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Economics of climate change adaptation: a case study of Ceres - South Africa

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The aim of this study is to develop an integrated model that can simulate the impact of climate change on farm structure and adaptation thereof. The future sustainability of the agricultural sector relies on the type of adaptation strategy put in place for farmers to cope with the projected impacts of climate change. The Ceres Dynamic Integrated Model (CDIM) was developed to evaluate different adaptation strategies, results show that it is unlikely that high water tariffs will reduce the level of water used for production. Depending on the availability of funds to make farm dams available for farmers, access to farm dam capacity and winter water allocations as well as increasing water use efficiency are potential adaptation options for the farmers. Improved water management practices that increase the productivity of irrigation water use may provide a significant adaptation potential under future climate.

Keywords: *Climate change, Agricultural Sector, Integrated model, Adaptation*

1 Introduction

Few studies in South Africa have used integrated model to estimate the benefits and costs of avoiding climate change damages at regional level. Notable among such studies are that of Callaway *et al.* (2008 and 2009) and Louw *et al.* (2012). Callaway *et al.* (2008) developed the Berg River Dynamic Spatial Equilibrium Model (BRDSEM). BRDSEM was developed to help water policy-makers and planners to examine the physical and economic impacts of rapid population growth and climate change; to assess the physical and economic benefits and costs of structural and non-structural measures for coping with both these problems; and to estimate the economic value of the physical damages that could be avoided by these options.

The modelling framework of BRDSEM consists of three main modules; the regional climate module (downscaling global climate models), a hydrological module using the Agricultural Catchments Research Unit (ACRU) model to estimate runoff at specific locations and a dynamic programming module with three components namely: regional typical farm models to simulate the demand for agricultural water under different climate scenarios, an intertemporal spatial equilibrium model to simulate the demand for agricultural water under different scenarios and lastly an urban demand module to simulate the demand for urban water use sectors. A good feature of the model is its ability to integrate different modules in one framework. The use of the model was illustrated using three deterministic climate scenarios to examine the incremental net economic benefits of adjusting to population growth and then to climate change by increasing the maximum storage capacity in the Berg River Dam and implementing a system of efficient water markets.

Louw *et al.* (2012) used the basic features of the BRDSEM to expand and improve the modelling framework for the IDRC (International Development Research Centre) project. Amongst others the adjustment made include; improvement in the downscaling methodology, the extension of the geographical area to include the entire Berg River catchments and parts of the Breede River (where inter basin transfers exist), improvement of the farm models, development of a methodology to match representative farm model regions with the hydrological regions, improvement of the urban demand module and improvement in the interfaces between the downscaled climate models, the hydrological models and the intertemporal spatial equilibrium model. The model was applied to simulate different adaptation strategies to cope with climate change in Berg River catchment and parts of the

Breede River. Despite the improvement, Louw *et al.* (2012) concluded that there is a need for more research to increase the sensitivity of the farm models to climate change variables.

Projected increase in temperature will have effect on water availability (Mimi and Jamous, 2010) and chill unit accumulation, especially in fruit producing areas. Water resources are of more concern because changes in the water supply will affect the water availability for household use, water use in agricultural practices, and the vast industrial water demand. Climate change will impact upon the availability of water resources for agriculture in the future through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales. Both the demand for and supply of water for irrigation will be affected by changes in the hydrological regimes. There will be concomitant increases in future competition for water with non-agricultural users owing to population and economic growth (Strzepek *et al.*, 1999). As such, adaptation measures need to be devised to help farmers cope with the projected impact of climate change. Some of the available adaptation options available for the farmers are; provision of farm dam with water rights, using water efficiently as well as increase in water tariff.

In addition to the impact on water supply, climate change is also expected to affect future winter chill and thus could have a major impact on the fruit species with chilling requirements (FAOSTAT, 2009). Rising temperatures over the next 30 years will have an impact on crop yield because of the impacts of temperatures that are above optimal during the pollination stage in all crops (FAO, 2011). Occurrences of these temperatures will cause yield reductions which could be further decreased by shortages of water required for optimal plant growth. These effects will be noticeable in grain, forage, fibre, and fruit crops. Various fruit trees must fulfil a chilling requirement to break their winter dormancy and resume growth in spring (Luedeling and Brown, 2010). Insufficient winter chill can severely affect fruit yields and fruit quality when chilling requirements are not fulfilled (Dennis, 2003). When chilling requirements are not completely fulfilled, trees display irregular and temporally spread out flowering, leading to inhomogeneous crop development (Luedeling *et al.*, 2009). This process eventually results in altering fruit sizes and maturity stages at the time of harvest, which can substantially reduce yield amount and value (Saure, 1985). Otherwise, farmers will rely on the use of artificial rest breaking chemicals in cases of low accumulation. This will increase the production costs and hence have an impact on the profitability of such enterprise.

In order to incorporate the impacts of future crop water requirement and chill unit, two additional modules, namely the crop water module and chill unit accumulation module, were integrated with the models devised by Callaway *et al.* (2008) and Louw *et al.* (2012) to form the Ceres Dynamic Integrated Model (CDIM). The aim of this study is to develop an integrated model that can simulate the impact of climate change on farm structure (crop combination, water use and welfare of the farmers). In addition to this, the model will be applied to evaluate the impact of different adaptation strategies to climate change on the agricultural sectors of Ceres, in Western Cape South Africa.

2. Study area and methodology

2.1 Study area

Ceres is a town with about 46251 inhabitants in the Western Cape Province of South Africa. Ceres is the administrative centre of the Witzenberg Local Municipality and it lies 130 kilometres to the north-east of Cape Town. It is an important agricultural town surrounded by affluent export-oriented fruit farmers. It is one of the largest deciduous fruit and vegetable producing districts in South Africa. Fresh fruit produced in Ceres is marketed both locally and internationally, as well as other products such as fruit juices, dried fruit, potatoes and onions, just to mention a few. Major crops include apples, pears, peaches, and to a lesser extent, grapes, plums, nectarines, cherries, and for good measure, potatoes and onions. Ceres produces large quantities of fruit juices (the local juicing plant is the largest in the country).

2.2 The Model

CDIM is an optimisation model that maximises the economic value of the net returns to water from urban and agricultural water users on a monthly basis over time. The runoff nodes, storage and farm reservoirs and water diversions are linked together by spatially differentiated flows consistent with basin hydrology. The model also maintains dynamic storage balances in all reservoirs. Urban water demand is characterised by monthly demand functions. Monthly runoff, reservoir evaporation and crop water use estimates in the optimisation model were linked directly to a spatially-differentiated water balance model that is, in turn, linked to a model that downscale climate data from Global Climate Model (GCM) scenarios to the regional level.

The schematic representation of the model is presented in Figure 1.

(Figure 1 here)

The modelling framework consists of five modules. These are:

- The regional climate change module – downscaling Global Climate Models (GCM's). Statistical downscaling utilises statistical methods to approximate the regional scale response to the large scale forcing. Various methods have been developed, including the SOMD (Self Organising Map based Downscaling) developed at the University of Cape Town which was used in this study. Details of the method can be found in Hewitson and Crane (2006). Downscaled climate data on rainfall and temperature was fed into the ACRU Model.
- A hydrological module. Using the *ACRU* model to estimate incremental runoff at specific locations within the study area. The output data from ACRU (evaporation coefficients and runoff) is then used as input into the dynamic spatial equilibrium model with embedded regional dynamic linear programming farm models to simulate the demand of agricultural water and urban water demand functions to simulate the demand for urban water
- A dynamic programming module with three components:
 - The farm model has data from representative farms to simulate the demand for agricultural water under different climate regimes (scenarios). These farmers are the farmers linked to the “Koekedouw” irrigation scheme in the Ceres district. Farm data was obtained through farm survey.
 - An intertemporal spatial equilibrium model to simulate the bulk water infrastructure
 - An urban demand module to simulate the demand for urban water use sectors. Urban water demand time series data was obtained from the Cape Town Water Utility and used to construct quadratic demand functions for the urban sector.
- SAPWAT3 (van Heerden *et al.*, 2008) was used to estimate crop water requirements for the base climate (1971-1990) and for the future climate (2046-2065). An artificial weather station was built into SAPWAT to calculate crop water requirements for the future because SAPWAT does not have information about the future climate. SAPWAT is founded on internationally accepted principles of estimating crop water requirements (FAO-56, Allan, Pereira, Raes and Smith, 1998) and is regarded as the standard in estimating crop water requirements in South Africa. As a result, the user

base is large. Furthermore, government also sees it as a tool to benchmark lawful water use under the National Water Act (Act 56 of 1998). Secondly, it is easy to use the model because it is supplied with weather data and a unique set of crop parameters that is specific to South Africa (Grove (2007). In addition to this, the crop varieties database in SAPWAT is extensive and it has provision for tree and deciduous crops which is not common in other models. SAPWAT uses the Koppen climate system (Koppen 1931; Strahler & Stralher 2002) for calculating crop coefficients and will therefore make it widely acceptable (Singels *et al.*, 2010).

- The Utah model of Richardson *et al.* (1974) and the Daily positive Utah (Infruitec) chill unit accumulation model of Linsley-Noakes *et al.* (1994) are used to estimate the chill unit requirements for various fruit crops planted in Ceres. These are the commonly used models in South Africa. The Richardson and Infuitec models accumulate the same way, with the exception that the Infruitec model does not allow one to lose units when the temperature exceeds 16°C once these units have been “banked” by not being forfeited within the first 24 hours after accumulation.

The last two modules, namely SAPWAT (crop water estimation model) and the chill unit accumulation model are the major improvement made to the BRDSEM model developed by Callaway *et al.* (2008).

The objective function of the model is to maximise the net present value of the economic returns to water.

The objective function is specified as:

$$MaxZ = \sum_{g,m,ph} dconst_{g,m} * URBDEM_{g,m,ph} + \frac{1}{2} dslope_{ph,g,m} * sqr(URBDEM_{g,m,ph}) + \sum_b ENDB_b - \sum_{dams,m,ph} FLOWBY_{dams,m,ph} - \sum_{ea,m,ph} FDFLOWBY_{ea,m,ph}$$

Where:

$dconst_{g,m} * URBDEM_{g,m,ph} + \frac{1}{2} dslope_{ph,g,m} * sqr(URBDEM_{g,m,ph})$ represents the willingness-to-pay for water;

$ENDB_p$ is the end balance after redemption of loans;

$FLOWBY_{dams,m,ph}$ and $FDFLOWBY_{ea,m,ph}$ represents dam spill and farm dam spill, respectively.

The model maximises an economic objective function, subject to constraints. As such, it simulates how water users would behave if they jointly maximise the net returns to water through actions under their control.

2.3. Climate projections and emissions scenarios

The climate projections and associated emissions scenarios that were developed by The Climate System Analysis Group at the University of Cape Town (CSAG) and applied in hydrological modelling are given in Table 1. The projections were available at a daily level for rainfall as well as for maximum and minimum temperatures.

(Table 1 here)

The University of Cape Town (UCT) climate projections are a regional downscaling of global projections derived from five IPCC coupled General Circulation Models (GCMs), namely, CGCM3.1(T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 (the GISS-ER projections were later excluded owing to errors in the source GCM data). The climate projections applied in hydrological modelling were limited to a “High” (ECHAM5/MPI-OM) and “Low” (IPSL-CM4) GCM (based on projected changes in annual rainfall) to limit the number of hydrological and economic simulations to a manageable level. The present period selected for hydrological and economic modelling was shortened to 20 years (from the number of years available in the climate projections) to ensure that the present and distant future periods were of the same length (for comparison purposes).

3. Results and discussion

Firstly, the CDIM model is used to determine the impact of climate change on the base climate (present and future). Based on the changes observed in the future, the model is used to simulate the impact of different adaptation strategies. Results will be presented under the following headings, namely; the impact of climate change on area (crop combinations), water use (crop water use), and welfare (Total welfare).

3.1. Comparisons of base climate change scenarios from the CDIM model.

Impact of climate change on area: The integrated framework (CDIM Model) developed in this study has different dimensions of outputs that relate to both the agricultural and the urban sectors. For the sake of clarity, the focus of the discussion in this study will be on the agricultural sector. Results will be presented under the following headings: the impact of climate change on area (crop combinations) and water use (agricultural water demand and crop water use).

Table 2 shows the change in crop combinations for the base scenarios.

(Table 2 here)

The average was calculated over a 20 year planning horizon. The general trend is the substitution of high valued crops (fruits) with vegetables and annual crops in the future scenarios. For instance, Table 2 shows a reduction in the average area cultivated for apples, nectarines, peaches, wine grapes, and an increase in the cultivated area for onions, cabbage, cauliflower, beetroot, etc. This substitution might be the result of water shortage leading to less land being irrigated; the irrigated area declined by 15.7%.

The shares of different crops changes; fruits from 85.5% to 82.1%; vegetables from 10.3% to 15.4%; pastures from 1.8% to 1.6% and cereals 2.4% to 1.9%. As water becomes scarcer relative to other inputs (mainly land), then it becomes more important to have higher returns to water than to other inputs. The emphasis therefore turns to get the best returns to water, rather o land (under assumption that capital or labour isn't more limiting than water or land). Therefore crops yielding better return to the decreased water availability and also less sensitive to accumulated chill units are preferable. However, good management practices and rest breaking chemicals are available to help crops meet the chill requirement, albeit at a cost. Increases in temperature will indeed have impact on deciduous fruit production in the future. The changes in cropping practices are expected to affect water use and welfare of the farmers. The effect of these changes on water use and welfare is presented next.

Impact of climate change on water use: The average annual water use per hectare is shown in Table 2. With climate change (increase in temperature) projected in the future, more water is expected to be used by crops because of the increased evaporation and evapo-transpiration that can accompany increases in temperature. On average, about 259m³ more water per

hectare will be used in the future, an indication that necessary action/plans need to be put in place in order to adapt agriculture to this expected change to ensure sustainability of the sector in the Ceres region.

Impact of climate change on welfare: Table 2 shows that total welfare (objective function value) for the base period is R1 305 million while that for the future period is R1 336 million. The increase in welfare can largely be attributed to the rational behaviour of farmers by concentrating more on crops with higher returns on the scarce resource (water).

Ultimately, the findings show that a substantial change can be expected in the profile of the farming community in Ceres. The typical crops currently cultivated will have to be replaced by crops yielding better returns to the decreased water availability and also less sensitive to accumulated chill unit. On a positive note, however, the changes seem to lead to an increase in welfare. With adaptations in the farm structure and welfare of the farmers can be improved. It is therefore important to evaluate what will be the impact of different adaptation strategies.

3.2. Climate change adaptation scenario

The impact of climate change has resulted in changes in area, water use and welfare of the farmers in the future climate. The future sustainability of the agricultural sector in the Ceres region of Western Cape relies greatly on the type of adaptation strategy to be put in place by and for the farmers to cope with the projected impact of climate change. Three sets of adaptation strategies namely; the availability of farm dams and water rights, improving water use efficiency, and increases in water tariffs are evaluated in order to help the farmers cope with climate change. Table 3 presents the various adaptation scenarios tested using the CDIM model. The scenarios were selected based on focus group discussion with contribution from the farmers, Non-Governmental Organizations (NGO's) and other interested parties.

(Table 3 here)

Irrigation water plays a crucial role in the production of fruits, vegetables and grains in the Ceres region. The emerging farmers in this area do not have access to on-farm storage (farm dam) facilities to store water for use and hence they enjoy no winter water rights (water release for irrigation during winter months). Using scenarios 1 to 5 in Table 3, we examine how the welfare of the farmers can be improved through the provision of farm dam storage

and allocation of water rights. The potential impact of giving farmers farm storage facilities, with and without water rights, is first considered, and then an increase in water rights to the farmers follows. The second adaptation option to climate change is where water is used more efficiently. Here, water use efficiency is increased by 10 %, 20 % and 30 % in Scenarios 6, 7, 8, respectively as shown in Table 3. Lastly, we investigated increases in water tariffs by 10 %, 20 % and 30 %, as an adaptation option to climate change, in Scenarios 9, 10 and 11, respectively. An increase in water tariffs is hypothesised to reduce water usage and also encourage farmers to use water economically. The results of the adaptation scenarios are presented next in terms of the impact on area, water use and welfare of the farming system.

3.2.1 Farm dam and winter water right adaptation scenario

Impact on area: Table 4 shows the changes in crop combination relative to the base, considering different options from Scenario 1 through to Scenario 5. Table 4 shows that in Scenario 1, where farmers are given farm dam capacity without giving them winter water allocation, farming operations will not improve. There are no changes between the base and Scenario 1 results. This means that making a farm dam supply available to farmers without the ability to extract such water for usage is of no benefit to the farmers. A capital-intensive project, such as dam construction, will be of little or no value if the farmers are not also awarded the required winter water rights to allow them to irrigate during winter months. Table 4 shows that in the remaining four scenarios the area under fruit production would increase, as will the area under vegetable production. More specifically, the area under pears and nectarines will increase if farmers have farm dam capacity and legal access to winter water. Areas under pears will increase to 246ha in Scenario 5, compared to 235ha in the base. Areas under onions and cauliflower also increase from 142ha to 147ha and 58ha to 67ha, respectively, under these scenarios. This is an indication that farm dam capacity accompanied by winter water rights will help the farmers adapt to the projected climate change impact.

(Table 4 here)

Impact on water use: Table 4 shows increases in agricultural water use: as more water is made available, the farmers respond by irrigating more. Table 4 shows that more water is used in Scenarios 2, 3, 4 and 5, whereby farmers are given access to farm dam capacity and winter water allocation rights. Farm dam capacity without winter water rights (Scenario 1)

shows no deviation from the base. This also confirms the fact that farm dam capacity without extraction rights will not be of benefit in improving the welfare of the farmers. Crop water use increased by approximately 51 m³ per ha for all the scenarios, except Scenario 1, where it remains constant, and in Scenario 4 where it was 45 m³ per ha. The increase can be attributed to structural changes and higher temperatures which result in an increase in the crop water use requirements.

Impact on welfare: Table 4 shows the changes in the objective function as a result of provision of farm dam capacity and winter water allocation to the farmers. The results indicate that with the exception of Scenario 1, farm dam availability and winter water allocation will be beneficial for all the farmers. The objective function increased at an average of R17 million from the base.

3.2.2 Water use efficiency adaptation scenario

Impact on Area: Table 5 shows the crop combination when water is used more efficiently. The area under fruit production increased, as did the area under vegetable production. More particularly, the area under pears increased from 235 ha in the base to 240, 242 and 246 ha, respectively, in Scenarios 6, 7 and 8. The areas under onions and cauliflower also increased, as can be seen in Table 5. The analysis shows that using water more efficiently will allow the farmers to save water and hence achieve a more profitable level of optimal irrigation. This is an indication that efficient water usage as an adaptation strategy will translate to an increase in the cultivation of high value crops.

(Table 5 here)

Impact on water use: The annual average crop water use is presented in Table 5. The table also shows a reduction in annual water usage compared to the base scenario. Crop water use decreased by approximately 391 m³, 850 m³ and 1 321 m³ per ha, respectively. Corresponding to 10%, 20% and 30% increases in water use efficiency. The decreases can be attributed to a more efficient water use strategy by the farmers, thus making more water available to put more area under irrigation and for converting crops from deficit irrigation to optimal irrigation, especially fruit crops that need to be irrigated optimally for good harvest.

Impact on welfare: Table 5 shows the changes in objective function as a result of the increase in water use efficiency by the farmers. The results indicate that efficient water usage can substantially improve the welfare of the farmers. The objective function increased by an

average of R11 million compared to the base. Accordingly, using water more efficiently could be a favourable adaptation strategy to improve the welfare of the farmers in the Ceres region of the Western Cape.

In the light of climate change, improving irrigation efficiency would be a plausible adaptive strategy. This could be achieved through the reduction of water leakages, changing to a more efficient irrigation system, irrigating during the night rather than day, the use of less thirsty crop cultivars and better water use monitoring.

3.2.3 Increase in water tariffs adaptation scenario

Impact on area: Table 6 shows the crop combinations when water tariffs are increased. Table 6 shows that the increase in water tariffs would not change the existing crop combination from the base. Instead of removing productive land from production, the farmers maintained the status quo by paying more for water to maintain the farm structure. However, a slight increase in area under pears was observed but this dropped back to 233ha in Scenario 11 because the increment cannot be sustained. The analysis above is an indication that increasing the water tariffs is not a favourable adaptation strategy for the farmers in Ceres.

(Table 6 here)

Impact on water use: The annual average crop water use is presented in Table 6. Table 6 shows a decrease in average annual water usage as tariffs increase. Crop water use decreased by approximately 6 m^3 , 10 m^3 and 15 m^3 per ha, respectively, for 10%, 20% and 30% increases in water tariffs. The decrease is the result of farmers cutting down on the expenses for water in the production cycle as a result of the increase in the costs of irrigation water. Such an adaptation strategy could impact negatively on the volume of production because water is an important input in the farming system. Despite decreases in per hectare usage of water, the total water usage remained the same.

Impact on welfare: Table 6 shows the changes in the value of objective function as a result of increases in water tariffs. The results indicate that increases in water tariffs reduce the welfare of the farmers. The objective function decreased by an average of R1 million compared to the base. The increase in water tariffs scenario is found not to improve the welfare of the farmers.

4. Conclusion

The integrated model developed in this study provided a framework for evaluating and making adaptation decisions related to agriculture. The results confirmed that the model developed in this study can be successfully used to simulate various climate change adaptation scenarios, and that the results correspond with what can be expected from the farming systems. Based on the application of the model to Ceres in Western Cape, South Africa, conclusions and recommendations can be made.

The irrigation demand for water is inelastic and it is unlikely that high water tariffs will reduce the level of water used for production. Depending on the availability of funds to make farm dams available for emerging farmers, increasing access to farm dam capacity and winter water allocations seems to be a good adaptation strategy from the analysis presented in this study. Increasing water use efficiency as an adaptation option, according to the analysis carried out in this study, is also a good adaptation option for the farmers. Improved water management practices that increase the productivity of irrigation water use may provide a significant adaptation potential under future climate change

The Government can play a major role in supporting farmers and businesses to overcome some of barriers that can emanate as a result of changing climate by creating an environment conducive to the appropriate adaptation decisions. Evidence on our level of adaptation to

current climate and the existence of barriers to adaptation demonstrates that self-interest will not always be sufficient, particularly as climate change will be much more rapid than previously experienced. For instance, in this study giving farmers farm dam capacity alone will not improve the situation of the farmers according to the analysis done.

However, caution should be taken when considering such an adaptation option. It is important to state that farm dam is a capital intensive infrastructure and if the farm dams don't fill up, it may worsen the situation of farmers since the high capital cost and resulting high unit cost of farm dam water will increase their financial vulnerability. Although the article was able to confirm what the impact of such adaptation strategy will be on the welfare of the farmer, a further analysis in terms of the benefit and cost of considering a dam as an adaptation option should be done to justify the usage of public funds.

Using water more efficiently improved the welfare of the farmers and also saved water for optimal irrigation usage. It can be referred to as a “no-regret” climate change adaptation option and could potentially make a substantial contribution towards increasing the water supply in the study region. Improvement in irrigation efficiency is crucial in ensuring the availability of water, both for food production and competing human and environmental needs. The findings from this adaptation scenario justify the investment that has been made by organisations such as the International Water Management Research Institute, Water Research Commission (WRC) South Africa, and Food and Agriculture Organization to mention a few, towards water use efficiency. Overall, a change in the profile can be expected as a result of climate change and adaptation thereto. Given the role of agriculture and the contribution of Western Cape to the South African balance of payments in terms of exports, adaptation that will improve the welfare of the farmers should be considered. In conclusion, Water resources management strategy is thus important in ensuring that agricultural production can withstand the stresses caused by climate change. Therefore, farmers must be equipped with a collection of management or adaptation tools to overcome climatic differences.

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Tables and Figures

Figure 1: Ceres Dynamic Integrated Model (CDIM) Schematic Diagram

Source: Developed from Callaway *et al.* (2008) and Louw *et al.* (2012)

Table 1: Summary of climate projections applied in hydrological modelling based on A2 (an emissions scenario that assumes continued increases in heat-trapping gases) emissions scenarios

Period	UCT
Present (1971 - 1990)	IPSL-CM4 ("Low") ECHAM5/MPI-OM ("High")
Distant future (2046 - 2065)	IPSL-CM4 ("Low") ECHAM5/MPI-OM ("High")

Source: Louw *et al.* (2012).

Table 2: Impact of Climate change – Base comparison

Impact of Crops (Ha)	IPSL-CMA Base (Present)	IPSL-CMA Base (Future)
Fruits		
Apples	9.7	4.9
Apricots	3.0	1.5
Pears	219.5	235.0
Nectarine	22.3	12.6
Peaches	117.0	58.5
Wwine	5.9	2.9
Plums	30.5	15.3
Total	407.9	330.7
Vegetables		
Potatoes	0.2	0.3
Tomatoes	0.2	0.4
Onions	96.8	142.4
Cabbage	51.1	74.1
Cauliflower	37.8	58.2
Carrots	0.1	0.1
Peas	0.4	0.6
Pumpkin	0.2	0.2
Squash	0.1	0.1
Butternuts	1.2	1.8
Lettuce	0.0	0.0
Spinach	0.1	0.0
Beetroot	47.7	60.1
Sweet melon	0.0	0.0
Total	49.3	62.2
Pastures		
LTPast	0.0	0.0
Lucerne	8.8	2.4
Total	8.8	2.4
Cereals		
Korog	0.0	0.0
Oats	0.4	0.5
Wheat	4.6	2.4
Maize	1.5	2.0
Barley	5.2	2.7
Total	11.7	7.6
Impact of climate change on water use		
Water use (m ³ per Ha)	4492.1	4750.8
Impact of climate change welfare		
Welfare (Million Rand)	1304.5	1336.2

Table 3: Climate change adaptation scenarios

Scenario	Explanation
Scenario 1	Farm dam capacity for emerging farmers, no winter water rights.
Scenario 2	Farm dam capacity for emerging farmers, with winter water rights
Scenario 3	20 % increase in farm dam capacity for emerging farmers, winter water right allocation
Scenario 4	20 % increase in farm dam capacity for emerging farmers, winter water right allocation increased by 20 %.
Scenario 5	30 % increase in farm dam capacity for emerging farmers, winter water right allocation increased by 30 %.
Scenario 6	10% increase in water use efficiency
Scenario 7	20% increase in water use efficiency
Scenario 8	30% increase in water use efficiency
Scenario 9	10% increase in water tariff
Scenario 10	20% increase in water tariff
Scenario 11	30% increase in water tariff

Table 4: Farm dam and winter water right adaptation scenario

Crops(Ha)	IPSL-CMA Base (Future)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Fruits						
Apples	4.9	4.9	4.9	4.9	4.9	4.9
Apricots	1.5	1.5	1.5	1.5	1.5	1.5
Pears	235.0	235.0	245.8	245.8	245.8	245.9
Nectarine	12.6	12.6	13.1	13.1	14.0	14.1
Peach	58.5	58.5	58.5	58.5	58.5	58.5
Wwine	2.9	2.9	2.9	2.9	2.9	2.9
Plums	15.3	15.3	15.3	15.3	15.3	15.3
Total	330.7	330.7	342.0	342.0	342.9	343.1
Vegetables						
Potatoes	0.3	0.3	0.3	0.3	0.3	0.3
Tomatoes	0.4	0.4	0.4	0.4	0.4	0.4
Onions	142.4	142.4	146.9	146.9	146.9	146.9
Cabbage	74.1	74.1	72.6	72.6	71.9	71.7
Cauliflower	58.2	58.2	65.5	65.5	67.5	67.3
Carrots	0.1	0.1	0.1	0.1	0.1	0.1
Peas	0.6	0.6	0.6	0.6	0.6	0.6
Pumpkin	0.2	0.2	0.2	0.2	0.2	0.2
Squash	0.1	0.1	0.1	0.1	0.1	0.1
Butternuts	1.8	1.8	1.8	1.8	1.8	1.8
Lettuce	0.0	0.0	0.0	0.0	0.0	0.0
Spinach	0.0	0.0	0.0	0.0	0.0	0.0
Beetroot	60.1	60.1	63.3	63.3	64.8	64.9
Sweet melon	0.0	0.0	0.0	0.0	0.0	0.0
Total	338.3	338.3	351.8	351.8	354.6	354.3
Pastures						
LTPast	0.0	0.0	0.0	0.0	0.0	0.0
Lucerne	2.4	2.4	3.0	3.0	3.1	3.1
Total	2.4	2.4	3.0	3.0	3.1	3.1
Cereals						
Korog	0.0	0.0	0.0	0.0	0.0	0.0
Oats	0.5	0.5	0.5	0.5	0.5	0.5
Wheat	2.4	2.4	2.4	2.4	2.4	2.4
Maize	2.0	2.0	2.0	2.0	2.0	2.0
Barley	2.7	2.7	2.7	2.7	2.7	2.7
Total	7.6	7.6	7.6	7.6	7.6	7.6
Impact of climate change on water use						
Water use (m ³ per Ha)	4750.8	4750.8	4802	4802	4795.9	4804.1
Impact of climate change welfare						
Welfare (Million Rand)	1336.4	1336.3	1352.7	1352.7	1354.2	1354.4

Table 5: Water use efficiency adaptation scenario

Crops	IPSL-CMA Base (Future)	Scenario 6	Scenario 7	Scenario 8
Fruits				
Apples	4.9	4.9	4.9	4.9
Apricots	1.5	1.5	1.5	1.5
Pears	235.0	239.6	242.3	246.0
Nectarine	12.6	12.4	13.0	12.8
Peaches	58.5	58.5	58.5	58.5
Wwine	2.9	2.9	2.9	2.9
Plums	15.3	15.3	15.3	15.3
Total	330.7	335.1	338.4	341.9
Vegetables				
Potatoes	0.3	0.3	0.3	0.3
Tomatoes	0.4	0.4	0.4	0.4
Onions	142.4	144.3	146.8	146.9
Cabbage	74.1	72.7	71.9	71.7
Cauliflower	58.2	60.3	60.0	64.4
Carrots	0.1	0.1	0.1	0.1
Peas	0.6	0.6	0.6	0.6
Pumpkin	0.2	0.2	0.2	0.2
Squash	0.1	0.1	0.1	0.1
Butternuts	1.8	1.8	1.8	1.8
Lettuce	0.0	0.0	0.0	0.0
Spinach	0.1	0.0	0.1	0.0
Beetroot	60.1	66.2	67.1	68.2
Sweet melon	0.0	0.0	0.0	0.0
Total	338.4	347.0	349.4	354.7
Pastures				
LTPast	0.0	0.0	0.0	0.0
Lucerne	2.4	2.6	2.8	3.0
Total	2.4	2.6	2.8	3.0
Cereals				
Korog	0.0	0.0	0.0	0.0
Oats	0.5	0.5	0.5	0.5
Wheat	2.4	2.4	2.4	2.4
Maize	2.0	2.0	2.0	2.0
Barley	2.7	2.7	2.7	2.7
Total	7.6	7.6	7.6	7.6
Impact of climate change on water use				
Water use (m ³ per Ha)	4750.8	4360.0	3901.2	3429.7
Impact of climate change Welfare				
Welfare (Million Rand)	1336.4	1342.5	1347.0	1351.6

Table 6: Increase in water tariffs adaptation scenario

Crops	IPSL-CMA Base (Future)	Scenario 9	Scenario 10	Scenario 11
Fruits				
Apples	4.9	4.9	4.9	4.9
Apricots	1.5	1.5	1.5	1.5
Pears	235.0	234.5	234.1	233.6
Nectarine	12.6	12.7	12.8	12.9
Peaches	58.5	58.5	58.5	58.5
Wwine	2.9	2.9	2.9	2.9
Plums	15.3	15.3	15.3	15.3
Total	330.7	330.3	330.0	329.6
Vegetables				
Potatoes	0.3	0.3	0.3	0.3
Tomatoes	0.4	0.4	0.4	0.4
Onions	142.4	142.4	142.4	142.4
Cabbage	74.1	74.5	75.0	75.4
Cauliflower	58.2	58.5	58.8	59.2
Carrots	0.1	0.1	0.1	0.1
Peas	0.6	0.6	0.6	0.6
Pumpkin	0.2	0.2	0.2	0.2
Squash	0.1	0.1	0.1	0.1
Butternuts	1.8	1.8	1.8	1.8
Lettuce	0.0	0.0	0.0	0.0
Spinach	0.0	0.0	0.0	0.0
Beetroot	60.1	60.3	60.5	60.7
Sweet melon	0.0	0.0	0.0	0.0
Total	338.3	339.2	340.2	341.2
Pastures				
LTPast	0.0	0.0	0.0	0.0
Lucerne	2.4	2.4	2.4	2.4
Total	2.4	2.4	2.4	2.4
Cereals				
Korog	0.0	0.0	0.0	0.0
Oats	0.5	0.5	0.5	0.5
Wheat	2.4	2.4	2.4	2.4
Maize	2.0	2.0	2.0	2.0
Barley	2.7	2.7	2.7	2.7
Total	7.6	7.6	7.6	7.6
Impact of climate change on water use				
Water use (m ³ per Ha)	4750.8	4745.1	4740.5	4735.8
Impact of climate change Welfare				
Welfare (Million Rand)	1336.4	1336.0	1335.7	1335.4