P/L	
30	Gaataan	Sekhukhune	Makhuduthamaga	155	155	Not Active	Gravity	Surface	Maize	24.61129	29.48857	B51C	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
31	Galakwena	Waterberg	Mogalakwena	23	23	Not Active	Pumped	Micro	Fruit	23.4865	28.6615	A62G	Mokgalakwena		Borehole	P/L	
32	Garside	Vhembe	Makhado	52	52	Active	Gravity	Surface	Maize	22.7114	30.15	A80G	Tshitedzi fountain			P/L	Canal
33	Gillemburg citrus	Waterberg	Mogalakwena	450	450	Active	Pumped	Overhead	Fruit	238375	28.9594	A62F			Borehole	P/L	
34	Goedvertrouend	Sekhukhune	Greater Marble hall	123	123	Not Active	Both	Overhead		24.828	29.5082	B51A	Motsephiri			P/L	canal
35	Goedverwacht	Sekhukhune	Makhudu Thamaga	90	90	Not Active	Pumped	Overhead	Wheat				Olifants/Lepelle			P/L	Flag Boshielo Canal
36	Gogobole	Vhembe	Makhado	16	16	Active	Pumped	Overhead	Fruits	23.08015	29.77887	A71H			Borehole	P/L	
37	Gompies -	Capricorn	Lepelle-Nkumpi	115	115	Not Active	Pumped	Overhead	Vegetables	24.44532	29.40509	B51G	Gompies				canal
38	Gonani	Vhembe	Thulamela	15	10	Active	Pumped	Micro	Vegetables	23.4112	30.1214		Levuvhu			P/L	
39	Grootfontein	Capricorn	Lepelle-Nkumpi	110	103	Not Active	Pumped	Overhead	Maize	24.21304	29.90683	B71A	Olifants/Lepelle			P/L	
40	Grootfontein B	Capricorn	Lepelle-Nkumpi	5	5	Active	Gravity	Surface	Cash Crops				Olifants/Lepelle				
41	Grootklip	Capricorn	Lepelle-Nkumpi	45	45	Active	Pumped	Overhead	Fruit	24.56369	29.52355		Olifants/Lepelle			P/L	
42	Haakdooringdraai	Capricorn	Lepelle-Nkumpi	102	102	Not Active	Pumped	Overhead	Wheat/maize	24.47091	29.67939	B52A	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
43	Hereford	Sekhukhune	Elias Motswaledi	154		Active	Pumped	Overhead	Vegetables				Olifants/Lepelle	Loskop			earth chanel
44	Homu	Mopani	Greater Giyani		240	Not Active	Pumped	Overhead	Vegetables								
45	Ipopeng	Sekhukhune	Elias Motswaledi			Active	Pumped	Overhead	Vegetables								
46	Julesburg	Mopani	Greater Tzaneen	109	86	Active	Pumped	Overhead	Ground Nuts	24.101	30.3222	B72E	Nwaveti	Tours dam		P/L	
47	Khumbe	Vhembe	Thulamela	172	172	Active	Gravity	Surface	Maize	23.03484	30.38861	A91E	Dzondo				canal
48	Khuvutlu Farm	Mopani	Baphalaborwa			Active	Pumped	Micro	Vegetables								
49	Klein Tshipise	Vhembe	Musina	9	9	Active	Gravity	Surface	Maize								
50	Kgotlelelo	Sekhukhune	Marble Hall														
51	Koedoeskop	Capricorn	Lepelle-Nkumpi	116	85	Active	Gravity	Surface	Vegetables	24.24053	29.82566	B52J	Malepies				canal
52	Krododilheuwel	Sekhukhune	Makhuduthamaga	240	243	Not Active	pumped	Overhead	Wheat	24.6864	29.4559	B51C	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
53	Kutama	Vhembe	Makhado	12		Not Active	Pumped	Micro	Fruits	23.1057	29.6779	A71H			Borehole	P/L	
54	Lambani	Vhembe	Thulamela	50	50	Active	Pumped	Overhead	Fruits	22.7664	30.8706	A91H	Levuvhu			P/L	
55	La-Rochelle	Vhembe	Makhado	200	200	Active	Pumped	Micro	Field Crops	23.12629	30.08726	A91C					
56	Lekgalameetse	Mopani	Maruleng	81	81	Active	Gravity	Surface	Fruits	24.1511	30.3066	B72F					canal
57	Lepellane	Sekhukhune	Fetakgomo	340	340	Not Active	Pumped	Overhead	Maize/cash crop	24.47029	29.81226	B52B	Lepelani	Lepelani dam			canal
58	Lephepane	Mopani	Greater Tzaneen	52	42	Not Active	Gravity	Surface	cash crops	23.98289	30.19316	B81D	Letsitele				canal
59	Lesedi	Sekhukhune	Tubatse														
60	Lorraine B	Mopani	Maruleng	40	40	Active	Gravity	Surface	Vegetables	24.2193	30.4523	B72A	Moungwana				canal
61	Lucern	Capricorn	Lepelle-Nkumpi	48	48	Active	Gravity	Surface	Vegetables	24.27452	30.22088	B71F	Mountain stream				canal
62	Luvhada	Vhembe	Makhado	29	28	Active	Gravity	Surface	Maize	22.87777	30.2		Spring/eye				canal

No	Project Name	District	Municipality	Size [ha] DWAF 2007	Size Ha JD 2007	Status JD 2006	Pumped or Gravity	Irrigation Method	Crop (1)	LATITUDE	LONGITUDE	Catchment	River	Dam / Weir	Borehole	Pipeline	Canal
63	Lwamondo																
64	Mabete	Mopani	Baphalaborwa			Active	Pumped	Micro	Fruit								
65	Mabunda	Mopani	Greater Giyani	350	300	Active	Pumped	Micro	Fruit	23.6848	30.8681	B81F	Great Letaba	Nondweni weir		P/L	
66	Madeira	Mopani	Maruleng	138	138	Active	Gravity	Surface	Vegetables	24.2418	30.4175	B72A	Moungwana				canal
67	Makgaung	Mopani	Maruleng	71	71	Active	Gravity	Surface	Vegetables	24.2809	30.4437	B72A	Moungwana				canal
68	Makhushane dairy	Mopani	Baphalaborwa	30	30	Not Active	Pumped	Overhead	Vegetables	23.9556	31.0555	B72K			Borehole	P/L	
69	Makhuva	Mopani	Greater Giyani			Active	Pumped	Micro	Vegetables								
70	Makonde	Vhembe	Mutale	200	70	Not Active	Pumped	Micro	Fruit	22.78933	30.54921	A92A	Mutale			P/L	
71	Makuleke	Vhembe	Thulamela	272	272	Active	Both	Overhead	Maize	22.8571	30.9359	B90B	Mphongola	Makuleke dam			canal
72	Makumeke	Vhembe	Thulamela														
73	Malavuwe	Vhembe	Thulamela	22	26	Active	Pumped	Overhead	Maize	22.8635	30.6455	A91G	Mutshindudzi			P/L	
74	Mamuhohi	Vhembe	Makhado	77	77	Active	Both	Surface	Maize	22.8778	30.1143	A80B	Mutshedzi			P/L	Canal
75	Mandagshoek	Sekhukhune	Greater Tubatse	23	21	Active	Pumped	Surface	Vegetables	24.6011	30.084	B41J			Borehole	P/L	
76	Mandiwana	Vhembe	makhado	67	67	Active	Gravity	Surface	Maize	22.87843	30.11454	A80B	Mutshedzi				Canal
77	Mangondi	Vhembe	Thulamela	17	17	Active	Pumped	Overhead	Vegetables	22.95455	30.61206	A91F	Levuvhu			P/L	
78	Mapela	Waterberg	Mogalakwena	96	96	Active	Pumped	Overhead	Vegetables	23.9857	28.8826	A61G	Pholotshi	Dam		P/L	
79	Marinaspruit	Capricorn	Blauberg														
80	Mariveni	Mopani	Greater Tzaneen	313	313	Active	Pumped	Surface	Fruits	23.8802	30.3401	B81C	Great Letaba			P/L	canal
81	Masalal 722 P1&4-7	Mopani	Baphalaborwa	174		Active	Pumped	Surface	Fruits				Great Letaba				earth chanel
82	Mashamba 1	Vhembe	Makhado	27	27	Active	Pumped	Overhead	Vegetables								
83	Mashushu	Capricorn	Lepelle-Nkumpi	23		Active	Gravity	Surface	Vegetables								
84	Matsika	Vhembe	Thulamela	101	101	Not Active	Pumped	Overhead	Vegetables	22.85208	30.70549	A91G	Mutshundudzi			P/L	
85	Mauluma	Vhembe	Makhado	73	73	Active	Gravity	Surface	Maize	22.925	30.1356	A80A					Canal
86	Mecklenburg	Sekhukhune	Tubatse	65	65	Not Active	Gravity	Surface	Maize/cash crop	24.37368	30.07562	B71E	Motse	Weir			canal
87	Metz	Mopani	Maruleng	265	265	Not Active	Pumped	Overhead	Orchard/veg.	24.231	30.4661	B72A	Moetladimo	Metz dam		P/L	
88	Mhinga - Xikundu	Vhembe	Thulamela	300	127	Not Active	Pumped	Micro	Fruit	22.77393	30.88322	A91H	Levuvhu			P/L	
89	Middle Letaba	Mopani	Greater Giyani	1,433	1,730	Not Active	Pumped	Overhead	Bananas/cash C.				Middle Letaba	Middle Letaba dam		P/L	Middle Letaba canal
90	Modjadji	Mopani	Greater Letaba	24	120	Not Active	Pumped	Surface	Mangos	23.65101	30.23081	B82C	Molototsi			P/L	
91	Modjadji Dairy	Mopani	Greater Letaba	30		Not Active	Pumped	Surface	Pastures	23.65173	30.22236	`			Borehole	P/L	
92	Mogalatsane	Sekhukhune	Marble Hall	127	131	Not Active	Both	Surface	cotton/maize	24.7292	29.42	B51C	Olifants/Lepelle	Flag Boshielo dam		P/L	
93	Moletjie	Capricorn	Aganang	70	70	Not Active	Pumped	Surface	Pastures	23.8126	2938844	A71A			Borehole	P/L	
94	Molototsi Mango	Mopani	Greater Letaba	81	940	Active	Pumped	Surface	Fruit				Molototsi			P/L	
95	Montevideo	Sekhukhune	Greater Marble hall	100	90	Not Active	Gravity	Surface	Vegetables	24.86151	29.58372	B51A	Motsephiri				canal
96	Mooiplaats	Sekhukhune	Fetakgomo	106	100	Active	Both	Surface	Maize/wheat	24.4352	29.7335	B52B	Olifants/Lepelle	Flag Boshielo dam		P/L	Flag Boshielo Canal
97	Moradu Farm	Mopani	Baphalaborwa														
98	Morgan	Vhembe	Thulamela	70	70	Active	Pumped	Surface	Vegetables	22.97656	30.63135	A91F	Levuvhu			P/L	
99	Mphaila	Vhembe	Makhado	71	71	Active	Pumped	Overhead	Vegetables	22.9074	30.1289	A80A	Mutshudzi	Mphaila weir		P/L	
100	Mphephu	Vhembe	Makhado	114	114	Active	Gravity	Surface	Maize	22.88966	30.14762	A80A	Nzhelele			P/L	Canal
101	Murara	Vhembe	Mutale	37	37	Active	Pumped	Overhead	Maize	22.9145	30.4881	A91G	Murara			P/L	
102	Mutele	Vhembe	Mutale	33	33	Not Active	Pumped	Overhead	Vegetables	22.478	30.9241	A92D	Mutale			P/L	
103	Mydarling	Capricorn	Lepelle-Nkumpi	10	5	Active	Pumped	Overhead	Vegetables	23.08978	28.77703	A63A			Borehole	P/L	
104	Naphuno Farms	Mopani	Greater Tzaneen	160	160	Not Active	Gravity	Surface	Vegetables	23.9663	30.2061	B81D	Letsitele				canal
105	Nesengani	Vhembe	Thulamela	13	40	Not Active	Pumped	Overhead	Maize	23.1076	30.3883	A91F	Levuvhu			P/L	
106	Nesengani B 1	Vhembe	Thulamela	20	71	Not Active	Pumped	Overhead	Maize	23.1076	30.3883	A91F	Levuvhu			P/L	
107	Nesengani B 2	Vhembe	Thulamela	40	20	Not Active	Pumped	Overhead	Maize	23.1076	30.3883	A91F	Levuvhu			P/L	
108	Nesengani C	Vhembe	Thulamela	31	31	Not Active	Pumped	Overhead	Maize	23.1076	30.3883	A91F	Levuvhu			P/L	
109	Nooitgesien	Sekhukhune	Makhuduthamaga	114	110	Not Active	Gravity	Overhead	Maize	24.57992	29.52217	B51C	Olifants/Lepelle				Flag Boshielo Canal
110	Oaks & Willow	Mopani	Maruleng	200	200	Not Active	Pumped	Micro	Fruit	24.3707	30.6658	B71H	Olifants/Lepelle			P/L	
111	Palmaryville	Vhembe	Thulamela	92	92	Active	Gravity	Surface	Maize	22.9861	30.4317	A91E	Lutavhe				canal
112	Phadzima Irrigation	Vhembe	Makhado	82	82	Not Active	Both	Surface	Maize	22.8804	30.2166	A80A	Tshiluvhadi			P/L	canal
113	Phalaborwa Dairy	Phalaborwa	Phalaborwa														
114	Phaswana	Vhembe	Thulamela	120	120	Active	Pumped	Micro	Fruit	22.8483	30.7079	A91H	Mutshindudi			P/L	
115	Phetwane	Sekhukhune	Marble Hall	52		Not Active	Pumped	Overhead	Maize/cash crop	24.7572	29.4317	B51C	Olifants/Lepelle			P/L	
116	Platklip	Sekhukhune	Makhuduthamaga	144	68	Not Active	Gravity	Surface	Maize/cash crop	24.90755	29.69207	B51A	catchment/fountain	earth dams			Canal
117	Prague	Capricorn	Aganang	30	30	Not Active	Pumped	Micro	Fruit	23.71259	2894199	A62F			Borehole	P/L	
118	Pretoria Farm	Sekhukhune	Makhuduthamaga	43	43	Active	Gravity	Surface	Vegetables	24.52949	30.39215	B41K	Steelpoort				Canal
119	Prieska 723 P1&2	Mopani	Baphalaborwa	81									Great Letaba				earth chanel
120	Rabali Irrigation	Vhembe	Makhado	84	87	Active	Gravity	Surface	Maize	22.871	30.0507	A80B	Nzhelele				Canal
121	Raliphaswa	Vhembe	Makhado	16	15	Active	Gravity	Surface	Maize	22.88888	30.1333		Mutshedzi				canal
122	Rambuda	Vhembe	Mutale	103	103	Active	Gravity	Surface	Maize	22.79108	30.43635	A92A	Tshala				canal
123	Rietfontein	Sekhukhune	Tubatse	50	50	Not Active	Gravity	Overhead	cashy crops	24.6131	30.538	B60H	Steelpoort				canal
124	Roodewaal	Sekhukhune	Greater Marble hall	30	69	Active	Pumped	Overhead					Olifants/Lepelle			P/L	

No	Project Name	District	Municipality	Size [ha] DWAF 2007	Size Ha JD 2007	Status JD 2006	Pumped or Gravity	Irrigation Method	Crop (1)	LATITUDE	LONGITUDE	Catchment	River	Dam / Weir	Borehole	Pipeline	Canal
125	Rust de Winter	Waterberg	Bela Bela	150		Active	Pumped	Overhead	Maize								
126	Sanari	Vhembe	Mutale	30	39	Active	Pumped	Overhead	Maize	22.47694	30.87124	A92D	Mutale			P/L	
127	Sekgakgapeng	Waterberg	Mogalakwena	28	28	Not Active	Pumped	Overhead	Vegetables	24.1807	28.9648	A61F	Mogalakwena		B/h	P/L	
128	Sekgopo	Mopani	Greater Letaba	253	253	Active	Pumped	Surface	Vegetables								
129	Sekorroro	Mopani	Maruleng	113	113	Active	Gravity	Surface	Vegetables	24.21548	30.4048	B72A	Morola				canal
130	Selwane	Mopani	Baphalaborwa	194	72	Active	Pumped	Micro	Fruit	23.67835	30.92163		Great Letaba			P/L	
131	Sepitsi	Capricorn	Lepelle-Nkumpi	88	88	Not Active	Pumped	Overhead	Vegetables	24.49612	29.56666		Olifants/Lepelle			P/L	
132	Setlaboswana	Sekhukhune	Makhuduthamaga	123	119	Not Active	Gravity	Surface	Miaze/wheat	24.6699	29.4671	B51C	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
133	Sofaya	Mopani	Maruleng			Active	Gravity	Surface	Vegetables								
134	Solani	Mopani	Greater Tzaneen	84	96	Active	Gravity	Surface	Vegetables	23.0653	30.3132	A91D	Nwaveti			P/L	
135	Steelpoortdrift	Sekhukhune	Tubatse	120	72	Active	Gravity	Surface	Vegetables	24.8891	30.0102	B41H	Steelpoort				Canal
136	Sterkspruit	Sekhukhune	Tubatse	456	360	Active	Pumped	Overhead	Maize	24.5282	30.7022	B60H	Origstad			P/L	canal
137	Strassburg	Mopani	Maruleng	90	90	Active	Gravity	Surface	Fruit	24.2497	30.41	B72A	Moungwana				canal
138	Strydkraal A	Sekhukhune	Fetakgomo	239	338	Active	Pumped	Overhead	Vegetables	24.4676	29.7096	B52A	Olifants/Lepelle	Flag Boshielo dam		P/L	Flag Boshielo Canal
139	Strydkraal B	Sekhukhune	Fetakgomo			Active	Pumped	Overhead	Vegetables								
140	Success	Capricorn	Lepelle-Nkumpi	116	135	Active	Gravity	Surface	Vegetables	24.21188	29.89544	B71A	Mountain stream				canal
141	Tswelopele	Sekhukhune	Tubatse		685	Active	Pumped	Overhead	Vegetables				Steelpoort			P/L	canal
142	Thabina	Mopani	Greater Tzaneen	228	228	Active	Gravity	Surface	Vegetables	23.959	30.2914	B81D	Thabina				canal
143	Tours	Mopani	Greater Tzaneen	125		Active	Gravity	Surface	Vegetables	24.09709	30.26877	B72E	Tours dam			P/L	
144	Tours coffee	Mopani	Greater Tzaneen	170	140	Active	Gravity	Micro	Vegetables	24.088	30.2782	B72E		Tours dam		P/L	
145	Tsatane	Sekhukhune	Makhudu Thamaga	40		Active	Pumped	Overhead	Vegetables				Tshirwa				
146	Tshaulu	Vhembe	Thulamela	90	150	Not Active	Pumped	Overhead	Fruit	22.79095	30.80013	A91H	Levuvhu			P/L	
147	Tshikonelo	Vhembe	Thulamela	54	54	Not Active	Gravity	Micro	Fruit	22.85182	30.72044	A91H	Levuvhu				canal
148	Tshimbupfe	Vhembe	Thulamela	12	12	Not Active	Pumped	Overhead	Vegetables	23.0834	30.4631	A91F	Levuvhu			P/L	
149	Tshiombo	Vhembe	Thulamela	137					Maize	22.79371	30.52316	A92A	Mutale	Tshiombo weir			canal
150	Tshiombo-Maraxwe	Vhembe	Thulamela	128					cash crops					Tshiombo weir			canal
151	Tshiombo-Matangari	Vhembe	Thulamela	363					cash crops					Tshiombo weir			canal
152	Tshiombo-Matombotwuka	Vhembe	Thulamela	80					cash crops					Tshiombo weir			canal
153	Tshiombo-Mbhahela	Vhembe	Thulamela	110					cash crops				Mutale	Tshiombo weir			canal
154	Tshiombo-Mianzwi	Vhembe	Thulamela	125					cash crops					Tshiombo weir			canal
155	Tshiombo-Mutshenzheni	Vhembe	Thulamela	60					cash crops					Tshiombo weir			canal
156	Tswinga	Vhembe	Thulamela	12	50	Active	Pumped	Overhead	Fruit	23.02	30.47432	A91E	Dzindi			P/L	
157	Vallies	Capricorn	Lepelle-Nkumpi	29	37	Active	Gravity	Surface	Vegetables	24.13583	30.11471	B71C	Mountain stream				canal
158	Vandermerweskraal	Sekhukhune	Marble Hall	150		Active	Pumped	Overhead	Vegetables				Olifants/Lepelle			P/L	
159	Veeplaas	Sekhukhune	Makhuduthamaga	390	463	Active	Pumped	Overhead	Maize	24.50826	2958854	B52A	Olifants/Lepelle	Flag Boshielo dam		P/L	Flag Boshielo Canal
160	Vhutuwa Nga Dzebo	Vhembe	Makhado	18	18	Active	Gravity	Surface	Vegetables	22.8865	30.13625	A80A	Mtshedzi				canal
161	Vlakplaas	Sekhukhune	Makhuduthamaga	74	74	Not Active	Gravity	Surface	Wheat/maize	24.47997	29.65548	B52A	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
162	Vlakspruit	Sekhukhune	Makhuduthamaga	120	120	Not Active	Gravity	Surface	Maize/cash crop	24.7592	29.4916	B51C	Spring/eye				canal
163	Waterbok 721 P1-3 &10-16	Mopani	Baphalaborwa	251									Great Letaba				earth chanel
164	Wonderboom	Sekhukhune	Makhuduthamaga	113	117	Not Active	Pumped	Overhead	Wheat	24.47236	29.6139	B52A	Olifants/Lepelle	Flag Boshielo dam			Flag Boshielo Canal
165	Xigalo	Vhembe	Thulamela														
166	Zebediela Citrus	Capricorn	Lepelle-Nkumpi	850	850	Active	Pumped	Micro	Fruit	24.32411	29.29718	B51G	Mogoto	Gompies dam	B/h	P/L	
167	Zeekoeigat	Waterberg	Mogalakwena	25	25	Not Active	Pumped	Overhead	Vegetables	23.60342	28.60964	A62C	Mogalakwena			P/L	

APPENDIX 3

SURVEY QUESTIONNAIRE

PART 1 - Scheme Descriptive Data					
Code	**Question**	**Data and Comments**			
DETAILS of INTERVIEWER					
101	Date:	Time:			
102	Day of the week (mon, tues etc.)				
103	Name of interviewer				
104	Cellphone number of interviewer				
105	Language of interview				
DETAILS of KEY INFORMANT					
106	FAMILY Name of informant				
107	First Name of informant				
108	Cellphone number of informant				
109	Office or occupation relative to scheme				
LOCATION					
110	Province				
111	District				
112	Local Municipality				
113	Nearest village				
114	Scheme name				
115	Sub-scheme name				
116	Latitude (degrees minutes seconds)				
117	Longitude (degrees minutes seconds)				
118	Name of nearest town				
119	Distance to nearest town by road	one way - km		km	
120	Distance to nearest tar road	one way - km		km	
121	Distance to nearest source of agrochemicals	one way - km		km	
122	Year first operational	Year			
REVITALISATION STATUS					
123	Since 2000, has the scheme ….				
124	**been fully revitalised**		Yes	No	
125	**been partially revitalised**		Yes	No	
126	**Not been revitalised**		Yes	No	
127	**What section of the scheme does this questionnaire refer to:**		Original scheme	Revitalised scheme	

PART 2 - Size and Soils						
Code	**Question**	**Data and Comments**				
SIZE of SCHEME AND PLOTS						
200	Commanded irrigation area - theoretical size	hectares		ha		
201	Total number of plotholders	Number		201.1	Number of Women	
202	Actual area that can currently be irrigated	hectares		ha		
203	Indicate size and number of plots	Size (ha)	No. of plots			
204	Foodplots					
205	Fields					
206	Farms					
207	Central commercial farm					
208	other					
209	**TOTAL**					
210	Average winter cropping intensity	ratio of total irrigation scheme area		%		
211	Average summer cropping intensity	ratio of total irrigation scheme area		%		
SOILS - MARK ON AERIAL PHOTOGRAPH / MAP						
212	**Soil depth** (mark in blue on map and label)	>1.5 m		% of total irrigated area		
213		0.75 to 1.5m		% of total irrigated area		
214		< 0.75m		% of total irrigated area		
215				**TOTAL (must equal 100%)**		
216	**Soil Colour** Red pen	red soils		% of total irrigated area		
217	Yellow pen	yellow or brown soils		% of total irrigated area		
218	Black pen	black soils		% of total irrigated area		
219	Green pen	grey soils		% of total irrigated area		
220				**TOTAL (must equal 100%)**		

PART 3 - WATER INFRASTRUCTURE

Code	Question	Data and Comments					
WATER SOURCE AND TECHNICAL DATA							
301	Water source	Storage on river (dam name)	YES	NO			
302		Groundwater	YES	NO			
303		Run-of-the river (river name)	YES	NO			
304		Both surface and groundwater	YES	NO			
305	Method of water abstraction	Pumped diversion	YES	NO			
306		Gravity diversion - weir	YES	NO			
307	Power source for pumping	Diesel	YES	NO			
308		Eskom electricity	YES	NO			
309	Length of main water delivery canal / pipe	lined open canal		km			
310	(estimate total kilometres)	unlined open canal		km			
311		pipeline		km			
312	How many hydraulic units from water management perspective (estimate No.)			No.			
313	Condition of irrigation infrastructure	pumps	not working	working	NA		
314	(mark one box)	infield sprinklers / drippers / pivots	leaking badly	some leaks	optimum	NA	
315		main and secondary canals	degradation prevents irrigation	major leaks	minor leaks	absence of concrete cracks	NA
316		tertiary canals	degradation prevents irrigation	major leaks	minor leaks	absence of concrete cracks	NA
317		canal control gates	none are operable	few are operable	most are operable	all are operable	NA
ON FARM IRRIGATION METHOD							
318	Surface methods	Furrow		ha	*Comments if needed*		
319	(estimate hectarage of each	Short furrow		ha			
320	where applicable)	Basin		ha			
321		Border strip		ha			
322		Wild flooding		ha			
323	Overhead methods	Dragline sprinkler		ha			
324		Sprinkler line		ha			
325		Raingun		ha			
326		Centre pivot		ha			
327		Floppy		ha			
328	Micro-irrigation	Drip		ha			
329		Microjet		ha			
330	Other	Sub-surface		ha			
331		Other (specify)		ha			

PART 3 continued - WATER						
Code	**Question**	**Data and Comments**				
CANAL WATER CONTROL EQUIPMENT						
332	Type of water control equipment on canals	Fixed proportional division	YES	NO	NA	*Comments if needed*
333		Gated - manual operation	YES	NO	NA	
334		Gated - automatic local control	YES	NO	NA	
335		Gated – automatic central control	YES	NO	NA	
336		None	YES	NO	NA	
337	Location of water control equipment on canals	main intake only	YES	NO	NA	
338		primary and secondary level	YES	NO	NA	
339		primary, secondary and tertiary level.	YES	NO	NA	
340	Type of discharge measurement on canals	Flow meter	YES	NO	NA	
341		Fixed weir or flume	YES	NO	NA	
342		Calibrated sections	YES	NO	NA	
343		Calibrated gates	YES	NO	NA	
344	Location of discharge measurement	Primary canal level	YES	NO	NA	
345		Secondary canal level	YES	NO	NA	
346		Tertiary canal level	YES	NO	NA	
347		Field level	YES	NO	NA	
348		None	YES	NO	NA	
PIPELINE WATER CONTROL EQUIPMENT						
349	Type of water control equipment on pipelines	Flowmeters on bulk pipeline only	YES	NO	NA	
350		Flowmeters at offtakes from bulk pipelines	YES	NO	NA	
OTHER INFRASTRUCTURE						
351	What proportion of the scheme is visibly affected by salinity (percentage)			%		
352	What proportion of the scheme is visibly affected by water logging (percentage)			%		
353	Are there any drainage ditches constructed to remove excess water from the fields		YES	NO		
354	Is the scheme fenced		No	Partially	Completely	
355	What is the condition of the fence		Ineffective	Partially effective	Fully effective	

PART 4 - WATER QUALITY AND AVAILABILITY AT SCHEME LEVEL						
Code	**Question**	**Data and Comments**				
Water quality and availability						
401	Water licensing for the scheme	Are farmers aware of any DWAF irrigation water allocation		YES	NO	*Comments if needed*
402	Does the DWAF allocation specify a volume ?		N / A	YES	NO	
402		If YES - what is the allocated volume ?				*state volume / time unit*
403	Is the allocated volume assured ?			YES	NO	
404	Adequacy of supply during the year	Water is adequately available throughout the year		YES	NO	
405		Water is available but subject to seasonal fluctuations		YES	NO	
406		There is virtually no water during the dry season		YES	NO	
407	Long term supply fluctuations	Water availability is affected by whether it is a wet or dry year		YES	NO	
408	Farmer response to limited supply	night irrigation		YES	NO	
409		water theft		YES	NO	
410		water exchanges		YES	NO	
411		Adaptation in crop selection		YES	NO	
412		Reduce the planted area		YES	NO	
413		Reduce the irrigation frequency		YES	NO	
414		evaporation control / mulching		YES	NO	
415		other (describe)				
416	Is there a difference in supply between the top-end and the tail-end irrigators (briefly provide details)			YES	NO	

PART 5 - INSTITUTIONS					
Code	**Question**	**Data and Comments**			
INSTITUTIONAL ARRANGEMENTS AND ORGANISATIONS					*Provide Names if applicable*
501	Which organisations are present on the scheme DRAW ORGANOGRAM of SCHEME MANAGEMENT ARRANGEMENT	Government agency or Department	YES	NO	
502		Private company or Joint Venture	YES	NO	
503		SchemeTrust	YES	NO	
504		Registered Farmers Cooperative	YES	NO	
505		Plotholders Group	YES	NO	
506		Water Users Association	YES	NO	
507		None	YES	NO	
508		Other (describe)			
509	Which organisations decide on irrigation water allocation to units and plots	Government agency or Department	YES	NO	*Provide Names if applicable*
510		Private company or Joint Venture	YES	NO	
511		Trust	YES	NO	
512		Farmers Cooperative	YES	NO	
513		Plotholders Group	YES	NO	
514		Water Users Association	YES	NO	
515		Farmers individually	YES	NO	
516		None	YES	NO	
517		Other (describe)			
518	Are water rules and regulations formalised	formalised by being written down	YES	NO	
519	Are there consequences for rule-breakers		YES	NO	
520	Which organisations are responsible for maintenance of scheme infrastructure	Government agency or Department	YES	NO	*Provide Names if applicable*
521		Private company or Joint Venture	YES	NO	
522		Trust	YES	NO	
523		Farmers Cooperative	YES	NO	
524		Plotholders Group	YES	NO	
525		Water Users Association	YES	NO	
526		Farmers individually	YES	NO	
527		None	YES	NO	
528		Other (describe)			

PART 5 continued - INSTITUTIONS (2)					
Code	**Question**	**Data and Comments**			
529	Which organisations are involved in catchment management activities	Government agency or Department	YES	NO	*Provide Names if applicable*
530		Private company or Joint Venture	YES	NO	
531		Trust	YES	NO	
532		Farmers Cooperative	YES	NO	
533		Plotholders Group	YES	NO	
534		Water Users Association	YES	NO	
535		Farmers individually	YES	NO	
536		None	YES	NO	
537		Other (describe)			
538	Which organisation assists in securing inputs (seed / mechanisation etc.)	Government agency or Department	YES	NO	*Provide Names if applicable*
539		Private company or Joint Venture	YES	NO	
540		Trust	YES	NO	
541		Farmers Cooperative	YES	NO	
542		Plotholders Group	YES	NO	
543		Water Users Association	YES	NO	
544		Farmers individually	YES	NO	
545		None	YES	NO	
546		Other (describe)			
547	Which organisation assists with marketing of produce	Government agency or Department	YES	NO	*Provide Names if applicable*
548		Private company or Joint Venture	YES	NO	
549		Trust	YES	NO	
550		Farmers Cooperative	YES	NO	
551		Plotholders Group	YES	NO	
552		Water Users Association	YES	NO	
553		Farmers individually	YES	NO	
554		None	YES	NO	
555		Other (describe)			

PART 5 continued - INSTITUTIONS (3)					
Code	**Question**	**Data and Comments**			
556	How is revenue collection for irrigation water calculated	Plot fee	YES	NO	*Comments if needed*
557		Fee based on area of irrigation	YES	NO	
558		Charge on crop type and area	YES	NO	
559		Charge on volume of water used	YES	NO	
560		Charge per irrigation event	YES	NO	
561		No charge	YES	NO	
562		Do not know if there is a charge	YES	NO	
563	If there is a water fee - how much is it (provide rand / time interval)				
564	Is there conflict (that cannot be resolved amicably) on the scheme in relation to:	Land	YES	NO	*Conflict means that two people cannot agree and need a third party to assist*
565		Theft of equipment	YES	NO	
566		Theft of produce	YES	NO	
567		Inter-organisational or factional conflict	YES	NO	
568	Is there conflict between plotholders and people off the scheme		YES	NO	
569	How much land (ha) on the scheme is	State land held by PTO's		ha	
570		State land held collectively		ha	
571		Collective title (eg. CPA)		ha	
572		Individual title		ha	
573	Is there any form of land exchange on the scheme		YES	NO	
			CONTINUE	**GOTO Part 6**	
574	Do land exchanges have to be formalised (sanctioned) by scheme management		YES	NO	*Comments if needed*
575	Do land exchanges have to be formalised (sanctioned) by the Tribal Authority		YES	NO	
576	If a farmer uses the land of another how is this organised	sharing of crops produced	YES	NO	
577		rental through cash payment	YES	NO	
578		based on land preparation services	YES	NO	
579		Other (describe)			
580	What durations of land-exchange are found on the scheme	single season exchange	YES	NO	
581		multiple seasons less than 2 years	YES	NO	
582		Multiple seasons more than 2 years	YES	NO	

PART 6 FARMING SYSTEM

Code	Question	Data and Comments			
Cropping					
601	Crops grown in summer	Grain crops		%	
602	(estimate % of total crops produced)	vegetables		%	
603		orchard crops		%	
604		industrial crops		%	
605		fodder crops		%	
606		other (describe)		%	
607		**summer total must equal 100**		%	
608	Crops grown in winter	Grain crops		%	
609	(estimate % of total crops produced)	fresh vegetables		%	
610		orchard crops		%	
611		industrial crops		%	
612		fodder crops		%	
613		other (describe)		%	
614		**winter total must equal 100**		%	
615	What is the **primary use of produce** (estimate % of farmers for each category)	Home use - food and animal fodder		%	
616		Equal cash sale and home use		%	
617		Mainly sale off-scheme		%	
618		other (describe)		%	
619		**total must equal 100**		%	
620	Do any of the plot holders on the scheme use the following techniques to sell their produce	Small traders or hawkers buying on the scheme	YES	NO	
621		Supply to local retailers	YES	NO	
622		Supply to distant retailers in major	YES	NO	
623		Contract farming	YES	NO	
624	How do farmers do primary tillage (ploughing) - estimate % of farmers for each category	hand tilling		%	
625		animal draft		%	
626		locally owned tractors		%	
627		tractors from outside the scheme		%	
628		**total must equal 100**		%	
629	Are there delays in securing ploughing services	Majority of farmers experience delays	YES	NO	
630		about half the farmers	YES	NO	
631		few farmers	YES	NO	
632		no delays	YES	NO	

PART 6 continued FARMING SYSTEM (2)					
Code	**Question**	**Data and Comments**			
Knowledge Sources and Quality					
633	If farmers need agronomic advice relating to soil prep / seed / fertiliser / pest control etc., where do they get it from	Other farmers	YES	NO	
634		Extension officer	YES	NO	
635		NGO's	YES	NO	
636		Private companies	YES	NO	
637		Tertiary institutions	YES	NO	
638		No advisory services	YES	NO	
639		other (describe)			
640	What is the quality of advice	All their questions are answered satisfactorily	YES	NO	
641		Most of their questions are answered satisfactorily	YES	NO	
642		Few of their questions are answered satisfactorily	YES	NO	
643		None of their questions are answered satisfactorily	YES	NO	
644		Not applicable	YES	NO	
645	If farmers need advice on marketing where do they get it from	Other farmers	YES	NO	
646		Extension officer	YES	NO	
647		NGO's	YES	NO	
648		Private companies	YES	NO	
649		Tertiary institutions	YES	NO	
650		No advisory services	YES	NO	
651		other (describe)			
652	What is the quality of advice	All their questions are answered satisfactorily	YES	NO	
653		Most of their questions are answered satisfactorily	YES	NO	
654		Few of their questions are answered satisfactorily	YES	NO	
655		None of their questions are answered satisfactorily	YES	NO	
656		Not applicable	YES	NO	

PART 7 TRANSECT WALK

Code	Question	Data and Comments			
Count number of crops per farm unit (bed / strip / pivot / field)					
701	Unit used for counting				
		Name of crop	Count units	Total PLANTED	Total FALLOW
702	add crop names as observed in the field	bare fallow			
703		weedy fallow			
704		land prepared (not planted)			
705		maize			
706					
707					
708					
709					
710					
711	**TOTAL NUMBER OF PLANTED UNITS**		**TOTAL 1**		
712	**TOTAL NUMBER OF FALLOW UNITS**		**TOTAL 2**		
713	**CROPPING INTENSITY (% cropped)**		Total 1 / (Totals 1 plus 2)		

APPENDIX 4

Scheme database used for statistical analysis

REF No.	Scheme Name	Status in 2010	Years Operated	Winter cropping intensity	Summer cropping intensity	Commercialisation index	Command Area	Plot size (Average)	Rainfall	D Market	Soil Suitability Index	Energy Source	INFRASTRUCTURE CONDITION INDEX	Water Resource Constraint Score	Conflict score	Land exchange index	Market diversity score	AGRIC. INFOR-MATION INDEX	MAIN IRRI-GATION METHOD
		0=Not operational 1=Operational	Years (integers from 0 to …)	Fraction 0 to 1	Fraction 0 to 1	Fraction 0 to 1	ha	ha	mm	km	Fraction 0 to 1 0=unsuitable 1=no limitation	0=gravity 1=pumped	Fraction 0 to 1 0=critical 1=good	Integer 1-4 1=no constraint 2=minor; 3=major; 4=critical	Integer 0-5 1=No conflict 5=Serious Conflict	Fraction 0 to 1 0=disabling 1=enabling	Integer 0-9 0=no diversity 1=high diversity	Fraction 0 to 1 0=no info 1=all info	1=surface 2=overhead 3=micro
		Var 1	Var 2	Var 3	Var 4	Var 5	Var 6	Var 7	Var 8	Var 9	Var 10	Var 11	Var 12	Var 13	Var 14	Var 15	Var 16	Var 17	Var 18
1	Nesengani	1	42	0.20	0.50	0.42	13.7	0.489	630	4	0.72	1	0.70	3	0	0.80	3	0.50	1
2	Nesengani B1	0	17				20.6	0.178	720	5	0.32	1	0.07	3					2
3	Nesengani B2	0	17				40.9	0.352	640	3.5	0.28	1	0.07	3					2
4	NesenganiC	0	17				31.2	0.238	630	4	0.39	1	0.07	3					2
5	Dzindi	1	56	0.50	0.80	0.37	136	1.335	640	7.2	0.80	0	0.56	3	1	0.32	3	0.33	1
6	Khumbe	1	56	0.20	0.60	0.70	145	1.051	850	10	0.39	0	0.50	3	2	1.00	6	0.67	1
7	Dzwerani	0	20				124	0.500	660	14	0.75	1	0.10	3	0	0.00			2
8	Palmaryville	1	59	0.50	0.90	0.90	92	1.314	700	2	0.78	0	0.35	3	3	1.00	3	0.50	1
9	Lwamondo	0	6	0.00	0.50	0.90	15	0.200	980	16	1.00	1	0.07	1	1	0.00	6	0.67	3
10	Mauluma	1	45	0.40	0.70	0.10	38	1.267	740	2	0.21	0	0.35	2	1	0.70	4	1.00	1
11	Mavhunga	1	45	0.25	0.65	0.30	47.5	1.532	730	38	0.45	0	1.00	3	0	1.00	4	0.83	1
12	Raliphaswa	1	46	0.40	0.70	0.09	15	1.154	920	43	0.96	0	1.00	3	1	0.56	1	0.83	1
13	Mandiwana	1	46	0.30	0.50	0.12	67	1.675	700	40	0.85	0	0.85	3	1	0.80	1	0.67	1
14	Mamuhohi	1	46	0.30	0.70	0.50	77	1.262	690	42	0.92	0	1.00	3	1	0.40	6	0.50	1
15	Mphaila	1	21	0.06	0.40	0.20	70.6	1.197	730	49	1.00	1	0.43	3	4	1.00	6	0.83	2
16	Luvhada	1	58	0.50	0.80	0.38	28.8	0.365	730	48.5	0.12	0	1.00	2	0	1.00	3	0.83	1
17	Rabali	1	46	0.35	0.45	0.42	87	1.279	680	40	1.00	0	1.00	3	5	0.40	1	0.67	1
18	Mphepu	1	49	0.20	0.60	0.18	132.8	0.998	720	43	0.80	0	0.35	2	2	0.80	3	0.67	1
19	Tshiombo Block 1	1	48	0.25	0.60	0.18	60.5	1.287	750	3	0.61	0	0.35	3	2	1.00	9	0.67	1
20	Tshiombo Block 1A	1	2	1.00	1.00	0.90	100	1.163	750	2.5	1.00	1	0.70	2	0	0.40	3	1.00	3
21	Tshiombo Block 1B	1	45	0.40	0.70	0.35	128.6	1.286	750	1.5	0.30	0	0.35	3	2	0.40	6	1.00	1
22	Tshiombo Block 2A	1	46	0.25	0.65	0.43	122	1.061	700	0.5	0.54	0	0.35	4	2	1.00	9	0.67	1
23	Tshiombo Block II B	1	48	0.20	0.60	0.39	126	1.286	700	0.1	0.74	0	0.35	4	1	1.00	6	0.67	1
24	Tshiombo Block III	1	45	0.30	0.60	0.51	173.5	1.522	700	1.1	0.79	0	0.56	4	2	0.80	3	0.67	1
25	Tshiombo Block IV	1	46	0.10	0.40	0.51	128.4	1.284	650	1.6	0.64	0	0.35	4	3	0.32	6	1.00	1
26	Lambani	0	4	0.00	0.40	0.00	56	0.500	530	79	0.88	1	0.09	1	2	0.00	0	0.67	2
27	Phaswana	0	8	0.01	0.01	0.90	260	16.250	550	46	0.82	1	0.07	1	0	0.00	6	1.00	3
28	Cordon A	1	45	0.50	0.80	0.00	16.7	1.044	960	45	1.00	0	0.80	2	1	1.00	1	0.50	1
29	Cordon B	1	45	0.20	0.60	0.05	43.7	1.150	920	45	0.68	0	0.50	3	2	1.00	1	0.50	1
30	Phadzima	1	45	0.20	0.60	0.05	82.3	1.266	920	45	0.88	0	0.35	3	2	1.00	1	0.50	1
31	Makuleke	1	3	1.00	1.00	0.90	342	7.953	450	84	0.91	1	0.80	1	3	0.40	3	1.00	2
32	Rambuda	1	58	0.45	0.80	0.21	102.3	0.993	750	0.5	0.98	0	0.56	2	2	0.00	4	1.00	1
33	Murara	1	42	0.30	1.00	0.27	37.3	1.286	730	12	0.70	0	0.35	3	1	1.00	3	0.67	1
34	Dopeni	1	46	0.20	0.60	0.00	170	1.288	900	44	1.00	0	0.35	3	2	1.00	3	0.67	1
35	Makhonde	0	10	0.00	1.00	0.90	70	10.000	650	36	0.70	1	0.09	1	1	0.00	3	1.00	3
36	Sanari	0	17	0.30	0.50	0.90	30	5.000	370	94	1.00	1	1.00	2	2	0.32	6	0.67	3
37	Tshikonelo	0	14			0.51	83	1.431	540	29	0.55	1	0.10	2	0	0.00	4	0.67	2
38	Chivirikani	1	28	0.60	0.80	0.60	17	1.545	500	49	0.75	1	0.70	1	1	0.56	6	0.33	2
39	Gonani	1	13	0.15	0.55	0.56	10	0.667	570	49	0.76	1	0.68	1	0	0.00	1	0.67	3
40	Folovhodwe	1	54	0.50	0.80	0.10	68.25	0.609	370	27	0.53	0	0.50	2	2	0.70	4	0.67	1
41	Klein Tshipise	1	36	0.65	0.90	0.50	8.84	0.295	370	3	0.15	0	0.68	3	1.5	0.00	1	0.67	1
42	Morgan	1	40	0.30	0.70	0.90	70	2.917	520	16	0.55	1	0.43	1	0	0.00	3	0.67	1
43	Makumeke	1	5	0.50	0.80	0.80	60	1.000	520	16	0.71	1	0.35	1	0	0.00	6	0.67	3
44	Dovheni	1	11	0.50	0.90	0.48	56.7	1.620	530	15	0.67	1	0.50	1	1	0.70	6	0.67	3
45	Mangondi	1	17	0.75	1.00	0.70	17	0.270	530	22	0.51	1	0.07	4	4	0.00	3	0.67	3
46	Xigalo	1	5	0.50	0.80	0.70	60	4.286	510	17	1.00	1	0.10	1	0	0.00	6	0.67	3
47	Garside	1	45	0.30	0.60	0.58	48	1.263	470	42	0.82	0	0.35	3	5	0.80	4	0.67	1
48	Malavuwe	1	19	0.20	0.50	0.34	22	0.917	590	30	0.70	1	0.56	1	1	0.32	3	0.83	2
49	Mapela	0	0			0.00	90	1.667	550	38	0.94	1	0.85	1	3	0.40			3
50	Sekgakgapeng	0	13	0.00	0.07	0.50	28	2.000	550	8	0.54	1	0.09	2	3	0.80	3	0.50	2
51	Success	1	55	0.10	0.25	0.81	120	1.224	510	90	0.72	0	0.10	4	2	1.00	6	0.50	1
52	Koedoeskop	0	56	0.00	0.07	0.50	114	1.152	500	95	0.85	0	0.50	4	2	0.00	2	0.33	1

REF No.	Scheme Name	Status in 2010	Years Operated	Winter cropping intensity	Summer cropping intensity	Commercialis ation index	Command Area	Plot size (Average)	Rainfall	D Market	Soil Suitability Index	Energy Source	INFRASTRUCT URE CONDITION INDEX	Water Resource Constraint Score	Conflict score	Land exchange index	Market diversity score	AGRIC. INFOR-MATION INDEX	MAIN IRRI-GATION METHOD
		0=Not operational 1=Operational	Years (integers from 0 to …)	Fraction 0 to 1	Fraction 0 to 1	Fraction 0 to 1	ha	ha	mm	km	Fraction 0 to 1 0=unsuitable 1=no limitation	0=gravity 1=pumped	Fraction 0 to 1 0=critical 1=good	Integer 1-4 1=no constraint 2=minor; 3=major; 4=critical	Integer 0-5 1=No conflict 5=Serious Conflict	Fraction 0 to 1 0=disabling 1=enabling	Integer 0-9 0=no diversity 1=high diversity	Fraction 0 to 1 0=no info 1=all info	1=surface 2=overhead 3=micro
53	Badfontein	0	22			0.90	80	0.851	460	80	0.85	1	0.07	2	3	0.40	8	0.67	2
54	Mashushu	1	49	0.15	1.00	0.62	40	0.851	700	120	0.94	0	0.50	3	0	0.32	9	0.67	1
55	Vallies	1	50	0.10	0.40	0.63	47	1.237	650	110	1.00	0	0.07	1	0	0.80	6	0.67	1
56	Adriaansdraai	0	31				90	5.000	470	80	0.53	1	0.10	2	1	0.00			2
57	Fertilis	1	52	0.30	0.60	0.62	92	1.108	640	140	1.00	0	0.35	4	0	0.32	9	0.67	1
58	Lucern	1	50	0.30	0.60	0.50	55	1.000	700	140	1.00	0	0.35	4	0	0.80	6	0.50	1
59	Grootfontein A	1	56	0.10	0.35	0.50	35	0.522	510	90	0.94	0	0.43	3	1	0.80	6	0.50	1
60	Grootfontein B	0	0			0.00	92	1.373	510	90	0.97	1	0.85	1	1	1.00	3	0.00	2
61	Homu	0	5			0.00	172	6.615	500	12	0.89	1	0.09	4	1	1.00	3	0.67	2
62	Makhuva	0	11			0.90	88	14.667	500	80	1.00	1	0.07	4	1	0.00	8	0.67	1
63	Lephaphane	1	48	0.10	0.30	0.70	42	1.500	750	35	0.70	0	0.07	3	2	0.40	2	0.17	1
64	Makgaung	1	52	0.00	0.35	0.05	71	0.645	740	15	0.54	0	0.50	4	1	1.00	1	0.00	1
65	Sofaya	1	56	0.10	0.25	0.35	156	1.000	780	12	0.85	0	0.43	3	2	1.00	1	0.83	1
66	Lorraine	1	48	0.10	0.50	0.90	40	0.400	640	5	0.94	0	0.07	4	1	1.00	6	0.33	1
67	Madeira	1	51	0.20	0.30	0.86	240	1.600	750	10	0.95	0	0.68	3	2	0.32	5	0.67	1
68	Metz	0	0			0.90	284	2.202	570	63	0.85	1	0.70	2	1	0.40	3		3
69	Solani	1	58	0.00	0.50	0.90	96	1.200	700	35	0.20	0	0.43	3	1	0.40	6	0.67	1
70	Thabina	1	61	0.30	0.50	0.90	333	2.162	650	20	0.68	0	0.43	3	2	0.32	1	0.33	1
71	Mid Letaba	0	14				1730	1.200	500	11	0.80	1	0.07	4					2
72	Tours	1	47	0.20	1.00	0.90	79	1.491	750	40	1.00	0	0.43	2	2	1.00	9	0.50	1
73	Julesburg	1	33	0.25	0.25	0.90	240	5.000	750	35	0.89	0	0.43	2	2	0.00	4	0.50	1
74	Tswelopele	1	2	1.00	1.00	0.90	410	4.881	550	35	0.97	1	1.00	2	4	0.00	3	0.67	3
75	Strydkraal A	1	3	1.00	1.00	0.88	180	1.818	470	80	0.84	1	0.85	2	1	1.00	3	0.33	3
76	Strydkraal B	0	46			0.00	113	1.256	470	80	0.87	1	0.07	2					1
77	Mooiplaats	0	44			0.00	103	1.170	470	80	0.93	1	0.07	2					1
78	Hereford	1	4	0.30	0.50	0.86	160	5.000	550	3	0.95	1	0.85	2	2	0.00	9	0.67	2
79	Phetwane	0	0				52	1.083	510	35	1.00	1	0.70	1					3
80	Setlaboswane	0	0				119	1.240	500	50	1.00	1	0.70	2					3
81	Tsatane	1	16	0.40	0.60	0.90	60	10.000	530	45	0.70	1	0.35	3	0	1.00	1	0.67	1
82	Elandsdoorn	1	31	0.05	0.05	0.70	90	1.915	550	50	0.64	0	0.07	4	2	0.40	6	0.33	1
83	Mecklenburg	1	72	0.00	0.30	0.00	116	1.487	530	60	0.91	0	0.35	4	5	0.28	0	0.67	1
84	Steelportdrift	1	38	0.50	1.00	0.90	69	1.000	580	65	0.85	0	0.68	3	1	0.49	1	0.67	1
85	Rietfontien	0	21	0.00	1.00	0.00	45	1.500	620	38	0.87	0	0.07	4	0	0.49	0	0.50	1
86	Sterkspruit	1	53	0.07	0.18	0.90	280	1.400	750	75	0.93	0	0.56	4	1	0.80	3	0.33	1
87	Boschkloof	1	35	0.05	0.05	0.50	320	1.280	550	35	0.99	0	0.35	3		0.70	6	0.33	1
88	Lepellane	0	11				340	1.498	500	80	0.48	0	0.07	4					1
89	Bono Idire	1	12	0.50	0.50	0.90	17	1.417	550	10	0.87	0	0.10	2	3	0.40	3	0.33	1
90	Montevideo	0	11				41	1.000	560	30	1.00	1	0.09	3	0	0.16			2
91	Goedvertrouend	0	7				45	1.500	530	40	0.94	1	0.09	2	1	0.00			2
92	Mogalatsane	0	0				130	1.313	510	40	0.91	1	0.68	2	0	1.00			3
93	Roodewal	0	0			0.00	30	1.000	510	30	0.88	1	0.09	1	3	1.00	3	1.00	3
94	Vlakspruit	1	53	0.10	0.60	0.80	120	1.846	520	38	0.59	0	0.80	2	1	0.16	3	0.67	1
95	Mphane	0	13				155	1.582	490	45	1.00	1	0.07	2	0	1.00			2
96	Malope	0	12				110	1.200	480	65	0.94	1	0.07	2	0	0.80			2
97	Makgwabe	0	12				66	1.200	490	58	0.94	1	0.07	2	0	0.80			2
98	Khuloane	0	10				74	1.156	460	90	0.85	1	0.07	2	0	0.80			2
99	Tswaing	0	16				102	1.244	460	90	0.85	1	0.07	2	0	0.80			2
100	Platklip	1	56	0.10	0.70	0.66	68	1.000	550	75	0.69	0	0.07	4	2	0.80	5	0.33	1
101	Wonderboom	0	14				117	1.286	450	100	0.94	1	0.07	2	0	0.80			2
102	Veeplaas	0	14				390	1.200	460	75	0.85	1	0.09	2					2