

**MULTI-DIMENSIONAL MODELS FOR THE
SUSTAINABLE MANAGEMENT OF WATER
QUANTITY AND QUALITY IN THE ORANGE-
VAAL-RIET CONVERGENCE SYSTEM**

**MF Viljoen • RJ Armour • JL Oberholzer •
M Grosskopf • B van der Merwe • G Pienaar**

WRC Report No. 1352/1/06



Water Research Commission



MULTI-DIMENSIONAL MODELS FOR THE SUSTAINABLE MANAGEMENT OF WATER QUANTITY AND QUALITY IN THE ORANGE- VAAL-RIET CONVERGENCE SYSTEM

By

M.F. Viljoen and R.J. Armour

UNIVERSITY OF THE FREE STATE

J.L. Oberholzer, M. Grosskopf †, B. van der Merwe and G. Pienaar

URBAN ECON

FINAL REPORT

for the

Water Research Commission

August 2006

Project leader: **M.F.VILJOEN**

Department of Agricultural Economics

UNIVERSITY OF THE FREE STATE

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and titled:

MULTI-DIMENSIONAL MODELS FOR THE SUSTAINABLE MANAGEMENT OF WATER QUANTITY AND QUALITY WITH REFERENCE TO THE ORANGE-VAAL-RIET CONVERGENCE SYSTEM.

The Reference Group responsible for this project, consisted of the following persons:

Dr GR Backeberg	Water Research Commission (Chairman)
Mr HM du Plessis	Water Research Commission
Prof MF Viljoen	Department of Agricultural Economics, University of the Free State
Prof LK Oosthuizen	Department of Agricultural Economics, University of the Free State
Dr JL Oberholzer	Urban-Econ, Pretoria
Prof JG Annandale	University of Pretoria
Prof SA Lorenz	University of Natal
Dr J van der Merwe	Department of Water Affairs and Forestry, Bloemfontein
Mr JJ Janse van Rensburg	Free State Department of Agriculture, Bloemfontein
Mr LB Terblanche	Northern Cape Department of Agriculture, Upington
Mr WF Bruwer	Orange-Vaal Water Users Association, Douglas
Mr AJ van Bergen	Orange-Vaal Water Users Association, Douglas
Mr B Grové	Department of Agricultural Economics, University of the Free State
Mr JF Taljaard	Minute's keeper
Mrs G Kruger	Water Research Commission (Co-ordinator: Committee Services)

Additional Reference Group members:

Mr SF Rademeyer	Department of Water Affairs and Forestry, Pretoria
Mr N Knoetze	Orange-Riet Water Users Association, Jacobsdal
Mr D Haarhoff	GWK Ltd., Douglas

Additional project members:

Prof CC du Preez	Department of Soil Science, University of the Free State
Dr B Usher	Institute for Groundwater Studies, University of the Free State

The financing of the project by the Water Research Commission, additional financial support by the Department of Water Affairs and Forestry and the University of the Free State, and the contribution of the members of the Reference Group is gratefully acknowledged. The astute management by Dr GR Backeberg and valuable input by Mr HM du Plessis is greatly appreciated. This project was only possible with the co-operation of many individuals and institutions. The authors therefore wish to record their sincere thanks to persons who directly or indirectly contributed to this research. Especially researchers who worked with the research team for a period of time, namely UFS researcher, Keneilwe Nailana and Urban Econ researcher, Litha Sapula, and the WRP Consultants who did the hydrology analysis, Pieter van Rooyen and Susan Swart. This report is also dedicated to Martin Grosskopf who tragically passed away after initiating the regional economic level modelling work.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	I
LIST OF TABLES.....	IX
LIST OF FIGURES	XII
ACRONYMS, TERMS AND DEFINITIONS	XVI
EXECUTIVE SUMMARY	XVIII
 CHAPTER 1. INTRODUCTION	 1
1.1. BACKGROUND	1
1.2. PROBLEM STATEMENT.....	3
1.2.1. SUB-PROBLEMS	3
1.2.2. HYPOTHESES	4
1.3. PROJECT AIMS.....	4
1.3.1. RESEARCH PRODUCTS AND TARGET GROUPS.....	5
1.4. APPROACH / METHOD FOLLOWED	6
1.4.1. ORIENTATION	6
1.4.2. MULTI-DIMENSIONAL BACKGROUND RESEARCH (LITERATURE STUDY).....	6
1.4.3. INTEGRATED CONCEPTUAL FRAMEWORK	7
1.4.4. MODEL DESIGN	7
1.4.5. DATA COLLECTION	7
1.4.6. ANALYSIS	7
1.4.7. MANAGEMENT POLICY RECOMMENDATIONS	8
1.5. SUMMARY	8
1.6. REPORT LAYOUT	8
 CHAPTER 2. THE STUDY AREA	 10
2.1. INTRODUCTION	10
2.2. GEOGRAPHY	10
2.3. TOPOGRAPHY	11
2.3.1. HYDROLOGY	11
2.4. CLIMATE.....	13
2.5. DEMARCATION OF THE STUDY AREA.....	13
2.5.1. REGIONAL DELINEATION	13
2.5.2. WUA DELINEATION.....	14
2.5.3. IRRIGATION BLOCK DELINEATION.....	18
2.5.4. PER HECTARE DELINEATION	21
2.6. HYDROLOGY DYNAMICS	22
2.6.1. SOURCE OF IRRIGATION WATER AND SALT CONCENTRATION	23
2.6.2. WET AND DRY RAINFALL CYCLES	23
2.6.3. FLOODING EVENTS.....	23
2.6.4. CHANGES IN POLICY REGARDING WATER ALLOCATION AND WATER USE CHARGES	24
2.6.5. ECONOMIC / POLITICAL BOUNDARIES	24
2.7. ECONOMIC ACTIVITIES	25
2.7.1. COMPOSITION OF GGP	25
2.7.2. AGRICULTURE	25
2.7.3. INFRASTRUCTURE	26

2.8. SUMMARY	27

CHAPTER 3. AN INTRODUCTION TO THE INTEGRATED MODEL FRAMEWORK 28

3.1. INTRODUCTION	28
3.1.1. A BRIEF MOTIVATION FROM THE LITERATURE	28
3.1.2. AIMS OF THE INTEGRATED MODEL	29
3.2. MAIN COMPONENTS OF THE INTEGRATED MODEL	29
3.3. SCENARIO SETUP PROCESS	30
3.3.1. SETUP DATA	30
3.3.2. SPATIAL AND TEMPORAL DIMENSIONS	32
3.3.3. LINKAGES	32
3.4. INPUT DATA PROCESSING	32
3.4.1. SETUP DATA	32
3.4.2. SPATIAL AND TEMPORAL DIMENSIONS	32
3.4.3. LINKAGES	32
3.5. MODEL FILES	33
3.5.1. HYDROLOGY MODEL	33
3.5.2. BIO-PHYSICAL SUB-COMPONENTS	33
3.5.3. MICRO ECONOMIC MODEL	34
3.5.4. REGIONAL ECONOMIC MODEL (MACRO-ECONOMIC LEVEL)	34
3.6. OUTPUT DATA AND RESULTS FILES	35
3.7. SUMMARY OF DATA SOURCES	36
3.8. SUMMARY	36

CHAPTER 4. HYDROLOGY MODEL DESCRIPTION 37

4.1. INTRODUCTION	37
4.1.1. BACKGROUND TO WATER RESOURCE MODELLING OF THE INTEGRATED VAAL RIVER SYSTEM	37
4.1.2. BRIEF DESCRIPTION OF WATER RESOURCE MODELLING PROCESSES	37
4.1.3. REASONS FOR CHOOSING THE WATER RESOURCES PLANNING MODEL (WRPM)	41
4.1.4. MODEL LIMITATIONS	42
4.1.5. METHOD ADOPTED FOR THE WRPM ANALYSES	42
4.2. DESCRIPTION OF THE MODEL	45
4.2.1. SPATIAL DIMENSIONS	45
4.2.2. TEMPORAL DIMENSIONS	45
4.2.3. STOCHASTIC MODELLING	46
4.2.4. MODEL SCHEME AND LINKAGES WITH THE ECONOMIC MODELS	46
4.3. DATA REQUIREMENTS	47
4.3.1. DATA SOURCES	48
4.3.2. PRIMARY DATA	48
4.3.3. DATA RELIABILITY AND CONFIDENCE LEVELS	48
4.4. MATHEMATICAL SPECIFICATION OF THE MODEL	49
4.4.1. MODEL SETUP AND ASSUMPTIONS	49
4.4.2. MODEL INPUT DATA AND SCENARIO DESCRIPTIONS	51
4.4.3. MODEL OUTPUT	52
4.5. SUMMARY	53

CHAPTER 5. BIOPHYSICAL INTEGRATION LINKAGES 54

5.1. INTRODUCTION	54
5.2. THE USE OF SAPWAT CROP COEFFICIENTS FOR HYDROLOGY MODEL SET-UP	54
5.2.1. THE INPUT DATA AND SOURCE, ...	54
5.2.2. COMPILATION OF THE SUB-MODEL, ...	56
5.2.3. RELEVANT RESULTS AND THEIR INTERPRETATION	56
5.2.4. MODEL LIMITATIONS AND ASSUMPTIONS.....	58
5.2.5. KEY LINKAGES.....	58
5.3. THE DERIVATION OF THE SATURATED SOIL SALINITY, ECE (MS/M)	58
5.3.1. THE INPUT DATA AND SOURCE	58
5.3.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.....	58
5.3.3. RELEVANT RESULTS AND THEIR INTERPRETATION	59
5.3.4. MODEL LIMITATIONS AND ASSUMPTIONS.....	59
5.3.5. KEY LINKAGES.....	59
5.4. THE SETTING UP OF SALINITY-YIELD FUNCTIONS USING THE MAAS AND HOFFMANN EQUATION.....	60
5.4.1. THE INPUT DATA AND SOURCE, ...	60
5.4.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.....	60
5.4.3. RELEVANT RESULTS AND THEIR INTERPRETATION	60
5.4.4. MODEL LIMITATIONS AND ASSUMPTIONS.....	61
5.4.5. KEY LINKAGES.....	61
5.5. HYDROLOGY – MACRO-ECONOMIC LINKAGE AND THE INDEX FOR SOCIO-ECONOMIC WELFARE (ISEW)	61
5.5.1. THE INPUT DATA AND SOURCE, ...	61
5.5.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.....	61
5.5.3. RELEVANT RESULTS AND THEIR INTERPRETATION	62
5.5.4. MODEL LIMITATIONS AND ASSUMPTIONS.....	62
5.5.5. KEY LINKAGES.....	62
5.6. SUMMARY	62
 CHAPTER 6. MICRO-ECONOMIC MODEL DESCRIPTION (PER HECTARE AND IRRIGATION BLOCK LEVEL)	 63
6.1. INTRODUCTION	63
6.2. REASONS FOR THE USE OF A DYNAMIC SIMULATION MODEL	63
6.2.1. NUMBER OF DECISION VARIABLES.....	63
6.2.2. MODEL INTEGRATION.....	64
6.2.3. DATA AVAILABILITY	64
6.3. MODEL DELINEATION	64
6.3.1. SPATIAL DIMENSIONS	64
6.3.2. TEMPORAL DIMENSIONS	65
6.3.3. MODEL ASSUMPTIONS AND LIMITATIONS.....	65
6.4. AIMS OF THE MODEL	66
6.5. DATA REQUIREMENTS.....	66
6.5.1. DATA SOURCES.....	66
6.5.2. PRIMARY DATA	68
6.5.3. SECONDARY DATA.....	69
6.6. MATHEMATICAL SPECIFICATION OF THE MODEL	76
6.6.1. MODEL SETUP (DEFINITION OF THE SETS AND SUB-SETS).....	76
6.6.2. INPUT DATA AND ITS USE	77
6.6.3. MODEL CORE	77
6.7. MICRO ECONOMIC MODEL INPUT / OUTPUT LINKAGES	79
6.8. SUMMARY	79

CHAPTER 7. REGIONAL MODEL DESCRIPTION	80
7.1. INTRODUCTION	80
7.1.1. MOTIVATION FOR THE CHOICE OF REGIONAL MODEL AND INDEX	80
7.1.2. MODEL ASSUMPTIONS	82
7.1.3. MODEL LIMITATIONS	82
7.2. MACRO-ECONOMIC MODEL EXPLANATION	82
7.2.1. THE TREATMENT OF ECONOMICS IN THE MACRO-ECONOMIC MODEL	82
7.2.2. MODEL SET-UP	83
7.2.3. DATA SOURCES AND STUDY AREA	85
7.2.4. BASELINE INDICATORS	90
7.2.5. METHOD OF INPUT-OUTPUT ANALYSIS	95
7.2.6. LINKAGE AND APPLICATION	100
7.3. SUMMARY	100
CHAPTER 8. DESCRIPTION OF SCENARIOS MODELLED	101
8.1. INTRODUCTION	101
8.1.1. RATIONALE	101
8.1.2. SCENARIO SETUP PROCESS	101
8.2. BASE CASE SCENARIO	103
8.3. SCENARIO 1: STATUS QUO DRAINAGE AND LEACHING WITH SALT TOLERANT CROPS	105
8.4. SCENARIO 2: STATUS QUO DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS	106
8.5. SCENARIO 3: IMPROVED DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS	107
8.6. SCENARIO 3+: IMPROVED DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS – ADDITIONAL DRAINAGE COSTS FACTORED IN	107
8.7. SCENARIO SETUP CHECKS	107
8.8. STOCHASTIC HYDROLOGY RUNS	109
8.9. IRRIGATION BLOCKS COMPARED	112
8.10. SUMMARY	112
CHAPTER 9. MICRO-ECONOMIC MODEL RESULTS	114
9.1. INTRODUCTION	114
9.2. HYDROLOGY MODEL RESULTS ANALYSIS	114
9.2.1. SOIL SALINITY CHANGES	115
9.2.2. IRRIGATION WATER SALINITY DATA	116
9.3. BIO-PHYSICAL EXAMPLE OF THE HYDROLOGY–ECONOMIC LINKAGE RESULTS	118
9.4. PER HECTARE LEVEL CROP ENTERPRISE BUDGET RESULTS	121
9.4.1. PER HECTARE CROP GROSS MARGINS	121
9.5. IRRIGATION BLOCK LEVEL MICRO-ECONOMIC RESULTS	123
9.6. WEIGHING UP THE SCENARIOS	126
9.6.1. IRRIGATION BLOCKS COMPARED	126
9.7. WUA LEVEL RESULTS	134
9.8. LINKAGES TO THE REGIONAL ECONOMIC MODEL	134
9.8.1. MICRO-MACRO LINKAGES	134

9.8.2. INDEX FOR SOCIO ECONOMIC WELFARE (ISEW).....	134
9.9. SUMMARY	137
 CHAPTER 10. REGIONAL MODEL RESULTS	 139
10.1. INTRODUCTION	139
10.2. BASE CASE SCENARIO.....	139
10.2.1. MODEL INPUT DATA: BASE CASE SCENARIO	140
10.2.2. REGIONAL MODEL RESULTS	142
10.2.3. SUMMARY OF THE RESULTS FOR BASE CASE SCENARIO.....	151
10.3. SCENARIO 1	152
10.3.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE	152
10.3.2. SECTORAL ECONOMIC IMPACTS.....	154
10.3.3. EMPLOYMENT EFFECT	155
10.3.4. OTHER SECONDARY IMPACTS	155
10.4. SCENARIO 2.....	156
10.4.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE	156
10.4.2. SECTORAL ECONOMIC IMPACTS.....	158
10.4.3. EMPLOYMENT EFFECT.....	159
10.4.4. OTHER SECONDARY IMPACTS	159
10.5. SCENARIOS 3 AND 3(+).....	160
10.5.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE	160
10.5.2. SECTORAL ECONOMIC IMPACTS.....	162
10.5.3. EMPLOYMENT EFFECT.....	163
10.5.4. OTHER SECONDARY IMPACTS	164
10.6. SCENARIO COMPARISON.....	166
10.7. LONG TERM SUSTAINABILITY OF IRRIGATION.....	171
10.7.1. INDEX FOR SOCIO-ECONOMIC WELFARE	171
10.8. SUMMARY	174
 CHAPTER 11. POLICY IMPLICATIONS AND RECOMMENDATIONS	 176
11.1. INTRODUCTION	176
11.2. POLICY OPTIONS	176
11.2.1. SALINITY LEACHING INCENTIVES.....	177
11.2.2. DRAINAGE GRANT ASSISTANCE.....	178
11.2.3. RETURN-FLOW MANAGEMENT OPTIONS	179
11.2.4. EFFICIENT AND EFFECTIVE WATER CHARGING	180
11.2.5. FARMERS' WILLINGNESS TO PAY FOR DRAINAGE: A SENSITIVITY ANALYSIS AND CROSS SUBSIDISATION OPTIONS	181
11.2.6. CHANGES IN CROPS GROWN	181
11.2.7. CORRECT INSTITUTIONAL FRAMEWORK FOR SALINITY MANAGEMENT	182
11.2.8. SALINITY AWARENESS PROGRAM	182
11.3. FARM LEVEL POLICY IMPLICATIONS	182
11.4. IRRIGATION BLOCK (/SUB-WUA) LEVEL POLICY IMPLICATIONS.....	185
11.5. WUA LEVEL POLICY IMPLICATIONS	187
11.5.1. CROP CHOICE IMPACT ON THE SHORT-TERM VERSUS. LONG-TERM DEMAND FOR WATER.....	187
11.6. REGIONAL LEVEL POLICY IMPLICATIONS.....	189
11.7. OPTIMAL TIMING OF THE INSTALLATION OF IRRIGATION DRAINAGE IN THE LIFE CYCLE OF A SCHEME: DISCUSSION.....	190

11.8. SUMMARY	191
11.9. RECOMMENDATIONS	192
 CHAPTER 12. SYNTHESIS, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	 193
12.1. INTRODUCTION	193
12.2. SYNTHESIS	193
12.2.1. BACKGROUND RESEARCH	193
12.2.2. INTEGRATED CONCEPTUAL FRAMEWORK	194
12.2.3. METHOD AND MODEL DESIGN	194
12.2.4. DATA ACCUMULATION AND ANALYSIS	194
12.2.5. RESULTS INTERPRETATION	194
12.2.6. REPORTING	195
12.3. SUMMARY	195
12.3.1. THE STUDY AREA	195
12.3.2. INTEGRATED MODEL STRUCTURE	196
12.3.3. HYDROLOGY MODEL	197
12.3.4. BIOPHYSICAL MODEL	197
12.3.5. MICRO ECONOMIC MODEL	198
12.3.6. REGIONAL MODEL	198
12.3.7. SCENARIOS MODELLED	199
12.3.8. MICRO-ECONOMIC RESULTS	200
12.3.9. REGIONAL MODEL RESULTS	201
12.3.10. POLICY IMPLICATIONS	201
12.4. CONCLUSIONS	202
12.4.1. CRITICAL MODEL EVALUATION AND USEFULNESS	203
12.4.2. LESSONS LEARNED IN WORKING IN A MULTI-DISCIPLINARY TEAM	204
12.5. RECOMMENDATIONS	205
12.5.1. PROPOSED FARM LEVEL MANAGEMENT STRATEGY	205
12.5.2. IRRIGATION BLOCK (/SUB-WUA) LEVEL OPTIONS	205
12.5.3. PROPOSED WUA LEVEL MANAGEMENT STRATEGY	206
12.5.4. PROPOSED REGIONAL MANAGEMENT STRATEGY	206
12.5.5. PROPOSED POLICY RECOMMENDATIONS	206
12.6. FUTURE RESEARCH NEEDS	207
12.6.1. WHOLE FARM LEVEL ECONOMIC MODEL REFINEMENT (OPTIMISATION)	207
12.6.2. HYDROLOGY REFINEMENT	208
12.6.3. LOCAL SALINITY YIELD RESPONSE	208
12.6.4. SOIL SALINITY DATA BASE	208
12.6.5. GIS LINKAGES	208
LIST OF REFERENCES	209
LITERATURE REVIEWED	214
 APPENDIX 1. SMSIM MODELLING SEQUENCE AND FILES	 216
 APPENDIX 2. HYDROLOGY SETUP DATA	 218
 APPENDIX 3. IRRIGATION BLOCK CEBS	 223

APPENDIX 5. REGIONAL MODEL RESULTS

A5.1. BASE CASE SCENARIO	229
A5.1.1. MODEL INPUT DATA	229
A5.1.2. REGIONAL MODEL RESULTS	231
A5.2. SCENARIO 1	238
A5.2.1. MODEL INPUT DATA	238
A5.2.2. REGIONAL MODEL RESULTS	240
A5.3. SCENARIO 2	248
A5.3.1. MODEL INPUT DATA	248
A5.3.2. REGIONAL MODEL RESULTS	250
A5.4. SCENARIO 3	258
A5.4.1. MODEL INPUT DATA	258
A5.4.2. REGIONAL MODEL RESULTS	260
A5.5. SCENARIO 3 (+).....	268
A5.5.1. MODEL INPUT DATA	268
A5.5.2. REGIONAL MODEL RESULTS	270
A5.6. INDEX FOR SUSTAINABLE ECONOMIC WELFARE	277
A5.6.1. BASE CASE SCENARIO	277
A5.6.2. SCENARIO 1	278
A5.6.3. SCENARIO 2	279
A5.6.4. SCENARIO 3	280
A5.6.5. SCENARIO 3(+)	281

LIST OF TABLES

Table 2.1. Sub-WUAs of the Orange-Riet WUA (Source: Ninham Shand, 2004).....	16
Table 2.2. Sub-WUAs of the Orange-Vaal WUA (source: CSIR, 2004).....	17
Table 2.3. Irrigation potential of the irrigable soils in the OV-WUA region (adapted from Van Heerden <i>et al.</i> 2001)	18
Table 2.4. Scheduled areas and quotas as used in the model for the irrigation blocks in the study area (2005).....	21
Table 2.5. Area (ha) under different irrigation systems in the OR-WUA (Ninham Shand, 2004).....	25
Table 2.6. Area (ha) under different irrigation systems in the OV-WUA region (adapted from Van Heerden <i>et al.</i> 2001)	26
Table 2.7. Soils affected by salinisation and water logging in the OV-WUA region (adapted from Van Heerden <i>et al.</i> 2001)	26
Table 3.1 A summary of the input data sources.....	36
Table 4.1. Irrigation information adopted for the initial assessment ¹	51
Table 4.2. Irrigation information adopted for the scenario analyses	52
Table 4.3. Output for water supply routes (channels)	52
Table 4.4. Output data for irrigation blocks	52
Table 5.1. Monthly mean pan evaporation (mm) as used in the WRPM setup.....	56
Table 5.2. The monthly crop water coefficients used in the WRPM setup for calculating crop water use (Van Heerden <i>et al.</i> , 2001).....	57
Table 6.1 A summary of the input data sources.....	66
Table 6.2. The monthly crop water requirement percentages of total requirement used (based on OV-WUA data).....	67
Table 6.3. The calculation of the costs of artificial drainage installation based on expert opinion from Reinders (2005) and Van der Merwe (2005)	68
Table 6.4. Main Crop Data used in the compilation of per hectare (ha) Crop Enterprise Budgets (CEBs)	69
Table 6.5. CEBs for maximum yield set up for the Lower Riet Irrigation Block base-case scenario, using 2005 values	73
Table 6.6 CEBs for reduced crop yield set up for the Lower Riet Irrigation Block base-case scenario, using 2005 values	74
Table 6.7. An example of the irrigation block level CEB, using the base case scenario run for Irrigation Block RloR - stochastic run 80 (2005 prices).....	74
Table 6.8 An example of the irrigation block level (RloR) total CEB for all crops, and the annual and cumulative TGMASC for stochastic run 80 (2005 prices).....	75
Table 7.1. Study area catchments.....	87
Table 7.2. Data Sources.....	87
Table 7.3. Socio-Economic Indicators, 2005.....	90
Table 7.4. Economic Indicators, 2005	91
Table 7.5. Growth performance of selected indicators in the study area, 2000 to 2004.....	94
Table 7.6. Input-Output Table at basic values (R' million 2005, imports shown separately) derived for the study area.....	96
Table 7.7. Technical Input Coefficients calculated for the study area, 2005.....	97
Table 7.8. Inverse Matrix for the study area, 2005.....	98
Table 7.9. Employment Multipliers (Type II) for the study area, 2005.....	99
Table 7.10. Multipliers: backward linkages per R1.00 change in total input	99

Table 7.11. Multipliers: forward linkages per R1.00 change in total output.....	99
Table 8.1. The 5 scenarios set up for analysis based on crop choice and drainage	102
Table 8.2. Percentage cropping composition and changes of the different scenarios.....	102
Table 8.3. The area (ha) cropping composition of different scenarios	103
Table 8.4. The basis cropping composition of the 4 Irrigation Blocks on which the Base-Case scenario is based.....	104
Table 8.5. Base Case areas (ha) planted to various crops of the irrigation blocks	104
Table 8.6. Scenario 1 area (ha) planted to various crops	105
Table 8.7. Scenario 2 and 3 area (ha) planted to different Salt Sensitive / Higher Value crops	106
Table 8.8. Water use (m ³ '000 / month) for the OV-WUA for different scenarios.....	108
Table 9.1. CEBs of 3 main crops, wheat, maize and lucerne in the Lower Riet Irrigation Block (<i>RloR</i>) calculated at maximum (target) yield using real 2005 data.	122
Table 9.2 CEBs of 3 main crops, wheat, maize and lucerne in the Lower Riet Irrigation Block (<i>RloR</i>) calculated at soil salinity EC _e = 480 mS/m (TDS = 3120 mg/l), using real 2005 data.	122
Table 9.3. Base-Case (2% return-flow) vs. Scen3 (17% return-flow) vs. Scen3 + (water charge added) crop TGMASC for stochastic runs (SR) 001, 080 and 044 in the Lower Riet Irrigation Block (<i>RloR</i>) using real 2005 data	123
Table 9.4. Cumulative 15 year annual average TGMASC (R'000 000) for all scenarios of all the irrigation blocks compared (real 2005 prices), based on 100 stochastic runs.....	127
Table 9.5. Per hectare average annual TGMASC (R) for all scenarios of all the irrigation blocks compared (real 2005 prices), based on 100 stochastic runs	127
Table 9.6. Average annual irrigation water use and percentage changes (m ³) across irrigation blocks for the different scenarios modelled, based on 100 stochastic runs	129
Table 9.7. A summary of various SMSim model results comparing stochastic runs 001, 080 and 044 and the 0.50 percentile value of the 100 stochastic runs (2005 prices).....	132
Table 10.1. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80 and 50% percentile).....	140
Table 10.2. Projected Gross Margins (R'000), 2005 – 2019	141
Table 10.3. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019	142
Table 10.4. Regional economic impact in terms of value added (GDP) (R'000), 2005 – 2019	143
Table 10.5. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019	144
Table 10.6. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)	146
Table 10.7. Index for Sustainable Economic Welfare, 2005 – 2019	149
Table 10.8. Net effect and resulting composite annual growth rate for selected indicators, 2005 to 2019.....	152
Table 10.9. Net effect and resulting composite annual growth rate in terms of business output (Rand) per economic sector, 2005 to 2019.....	152
Table 10.10. Net effect on the production output (Rand) per economic sector (2005 to 2019).....	154
Table 10.11. Net effect of Scenario 1 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019	156
Table 10.12. Net effect on the production output (Rand) per economic sector (2005 to 2019).....	158
Table 10.13. Net effect of Scenario 2 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019	160
Table 10.14. Net effect on the production output (Rand) per economic sector (2005 to 2019).....	163
Table 10.15. Net effect of Scenarios 3 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019	165

Table 10.16. Net effect of Scenarios 3(+) on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019	165
Table 10.17. Comparison of regional economic impact results in Scenarios 1, 2, 3 and 3+ with Base Case Scenario, 2005 to 2019.....	175
Table 11.1. The determination of the increased water charge to pay for 15% additional underground leaching for Scenario 3	178
Table 11.2. Corresponding weighted average ECe (mS/m) with 15% increased drainage area and a 15% leaching fraction	184
Table 11.3. Average annual TGMASC (R/ha) with different leaching fractions (2005 input costs and average 10yr real average crop prices)	184
Table 11.4. Annual TGMASC (R/ha/year) for different scenarios with a 15% increase in leaching and drainage implemented in all irrigation blocks (for actual and standardized crop composition percentages)	185
Table 11.5. Change in annual TGMASC (R/ha/year) for different scenarios with adjusted additional leaching and drainage implemented for the different irrigation blocks (for actual and standardized crop composition percentages)	186
Table 11.6 Vall net returns of subsidised drainage costs (2005 constant prices - R'000 000)	188
Table 11.7 <i>R/oR</i> net returns of subsidised drainage costs (2005 constant prices - R'000 000)	189
Table 12.1. A table summarising the level to which original objectives have been met	203

LIST OF FIGURES

Figure 2.1. The position of the study area within South Africa	11
Figure 2.2 River catchments and inter-basin transfers of South Africa (Ninham Shand, 2004)	11
Figure 2.3 Generalised mean annual precipitation (mm) isohyet, seasonal rainfall zones and the main two rivers of South Africa in relation to the study area at the confluence of the Orange and Vaal Rivers	12
Figure 2.4. Screen from SAPWAT showing the reference Evaporation (mm) at the Douglas jail.	13
Figure 2.5. A schematic diagram of the regional hydrology impacting on the WUAs that make up the study area	15
Figure 2.6. An indication of the layout of the Irrigation Blocks (OV-WUA farms, <i>Vall</i> , coloured Yellow and OR-WUA farms, <i>RloR</i> , <i>Rszg</i> and <i>Rscm</i> , coloured green).	19
Figure 2.7. A simplified diagram of the hydrology set-up of the study area (indicating channels, nodes, ...	20
Figure 2.8. An inverted colour spectral imagery view (aerial photo) of a salt affected centre pivot land (courtesy GWK, 2002).....	21
Figure 2.9. Gross Geographical Product (R'000) of the study area by economic sector, 2005.....	25
Figure 3.1. The integrated conceptual framework.....	31
Figure 4.1. Hydrological analysis.....	38
Figure 4.2. Stochastic Stream-flow generation	39
Figure 4.3. Sub-system Yield Analysis	40
Figure 4.4. System Planning Analysis	41
Figure 4.5. Hydrology map 1- <i>WRPM</i> set-up / representation of the Lower Vaal and Riet/Modder sub-systems	43
Figure 4.6. Hydrology map 2 - <i>WRPM</i> set-up / representation of the Upper Orange sub-systems	44
Figure 4.7. Model scheme depicting the salt and water balance paths in the <i>WRPM</i> (modified from Allen and Herold, 1988) - see Table 4.3 and Table 4.4 for a more comprehensive legend and definition of terms	47
Figure 5.1. Reference Evaporation (mm) and A-pan readings used in compiling the monthly crop coefficients for the OV-WUA (Douglas) and OR-WUA (Rietrivier).....	55
Figure 5.2 An example of the SAPWAT crop coefficients obtained for wheat	55
Figure 6.1. Ten year real crop price (R/ton) spread for the 20 crops modelled in <i>SMsim</i> (2005 base year)	70
Figure 7.1 The concept of sustainable development.....	81
Figure 7.2. Regional model set-up and process.....	84
Figure 7.3. Local municipal areas in the study area.....	86
Figure 7.4. Quaternary catchments falling in the study area.....	86
Figure 7.5. Gross Geographical Product (R'000) of the study area by economic sector, 2005.....	91
Figure 7.6. Gross Geographical Product (R'000) per local municipal area in the study area, 2005.....	92
Figure 7.7. Gross Economic Output (R'000) of the study area by economic sector, 2005.....	92
Figure 7.8. Total employment in the study area by economic sector, 2005.....	93
Figure 7.9. Total labour compensation (R'000) in the study area by economic sector, 2005.....	94
Figure 8.1. The selection of specific stochastic runs from the Base-Case scenario run for the Lower Riet Irrigation Block (<i>RloR</i>) to analyse as “best-” “average-” and “worst case” hydrology sequences when comparing scenarios.....	110
Figure 8.2. Annual TGMASC over 15 years for 100 stochastic runs for <i>RloR</i> Base-Case scenario showing stochastic runs 1, 80 and 44 in relation to the 0.05, 0.50 and 0.95 percentiles.....	110
Figure 8.3. A comparison of saturated soil salinity concentrations - <i>C_{Ue}</i> (mg/l) - in different irrigation blocks for the Base Case stochastic runs analysed, with linear trends indicated.....	111

Figure 9.1. The 0.50 percentiles of 100 stochastic runs of the base-case scenario upper zone saturated soil salinity - CUE (mg/l) for all irrigation blocks	115
Figure 9.2. The impact of different scenarios on the saturated extract salt concentration - CUE (mg/l) for Stochastic run 080 in the Lower Riet Irrigation Block (<i>RloR</i>) for 15 years.....	116
Figure 9.3. The impact of increased drainage in Scenario 3 on the saturated extract salt concentration - CUE (mg/l) for Stochastic run 080 in the Orange Vaal WUA block (<i>Vall</i>) for 15 years	117
Figure 9.4. Monthly irrigation water salinity concentration, TDS (mg/l) spread in WRPM channel number 490 which feeds into the Lower Riet Irrigation Block (<i>RloR</i>).....	117
Figure 9.5. Annual irrigation water expected salinity, TDS (mg/l) spread in Channel 490, which feeds into the Lower Riet Irrigation Block (<i>RloR</i>).....	118
Figure 9.6 The working of the Maas and Hoffmann (1977) threshold and gradient graph for determining yield response to saturated soil salinity - ECE (mS/m) for the Lower Riet Irrigation Block, stochastic run 080 (closest fit to the 0.50 percentile).....	119
Figure 9.7. The fifty percentile (0.50) crop yield of the 20 main crops over 15 years in the Lower-Riet Irrigation Block (Crop names written in bold type achieve a 100% yield).....	119
Figure 9.8. Stochastic spread of maize yield over 15 years in the Lower-Riet Irrigation Block	120
Figure 9.9. Base-case total annual CEB composition values for all crops in the RloR Irrigation Block for stochastic run 80 over 15 years	124
Figure 9.10. Base-case scenario annual TGMASCs (R' mil) for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles for 100 stochastic runs	125
Figure 9.11. Base-case scenario cumulative annual TGMASCs (R'mil) for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles and most closely fitting stochastic runs 001, 080 and 044 respectively for 100 stochastic runs.....	125
Figure 9.12 Base-case scenario annual TGMASCs (R' mil) at 2005 prices for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles and corresponding selected stochastic runs 001, 080 and 044 respectively, for 100 stochastic runs.....	126
Figure 9.13. Land (R/ha/yr) and water (R/mm/ha/yr) productivity and cumulative probability functions based on 2005 prices (GM=TGMASC in this graph) for different scenarios based on 100 stochastic runs	130
Figure 9.14. Land (R/ha/yr) and water (R/mm/ha/yr) productivity percentile spreads per irrigation block based on 2005 prices (GM=TGMASC in this graph) for different scenarios based on 100 stochastic runs	131
Figure 9.15. OV-WUA (<i>Vall</i>) versus OR-WUA (<i>Rall</i>) annual and 15 year cumulative average TGMASCs (2005 prices) for stochastic run 80.....	133
Figure 9.16. The salt mass balance (tonnes) calculated from the Vall base-case irrigation abstraction mass, SA(tonnes) minus the return-flow mass, SR (tonnes).....	135
Figure 9.17. The salt mass balance (Sbal in tonnes) from irrigation abstraction (SA) minus returnflows (SR) for Scenario 3 in RloR.....	136
Figure 9.18. The impact of increased drainage on the lower zone salinity concentration, CLe(mg/l) – Base-case vs. Scenario 3.	136
Figure 10.1. Gross Income per year, 2005 to 2019 (Stochastic runs 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)	140
Figure 10.2. Gross margins, 2005 to 2019 (Stochastic runs 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)	141
Figure 10.3. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO).....	143
Figure 10.4. Regional Economic Impact in terms of generated GGP, 2005 to 2019 (Source: ISIM.MACRO)	144
Figure 10.5. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)	145
Figure 10.6. Total economic impact per economic sector (total output), 2005 to 2019 (50% percentile) (Source: ISIM.MACRO).....	147

Figure 10.7. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO).....	148
Figure 10.8. Total regional economic impact (output) for.....	148
Figure 10.9. Index for Sustainable Economic Welfare, 2006 – 2019 (50% Percentile)	149
Figure 10.10. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic Run 01)	150
Figure 10.11. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic 44).....	150
Figure 10.12. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic Run 80)	151
Figure 10.13. Direct output in the agriculture sector (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	153
Figure 10.14. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	153
Figure 10.15. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)	154
Figure 10.16. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	155
Figure 10.17. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile	156
Figure 10.18. Direct output in the agriculture sector (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	157
Figure 10.19. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	157
Figure 10.20. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)	158
Figure 10.21. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile.....	159
Figure 10.22. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile	160
Figure 10.23. Direct output in the agriculture sector (R'000), 2005-2019 for stochastic runs 01, 44 and 80.....	161
Figure 10.24. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80	161
Figure 10.25. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)	162
Figure 10.26. Total output in the regional economy (R'000), per economic sector excluding agriculture and households for the period 2005 to 2019 (50th percentile)	162
Figure 10.27. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80.....	163
Figure 10.28. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80 for Scenario 3.....	164
Figure 10.29. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80 for Scenario 3+	165
Figure 10.30. Comparative output (R'000)	167
Figure 10.31. Comparative total output (R'000)	168
Figure 10.32. Comparative GGP (R'000)	169
Figure 10.33. Comparative employment (R'000)	170
Figure 10.34. Scenario 1: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)	172
Figure 10.35. Scenario 2: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)	172

Figure 10.36. Scenario 3: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)	173
Figure 10.37. Scenario 3(+): ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)	173
Figure 11.1. A possible infield ECe testing kit comprising of a soil bore, vacuum pump and filter (far left), salt meter (left) and a conversion chart (top)	177
Figure 11.2. CUe for the 3 stochastic runs under analysis averaged for the Base-Case, Scenario 1 and Scenario 2 and the average of the 3 stochastic runs for Scenario 3 for all irrigation blocks	180

ACRONYMS, TERMS AND DEFINITIONS

WRC	Water Research Commission
DWAF	Department of Water Affairs and Forestry
GWK	The old Griqualand West Co-operative, now GWK Pty. Ltd.
SALMOD	Salinity and Leaching Model for optimal Irrigation Development
WUA	Water Users Association
OV-WUA	Orange-Vaal WUA
OR-WUA	Orange-Riet WUA
WRPM	Water Resources Planning Model (funded by DWAF and administrated by WRP Consultants, Pretoria)
WRYM	Water Resource Yield Model
IVRS	Integrated Vaal River System
VRSAU	Vaal River System Analysis Update

WATER QUALITY TERMS

Water quality High concentrations of inorganic salts have been identified as the main water quality problem for irrigation in the study area; thus, unless otherwise specified, the term water quality as used in this document refers to the salinity status of the irrigation water measured in EC or TDS.

TDS	Total dissolved solids (mg/l)
SAR	Sodium adsorption ratio
CU	The concentration of salts in the upper zone, measured TDS in mg/l
CUe	The saturated extract concentration of salts in the upper zone, (TDS in mg/l)
ECiw	Electrical conductivity of the irrigation water (measured in mS/m)
ECe	Electrical conductivity of the saturated soil extract (measured in mS/m)

DEFINITIONS

CEB Crop Enterprise Budget. The CEBs set up in this report incorporate all crop enterprise income minus all directly allocatable costs, and are set up to per hectare gross margin (GM) level.

GM Gross Margin. The GM for the enterprise referred to is the gross value of production for that enterprise minus all the directly allocatable costs. In this report fuel and lubrication, and maintenance and repairs have been allocated, but permanent labour not, only temporary labour. Permanent labour is included in the fixed cost component.

NFI Net Farm Income. The NFI is the total gross margin (TGM) minus fixed costs.

TGMASC - Total Gross Margin Above Specified Costs. In SALMOD the TGMASC generated is at case study farm level and is the difference between all farm income and allocatable production costs, including

water, electricity, an interest component and harvesting costs, as well as the annualised capital repayment costs of management options brought into the optimal solution. The specified costs include all annual non-allocatable costs, and is a constant in SALMOD, obtained from the financial analysis survey. TGMASC is equivalent to net farm income (NFI) excluding the depreciation component.

SMsim Salinity simulation Model. The acronym used when referring to the integrated micro-economic model.

WRPM Water Resources Planning Model. Developed for the DWAF, it is the hydrology model that generates the stochastic hydrology sequences for use in SMsim.

ISIM Integrated Salinity Impact Model. The acronym used when referring to the regional economic Irrigation SIMulation model developed by the macro-economic project team of UrbanEcon, that uses *inter alia* SMsim results as inputs.

ISEW Index for Sustainable Economic Welfare. The weighted index of the Social, Environmental and Economic Welfare impacts used to compare different scenarios at regional level using ISIM data as input.

SPATIAL DEFINITION TERMS

WUA level – or, **Scheme level** refers to the OV- and OR-WUAs specifically.

sub-WUA level – or, **Sub-Scheme level** refers to internal divisions within the Scheme/WUA based on water source, and managed differently by the WUA.

Irrigation Block – is the specific term used in the WRPM to define a hydrology block made up of one or more sub-scheme/sub-WUA level areas.

Regional level – used in the regional model to demarcate the municipal areas (local government areas) as economic units through which the particular river reaches under analysis flow (i.e. the area managed by both the OV- and OR-WUA).

Study area – the study area referred to in this report encompasses all of the above.

EXECUTIVE SUMMARY

NEED FOR THE RESEARCH:

Background and Problem Statement

Salinisation of irrigation schemes has become a major problem in many parts of the world, with detrimental effects varying between reduced crop yields and increased production costs, to the complete withdrawal of irrigation land. Salinisation of various irrigation schemes has also become a problem in South Africa. One such area that experiences salinisation problems selected for this research is the Lower Vaal and Lower Riet irrigation areas, upstream from where these rivers converge and flow into the Orange River. From a total irrigation area of 12 556 ha in the Orange-Vaal Water Users Association, 23% is either slightly (13%) or severely (10%) affected by salinity problems (van Heerden, *et al.* 2001).

The salinisation problem in the area is of a long-term and cyclical nature. Previous research conducted in the area, namely to determine the nature and extent of the salinity problem and how to effectively address it has provided some answers (Armour and Viljoen 2002b, Du Preez *et al.* 2000, Moolman and Quibel 1998 and Allen and Herold 1988). New research was however necessary to integrate existing multidisciplinary research and to address the unsolved questions regarding the dynamic long-term economic impact of salinity on farm, water user association and regional level in the study area, and the economic and environmental effects of different strategies to address the problem on the different levels of decision making.

By understanding the dynamics and interactions between irrigation water quality and the soil salinity status on crop yield over time, mistakes made in the past by choosing unsustainable irrigation sites and practices can be prevented. Furthermore the impact of various natural or artificial (e.g. policy mechanism) scenarios on existing schemes can be more accurately modelled, leading to increased economic efficiency and sustainability of the irrigation industry as a whole.

Aims of the Research

The overall aim of this study was to develop and integrate multi-dimensional models for sustainable management of water quantity and quality in the Orange-Vaal-Riet (OVR) convergence system.

More specifically the following sub-objectives were addressed:

1. To better understand the polluting chemical processes and interactions in and in-between the plant and surface-, vadose zone- and ground- water, to achieve efficient and sustainable water quality management
2. To develop new economic models at both,
 - a. Micro level, namely dynamic long term simulation¹ models, and at
 - b. Macro level, using regional dynamic Input / Output model

¹ The initial aims stated that an optimization model would be used, but this aim was changed at a later Reference Group meeting to a simulation approach as too many decision variables required for the bio-physical process modelling prevented the developed of an optimisation model from producing meaningful (globally optimal) results.

3. To integrate these new economic models with models from the other disciplines¹ of:
 - a. Hydrology (incorporating a salt mass balance and flow), and
 - b. Agronomy (crop growth in the presence of salinity model)
4. To determine and prioritise best management practises at:
 - a. Micro level, (i.e. per hectare and irrigation block level) and at
 - b. Regional level.
5. Through a better understanding of the multi-dimensional interactions, to enhance water use efficiency as the quantity and quality of water available for agriculture inevitably decreases
6. To develop policy guidelines to ensure social, environmental and economic sustainability
7. To achieve all these aims based on using the complex OVR convergence system as a study area, but developing a method and models that can be applied elsewhere with relative ease.

Demarcation of the Study Area Impacted by Salinisation

Hydrologically, the study area is defined in relation to the following rivers;

- *Vaal River*, downstream of the Bloemhof Dam to the confluence with the Orange River
- *Orange River*, the Orange-Riet and Orange-Vaal Canal extraction points downstream of the Vanderkloof Dam to the Orange-Vaal Confluence where the returnflows of the study area re-enter the Orange River
- *Riet River*, downstream of the Kalkfontein Dam, including the confluence with the Modder River to the confluence with the Vaal River.

This encompasses the Orange-Vaal (OV) and Orange-Riet (OR) Water Users Associations (WUAs).

At micro hydrology level, four irrigation blocks in the two WUA's, represent the main receiving water quality areas modelled within the Orange-Vaal-Riet-Modder confluence area, namely:

- the Riet River Scheme, Orange Riet Canal and Ritchie sub-WUAs of the OR-WUA, all receiving Orange River water directly from the Orange Riet Canal, combined make up the **Rscm** Irrigation Block,
- the Scholtzburg sub-WUA of the OR-WUA, lying mainly at the confluence of the Modder and Riet Rivers, but receiving a large portion of Orange River water diluting the tail ends of the Riet and Modder Rivers upstream, is the **Rszg** Irrigation Block,
- the Lower Riet River sub-WUA of the OR-WUA, stretching from Ritchie to Soutpansdrift in the Riet River, and mainly receiving Riet Scheme and Scholtzburg returnflows, is the **RloR** Irrigation Block,
- the whole Orange Vaal WUA constitutes the **Vall** Irrigation Block, and receives Vaal River system excess spillage and a large portion of Orange River water pumped via the Orange-Vaal and Orange-Riet Canals, with the latter carrying the returnflows of the whole OR-WUA that lies upstream.

¹ The initial aims also stated that vadose zone chemical balance and groundwater models were also to be linked, but these linkages were dismissed at the first Reference Group meetings as impractical and overly ambitious.

Main characteristics of the study area identified of particular importance for integrated salinity modelling are:

- The spatial dimensions and boundaries spanning two provinces, various municipal management areas (see Figure 7.3), the confluence of the two major rivers in South Africa, various quaternary catchments and different water management areas (Figure 7.4) that influence the anthropogenic (social, political, economic) and natural (bio-physical, hydrology, environment) dynamics over time in the study area.
- According to Van Veele (2004), “the Riet-Modder catchment is a “feast or famine” catchment with only 8 years in 50 being ‘average’ years”, necessitating analysing actual simulations and not average values.

METHOD

Development of the integrated conceptual framework

Multidisciplinary and integrated research method was identified to be necessary at two levels, namely micro and macro/regional level. At micro level, biophysical (agronomy, hydrology and salinisation:crop yield functions) are linked to farm level micro economic model which extrapolates to irrigation block level, providing the data required for the regional economic model. For the integrated conceptual framework see Figure 3.1.

The use of stochastically simulated salinisation data

The WRPM (hydrology model) results provide a set of 100 stochastic water quality and quantity simulations for the various river reaches and irrigation blocks in the study area for the scenarios tested, based on approximately 70 years of historical data. From cumulative economic results based on all 100 stochastic sequences, a worst case (0.05 percentile), best case (0.95 percentile) and most probable (0.50 percentile) sequences are selected for further analysis. These percentile values however are “too smooth”, not reflecting the true dynamics of a realistic hydrology sequence. Therefore actual stochastic runs 001, 044 and 080, are selected as the best fits representing the cumulative 0.05, 0.95 and 0.50 Total Gross Margin Above Specified Costs (TGMASC) percentiles (see Figure 8.1).

Results from the Water Resources Planning Model (WRPM) indicate the changes in hydrology, irrigation block upper and lower layers and return flow impacts of the management options tested in the various scenarios.

Hydrology model results discussed in Chapter 9 show the highly stochastic nature of especially the **RioR** and **Vall** Irrigation Block that receive water from a number of different sources.

Development of realistic scenarios

Confronted with different hydrology cycles and associated irrigation water salinity regimes, farmers would like to know what the impact of different farm management options can be on the profitability of farming for the different situations. Two farm management options identified are to change the crop composition and to increase the drainage and leaching practices. Scenarios are thus developed to investigate the impact of these options at a per hectare crop enterprise budget (CEB) level, irrigation block level, Water Users Association (WUA) level and regional level.

The following five scenarios are analysed in this report:

1. The *base-case scenario* is set up for *status quo* conditions for the base year of 2005
2. *Scenario 1* is set up with *status quo* drainage, but with a more salt tolerant cropping composition
3. *Scenario 2* is set up with *status quo* drainage, but with a more salt sensitive, yet higher value cropping composition
4. *Scenario 3* is set up with additional drainage and leaching, with a more salt sensitive, yet higher value cropping composition
5. *Scenario 3+* is exactly the same as Scenario 3 except that the infrastructure cost of the additional leaching and drainage is factored into the irrigation water price

Micro-level modelling and results analysis

The proposed micro-level research follows on a previous study by Armour and Viljoen (2002) entitled “The Economic Effects of Changing Water Quality on Irrigated Agriculture in the Lower Vaal and Riet Rivers”. The water quality problem set out to be studied in the previous project was initially perceived with the main variable being the water quality changes of in stream irrigation water. DWAF data recorded over many years was studied and incorporated into models, but the essence of the problem remained unresolved. This being the indirect and long-term accumulation effects of irrigation water carried constituents within irrigated soils, and the effects of the resulting returnflows from these soils on downstream irrigation water quality.

To address these issues the WRPM is linked in this research through various bio-physical algorithms into a comprehensive per hectare economic simulation model, generating spatially differentiated Crop Enterprise Budget (CEB) data sets to produce per hectare and irrigation block level TGMASC results. Each element of the CEB data set (e.g. seed, fertilizer, labour, water use, electricity, harvesting costs, interest, etc) is kept separate in the micro level modelling to irrigation block level where it is transferred to the regional economic model where it interact with input/output matrix components and multipliers.

Regional-level modelling and results analysis

Macro-level research to determine economic and environmental impacts at regional level follows on an Urban-Econ study that was successfully completed using economic simulation modelling to identify and quantify the economic impacts of salinity in the Middle Vaal River System. The input/output analysis technique is used in the simulation model, ISIM, to determine the regional economic impacts (e.g. change in total production output) and social impacts (e.g. change in employment) resulting for the micro-economic level CEB analysis. These together with the salt mass balance entering and leaving an irrigation block make up the Index for Social Economic Welfare (ISEW).

MAIN RESULTS

The main results from the research are the following:

- Salinisation is an important problem in the study area that needs special management attention
- The relative importance of the problem differs between WUAs and irrigation blocks

- The hydrology results show that the Lower Riet Irrigation Block (**RloR**) has the highest soil salt concentration in the upper zone, CU (mg/l) followed by the Orange-Vaal Irrigation Block (**Vall**) and the Scholtzburg Irrigation Block (**Rszg**), with the lowest soil salt concentrations occurring in the Orange-Riet Scheme Irrigation Block (**Rscm**).
- In the irrigation blocks where the CU is highest, the crop yields are worst affected.
- Economic results (see Table 9.5) show that the greatest loss due to salinity is experienced in the Lower Riet Irrigation Block (**RloR**), to the value of R6962 per hectare per year, followed by Scholtzburg (**Rszg**) with R2596 and the Orange-Vaal Irrigation Block (**Vall**) with R2218.
- From the various management options, drainage installation and consequent leaching is a better option financially, environmentally and socially than changing to more salt tolerant crops at farm, WUA and regional level
- At regional level the direct and indirect effects of modelled improved drainage (and subsequent investment in higher value crops) proved far greater than the costs of the drainage, and produced the highest index for socio-economic welfare (ISEW), and an addition of jobs to the irrigation and linked industries over the long term.
- The total real cumulative cost (2005 basis) of salinisation over a period of 15 years for the whole study area was calculated at R955 million¹, a good benchmark to use to leverage funds for remediation action.

This above mentioned presents an overwhelming case for the full sustainability (“green box”) grant assistance of additional irrigation drainage in the interest of increased sustainable regional socio-economic welfare.

RECOMMENDATIONS

The main recommendations of this research are the following:

- Drainage installation for facilitation of leaching needs to be promoted in the Orange-Vaal WUA (**Vall**) and especially in the Lower Riet (**RloR**) Irrigation Blocks in the study area. 10% and 20% of **RloR** and **Vall** Irrigation Blocks irrigable area respectively are indicated to be drained. Factoring in the costs of drainage into irrigators’ water tariffs, is less than the additional financial benefits derived from the drainage, and should therefore be acceptable to farmers. This should however be re-evaluated with a detailed survey and feasibility study.
- If the **Rscm** and **Rszg** Irrigation Blocks are to be drained, before salinity builds up to levels which result in financial losses, at least a 50% assistance grant of the total drainage costs would be needed to make the option financially viable and acceptable for the irrigators.

¹ R995 million is the 50th percentile value for 100 stochastic runs. At a “worst case” modelled sequence (stochastic run 080) this figure could be as high as R1.1 billion, and at a “good case” modelled sequence (stochastic run 044) this figure could be as low as R839 million (see Table 9.7)

- Just as in an environmental management plan, remedial action for possible environmental and unsustainable practises have to be planned and budgeted for at initialization, the results confirm the recommendation for the planning and installation of drainage before the implementation of any new scheme (i.e. Oppermansgronde).
- The improvement of agricultural productivity from increased investment in irrigation drainage far outweighs the costs and has a positive ripple effect through the economy. Financial support from National Government can thus be motivated to provide sustainability assistance grants to farmers.

Other recommendations that could be implemented or initiated by the Department of Agriculture, WUAs, GWK, etc. in the irrigation areas include:

- Subsidise agricultural extension to regularly measure, archive and communicate soil salinity status, trends and threats.
- Promote soil salinity status readings by fertilizer companies when conducting soil analyses and making fertilization recommendation.
- Promote inquiry into the salinity status of soils when purchasing irrigation land.
- Increase awareness to insurance companies of the potential increased risk of salinised soils if not managed properly.

These salinity awareness programmes must be coupled with a centralised soil salinity database to facilitate the accumulation of soil salinity data for better policy analysis and research in the future, as one of the limitations identified in this study is a shortage of historical soil salinity data.

POTENTIAL USERS OF THIS RESEARCH

The following uses by different stakeholders are *inter alia* envisaged:

- For the WRC and policy planners, information on the nature and extent of the problem at regional level are provided. This will inform future research needs and policy development.
- For the WUA managers, an indication of the source of the cause of the salinity problem, the financial extent of the problem, the potential gains of remedying the problem and cost effective options to manage irrigation salinity are presented to build their capacity to do more effective and sustainable water quality management.
- For farmers, practical per hectare benchmarks of the impact and extent of salinity (CEBs), and a simple method of calculating the per hectare reduction in yield and subsequent impact of crop profitability is described; information useful for more efficient and sustainable management of salinisation at farm level.

DEGREE TO WHICH THE AIMS HAVE BEEN MET

Although less elaborate than initially proposed, this project has succeeded in refining and identifying critical obstacles towards more integrated salinity economics modelling, and in coming up with plausible results suitable for meaningful farm, sub-WUA, WUA, CMA and national policy interventions and strategic decision making.

On the one hand the decision to abandon the optimisation approach for the simulation approach resulted in the loss of useful management information such as the determination of optimal cropping combinations and related shadow prices. On the other hand, there were also meaningful gains in applying the simulation approach. A more thorough and practically applicable scenario analysis was for instance possible with simulation. All in all, the stated aims of this research were accomplished to a satisfactory degree.

FUTURE RESEARCH NEEDS

- *Internalising externalities* – determine the best way and acceptability to internalise the costs of salinisation created by farmers at different locations along the river.
- *WRPM upgrade* - A more user friendly version of the WRPM model needs to be developed that other operators can use. A suggestion would be to transfer the existing data bases and setup information from the outdated model coding platform, into a user friendly GIS based model framework / application already developed, (e.g. DHI's Mike Basin).
- *Hydrology Model refinement* - The refinement of the WRPM set-up (once its been upgraded) to include the sub-WUAs identified in Chapter 3 as irrigation blocks, will provide better results especially to differentiate the Orange-Vaal WUA (*Vall*) Irrigation Block.
- *Local salinity yield response data* - More up to date and locally applicable measures of crop salinity threshold and gradient values, may be more applicable and relevant as those used in this study, mostly calculated in laboratory situations in California.
- *Soil salinity data base* - one of the limitations identified in this study was a shortage of historical soil salinity data. Salinity awareness programmes must be coupled with a centralised soil salinity database to facilitate the accumulation of soil salinity data for better policy analysis and research in future.

CAPACITY BUILDING ACHIEVED WITH THIS STUDY

Research capacity was built at graduate level in two female researchers from previously disadvantaged communities, one working with UrbanEcon and one at the UFS. Both however left the organisations to work at other institutions. Miss K. Nailana (UFS student) plans to complete her master dissertation at the UFS based on the work done through this project with developing irrigation farmers in the project study area.

At post graduate level research capacity was built at Ph.D. level with one white male student at the UFS, and with two working at UrbanEcon.

Further capacity will be built with different decision makers as elaborated in the next paragraph.

PROPOSED TECHNOLOGY TRANSFER ACTIONS

To effectively disseminate the results of this study, a technology transfer phase is proposed. Besides further applying the models at case study farm level in the already researched area, applying them in an additional study area, the Lower-Orange Irrigation area, researched from a bio-physical perspective by Volschenk *et al.*

(2005) is deemed necessary. This will aid in the development of policy guidelines for obligatory state assistance (e.g. sustainability grants) for irrigation drainage installation for sustainable national resource protection and conservation and contribute to capacity building with different groups and institutions.

The six main activities of the technology transfer exercise would be:

1. To present the results of the existing study to the National, Free State (FS) and Northern Cape (NC) Departments of Agriculture (DoA) to get their buy-in, co-operation and support for the application of the developed economic models to case study farms with salinity problems in the OVR and Lower-Orange Irrigation areas
2. To hold information sessions/workshops with DWAF, the Orange-Riet and Orange-Vaal WUAs, Agri-businesses (e.g. GWK Pty.Ltd.) and farmers to explain the findings of the current study and to get practical pointers for the farm level analysis to follow.
3. To apply the developed economic models to identified case-study farms in the already researched study areas for farm level drainage feasibility analyses.
4. To adapt (mainly for viticulture) and apply the developed economic models to identified case-study farms in the additional study area of the Lower-Orange Irrigation region for farm level drainage feasibility analyses.
5. To present the results from the additional Technology Transfer Study (case-study farm specific) to farmers, Water Users Association (WUA) staff, government and agribusiness officials / extension officers, and irrigation research professionals through farmers day presentations, brochures and the internet.
6. To compile a user friendly technology transfer report to effectively aid in grassroots level salinisation management.

CHAPTER 1. INTRODUCTION

by R.J. Armour, and M.F. Viljoen – UFS

The purpose of this introductory chapter is the following:

- to sketch the background situation leading to the identification of this research
- to state the problem stemming from the background overview
- to formulate the project aims of this research
- to briefly discuss the methods followed, and
- to map/lay-out the rest of this report for the reader.

1.1. BACKGROUND

The purpose of the The National Water Act (39 of 1998) which gets its mandate from (amongst others) Section 24 of the Bill of Rights in the Constitution, is to ensure that the Nation's water resources are protected, used, developed, conserved, managed and controlled, to *inter alia* promote the efficient, sustainable and beneficial use of water. To achieve this, ongoing research on the different aspects mentioned is needed. For instance, further research to ensure the sustainability of irrigation schemes in South Africa is essential to ensure national food security and employment in some otherwise barren area of the country.

It has been predicted that by the year 2025 South Africa will be the only surplus food producer in the whole of Sub-Saharan Africa, thus making the stability of food supply, made possible by irrigated agriculture, a stabilising force not only in South Africa but also in most of the rest of Africa (Winpenny, 2002). At the same time however it is also predicted by a recent World Bank study (Seckeler *et al.*, 1999) that water scarcity in South Africa will increase drastically in the nearby future moving its status from somewhere between 2005 and 2040 from a water scarce to a water stressed country. Together with increasing water scarcity, declining water quality levels in most of our rivers will further threaten the productive use of this water for food production.

With irrigation being the largest user of water, field-, farm- and Water Users Association -level research that can contribute to more efficient water use and better water quality management is essential to maintain our most valuable resource and the agriculture which it supports, and also to release water for other sectors of the economy. However, macro-level research is also needed to place into perspective the national benefit of improving water use efficiency and better water quality management (and the costs of not doing so), as well as to guide the public policy making process in the right direction. Furthermore, macro research takes into consideration the secondary economic, socio-economic and environmental effects that stem from the results of the micro research.

The dynamics of water -use, -pollution and -control are so tightly interwoven by a multitude of external factors that the traditional style of mono-disciplinary research is no longer suited to achieve overall satisfactory results (McKinney *et al.* 2000). To proactively manage and implement policy to anticipate problems, and sustainably introduce change, the best information obtained from comprehensive multi-disciplinary research is needed.

By understanding the full dynamics and interactions between irrigation water quality and the soil salinity status on crop yield over irrigated time, mistakes made in the past by choosing unsustainable irrigation sites and practices can be prevented. Furthermore the impact of various natural or artificial (e.g. policy mechanism) scenarios on existing schemes can be more accurately modelled, leading to increased economic efficiency and sustainability of the irrigation industry as a whole. However “current USDA Salinity Laboratory evidence suggests these interactions are far more complex than originally thought... Rhoades, the doyen of soil/plant/salinity interactions, contends that no one has succeeded in combining all the refinements necessary to overcome the inherent problems of relatively simple salt balance models and geophysical sensors, to address the enormous field variability of infiltration and leaching rates” (Blackwell, *et al.* 2000).

Current literature and research on salinity management in irrigation agriculture also fails to capture the stochastic nature of inter-seasonal irrigation water quality as well as the cumulative economic and sustainability effects of irrigating with stochastic water quality levels. DWAF, 1996 mentioned the following in this respect: “Further limitations for setting criteria for salinity include: (i) The need to make assumptions about the relationship between soil saturation extract salinity (for which yield response data is available) and soil solution salinity. (ii) The deviation of the salinity of the soil saturation extract from the mean soil profile salinity, to which crops would respond. (iii) The criteria for crop salt tolerance do not consider differences in crop tolerance during different growth stages.”

The proposed micro-level research follows on a previous study entitled “The Economic Effects of Changing Water Quality on Irrigated Agriculture in the Lower Vaal and Riet Rivers”. The water quality problem set out to be studied in the previous project was initially perceived with the main variable being the water quality changes of in stream irrigation water. DWAF data recorded over many years was studied and incorporated into models, but the essence of the problem remained unresolved. This being the indirect and long-term accumulation effects of irrigation water carried constituents within irrigated soils and their underlying water tables, and the effects of the resulting returnflows from these soils and groundwater on downstream irrigation water quality.

The proposed macro-level research, to determine impacts at regional level, follows on an Urban-Econ study that was successfully completed using economic simulation modelling to identify and quantify the economic impacts of salinity in the Middle Vaal River System. The Input/Output technique was used as the simulation model and various applications of the model were used to determine the results.

This project therefore essentially consists of two separate projects, but it was deemed necessary for synergy and the achievement of optimal project results that the micro and macro level models be linked. Also, for Urban-Econ to extend the scope of their previous salinity research downstream and for the Department of Agricultural Economics to enhance their static model by developing a dynamic model for the area, the complex Orange-Vaal-Riet convergence system was suggested as the study area for this project. Degraded returnflows from 3 major irrigation schemes comprising $\pm 60\,000$ hectares all come together within the proposed study area where the dilution effect of Orange River water is critical. The area is also a main economic force in the Northern Cape with strong agriculturally based industry such as GWK Pty. Ltd., many strong farmers reliant on irrigation and further irrigation potential for previously disadvantaged farmers. Isolated from other crop farming areas the area is strategically located for the production of a large portion of the country's seed, further stressing the importance of irrigation in this area and thus the large negative effects of proposed water transfers away from the area.

Concerning land redistribution, there are areas within the study area that are earmarked for resettlement of historically disadvantaged individuals. To avoid making mistakes of the past and designing irrigation schemes in areas which might not be economically and environmentally sustainable, a thorough understanding of potentially land degrading processes such as salinisation, sodification water logging etc. is essential.

This research proposed to address the current void in existing research and within a multidisciplinary framework, aims to better understand the dynamic interactions between the hydrology, bio-physical and socio-economy for irrigated agriculture in the Orange-Vaal-Riet convergence system. The objective is to determine the current trends, private-, social- and regional- impacts, externalities, and the long-term sustainability of these practices. With these interactions better understood the impact of various policy measures and management practices at farm, WUA, inter-WUA and at a regional level will be able to be modelled to determine the potential impacts on the sustainability of irrigated agriculture, communities and the eco-system of the Lower Vaal, Riet and Middle Orange River systems.

The resulting models will be used to monitor the economic impact of changing water quality over time and the method developed can be applied with the necessary modifications to other river reaches.

1.2. PROBLEM STATEMENT

The main problem for investigation in this study is the serious threat to the long-term sustainability of irrigation in the Orange-Vaal-Riet convergence system posed by salinisation, and the serious impact that this can have on the social welfare of the region as a whole. Various policy and management options have been identified in previous studies, but an inter-disciplinary approach is required to test the applicability and sustainability of these options, posing its own set of problems.

1.2.1. SUB-PROBLEMS

1.2.1.1. Interdisciplinary model integration for effective soil salinity impacts interpretation

The short-term economic impact of irrigation water quality fluctuation in the Lower Vaal and Riet Rivers was quantified in a study by Armour and Viljoen (2002), but the build-up of salts in the soil was identified as a potential long-term problem. The integration of this build-up of salts in the soil over time together with the hydrology of the study area, the biophysical interactions that relate soil salinity to crop yield, and the economic impact of changing crop yields due to salinity, form the basis of investigation for this study.

1.2.1.2. Deciding on additional leaching versus switching to salt tolerant crops as the best salinity management option

The application of additional irrigation water for leaching is required to wash salts out that have built up in the soils over time, however where soil type or topography does not allow for natural drainage from the soil, either salt tolerant crops need to be planted or expensive artificial drainage installation is required. Whether farmers can survive planting salt tolerant crops or whether they can afford to pay for the additional drainage, and what grant assistance policy may be required are the second and third sub-problems analysed in this study.

1.2.1.3. Internalising the downstream impacts of additional leaching and drainage

Downstream externalities from point and non-point source drainage as a result of additional leaching needs to be quantified, together with the impact of the additional leaching on downstream farmers, so that effective policy decisions as to who pays for remediation action, and at what cost to effectively internalise the costs of leaching, can be made.

1.2.1.4. Quantifying the importance of salinisation at a regional level

As salts, mobilised through leaching and drainage, migrate, a solution to one farmer may be a problem to another. Furthermore, a solution for farmers in general in an area, may have serious repercussions on employment / the environment / other secondary industries either supplying inputs to irrigation agriculture or be involved in further benefaction of the produce from irrigated agriculture. Therefore, the analysis at a regional level is required to holistically assess the salinity problem.

1.2.2. HYPOTHESES

The hypotheses that follow tie up with the sub-problems identified in the preceding paragraph, and each one is followed by a relevant research question:

- Soil / plant / atmosphere interactions and salt balance models can be successfully incorporated onto economic models to effectively interpret soil salinity at micro and regional levels.

The research question is which models and how?

- In low rainfall areas, the inevitable salinisation of soils irrigated with poor quality water can be managed sustainably through either increased leaching, or shifting to more salt tolerant crops.

The research question is which management option is more sustainable?

- Through the application of correct policy and management interventions, the downstream externalities associated with additional leaching and drainage can be internalized with a positive net regional benefit.

The research question is which policy and management interventions are required and what institutional framework needs to be in place?

- Irrigation agriculture is essential for sustainable regional social economic welfare in the study area.

The research question is how would one go about determining regional social economic welfare?

1.3. PROJECT AIMS

The overall aim of the project was the development and integration of multi-dimensional models for the sustainable management of water quantity and quality in the Orange-Vaal-Riet convergence system. To achieve this, the following sub aims are identified:

1. To better understand the polluting chemical processes and interactions in and in-between the plant and surface-, vadose zone- and ground- water, to achieve efficient and sustainable water quality management

2. To develop new economic models at both,
 - a. Micro level, namely dynamic long term simulation¹ models, and at
 - b. Macro level, using regional dynamic Input / Output model
3. To integrate these new economic models with models from the other disciplines of:
 - a. Hydrology² (incorporating a salt mass balance and flow), and
 - b. Agronomy (crop growth in the presence of salinity model)
4. To determine and prioritise best management practises at:
 - a. Micro level, (i.e. per hectare and irrigation block level) and at
 - b. Regional level.
5. Through a better understanding of the multi-dimensional interactions, to enhance water use efficiency as the quantity and quality of water available for agriculture inevitably decreases
6. To develop policy guidelines to ensure social, environmental and economic sustainability
7. To achieve all these aims based on using the complex Orange-Vaal-Riet convergence system as a study area, but developing the method followed and models so that they can be applied elsewhere with relative ease.

1.3.1. RESEARCH PRODUCTS AND TARGET GROUPS

1.3.1.1. Regional hydrology model (WRPM) results

The Water Resources Planning Model (WRPM) results provide stochastic water quality and quantity predictions for the various river reaches and irrigation blocks in the study area for the various scenarios tested, based on approximately 70 years of historical data. Results from the WRPM indicate the changes in hydrology, irrigation block upper and lower layers and return flow impacts of the management options tested in the various scenarios. These results should prove useful for farmers, WUA managers and policy planners.

1.3.1.2. Bio-physical (Vadose zone salt balance) model results

Although very rough, the salt balances worked out in the WRPM for the Upper and lower soil zones, provide farmers with an indication of the state of their soil salinity for assessment of future improvement / degradation, contributing to a greater understanding of the soil salinisation process, and resulting in more effective management of soil salinity in the study area.

1.3.1.3. Irrigation Block level simulation model (SMSim)

SMSim results help guide the management of irrigation water of varying quality and help determine the sustainability of current and simulated farm practices. SMSim also evaluates the impact at variable cost level, of

¹ The initial aims stated that an optimization model would be used, but this aim was changed at a Reference Group meeting to a simulation approach.

² The initial aims also included the integration of vadose zone (unsaturated root zone) chemical balance models and groundwater (saturated - below water table) models. The incorporation of the WRPM as the hydrology model fulfilled both there requirements to a certain degree.

policies and management options aimed at improving the economic sustainability of farms at per hectare and irrigation block levels.

1.3.1.4. Regional Input / Output model (ISIM)

The regional economic model, ISIM, through the use of an elaborate input/output matrix, determines the secondary effects on other sectors of the regional economy, the environment and job creation of various policies / management options modelled, and provides a potential method for input/output analysis modelling of other river reaches. Through the use of the index for socio-economic welfare (ISEW) different policy and management options can be compared, taking the environmental, social and secondary economic implication into consideration. This is an important tool for water policy makers, local government and regional planners.

1.4. APPROACH / METHOD FOLLOWED

The approach followed for this report consisted of the following steps:

- Study area and research orientation and planning
- Multi-dimensional background research and literature study
- The formulation of the integrated conceptual framework
- Model design and testing
- Data collection and processing
- Model runs, validation and the analysis of the data
- Management and policy recommendations

The report writing process was ongoing throughout the duration of the project, preparing reports for reference group meetings.

1.4.1. ORIENTATION

The following actions were carried out in the initial orientation phase of this research:

- The classification of land-uses and economic activities according to generally acceptable systems (integrating an economic classification system with a hydrological system),
- The delineation of the study area, and
- The identification and sourcing of background information.

1.4.2. MULTI-DIMENSIONAL BACKGROUND RESEARCH (LITERATURE STUDY)

The purpose of this step was to undertake a detailed specialist evaluation of the multi-dimensional components underlying the integrated modelling. The research undertaken during this step was aimed at understanding and identifying relevant applicable models, obtaining an indication of the type of base / set-up data required, compiling profiles, identifying trends and identifying the main problem areas.

A combination of study area specific information gleaned from existing reports and documents was used in compiling Chapter 2 and discipline specific information used for Chapters 4 (Hydrology), 5 (Bio-physical) and 7 (Macro-economic) chapter formulation.

1.4.3. INTEGRATED CONCEPTUAL FRAMEWORK

The purpose of this step was to develop an integrated conceptual framework that provides a reference framework for the salinity modelling. This framework guided the design and the development of the model. The first action was to conceptualise the problem and express it as a functional relationship (i.e. the objective function). Such a relationship is the first move towards economic modelling as it represents the base formula for the model. In finalising the framework, the data needs of the model were identified providing the specifications for the data gathering actions. A conceptualisation workshop was held with key role-players and technical experts to finalise the conceptual and generic modelling approach of the study.

1.4.4. MODEL DESIGN

To ensure that the model functions optimally, it is essential that the modelling and database design is done in terms of generally accepted IT principles and criteria. These also provide indications for the format of input data, which in turn provides guidelines for the data gathering actions. The design of the database (or collection of files) is primarily based on the data needs as determined in step three, generally referred to as User Requirements Specifications (URS).

An integral part of the design of the model was piloting the system to test the operation, interface capabilities, reporting, etc. All the relevant information obtained during steps one and two are included in the model. This phase of the model development process is therefore the first order model, representing existing profiles and interrelationships. As part of the testing process, all changes or adaptations to the model design were done at this stage.

1.4.5. DATA COLLECTION

The purpose of this step is to undertake primary and secondary data gathering exercises to obtain data for each of the functional relationships as specified in the model. The data gathering exercises are thus aimed at obtaining data in accordance with the URS of model. The data collection included selected surveys and sampling as well as interviews with specialists and key role-players. The information obtained by means of the data gathering exercises is computerised for inclusion in the model.

1.4.6. ANALYSIS

The purpose of this step is to analyse and transform the data to be used in the model. The data gathered during the data collection step is computerised, analysed and utilised in the model framework developed during integrated conceptual framework formulation step. An integral part of this analysis is to undertake sectoral and technical evaluations which provide the necessary background for interpreting the data. The results of the analysis are used to determine the nature and extent of water quantity and quality impacts at both micro and macro level.

1.4.7. MANAGEMENT POLICY RECOMMENDATIONS

The purpose of this final step is to utilise and interpret results from the preceding steps to formulate strategic guidelines for micro and regional level management and policy formulation.

Recommendations are formulated based on the integrated economic, biophysical and hydrologic modelling results. These include the following: Policy recommendations, modelling applications suggestions, pricing options, water resource allocation options, pro-active intervention focus area, Application of research findings, Policy guidelines, Governance and intervention, and Sectoral focus on intervention.

1.5. SUMMARY

In summary, this chapter:

- sketched the background situation leading to the identification of this research,
- listed the problem statement stemming from the background overview,
- formulated the project aims of this research, and
- briefly discussed the method followed.

The final paragraph of this chapter that follows, maps the lay-out of the rest of this report for the reader.

1.6. REPORT LAYOUT

The rest of this report consists of the following:

- Chapter 2, which sketches the spatial and temporal delineation and main characteristics of the study area.
- Chapter 3, also an introductory chapter in a sense, formulating and mapping out the integrated conceptual framework of the research that follows, briefly introducing other chapters and integrating them as a whole.
- Chapter 4, compiled by WRP consultants, explains the set-up and working of the Water Resources Planning Model (WRPM) selected for this study to generate applicable hydrology data sequences.
- Chapter 5, which is an explanation of the various bio-physical components and sub-models that link the hydrology and economic models together.
- Chapter 6, is a detailed layout and explanation of the micro-economic model (SMsim) developed for this study, calculating per hectare crop enterprise budgets (CEBs) and taking these to irrigation block level total gross margin above specified cost (TGMASC) level results for analysis of the economic impact of salinisation.
- Chapter 7, compiled by UrbanEcon, is a detailed layout and explanation of the regional economic model (ISIM) developed for this study, taking the irrigation block level TGMASC results to regional level and incorporating the forward and backward linkages on the regional economy through the use of Input / Output tables. An index for socio-economic welfare (ISEW) is also calculated as an indication of the long-term economic, environmental and social sustainability of the various options analysed.
- Chapter 8 which motivates, sketches and discusses the various scenarios modelled.

- Chapter 9 is the presentation and discussion of the micro-economic level model results.
- Chapter 10, also compiled by UrbanEcon, is the presentation and discussion of the regional economic level model results.
- Chapter 11 is a discussion and on the implication of the results for management and policy decisions.
- Chapter 12 summarises the report, lists the overall conclusions and provides a synthesis of the work done in this study, leading to important lessons learnt and further research needs.

Five appendixes also follow consisting of the following:

- Appendix 1 is a detailed description of the physical process followed in compiling, setting up, running, transferring and interpreting data to operate the SMsim.
- Appendix 2 tabularises the full set of hydrology set-up data used, showing updates implemented through this project to the national WRPM.
- Appendix 3 lists complete crop enterprise budgets, the basis of the SMsim, for all 20 crops incorporated in the model.
- Appendix 4 is a summary of the mathematical formulation of SMsim as described in full in Chapters 5, 6 and 7.
- Appendix 5 is an elaboration of the data setup tables and results of the regional economy model, ISIM, and relate to chapters 7 and 10.

CHAPTER 2. THE STUDY AREA

by R.J. Armour, and M.F. Viljoen - UFS

2.1. INTRODUCTION

The aim of this chapter is to describe the study area of this report, highlighting only of the main characteristics relevant for this report. Aspects addressed include:

- the study area in general, defined by geography, topography, climate, and economic activity
- the Water User Associations (WUAs) that fall within the study area,
- and the irrigation blocks that are made up of sub-WUAs areas, and are the spatial level at which the majority of analysis of this report takes place.

As Chapter 4 and Chapter 7 deal specifically with the hydrology and regional dimensions respectively, finer study area delimitation and detail occurs in these chapters.

The physical boundaries and characteristics of the various hierarchical levels (per hectare up to regional level) modelled in this study, are compiled from biophysical, hydrologic, economic and political boundaries that further differentiate areas within the study area.

As this study is based on hydrology model data, the significance of the different hydrology dynamics between irrigation blocks, and how these dimensions are to be captured in this study, are discussed in the final paragraph before the summary in this chapter.

2.2. GEOGRAPHY



Figure 2.1 shows the placement of the study area in South Africa. The study area spans two provinces, namely the Northern Cape and Free State. The provinces are subdivided into district municipalities as discussed in Chapter 7, where the selection of the relevant regional municipalities for delineation of boundaries for regional economic analysis in this study is described.

Figure 2.1. The position of the study area within South Africa

2.3. TOPOGRAPHY

Douglas, the main town in the OV-WUA is positioned 1030 meters (3263 ft) above sea level at the following GPS coordinates 29°03'16.85" S, 23°46'41.64" E (Google Earth, 2006).

Jacobsdal, the main town of the OR-WUA is positioned 1140 meters (3791 ft) above sea level at the following GPS coordinates 29°13'05.71" S, 24°48'48.41" E (Google Earth, 2006).

The topography of the area is typical Kalahari plains with small hills. Large salt pans have formed in the troughs and often hill tops and higher lying areas are covered in deep red soil. Limestone layers are also exposed in places, which can cause impermeable layers and can *inter alia* lead to water-logging.

2.3.1. HYDROLOGY

Shown in Figure 2.2, the study area falls within 3 major river catchments in South Africa, namely the Upper Orange, Lower Orange and Lower Vaal River catchments. Also shown in Figure 2.2 are the transfers from the Upper Orange River catchment via the Orange-Vaal and Orange-Riet canals into the Lower Vaal catchments

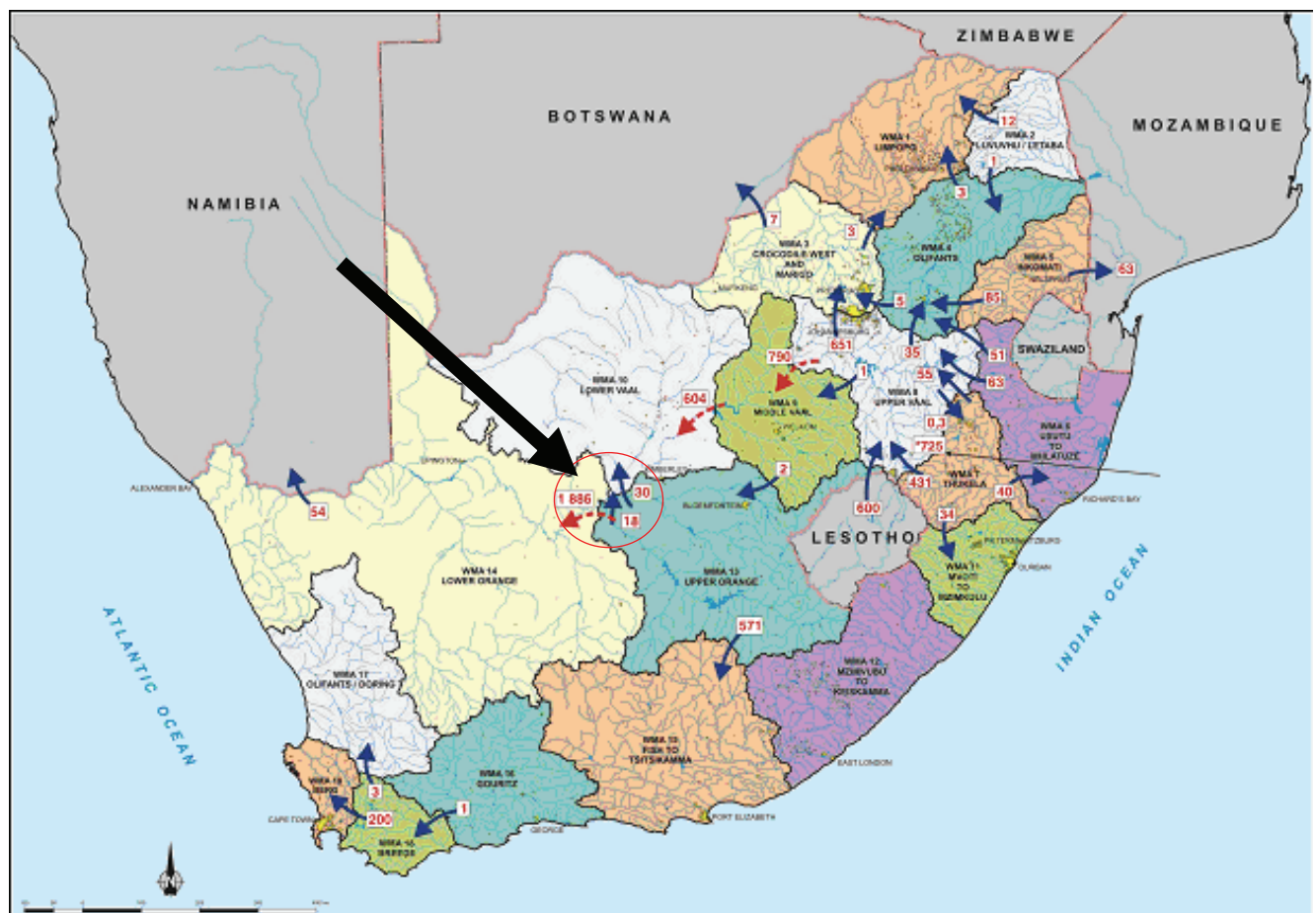


Figure 2.2 River catchments and inter-basin transfers of South Africa (Ninham Shand, 2004)

Figure 2.3 shows the generalised mean annual precipitation isohyets in millimetres after, seasonal rainfall zones and the main two rivers of South Africa in relation to the study area, positioned at the confluence of the Orange and Vaal Rivers. Deduced from Figure 2.3, the study area lies in an arid summer rainfall region receiving approximately 325 mm of rain annually. Also indicated, and of particular significance to this study, is that the Orange River headwaters are in the sparsely populated Maloti Mountains of Lesotho, receiving pure snowmelt and rainfall, resulting in a good irrigation water quality downstream. The Vaal River on the other hand has its headwaters in the densely urbanized, mining and industrial hub of South Africa around Johannesburg, receiving potentially polluted returnflows that could contribute to poorer irrigation water quality (du Preez, *et al.* 2000). The water quality is however effectively managed at the Vaal barrage long before reaching the study area. The returnflows from the Vaal-Harts WUA, situated upstream of the study area, collect in the Spitskop Dam in the Harts River tributary to the Vaal River, where salts have been concentrated over time. Spitskop Dam releases can have an impact on the salinity of Vaal river water entering the study area. Although levels of dissolved salts elevate as one moves downstream, the main cause of soil salinisation is as a result of the process of irrigation itself (Volschenk *et al.*, 2005), releasing latent salts accumulated in the soils in the low rainfall areas as depicted in Figure 2.3.

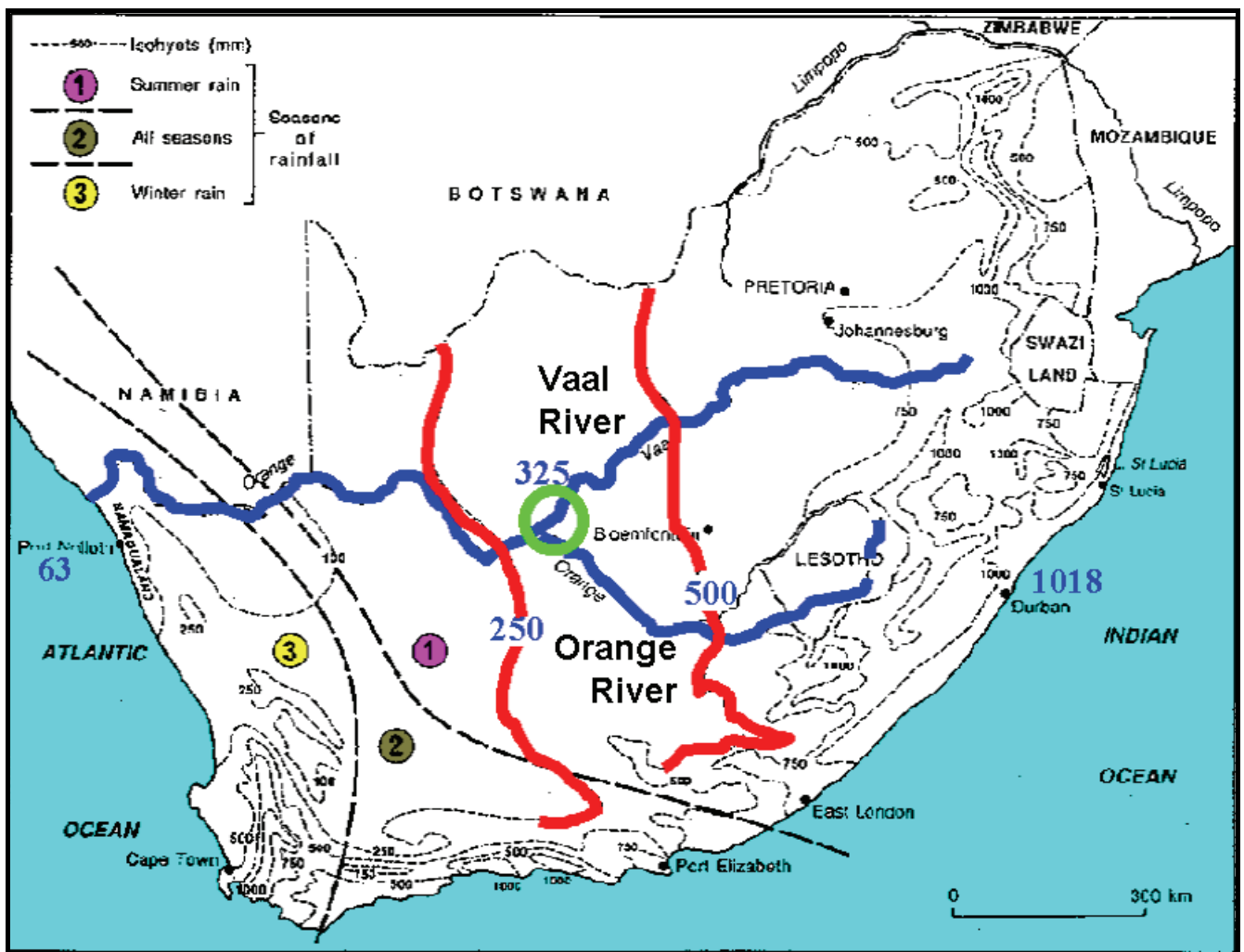


Figure 2.3 Generalised mean annual precipitation (mm) isohyet, seasonal rainfall zones and the main two rivers of South Africa in relation to the study area at the confluence of the Orange and Vaal Rivers

2.4. CLIMATE

Rainfall - Figure 2.3 shows that the study area lies between the 250 mm and 500 mm isohyet and in a summer rainfall season region. Historical mean annual precipitation at the town of Douglas, in the OV-WUA is 355 mm per annum, and at Jacobsdal in the OR-WUA 366 mm per annum. Summer rainfall occurs mainly from November to March.

Evapo-transpiration - Figure 2.4 shows the reference evaporation (mm) for Douglas and the Riet River scheme using the Douglas jail data set. With evapo-transpiration reaching 2000 mm per annum, and a rainfall of only 300 to 400 mm per year, the need for a large volume of irrigation to grow crops is evident.

Temperature – temperatures often exceed 40°C at midday in the hot summer months from December for February, with frost occurring in the winter months, limiting the choice of certain high value crops and the duration others can be planted.

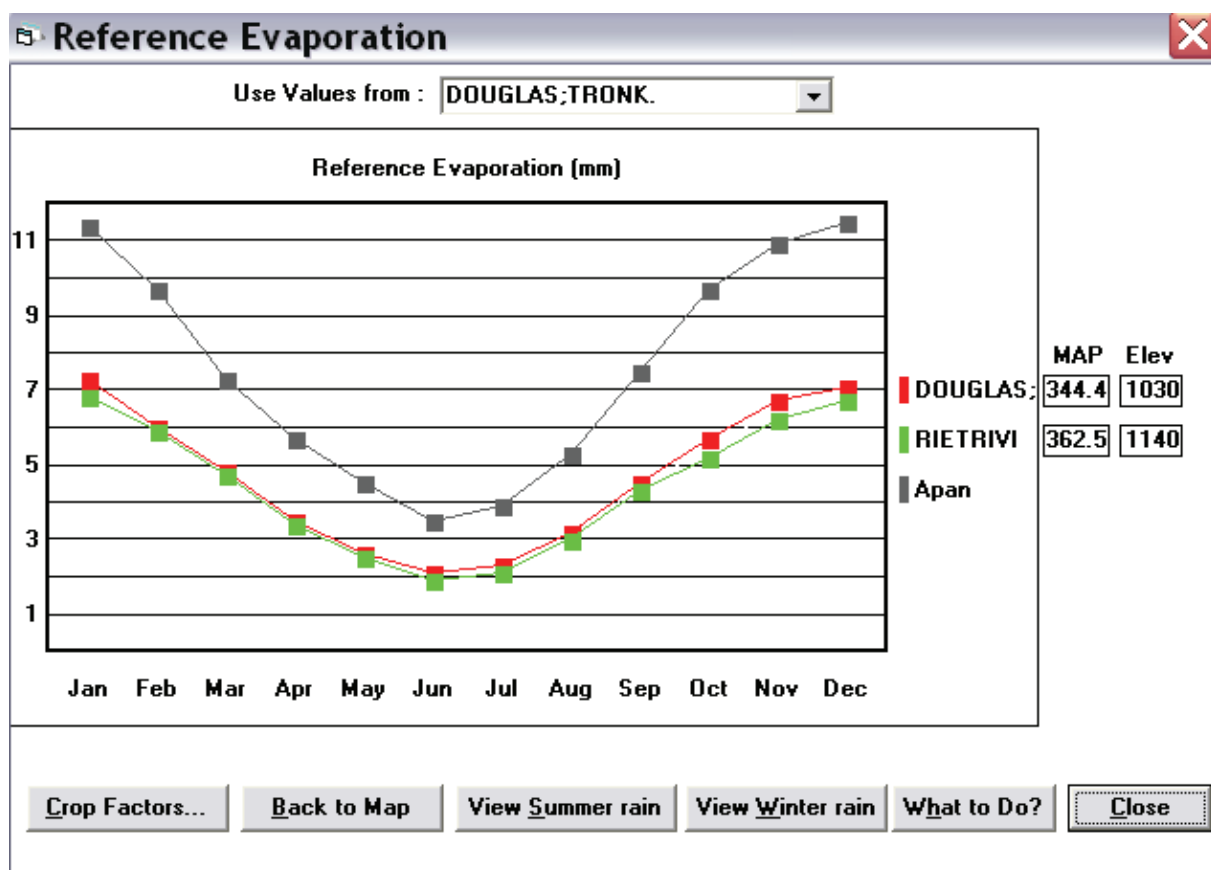


Figure 2.4. Screen from SAPWAT showing the reference Evaporation (mm) at the Douglas jail.

2.5. DEMARCATION OF THE STUDY AREA

2.5.1. REGIONAL DELINEATION

This study does not look at the impacts at national and provincial level, but focuses on the regional level enclosed by the municipal boundaries that overlap the hydrology demarcation of the study area. The outer

perimeters of the total study area under investigation follow both administrative and hydrologic borders. The administrative boundaries used in the regional analysis of this study are the boundaries of the municipalities shown in Figure 7.3. The quaternary catchments covered in this study are shown in Figure 7.4. The study area boundaries are also indicated schematically in Figure 2.5 and Figure 2.7.

Hydrologically, the study area falls within these boundaries;

- Vaal River, downstream of the Bloemhof Dam to the confluence with the Orange River
- Orange River, the Orange-Riet and Orange-Vaal Canal extraction points downstream of the Vanderkloof Dam to the Orange-Vaal Confluence where the returnflows of the study area re-enter the Orange River
- Riet River, downstream of the Kalkfontein Dam to the confluence with the Vaal River

This encompasses the Orange-Vaal (OV-WUA) and Orange-Riet (OR-WUA) Water Users Associations (WUAs).

2.5.2. WUA DELINEATION

Figure 2.7 is a schematic diagram of the regional hydrology and some external factors that impact on the salinisation of the study area, also showing the position of the WUAs in the regional geography and in relation to one another.

Shown in Figure 2.5 is that:

- the OV-WUA lies directly downstream of the OR-WUA along the Riet River
- Besides OR-WUA returnflows, the OV-WUA is also subject to the Vaal-Harts irrigation scheme returnflows when released from Spitskop dam into the Vaal river upstream
- The Orange-Vaal and Orange-Riet extraction canals that pump Orange River water to the Vaal and Riet WUAs respectively
- Canal, Scheme, Scholtzburg and Lower Riet are the sub-WUAs¹ of the OR-WUA
- Olierivier, Vaallus, Atherton, Bucklands and New Bucklands are the sub-WUAs of the OV-WUA
- Besides irrigation agriculture there are also water demands from mining, municipalities, and for the environmental reserve
- The Oppermansgronde (800ha) is also indicated in Figure 2.5 as a planned future sub-WUA of the OR-WUA for the previously disadvantaged community living there. The area has deep red sandy soils with high irrigation potential and its development will promote equity in irrigation water use in the Free State province. Although good quality Orange River irrigation water may be received via the Orange Riet Canal, good natural drainage alone may not be sufficient for the effective leaching of salts that may accumulate over time from the soil.

¹ Ritchie is not shown in Figure 2.5 as a sub-WUA

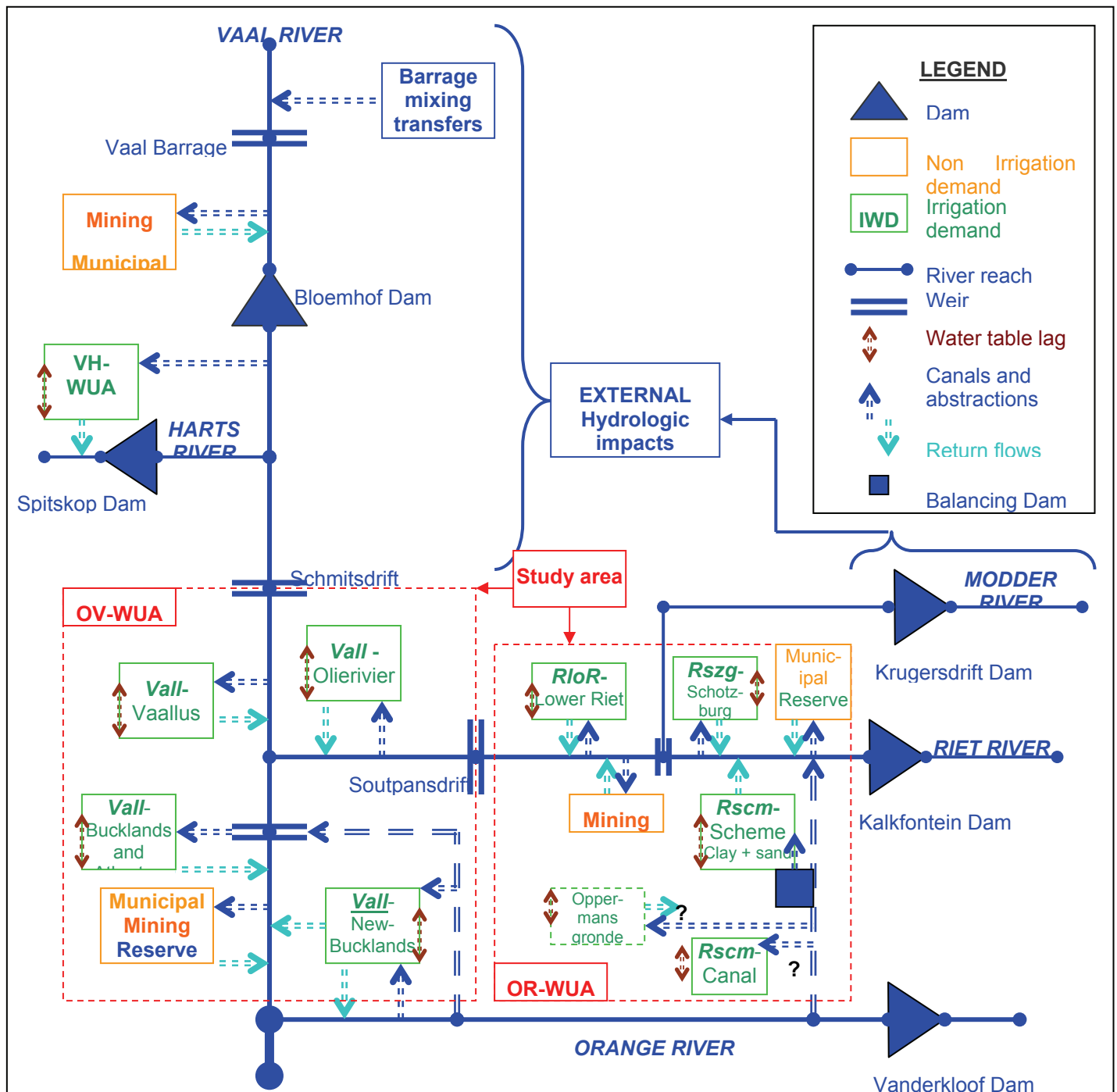


Figure 2.5. A schematic diagram of the regional hydrology impacting on the WUAs that make up the study area

2.5.2.1. Orange-Riet WUA

The Orange-Riet WUA is divided into 5 sub-WUAs, as shown in Table 2.1, covering a total area of 16 771,3 hectares on which 371 irrigators farm:

- The **Riet River Scheme sub-WUA** makes up 48% of the OR-WUA irrigated area, with 50% of the 371 irrigators in the OR-WUA farming on an average farm size of 43.5 hectares.

- The **Orange Riet Canal sub-WUA** is the newest sub-WUA, formed after completion of the Canal in 1987. The area comprises 3970 hectares (24% of the WUA area), with 44 farmers irrigating on an average farm size of 90.2 hectares per farmer, the largest average farm size in the WUA.
- Developed in 1932 as small holder irrigation plots, the **Ritchie sub-WUA** is the smallest, comprising 96.8 hectares (1% of WUA area) on which 75 irrigators farm (20% of the WUA irrigators) on an average of 1.3 hectares.
- The **Scholtzburg sub-WUA** comprising 721.6 hectares (4% of the WUA area) is the second smallest sub-WUA in the OR-WUA and smallest irrigation block analysed in this study.
- The **Lower Riet sub-WUA** of the OR-WUA comprises 3937.9 hectares irrigated lands, (23% of the OR-WUA total) occupied by 51 irrigators (14% of the OR-WUA irrigators) with an average farm size, the second largest in the OR-WUA, of 77.2 hectares.

The three sub-WUAs, namely the Scheme, Canal and Ritchie sub-WUA, are joined as one irrigation block (**Rscm**) for the purposes of this study, whereas Scholtzburg (**Rszg**) and the Lower Riet (**RloR**) sub-WUAs are analysed as such.

Table 2.1. Sub-WUAs of the Orange-Riet WUA (Source: Ninham Shand, 2004)

Sub-WUA	Irrigation Block	Irrigated Area (ha)	% of total area	Irrigators	% of irrigators	Average irrigated area (ha)
Orange-Riet Canal	Rscm	3 970.0	24	44	12	90.2
Ritchie		96.8	1	75	20	1.3
Riet River Scheme		8 045.0	48	185	50	43.5
Scholtzburg	Rszg	721.6	4	16	4	45.1
Lower Riet	RloR	3 937.9	23	51	14	77.2
TOTAL		16 771.3	100	371	100	45.2
Irrigation Block						
Rscm (Riet scheme)		12 111.8	72	304	82	135.0
Rszg (Riet Scholtzburg)		721.6	4	16	4	45.1
RloR (Riet Lower Riet)		3 937.9	24	51	14	77.2
TOTAL		16 771.3	100	371	100	257.3

2.5.2.2. Orange-Vaal WUA

The Orange-Vaal WUA comprised in 2005 of five sub-WUAs with the development of a sixth sub-WUA taking place. The sixth area extracts irrigation water directly from the Orange River and is therefore excluded from this study. Shown roughly in Figure 2.7 is the spatial layout of Olierivier, Vaallus, Bucklands (Erwe) and Atherton. New Bucklands is the area indicated in Figure 2.7 as OV Canal.

- The **Vaallus sub-WUA** irrigates predominantly with Vaal River water and Spitskop dam releases while there is overflow over the Schmidtsdrift weir (the Vaal River boundary of the OV-WUA). Otherwise Orange River water pumped into the Douglas weir builds up and “flows upstream” to feed Vaallus. Vaallus constitutes 33% of the OV-WUAs irrigated area, farmed by 15 (9%) of the farmers on the largest average farm size of 177 ha (Table 2.2).

- **Olierivier sub-WUA** receives all the OR-WUA returnflows from over the Soutpansdrift weir, as well as Orange River water possibly mixed with some Vaal River water at the Douglas weir that pushed upstream when the flow over the Soutpansdrift weir is low. Olierivier also constitutes 33% of the OV-WUAs irrigated area, farmed by 24 (14%) of the farmers on an average farm size of 112 ha.
- **Bucklands sub-WUA** (also called “die erwe” or “the plots”) and **Atherton sub-WUA** both receive Douglas weir water, but Atherton is situated mainly along earthen canals to the west of the Vaal River, and Bucklands along a concrete canal that runs east of the Vaal River. Returnflows from both these sub-WUAs flow back into the Vaal River affecting only farmers irrigating directly out of the river below the Douglas weir, thereafter it is diluted with low TDS Orange River water at the confluence of the Vaal with the Orange River. Bucklands constitutes 17% of the OV-WUAs irrigated area, farmed by 110 (63%) of the farmers on an average farm size of 32 ha. Atherton constitutes only 4% of the OV-WUAs irrigated area, farmed by 10 (6%) of the farmers on an average farm size of 12 ha.
- **New Bucklands sub-WUA** consists of farmers irrigating out of the Orange Riet Canal. There are only 7 irrigators (4% of the total) irrigating 13% of the total WUA area (Table 2.2). The average irrigated area is 150 hectares, the second largest of all OV-WUA sub-WUAs after Vaallus.
- The “**Samevloei**” **sub-WUA** (or confluence) is the newest sub-WUA, but which is not included in this study as it falls within the hydrology boundaries of the Orange River catchment. There are 9 irrigators in this sub-WUA with an average farm size of nearly 75 hectares each.

All these sub-WUA combined make up the Orange-Vaal WUA Irrigation Block, **Vall**.

Table 2.2. Sub-WUAs of the Orange-Vaal WUA (source: CSIR, 2004)

Sub-WUA	Irrigation block	Irrigable area (ha)	Irrigation rights (ha)	% of scheduled area	Irrigators	% of irrigators	Average irrigated area (ha)
Olierivier	Vall	2 702	2 683	33	24	14	112
Vaallus		2 778	2 659	33	15	9	177
Atherton		349	349	4	11	6	32
Bucklands ("Erwe")		1 271	1 340	17	110	63	12
New Bucklands		1 876	1 049	13	7	4	150
Confluence ("Samevloei")		673	0	0	9	5	75
Total		9 649	8 081	100	176	100	46
Irrigation Block							
Vall (All Orange-Vaal WUA)		8 976	8 080	100	167	96	48

Table 2.3 gives an indication of irrigation potential (according to van Heerden *et al.* 2001) in the sub-WUA areas of the OV-WUA. It shows that Bucklands has no high potential irrigation soil and that Atherton with only 349 ha is the smallest sub-WUA, justify joining these two sub-WUA as one for the purpose of analysis. Olierivier, with the largest hectareage irrigated (3125 ha) thus has two case study farmers, namely one situated south of the Riet River with predominantly heavy soils and one to the north of the Riet River, farming on predominantly sandy soils.

Table 2.3. Irrigation potential of the irrigable soils in the OV-WUA region (adapted from Van Heerden *et al.* 2001)

Sub-WUA		<u>IRRIGATION POTENTIAL</u>			TOTAL (Ha)
		High (%)	Medium (%)	Low (%)	
1	Olierivier	73	14	13	3125
2	Vaallus	41	59	0	2659
3	Atherton	76	24	0	349
4	Bucklands	0	50	50	1341
5	New Bucklands	83	16	1	617
TOTAL		51	36	13	8075

2.5.2.3. Interactions between WUAs

The following interaction between WUAs are taken into consideration in this study:

- Potential externalities to downstream WUAs
- Potential impacts downstream of the study area
- Irrigation water transfers within and in-between WUAs

The externalities from upstream water sources, namely the Kalkfontein and Vaal Harts WUAs, are implicitly taken into consideration in the water resources planning model (WRPM) used to model the hydrology of the study area and are assumed to remain the same as in the past. Irrigation water transfers within and in-between schemes are also assumed the same as set up in the past in the WRPM. It is noted that additional pumping of good quality Orange River water has already been approved to dilute the poor Lower-Riet irrigation water quality, but this has not been included in this study, although the motivation / reinforcement of this WUA level management option is mentioned in the conclusion. Although irrigation water quality is improved, salts found inherently in the soil still need to be removed to prevent soil salinisation.

2.5.3. IRRIGATION BLOCK DELINEATION

For the purposes of micro hydrology level modelling, four irrigation blocks were identified through the WRPM (Water Resources Planning Model) in the two WUAs consisting of one or more sub-WUAs, to represent the main receiving water quality areas within the Orange-Vaal-Riet-Modder confluence area, namely:

- the Riet River Scheme, Orange Riet Canal and Ritchie sub-WUAs of the OR-WUA combined, **Rscm**, all receiving Orange river water directly from the Orange Riet Canal,
- the Scholtzburg sub-WUA of the OR-WUA, **Rszg**, lying mainly at the confluence of the Modder and Riet Rivers, but receiving a large portion of Orange River water diluting the tail ends of the Riet and Modder Rivers upstream,
- the Lower Riet River sub-WUA of the OR-WUA, **RloR**, from Ritchie to Soutpansdrift, mainly receiving Riet Scheme and Scholtzburg returnflows, and

- the whole Orange Vaal WUA, **Vall**, receiving Vaal River system excess spillage and a large portion of Orange River water pumped via the Orange-Vaal and Orange-Riet Canals, with the latter carrying the returnflows of the whole OR-WUA.

Figure 2.6 shows schematically the placement of the irrigation blocks in relation with one another, and to the Orange, Vaal, Riet and Modder Rivers. Farm boundaries are also shown as the shaded areas within the irrigation blocks, with the darker shaded predominantly round dots within the farm boundaries indicating the placement of Centre pivot irrigation systems. Clearly centre pivot irrigation is the predominant form of irrigation and most irrigation lands lie close to the water source, be it a river or canal.

In the discussions on the two WUAs in Paragraph 2.5.2 reference has already been made to the basic delineation of the irrigation blocks. Figure 2.6 also shows where the irrigation blocks lie in relation to each other, and the river reaches and canals that serve them.

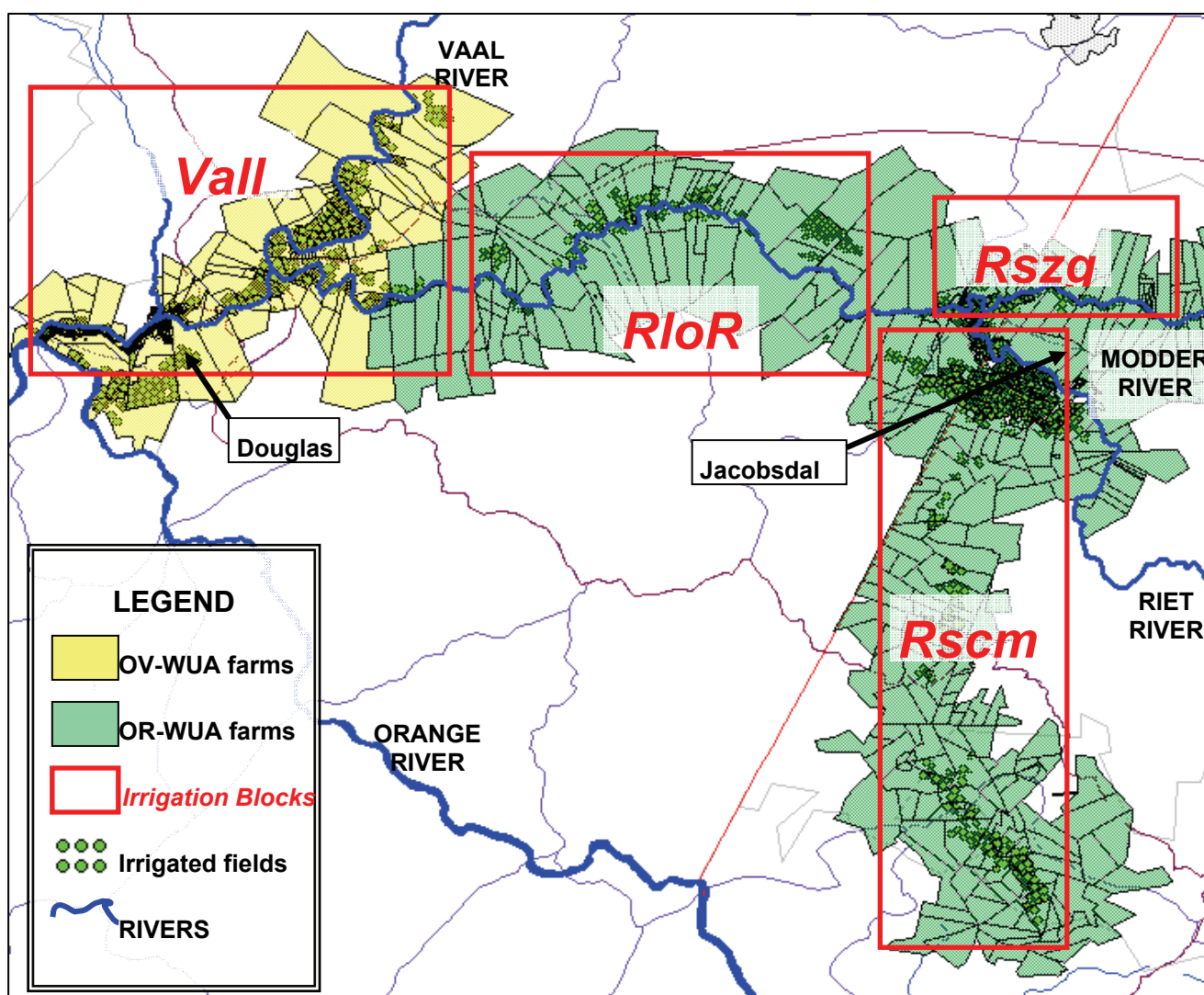


Figure 2.6. An indication of the layout of the Irrigation Blocks (OV-WUA farms, **Vall**, coloured Yellow and OR-WUA farms, **RloR**, **Rszq** and **Rscm**, coloured green).

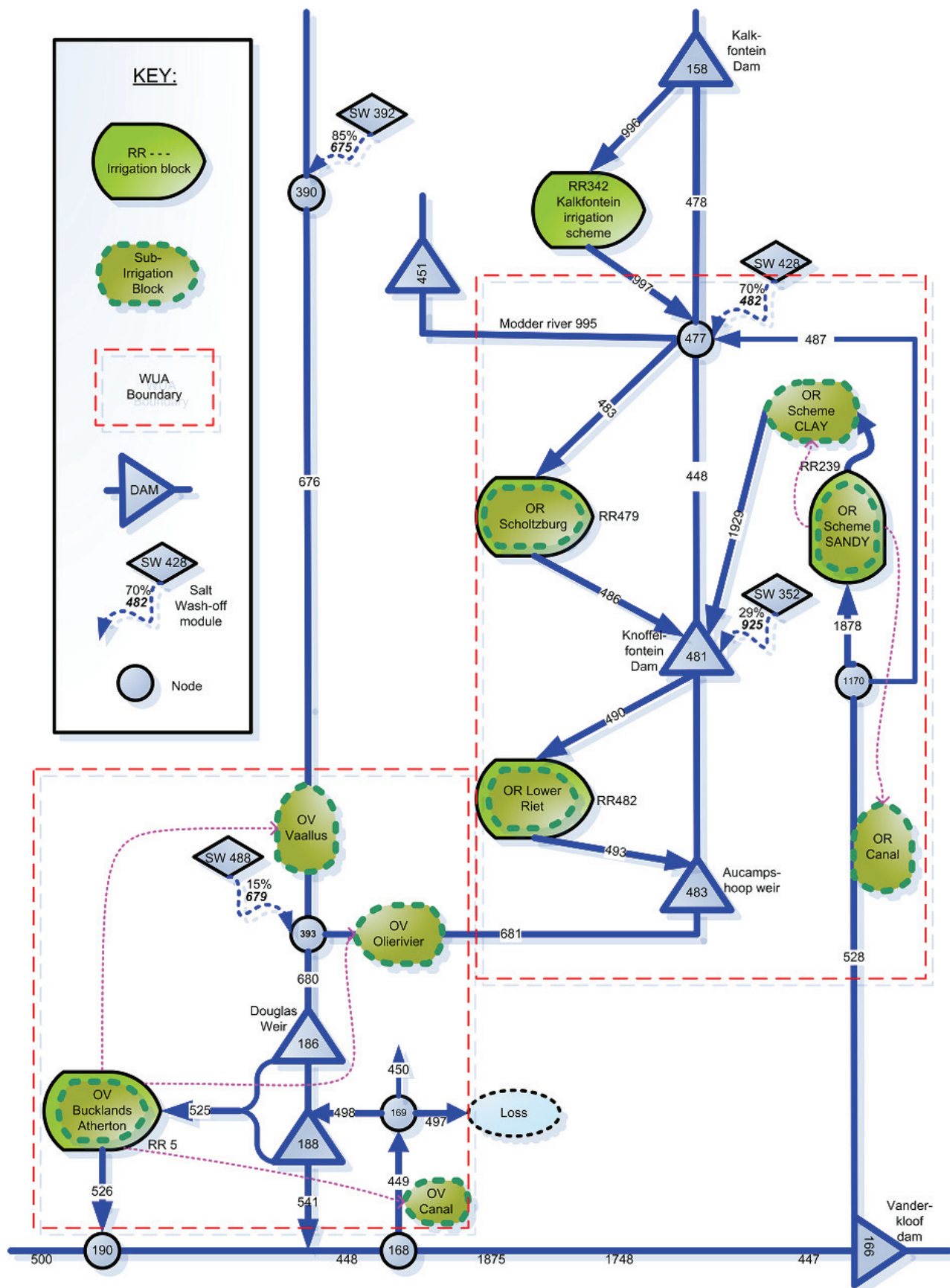


Figure 2.7. A simplified diagram of the hydrology set-up of the study area (indicating channels, nodes, irrigation blocks, WUAs and sub-irrigation blocks/sub-WUAs)

Figure 2.7 is a simplified schematic diagram of the hydrology set-up of the study area. For the complete channel and node diagram of the WRPM setup applicable to the study area, see Chapter 4, Figure 4.5 and Figure 4.6. The irrigation blocks modelled in this study are the ones in the figure with solid perimeter lines, and these include the WUA sub-WUA connected to them with the dotted lines indicated with dashed perimeter lines.

The four irrigation blocks predominantly analysed in this study therefore are:

- OR Scheme Sandy, which includes OR Scheme Clay and OR Canal
- OR Scholtzburg
- OR Lower Riet
- OV Bucklands and Atherton, and which includes OV Vaallus, OV Olierivier and OV Canal (farmers irrigating directly from the Orange River in the OV WUA are not included in this study)

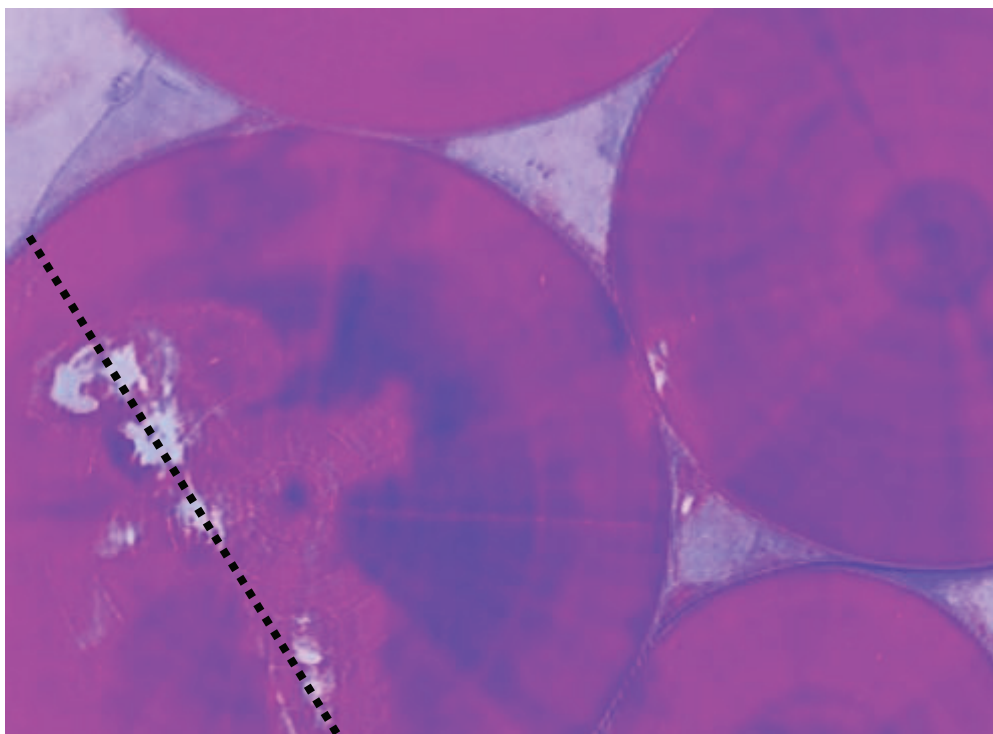
Table 2.4 lists the water allocations (ha) and total annual water quota supplied (million m³) to give an indication of the water volume allocated in each irrigation block.

Table 2.4. Scheduled areas and quotas as used in the model for the irrigation blocks in the study area (2005)

WUA			Irrigation blocks (WRPM codes)		Scheduled areas (ha)	Quota (m ³ /ha)	Annual allocation (mil.m ³)
1	Orange-Vaal WUA	1.1	Vall	(RR5)	10 014	11 000 ¹	110.15
Orange-Vaal WUA		TOTAL			10 014		110.15
2	Orange-Riet WUA	2.1	Rscm	(RR239)	12 335	11 000	135.69
		2.2	Rszg	(RR479)	641	11 000	7.05
		2.3	RloR	(RR482)	3 853	11 000	42.38
Orange-Riet WUA		TOTAL			16 829		185.12
STUDY AREA TOTAL					26 843		295.27

¹ Technically the water quota for Orange-Vaal WUA farmers for 2005 was 10 000 m³/ha but to compensate for poorer water quality the farmers are allowed to use 11 000 m³/ha without being penalised, and therefore 11 000 m³/ha is used. Also better for comparison.

2.5.4. PER HECTARE DELINEATION



The discussion that follows on Figure 2.8 is hypothetical, aimed at illustrating the enormous in-field variability in soil salinisation and possible remediation actions.

Figure 2.8. An inverted colour spectral imagery view (aerial photo) of a salt affected centre pivot land (courtesy GWK, 2002)

Figure 2.8 is an aerial view of an irrigation field under centre pivot in the study area (2001) affected by salinisation. The white areas clearly show salinisation and the darkest areas show good crop growth. The areas in-between are where crop growth occurs, but where the effect of salinisation is not yet clearly visible to the naked eye. If the field is 40 hectares, then roughly 10 hectares has near optimal crop growth, 5 hectares no growth and the rest in-between. The purpose of this illustration is to show that salinity is not clearly constrained in a certain land, but that the in field variability in soil salinity values is large, making the determination of a starting point soil salinity value very difficult. Salinity sampling only at the edge of the field may be misleading. Inter-field level specific remediation therefore needs to be applied.

In Figure 2.8, the installation of one straight sub surface drain, depending of the slope of the field along the dashed line drawn in the diagram, may suffice to sufficiently leach out the salts accumulated. The dashed line may also represent a dip in the field where salts have accumulated, causing water logging problems which exacerbate the impacts of salinity, though salinity doesn't have as great an effect on crop yields under wet conditions than under dry conditions. The dashed line may also represent a peak in the field where salts have migrated to along the moisture gradient of the field, or may represent an underground soil bank that has a significantly different texture from the rest of the field.

The discussion on Figure 2.8 highlights the need of field specific solutions for isolated serious salinisation problems, e.g. salinity mapping and/or precision farming solutions. These however fall out of the scope of this study which models at irrigation block level (50 to 300 times larger than this picture) where the average soil salinity, derived from a hydrology salt balance model for an irrigation block is used.

2.6. HYDROLOGY DYNAMICS

As this study is based on hydrology model data, the significance of the different hydrology dynamics between irrigation blocks, and how these dimensions are to be captured in this study, are discussed under the following headings:

- Source and salt concentration of irrigation water
- Wet and dry rainfall cycles
- Flooding events
- Changes in policy regarding water allocation and water use charges
- Economic / political boundaries

The WUAs and corresponding irrigation blocks are essentially defined according to hydrology boundaries. The micro-economic level of analysis of this study takes place at per hectare level (a standard agricultural economic unit for farm level analysis) and is extrapolated to irrigation block level. Further analysis combines irrigation blocks into WUAs, and WUAs into the regional unit of analysis for the whole study area.

For a more detailed discussion on the hydrology modelled in the study see Chapter 4 for a table of irrigation area (km²), gross irrigation demand (million m³/a), irrigation efficiency (%) and canal losses (%) (see Table 4.1 and Table 4.2).

2.6.1. SOURCE OF IRRIGATION WATER AND SALT CONCENTRATION

The irrigation blocks are differentiated mainly according to their source of irrigation water.

- the Riet River Scheme, **Rscm**, gets predominantly Orange river water directly from the Orange Riet Canal,
- the Scholtzburg sub-WUA, **Rszg**, receives a large portion of good quality Orange River water that dilutes the tail end outflows of the Riet and Modder Rivers upstream,
- the Lower Riet River sub-WUA **RloR**, mainly receives Riet Scheme and Scholtzburg returnflows together with additional Orange River water pumped for dilution along the Lower Riet section of the OV-WUA, and
- the Orange Vaal WUA, **Vall**, receives a large portion of Orange River water pumped via the Orange-Vaal and Orange-Riet Canals, but the latter carrying the returnflows of the whole OR-WUA.

Hydrology model results discussed in Chapter 9 show the highly stochastic nature of especially the **RloR** and **Vall** Irrigation Block that receive water from a number of different sources.

2.6.2. WET AND DRY RAINFALL CYCLES

Besides annual wet and dry cycles, there are longer term wet (flood) and dry (drought) cycles of between 6 and 8 years. To accommodate this in this study the time frame of analysis in the hydrology model is 25 years and 15 years in the economic model. Only the first 15 years of output data from the hydrology model is fed into the economic model, with the last 5 years of hydrology data only used to analyse longer term trends to help explain economic data. As the Water Resource Planning Model (WRPM) used for stochastic hydrology forecasting in this study, runs for the entire Integrated Vaal River System (IVRS), which includes several major sub-catchments upstream such as the Upper Vaal, Vaal Barrage, Middle Vaal, Lower Vaal, Riet-Modder, Komati, Usutu, Tugela and Upper and Lower Orange, different rainfall cycles in these catchments upstream result in different wet and dry cycles in the different irrigation blocks.

2.6.3. FLOODING EVENTS

One of the questions often asked in extension exercises with the farmers in the study area is, if salts build up in soils over time, then why are some of the oldest irrigated lands (irrigated for over 70 years!) not already totally salinised? The answer to this is, besides unintentional leaching from “inefficient” irrigation practices, the occasional high rainfall event (a few months in a row of above average high rainfall) or flood (very high rainfall over a very short period of time) has washed out the salts in the soil. As these events are very important to the soil salinity dynamics and resulting economic impacts through crop yield (particularly examined in this study), they are accounted for by running 100 stochastic sequences of possible monthly hydrology events for 25 years for each irrigation block and for each scenario examined in this study.

From cumulative economic results based on all 100 stochastic sequences, a worst case (0.05 percentile), best case (0.95 percentile) and most probable (0.50 percentile) sequences are selected for further analysis. The best case sequence (in respect to soil salinity build-up) will include more high rainfall events than the worst case sequence. In the economic analysis of this study the economic costs due to damages from flooding are not included.

2.6.4. CHANGES IN POLICY REGARDING WATER ALLOCATION AND WATER USE CHARGES¹

Not implicitly taken into account in this study, yet important to mention are factors that influence / impact on the water quality received in the study area. These factors are *inter alia*:

- the improvement of water distribution and use efficiency as currently promoted
- the implementation of the environmental reserve in river reaches, and
- policy changes in the mining industry on discharge

The improvement of water distribution and use efficiency as currently promoted by the DWAFs “more crop per drop” slogan (together with minimum wage labour policy) has resulted in the expansion of centre pivot irrigation systems. This, together with the dramatic improvement in irrigation scheduling due to GWK’s irrigation scheduling service using SAPWAT and Neutron moisture meters, have made irrigation farmers in the study area far more efficient, thus less over irrigation takes place resulting in less unintentional leaching or drainage and therefore a faster accumulation of salt in the soil if provision isn’t deliberately made in irrigation planning for additional water for leaching. This positive increasing efficiency trend has also seen an increase in soil salinity over the last few years (Du Preez *et al.* 2000). National water policy principles such as the waste discharge charge system (WDCCS) and polluter pays principle (PPP) could have further made farmers reluctant to leach and even to install additional irrigation drains that make a non-point source pollution (NPS) problem a point source pollution problem that is easier to trace and to fine the perpetrator.

A study is currently being conducted on the Spitskop dam (DWAF) by WRP consultants examining the effect of different releases from Spitskop dam on *inter alia* algae downstream. Depending on the results of this study, an increase in Spitskop dam releases may further increase the salinity in the Lower Vaal River.

Increased Spitskop dam releases could also be implemented to maintain the environmental reserve requirement in the Lower Vaal River - this can have a trade-off of increased salinity loads.

Mining policy on mine water decanting could also influence irrigation water quality in the Lower Vaal River.

Changes in water use charges¹ (up to a 35% increase modelled by Greengrowth Strategies cc, 2003) could also have an impact on hydrology dynamics. Due to the increase in the cost of water for irrigation, farmers will either be forced to become more efficient on existing crops (exacerbating salinity build-up if leaching and drainage isn’t practised) and / or plant higher value crops. The financial benefit from paying for additional water to leach to attain a better yield will be less, resulting in possibly less leaching, lower yields and weaker financial returns.

2.6.5. ECONOMIC / POLITICAL BOUNDARIES

Local municipality boundaries form the economic / political boundaries of the study area and are the main unit of modelling for the regional economic model. Output from the micro economic model, which contains economic data at the irrigation block level, is combined to feed into the regional economic model. For a finer delineation of the regional economy modelled in this study see Chapter 7. Figure 7.3 shows the local municipal areas in the study area and Figure 7.4 shows the quaternary catchments falling in the study area.

¹ Where the term “water use charges” is used, it refers to the lumped term comprising of all the water use charges including: the water volume charge, water management cost, use of water works costs, and where applicable, the waste discharge charge.

2.7. ECONOMIC ACTIVITIES

2.7.1. COMPOSITION OF GGP

A complete description of the regional economy of the study area appears in Chapter 7. This brief overview merely aims to sketch the level of economic activity and relation between economic sectors. In Figure 2.9 the relatively small contribution to gross geographical product (GGP) by agriculture in relation to mining, trade, transport, finance, services and government is shown. A large portion of these sectors' GGP however are generated in Kimberley, the main centre of the Northern Cape, that falls within the Sol Plaatjie district municipality that borders on the Riet River at Jacobsdal. Away from Kimberley, agriculture is expected to be a dominant sector in the otherwise barren country side. Agriculture and people employed in agriculture are major contributors to the trade, transport, finance and services sectors.

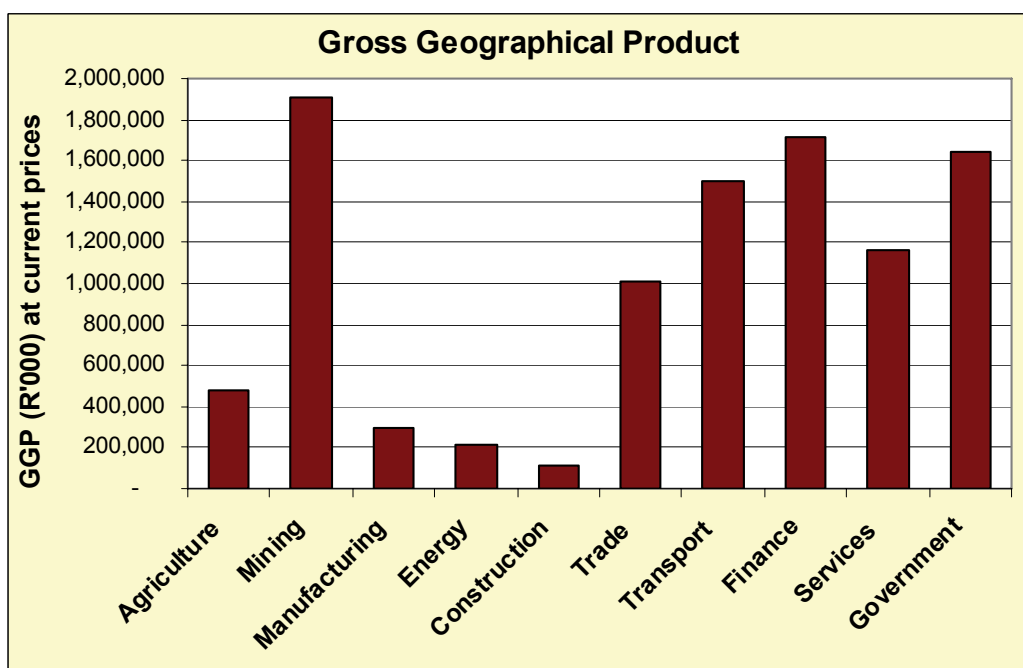


Figure 2.9. Gross Geographical Product (R'000) of the study area by economic sector, 2005

2.7.2. AGRICULTURE

Table 2.5. Area (ha) under different irrigation systems in the OR-WUA (Ninham Shand, 2004)

Sub-WUA	Total area in ha	Centre Pivot %	Flood Irrigation %	Sprinkler Irrigation %	Micro-jet Irrigation %
Orange-Riet	3 970.0	95	0	5	0
Riet River	8 045.0	60	20	19	1
Scholtzburg	721.6	70	20	10	0
Lower Riet	3 937.9	70	20	10	0
Ritchie	96.8	0	75	25	0

Table 2.5 shows that the centre pivot irrigation system is the predominant irrigation system in the OR-WUA, followed by flood. Flood irrigation is only dominant in the Ritchie sub-WUA.

Table 2.6. Area (ha) under different irrigation systems in the OV-WUA region (adapted from Van Heerden *et al.* 2001)

Sub-WUA		Micro and Drip	Sprinkler	Flood	TOTAL
1	Olierivier	31	2969	125	3125
2	Vaallus	27	1861	771	2659
3	Bucklands/Atherton	99	229	1362	1690
4	New Bucklands	19	598	0	617
TOTAL		176	5657	2258	8091
%		2	70	28	100

From Table 2.6 it is clear that sprinkler (which includes centre pivot and drag line) irrigation is the main type of irrigation practised in the OV-WUA. This is also evident in Figure 2.6 or from any aerial or satellite photo of the area. Also evident from the air are large white salt pans where salts accumulate and wash off into the system, a possible cause of salinisation in the area. Table 2.7 shows that in the year 2000 23% of the land in the OV-WUA was already slightly (13%) or severely (10%) affected by salinisation.

Table 2.7. Soils affected by salinisation and water logging in the OV-WUA region (adapted from Van Heerden *et al.* 2001)

Sub-WUA		LEVEL OF SALINISATION AND WATER LOGGING		TOTAL (ha)
		Slight ¹ (%)	Severe ² (%)	
1	Olierivier	16	4	625
2	Vaallus	40	40	2127
3	Atherton and Bucklands	10	3	124
4	New Bucklands	0	2	12
TOTAL		13	10	2888

¹ Slight salinisation and water logging is defined as that agricultural production can still take place, but that production potential and/or choice are restricted.

² Severe salinisation and water logging is defined as that agricultural production can no longer take place without special remediation actions such as artificial drainage or gypsum being applied.

According to Du Preez *et al.* (2000:155) the leaching of excess salts from the root zone with centre pivot irrigation proved to be almost impossible because of the high application rates required at the outer circumference of the fields when irrigating more than 30mm per round. On the farm land not utilised for irrigation most farmers keep cattle, sheep and/or goats extensively as the carrying capacity of the natural grazing is over 15 hectares per livestock unit. Many farmers also keep wild game. The economic contribution of game and livestock farming is however not factored into the micro economic analysis of this study and kept constant for the macro economic level of analysis.

2.7.3. INFRASTRUCTURE

The study area has a good road and rail network, however the distance from the main cities in South Africa is a large constraint for high value, fresh market crop choices. GWK Pty. Ltd. Is the agricultural company that has evolved from the old GWK co-operative. GWK has taken over and further developed an extensive network of

inter alia, grain handling, storage and value adding infrastructure, a wine press and cellar (a capacity constraint to the further expansion of vineyards for wine grapes), etc. A cotton gin within the study area closed down in 2005, placing a constraint on the production of cotton.

2.8. SUMMARY

In summary, the main characteristics of the study area are:

- it spans over two provinces, namely the Free State and Northern Cape provinces
- it falls within and impacts various municipal / local government management areas (see Figure 7.3)
- it covers the confluence of the two major rivers in South Africa, namely the Orange and the Vaal Rivers, and receives returnflows from the Harts, Riet and Modder Rivers.
- it is impacted by various quaternary catchments and different water management areas (see Figure 7.4)
- it falls within an arid / low rainfall area with average annual rainfall of less than 370 millimetres and evapo-transpiration exceeding 2000 mm
- the municipal (i.e. economic zone) boundaries are quite different from the quaternary catchment (i.e. hydrology) boundaries posing a challenge to model integration
- a major economic driver of the regional economy is irrigated agriculture
- water reform and redistribution away from the study area, and from irrigated agricultural use within the area, could negatively impact the overall long term sustainability of the area
- the distance from the major urban centres in South Africa limits the type of crops that can be grown in the area, limiting the water use efficiency / productivity attainable, and
- according to Van Veele (2004), “the Riet-Modder catchment is a “feast or famine” catchment with only 8 years in 50 being ‘average’ years”. This statement can be applied to the rest of the study area as the runoff from the Riet-Modder catchment is a large contributor to the salt loads in the study area.

In short, the area is not suited to dry-land agriculture except extensive grazing, and is reliant on the stability that irrigated agriculture brings for socio economic sustainability. However, increasing pressure on the use of water for irrigation, together with degrading irrigated soils due to salinity, is placing increasing financial pressure on farmers, and hence on the regional economy.

CHAPTER 3. AN INTRODUCTION TO THE INTEGRATED MODEL FRAMEWORK

by R.J. Armour, and M.F. Viljoen - UFS

3.1. INTRODUCTION

This chapter serves as a brief overview of how the various components that make up this study are integrated and flow from their individual disciplines towards an integrated whole. Subsequent chapters will outline the detail of each of these sub-components. As part of this introduction a brief motivation paragraph from the literature is given, followed by the aims of the integrated model.

A paragraph introducing the main components of the integrated model is followed by a separate paragraph on each of the main components individually, namely:

- The scenario setup process
- The input data and data processing
- The sub-disciplinary models
 - 1.1. *Hydrology model (WRPM)*
 - 1.2. *Bio-physical sub-components*
 - 1.3. *Micro economic model*
 - 1.4. *Regional economic model*
- The output data and results files

Under each individual model component paragraph, the setup data, spatial and temporal dimensions and linkages of the model components are discussed, with relevant reference made to other chapters in this document where the specific component is discussed in more detail.

Appendix 1 lists the step by step process and hyperlinks to each model file used in the construction of the complete integrated model.

The chapter concludes with a discussion of the main linkage limitations and assumptions, followed by a summary of the data sources and a chapter summary.

3.1.1. A BRIEF MOTIVATION FROM THE LITERATURE

As a motivation for multidisciplinary research McKinney *et al.* (2000) state that *“the dynamics of water -use, -pollution and -control are so tightly interwoven by a multitude of external factors that the traditional style of mono-disciplinary research is no longer suited to achieve overall satisfactory results.”* To proactively manage and implement policy to anticipate problems, and sustainably introduce change, the best information obtained from comprehensive multi-disciplinary research is needed.

In the foreword to their book, Quaddus and Siddique (2004), state that *“Taking account of the fact that sustainable development planning is multidisciplinary by nature, the contributors concede that a single exemplary model does not exist. The aims of the stakeholders, along with preferences and priorities surrounding the planned objectives determine the ways and means of sustainable development planning”*

At the outset of this report, the challenges cited by preceding authors of the integrated modelling approach required for the economic interpretation of irrigation salinity over larger areas than the farm field are listed;

“Current USDA Salinity Laboratory evidence suggests these interactions are far more complex than originally thought. Rhoades, the doyen of soil/plant/salinity interactions, contends that no one has succeeded in combining all the refinements necessary to overcome the inherent problems of relatively simple salt balance models and geophysical sensors, to address the enormous field variability of infiltration and leaching rates” (Blackwell, et al. 2000).

According to Antle and Stoorvogel (2003) *“It seems unlikely that a general, integrated model applicable to many different production systems will be available in the foreseeable future, nor will data adequate to support such a model be available”* Although far less elaborate than initially proposed, this project has succeeded in refining and identifying critical obstacles towards fully integrated salinity economics modelling and to a certain degree in coming up with plausible results suitable for meaningful farm, sub-WUA, WUA, CMA and national policy interventions and strategic decision making.

3.1.2. AIMS OF THE INTEGRATED MODEL

The aim of the SMSim (micro-economic salinity simulation model) suite of models is to integrate holistically the bio-physical components/processes (including the hydrology) involved in irrigation salinisation, into a long-term (dynamic) economic model. The objective of which is to improve the financial sustainability of irrigation agriculture while also ensuring social and environmental sustainability. A further objective is to achieve this aim using existing hydrology and bio-physical models as far as possible and to build on the salinity economics work already done in SALMOD by Armour and Viljoen (2002).

3.2. MAIN COMPONENTS OF THE INTEGRATED MODEL

SMSim consists of the following loosely coupled interlinking components without a continuous feedback loop:

- The scenario setup process
- The input data and data processing
- The sub-disciplinary models
 - *Hydrology model (WRPM)*
 - *Bio-physical sub-components*
 - *Micro economic model*
 - *Regional economic model*
- The output data and results files

Figure 3.1 is a schematic diagram of the components of SMSim and its linkages with the hydrology model and the regional economic model. The Hydrology data files generated in the WRPM as text files, are grouped together and rearranged within a model coded in GAMS (general algebraic modelling system) and the relevant data stored in spreadsheet format in MS Excel files, to feed the hydrology data into the micro-economic model section of SMSim. Crop enterprise budget (CEB) data and sub-WUA description data are also fed into SMSim to provide the financial drivers and resource composition differences between WUAs.

Certain per hectare and irrigation block level model outputs are calculated within SMSim, but the data required to link with the regional economic model is saved in a separate micro-economic output file, from where it is fed into the macro-economic model. Data output for both the SMSim and regional economic models provide valuable feedback information for setting up subsequent hydrology scenarios.

Once the integrated model is setup in its entirety in MSExcel, for each block in Figure 3.1 any changes that are made will reflect all the way through the forward linkages in the model. The hydrology model however has to be manually rerun taking approximately one day to run, check and interpret a run. There are also macros that have to be run in the micro-economic model, which are set up only for one stochastic run at a time, to automatically incorporate all 100 stochastic runs.

3.3. SCENARIO SETUP PROCESS

The scenarios set-up process consists of the following¹:

- the identification and compilation of the set-up data
- the establishment of the spatial and temporal dimensions
- the establishment of the model linkages

For a complete discussion on the scenarios see Chapter 8.

3.3.1. SETUP DATA

The following set-up data is needed:

- Crop coefficient data generated using the SAPWAT model by Van Heerden *et al.* (2001).
- The base-case year is set at 2005 levels and the cropping composition of the 20 (max) crops modelled is compiled from the sub-WUAs description data files.
- The cropping composition for the scenarios are then generated and set up for Scenarios 1, 2, 3 and 3+. A salt tolerant crop mix is generated for Scenario 1 and a salt sensitive (yet higher value) crop mix is generated for Scenarios 2, 3 and 3+.
- The data changes required to simulate more crop drainage in the WRPM are required for Scenario 3 and 3+, and for Scenario 3+ the additional costs of the increased drainage are also factored into the crop costs, through increased water costs.

Other data from the sub-WUAs description data files used in the scenario set up are the:

- irrigated areas of each irrigation block, and the
- the distribution losses

¹ Before setting up the scenarios, the working of the hydrology model (WRPM) needs to be known by the modeller, as well as the factors driving the model, and their relation to the scenarios identified. Once the data sources required for scenario setup have been identified, the data is collected / generated and processed in the sub-WUA description data files.

SMSim design (unless otherwise stated, links to all files in c:/SALMOD/SMSim/...)

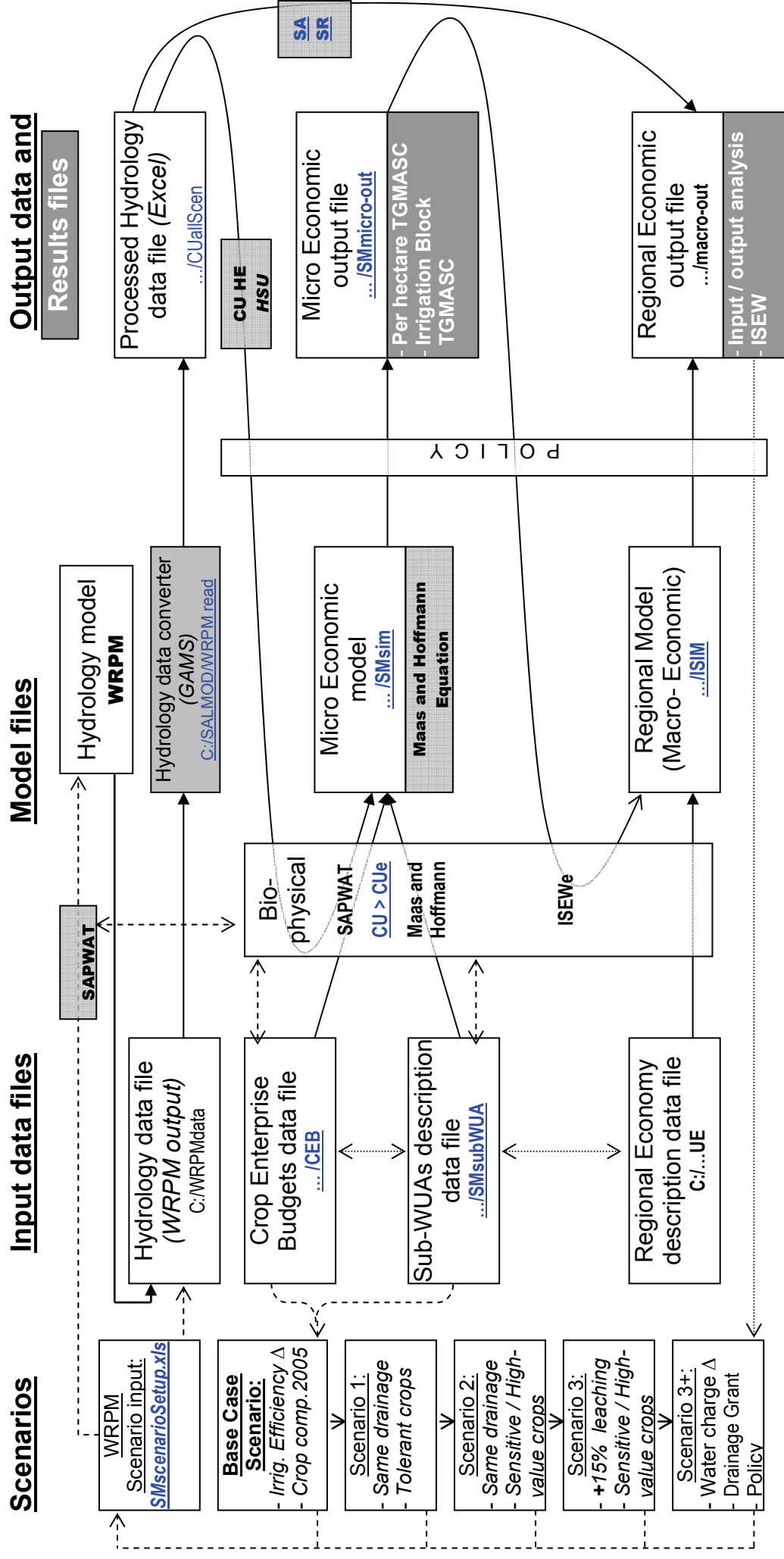


Figure 3.1. The integrated conceptual framework

3.3.2. SPATIAL AND TEMPORAL DIMENSIONS

The spatial unit at which the scenarios modelled are the irrigation blocks as set up in the WRPM and explained in Chapter 2. The cropping compositions and water use factors are set up at annual levels with a hydrologic year starting in May and ending in April the following year.

3.3.3. LINKAGES

To drive the scenarios required for economic modelling, the main input data linkages for scenario setup are the sub-WUAs description data files, providing cropping composition and area input data, and the SAPWAT model that provides the cropping factors for the maximum of 20 crops that can be modelled in the WRPM. The scenario setup data provide the variables for scenario analysis in the WRPM.

3.4. INPUT DATA PROCESSING

The four sets of input data files that are generated / compiled are:

- Hydrology data files,
- Crop enterprise budget (CEB) data files,
- Sub-WUA description data file and the, and
- Macro economic description data files

3.4.1. SETUP DATA

The hydrology data files are the raw output from the WRPM, that have to be processed through a small sub-routine in GAMS to get them into MSExcel format. This is done to present the hydrology data effectively, and to prepare the data as input for the micro-economic model.

The CEB data files are compiled predominantly from GWK 2005 study group CEB results, and Sub-WUA data was obtained predominantly from the WUA management plans and adjusted for 2005 conditions using expert panel opinion.

The main source of data used in setting up the regional economic data files are secondary data from previous studies and national data required for setting up the input / output tables.

3.4.2. SPATIAL AND TEMPORAL DIMENSIONS

The hydrology and CEB data are all monthly data, while sub-WUA set up data is specifically for the year 2005, and the regional-economic data based on 2002 data and converted to 2005 data using appropriate indices. The hydrology and CEB data is irrigation block specific as defined in the sub-WUA setup data files. The macro-economic data is national and provincial level data, adjusted to the regional level.

3.4.3. LINKAGES

The setup and processing for the hydrology data is discussed in the Chapter 4, the CEB and sub-WUA set up data in Chapter 6 and the regional economic model in Chapter 7.

3.5. MODEL FILES

3.5.1. HYDROLOGY MODEL

The hydrology model is discussed in full in Chapter 4 of this report.

3.5.1.1. *Setup data*

The hydrology model and data files are operated and generated, by WRP consultants Pty. Ltd.. The project team in conjunction with WRP consultants compiled the scenarios to be run through the WRPM. WRP consultants ran the model and generated the raw output data for the project team at the UFS to process, display and use as input in the micro and macro economic model.

3.5.1.2. *Spatial and temporal dimensions*

The hydrology model is specified for 4 irrigation blocks within the study area, namely:

- the Orange Vaal Irrigation Block (**Rscm**) comprising of the Orange-Riet irrigation farmers, the Riet River irrigation scheme and Ritchie in the OR-WUA.
- The Scholtzburg Irrigation Block (**Rszg**) in the OR-WUA.
- The Lower-Riet Irrigation Block (**RloR**), positioned downstream of both the **Rscm** and **Rszg** in the OR-WUA, and
- The whole of the Orange-Vaal WUA (**Vall**) all modelled together as one irrigation block.

The temporal scale of the hydrology model is monthly.

3.5.1.3. *Linkages*

The hydrology model receives its setup data from the scenario setup files, and its crop coefficients from a biophysical sub-component of the hydrology sub-component. Output from the hydrology model is raw hydrology data, outputted as a large set of separate text (._.txt) files. Using a small subroutine in GAMS recorded by the project team, these individual text files get rearranged and further processed for easier use in MSExcel.

3.5.2. BIO-PHYSICAL SUB-COMPONENTS

The bio-physical section of the model is not a model on its own, but a collection of sub-components that facilitate the linkage from bio-physical to economic. For a full discussion on the biophysical sub-components see Chapter 5.

3.5.2.1. *Setup data*

The following set-up data was used:

- crop functions
- salinity conversions
- salt index

The SAPWAT model generates the crop coefficients for use in the hydrology model. For the conversion from CU to CUE, HE generated in the WRPM and HSU, a constant used in setting up the WRPM, are required.

Similarly, the abstraction (SA) and returns (SR) to and from the irrigation block in tonnes provide the salt mass balance used as the environmental component of the index for socio-economic welfare (ISEW).

3.5.2.2. Spatial and temporal dimensions

The crop coefficients and CUE values are both monthly data calculated for all irrigation blocks separately. The salt balance in the macro-economic model is calculated annually for each irrigation block, but summed up to the regional level for calculation of the ISEW.

3.5.2.3. Linkages

The biophysical sub-components, SAPWAT crop coefficients, CU-CUE and SA-SR, are critical biophysical–hydrology, hydrology–micro-economic and hydrology–macro-economic linkages respectively at different positions within the integrated model.

3.5.3. MICRO ECONOMIC MODEL

The micro-economic model, as the core model of the integrated model framework, is discussed in Chapter 6 of this report.

3.5.3.1. Setup data

The processed hydrology data, further refined in the biophysical sub-component (CY-CUE) together with CEB data and sub-WUA setup data, are fed into the micro-economic model to determine (using the Maas and Hoffmann equation), yield and subsequent per hectare CEB changes subject to saturated soil salinity.

3.5.3.2. Spatial and temporal dimensions

The per hectare CEB results are extrapolated to irrigation block level total gross margin above specified costs (TGMASC) to give the average annual irrigation block level impact of irrigation salinity for the scenarios modelled. The 15-year cumulative TGMASC is also calculated. This is *inter alia* to work out the costs and benefits of increasing returnflows through installation of artificial drainage and increased leaching for a long-term (15) year loan.

3.5.3.3. Linkages

Results generated in the micro-economic model are fed into the regional economic model as annual and cumulative crop TGMASCs for 100 stochastic runs for each of the scenarios.

3.5.4. REGIONAL ECONOMIC MODEL (MACRO-ECONOMIC LEVEL)

3.5.4.1. Setup data

The set-up data used are:

- The individual CEB components that make up the CEB (e.g. total seed, fertilized, herbicide, etc. bought per year) for stochastic runs 001, 044 and 080, representing the 0.05, 0.95 and 0.50 percentiles,
- Individual CEB components averaged over the 100 stochastic runs
- Annual and cumulative crop TGMASCs for all 100 stochastic runs

- Relevant setup data from the micro-economic model setup data file is also inputted into the regional economic model.

The setup of the regional economic model (ISIM) is described in full in Chapter 7 and the results interpreted and discussed in Chapter 10.

3.5.4.2. *Spatial and temporal dimensions*

At the regional level the irrigation-blocks are combined to model regional impacts at the complete study-area level as described in Chapter 2. The regional model models at an annual time scale, with the Index for Social Economic Welfare (ISEW) modelling the change from one year to the next, with 2005 being the base year.

3.5.4.3. *Linkages*

The data inputted into the regional economic model are run through an input/output matrix to calculate the economic multipliers of the forward and backward economic linkages within the study area. The resulting annual change in gross geographic product (GGP) and employment are expressed as the economic sustainability and social sustainability components of the ISEW respectively. The salt mass balance of each irrigation block summed together forms the environmental component of the ISEW.

3.6. OUTPUT DATA AND RESULTS FILES

The processed output data from the various levels of modelling are the results of the model, and are also used to formulate policy as presented in Chapter 12.

3.6.1.1. *Setup data*

The output data files are populated with data from the preceding model files. Careful consideration has to be taken of the format in which the data is presented for results discussion and of the format in which the data is required for the following model.

3.6.1.2. *Spatial and temporal dimensions*

The processed hydrology data displays the spread of 100 stochastic runs, as an annual trend and as the monthly-expected distribution spread over 25 years. Although the economic model only examines a 15-year period, a 25-year period is used in the hydrology model to identify long-term hydrology trends; this facilitates the correct interpretation of the economic data.

Per hectare total gross margin above specified costs (TGMASC) and irrigation block level TGMASC for all crops analysed, are setup for annual and 15-year cumulative analysis and display of the micro-economic model. The regional economic output data is displayed as annual changes in regional GGP, employment and production in the different sectors of the regional economy resulting from the different scenarios modelled.

The ISEW, calculated in the regional economic model, is displayed as annual changes in production, employment and environmental indicators for the actual stochastic runs that best represent the 0.05, 0.50 and 0.95 percentiles of the cumulative TGMASC in the micro-economic model.

3.6.1.3. Linkages

Monthly soil salinity concentration (**CU**) and effective soil moisture (**HE**) in the upper zone data for each scenario and each irrigation block over 15 years is set up and transferred as input for the micro economic model. Annual average salt abstraction (**SA**) and return flow (**SR**) mass in tonnes for each scenario and each irrigation block over 15 years is set up and transferred as input for the regional economic model.

For input into the regional economic model, the full CEB composition (break-down) over 15 years, for each irrigation block, for each of the 3 stochastic runs selected to represent the 0.05, 0.50 and 0.95 percentiles of all 100 stochastic runs, for each scenario, are set up in, and transferred from the micro-economic model to the regional-economic model. Regional economic results generated are used to motivate the best policy options in Chapter 12.

3.7. SUMMARY OF DATA SOURCES

Table 3.1 is a summary of the data sources for the integrated model sub-components as presented in Figure 3.1.

Table 3.1 A summary of the input data sources

Category	Details	Sources
Hydrology	Crop coefficients	SAPWAT (van Heerden <i>et al.</i> 2001), Green (1985)
	WRPM setup	Allen and Herold (1988)
	Pumping capacities	WUAs, DWAF
Farm level data	Temporary labour requirements	Case study farmer survey, Expert panel opinion, GWK and WUAs
Micro-economic data	Regional average CEBs	GWK
	Farm level CEBs	Case study farmer survey
Macro-economic data	National input/output matrix data	Study area survey
Agronomy	Monthly crop water requirements	Van Heerden, <i>et al.</i> (2001)
	Factors influencing yield	Bristow Du Plessis and Annandale (pers. Comm., 2005)
	Crop water demand	WUAs, DWAF
Salinity	Base salinity	Case study farmer survey, WRPM manually set
	Threshold and Gradients	Maas and Hoffmann (1977)
	Crop growth stage sensitivities	n/a
Soil data	Soil type division	Case study farmer survey, Expert panel opinion
Groundwater		n/a

3.8. SUMMARY

This chapter serves only as an introduction for a full discussion in the chapters to follow. The hydrology model (WRPM) is discussed in Chapter 4, the biophysical model in Chapter 5, the micro economic model in Chapter 6, the regional (or macro-economic) model in Chapter 7, the scenarios in Chapter 8, and the micro-economic and regional (or macro-economic) results are discussed in Chapter 9 and Chapter 10 respectively.

CHAPTER 4. HYDROLOGY MODEL DESCRIPTION

by HS. Swart and P.G. van Rooyen – WRP Consultants¹

4.1. INTRODUCTION

4.1.1. BACKGROUND TO WATER RESOURCE MODELLING OF THE INTEGRATED VAAL RIVER SYSTEM

The irrigation schemes in the Lower Vaal and Riet Modder sub-systems that are of specific interest to this study are modelled as part of the Integrated Vaal River System (IVRS). The IVRS comprises of water supply schemes in the Vaal River Basin together with inter-basin transfer schemes linking the Vaal and adjoining basins. The system therefore includes several major sub-catchments such as the Upper Vaal, Vaal Barrage, Middle Vaal, Lower Vaal, Riet-Modder, Komati, Usutu and Tugela as well as the Upper and Lower Orange.

Since the Vaal River System is the most important water resource system in South Africa, advanced computer models and analytic techniques were developed as an aid to ensure the successful planning of future developments as well as the optimal operation of the system. Several Vaal River System studies have been commissioned by the Department of Water Affairs and Forestry (DWAF) since 1985 and the extended computer models and improved analysis techniques developed in the process have since become standard methods used for water resource studies in South Africa. The most recent comprehensive study, the Vaal River System Analysis Update (VRS AU) study, was commissioned in 1995. The purpose of the VRS AU study (DWAF, 2001) was to revise and update the hydrological and water quality databases used in the earlier studies and to re-assess the water quantity and quality situation in the whole Vaal River System. The hydrological database resulting from the VRS AU study has subsequently been incorporated in the configurations of the Water Resource Yield Model (WRYM) and the Water Resource Planning Model (WRPM).

The WRYM was used to establish the yield capabilities of the various sub-systems. In order to facilitate the optimum operation of the existing system, the WRPM is utilised to revise the short-term operating rules for the IVRS on an annual basis. Although updated information on water requirement projections of major water users and bulk water suppliers such as Eskom and Rand Water are obtained on an annual basis and refinements to the overall system configuration are done as new information becomes available, the hydrological database adopted for the WRYM and WRPM (resulting from the VRS AU study) remained unchanged.

4.1.2. BRIEF DESCRIPTION OF WATER RESOURCE MODELLING PROCESSES

The following sequential tasks were undertaken as part of the VRS AU study:

- Hydrological analysis
- Calibration of the salinity model
- Stochastic stream-flow generation (verification and validation)

¹ WRP Consultants are not part of the project team, nor is this work funded by the WRC project, but by the DWAF.

- Sub-system yield analysis
- System planning analysis

The main steps involved in the hydrological analysis are shown in Figure 4.1. In the updating of the hydrology database use was made of the WRSM90 rainfall-runoff model (SSI, 1997). This model is an updated version of the Pitman (or HDYP09) model used by the Water Research Commission (WRC) for the assessment of the surface water resources of South Africa (WRC, 1994). WRSM90 is a monthly time step network model that can simulate the impact of catchment developments such as impoundments, water requirement abstractions, irrigation and afforestation. Rainfall is used as primary input to the WRSM90 model and the model has the capability to produce monthly time series files of simulated natural runoff as well as irrigation water requirements and reduction in runoff due to afforestation. As indicated in Figure 4.1 pre-processors (CLASSR and PATCHR, (DWAF, 1997) are used for the patching of the rainfall data. The patched catchment rainfall data are then used as input to the WRSM90 model. The model requires a physical description of the system and a set of catchment parameters that govern the way in which the model generates runoff within each catchment. The catchment parameters for a specific catchment have to be estimated through the process of calibration whereby the simulated stream-flow is compared against observed stream-flow. The main output from the WRSM90 model is simulated natural historic stream-flow sequences.

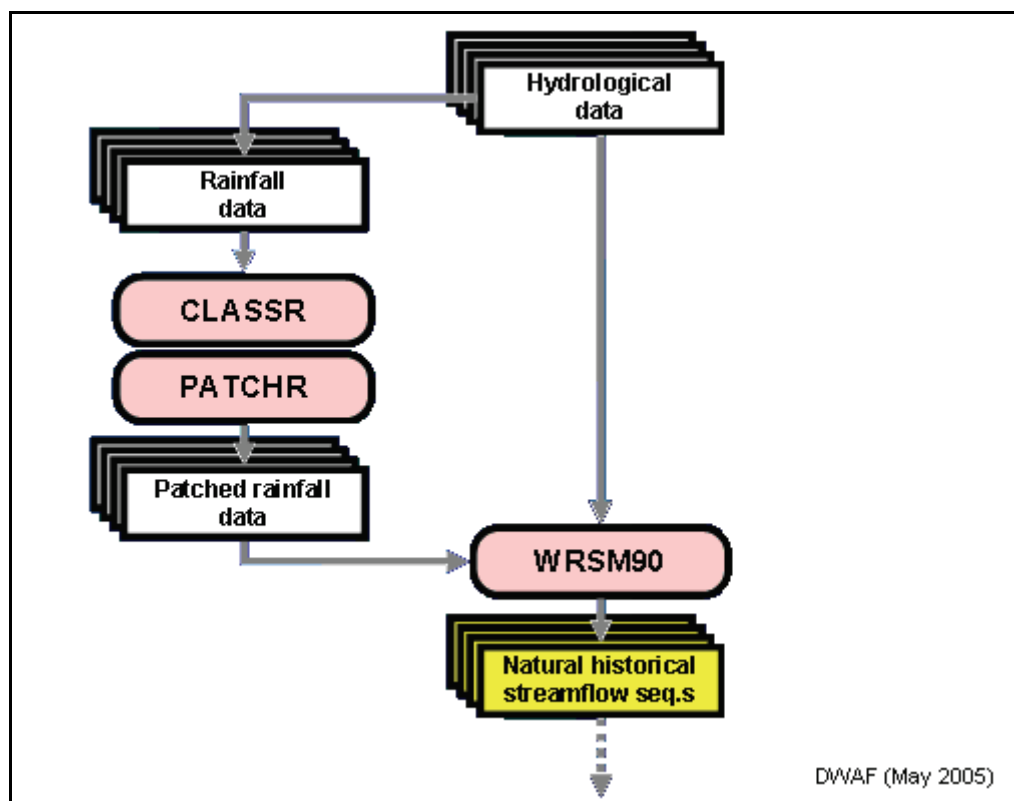


Figure 4.1. Hydrological analysis

The natural historic stream-flow record embodies the information available to evaluate the historic water yield of a catchment. However, the yield derived from a single historic flow sequence can be very misleading and depends, to a large extent, on the period of record and the severity of the critical period of the record. Furthermore, the difficulty working with the historic record is that it is almost surely never to be repeated and it is

not possible to relate the historic firm yield to a specific risk of failure or reliability of supply. Since water resources systems became more complex and capital intensive, the need to estimate the likely risk of failure associated with specific yield values were identified and led to the development of a stochastic stream-flow model. The Monthly Multi-Site Stochastic Stream-flow Model, referred to as STOMSA (WRC, 2003), which is incorporated in the WRYM and WRPM, was developed and refined over the years with the major objective of generating alternative natural stream-flow sequences that can be analysed by the standard water resources models (WRYM and WRPM). Since the statistical characteristics of the historic stream-flow sequences and the cross correlation of stream-flow at many sites should be preserved in the stochastic stream-flow generation process, several standard verification and validation tests are performed to ensure that the stochastic stream-flow sequences are indeed plausible. Figure 4.2 shows the various steps involved in the stochastic stream-flow generation process and a detail description of the fundamental principles of the process can be found in the STOMSA User Guide (WRC, 2003).

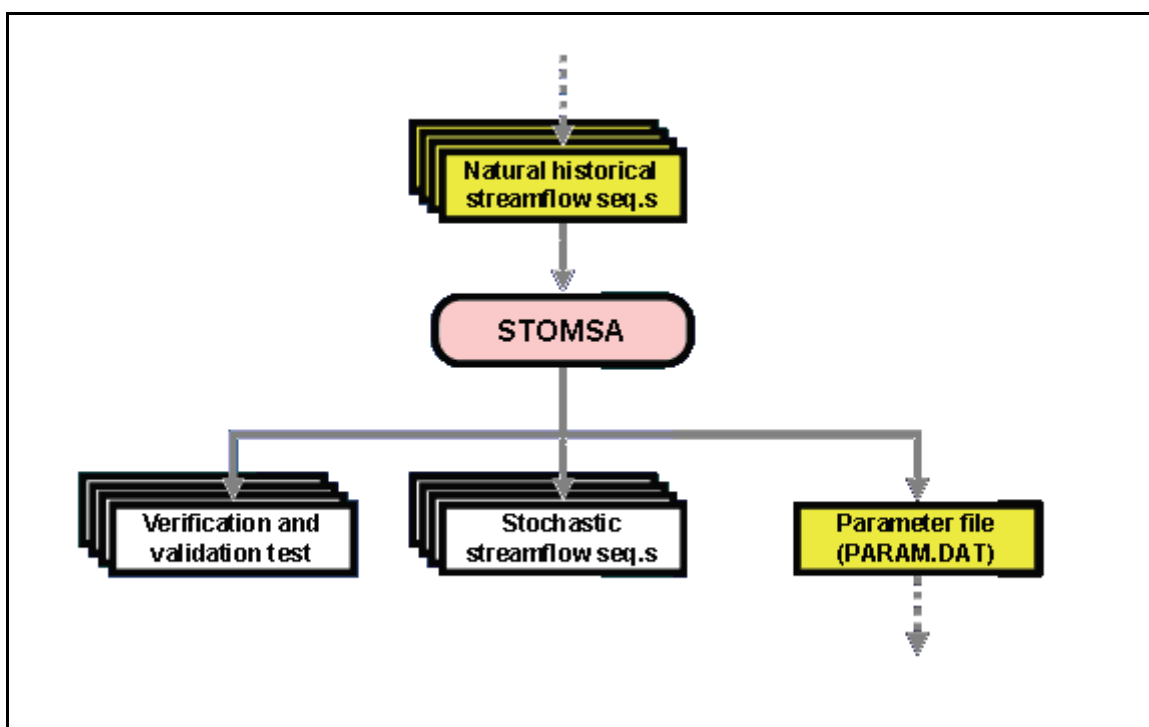


Figure 4.2. Stochastic Stream-flow generation

The Water Resource Yield Model (DWAF, 1999) is a general multi-purpose multi reservoir simulation program. It is a monthly time step model which uses a sophisticated network solver in order to analyse complex water resources systems under various operating rules. The WRYM is designed to assess the long-term yield capabilities of a system for a given operating policy. It is used to analyse systems at constant development levels, i.e. the system and the system demands remain constant throughout the full simulation period. Furthermore, analyses undertaken with the WRYM can be based on either the natural historic stream-flow sequences or generated alternative stochastic sequences. The input and output data of the WRYM are shown in Figure 4.3.

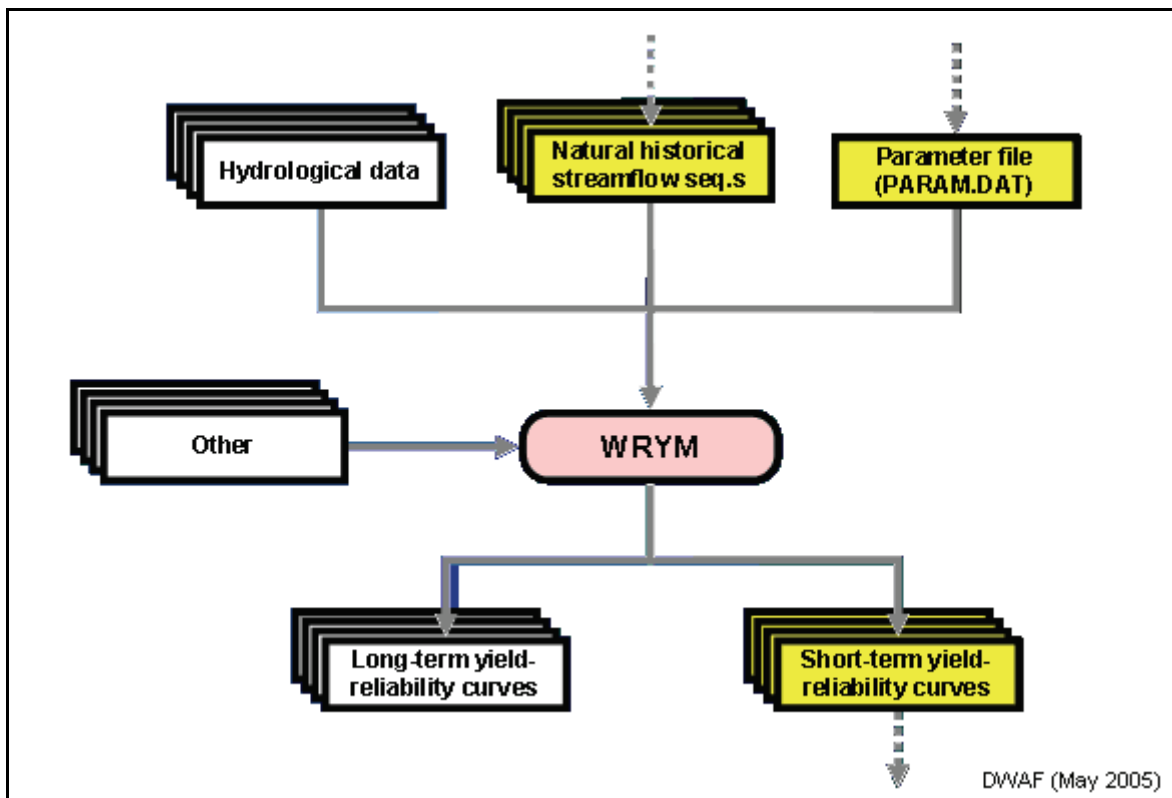


Figure 4.3. Sub-system Yield Analysis

The Water Resource Planning Model (WRPM) is considerably more complex than the WRYM and was designed for decision support in operation and development planning of water resource systems. The model is capable of modelling growing water requirements. Changes to the system configuration can also be accommodated over time, i.e. new infrastructure elements can be activated at a specific point in time during the simulation period and existing features (such as a transfer channel) can become obsolete. The WRPM can be used both as a planning tool to assess the likely implementation dates of new schemes or resources, as well as an operating tool for the month to month operation of a system. Water quality is also be modelled within the WRPM. Since salinity has been identified as the most serious water quality problem in the Vaal River system, water quality modelling within the IVRS has focused on the simulation of TDS (Total Dissolved Solids). The salinity models were re-calibrated as part of the VRSAU study and the resulting water quality information was included in the WRPM configuration. Figure 4.4 shows the input requirements of the WRPM as well as the typical output from the model.

The IVRS is analysed with the WRPM on an annual basis in order to determine the operating rules to be applied during the next planning year (DWAF, 2004b). To this end, the WRPM system configuration is constantly being updated as new information becomes available. Although the general purpose of the WRPM is to quantify the capability of dynamic changing water resource systems, it can also be used for the analysis of constant development levels.

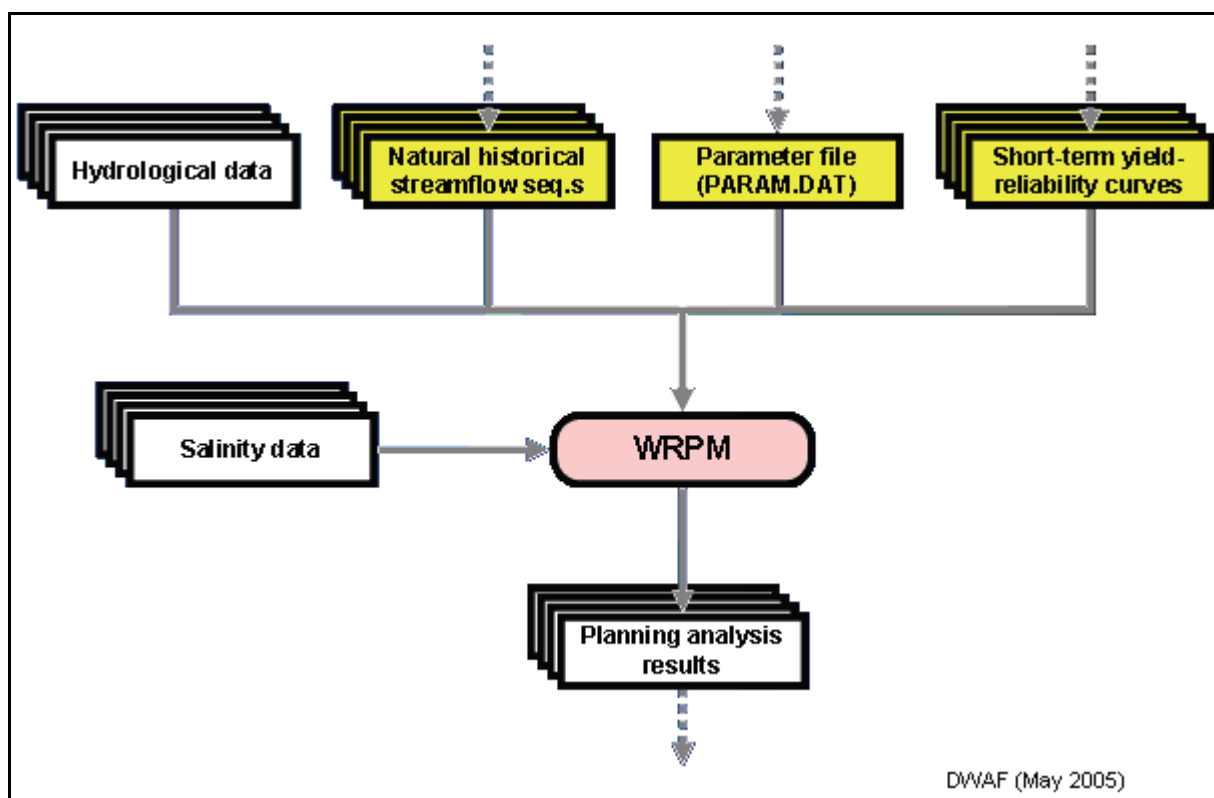


Figure 4.4. System Planning Analysis

4.1.3. REASONS FOR CHOOSING THE WATER RESOURCES PLANNING MODEL (WRPM)

The study area encompasses several irrigation schemes in the Lower Vaal and the Lower Riet/Modder sub-systems which receives water from various sources consisting of two abstractions from the Orange River (through the Orange-Riet Canal and the Orange-Vaal transfer to the Douglas irrigation area) as well as uncontrolled spills and returnflows from the Vaal, Riet and Modder sub-systems. As mentioned in Paragraph 4.1.1, these sub-systems are included in the WRPM configuration of the IVRS and the water requirement abstractions and returnflows of the irrigation schemes are modelled by means of so-called irrigation blocks. The irrigation block sub-model has been developed to account for the continuity of mass for salt and allows for further flushing of salt from the irrigated lands (DWAF, 1988). Input to the irrigation blocks comprises of detailed information on *inter alia* irrigation areas, crop coefficients, average monthly evaporation, rainfall efficiency factors and monthly rainfall time series data.

The investigation of irrigation practices undertaken as part of this study is focused on the analysis of the salinity contents of the water supply as well as the modelling of the salinity balance in the soil profiles of the irrigated areas. Since water supply time series data (both volumes and TDS concentrations) were required for the detail modelling of the irrigation activities within the study area, the WRPM as configured for the IVRS was identified as the best source of information. However, since the WRPM simulates salinity for the Vaal and Riet/Modder sub-systems only, it was necessary to make appropriate assumptions regarding the salinity contents of the water sourced from the Orange River system as discussed in Paragraph 4.1.5. A further advantage of the WRPM model is its capability to generate and analyse any number of alternative stochastic stream-flow sequences which ultimately provide a number of possible outcomes.

4.1.4. MODEL LIMITATIONS

As mentioned in Paragraph 4.1.2, the WRPM was designed to model a dynamic system configuration with growing water requirements. The WRPM system configuration can, however, be adjusted to represent a fixed catchment development level. The initial water quality parameter values included in the WRPM configuration were obtained from the VRSAU study and are representative of the 1995 conditions. Therefore, trends may occur in the salinity results when running the model for a fixed development level (e.g. 2005 conditions). These trends are caused by the relatively long lag times that are typically experienced with water quality responses. Consequently, it was necessary to make certain adjustments to the initial salt storage parameter values.

4.1.5. METHOD ADOPTED FOR THE WRPM ANALYSES

The WRPM can be run in either the historic or stochastic mode. Natural historic stream-flow records (resulting from the hydrological analysis) are used when running the WRPM in historic mode. A historic analysis requires less computing time and can therefore be used for testing and evaluation purposes. It was decided that stochastic analyses based on 100 sequences would be undertaken for selected scenarios once the WRPM configuration had been tested and refined to an acceptable level of detail.

The method adopted for the WRPM analyses of this study was as follows:

- The exact points in the WRPM network configuration, for which the time series data were to be produced, were defined and these points were matched with the boundaries of the detailed salinity model.
- The water requirements and supply rules to be implemented in the WRPM analysis for the irrigation areas that are included in this study were confirmed and updated where necessary.
- A historic analysis (covering a period of 68 years) was undertaken with the WRPM and historic time series data (flow and TDS concentrations) were produced for the points of interest based on the updated IVRS configuration.
- The results were communicated to the UFS Project Team for detailed evaluation of the economic model (SMsim).
- Based on the results of the historic analysis, the required scenarios to be analysed with the WRPM in stochastic mode were defined.
- For each of the identified scenarios the relevant input data were incorporated in the WRPM configuration and a historic analysis was undertaken for testing purposes.
- The WRPM output results were evaluated and compared against previous results to ensure that they were realistic.
- Finally, stochastic analyses based on 100 stochastic sequences, covering a period of 25 years in length, were undertaken for each of the alternative scenarios.
- The stochastic results were provided to the Salinity Project Team for further manipulation.

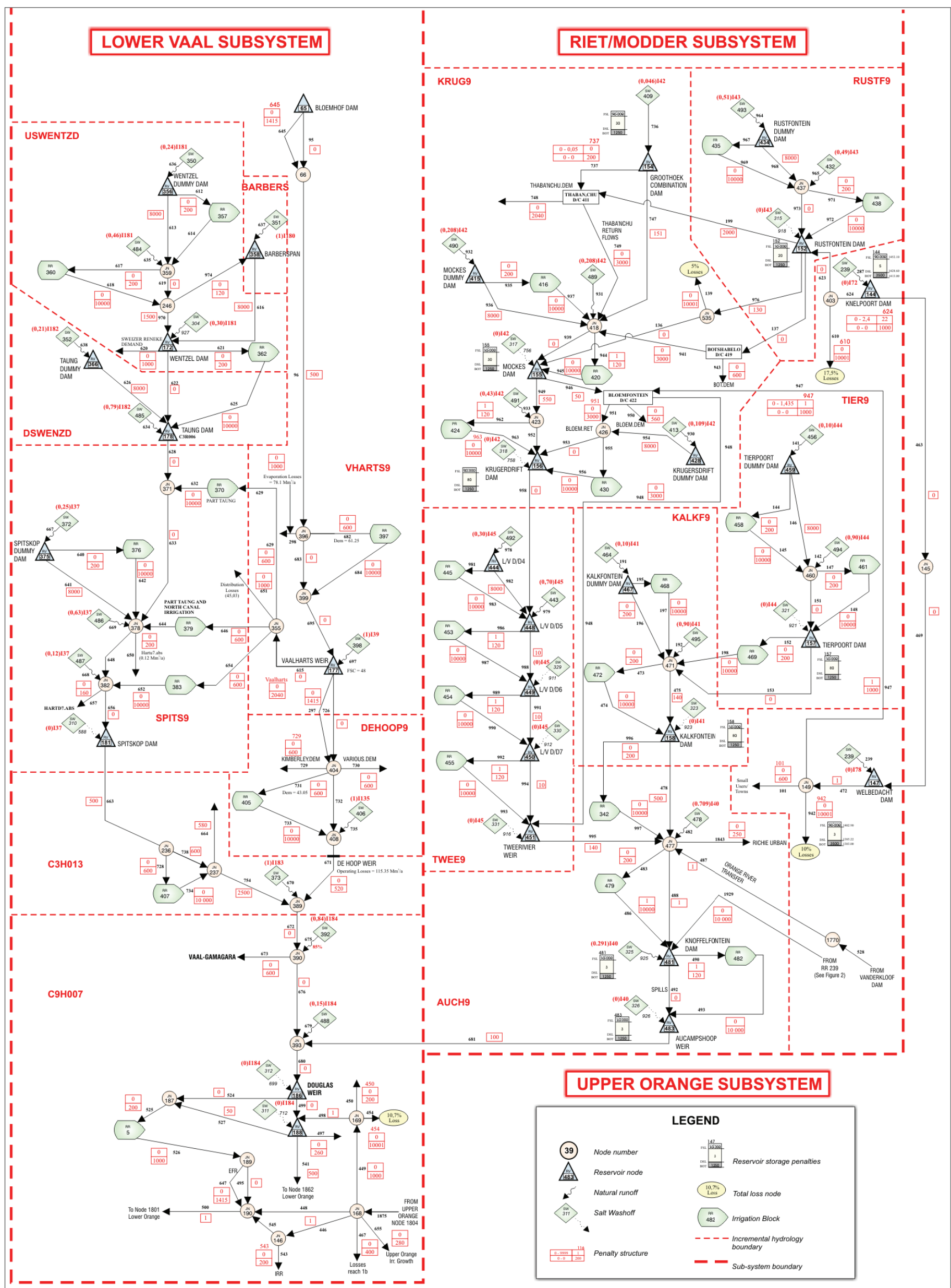
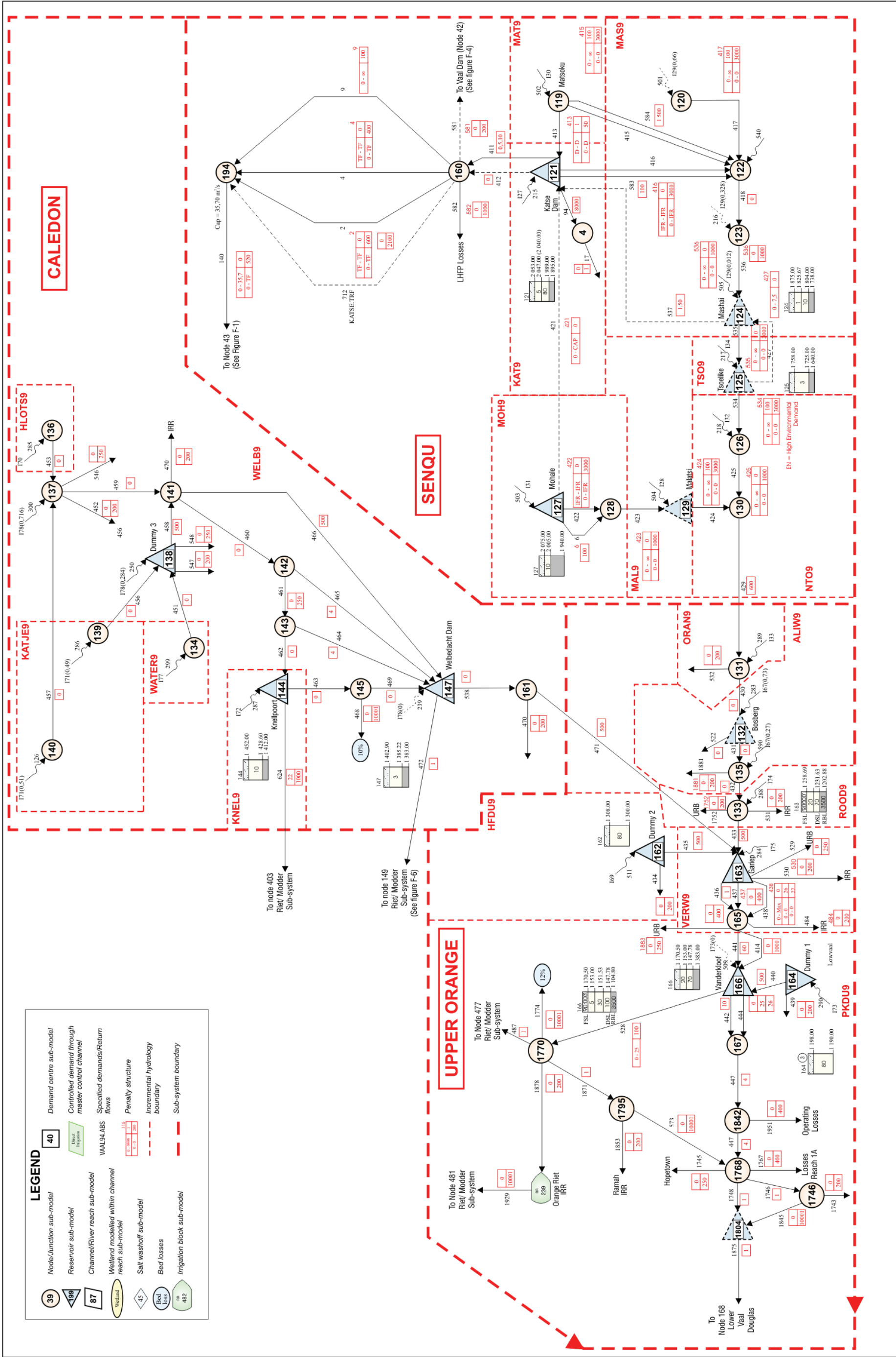


Figure 4.5. Hydrology map 1- WRPM set-up / representation of the Lower Vaal and Riet/Modder sub-systems



4.2. DESCRIPTION OF THE MODEL

4.2.1. SPATIAL DIMENSIONS

The WRPM as configured for the Integrated Vaal River System was adopted for the analysis. Therefore, although the focus of this study was on irrigation schemes located in the Lower Vaal and Riet-Modder sub-systems, the impact of all catchment developments of interest upstream of these irrigation areas was also taken into account in the analysis. The diagram representing the WRPM configuration of the Lower Vaal and Riet/Modder sub-systems is provided in Figure 4.5 and Figure 4.6 represents the WRPM configuration of the Orange River sub-system¹. As shown in these figures, the IVRS catchments were divided into incremental catchments and the required hydrological data sets were derived for each of these incremental catchment units. A hydrological data set comprises of the following time series files:

- Natural stream-flow (in million m³/month);
- Point rainfall at major reservoir (in mm/month);
- Diffuse irrigation water requirements, i.e. uncontrolled demands within the catchment (in million m³/month);
and
- Reduction in runoff due to afforestation (in million m³/month).

It should be noted that the point rainfall record mentioned above is used for the assessment of evaporation losses from the open water surface of reservoirs within the catchment, as well as the irrigation water requirements of irrigation areas modelled by means of an irrigation block. Controlled water requirements such as irrigation, urban and industrial requirements are supported by storage and are modelled either as monthly time series or as 12 monthly values. The abstraction points of controlled demands are shown on the schematic diagrams.

4.2.2. TEMPORAL DIMENSIONS

The WRPM is a monthly time step model. With the exception of the Upper and Lower Orange River catchments, the hydrology of the remainder of the sub-catchments of the IVRS was updated as part of the VRSAU study and covers the period from October 1920 to September 1995 (i.e. 75 years). The hydrology of some of the incremental sub-catchments of the Upper and Lower Orange River catchments, however, only extends up to September 1988. Therefore, when running the WRPM in historic mode, the analysis can only be based on the common period of record (i.e. on a 68 year period extending from October 1920 to September 1988). The effect of the cyclicity and seasonality of rainfall experienced within an incremental catchment is reflected in the naturalized stream-flow time series record that was simulated for the relevant incremental catchment.

¹ For a simplified version of Figure 4.5 and Figure 4.6, scaled down to only the irrigation blocks, channels and salt wash-off modules of interest, see Figure 2.7, a simplified diagram of the hydrology set-up of the study area

A planning horizon of between 15 and 30 years is typically considered for planning analyses and the length of the planning period is determined by the projection period of the water requirements. A 25 year planning period was considered for all the stochastic analyses undertaken as part of this study.

Although the WRPM has the capability of modelling growing water requirements, for the purposes of this study the system configuration was adjusted to represent a constant development level. All developments and water use were set at the 2005 level. A monthly water requirement distribution pattern (for the twelve months of the year) is specified for each water requirement that is not modelled by means of a monthly time series file.

The month of May has been selected as the decision month for the IVRS which means that demand allocation decisions are taken at the beginning of May of each year of the analysis period. Consequently, the WRPM configuration adopted for this study has also been set up with May as starting month for the analyses. The actual reservoir storage levels as recorded on 3 May 2004 were therefore considered as the starting storage conditions for all the major dams in the IVRS. Information on the concentration of Total Dissolved Solids (TDS) for all the major dams was also updated to reflect water quality starting conditions that are representative of the May 2004 TDS concentrations.

4.2.3. STOCHASTIC MODELLING

As mentioned in Paragraph 4.1.5, the WRPM can be run in either historic or stochastic mode. It should be noted that historic point rainfall records (mentioned in Paragraph 4.2.1) are used for the historic analyses whereas stochastic rainfall is used with the modelling of the 100 stochastic stream-flow sequences. The generation of stochastic rainfall is, however, not similar to that of stochastic stream-flow sequences. When running the WRPM in stochastic mode, it generates annual stochastic stream-flow values. The historic rainfall data are then used together with the generated annual stochastic stream-flow values to create corresponding “stochastic” rainfall records. The way this is done, is as follows: for each year of the simulation the model compares the generated stochastic annual stream-flow value against that of the historic stream-flow record and identifies the hydrological year associated with the historic annual value closest to the generated stochastic annual stream-flow value. The historic monthly rainfall data corresponding to the identified hydrological year are then selected as being representative of the stochastic rainfall for the relevant simulation year (a common historical year is selected for all the gauges).

4.2.4. MODEL SCHEME AND LINKAGES WITH THE ECONOMIC MODELS

Figure 4.7 is a schematic presentation of the workings of the WRPM model, depicting the water and salt flows, balances and interactions in the WRPM. The discussion that follows serves only to highlight the main WRPM variables used in the economic models SMSim (micro) and ISIM (regional).

The main linkages with the micro-economic level model are the HE, the effective soil moisture storage depth in the upper zone (UZ) and the SCU, the salt concentration in the UZ at effective soil moisture HE. With equation 5.1, explained in Chapter 5, the saturated soil salt concentration is calculated from these two variables. The SCU and SCL, salt concentration in the lower zone, are used in the regional economic model for the calculation of the environmental sustainability index for the combined Index for Sustainable Economic Welfare (ISEW). The ISEW is used in comparing different scenarios on the triple bottom line, i.e. financial, environmental and social sustainability.

The irrigation returnflow (-IR) variables (QIR and CIR) are also analysed in this report to calculate the impact of returnflows on downstream users. The gross irrigation demand (-ID) variables (QID and CID) and irrigation area are variables also synchronised between WRPM and SMSim.

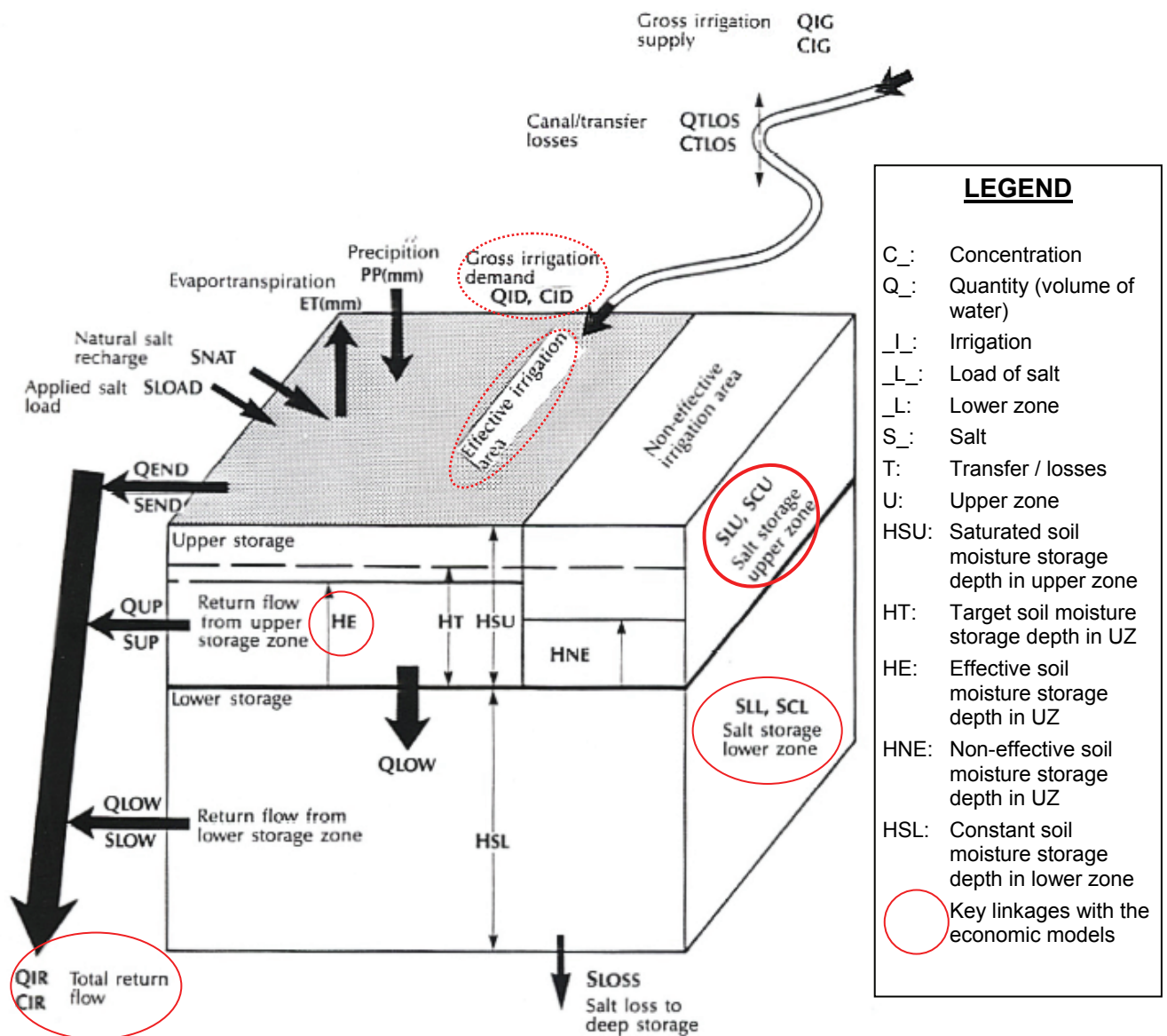


Figure 4.7. Model scheme depicting the salt and water balance paths in the WRPM (modified from Allen and Herold, 1988) - see Table 4.3 and Table 4.4 for a more comprehensive legend and definition of terms

4.3. DATA REQUIREMENTS

Data sets for each of the variables listed in Figure 4.7 are required.

4.3.1. DATA SOURCES

The hydrological database of the WRPM was established as part of the VRSAU study and represents the most recent hydrological information available. Revised water requirement projections of bulk water suppliers (such as Rand Water, Sedibeng Water and Midvaal Water) as well as strategic water users (Eskom and Sasol) are obtained on an annual basis. Information on the water requirements of the remainder of the rural, urban and industrial users are based on the water requirement projections of the National Water Resources Strategy.

With regards to the Lower Vaal and Riet-Modder sub-systems, the irrigation information included in the WRPM configuration (resulting from the Vaal River System Analysis Update Study) was verified against the more recent information obtained from the study entitled “Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River” (July 2004). The WRPM configuration (resulting from the VRSAU Study) was also discussed with the UFS Project Team and compared against the system configuration incorporated in the detailed economic model of the UFS research team. Information was also obtained from the “Water Management Plan: 2004” as compiled for the Orange-Riet Water Users Association by Ninham Shand.

4.3.2. PRIMARY DATA

The following primary data are required to run the WRPM:

- A representative hydrological database (comprising of the incremental catchment data sets described in Paragraph 4.2.1);
- Water requirement projections for all user groups;
- Detail information on irrigation schemes modelled by means of irrigation blocks (e.g. irrigated area, crop types, crop compositions, crop coefficients, irrigation efficiency, rainfall efficiency, return flow proportion, transfer canal losses, etc.)
- Information on the physical infrastructure elements (e.g. reservoir characteristic, transfer capacities of pipelines, canals and tunnels, etc.)
- Information on existing and/or proposed operating rules;
- Water quality information.

4.3.3. DATA RELIABILITY AND CONFIDENCE LEVELS

Hydrology is not an exact science. However, the method applied and simulation models used for the establishment of the existing IVRS hydrological and water quality databases comply with the standard techniques adopted by the Department of Water Affairs and Forestry. Since the best information available was used for the hydrological and water quality calibration processes, it is concluded that the reliability of the resulting databases is within acceptable limits.

Information on the irrigation schemes that were of specific interest to this study was also updated based on the most recent and reliable data that were available.

4.4. MATHEMATICAL SPECIFICATION OF THE MODEL

4.4.1. MODEL SETUP AND ASSUMPTIONS

The WRPM system configurations relevant to this study are shown in Figure 4.5 and Figure 4.6. As indicated on these schematic diagrams, irrigation water requirements and returnflows in the Lower Vaal and Riet-Modder sub-systems are modelled by means of irrigation blocks. The following irrigation schemes/areas were of specific interest to this study:

- Kalkfontein Irrigation Canals;
- Scholtzburg Irrigation;
- Riet River Settlement;
- Ritchie;
- Orange-Riet Canal Irrigation;
- Lower Riet Irrigation Board;
- Douglas Irrigation supplied from Orange-Vaal transfer canal; and
- Douglas Irrigation supplied from Douglas Weir.

As part of the initial WRPM system configuration, the irrigation water requirements of the Riet River Settlement, Ritchie and the Orange-Riet Canal Irrigation were grouped together and the total demand was modelled as a fixed annual abstraction supplied from the Orange-Riet Canal. With the exception of the Douglas Irrigation Area supplied from the Orange-Vaal transfer canal (also modelled as a fixed annual abstraction), the remaining irrigation areas are modelled by means of irrigation blocks.

- As mentioned in Paragraph 4.3.1, updated information on the irrigation schemes was incorporated into the irrigation block definitions and refinements were also made in terms of the WRPM configuration. The following adjustments were made during the initial testing phase of the analyses:
- Incorporation of an irrigation module downstream of Spitskop Dam;
- Representing the Riet River Settlement, Ritchie and Orange-Riet canal irrigation by means of an irrigation module as opposed to the modelling of this irrigation abstraction as a constant annual demand (i.e. to allow for the representative return flow modelling in terms of both the volumes and TDS concentrations);
- Refining the modelling of the Scholtzburg Irrigation Scheme (changes were made to the natural incremental runoff contributing to the relevant irrigation module);
- Iterative refinement of irrigation module input data (e.g. irrigation efficiency factors, rainfall efficiency factors, return flow factors, transfer canal losses, crop coefficients and crop compositions); and
- Iterative adjustments to the initial salt storage parameters to remove the growing trends observed in the TDS concentrations associated with the irrigation returnflows.

The refinements mentioned above were necessary in order to obtain realistic irrigation abstraction and return flow results for the irrigation schemes of interest as well as to ensure compatibility with the salinity model configuration. Owing to lack of detail information, the Douglas irrigation supplied from the Orange-Vaal canal could not be modelled by means of an irrigation block. This abstraction was, therefore, simulated as a fixed annual abstraction in all of the scenario analyses. One of the most important assumptions made in terms of the modelling of the irrigation water requirements was that the rainfall efficiency factors were all set to zero. Therefore, in the WRPM analyses zero contribution was assumed from rainfall and by implication the full irrigation water requirements were supplied from surface water. Furthermore, the irrigated area is modelled as an isolated area within the irrigation module and only the volume of the surface runoff generated within the Salt Washoff Module that is associated with the irrigation area is allocated to the irrigation model. The runoff associated with the irrigation area is, however, not available for supplying a portion of the irrigation water requirements, but is modelled as part of the total return flow resulting from the irrigated land (refer to Equations 4.25 and 4.26 on Page 4.26 of the Water Quality Modelling report (DWAF, 1988)).

In addition to the irrigation schemes listed above, the following water supply routes were also of interest:

Route 1: Uncontrolled spills and returnflows from the Vaal River sub-system just upstream of the confluence with the Riet-Modder sub-system (WRPM network channel number 676);

Route 2: Uncontrolled spills and returnflows from the Modder River sub-system downstream of the Tweerivier Weir and just upstream of the confluence with the Riet River (WRPM network channel number 995);

Route 3: Uncontrolled spills and returnflows from the Riet River sub-system just downstream of Kalkfontein Dam (WRPM network channel number 478);

Route 4: Abstractions from the Orange River through the Orange-Riet Canal (WRPM network channel number 528); and

Route 5: The Orange-Vaal transfer to the Douglas irrigation area (WRPM network channel number 449).

Although a number of alternative operating rules were identified during the initial stages of the study, a decision was made that only realistic operating rules should be considered for the irrigation assessments. Therefore, the long-term operating rules of the IVRS incorporated into the WRPM configuration were adopted as a basis for the analyses. Since most of the long-term operating rules have an impact on the sub-systems upstream of Vaal Dam and will not influence the Lower Vaal sub-system, it was not deemed necessary to discuss these rules. Releases are required from Vaal Dam in order to maintain a TDS concentration of 600 mg/l downstream of Vaal Barrage. However, changes to the adopted blending rule will not impact on the situation in the Lower Vaal catchment since the portion of the releases that reaches Bloemhof Dam will be captured within the dam. For the purposes of this study the following assumptions should, however, be noted:

- Operating losses currently modelled in the Lower Vaal catchment amount to almost 115 million m³/a and it would be feasible to reduce these losses in future.
- The existing WRPM configuration does not include Environmental Water Requirements. If such requirements are implemented it could have a significant impact on the water quality.

4.4.2. MODEL INPUT DATA AND SCENARIO DESCRIPTIONS

In the WRPM analyses the irrigation areas of specific interest to this study were modelled by means of five irrigation blocks and a fixed abstraction channel. The basic input data used to configure each of the irrigation blocks as part of the refinements mentioned in Paragraph 4.4.1 are summarised in Table 4.1.

It should be noted that the gross irrigation demands shown in Table 4.1 include canal losses. These values were, therefore, also considered as the maximum water allocation per year that should be allowed from each of the respective irrigation blocks. The information on the total returnflows (which also includes tail-water) and the net irrigation demands given in Table 4.1 was obtained through long-term analysis undertaken as part of the Feasibility Study into Measures to Improve the Management of the Lower Orange River (DWAF, 2004a). These values were used for comparison and evaluation purposes during the initial refinement of the input data.

Table 4.1. Irrigation information adopted for the initial assessment¹

Description of irrigation area	WRPM reference ²	Irrigation Area (km ²)	Gross Irrigation Demand (million m ³ /a)	Irrigation Efficiency (%)	Total Return Flow (million m ³ /a)	Net Irrigation Demand (million m ³ /a)
Orange-Riet Canal ³	RR239	121.12	156.9	65	4.5	130.0
Scholtzburg	RR479	6.46	8.4	65	0.4	7.9
Lower Riet	RR482	39.38	51.0	65	2.5	41.2
Douglas (Weir and River)	RR5	70.25	75.5	69	9.8	65.7
Douglas (Orange-Vaal canal)	Ch 450	15.83	17.0	-	1.9	15.1

¹ Information obtained from the Pre-Feasibility Study into Measures to Improve the Management of the Lower Orange River (DWAF, 2004a) and the Orange River Development Project Re-planning Study (DWAF, 1998).

² Refer to Figure 4.5 and Figure 4.6 for schematic location of these irrigation schemes

³ This irrigation block includes Orange Riet Canal, Ritchie and Riet River Settlement irrigation schemes

Subsequent to the initial refinements incorporated in terms of the irrigation block definitions, it was recommended that the following four scenario analyses be undertaken with the WRPM:

- **Base Case Scenario:** This scenario is defined as the status quo scenario since it will evaluate the current agricultural practice situation (i.e. the crop compositions of the irrigation schemes will comprise of a mixture of salt tolerant and salt sensitive crops, the irrigation efficiency will be set for current irrigation practises and the drainage and return flow parameters will be set at the 2004/2005 levels).
- **Scenario 1:** Only salt tolerant crops will be considered for this scenario and the rest of the input data will be identical to the status quo (Base Case) scenario.
- **Scenario 2:** Salt sensitive (and high value) crops will be considered as part of this scenario.
- **Scenario 3:** This scenario will be based on **Scenario 2** (i.e. salt sensitive cropping patterns), but will allow for coupled leaching and additional drainage practices.

The irrigation block input data were adjusted to reflect the current (2004/2005) cropping patterns and irrigation practices. Updated information on canal losses was obtained from the individual irrigation scheme operators. This information was used in combination with the current irrigation areas and common annual allocation of 11000 m³/ha/a to calculate the corresponding gross irrigation demands. The irrigation efficiencies were also adjusted to comply with the current irrigation practices.

The basic irrigation block input data used for the analysis of the four scenarios described above are summarised in Table 4.2. As shown in Table 4.2 no changes were made to the modelling of the Douglas irrigation area supplied from the Orange-Vaal canal.

Table 4.2. Irrigation information adopted for the scenario analyses

Description of irrigation area	WRPM reference ¹	Irrigation Area (km ²)	Gross Irrigation Demand (million m ³ /a)	Irrigation Efficiency (%)	Canal Losses (%)
Orange-Riet Canal ²	RR239	123.4	157.8	85	14
Scholtzburg	RR479	6.4	8.3	84	15
Lower Riet	RR482	38.5	65.2	84	35
Douglas (Weir and River)	RR5	73.9	129.0	80	37
Douglas (Orange-Vaal canal)	Ch 450	15.8	17.0	- ³	- ³

¹ Refer to Figure 4.5 and Figure 4.6 for schematic location of these irrigation schemes.

² This irrigation block includes the Orange Riet Canal, Ritchie and Riet River Settlement irrigation schemes.

³ No values are used for the Orange-Vaal Canal as it serves farmers irrigating in the Upper Orange catchment and is therefore not relevant for this study.

4.4.3. MODEL OUTPUT

A WRPM analysis based on 100 stochastic sequences of 25 years in length was undertaken for each of the four scenarios described in Paragraph 4.4.2. Similar results were produced for each of the scenarios that were analysed. The monthly time series data of flow and TDS concentrations were simulated for each of the supply routes of interest. The coded naming conventions adopted for the water quality related channel output files are shown in Table 4.3.

Table 4.3. Output for water supply routes (channels)

Common Pre-fix	Code ¹	Description of output file	Units
TSRT	C	TDS concentration in specified channel	mg/l
TSRT	Q	Flow volume in specified channel	million m ³ /month

¹ The WRPM channel number follows the code in the naming convention of the output files.

In terms of the irrigation blocks all the water quality related output files that can possibly be generated by the WRPM were created. Table 4.4 provides a complete list of the output files that were produced as well as coded naming conventions adopted for the water quality related output files.

Table 4.4. Output data for irrigation blocks

Common Pre-fix	Code ¹	Description of output file	Units
TSRR	CL	Salt concentration in the lower soil zone	mg/l
TSRR	CU	Salt concentration in the upper soil zone	mg/l
TSRR	HE	Effective soil moisture depth in the upper soil zone	mm
TSRR	HN	Non-effective soil moisture depth in upper soil zone	mm
TSRR	QA	Irrigation abstraction flow	million m ³
TSRR	QR	Irrigation return flow	million m ³
TSRR	SA	Salt load associated with the irrigation abstractions	tonnes
TSRR	SL	Salt storage in lower zone	tonnes
TSRR	SR	Salt load associated with the returnflows	tonnes
TSRR	SU	Salt storage in upper zone	tonnes

¹ The WRPM irrigation block number follows the code in the naming convention of the output files.

The WRPM output files were provided to the UFS Project Team for input into detailed economic models and for further manipulation.

4.5. SUMMARY

The study area of this project falls within the area of analysis of the Integrated Vaal River System (IVRS) which includes several major sub-catchments such as the Upper Vaal, Vaal Barrage, Middle Vaal, Lower Vaal, Riet-Modder, Komati, Usutu and Tugela as well as the Upper and Lower Orange River catchments.

The Vaal River System Analysis Update (VRS AU) study, commissioned in 1995, revised and updated the hydrological and water quality databases of the IVRS, results of which are incorporated in the configurations of the Water Resource Planning Model (WRPM) used annually to revise the short-term operating rules for the IVRS.

Spatial sub-systems are included in the WRPM configuration of the IVRS and the water requirement abstractions and returnflows of the WUAs and surrounding areas are modelled by means of irrigation block units and salt wash-off modules. The irrigation block sub-model has been developed to account for the continuity of mass for salt and allows for further flushing of salt from the irrigated lands (DWAF, 1988).

Input data required for setting up the irrigation blocks for WRPM comprises of detailed information on *inter alia* irrigation areas, crop coefficients, average monthly evaporation, rainfall efficiency factors and monthly rainfall time series data.

The investigation of irrigation practices undertaken as part of this study is focused on the analysis of the salinity contents of the water supply as well as the modelling of the salinity balance in the soil profiles of the irrigated areas. Since monthly water supply time series data (both volumes and TDS concentrations) were required for the modelling of the irrigation activities within the study area, the WRPM as configured for the IVRS was identified as the best source of information. A further advantage of the WRPM model is its capability to generate and analyse any number of alternative stochastic stream-flow sequences which ultimately provide a number of possible water quantity and quality outcomes for risk analysis.

CHAPTER 5. BIOPHYSICAL INTEGRATION LINKAGES

by R.J. Armour, and M.F. Viljoen - UFS

5.1. INTRODUCTION

The aim of this chapter is to describe the various components and linkages that make up the biophysical sections of the integrated model.

The following sections are each discussed as main paragraphs of this chapter:

- The use of SAPWAT crop coefficients for hydrology model set-up
- The derivation of the saturated soil salinity, ECe (mS/m)
- The setting up of salinity-yield functions using the Maas and Hoffmann equation
- The hydrology – macro-economic linkage and the Index for Socio-Economic Welfare (ISEW)

Under each section, the following sub-headings are used.

- the input data and source,
- mathematical formulation of the sub-model,
- relevant results and their interpretation
- model limitations and assumptions
- key linkages.

The chapter concludes with a summary of the main points made in this chapter.

5.2. THE USE OF SAPWAT CROP COEFFICIENTS FOR HYDROLOGY MODEL SET-UP

5.2.1. THE INPUT DATA AND SOURCE.

To set up the WRPM hydrology model, crop coefficients are required as input parameters of the monthly water requirements of each crop included in the surface characterization and water usage profiles of the WRPM. Using as a fully functional, standalone irrigation scheduling model, SAPWAT (van Heerden *et al.*, 2001), basic data could be inputted and SAPWAT would calculate the monthly crop coefficient. The crop coefficient, together with reference evaporation (mm), is used to calculate the monthly crop water requirements of a specific crop. Figure 5.1 is the reference evaporation used for the calculation of the monthly crop coefficients in Figure 5.2. Note the similarity between the Douglas and Riet River reference evaporations. These two sets of data cover the two WUAs that make up the study area of this research, giving a small level of spatial variability to the data used in the economic models.

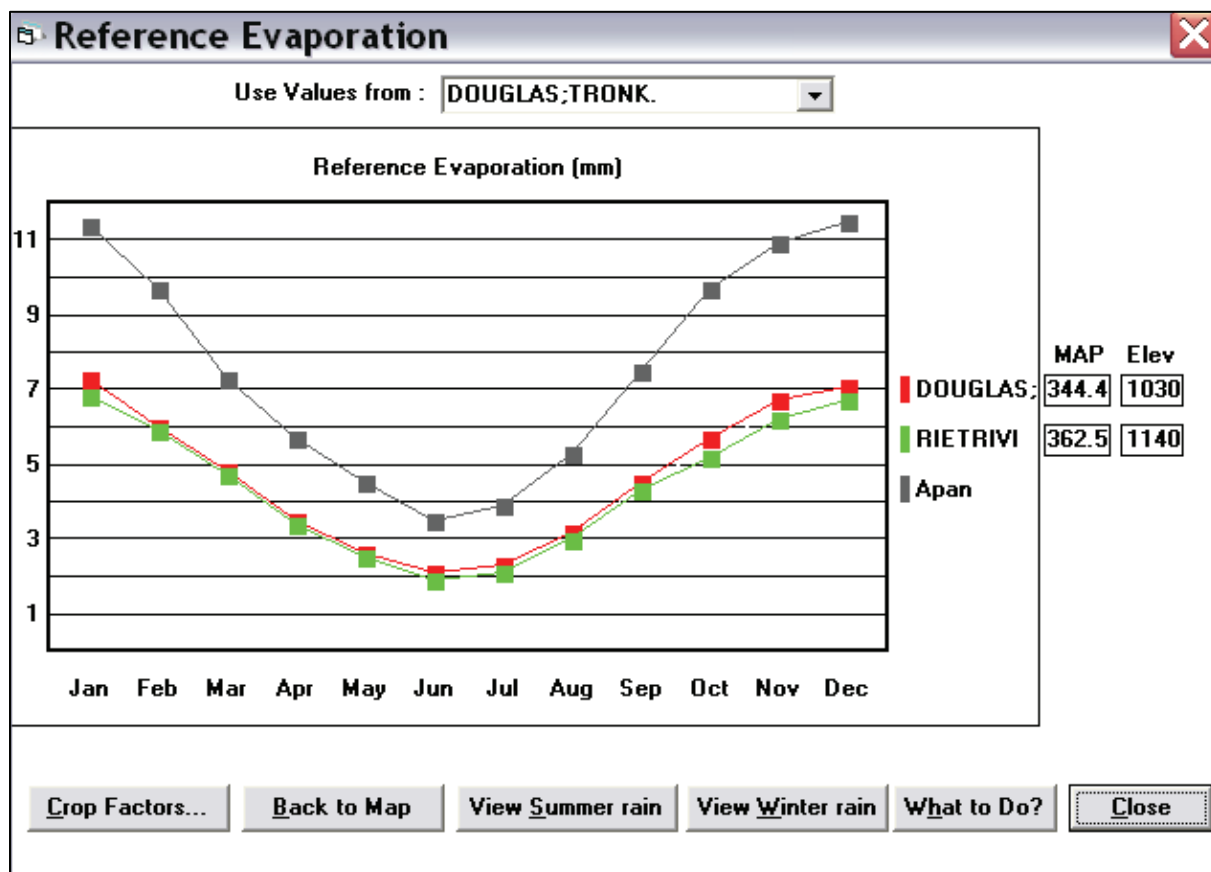


Figure 5.1. Reference Evaporation (mm) and A-pan readings used in compiling the monthly crop coefficients for the OV-WUA (Douglas) and OR-WUA (Rietrivier)

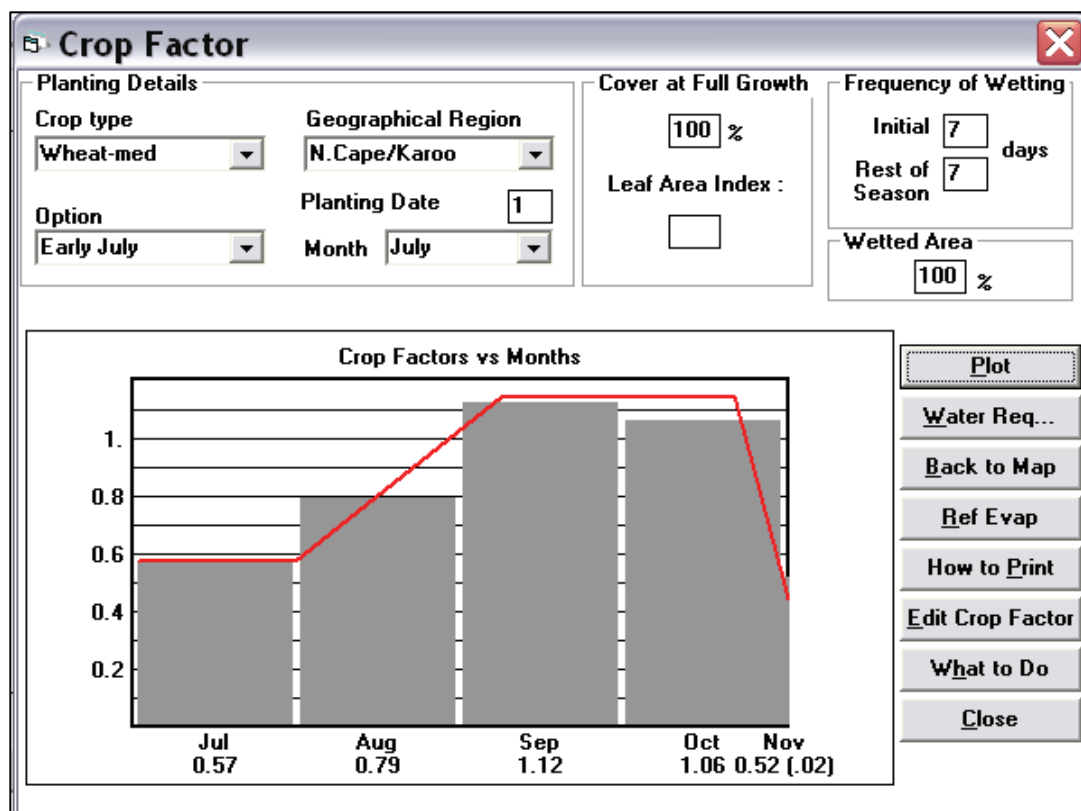


Figure 5.2 An example of the SAPWAT crop coefficients obtained for wheat

5.2.2. COMPILATION OF THE SUB-MODEL

For a full discussion on the derivation of crop coefficients see van Heerden (2001). Very simplistically put, crop water use factors determined by Green (1985) for each physiological growth stage of a crop for different regions in SA, are converted to monthly crop coefficients using the following data:

- Reference pan evaporation (mm) – see Figure 5.1
- growing length of the specific crop, and
- planting date.

The model interface as displayed in Figure 5.2 was set up for all 20 crops used in the WRPM, and the resulting monthly crop coefficients read off the screen and inputted into the WRPM setup tables. For all crops, the planting date was selected as the 1st day of the relevant planting month. The monthly mean pan evaporation values used in the WRPM model are listed in Table 5.1, and accepted from the initial setup and calibration of the WRPM model.

Table 5.1. Monthly mean pan evaporation (mm) as used in the WRPM setup

<i>Month</i>	<i>Unit</i>	<i>Douglas area</i>	<i>Riet River area</i>
May	mm	119	112
Jun	mm	93	85
Jul	mm	110	94
Aug	mm	139	138
Sep	mm	196	204
Oct	mm	262	272
Nov	mm	300	322
Dec	mm	344	365
Jan	mm	349	354
Feb	mm	259	272
Mar	mm	208	224
Apr	mm	134	158

5.2.3. RELEVANT RESULTS AND THEIR INTERPRETATION

Table 5.2 lists the results of the monthly crop water use factors for the Orange-Riet (Riet River) and Orange-Vaal (Douglas) WUAs. Certain crops can be planted over a long planting season, and other crops consist of a number of varieties with different characteristics, e.g. the generic name maize, includes early-, late, waxy-, popcorn-, yellow- and white- maize, and the generic name vegetables, include garlic and peas, etc.. But these crops have been grouped under a generic name because of the maximum limit of only 20 crops that can be modeled in WRPM. For these crops, a weighted average crop coefficient for that crop combination is calculated based on the actual crop combination area planted in the basis year of this model, i.e. 2005.

5.2.4. MODEL LIMITATIONS AND ASSUMPTIONS

Because *inter alia* of the weighted average crop coefficients used, it is assumed that the cropping combination remains constant for the full 15 years of analysis. Using an exact planting date as the beginning of the month is also unrealistic, one could have used a weighted average over the spread of the planting season, but this in reality is very variable and is weather dependent. Therefore the assumption that all crops planting date is the 1st of the relevant planting month.

5.2.5. KEY LINKAGES.

The key linkage of the crop coefficients is for the setup of the hydrology model (WRPM). Other related data used in the micro-economic model is the monthly crop water use of the total crop water requirement, which is related to these crop coefficients.

5.3. THE DERIVATION OF THE SATURATED SOIL SALINITY, ECe (mS/m)

5.3.1. THE INPUT DATA AND SOURCE

One of the main data outputs of the hydrology model (WRPM) is factor CU (mg/l), measuring the field level salt concentration in the upper soil zone, set up for each month (**t**) over 15 years (**y**) for each irrigation block (**s**) and run with 100 stochastic variations(**sr**). This data set needs to be converted to a saturated soil extract salinity concentration CUE (mg/l), and from there, an electrical conductivity of the saturated soil paste, ECe (mS/m) is determined. These monthly ECe values then need to be converted to crop specific annual averages by working out the weighted average ECe based on the monthly crop water requirement (see 5.2.5) and the ECe in each month.

5.3.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.

Equation 5.1:
$$CUE_{t,s} = (CU_{t,s} \cdot HE_t) / HSU$$

where:

$CUE_{t,s}$	is the monthly saturated soil salinity concentration (mg/l) in the upper soil layer for each sub-WUA (s) for each time period (t)
$CU_{t,s}$	is the monthly natural field level (un-saturated) soil salinity concentration (mg/l) in the upper soil layer for each sub-WUA (s) for each time period (t)
HE_t	is the monthly (t) effective soil water volume (mm/ha)
HSU	soil moisture storage capacity in the upper zone (mm/ha) = constant 400 mm/ha

Equation 5.2:
$$ECe_{t,s} = CUE_{t,s} / SCF$$

where:

$ECe_{t,s}$	is the monthly ECe in the upper soil layer for each sub-WUA (s) for each time period (t)
SCF	is the TDS to EC salinity conversion factor = constant 6.5 (Moolman and Quibell, 1995)

Equation 5.3: $ECc_{c,y,s} = \sum_{t,m} ECe_{t,s} * CWR_{c,m}$

where:

$ECc_{c,y,s}$ is the weighted average ECe for each crop (**c**) for each year (**y**) and in each irrigation block (**s**)

$CWR_{c,m}$ is the crop water requirement percentage, monthly (**m**) for all crops (**c**)

5.3.3. RELEVANT RESULTS AND THEIR INTERPRETATION

Graphs depicting CUE (mg/l) for the various scenarios in the different irrigation blocks are depicted in Figure 11.2 in Chapter 11.

5.3.4. MODEL LIMITATIONS AND ASSUMPTIONS

A limitation in the WRPM model is the number of soil zones, and the abstract division between the upper and lower zones. Because of the monthly time-step and great spatial diversity of soil types and depths at the irrigation block level, a spatial unit of the WRPM merely referring to the upper zone and lower zone without a quantitative divide is accepted in this study as one of the assumptions. The assumption therefore is that soil depth in the WRPM is roughly grouped into an upper and lower zone, with only soil salinity in the upper zone affecting crop yield.

From a farm level perspective, the unit for assessing soil salinity in the upper zone affecting crop yield, ECE (mS/m) is a very abstract measure, and also a value a farmer or WUA officer could not quickly and easily determine in the field. In response to this, the Australian CSIRO and American ARS of the USDA have produced a very basic conversion chart, named the “SWAGMAN Salimeter” (Meyer *et al.* 1994) to convert irrigation water quality (TDS in mg/l) to soil water quality for extension purposes. Very basically, and adapted for South Africa:

- the “Salimeter” calculates EC_e by multiplying irrigation water salinity (TDS_{iw} in mg/l) by a rule of thumb factor of 2 to get the soil salinity, TDS_e (mg/l) after concentration by evapotranspiration,
- TDS_e is then further divided by 6.5 to get an indication of saturated soil electrical conductivity (EC_e mS/m),
- From EC_e , by using the Maas and Hoffmann threshold and gradient functions, expected yield reductions are then calculated.

5.3.5. KEY LINKAGES.

The $ECc_{c,y,s}$ calculated up to Equation 5.3 is the critical hydrology-economy linkage to be fed into the Maas and Hoffmann equation and to be related into the impact that salinity has on crop yield.

5.4. THE SETTING UP OF SALINITY-YIELD FUNCTIONS USING THE MAAS AND HOFFMANN EQUATION

5.4.1. THE INPUT DATA AND SOURCE.

The electrical conductivity of the saturated zone, ECe (mS/m) is inputted into the Maas and Hoffmann equation to determine the impact on yield in the micro-economic model. The $EC_{c,y,s}$ calculated in Equation 5.3 is the main input for the Maas and Hoffmann equation, together with crop salinity threshold (Thrsh) and crop salinity gradient (Grad) values.

5.4.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.

Equation 5.4: $ThrshLF_c = Thrsh_c * (1 + LF_s)$

where:

$ThrshLF_c$	is the crop (c) specific salinity threshold value adjusted for leaching
$Thrsh_c$	is the crop (c) specific salinity threshold value (assumed constant for all irrigation blocks)
LF_s	is the leaching fraction ¹¹ (% additional water) applied in each irrigation block (s)

Equation 5.5: $Yf_{c,y,s} = \{100 - Grad_c * (EC_{c,y,s} - ThrshLF_c)\} / 100$

where:

$Yf_{c,y,s}$	is the fraction of maximum yield obtainable when subject to salinity $EC_{c,y,s}$
$ThrshLF_c$	is the crop (c) specific salinity yield reduction threshold value adjusted for leaching
$Grad_c$	is the crop (c) specific salinity yield reduction gradient (assumed constant for all irrigation blocks)
$EC_{c,y,s}$	is the weighted average ECe for each crop (c) in each year (y) for each irrigation block (s)

Equation 5.6: $Ys_{c,y,s} = Yf_{c,y,s} * Ym_c$

where:

$Ys_{c,y,s}$	is the new yield (ton / ha) subject to salinity
$Yf_{c,y,s}$	is the fraction of maximum yield obtainable when subject to salinity $EC_{c,y,s}$
Ym_c	is the max potential / physiological yield (ton / ha)

5.4.3. RELEVANT RESULTS AND THEIR INTERPRETATION

A worked example of salinity-yield functions and the Maas and Hoffmann equation can be found in Figure 9.6

¹¹ In this study the **Leaching Fraction (LF)** is defined as follows: If CWR is the crop water requirement, then the irrigation water requirement (IWR) is the CWR with the leaching requirement added. With a leaching fraction (LF) of x %, $IWR = CWR + (CWR \cdot x)$, or $IWR = CWR(1+x)$.

5.4.4. MODEL LIMITATIONS AND ASSUMPTIONS

The existence of better methodologies than the Maas and Hoffmann equation is acknowledged for quantifying the relationship between crop yield and soil salinity. In some models, functions of plant growth are compiled, which show a direct correlation to water uptake, and based on the premise that soil salinity creates a physiological drought in the soil, the function is proportionally adjusted, depending on the levels of salinisation and moisture in the soil. The SALTMED model (Ragab, 2000) uses this approach, based on incorporating the Penman-Monteith (evapo-transpiration) and Richards (transient-state soil water flow) equations with the Cardon and Letey plant water uptake model, in the presence of salts. The existing irrigation scheduling model, SWB (Annandale, *et al.* 2005) also uses a similar approach, and ACRUsalinity (Teweldebrhan, 2003) applies it to a catchment level, but all these models are too detailed and data intensive for the purposes of this study. Thus the combination of SAPWAT, WRPM and the Maas and Hoffmann equation was decided on.

The applicability of the thresholds and gradients to real life South African conditions with new crop varieties and management techniques may seem dated, but care was taken to get the most local and most up-to date threshold and gradient values (DWAF Water Quality Guidelines -1996, ILRI irrigation design manual, etc.).

The maximum physiological yield values were discussed at expert panel meetings and accepted as a good indication of very good yields. With new cultivars these yields could still improve. The assumption is that only salinity affects yield in the model – all other factors such as management, water, etc are assumed optimal.

5.4.5. KEY LINKAGES.

The key linkage is the conversion from soil salinity to yield reduction results, which forms the foundation on which the micro-economic model builds. $Y_{s,c,y,s}$ is the key factor fed into the micro economic model that relates soil salinity into yield for further economic analysis.

5.5. HYDROLOGY – MACRO-ECONOMIC LINKAGE AND THE INDEX FOR SOCIO-ECONOMIC WELFARE (ISEW)

WRPM hydrology mass balance results are processed in this biophysical sub-routine for use in the Macro-economic model for the calculation of the index for socio-economic welfare (ISEW).

5.5.1. THE INPUT DATA AND SOURCE.

The salt load associated with the irrigation abstractions (SA) and with the returnflows (SR), measured as the total tons per irrigation block (tons) are direct outputs of the hydrology model, WRPM, calculated internally in the WRPM. The SA and SR values are used in the regional economic model to determine the environmental component of the ISEW.

5.5.2. MATHEMATICAL FORMULATION OF THE SUB-MODEL.

The environmental index of the ISEW, $ISEW_e$, is an annual index of the soil salt mass balance derived from subtracting sum over all irrigation blocks annual average SR from SA, dividing by 10 000 and adding 1 to get a factor around 1 as shown in Equation 5.7.

Equation 5.7:
$$ISEWe_y = 1 + ((\sum_m SA_{y,m} - \sum_m SR_{y,m}) / 10\,000)$$

where:

- ISEWe_y is the environmental component of the Index for Socio Economic Welfare (ISEW)
- SA_{y,m} is the monthly (*m*) salt load associated with the irrigation abstractions over 15 years (*y*)
- SR_{y,m} is the monthly (*m*) salt load associated with the irrigation returnflows over 15 years (*y*)

5.5.3. RELEVANT RESULTS AND THEIR INTERPRETATION

The results of the environmental leg of the ISEW are discussed in Chapter 11, Paragraph 9.8.2.

5.5.4. MODEL LIMITATIONS AND ASSUMPTIONS

As a starting point, soil salinity in the WRPM is manually set for the base-case scenario at an equilibrium level i.e. at a level so that no major trend exists for the timeframe of the model. The build-up and decline of salts in the soil at field scale from real levels are not observed in the base case. Deviations from the base-case in the subsequent scenarios however give an indication of the extent to which the scenario is an improvement / worsening from the basis.

5.5.5. KEY LINKAGES

The environmental component of the ISEW together with the economic and social components culminate in the ISEW which is the final value generated in the integrated model. This ISEW indicates whether a certain scenario is sustainable or unsustainable, and whether the scenario in question is tending towards becoming more or less sustainable.

5.6. SUMMARY

The biophysical sub-models discussed in this chapter refer to a group of biophysical-hydrology, hydrology-biophysical and biophysical-economic linkages, assumptions and procedures, using recognized existing models and algorithms to integrate the hydrology and economic models.

Paragraph 5.2 shows how SAPWAT is used to determine crop coefficients for setting up the hydrology model (WRPM). From the results of the WRPM, the saturated soil salinity, EC_e (mS/m) is derived (see Paragraph 5.3) for the setting up of salinity-yield functions using the Maas and Hoffmann equation discussed in Paragraph 5.4.

The biophysical model generates the important linkage between the hydrology results and yield which form the basis of the economic models, as well as an important component of the final output in the regional economic model as the environmental component of the Index for Socio-Economic Welfare (ISEW). As such the biophysical model doesn't produce results of its own, but is an important linkage in transferring data from one discipline to another to culminate in the final answer.

CHAPTER 6. MICRO-ECONOMIC MODEL DESCRIPTION (PER HECTARE AND IRRIGATION BLOCK LEVEL)

by R.J. Armour, and M.F. Viljoen - UFS

6.1. INTRODUCTION

The aim of this chapter is to describe the process followed in setting up and running the micro-economic model.

The layout of this chapter is as follows:

- *Reasons for the use of a dynamic simulation model*
- *Model delineation*
- *Model aims*
- *Data requirements*
- *Mathematical specification of the model*
- *Model linkages*
- *Summary*

Under the paragraph on reasons for the use of a dynamic simulation model, the difficulties of optimizing, full model integration and data acquisition for optimization due to the nature of this work are discussed as motivation for the model framework selected.

The model delineation paragraph deals with the spatial and temporal dimensions of this project, listing the model assumptions and limitations. These preceding paragraphs introduce the terms of reference for defining the aims of the micro-economic model, in context with the integrated whole. Paragraphs on the data requirements and the mathematical specification of the model follow. The chapter ends with the important linkages of the micro-economic model within the integrated whole discussed, and a chapter summary.

6.2. REASONS FOR THE USE OF A DYNAMIC SIMULATION MODEL

The main reasons for adopting the dynamic simulation modelling approach lie in factors such as the number of decision variables required, the nature of the data required and the sub-model composition. As the hydrology isn't modelled implicitly within SMSim (i.e. not fully integrated), it produces a series of simulated data, on which the economic model builds. The micro-economic model is dynamic as it models over a 15 year time period and considers a stochastic range of 100 possible data series.

6.2.1. NUMBER OF DECISION VARIABLES

The relatively large number of decision variables required to set-up an optimization model for the salinity problem described in this report, makes it difficult to solve; and if results are generated they may even not be globally optimal answers. A larger number of decision variables can be handled much easier with a simulation model, especially when making use of a series of stochastic data.

6.2.2. MODEL INTEGRATION

For optimization a fully integrated model would have to be built, incorporating sub-models from different disciplines into one model. The differing spatial and temporal scales of the different sub-models, make the integration for optimization very difficult.

6.2.3. DATA AVAILABILITY

The simulation option where only a selected cropping and management combination is selected is far less data intensive than an optimisation model where the data for all possible cropping and management combinations have to be compiled. In this regard Antle and Stoorvogel (2003) stated that *“It seems unlikely that a general, integrated model applicable to many different production systems will be available in the foreseeable future, nor will data adequate to support such a model be available.”* Furthermore, using the Maas and Hoffmann equation to calculate the crop response to soil salinity is also far less data intensive than using sophisticated crop growth and irrigation scheduling models such as SALTMED (Ragab 2000) and SWB (Annandale *et al.* 2005; Benade *et al.* 2002).

6.3. MODEL DELINEATION

6.3.1. SPATIAL DIMENSIONS

As described in Chapter 2. the spatial dimensions of the micro-economic model are set up and run for two WUAs (the OV-WUA and the OR-WUA), one downstream of the other, comprising 4 irrigation blocks in accordance with the set up parameters of the hydrology model WRPM. The basic economic data needed for specifying the irrigation blocks are crop enterprise budgets (CEBs) set up on a per hectare level.

The objective of the SMSim model is to compare the effect of various cropping and drainage scenarios on the long-term sustainability of the study area as a whole, and for each irrigation block individually and in combination with one another. The model is set up to produce results that show the different financial and water use efficiencies of the different irrigation blocks on a per hectare level, and to identify the most sustainable management options for each irrigation block and the implication on a WUA as a whole. The irrigation blocks are differentiated physically according to the source of their irrigation water, general soil characteristics, and micro-economic variations reflected in CEBs mainly as a result of differences in distance from agricultural service providers.

The CEBs set up on a per hectare level are differentiated according to the various irrigation block characteristics. After determining the impact on yield on a gross margin per hectare level, the adjusted per hectare CEBs are multiplied by the irrigation block irrigable area (see scheduled areas in Table 2.4) to get irrigation block level CEBs. The assumption is that the irrigation block is one big farm, repeating exactly the same cropping combination for 15 years at the same 2005 base year crop prices.

At the regional economic level the study area is analysed to show the effect of scenario changes on the following components of the Index for Sustainable Socio-Economic Welfare (ISEW):

- Financial – change in agricultures contribution to regional GGP (including secondary effects)

- Social – change in employment patterns
- Environmental – change in salt status of the various irrigation blocks

The micro-economic model output data used as inputs for the ISEW is presented in Paragraph 9.8.2, and a detailed discussion on the ISEW is presented in Paragraph 7.1.1 with the regional model results culminating in the ISEW results discussed in Paragraph 10.7.1 where each irrigation block is discussed separately.

6.3.2. TEMPORAL DIMENSIONS

The hydrology data produced by WRPM is monthly data, projected using 100 stochastic data sequences, over a period of 25 years. The economic models (micro and regional) are annual models, projected using 100 stochastic data sequences, over a period of the first 15 years obtained from the hydrology model, to produce annual economic model outputs.

6.3.3. MODEL ASSUMPTIONS AND LIMITATIONS

The core of the integrated model is the micro-economic model (SMsim). The following assumptions and limitation of SMsim are discussed:

- not an irrigation scheduling model
- limited to specific water quality management as set up in WRPM
- not a crop growth subject to salinity model
- besides converting soil salinity to saturated soil salinity there is no further soil chemistry incorporated into the model.

6.3.3.1. Irrigation scheduling

SMsim is not an irrigation scheduling model; it assumes sufficient irrigation water distribution and supply to fully meet crop needs as specified in the monthly crop water requirement percentages of the total annual crop water demand as set by the WUAs for the calculation of irrigation accounts (also determined in Van Heerden *et al.* 2001).

6.3.3.2. Water quantity management

As far a water quantity management is concerned SMsim calculates the expected changes in water quantity demand for the various scenarios modelled. Care was taken in the setting up of scenarios modelled not to exceed the maximum monthly irrigation block water delivery volume constraints identified in the base case model setup (see Table 9.6 in Chapter 9).

6.3.3.3. Crop growth

SMsim is also not a crop (subject to salinity) growth model (e.g. SALTMed by Ragab, 2000) based on evapotranspiration. It solely uses the Maas and Hoffmann (1977) equation to relay the impact of saturated soil salinity (measured as electrical conductivity of the saturated soil paste, ECe in milli-Siemens per metre, mS/m) on crop yield, using laboratory determined, crop specific, salinity threshold and gradient values. The salinity threshold is the maximum ECe at which no reduction in yield will occur, and the gradient, the linear slope at which yield decreases with an increase in ECe above the threshold value.

6.3.3.4. Vadose zone chemistry

SMSim is not a soil chemical equilibrium model (UNSATCHEM, etc.); it purely uses a range of possible simulated soil salinity values calculated by the WRPM process based hydrology model, based on the statistical analysis of 70 years of historical data in the study area in question.

6.3.3.5. Geo-hydrology

With reference to Ellington *et al.* (2004), and Ellington (2003), it was decided not to include a geo-hydrology component in the integrated model due to very long temporal dimensions of a geo-hydrology model, compared to the short time frame of the integrated model.

6.4. AIMS OF THE MODEL

The aim of the micro-economic model is to integrate holistically the key hydrology and bio-physical components influencing salinity into a long-term (dynamic) economic model to compare the financial response of irrigation blocks to various scenarios. SMSim simulates the financial impact of water quality changes (inter-seasonal, annual and long-term), subject to various salinity management option setup scenarios.

6.5. DATA REQUIREMENTS

6.5.1. DATA SOURCES

Table 6.1 is a summary of the data sources used for the integrated model sub-components as discussed in Chapter 6.

Table 6.1 A summary of the input data sources

Category	Details	Sources
Hydrology	Crop coefficients WRPM setup Pumping capacities	SAPWAT (van Heerden <i>et al.</i> 2001), Green (1985) Alan and Herold (1988) and Van Rooyen <i>et al.</i> (2004b) WUAs, DWAF
Farm level data	Temporary labour requirements	Case study farmer survey, Expert panel opinion, GWK and WUAs
Micro-economic data	Regional average CEBs Farm level CEBs	GWK Case study farmer survey
Macro-economic data	National input/output matrix data	Statistics SA, National Survey Regional survey
Agronomy	Monthly crop water requirements Crop water demand	OV and OR WUA management plans, Van Heerden, <i>et al.</i> (2001) WUAs, DWAF
Salinity	Base salinity Threshold and Gradients Crop growth stage sensitivities	Case study farmer survey, WRPM manually set Maas and Hoffmann (1977) n/a
Soil data	Soil type division	Case study farmer survey, Expert panel opinion
Groundwater		n/a

For the hydrology model, the initial setup data as compiled by Allen and Herold (1988) and later modified by Van Rooyen *et al.* (2004b) was used for the trial run. Once the critical factors are identified that need to change for scenario analysis, the base case scenario is compiled, updating the initial setup data with the most current

data obtained from the DWAF and WUAs, mainly from the water management plans of the WUAs (Ninham Shand, 2004 and CSIR, 2004).

Crop coefficients required for the WRPM setup are generated using the SAPWAT model by Van Heerden *et al.* (2001). These crop coefficients differ somewhat from the monthly crop water requirements which are calculated from the crop coefficients as monthly percentages of the total annual crop water requirement. The total annual crop water requirements are fixed for the duration of the model at long-term average levels for each WUA as determined by the WUAs for calculation of water charges based on the hectares planted to a specific crop. The monthly crop water requirement percentages in Table 6.2 are used in SMSim to calculate the weighted average EC_e that a crop will be exposed to.

Table 6.2. The monthly crop water requirement percentages¹ of total requirement used (based on OV-WUA data)

	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
May	0.04	-	-	-	-	-	0.01	-	-	-	0.11	0.01	-	0.03	-	-	-	0.04	0.02	0.04
Jun	0.09	-	-	-	-	-	0.03	-	-	0.03	0.16	0.01	-	0.04	0.00	-	-	0.06	0.03	0.09
Jul	0.23	-	-	-	0.02	-	0.05	0.07	-	0.05	0.25	0.07	-	0.05	0.00	-	-	0.10	0.05	0.23
Aug	0.36	0.20	-	-	0.04	-	0.08	0.13	-	0.08	0.01	0.11	-	0.08	0.00	-	-	0.21	0.08	0.36
Sep	0.28	0.37	-	0.22	0.06	-	0.12	0.17	0.00	0.10	0.01	0.14	-	0.15	0.00	0.00	-	0.28	0.14	0.28
Oct	-	0.43	-	0.38	0.06	-	0.17	0.18	0.11	0.18	0.01	0.09	0.14	0.16	0.00	0.11	-	0.30	0.16	-
Nov	-	-	0.45	0.40	0.34	0.28	0.17	0.18	0.23	0.18	0.00	0.10	0.33	0.16	0.19	0.23	0.19	-	0.16	-
Dec	-	-	0.37	-	0.26	0.45	0.15	0.16	0.31	0.16	-	0.09	0.25	0.14	0.28	0.31	0.37	-	0.14	-
Jan	-	-	0.18	-	0.21	0.27	0.10	0.12	0.24	0.10	-	0.17	0.17	0.09	0.31	0.24	0.44	-	0.09	-
Feb	-	-	-	-	-	-	0.06	-	0.11	0.06	0.21	0.14	0.12	0.06	0.21	0.11	-	-	0.06	-
Mar	-	-	-	-	-	-	0.03	-	-	0.03	0.16	0.05	-	0.03	-	-	-	-	0.03	-
Apr	-	-	-	-	-	-	0.02	-	-	0.02	0.09	0.03	-	0.02	-	-	-	-	0.02	-
Sum:	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The main farm level data collected is temporary labour requirements, comparisons of actual farm practise to GWK data and saturated soil salinity measures. The GWK CEBs, spatially differentiated for different irrigation blocks were verified as good representations of the reality, as were the temporary labour values used in the GWK CEBs. The saturated soil salinity measures were however not used due to unreliability of the data and the fact that in the WRPM setup, the starting soil salinity concentrations are manually set to irrigation block equilibrium levels to eliminate trends; that is to get the full effect of the stochastic nature of the hydrology in the system. The soil salinity data collected was however useful in delineating the sub-WUA areas. Other salinity related data used is the threshold and gradient data for each crop, derived from Du Preez *et al.* (2000), the ARC-ILI irrigation design manual (ARC-ILI, 1997) and Maas and Hoffmann (1977). Crop growth stage sensitivities and groundwater salinity data, initially proposed to be collected, were not deemed necessary after the conceptual model design was formulated.

¹ These values are very different from the crop coefficients shown in Table 5.2. They indicate the monthly water distribution of the total water requirement as calculated from the crop coefficients.

6.5.2. PRIMARY DATA

6.5.2.1. Fixed cost component - financial constraints

A total gross margin above specified costs (TGMASC) approach is used to compare irrigation blocks based on their natural resource endowment position. Where a fixed / non-allocatable cost component is added in the model – i.e. where the subsurface artificial drainage area is increased as in Scenario 3+, this fixed costs component, calculated from the total drainage costs in Table 6.3, is factored into the water use charge.

Table 6.3. The calculation of the costs of artificial drainage installation based on expert opinion from Reinders (2005) and Van der Merwe (2005)

	<u>Unit</u>	<u>Minimum spacing</u>	<u>Average spacing</u>	<u>Maximum spacing</u>
Inter row spacing distance (meters) of different soil types for effective drainage:				
Heavy soils (>35% clay)	m	20	25	30
Medium soils (15-35% clay)	m	40	45	50
Light soils (<15% clay)	m	70	75	80
The total meters of drainage required per hectare :				
Heavy soils (>35% clay)	m/ha	500.0	400.0	333.3
Medium soils (15-35% clay)	m/ha	250.0	222.2	200.0
Light soils (<15% clay)	m/ha	142.9	133.3	125.0
Cost of installing drainage	R/m	100.00	100.00	100.00
Total cost per ha of drainage on different soil types:				
Heavy soils (>35% clay)	R/ha	50 000.00	40 000.00	33 333.33
Medium soils (15-35% clay)	R/ha	25 000.00	22 222.22	20 000.00
Light soils (<15% clay)	R/ha	14 285.71	13 333.33	12 500.00

6.5.2.2. WUA level

Most of the WUA operation data is obtained from the WUA WMPs and verified through expert panel discussions and questionnaires.

The OV-WUA as a whole was modelled as one Irrigation Block (**Vall**), where the OR-WUA was modelled as 3 separate irrigation blocks, namely the Orange-Riet (**Rscm**) block (comprising the Canal, Scheme and Ritchie), the Scholtzburg (**Rszg**) block and the Lower Riet (**RloR**) block.

6.5.2.2.1. Water Transfer constraints

Care was taken in the selection of alternative cropping combinations not to exceed the maximum monthly water requirements of the study area as a whole. See Table 8.8 for the resulting water requirements from the set up of the cropping combinations used in the various scenarios modelled.

6.5.2.2.2. Externality constraints

The WRPM models all the hydrology externalities within its specific setup data and capabilities, and these are captured in the hydrology results inputted into the micro-economic model.

6.5.3. SECONDARY DATA

The secondary data used in SMSim is presented in Table 6.4. Columns printed in bold are the data used in the final model runs.

Table 6.4. Main Crop Data used in the compilation of per hectare (ha) Crop Enterprise Budgets (CEBs)

	ECe Threshold ¹ and ²	ECe Gradient ¹ an d ²	Max. Phys. Yield ²	OR/OV - WUA Ave. Planned Yield	GWK Ave. Planned Yield	GWK / CEB Water require- ments	OV-WUA Water require- ments ²	OR-WUA Water require- ments	Average Price ² (1996- 2005)	GWK CEB Prices
	mS/m	%/mS/m	ton/ha	ton/ha	ton/ha	mm/ha	mm/ha	mm/ha	R/ton	R/ton
Barley	800	0.07	6.0	0.0	6.00	660	601	590	1 030	1 410
Beets	400	0.09	25.0	0.0	25.00	460	392	450	1 061	1 061
Carrots	100	0.14	25.0	0.0	25.00	650	377	469	1 142	1 142
Cotton	770	0.05	5.0	0.0	5.00	850	753	753	3 016	1 800
Cucurbits	250	0.13	50.0	0.0	50.00	650	509	534	560	560
Dry_Beans	160	0.10	3.5	0.0	3.00	450	328	351	2 782	3 000
Fruit	170	0.21	6.0	0.0	6.00	971	1188	1188	3 000	3 000
Lucerne	200	0.07	20.4	0.0	18.75	1300	1156	1275	552	318
Maize	170	0.12	14.0	0.0	12.00	700	749	728	832	475
Olives	300	0.19	4.0	0.0	4.00	1029	547	850	5 400	5 400
Onions	120	0.16	55.0	0.0	55.00	660	241	636	1 378	1 000
Pastures	600	0.07	8.0	8.00	8.00	1000	827	1284	800	800
Peanuts	320	0.29	4.0	0.0	4.00	580	592	592	2 591	2 867
Pecan_nuts	150	0.19	0.7	0.0	0.69	921	626	1188	16 500	16 500
Potatoes	170	0.12	45.0	0.0	35.00	600	545	640	1 412	1 720
Soybeans	500	0.20	6.0	6.0	3.75	600	633	633	1 693	2 250
Sunflower	500	0.09	4.0	0.0	0.80	550	411	424	1 451	12 000 ³
Vegetables	700	0.09	40.0	40.00	40.00	1026	604	542	750	750
Vineyards	150	0.10	5.2	0.0	5.17	1058	625	819	725	725
Wheat	600	0.07	7.0	0.0	6.5	660	601	632	1 208	1 300

¹Maas and Hoffmann (1984)

²Columns in bold are the final values used in the model. Other columns are included for comparison between various data sources

³Seed

For the 20 crops modelled, the first 2 data columns in Table 6.4 are the threshold and gradient values required in the Maas and Hoffmann equation, collected from Du Preez *et al.* (2000), ARC-ILI (1997) and Maas and Hoffmann (1977). The threshold and gradient for beets (which include beetroot and sugar beet) is set at 400 mS/m, the value for beetroot, as predominantly beetroot is grown, even though the threshold for sugar-beet is much higher at 700 mS/m.

The third column, maximum physiological yield (ton/ha), is the maximum of the fourth and fifth columns and verified with expert opinion as good maximum expected yield targets for the 20 crops modelled. The percentages of maximum yield calculated from the Maas and Hoffmann equation using the threshold and gradients in columns 1 and 2 are multiplied by this maximum physiological yield (ton/ha) to give the reduced crop yield (ton/ha) subject to soil salinity.

Columns 6, 7 and 8 compare the annual average crop water requirements as determined by GWK and the 2 WUAs in the setting up of CEBs. The GWK values are generally higher than the WUA values, and the OV-WUA and OR-WUA values differ due to differences in evapo-transpiration in the spatially different locations. GWK values are derived from actual water use measured by the study groups and include wastage, leaching and

inefficiencies, whereas the WUA values reflect long term (last 5 production seasons) crop transpiration requirements calculated scientifically as measured from evaporation pans and do not include wastage and leaching. The WUA values are therefore more accurate for use in the integrated model as in the WRPM model, as provision is also made for drainage, leaching, irrigation inefficiencies and distribution losses. Water and electricity prices calculated in the CEBs are minimal costs and farmers using this information would have to factor in additional costs of water use above the OV-WUA values (column 7) selected.

The last 2 columns in Table 6.4 show the long-term (10 year) real average crop price, as also presented in Figure 6.1 and used in the model, and the 2005 GWK planned crop price.

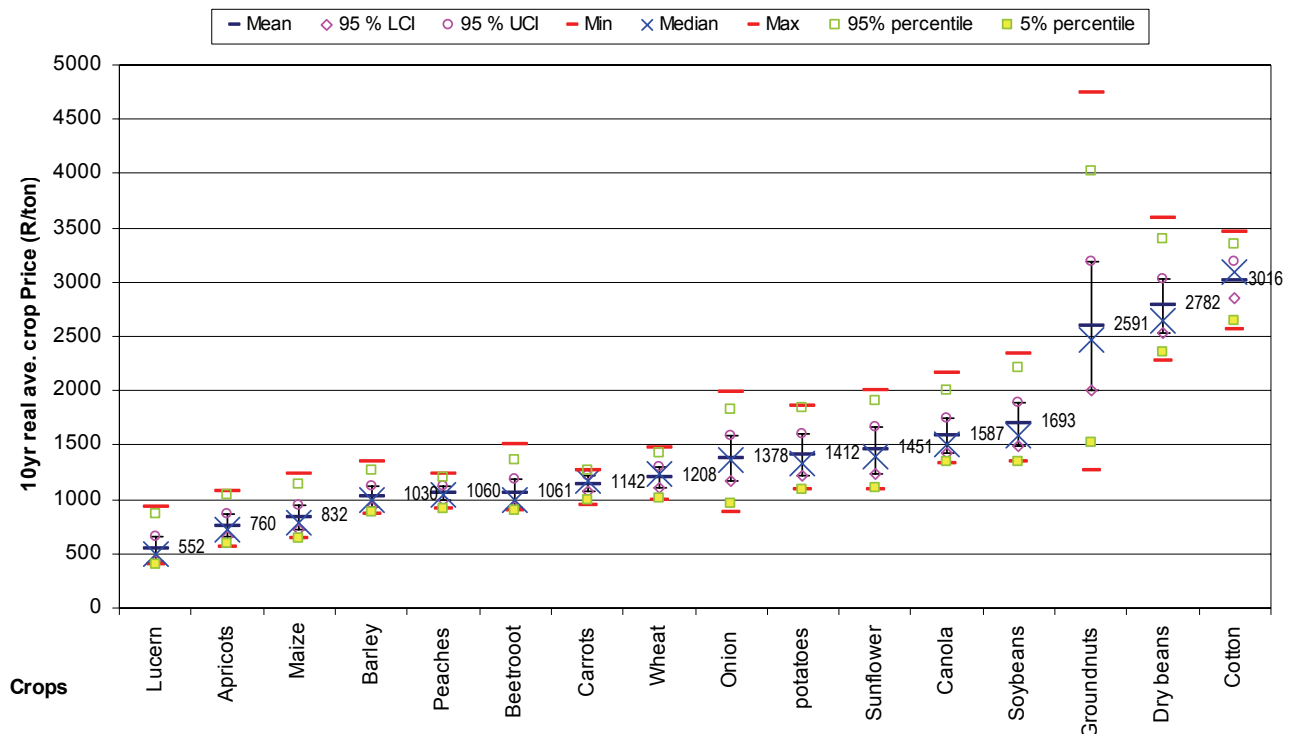


Figure 6.1. Ten year real crop price (R/ton) spread for the 20 crops modelled in SMSim (2005 base year)

6.5.3.1. The calculation of the crop prices used

Figure 6.1 lists the spread of real crop prices (production price index – DoA 2005) for a 10 year period, using 2005 as the basis year. The historical national average producer crop prices from 1995 to 2005 were converted to 2005 level real crop prices using the production price index from the Abstract of Agricultural Statistics (2005). By using these mean prices as the crop prices in SMSim, annual price fluctuations and intercrop price dynamics are eliminated.

6.5.3.2. Crop enterprise Budgets (CEBs)

6.5.3.2.1. CEB Assumptions

- The crop enterprise budgets (CEBs) are set up on a per ha basis, reflecting only direct production costs, and ignoring the farm level specific fixed cost component. This is because these CEBs get extrapolated to irrigation block level, where the fixed / capital cost and tax component of specific farms are very different.

- b. For this study farm level modelling is not necessary as per hectare data is extrapolated directly to irrigation block level data. Per hectare level data generated in SMSim can however be used by farmers wanting to conduct their own farm level analysis.
- Long-term crops enterprise budget data are annualised: e.g. lucerne is a 4yr crop so 1 ha out of 4 will be in the establishment phase and the other 3 in full production. Only one CEB will thus be set up for the full lifecycle of the crop to produce an average / weighted budget.
- c. For this study it is assumed that no temporary labour is used for lucerne - only fulltime on-farm workers are used as lucerne harvesting is a regular action in the growing season.
 - i. As lucerne harvesting costs are worked out on a per bale price, one square bale is assumed 40 kg therefore 25 bales per ton
 - ii. Fuels contribution to harvesting costs is assumed constant for different lucerne yields
- d. Crop and inputs used over the 15 years are valued / modelled at constant 2005 prices.
- e. Crop threshold and gradients are assumed constant for all irrigation blocks over the full crop growth cycle and for all 15 years modelled. Thresholds only vary per crop with the amount of drainage accounted for – a crop threshold is increased by the same percentage as the drainage / leaching percentage, to internalise the benefit of leaching on yield into the CEB. The additional water costs of leaching are also accounted for.
- f. Maintenance and repair costs include maintenance and repair costs for centre pivot irrigation systems for all crops (i.e. for flood irrigated crops, maintenance and repair costs are added as centre pivot irrigation is the predominant form of irrigation at irrigation block level)
- g. Regional changes in CEB prices as identified in the GWK CEBs are used to differentiate between model CEBs. (i.e. instead of using case study / representative farm data). The main CEB costs components that differ between irrigation blocks are pesticides (distance from airfield for aerial spraying costs), insurance (hail, drought, water supply reliability), water (WUA differentiated price) and harvesting costs (distance from silos).
- h. Packaging and contract transport costs are all included under harvesting costs
- Water use charges vary per irrigation block, but electricity costs are assumed the same for all irrigation blocks (it is assumed that everyone uses the same Flexi-Time / Peak-Time ratio and that all pump similar distances)

Table 6.5 to Table 6.8 are a demonstration of the conversion of standard per hectare CEBs to reduced yield per hectare CEBs, and the resulting per hectare to irrigation block level TGMASC results. The reduced crop yield due to salinity is worked through the CEB to per hectare TGMASC level, and to irrigation block level total expenditure on different crop inputs, total production value (gross income) and irrigation block level TGMASC.

All the examples are taken from stochastic run 80 for the Lower Riet Irrigation Block (**RioR**) base-case scenario, using 2005 values (for the other irrigation blocks see Appendix 3);

- Table 6.5 is a collection of 20 CEBs, set up for maximum yield over 1 year.

- Table 6.6 is the same collection of 20 CEBs, but set up for reduced yield as a result of the impact of the weighted average electrical conductivity of the saturated extract, $EC_{e,y,c}$ on crop yield over 1 year.
- Table 6.7 is an example of the irrigation block level CEBs over 1 year, based on the per hectare CEBs in Table 6.5.
- Table 6.8 is the listing of the annual TGMASCs, culminating in the irrigation block level TGMASC for each year and the cumulative TGMASC for all 15 years.

Results show negative returns for carrots, peanuts, dry-beans and potatoes, and the largest TGMASC from onions, pumpkins, soybeans and beets, for stochastic run 80 of the base case models.

In Table 6.7 the total value of production or gross product income (GPI) is R69 million and TGMASC R6.6 million. The values of seed, fertilizer, etc. bought over the whole season in the irrigation block are also listed.

From Table 6.8 (the annual irrigation block level CEB breakdown) it is evident that the pre-harvest input costs are assumed constant over the 15 years, with only the harvesting, gross income and TGMASC changing each year. The 100 stochastic run results of the TGMASC and cumulative TGMASC are discussed in Chapter 9 of this report.

Table 6.5. CEBs for maximum yield set up for the Lower Riet Irrigation Block base-case scenario, using 2005 values

LOWER RIET	Unit	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
ECe Threshold (BC, S1 and S2)	mS/m	816	408	102	785	255	163	173	204	173	306	122	612	326	153	173	510	510	714	153	612
ECe Gradient	%/mS/m	0.071	0.090	0.140	0.052	0.130	0.096	0.210	0.073	0.120	0.190	0.160	0.071	0.290	0.190	0.120	0.200	0.087	0.090	0.096	0.071
Crop water requirement	mm/ha	613	400	385	768	520	335	1212	1179	764	558	246	843	604	639	556	645	419	616	637	613
Crop Enterprise Budgets:																					
PRICE	R/ton	1030	1061	1142	3016	560	2782	3000	552	832	5400	1378	800	2591	16500	1412	1693	1451	750	725	1208
Max Physiological yield	ton/ha	6.00	35.00	50.00	5.00	50.00	3.50	21.00	20.40	14.00	6.40	55.00	8.00	4.00	1.60	45.00	6.00	4.00	40.00	20.38	7.00
Total/Gross potential income	R/ha	6180	37133	57091	15079	28000	9739	63000	11255	11651	34560	75774	6400	10364	26400	63557	10160	5805	30000	14778	8454
SEED	R/ha	504	2680	3900	1114	224	1120	7683	375	1080	578	2742	1175	1040	373	16000	475	61	585	2349	756
FERTILIZER	R/ha	1424	2881	3162	2145	2389	1218	1535	1414	2402	1754	3372	1153	1120	1149	4718	1070	1167	1754	756	1858
HERBICIDES	R/ha	84	368	334	85	103	204	506	165	277	539	537		94	25	117	233	140	270	2204	84
PESTICIDES	R/ha	157	40	309	1792	257	1021	4	13	594	830	1156		754		9574	159	188	612		409
INSURANCE	R/ha	341		2376	2217	3780	1032	11201		373		5759		321		2224	0	192	2640	901	364
FUEL	R/ha	206	281	426	444	271	225	43	464	194	127	426	233	295	82	828	171	274	233	146	287
MAINTENANCE	R/ha	481			567		418	66	1078	336	1000	223	698	811	29	1154	145	418	406	207	913
Temp LABOUR	R/ha		4597	5307	988	1900	554	900			567	491		1070	643	268	160		300	1434	
ELEC. @ R 0.489 / mm	R/mm/ha	300	196	188	376	254	164	593	205	301	273	120	412	295	312	272	316	205	301	312	300
WATER @ R 0.677 / mm	R/mm/ha	415	271	260	520	352	227	821	284	417	378	166	571	409	432	377	437	284	417	432	415
HARVESTING COSTS	R/ton	122	539	600	280	20	249	82	44	50	3000	184		471	233	368	127	113	270	12	103
	R/ha	734	18865	30000	1400	1000	873	1716	899	704	19200	10104		1886	373	16557	760	450	10812	240	723
Total expenses pre harvest	R/ha	3913	11313	16263	10248	8530	6181	23351	3997	5974	6046	14992	4243	6210	3045	35532	3167	2928	7519	8741	5386
Total expenses with max harvest	R/ha	4647	30178	46263	11648	10530	7054	25067	4897	6678	25246	25095	4243	8096	3418	52089	3927	3378	18331	8981	6109
TGMASC	R/ha	1533	6955	10829	3431	17470	2684	37933	6359	4973	9314	50679	2157	2268	22982	11467	6233	2426	11669	5797	2345
Co-op interest charge	R/ha	88	298	725	257	409	159	603	96	145	593	404	359	151	63	959	66	67	187	880	128
Bank interest charge	R/ha	40	532	48	63	74	35	86	38	39	2184	286	108	71	31	473	42	26	317	108	40
Total Interest	R/ha	128	830	773	320	483	194	689	135	184	2777	690	467	223	94	1432	108	93	504	998	168
Crop TGMASC less Interest	R/ha	1405	6125	10056	3110	16987	2490	37243	6224	4789	6537	49989	1691	2045	22888	10035	6125	2333	11165	4809	2177

Table 6.6 CEBs for reduced crop yield set up for the Lower Riet Irrigation Block base-case scenario, using 2005 values

LOWER RIET	Unit	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
ECe Threshold (BC, S1 and S2)	mS/m	816	408	102	785	255	163	173	204	173	306	122	612	326	153	173	510	510	714	153	612
ECe Gradient	%/mS/m	0.071	0.090	0.140	0.052	0.130	0.096	0.210	0.073	0.120	0.190	0.160	0.071	0.290	0.190	0.120	0.200	0.087	0.090	0.096	0.071
Crop water requirement	mm/ha	613	400	385	768	520	335	1212	1179	764	558	246	843	604	639	556	645	419	616	637	613
Weighted ave. ECe	mS/m	471	510	519	513	521	527	515	511	534	516	500	526	529	514	543	534	541	493	514	471
Weighted ave. TDS	mg/l	3061	3317	3370	3333	3388	3427	3349	3319	3474	3357	3248	3417	3440	3341	3533	3474	3518	3205	3341	3061

Crop Enterprise Budgets:

PRICE	R/ton	1030	1061	1142	3016	560	2782	3000	552	832	5400	1378	800	2591	16500	1412	1693	1451	750	725	1208
Max Physiological yield	ton/ha	6.00	35.00	50.00	5.00	50.00	3.50	21.00	20.40	14.00	6.40	55.00	8.00	4.00	1.60	45.00	6.00	4.00	40.00	20.38	7.00
Modeled yield	ton/ha	6.00	31.78	20.84	5.00	32.70	2.28	5.92	15.83	7.93	3.84	21.79	8.00	1.65	0.50	25.01	5.71	3.89	40.00	13.32	7.00
Total/Gross potential income	R/ha	6180	33713	23799	15079	18310	6336	17770	8737	6603	20738	30025	6400	4270	8290	35330	9663	5647	30000	9658	8454
SEED	R/ha	504	2680	3900	1114	224	1120	7683	375	1080	578	2742	1175	1040	373	16000	475	61	585	2349	756
FERTILIZER	R/ha	1424	2881	3162	2145	2389	1218	1535	1414	2402	1754	3372	1153	1120	1149	4718	1070	1167	1754	756	1858
HERBICIDES	R/ha	84	368	334	85	103	204	506	165	277	539	537		94	25	117	233	140	270	2204	84
PESTICIDES	R/ha	157	40	309	1792	257	1021	4	13	594	830	1156		754	0	9574	159	188	612		409
INSURANCE	R/ha	341		2376	2217	2472	672	3160	0	211		2282		132	0	1237	0	186	2640	589	364
FUEL	R/ha	206	281	426	444	271	225	43	464	194	127	426	233	295	82	828	171	274	233	146	287
MAINTENANCE	R/ha	481			567	1900	418	66	1078	336	1000	223	698	811	29	1154	145	418	406	207	913
Temp LABOUR	R/ha		4597	5307	988		554	900	0	0	567	491		1070	643	268	160	0	300	1434	0
ELEC. @ R 0.489 / mm		300	196	188	376	254	164	593	205	301	273	120	412	295	312	272	316	205	301	312	300
WATER @ R 0.677 / mm		415	271	260	520	352	227	821	284	417	378	166	571	409	432	377	437	284	417	432	415
HARVESTING COSTS	R/ton	122	539	600	280	20	249	290	44	50	3000	184		471	233	368	127	116	270	18	103
	R/ha	734	17127	12506	1400	654	568	1716	698	399	11521	4003	0	777	117	9204	723	450	10812	240	723
Total expenses pre harvest	R/ha	3913	11313	16263	10248	7568	5821	15309	3997	5813	6046	11515	4243	6021	3045	34544	3167	2923	7519	8429	5386
Total expenses with max harvest	R/ha	4647	28441	28768	11648	8876	6389	17025	4695	6211	17567	15518	4243	6798	3162	43748	3890	3373	18331	8669	6109
TGMASC	R/ha	1533	5272	-4969	3431	9434	-53	745	4041	392	3171	14507	2157	-2528	5128	-8418	5773	2274	11669	989	2345
Co-op interest charge	R/ha	88	298	725	257	349	149	382	96	140	593	309	359	146	63	932	66	67	187	845	128
Bank interest charge	R/ha	40	484	48	63	58	26	86	33	31	1339	118	108	41	24	271	41	26	317	108	40
Total Interest	R/ha	128	782	773	320	407	176	468	129	171	1932	427	467	187	87	1203	107	93	504	954	168
Crop TGMASC less Interest	R/ha	1405	4490	-5742	3110	9027	-229	277	3912	221	1239	14080	1691	-2715	5041	-9621	5666	2181	11165	35	2177

Table 6.7. An example of the irrigation block level CEB, using the base case scenario run for Irrigation Block RIoR - stochastic run 80 (2005 prices)

	Barley	Beets	Carrots	Cotton	Cucurbits	Dry Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan nuts	Potatoes	Soybeans	Sun-flower	Veg- etables	Vineyards	Wheat	TOTAL
NFI	1 125 940	0	0	211 106	137 324	114 044	0	3 025 589	17 417 987	0	3 338 803	341 120	462 750	0	16 048 467	0	491 268	210 000	422 526	25 730 914	69 077 838
SEED	91 829	0	0	15 596	1 679	20 160	0	129 710	2 848 835	0	304 931	62 628	112 715	0	7 267 840	0	5 312	4 094	102 790	2 301 030	13 269 147
FERT	259 491	0	0	30 034	17 918	21 915	0	489 693	6 335 255	0	374 939	61 428	121 363	0	2 143 082	0	101 551	12 277	33 068	5 656 120	15 658 133
HERB	15 350	0	0	1 196	770	3 676	0	57 090	731 438	0	59 727	0	10 216	0	53 288	0	12 197	1 890	96 440	256 431	1 299 709
PEST	28 682	0	0	25 084	1 930	18 381	0	4 463	1 566 648	0	128 509	0	81 676	0	4 348 921	0	16 356	4 281	0	1 245 420	7 470 352
INSUR	62 137	0	0	31 033	28 350	18 582	0	0	983 420	0	640 381	0	34 819	0	1 010 447	0	16 665	18 480	39 439	1 106 429	3 990 183
FUEL	37 514	0	0	6 217	2 034	4 048	0	160 838	512 247	0	47 384	12 432	32 013	0	376 169	0	23 807	1 633	6 390	872 390	2 095 115
MAINT	87 660	0	0	7 937	0	7 516	0	373 176	885 449	0	24 754	37 228	87 943	0	524 120	0	36 327	2 845	9 043	2 778 615	4 862 614
LABOR	0	0	0	13 835	14 250	9 963	0	0	0	0	54 574	0	115 977	0	121 555	0	0	2 100	62 731	0	394 985
WAT	54 624	0	0	5 262	1 906	2 945	0	71 001	794 764	0	13 364	21 979	32 006	0	123 515	0	17 837	2 109	13 639	912 499	2 067 449
ELEC	75 634	0	0	7 285	2 639	4 078	0	98 311	1 100 463	0	18 505	30 433	44 317	0	171 024	0	24 698	2 920	18 885	1 263 484	2 862 676
HARV	133 735	0	0	19 600	4 904	10 225	0	241 738	1 051 759	0	445 187	0	84 204	0	4 180 866	0	38 086	75 684	6 862	2 200 588	8 493 438
TGMASC	279 284	0	0	48 028	60 944	-7 444	0	1 399 570	607 709	0	1 226 547	114 992	-294 499	0	-4 272 359	0	198 432	81 686	33 238	7 137 908	6 614 037

Table 6.8 An example of the irrigation block level (RloR) total CEB for all crops, and the annual and cumulative TGMASC for stochastic run 80 (2005 prices)

	Total Income	SEED	FERT	HERB	PEST	INSUR	FUEL	MAINT	LABOR	WAT	ELEC	HARV	TGMASC	Cumulative TGMASC
2005	69 077 838	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 493 438	6 614 037	6 614 037
2006	69 635 849	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 525 272	7 140 214	13 754 250
2007	70 698 209	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 742 297	7 985 549	21 739 799
2008	67 924 175	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 321 023	5 632 788	27 372 587
2009	70 461 417	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 728 428	7 762 626	35 135 213
2010	68 083 358	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 395 812	5 717 182	40 852 395
2011	74 011 036	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	9 269 894	10 770 778	51 623 174
2012	72 537 933	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	9 061 124	9 506 445	61 129 619
2013	70 907 342	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 828 269	8 108 709	69 238 328
2014	70 102 901	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 683 600	7 448 937	76 687 265
2015	72 012 510	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 946 364	9 095 782	85 783 047
2016	70 279 621	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 646 272	7 662 985	93 446 032
2017	74 141 748	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	9 268 581	10 902 803	104 348 836
2018	69 527 060	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 586 301	6 970 395	111 319 231
2019	71 252 542	13 269 147	15 658 133	1 299 709	7 470 352	3 990 183	2 095 115	4 862 614	394 985	2 067 449	2 862 676	8 816 860	8 465 319	119 784 550

6.6. MATHEMATICAL SPECIFICATION OF THE MODEL

6.6.1. MODEL SETUP (DEFINITION OF THE SETS AND SUB-SETS)

6.6.1.1. SETS:

<i>m</i>	=	months in the model as follows:	
		in the hydrology model, rainfall	<i>m</i> = {Oct, Nov, ... Sep.}
		in WRPM output	<i>m</i> = {May, Jun, ... Apr.}
		in SMSim an agricultural season	<i>m</i> = {Jul, Aug, ... Jun.}
<i>y</i>	=	years in the model as follows	
		in WRPM (25 Years)	<i>y</i> = {yr1, yr2, ... yr25}
		in SMSim (15 years)	<i>y</i> = {2005, 2003, ... 2019}
<i>t</i>	=	monthly (<i>m</i>) time step of the model over a number of years (<i>y</i>)	
<i>t</i>	=	$f(m, y) = 1, 2, \dots, 180.$ (12 months x 15 years)	
<i>s</i>	=	Irrigation Blocks in the model	<i>{RloR, Rscm, Rszg, Vall}</i>
<i>r</i>	=	stochastic model runs	{1, 2, ... 100}
<i>c</i>	=	all crops modelled in SMSim	{wheat, maize, lucerne}
<i>i</i>	=	a set of all inputs / direct production costs	{seed, fertilizer, ... transport}

Sets ***m***, ***y*** and ***t*** describe the temporal dimensions of the model, set ***s*** the spatial dimensions, set ***r*** the 100 stochastic runs, set ***c*** the 20 crops modelled, and set ***i*** the direct crop input cost items.

6.6.1.2. Sub-Sets

<i>sr of s</i>	=	irrigation blocks of the OR-WUA	<i>{RloR, Rscm, Rszg}</i>
<i>sv of s</i>	=	irrigation blocks of the OV-WUA	<i>{Vall}</i>
<i>fi of i</i>	=	all the fixed inputs (R/ha)	{seed, fertilizer, etc.}
<i>yi of i</i>	=	all the yield dependant production costs (R/ton)	{harvesting, packaging, transport, etc.}

The subsets of the model, ***sr*** and ***sv*** group the spatial dimensions of the model into the OR-WUA and OV-WUA. Subsets ***fi*** and ***yi*** differentiate the fixed input cost items from the yield dependent, post harvest input cost components.

6.6.1.3. Scalars / constants:

SCF	TDS to EC salinity conversion factor	=	6.5

The scalar or constant, SCF is the salinity conversion factor converting TDS (mg/l) to EC (mS/m).

6.6.2. INPUT DATA AND ITS USE

$TDS_{c,t,s,r}$	is a data set of the salt concentration (mg/l) in the upper layer calculated in the WRPM as output data used as input for SMSim. The data set $TDS_{c,t,s,r}$ comprises monthly data for all years (t) in all irrigation blocks (s) for 100 stochastic runs (r).
$CWR_{c,m}$	is the crop water requirement percentage for each month (m) for all crops (c). The sum over m for each c gives a result 1 = 100%.
$Thrsh_c$	is the crop (c) specific salinity yield reduction threshold value (mS/m) (assumed constant for all irrigation blocks)
$Grad_c$	is the crop (c) specific salinity yield reduction gradient value (ton/ mS/m) (assumed constant for all irrigation blocks)
$P_{c,y,s}$	is an array of different crop (c) prices (R/ton) in each year (y) and in each irrigation block (s). An assumption of the model is constant prices over the 15 years therefore y remains unchanged, however the price $P_{c,y,s}$ can change between irrigation blocks.
$I_{fi,c,y,s}$	are the fixed input costs (fi) i.e. seed, fertilizer, chemicals, etc. (R/ha), for the different crops (c) which remain unchanged in each year (y), but which can change between irrigation blocks (s).
$I_{yi,c,y,s}$	are the yield dependant production costs (yi) i.e. harvesting, packaging, transport, etc. (R/ton), for the different crops (c) in each year (y) and in each irrigation block (s).

6.6.3. MODEL CORE

The core of the model is Equation 6.1 where reduced crop yield due to salinity ($Y_{s_{c,y,s,r}}$) is related to a per hectare financial value $TGMASCh_{c,y,s,r}$

Equation 6.1:
$$TGMASCh_{c,y,s,r} = Y_{s_{c,y,s,r}} * P_{c,y} - \sum I_{fi,c,y,s} - \sum I_{yi,c,y,s} * Y_{s_{c,y,s,r}}$$

where:

$TGMASCh_{c,y,s,r}$	is the TGMASC per hectare (R/ha) for each crop (c) in each year (y) and in each irrigation block (s) for each stochastic run (r)
$Y_{s_{c,y,s,r}}$	is the new yield (ton / ha) subject to salinity for each stochastic run (r)
$P_{c,y,s}$	are the different crop (c) prices (R/ton) in each year (y) and in each irrigation block (s)
$I_{fi,c,y,s}$	are the fixed input costs (fi) i.e. seed, fertilizer, chemicals, etc. (R/ha), for the different crops (c) which remain unchanged in each year (y), but which can change between irrigation blocks (s).
$I_{yi,c,y,s}$	are the yield dependant production costs (yi) i.e. harvesting, packaging, transport, etc. (R/ton), for the different crops (c) in each year (y) and in each irrigation block (s).

$I_{fi,c,y,s}$ and **$I_{yi,c,y,s}$** are run through to the macro model as individual components where the regional and secondary impact of each of the sectors supplying the inputs is determined.

Equation 6.2 converts per hectare TGMASC to irrigation block level TGMASC by adding together the products of the per hectare TGMASCs, irrigation block irrigable areas (SA) and cropping percentage (CP) for each irrigation block.

Equation 6.2:
$$TGMASCs_{y,s,r} = \sum_c TGMASCh_{c,y,s,r} * SA_s * CP_{c,s}$$

where:

$TGMASCs_{c,y,s,r}$ is the irrigation block TGMASC (R) of crop (c) planted per irrigation block (s) for each stochastic run (r)
 SA_s is the Irrigation block irrigated area
 $CP_{c,s}$ Percentage of crop (c) planted per irrigation block (s) (= % planted per representative farm)

Equation 6.3 and Equation 6.4 combine the OR-WUA and OV-WUA Irrigation Block sub-sets by summation into WUA level TGMASC.

Equation 6.3:
$$TGMASCwr_{y,sr,r} = \sum_{sr} TGMASCs_{y,sr,r}$$

where:

$TGMASCwr_{y,sr,r}$ is the OR-WUA level (sr) annual TGMASC for each stochastic run (r)

Equation 6.4:
$$TGMASCwv_{y,sv,r} = \sum_{sv} TGMASCs_{y,sv,r}$$

where:

$TGMASCwv_{y,sv,r}$ is the OV-WUA level (sv) annual TGMASC for each stochastic run (r)

Equation 6.5 calculates the array of annual TGMASC for each of the 100 stochastic model runs (r)

Equation 6.5:
$$TGMASCr_{y,r} = \sum_s TGMASCs_{y,s,r}$$

where:

$TGMASCr_y$ is the regional level TGMASC per year

Equation 6.6 calculates the 15 year cumulative TGMASC for each of the 100 stochastic model runs (r)

Equation 6.6:
$$TGMASCrc_r = \sum_y TGMASCr_{y,r}$$

where:

$TGMASCrc$ is the regional level TGMASC for the full number of years examined (15 years in this model)

All 100 stochastic run results of the TGMASC and cumulative TGMASC are discussed as model results in Chapter 9 of this report.

6.7. MICRO ECONOMIC MODEL INPUT / OUTPUT LINKAGES

Inputs into the micro-economic model include:

- per hectare basis CEB data (SMCEBs.xls),
- sub-WUA (/irrigation block) level setup data (SMsub-WUA.xls), and
- hydrology model output data generated from the WRPM; specifically CU, measuring the salt concentration in the upper zone of the irrigation block (...CUallScen.xls).

As an output, CEB component specific irrigation block level data for the average scenario and stochastic runs 001, 044 and 080, are arranged in a collection of files (...ISMmicro-out.xls) for each scenario for use as input in the regional economic model (...ISIM.Macro.xls) described in Chapter 7.

6.8. SUMMARY

This chapter starts by indicating the reasons for using a dynamic simulation model instead of a dynamic optimisation model. The nature and extent of data availability, the complexity of sub-models, as well as budget, time and human resource constraints, are some of the main reasons.

The spatial dimensions of the model are delineated to build from per hectare level CEBs to irrigation block level and higher up. The CEBs set up on a per hectare level are differentiated according to the various irrigation block characteristics. After determining the impact on yield on a gross margin per hectare level, the adjusted per hectare CEBs are multiplied by the irrigation block irrigable area (see scheduled areas in Table 2.4) to get irrigation block level CEBs. The assumption is that the irrigation block is one big farm, repeating exactly the same cropping combination for 15 years at the same 2005 base year crop prices. Irrigation blocks are combined into WUAs, and WUAs are combined to form the regional economic model.

The temporal dimensions of the model are delineated to monthly, annual and 15 year cumulative results. The model aims to simulate over a range of 100 stochastic runs, the per hectare financial impacts and possible range of financial results of salinity for different irrigation blocks per year and over 15 years. Data requirements are discussed in this chapter with particular reference to the primary data collected through mainly expert panel opinion and the secondary data obtained predominantly from GWK and the WUA WMPs.

The mathematical specification of the model is an expansion of per hectare level CEBs; per hectare TGMASCs are expanded to irrigation block and WUA level TGMASC results for use in micro-level analysis and as input into the regional economic model. Farm level analysis incorporating the fixed cost component is therefore not conducted in this study.

The data input requirements, and data outputs of the micro-economic model are discussed in the final paragraph of this chapter, explaining the interdisciplinary linkage from bio-physical to micro-economic to regional models.

CHAPTER 7. REGIONAL MODEL DESCRIPTION

by Oberholzer J.L., Van der Merwe, B.J. and Pienaar, G.J – Urban-Econ: Development Economists

7.1. INTRODUCTION

The aim of this chapter is to estimate and quantify the secondary and macro economic impacts at the regional level of the project by utilising recognised economic modelling techniques. As such, the section consists of:

- A motivation for the choice of utilized economic modelling techniques
- The provision of a regional economic perspective of the study area against which economic impacts will be weighed
- Specification of the regional economic parameters

7.1.1. MOTIVATION FOR THE CHOICE OF REGIONAL MODEL AND INDEX

7.1.1.1. *The input-output model*

Recent advances in the economic forecasting and modelling techniques consider not only the direct benefits of proposed developments on its udders, but also the broader impacts on the local and regional economy. The regional economic impact of increasing soil salinity levels and the proposed water management measures in the study area is done by applying the Input-Output (I/O) Modelling technique.

I/O Models are essentially *accounting tables* which trace the linkages of inter-industry purchases and sales within a given region, province or country. It is thus a set of equations describing the relationships that link the output of one industry with all the industries in the economy. I/O Models can be used to estimate impacts within each industry in the model and thereby provide much more information than simple total economic impacts on income, output and employment.

The I/O model yields *multipliers* that are used to calculate the total direct, indirect and induced effect of exogenous economic inputs on jobs, income and output generated per rand of spending on various types of goods and services in the study area. I/O Models can be used directly to estimate the full income and job effects of changes in business activity levels and with “demand translator” (budget breakdown) tools, to estimate the effects of changes in spending.

7.1.1.2. *The index for sustainable economic welfare*

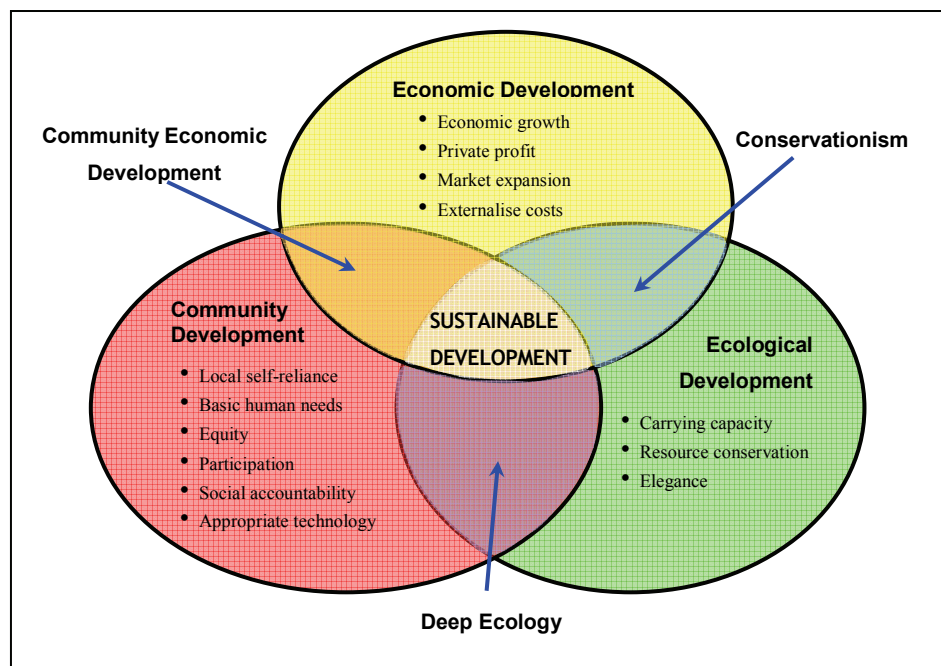
The objective of the macro economic and hydrology model (ISIM) is to *maximise economic welfare in the region* using a weighted index of sustainable economic welfare (ISEW).

In essence, sustainable development can be defined as “development that delivers basic environmental, social and economic services to all, without threatening the viability of the natural, built and social systems on which these services depend”. (ICLEI, 1996.)

The ISEW was developed to capture the main elements of sustainable development, as formulated through the Agenda 21 Program, which stipulated three sub-components, namely:

- *Economic sustainability*, which involves capitalising on existing infrastructure, stimulation of greater self-reliance, encouraging the informal sector as a self-sustaining form of economy, sharing and multi-use of facilities and development with affordability as focus.
- *Social/community sustainability*, which involves the enhancement of the quality of life of the local community. This includes the provision of public facilities, ensuring community involvement and participation and guarantee that development will be to the benefit of all stakeholders.
- *Environmental/ecological sustainability*, which ensures integration of development and nature conservation, appropriate resource management, monitoring the use of resources and the re-establishment of the link between humans and the natural environment (ICLEI, 1996).

These three components are interrelated and sustainable development is only achieved when these sub-systems are in balance, as indicated in Figure 7.1.



Source: adapted from ICLEI - Local Governments for Sustainability, 1996

Figure 7.1 The concept of sustainable development

In the above diagram, the following cross-cutting areas are also relevant where only two of the main elements of sustainable development are applied:

- *Deep ecology* is a philosophy based on a shift away from the anthropocentric bias of established environmental and green movements. Deep ecology describes itself as "deep" because it is concerned with fundamental philosophical questions about the role of human life as one part of the ecosphere, in distinction to ecology as a branch of biological science, and to merely utilitarian environmentalism based on the well-being of humans alone. Proponents of deep ecology believe that the world does not exist as a resource to be freely exploited by humans. The ethics of deep ecology holds that a whole system is superior to any of its parts (Wikipedia, 2006).

- *Community Economic Development* can be described as a community-based process that engages local communities to identify, implement, and manage their own solutions to local economic problems through the commercialisation of community-owned assets (Republic of South Africa, n.d).
- *Conservationism*, today, firstly focuses on the conservation of the natural environment and habitat by employing market-based mechanisms and, secondly, the amelioration of adverse environmental effects of economic activity.

7.1.2. MODEL ASSUMPTIONS

The Input-Output Model rests upon the following main assumptions:

- All production activities in the economy are grouped in homogenous sectors and it is necessary that the mutual inter-dependence of these sectors can be expressed in meaningful input functions. The model used utilises 36 primary homogenous sectors.
- The production by different sectors is equal to the sum of the separate sectors' of production. This concept is referred to as the "additive principle", which negates external advantages and disadvantages, as well as location.
- If the I/O Model is used as an economic forecasting model, the assumption is made that the technical coefficients remain constant for the period over which the projection is made, within a reasonable period. This implies that (1) there will be no input substitution resulting from a price change in the particular sector and (2) there will be no major change in technology (Conningarth Consulting Economists, 1999).
- All Rand values have been updated to represent 2005 Rand values.

7.1.3. MODEL LIMITATIONS

Based on the assumptions indicated, the model has the following limitations:

- The model is calibrated and run on the costs estimates resulting from micro-economic modelling exercise. As such it therefore highly relies on the accuracy and validity of the results.
- Price fluctuations and market penetration in the agricultural sector has not been incorporated into the model or the use of multipliers.
- It is assumed that the multipliers applied will remain the same for the duration of the period modelled.
- The most heavily weighted index has proved to be the build up of salts in the soil (salinity).

7.2. **MACRO-ECONOMIC MODEL EXPLANATION**

7.2.1. THE TREATMENT OF ECONOMICS IN THE MACRO-ECONOMIC MODEL

At the macro-economic level of modelling (ISIM) the social and environmental dimensions are included. The linkage between the regional level model and the macro-economic model is a matrix of annual financial performance data of all of each of the farm input sectors, and the resulting farm financial performances for each sub-region.

In essence, economic impacts are effects on the level of economic activity in a given area. They may be viewed in terms of (1) business output (or sales volume), (2) value added (or gross regional product), (3) wealth (including property values), (4) personal income (including wages), or (5) jobs. The net economic impact is usually viewed as the expansion or contraction of an area's economy, resulting from changes in (i.e. opening, closing, expansion or contraction of) a facility, project or program. This is expressed in terms of the jobs, income and/or business sales that are directly or indirectly supported by the project or program. Such measures represent the gross effect – i.e. the programme's or project's role in (or contribution to) the area economy.

Economic impacts also lead to fiscal impacts, which are changes in government revenues and expenditures. Economic impacts on total business sales, wealth or personal income can affect government revenues by expanding or contracting the tax base. Impacts on employment and associated population levels can affect government expenditures by changing demand for public services.

7.2.2. MODEL SET-UP

The regional model builds on the results obtained from the Bio-Physical Model and the Micro-Economic Model (SMsim) (refer to Chapters 5 and 6 of this report). The main indicators used include:

- Gross income
- Total variable costs
- Total gross margin

The *I/O Model* that was used to determine the impact multipliers was derived from the National Accounts for the province(s) relevant to the study area and recalibrated for the study area to provide a model that reflects the economic structure for the area in 2005. The modelling set-up and system is illustrated in Figure 7.2.

The following impacts can usually be quantified:

- *Direct impact:* The direct impact is calculated from macro-economic aggregates occurring as a direct result of the project. The initial impact on GDP, for example is taken from the financial information and equals the value added generated by a specific scenario;
- *Indirect impact:* Indirect impacts are calculated from the activities of suppliers through application of the model. For purposes of this study, indirect suppliers include those industries who deliver goods and services to the farmers in the study area (first round suppliers), including suppliers who on their part deliver goods and services to the first mentioned indirect suppliers;
- *Induced impacts:* The induced impacts are the impacts on goods and services demanded due to increased expenditure by households from income earned due to the project. Examples include the household income spent by farm labourers, as well as the income arising through the backward linkages of this spending in the economy. The impact is sometimes confused with the forward linkage of a project.

In order to simplify the impact assessment, households have been incorporated in the I/O Model as a productive sector as they provide inputs in the form of labour and their reward (i.e. income) is spent in the economy. Thus, by closing the I/O model with respect to households, the direct and indirect multipliers are higher in order to accommodate the induced effects of household expenditure in the economy.

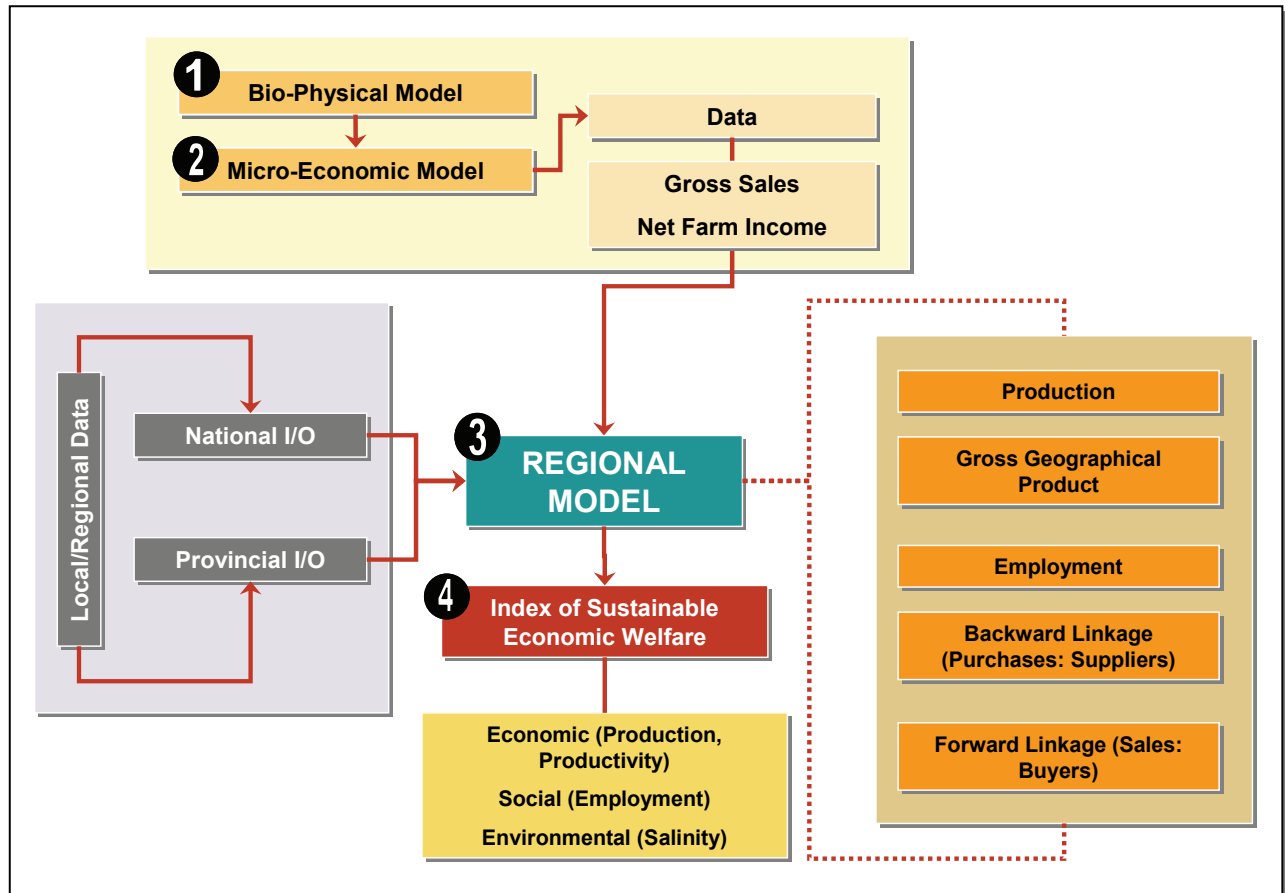


Figure 7.2. Regional model set-up and process

Multipliers have been determined to provide an indication of the regional economic effect of the project in terms of the following indicators:

- Total employment reflects the number of additional jobs created by economic growth or lost. This is the most popular measure of economic impact because it is easier to comprehend than large, abstract Rand figures. The total employment can be interpreted in terms of generally accepted definitions of job creation.
- Business Output (also referred to as revenue or sales volume) is the broadest measure of economic activity, as it generates the largest numbers. It includes the full (gross) level of business revenue, which pays for costs of materials and costs of labour, as well as generating net business income (profits).
- Value Added (which is normally equivalent to Gross Domestic Product or Gross Regional Product) is a broader measure of the full income effect. This measure essentially reflects the sum of wage income and corporate profit generated in the study area.
- Backward and forward linkages, which is incorporated in the multipliers of the above.

As indicated, the calculation of the *Index of Sustainable Economic Welfare (ISEW)* is based on three types of (theme-based) indicators, namely:

- A measure of economic productivity (economic pillar), such as change in GDP, business sales, income levels or exports
- A measure of socio-economic development (social pillar), such as changes in employment, labour absorption, household income or poverty levels
- A measure of environmental improvement or decline (environmental pillar), with indicators such as water and soil quality, ecological footprint or number of key species

The measurement of the ISEW is based on the selection of indicators that will accurately reflect the dynamics in the systems that is measured. The systems for which indicators are sought are all dynamic: populations and economies grow or shrink, pollution accumulates or is absorbed, resources are being depleted. Sustainable development in itself implies continuing but unpredictable change—sometimes slow, sometimes fast. Change in this case refers to the change of system states (like population, pollution level or food stocks). The rates of change provide the most important information about changes in a system, and they are important candidates for indicators.

For this project, the following indicators were used as representation of the three pillars:

- The *economic pillar* is taken as the incremental change in production value adding in the regional economy, which is calculated by the sum of the net profit generated in the study area and labour remuneration. This captures the operational costs of salinity management options only (capital costs only accounted for in Scenario3+), subtracted from total increase/decrease in production.
- The *social pillar* is determined by assessing the number of persons being employed as a direct result of the project (as determined by increased labour costs) as a proportion of the total economically active population in the study area.
- Soil salinity represents the *environmental or resource aspect* of the ISEW. If aggregate soil salinity at the end of the modelling period is higher than in the beginning of the period, the ISEW value will decrease and vice versa. Soil salinity in this case is a function of the balance between abstraction channel salt and return flow salts (therefore the build up of salt levels).

7.2.3. DATA SOURCES AND STUDY AREA

For macro economic analysis, the results of the integrated micro economic level model (which is optimised up to regional level, i.e. the combination of the two WUA's into one model) are used. The outer perimeters of the total study area under investigation follow both administrative and hydrologic borders. The administrative boundaries used in the macro economic component of this study are the boundaries of the municipalities shown in Figure 7.2, while the quaternary catchments covered in this study are shown in Figure 7.3.

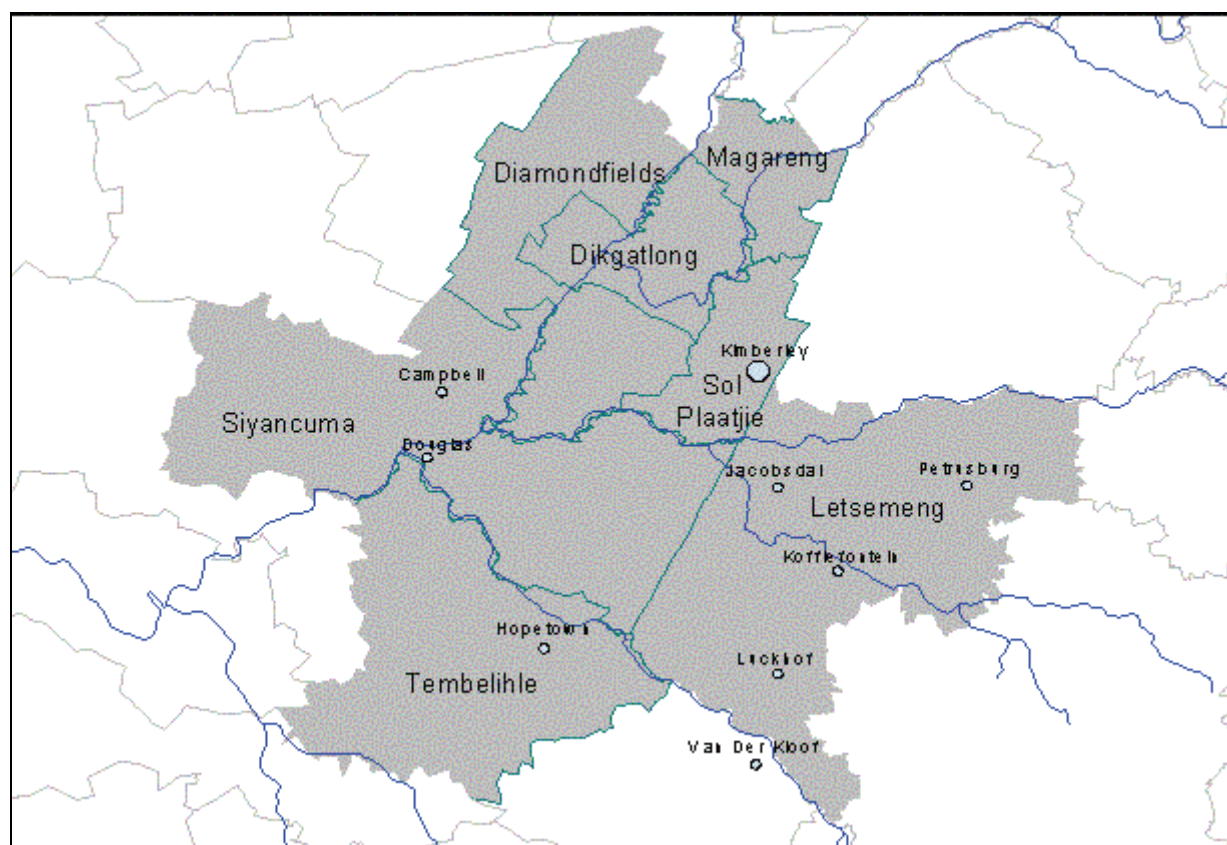


Figure 7.3. Local municipal areas in the study area

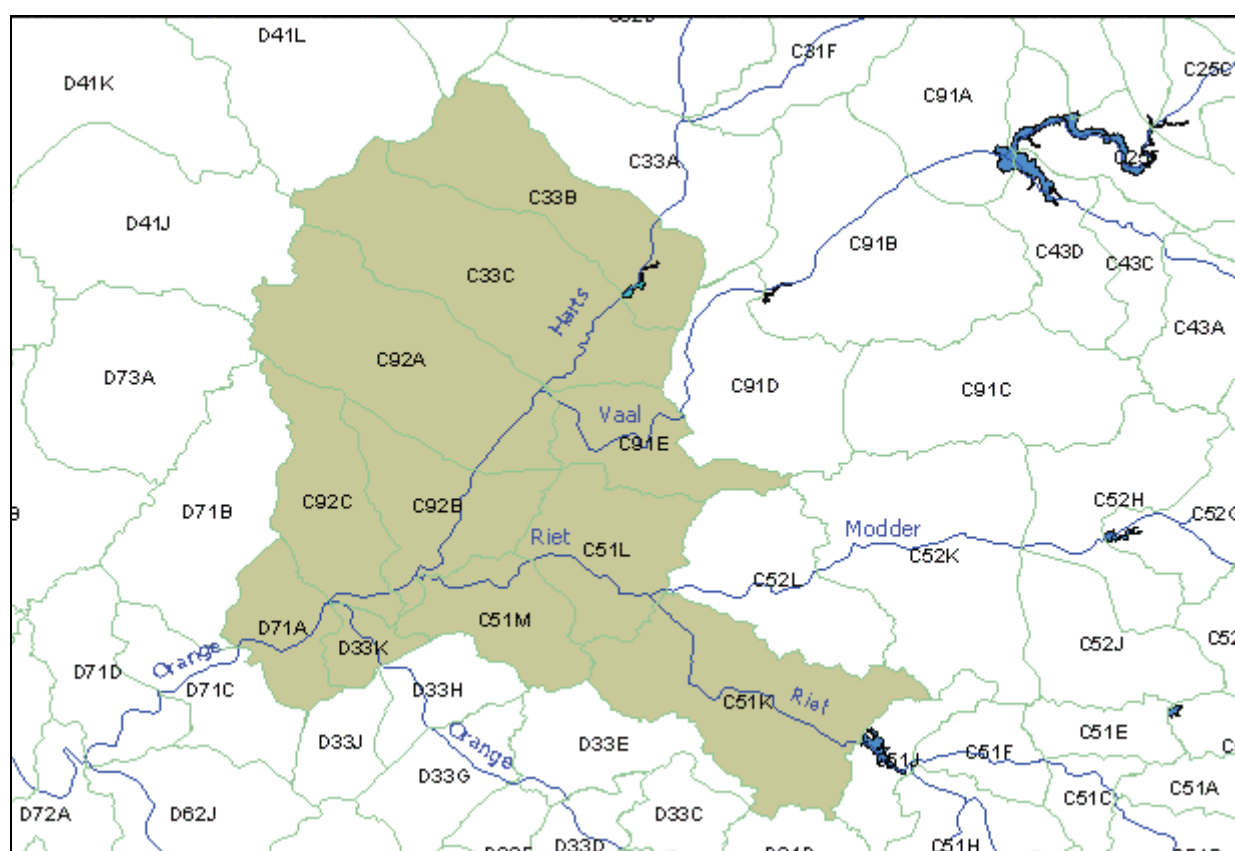


Figure 7.4. Quaternary catchments falling in the study area

Table 7.1. Study area catchments

Quaternary catchment	Primary river	Municipality(ies)
C33B	Harts	Magareng, Diamondfields (Northern Cape Province)
C33C	Harts	Dikgatlong, Diamondfields (Northern Cape Province)
C51K	Riet	Letsemeng (Free State Province)
C51L	Riet	Diamondfields, Sol Plaatjie (Northern Cape Province)
C51M	Riet	Diamondfields, Siyancuma (Northern Cape Province)
C91E	Vaal	Dikgatlong, Diamondfields, Sol Plaatjie (Northern Cape Province)
C92A	Vaal	Dikgatlong, Diamondfields (Northern Cape Province)
C92B	Vaal	Siyancuma, Diamondfields (Northern Cape Province)
C92C	Vaal	Siyancuma (Northern Cape Province)
D33K	Orange	Siyancuma, Thembelihle (Northern Cape Province)
D71A	Orange	Siyancuma, Thembelihle (Northern Cape Province)

The specific economic and socio-economic/demographic databases and indicators that were applied are indicated in the following table:

Table 7.2. Data Sources

Category	Details	Sources
Economic Production	Gross Geographical Product at basic values (Rand, current prices) - 2005 Gross Economic Output at basic values (Rand, current prices) - 2005 Labour compensation (Rand) - 2005	Quantec Research (Pty) Ltd. Projections for 2005 by Urban-Econ
Socio-Economic	Total population – 2005 to 2016 Total employment per economic sector Unemployment and Non-Economically Active Population	Census 2001 (Statistics SA) Projections by Urban-Econ Quantec Research (Pty) Ltd.
Regional Impact	Accounting Matrix Economic Impact multipliers - 2005	Urban-Econ's in-house I/O Model, recalibrated for the study area, 2005
Salinity and Cost Indicators	Parameters of salinity Surface area of irrigation Input costs and gross income	Micro-Economic Model Bio-Physical Model

7.2.3.1. Linkages of economics with other disciplines in the model at macro level

- Hydrology

The costs of infrastructure to implement optimal management options, such as transfers, as well as the operating costs thereof, are accounted for at the macro-economic level. The costs can be compared to the benefits in terms of increased production, employment and resource quality. Water use charges will have an impact on production via the micro-economic level.

7.2.3.2. Critical calculations involving economics in the model at macro level

- Index of sustainable economic welfare (ISEW)

Equation 7.1: $ISEW_y = w_i(P_y/P_{y-1}) + w_i(E_y/E_{y-1}) + w_i(S_y/S_{y-1})$

where:

- P_y is a measure of production in year y
 E_y is percentage employed in year y
 S_y is a measure of soil salinity in year y
 w_i is weighting factor so that $\sum w_i = 1$

- Measure of production

Production (**P**), or value added, is the sum of net profit and labour remuneration:

Equation 7.2: $P = (Pa + Pfl + Pbl) + (ERa + ERfl + ERbl)$

where:

- Pa is net profit from irrigation agriculture
 Pfl is net profit from by-products (forward linkages)
 Pbl is net profit from suppliers (backward linkages)
 ERa is remuneration of labour in irrigated agriculture
 $ERfl$ is remuneration of labour in by-product activities (forward linkages)
 $ERbl$ is remuneration of labour in supplying activities (backward linkages)

- Measure of employment

The number of employed persons (**EMP**) is derived from cost of labour divided by the average wage rate.

Equation 7.3: $EMP = (ERa + ERbl + ERfl)/wr$

where:

- wr is average wage rate

The number of people employed (**E**) as a result of irrigated agriculture is derived as follows:

Equation 7.4: $E = EMP_i / (PEA_i - NEA_i) \times 100$

where:

- EMP is the number of Employment opportunities created / lost as a result of scenario in Year i
 PEA_i is the Potentially Economically Active Population (14 – 64 years of age) in Year i

NEA_i is the number of people Not Economically Active in the broader study area, i.e. students, pensioners, housewives and people not looking for employment in Year i

- Measure of soil salinity

Soil salinity (S) is measured as electrical conductivity (mS/m), and is obtained at the macro-economic level as follows:

Equation 7.5:
$$S = \sum(EC_s \times ha_s) / \sum ha_s$$

where:

EC_s is the soil salinity for irrigated area s

ha_s is the surface area of irrigated area s

A soil salinity index (ISe) was calculated to determine the salt mass balance:

Equation 7.6:
$$ISe_y = 1 + ((SA_y - SR_y) / 1000)$$

where:

SA_y is the Abstraction channel Salt load in year y

SR_y is the Salt load in the Returnflows in year y

- Multiplier effects

Multiplier effects for production are obtained from the crop enterprise budgets. Only direct effects can be determined from inputs required for different crops from different sectors:

Equation 7.7:
$$m_i = CI_i / Pa$$

where:

m_i is the Multiplier for sector i

CI_i is the input costs with respect to sector i

Pa is the Profits from irrigation agriculture

Multipliers for household income are obtained from the input-output table, and can be applied to each input sector.

7.2.3.3. Potential economics related outputs at macro level

The sum of the capital and operating costs of desalination, blending and transfers are obtained and subtracted from the increase in production to obtain net benefit:

Equation 7.8:
$$Net\ Benefit_y = (P_y - P_{y-1}) - \sum WI_i$$

where:

W_i is the capital and operating costs of Water- and drainage related Infrastructure during modelling period for each investment i.

P_y is a measure of Production (value added) in year y

7.2.4. BASELINE INDICATORS

The measuring of the regional economic impact of salinity levels and methods to alter the current situation needs to be put into perspective by comparing it with the current economic and socio-economic environment in which these changes will occur. This section aims to provide an overview of the broader economy of the study area and to quantify the main indicators that will be analysed during the economic impact assessment.

The following data was also used to calibrate the regional model in such as way that it will give a true reflection of the economic impacts that could be expected.

Table 7.3. Socio-Economic Indicators, 2005

Municipal Area	Population 2005	Number of people		Unemployment Rate	
		<i>Economically Active</i>			<i>Not Economically Active</i>
		<i>Employed</i>	<i>Unemployed</i>		
Diamondfields	4 240	1 973	194	679	8.9
Letsemeng	44 307	9 521	5 270	10 748	31.6
Siyancuma	38 242	7 488	3 432	11 357	27.8
Sol Plaatjes	216 182	38 994	35 339	58 191	41.5
Thembelihle	14 639	3 599	1 168	4 235	24.1
Total	317 610	61 575	45 402	85 210	

The following is evident:

- The total population in the study area (municipal boundaries) is estimated at 317 610 people in 2005. Approximately 60.5% of the population is considered to be *Potentially Economically Active* (i.e. people between the ages of 14 and 64 years).
- Approximately 33.7% of the 2005 population can be considered Economically Active, which include people able and willing to work (both those that are formally employed and those unemployed). About 106 977 people are grouped under this segment. Of these, approximately 45 402 are unemployed.
- The weighted Unemployment Rate of the study area is 37.2%, with the highest rate being experienced in the Sol Plaatjes Municipal Area (41.5%). This rate represents the expended definition of unemployment and denotes people that did not work in the seven days prior to the Census survey and who are able and willing to work.

The main economic indicators for the study area are indicated in Table 7.4:

Table 7.4. Economic Indicators, 2005

Municipal Area	GGP (R current prices)	Output (R current prices)	Employment (number of people)	Labour Remuneration (Rand)
Diamondfields	106 495 660	219 830 640	1 970	43 830 790
Letsemeng	1 002 256 300	2 022 150 880	9 520	461 585 400
Siyancuma	1 024 950 380	2 038 673 270	7 490	514 140 930
Sol Plaatjes	7 613 231 000	15 328 161 610	38 990	4 000 339 860
Thembelihle	285 259 280	585 860 300	3 600	133 762 100
Total	10 032 192 630	20 194 676 700	61 580	5 153 659 100

The above economic indicators are graphically depicted in Figure 7.5 to Figure 7.9 and indicate the following:

- In terms of Gross Geographical Product (GGP), the mining sector and the tertiary economic sectors are the largest contributors to the local economy of the study area. The mining sector contributed 19.0% to the total GGP, followed by financial services (17.1%), government (16.3%) and transport (15.0%).
- In terms of production output, the transport sector contributed to most to total output in the study area (18.5%), followed by financial services (15.1%) and government (13.0%).
- The agriculture sector contributed 4.5% to total GGP in the area, 4.8% to production output, 16.6% to employment and only 2.8% to total labour compensation.
- It is also evident that the total value added in the study area (measured in terms of GGP) is mainly concentrated in the Sol Plaatje Local Municipal Area (75.9%). This is followed by the local municipal areas of Letsemeng and Siyancuma (approximately 10% each). Thembelihle and Diamondfields contributed 2.8% and 1.1% respectively by 2005 (measured in terms of current prices) - refer to Figure 7.6.

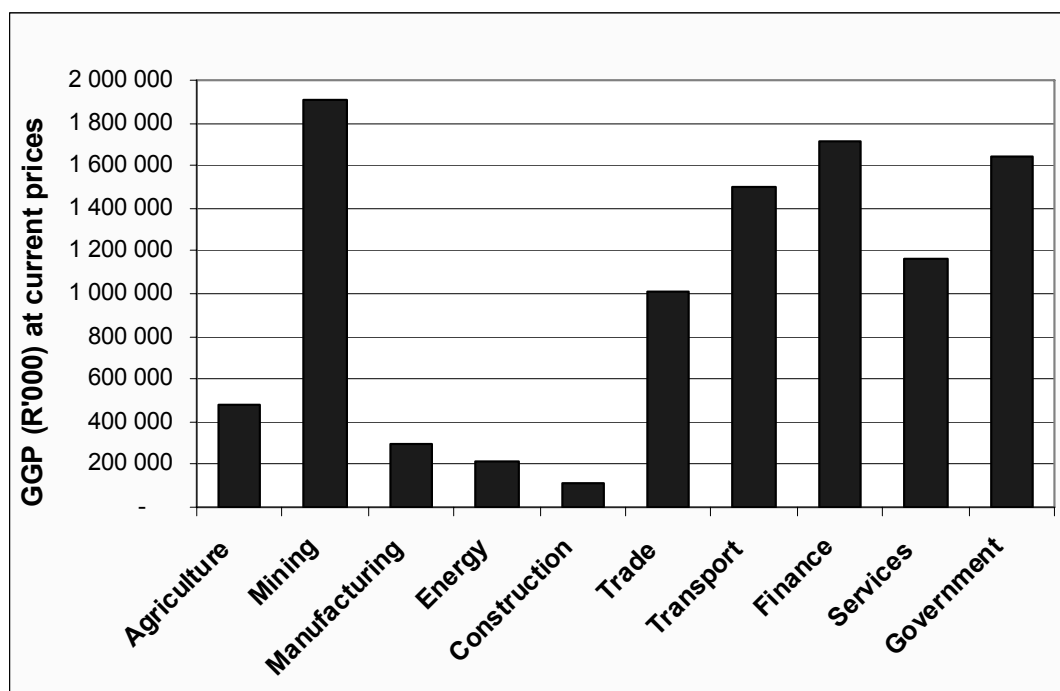


Figure 7.5. Gross Geographical Product (R'000) of the study area by economic sector, 2005

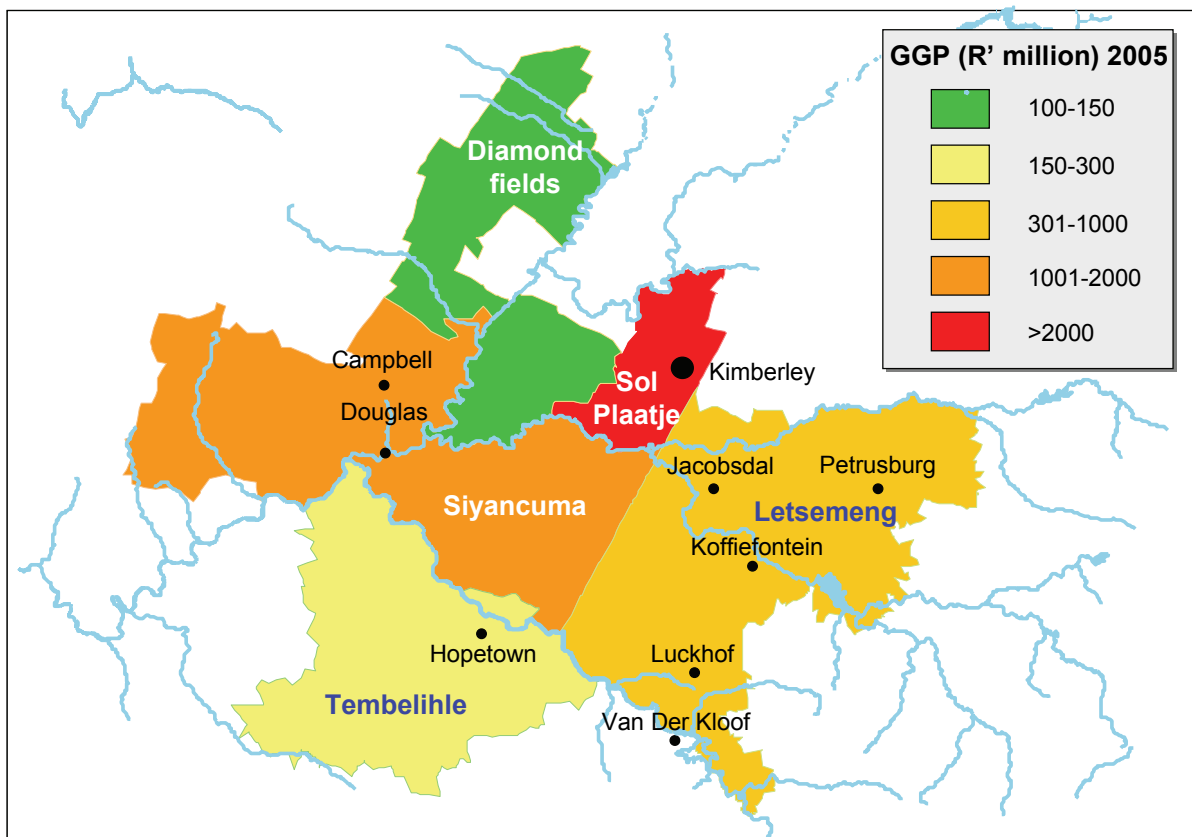


Figure 7.6. Gross Geographical Product (R'000) per local municipal area in the study area, 2005

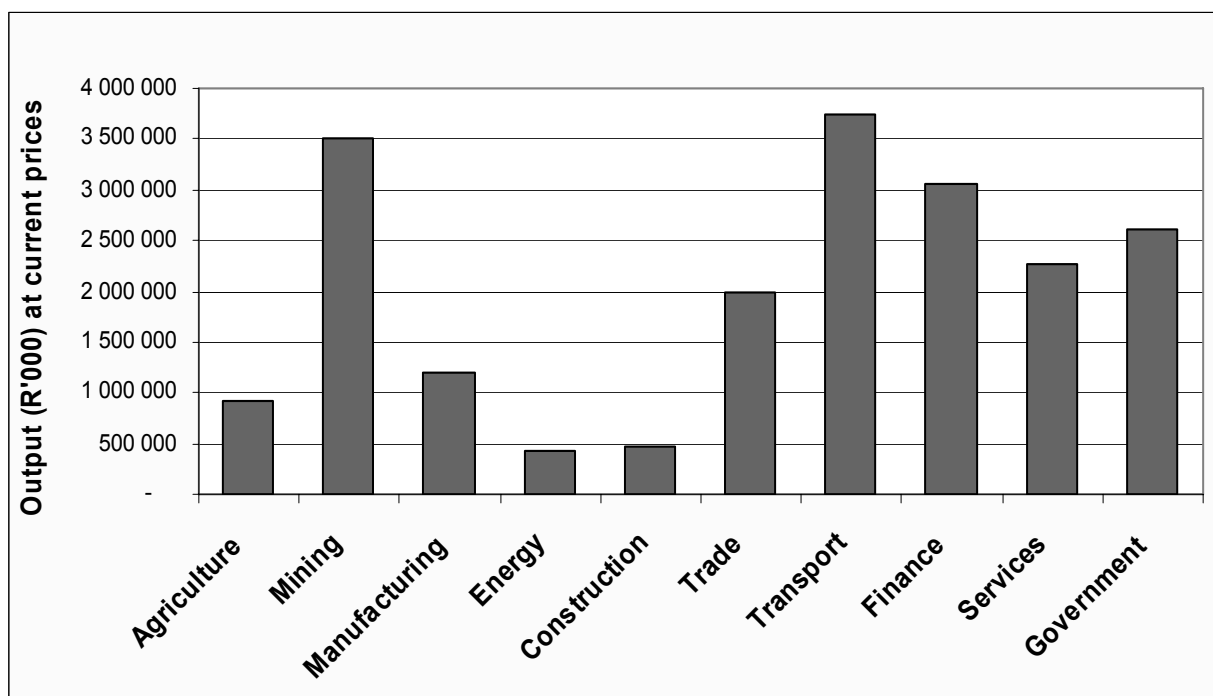


Figure 7.7. Gross Economic Output (R'000) of the study area by economic sector, 2005

Figures for the *agriculture sector* in the study area indicated the following:

- The sector registered a negative growth rate of -0.9 percentage points during the period 2000 to 2004. Municipal areas where apposite annual growth rate was experienced include Tembelihle (6.5%), Siyancuma (0.9%) and Diamondfields (0.4%). Sol Plaatje Municipal Area and Letsemeng Municipal Area both registered high negative growth rates of -5.1% and -5.9% respectively. This growth is measured in terms of constant prices with 2000 as base year.
- Given the above rates, it can be expected that the study area's GGP contribution in the agriculture sector in 2019 will amount to R10,1 billion (at constant price values).
- The highest GGP figures were measured in the Siyancuma and Letsemeng Municipal Areas (with 29.1% and 28% contribution respectively to total agricultural GGP in the study area. Thembelihle LM contributed 24.3%, followed by Sol Plaatje LM (10.8%) and Diamondfields LM (7.8%).
- Total output in the agriculture sector grew with 0.6% during the period 2000 to 2004, while total output in the regional economy grew with 3.2 percentage points. Agriculture output in the Siyancuma Local Municipal Area was the highest at 29.1% contribution to the total agricultural output in the study area by the start of 2005.
- In terms of employment in the agriculture sector, estimates indicate that the agricultural labour force has declined at a rate of 1.0% during 2000 to 2004. This decline was the most apparent in the Siyancuma and Diamondfields LM areas, with growth rates of -2.1 and -3.6 percentage points respectively.
- The largest concentration of agriculture labourers can be found in the Letsemeng LM (with 37.7% contribution to the agricultural labour force in the study area) and Siyancuma LM (with 27.4%)

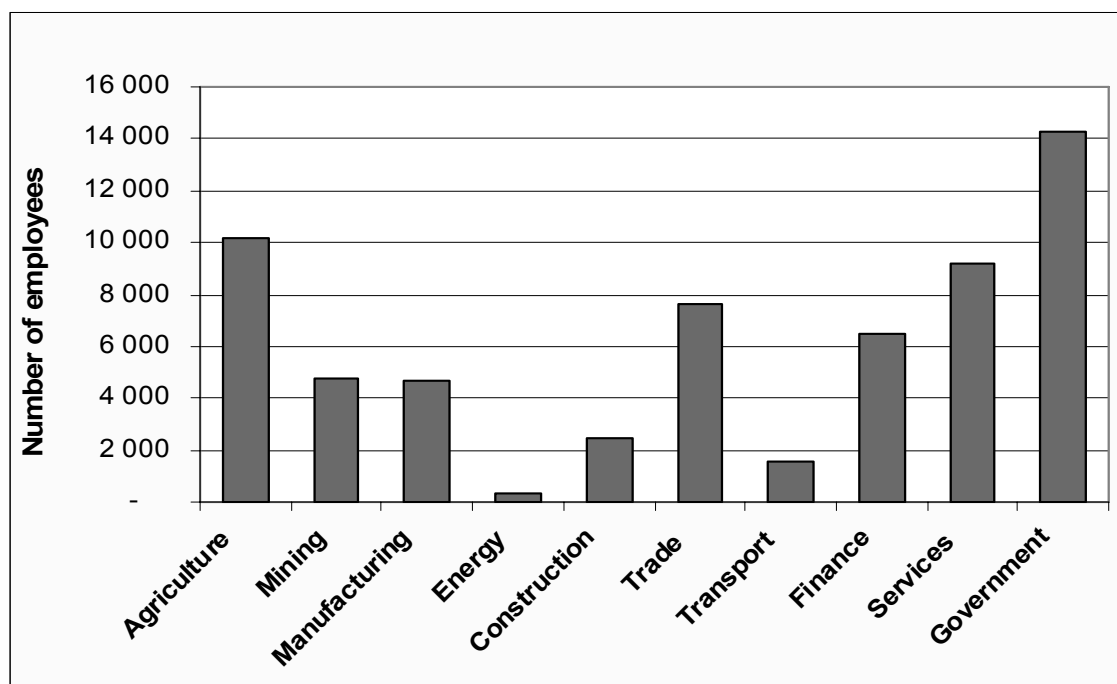


Figure 7.8. Total employment in the study area by economic sector, 2005

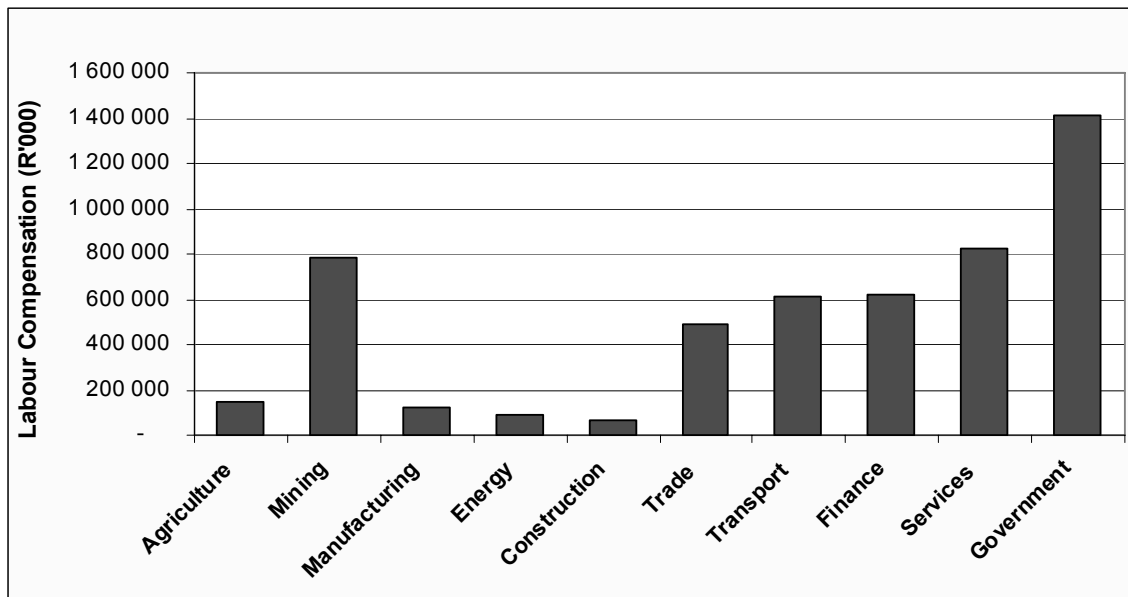


Figure 7.9. Total labour compensation (R'000) in the study area by economic sector, 2005

- Total labour compensation in the study area (all sectors) grew with 9.9%. This figure is calculated at current levels and therefore includes price inflation. Should this trend prevail, it is estimated that the total compensation of labour in 2019 will amount to around R24.2 billion. Of this figure, only 3.8% will be generated in the agriculture sector. The mining sector has the highest contribution with 22.2% to labour compensation created in the study area, followed by 71.4% of the secondary sectors¹ combined.

The different growth rates described above are summarised in Table 7.5.

Table 7.5. Growth performance of selected indicators in the study area, 2000 to 2004

Area	Annual Growth (%)			
	Value Added (GGP) @ constant 2000 prices	Production Output @ constant 2000 prices	Employment	Labour Compensation
<i>Regional Economy of the Study Area</i>				
Study Area	1.8	3.1	-0.2	9.9
Thembelihle	3.0	4.6	-1.4	12.0
Siyancuma	4.9	6.1	-0.3	13.6
Sol Plaatje	1.3	2.7	-0.4	9.3
Diamondfields	3.3	4.1	0.0	14.1
Letsemeng	2.4	3.4	1.3	9.9
<i>Agricultural Sector in the Study Area</i>				
Study Area	-0.9	0.6	-0.9	13.2
Thembelihle	6.5	8.1	-0.6	20.1
Siyancuma	0.9	2.4	-2.1	13.7
Sol Plaatje	-5.1	-3.7	-0.6	7.1
Diamondfields	0.4	1.8	-3.6	13.2
Letsemeng	-5.9	-4.5	0.7	10.9

Source: Urban-Econ calculations, 2006 based on data provided by Quantec Research Pty (Ltd)

¹ The Secondary Economic Sectors refer to wholesale and retail trade, catering and accommodation, transport and communication, financial and business services, community-, social- and personal services, as well as government services.

These indicators were used to recalibrate the Input/Output Model in order to calculate representative multipliers based on the study area's economic structure and linkages

7.2.5. METHOD OF INPUT-OUTPUT ANALYSIS

The Input-Output Model, as described in section 7.1.1(a) makes provision for two kinds of transactions on an economic sectoral level, namely the purchase of intermediate and primary input on the one side and the supply of intermediate and final outputs on the other side (Conningarth Consulting Economists, 1999). The Input-Output Table, as an economic model, involves the exposition of the relationship between economic variables in the form of equations, which show mutual dependence or interrelationships of economic variables. The Input-Output Table derived for the study area is indicated in Table 7.6.

Economic analysis is done by means of deriving a set of matrices from the Input-Output Tables, called *Technical Input Coefficients* and the *Leontief Inverse Matrix*. The Technical Input Coefficient Matrix forms the basis of the Input-Output Model and can be expressed in monetary or physical units. The Technical Coefficient can be defined as the quantity of intermediate inputs which a particular sector requires from another sector in order to supply a Rand unit of output. The technical coefficients are calculated by dividing all the elements in each column of the transaction matrix by the total of the gross inputs/outputs of the different sectors (refer to Table 7.7).

Because of the interrelationship between different sectors of an economy, a change in the final demand for the products of one sector will cause ramifications throughout the system which change not only the outputs of the sector concerned, but also those of most or perhaps all of the other sectors of the economy. Whereas the Technical Input Coefficients can only be used to analyse the first order or direct effects of changes in final demand, so-called Total or Independent Coefficients must be determined to calculate the second order or indirect effects (O'Connor and Henry, 1975). This is done by calculating the relevant multipliers from the *Leontief Inverse Matrix*.

In essence, the multiplier is the number by which the change in investment must be multiplied in order to present the resulting change in investment or income (Conningarth Consulting Economists, 1999). The most important causal factors which determine the multipliers are firstly the industry structure (as assessed through the technical coefficients) and secondly, the final demand structure.

Table 7.6. Input-Output Table at basic values (R' million 2005, imports shown separately) derived for the study area

SECTORS	SIC Codes	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	Households	Intermediate	CG_Total	IK_Total	IC_Total	T_Export	Final_Tot	PROD_TOT
Agriculture	1	193.0	1.4	253.8	0.3	0.0	35.8	0.2	0.6	29.7	1 428.1	1 943.0	-	-395.0	-	3 263.7	2 868.7	4 811.6
Mining	2	417.3	445.2	713.0	20.5	439.6	14.3	454.2	47.7	764.8	0.2	3 316.7	-	98.4	-	12 955.0	13 053.4	16 370.2
Manufacturing	3	69.4	327.8	270.7	15.7	65.6	92.6	151.1	55.9	200.7	945.7	2 195.2	-	52.4	170.3	1 709.7	1 932.4	4 127.5
Energy	4	7.1	111.8	5.4	41.7	0.3	29.2	36.9	10.1	34.5	306.8	583.7	-	-	-	610.9	610.9	1 194.6
Construction	5	7.2	96.0	-	31.3	64.4	77.9	35.0	42.8	61.5	-	416.1	-	-	1 007.1	3.4	1 010.5	1 426.6
Trade	6	27.8	75.7	37.7	4.0	3.3	109.3	144.2	35.3	139.4	2 594.2	3 170.9	-	23.5	806.5	1 624.6	2 454.7	5 625.6
Transport/ Communication	7	43.2	1 075.0	19.9	4.1	2.0	233.4	235.0	62.4	125.7	1 518.2	3 318.8	-	4.2	57.7	5 047.2	5 109.1	8 427.8
Finance	8	7.9	69.2	39.3	5.6	7.1	339.6	173.1	340.7	282.8	1 563.8	2 829.0	-	-	1 044.5	2 104.6	3 149.1	5 978.0
Services	9	31.2	919.3	194.0	1.1	4.4	50.7	124.3	71.1	234.2	3 981.8	5 612.0	4 600.0	0.3	-	518.8	5 119.1	10 731.1
Households		702.5	3 233.8	450.2	288.1	156.7	1 555.2	1 712.9	1 365.5	4 342.3	367.5	14 174.6	618.9	-	-	-	618.9	14 793.4
Sub-Total: Intermediate input		1 506.4	6 355.0	1 984.0	412.4	743.6	2 537.8	3 066.9	2 032.0	6 215.5	12 706.3	37 559.8	5 218.9	-216.2	3 086.0	27 837.9	35 926.6	73 486.4
Total imports	T_Imports	1 292.3	4 649.3	1 428.8	436.9	489.3	1 600.8	2 910.6	1 844.1	3 047.1	1 003.6	18 702.7	-	-0.4	584.7	3 147.8	3 732.1	22 434.83
Total Intermediate input		2 798.6	11 004.2	3 412.9	849.3	1 232.8	4 138.6	5 977.5	3 876.1	9 262.6	13 710.0	56 262.6	5 218.9	-216.6	3 670.7	30 985.7	39 658.7	95 921.2
Gross operating surplus	GOS	1 806.2	5 168.4	626.7	327.7	146.5	1 413.7	1 997.0	2 007.2	1 132.1	-	14 625.5	-	-	-	-	-	14 625.5
Net indirect taxes	NIT	206.8	197.5	88.0	17.6	47.3	73.3	453.3	94.7	336.4	1 083.5	2 598.3	-	-	484.0	-94.0	390.0	2 988.37
Total Primary Inputs		2 013.0	5 365.9	714.7	345.3	193.7	1 487.0	2 450.3	2 101.9	1 488.5	1 083.5	17 223.8	-	-	484.0	-94.0	390.0	17 613.9
Total Input		4 811.6	16 370.2	4 127.5	1 194.6	1 426.6	5 625.6	8 427.8	5 978.0	10 731.1	14 793.4	73 486.4	5 218.9	-216.6	4 154.7	30 891.7	40 048.7	113 535.1
Employment		49 589	17 953	12 521	1 126	7 134	22 682	3 879	14 522	59 328	26 151	214 886						

Table 7.7. Technical Input Coefficients calculated for the study area, 2005

SECTORS	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	Households	Intermediate	CG_Total	IK_Total	IC_Total	T_Export	Final_Tot	PROD_TOT
Agriculture	0.0401	0.0001	0.0615	0.0003	0.0000	0.0064	0.0000	0.0001	0.0028	0.0965	0.0264	0.0000	1.8237	0.0000	0.1057	0.0716	0.0424
Mining	0.0867	0.0272	0.1728	0.0172	0.3082	0.0025	0.0539	0.0080	0.0713	0.0000	0.0451	0.0000	-0.4545	0.0000	0.4194	0.3259	0.1442
Manufacturing	0.0144	0.0200	0.0656	0.0132	0.0460	0.0165	0.0179	0.0093	0.0187	0.0639	0.0299	0.0000	-0.2420	0.0410	0.0553	0.0483	0.0364
Energy	0.0015	0.0068	0.0013	0.0349	0.0002	0.0052	0.0044	0.0017	0.0032	0.0207	0.0079	0.0000	0.0000	0.0000	0.0198	0.0153	0.0106
Construction	0.0015	0.0059	0.0000	0.0262	0.0452	0.0139	0.0042	0.0072	0.0057	0.0000	0.0057	0.0000	0.0000	0.2424	0.0001	0.0252	0.0126
Trade	0.0058	0.0046	0.0091	0.0033	0.0023	0.0194	0.0171	0.0059	0.0130	0.1754	0.0432	0.0000	-0.1085	0.1941	0.0526	0.0613	0.0500
Transport	0.0090	0.0657	0.0048	0.0034	0.0014	0.0415	0.0279	0.0104	0.0117	0.1026	0.0452	0.0000	-0.0192	0.0139	0.1634	0.1276	0.0742
Finance	0.0016	0.0042	0.0095	0.0047	0.0050	0.0604	0.0205	0.0570	0.0264	0.1057	0.0385	0.0000	0.0000	0.2514	0.0681	0.0786	0.0527
Services	0.0065	0.0562	0.0470	0.0009	0.0031	0.0091	0.0148	0.0119	0.0218	0.2692	0.0764	0.8814	-0.0013	0.0000	0.0168	0.1278	0.0945
Remuneration	0.2098	0.2172	-0.1066	0.1350	-0.1636	0.2302	0.0410	0.2399	0.1949								
Households	0.1460	0.1975	0.1091	0.2411	0.1099	0.2765	0.2033	0.2284	0.4046	0.0248	0.1929	0.1186	0.0000	0.0000	0.0000	0.0155	0.1303
Sub-Total: Intermediate input	0.3131	0.3882	0.4807	0.3452	0.5212	0.4511	0.3639	0.3399	0.5792	0.8589	0.5111	1.0000	0.9983	0.7428	0.9011	0.8971	0.6473
Total imports	0.2686	0.2840	0.3462	0.3657	0.3430	0.2846	0.3454	0.3085	0.2840	0.0678	0.2545	0.0000	0.0017	0.1407	0.1019	0.0932	0.1976
Total Intermediate input	0.5816	0.6722	0.8269	0.7109	0.8642	0.7357	0.7093	0.6484	0.8632	0.9268	0.7656	1.0000	1.0000	0.8835	1.0030	0.9903	0.8449
Gross operating surplus	0.3754	0.3157	0.1518	0.2743	0.1027	0.2513	0.2369	0.3358	0.1055	0.0000	0.1990	0.0000	0.0000	0.0000	0.0000	0.0000	0.1288
Net indirect taxes	0.0430	0.0121	0.0213	0.0147	0.0331	0.0130	0.0538	0.0158	0.0314	0.0732	0.0354	0.0000	0.0000	0.1165	-0.0030	0.0097	0.0263
Total Primary Inputs	0.4184	0.3278	0.1731	0.2891	0.1358	0.2643	0.2907	0.3516	0.1369	0.0732	0.2344	0.0000	0.0000	0.1165	-0.0030	0.0097	0.1551
Total Input	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

The Technical Coefficient Matrix forms the basis of the Input-Output Model, but it also has an economic meaning when considered in isolation. As indicated, the effect of change in demand (for the products of a specific sector) on production, consist not only of a direct production effect (as indicated through the Technical Coefficients), but also of a secondary (indirect) production effect. The increase in the production of a specific sector leads directly to additional production in that sector which supplies the inputs. This effect is incorporated in the Leontief Inverse (Conningarth Consulting Economists, 1999). The Leontief Inverse is calculated through matrix manipulation techniques. The resulting Inverse Matrix for the Study Area is indicated in Table 7.8.

Table 7.8. Inverse Matrix for the study area, 2005

SECTORS	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	Households
Agriculture	1.0757	0.0344	0.0646	0.0206	-0.0082	0.0425	0.0109	0.0358	0.0351	0.1335
Mining	0.1165	1.0610	0.2019	0.0414	0.3408	0.0344	0.0700	0.0338	0.0999	0.0704
Manufacturing	0.0447	0.0512	1.0741	0.0321	0.0508	0.0481	0.0298	0.0394	0.0477	0.1048
Energy	0.0100	0.0155	0.0023	1.0410	0.0002	0.0139	0.0075	0.0102	0.0113	0.0308
Construction	0.0048	0.0097	0.0019	0.0301	1.0491	0.0182	0.0063	0.0107	0.0094	0.0089
Trade	0.0639	0.0636	0.0045	0.0374	-0.0156	1.0810	0.0350	0.0674	0.0676	0.2315
Transport	0.0543	0.1091	0.0158	0.0282	0.0120	0.0851	1.0451	0.0529	0.0541	0.1530
Finance	0.0448	0.0497	0.0090	0.0304	-0.0060	0.1104	0.0365	1.1057	0.0692	0.1683
Services	0.1009	0.1491	0.0519	0.0551	-0.0059	0.1045	0.0455	0.1076	1.1104	0.3563
Households	0.3017	0.3003	-0.0442	0.1777	-0.1132	0.3172	0.0850	0.3222	0.2817	1.2349
TOTAL FINAL DEMAND	1.82	1.84	1.38	1.49	1.30	1.86	1.37	1.79	1.79	2.49

Specific *Industry Multipliers* can be calculated from the Leontief Inverse that enables the measurement of economic impact in terms of the change in the value of production (GGP) and employment. For the purpose of this study, so-called Type II industry multipliers were calculated, i.e. multipliers calculated from a transaction matrix which is closed with regards to households. Consequently, the dual relationship between income and consumption, and consumption and income is fully taken into account, as the households' in- and output functions are determined simultaneously with those of the sectors. The Type II multipliers are calculated by means of aggregating of the elements in each of the columns of the Leontief Inverse, which, in turn, is calculated from a closed transaction matrix with regards to households.

Type II industry multipliers were calculated in terms of the following:

- Employment
- Backward linkages in terms of change in inputs
- Forward linkages in terms of change in outputs

The latter two multiplier groups were calculated to provide the total change in *production output* for the study area. These respective multipliers are indicated in Table 7.9 to Table 7.11.

Table 7.9. Employment Multipliers (Type II) for the study area, 2005

SECTORS	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	House-holds
Agriculture	11.0866	0.3549	0.6653	0.2126	-0.0845	0.4377	0.1119	0.3691	0.3613	1.3759
Mining	0.1277	1.1636	0.2214	0.0454	0.3737	0.0377	0.0768	0.0371	0.1095	0.0773
Manufacturing	0.1358	0.1553	3.2585	0.0974	0.1542	0.1458	0.0905	0.1195	0.1448	0.3178
Energy	0.0094	0.0146	0.0022	0.9811	0.0002	0.0131	0.0071	0.0096	0.0107	0.0290
Construction	0.0239	0.0483	0.0096	0.1505	5.2465	0.0908	0.0313	0.0534	0.0469	0.0446
Trade	0.2574	0.2566	0.0180	0.1508	-0.0631	4.3586	0.1410	0.2718	0.2727	0.9333
Transport	0.0250	0.0502	0.0073	0.0130	0.0055	0.0392	0.4810	0.0244	0.0249	0.0704
Finance	0.1089	0.1208	0.0219	0.0738	-0.0146	0.2682	0.0887	2.6862	0.1681	0.4089
Services	0.5581	0.8243	0.2867	0.3047	-0.0328	0.5777	0.2513	0.5950	6.1390	1.9698
Households	0.5333	0.5308	-0.0782	0.3141	-0.2002	0.5607	0.1502	0.5695	0.4980	2.1830
Employment multiplier/R1m	12.8660	3.5195	4.4127	2.3434	5.3850	6.5296	1.4297	4.7356	7.7758	7.4099

Table 7.10. Multipliers: backward linkages per R1.00 change in total input

SECTORS	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	House-holds
Agriculture	0.04011	0.00009	0.06149	0.00027	0.00002	0.00636	0.00002	0.00011	0.00276	0.09654
Mining	0.08672	0.02719	0.17275	0.01715	0.30817	0.00254	0.05389	0.00798	0.07127	0.00001
Manufacturing	0.01442	0.02002	0.06559	0.01315	0.04599	0.01646	0.01793	0.00934	0.01871	0.06393
Energy	0.00146	0.00683	0.00130	0.03494	0.00024	0.00518	0.00437	0.00169	0.00322	0.02074
Construction	0.00149	0.00586	-	0.02623	0.04515	0.01385	0.00415	0.00715	0.00573	-
Trade	0.00577	0.00463	0.00914	0.00333	0.00231	0.01942	0.01711	0.00590	0.01299	0.17536
Transport	0.00897	0.06567	0.00482	0.00340	0.00143	0.04148	0.02789	0.01043	0.01171	0.10263
Finance	0.00163	0.00422	0.00953	0.00472	0.00498	0.06036	0.02054	0.05700	0.02635	0.10571
Services	0.00648	0.05615	0.04700	0.00088	0.00308	0.00901	0.01475	0.01189	0.02182	0.26916
Households	0.14600	0.19754	0.10907	0.24113	0.10986	0.27645	0.20325	0.22842	0.40464	0.02484
Total imports	0.26857	0.28401	0.34617	0.36573	0.34297	0.28456	0.34536	0.30849	0.28395	0.06784
Gross operating surplus	0.37538	0.31572	0.15183	0.27432	0.10267	0.25130	0.23695	0.33577	0.10550	-
Net indirect taxes	0.04298	0.01207	0.02131	0.01474	0.03313	0.01303	0.05379	0.01584	0.03135	0.07324
Total Inputs	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 7.11. Multipliers: forward linkages per R1.00 change in total output

SECTORS	Agric	Min	Man	Energy	Const	Trade	Transport	Finance	Services	Exports
Agriculture	0.04011	0.00029	0.05275	0.00007	0.00001	0.00744	0.00004	0.00013	0.00617	0.67829
Mining	0.02549	0.02719	0.04356	0.00125	0.02686	0.00087	0.02774	0.00291	0.04672	0.79138
Manufacturing	0.01681	0.07941	0.06559	0.00381	0.01589	0.02243	0.03661	0.01353	0.04863	0.41421
Energy	0.00590	0.09355	0.00448	0.03494	0.00029	0.02440	0.03087	0.00844	0.02890	0.51138
Construction	0.00504	0.06728	-	0.02196	0.04515	0.05461	0.02453	0.02997	0.04314	0.00239
Trade	0.00494	0.01346	0.00671	0.00071	0.00059	0.01942	0.02564	0.00627	0.02478	0.28879
Transport	0.00512	0.12755	0.00236	0.00048	0.00024	0.02769	0.02789	0.00740	0.01491	0.59888
Finance	0.00131	0.01157	0.00658	0.00094	0.00119	0.05680	0.02895	0.05700	0.04730	0.35206
Services	0.00290	0.08566	0.01808	0.00010	0.00041	0.00472	0.01159	0.00663	0.02182	0.04834
Households	0.04749	0.21860	0.03043	0.01947	0.01059	0.10513	0.11579	0.09230	0.29353	-

7.2.6. LINKAGE AND APPLICATION

The multipliers described and calculated in the this section are linked and applied to the outcome of the Farm and WUA Level Economic Model, as described in Chapter 6 of this report. The Regional Economic Model is then applied for each of the development options or scenarios (described in Chapter 8) and serves as the final link in the modelling chain.

7.3. SUMMARY

This chapter highlighted the main elements and application methods of the Regional Economic Model developed as part of the Multi-Dimensional Models for the Sustainable Management of Water Quantity and Quality in the Orange-Vaal-Riet Convergence System.

As such, it describes the application and calibration of the Input-Output Model for the analysis of the regional economic impacts that the development of the Convergence Systems will have on the regional economy of the study area. Additionally, the Index for Sustainable Economic Welfare (ISEW) was developed as a tool to assess the long term effects that directed investment in the agricultural sector of the study area will have on the regional economy. The ISEW incorporates the main elements of sustainable development, namely economic-, social- and environmental sustainability.

The Regional Economic Model is subsequently used to assess and analyse the regional economic effects that the application of different development options or scenarios will have on the study area. These analyses are described in the following chapters of this report.

CHAPTER 8. DESCRIPTION OF SCENARIOS MODELLED

by R.J. Armour, and M.F. Viljoen - UFS

8.1. INTRODUCTION

The aim of this chapter is to present information on the scenarios modelled during this research:

- first the rationale in selecting scenarios is presented,
- then the different scenarios are specified with regards to crop composition,
- criteria used in testing the executeability of the scenarios is discussed (scenario setup checks), and
- interpretation of scenario results for a number of stochastic runs is presented

The chapter concludes with a summary of the scenario setup process and key features of each scenario.

8.1.1. RATIONALE

Confronted with different hydrology cycles and associated irrigation water salinity regimes, farmers would like to know what the impact of different farm management options can be on the profitability of farming for the different situations. Two obvious farm management options would be to change the crop composition and to change the leaching and drainage practices.

Scenarios were thus developed to investigate the impact of these options at a per hectare crop enterprise budget (CEB) level, irrigation block level, Water Users Association (WUA) level and regional level.

8.1.2. SCENARIO SETUP PROCESS

The following five scenarios are setup and discussed in this chapter:

- 1. The **base-case scenario** is set up for status quo conditions for the base year of 2005
- 2. **Scenario 1** is set up with status quo drainage, but with a more salt tolerant cropping composition
- 3. **Scenario 2** is set up with status quo drainage, but with a more salt sensitive, (yet higher value) cropping composition
- 4. **Scenario 3** is set up with the same salt sensitive (yet higher value) cropping composition as in Scenario 2, but with additional drainage and leaching
- 5. **Scenario 3+** is exactly the same as Scenario 3 except that the infrastructure cost of the additional leaching and drainage is factored into the irrigation water usage charge.

Paragraphs 8.2 to 8.6 discuss the base-case, Scenarios 1 to 3 and 3+ respectively as set out in Table 8.1 below.

Table 8.1. The 5 scenarios set up for analysis based on crop choice and drainage

		CROP CHOICE		
		status quo	more salt tolerant	more salt sensitive yet higher value
DRAINAGE	status quo	Base-Case	Scen1	Scen2
	increased			
	<i>Not factored in</i>	-	-	Scen3
DRAINAGE COSTS	increased	-	-	
	<i>factored in</i>	-	-	Scen3+

Table 8.2 and Table 8.3 compare the set-up data of the scenarios in Table 8.1 according to the crop choice combinations, checking the reality of the combinations against the change in water use patterns brought about. Improved drainage is only applicable in Scenarios 3 and 3+.

Table 8.2. Percentage cropping composition and changes of the different scenarios

Crops	% Crop composition for different Scenarios			% change from the base-case	
	Base-case	High Value	Salt Tolerant	High Value	Salt Tolerant
Barley	5.08	4.5	6.2	-11	22
Beets	0.09	0.09	0.89	0	881
Carrots	1.70	2.3	1.3	32	-22
Cotton	0.86	1.4	11.5	57	1235
Cucurbits	1.87	4.5	1.3	141	-29
Dry_Beans	0.90	4.5	0.4	400	-51
Fruit	0.01	0.5	0.01	4405	-11
Lucerne	16.18	15.3	6.2	-5	-62
Maize	64.62	54.1	44.3	-16	-32
Olives	0.20	0.3	0.3	38	35
Onions	1.23	1.3	0.1	2	-94
Pastures	6.09	4.5	15.0	-26	147
Peanuts	2.01	3.6	0.9	79	-56
Pecan_nuts	0.79	1.4	0.7	71	-11
Potatoes	3.99	5.4	3.5	36	-11
Soybeans	0.25	2.7	0.2	991	-29
Sunflower	3.83	3.6	11.5	-6	201
Vegetables	0.24	0.9	0.3	280	12
Vineyards	1.75	2.1	2.1	20	18
Wheat	51.10	49.56	53.11	-3	4
TOTAL	162.78	162.32	159.82	64.85	21.48

The percentage cropping composition of the 20 main crops (column 1) grown in the study area is shown in column 2 in the Table 8.2. The total of 162.78% for the base-case indicates that farmers in the whole study area are planting an average of 1.62 crops per irrigated area per year. This factor is used as an indicator in setting up new cropping scenarios. The total for the more salt sensitive yet higher value crop selection is 162.32% and for the salt resistant crop selection 159.82%. The adjusted areas for salt sensitive yet high value crops (column 3) and salt tolerant crops (column 4) were finalised in consultation with agriculturalists in the study area.

Table 8.3. The area (ha) cropping composition of different scenarios

	<u>Crop composition for different Scenarios (ha)</u>			<u>Change from base-base (ha)</u>	
	<i>Base-case</i>	<i>High Value</i>	<i>Salt Tolerant</i>	<i>High Value</i>	<i>Salt Tolerant</i>
Barley	1 229	1 091	1 501	-138	271
Beets	22	22	214	-0	193
Carrots	412	546	322	133	-91
Cotton	209	327	2 787	119	2 578
Cucurbits	452	1 091	322	639	-130
Dry_Beans	218	1 091	107	873	-111
Fruit	-	109	2	109	2
Lucerne	3 919	3 710	1 501	-209	-2 418
Maize	15 650	13 093	10 720	-2 556	-4 930
Olives	48	66	64	18	17
Onions	299	306	19	7	-279
Pastures	1 475	1 091	3 645	-384	2 169
Peanuts	487	873	214	386	-272
Pecan_nuts	191	327	169	136	-22
Potatoes	966	1 309	858	343	-109
Soybeans	60	655	43	595	-17
Sunflower	927	873	2 787	-54	1 860
Vegetables	57	218	64	161	7
Vineyards	425	512	503	87	78
Wheat	12 375	12 002	12 863	-373	489
TOTAL	39 422	39 312	38 705	-110	-716

8.2. BASE CASE SCENARIO

The first step in setting up the scenarios is to update the irrigation block module data files of the WRPM to reflect a certain base level of actual irrigation conditions. This set of data, set up for the base level year of 2005 serves as the Base-Case scenario. Extreme care is taken in setting up the base case, as it is the common basis from which all the scenarios are adapted, where, for the different scenarios, various factors relating to cropping choice and drainage are changed to analyse the impacts of different cropping patterns and drainage installation scenarios. All other WRPM set-up factors not mentioned above are assumed the same as the initial set up values as determined by Allen and Herold (1988) The calculations of these factors are done in the scenario setup file, which is part of a group of files making up the Biophysical sub-model as described in Chapter 5.

Table 8.4 forms the basis for the calculation of the cropping composition percentage index for the different scenarios for the whole scheme shown in Table 8.2. Table 8.4 together with index Table 8.2 therefore form the basis from which Table 8.5, Table 8.6 and Table 8.7 are calculated.

Table 8.4. The basis cropping composition of the 4 Irrigation Blocks on which the Base-Case scenario is based

	<u>Vall</u>	<u>RloR</u>	<u>Rscm</u>	<u>Rszb</u>	
<i>Irrigation Block Code:</i>	5	482	239	479	TOTAL
Area (ha)	7 389.6	3 852.8	12 335.1	641.2	24 218.7
Barley	7.1%	4.7%	4.2%	0.0%	1 229.4
Beets	0.0%	0.0%	0.2%	0.0%	21.9
Carrots	0.1%	0.0%	3.3%	0.0%	412.9
Cotton	0.0%	0.4%	1.6%	0.0%	208.8
Cucurbits	1.1%	0.2%	2.9%	0.0%	451.9
Dry_Beans	0.0%	0.5%	1.5%	3.1%	218.4
Fruit	0.0%	0.0%	0.0%	0.0%	0.0
Lucerne	22.5%	9.0%	15.5%	0.0%	3 919.0
Maize	53.5%	68.5%	69.2%	81.6%	15 649.7
Olives	0.1%	0.0%	0.3%	0.0%	47.5
Onions	1.7%	2.9%	0.5%	0.0%	298.7
Pastures	3.8%	1.4%	9.2%	0.0%	1 475.4
Peanuts	0.0%	2.8%	3.1%	0.0%	486.6
Pecan_nuts	1.1%	0.0%	0.9%	0.0%	191.3
Potatoes	2.6%	11.8%	2.0%	12.0%	966.1
Soybeans	0.0%	0.0%	0.5%	0.0%	60.0
Sunflower	4.5%	2.3%	3.2%	17.0%	926.7
Vegetables	0.1%	0.2%	0.4%	0.0%	57.4
Vineyards	2.3%	1.1%	1.7%	0.0%	424.9
Wheat	50.1%	79.0%	45.7%	0.0%	12 375.0
	150.7%	184.7%	165.7%	113.7%	39 421.5
Study area level base-case cropping percentage:					162.77%

Table 8.5. Base Case areas (ha) planted to various crops of the irrigation blocks

<u>Base Scenario (ha)</u>	<u>Vall</u>	<u>RloR</u>	<u>Rscm</u>	<u>Rszb</u>	<u>TOTAL</u>
Area (ha)	7 390	3 853	12 335	641	24 219
Barley	526	182	522	0	1 229
Beets	3	0	19	0	22
Carrots	10	0	403	0	413
Cotton	0	14	195	0	209
Cucurbits	83	8	361	0	452
Dry_Beans	0	18	180	20	218
Fruit	0	0	0	0	0
Lucerne	1 660	346	1 913	0	3 919
Maize	3 955	2 638	8 534	523	15 650
Olives	10	0	38	0	48
Onions	129	111	59	0	299
Pastures	282	53	1 140	0	1 475
Peanuts	0	108	378	0	487
Pecan_nuts	80	0	111	0	191
Potatoes	192	454	243	77	966
Soybeans	0	0	60	0	60
Sunflower	335	87	396	109	927
Vegetables	7	7	43	0	57
Vineyards	167	44	214	0	425
Wheat	3 699	3 044	5 632	0	12 375
TOTAL ha	11 137	7 114	20 441	729	39 422
Study area level base-case cropping percentage:					162.77%

8.3. SCENARIO 1: STATUS QUO DRAINAGE AND LEACHING WITH SALT TOLERANT CROPS

For Scenario 1, a salt tolerant cropping combination is selected, taking careful precaution not to exceed expert opinion and physical infrastructure constraints the new cropping compositions would place. Artificial drainage and leaching is kept constant at the base case scenario level. The reason for choosing a scenario with more salt tolerant crops planted is to be able to compare the benefits of management option of drainage versus changing cropping composition to more tolerant crops. If for instance strict regulation and heavy fines were to be implemented on irrigation returnflows then this would be one of the few salinity mitigation management options available. Furthermore for financially poor farmers the exorbitant capital outlay from the installation of artificial drainage if not subsidised, would also limit this option leaving virtually only the option of planting tolerant crops.

A scenario of increased drainage together with salt tolerant crops would be superfluous in the study area in question as the irrigation water and soils salinity is far from being so bad that even salt tolerant crops would need drainage and leaching. The salt tolerant crops are also generally lower value crops, or crops with limited room for expansion due to a very limited or closed market, or in the case of sugar beet, the economies of scale to justify the facilities to process it.

Table 8.6 lists the hectares calculated for planting the salt tolerant cropping combination for scenario 1. For the study area as a whole, very close to 160% of the area is planted, indicating 1.6 crops per area per year. The main crops planted in scenario 1 are wheat (12 963 ha), followed by maize (10 720 ha – less than in base case), pastures (3 645 ha – less than in base case), sunflowers and cotton (both 2 787ha), barley and lucerne (both 1 501 ha each) and beets (214 ha – up from 22 ha in the base case). See Table 8.3 for the change in hectares from the base-case.

Table 8.6. Scenario 1 area (ha) planted to various crops

<u>Salt Resistant scenario (ha)</u>					
	<i>Vall</i>	<i>RloR</i>	<i>Rscm</i>	<i>Rszb</i>	
Area (ha)	7 390	3 853	12 335	641	24 219
Barley	641.7	222.4	636.6	-	1 501
Beets	25.6	-	188.8	-	214
Carrots	7.8	-	313.8	-	322
Cotton	-	186.9	2 600.2	-	2 787
Cucurbits	59.3	5.3	257.0	-	322
Dry_Beans	-	8.8	88.5	9.8	107
Fruit	0.7	0.3	1.1	0.1	2
Lucerne	635.7	132.6	732.4	-	1 501
Maize	2 708.7	1 806.8	5 845.8	358.2	10 720
Olives	12.9	-	51.5	-	64
Onions	8.3	7.2	3.8	-	19
Pastures	697.3	131.7	2 815.6	-	3 645
Peanuts	-	47.8	166.6	-	214
Pecan_nuts	70.9	-	98.5	-	169
Potatoes	170.7	403.2	215.3	68.3	858
Soybeans	-	-	42.9	-	43
Sunflower	1 006.7	261.7	1 191.0	327.8	2 787
Vegetables	7.8	7.8	48.6	-	64
Vineyards	197.6	51.8	253.6	-	503
Wheat	3 845.5	3 163.8	5 854.1	-	12 863
TOTAL ha	10 097	6 438	21 406	764	38 705
Study area level scenario 1 cropping percentages:					159.82%

8.4. SCENARIO 2: STATUS QUO DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS

For Scenario 2, a salt sensitive yet high value cropping combination is selected, taking careful precaution not to exceed expert opinion and physical infrastructure constraints the new cropping compositions would place. Artificial drainage and leaching is kept constant at the base case scenario level.

Table 8.7 lists the hectares calculated for planting to salt sensitive yet higher value cropping combinations for scenarios 2 and 3. For the study area as a whole, just over 162% of the area is planted, indicating 1.62 crops per area unit per year. The main crops planted in scenarios 2 and 3 are maize (13 093 ha – still less than in the base case scenario) followed by, wheat (12 002 ha), lucerne (both 3 710 ha), potatoes (1 309 ha) and barley, cucurbits, dry-beans and pastures (all 1 091 ha). See Table 8.3 for the change in hectares from the base-case.

Scenario 2 lists only the cropping area changes to more sensitive, yet higher value crops, to test whether the increased returns from higher value crops would compensate for the reduced yields due to salinity. Furthermore, a scenario is also run (just through the micro-economic model) for optimal yield, where the reduced yield due to salinity is replaced with maximum yield, to give an indication of the maximum productivity of the irrigation blocks under optimal conditions without the impact of salinity.

Table 8.7. Scenario 2 and 3 area (ha) planted to different Salt Sensitive / Higher Value crops

<u>High Value scenario (ha)</u>	<i>Vall</i>	<i>RloR</i>	<i>Rscm</i>	<i>Rszb</i>	TOTAL
Area (ha)	7 390	3 853	12 335	641	24 219
Barley	467	162	463	-	1 091
Beets	3	-	19	-	22
Carrots	13	-	532	-	546
Cotton	-	22	305	-	327
Cucurbits	201	18	872	-	1 091
Dry_Beans	-	90	901	100	1 091
Fruit	33	17	56	3	109
Lucerne	1 572	328	1 810	-	3 710
Maize	3 309	2 207	7 140	438	13 093
Olives	13	-	52	-	65
Onions	132	114	60	-	306
Pastures	209	39	843	-	1 091
Peanuts	-	194	678	-	873
Pecan_nuts	137	-	190	-	327
Potatoes	261	616	329	104	1 309
Soybeans	-	-	655	-	655
Sunflower	315	82	373	103	873
Vegetables	27	27	165	-	218
Vineyards	201	53	258	-	512
Wheat	3 588	2 952	5 462	-	12 002
TOTAL ha	10 479	6 920	21 165	747	39 312
Study area level Scenario 2 and 3 cropping percentages:					162.32%

8.5. SCENARIO 3: IMPROVED DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS

In Scenario 3 the same cropping combination is used as in scenario 2, but artificial drainage and leaching is accounted for by increasing the return-flow factor by 15% to calculate the financial benefits of increased leaching and drainage.

Additional artificial drainage and the resulting improved leaching, should result in the increase of higher value crops due to the reduced salinity risks of production. On the other hand, the increased returns from planting higher value crops can justify the increased drainage to improve the sustainability of the farm.

8.6. SCENARIO 3+: IMPROVED DRAINAGE AND LEACHING WITH SALT SENSITIVE (AND HIGHER VALUE) CROPS – ADDITIONAL DRAINAGE COSTS FACTORED IN

A scenario 3+ is run, set up exactly like scenario 3, except that the additional costs of increased leaching and drainage are factored into the water costs, to test if the additional outlay could be justified by higher returns.

The factors used in calculating the annual repayments in scenario 3+ are as follows:

- Installation of artificial drainage **R 30 000¹** per ha (in-between the cost of drainage for medium and heavy soils – see Table 6.3, and slightly inflated for the average soil types irrigated in the study area, to include in the costs of drainage other secondary / hidden costs),
- A sustainability grant portion of **10%, 50% and 100%** of the total drainage costs
- Repaid over a period of **15, 20, 25 and 30** years,
- and at a **9%** interest rate (subsidised at prime, 11% in 2005, minus 2%), and for policy analysis discount rates of **0%, 5%, 8% and 10%**.

These factors are all variables and can be changed to determine the impacts of different combinations of the assistance grant, term and interest rate on the repayment ability of the farmers. The results are discussed further in Chapter 11 that deals with the various policy options.

8.7. SCENARIO SETUP CHECKS

Two checks are done, namely a water check and an area check. Table 8.8 indicates the change in monthly water use brought about by the change in cropping composition from the base-case (*status quo*) to salt tolerant and salt sensitive (yet high value) cropping composition scenarios. The two columns on the right indicate the unit change in water consumption for the salt sensitive (yet high value) and salt tolerant scenarios. Results for the high value scenario show that for all months May and June that the High Value scenario would use less water in every month. May and June are the months in which the least water is historically used and there is therefore no chance of exceeding the delivery capacity of the study area during these months.

¹ Note: drainage costs can range from R12000-R15000 on sandy soils (<15% clay), R20000-R25000 on Medium soils (15-35% clay), and R30000-R50000 on heavy soils (>35% clay) – see Table 6.3.

As a benchmark of the maximum capacity of the study area, the highest monthly value in the base-case scenario is used, namely 1 345 690 000 m³. In both the high value and salt tolerant scenarios water demand in this critical month (February) is reduced by 10% and 26% respectively. The maximum water demand for all the months in the high value scenario, also occurring in February is 10% less than the critical February maximum in the base-case, and 16% less in the Salt Resistant scenario, but occurring in October, where the demand is still 5% less than in the base year.

In the salt tolerant scenario the base-case water requirements are also exceeded in July and August, the second least critical months after May and June. The large reduction in water demand for the salt resistant scenario for the months from December to April, results in a net reduction of water demand for the salt resistant scenario of 30.3% versus the 13% reduction for the salt sensitive scenario.

Table 8.8. Water use (m³ '000 / month) for the OV-WUA for different scenarios¹

		<i>(m³ '000 / month)</i>			<i>% change from base</i>	
		<i>Base</i>	<i>Salt Sensitive</i>	<i>Salt Tolerant</i>	<i>Salt Sensitive</i>	<i>Salt Tolerant</i>
Pre – year	Jul	119 186	116 940	125 766	-0.02	0.06
	Aug	246 213	240 278	260 775	-0.02	0.06
	Sep	733 479	706 793	707 597	-0.04	-0.04
	Oct	1 193 960	1 149 702	1 136 866	-0.04	-0.05
	Nov	1 109 372	1 073 072	1 006 182	-0.03	-0.09
Aft – year	Dec	701 133	649 570	430 462	-0.07	-0.39
	Jan	1 137 043	1 045 197	789 427	-0.08	-0.31
	Feb	1 345 690	1 215 916	996 910	-0.10	-0.26
	Mar	1 117 949	1 006 114	921 737	-0.10	-0.18
	Apr	400 732	352 639	338 405	-0.12	-0.16
	May	21 283	21 260	34 157	-0.00	0.60
	Jun	13 699	14 010	22 126	0.02	0.62
Scenario TOTAL		8 139 740	7 591 491	6 770 409		
% change:		100.00%	-6.74%	-16.82%		
Total change from Base:			-548 249	-1 369 331		
Monthly extremes compared to check delivery exceedance						
Min		13 699	14 010	22 126	0.02	0.62
Max		1 345 690	1 215 916	1 136 866	-0.10	-0.16
Pre- and Aft- years compared						
Pre-	Total	3 402 211	3 286 785	3 237 186	-0.03	-0.05
Aft-	Total	4 737 529	4 304 706	3 533 224	-0.09	-0.25
TOTAL SEASON CHANGE		8 139 740	7 591 491	6 770 410	-0.07	-0.17

From the comparison it follows that the two alternative cropping choice scenarios selected will not exceed the monthly water supply capacity of the study area. Both will actually contribute to a more even distribution of water demand over the year, especially the salt tolerant scenario, effectively reducing water delivery risk and capacity strain on the delivery network.

¹ The OV-WUA irrigation block is used for testing that new water demand does not exceed delivery capacity because it has two water - seasons, a pre-year and an after-year, with water being relatively more scarce in the pre-year than in the other irrigation blocks. The OV-WUA is also more limited in its options for acquiring additional water than the OR-WUA irrigation blocks.

8.8. STOCHASTIC HYDROLOGY RUNS

For each scenario discussed in this chapter, 100 stochastic model runs are completed as described in Chapter 4. These runs depict 100 possible monthly sequences based on statistical analysis of approximately 70 years of actual recorded data from 1920-1994 (van Rooyen, *et al.* 2004b).

These stochastic runs implicitly model the following:

- seasonal hydrology
- long-term wet and dry cycles
- unexpected exceptional flood / drought events

These extremes and trends are not run as separate scenarios, but the 0.05 and 0.95 percentile results of the 100 runs are calculated and analysed to point out the effect and impact of these extremes and trends as a separate analysis within a scenario. As the 0.05 and 0.95 percentiles are only averages, actual stochastic sequences are selected which best fit the cumulative total gross margin above specified costs (TGMASC) calculated in Chapter 9. , and as depicted in Figure 8.1. Stochastic run (SR) 001, 044 and 080 are selected from the 100 stochastic runs of each year to represent the 0.05 and 0.95 percentile extremes and 0.50 percentile “average” in the discussion of scenario results that follows in Chapter 9.

When viewing the cumulative TGMASC in Figure 8.1 as annual TGMASC (see Figure 8.2) the close fit of stochastic runs 001, 044 and 080 to the 0.05, 0.95 and 0.50 percentiles can no longer be observed. However, the selected stochastic runs represent the realistic fluctuation of events and capture the dynamic nature of the data far better.

Furthermore, the stochastic runs are useful in comparing a realistic “best case”, “worst case” and “average case” probability of events for each irrigation block, such as depicted in Figure 8.3. In Figure 8.3 the stochastic spread of the saturated soil salinity concentration, CUE (mg/l) in the 4 Irrigation Blocks is compared, using only the selected stochastic runs to show the extent of variation.

Each specific stochastic run in the WRPM, models a sequence of catchment level hydrology of which the area analysed in this study forms only a very small part, encompassing the four Irrigation Blocks. Stochastic run 080 for example in the Lower Riet Irrigation Block is set up with the same hydrology reference as stochastic run 080 for all the other scenarios as well as in all the other irrigation blocks, as all the irrigation blocks are linked in hydrology sequence.

In analysing these stochastic runs, they are essentially realistic “best case”, “worst case” and “average case” scenarios within the 5 main scenarios set-up and described in the sections 8.2 to 8.6.

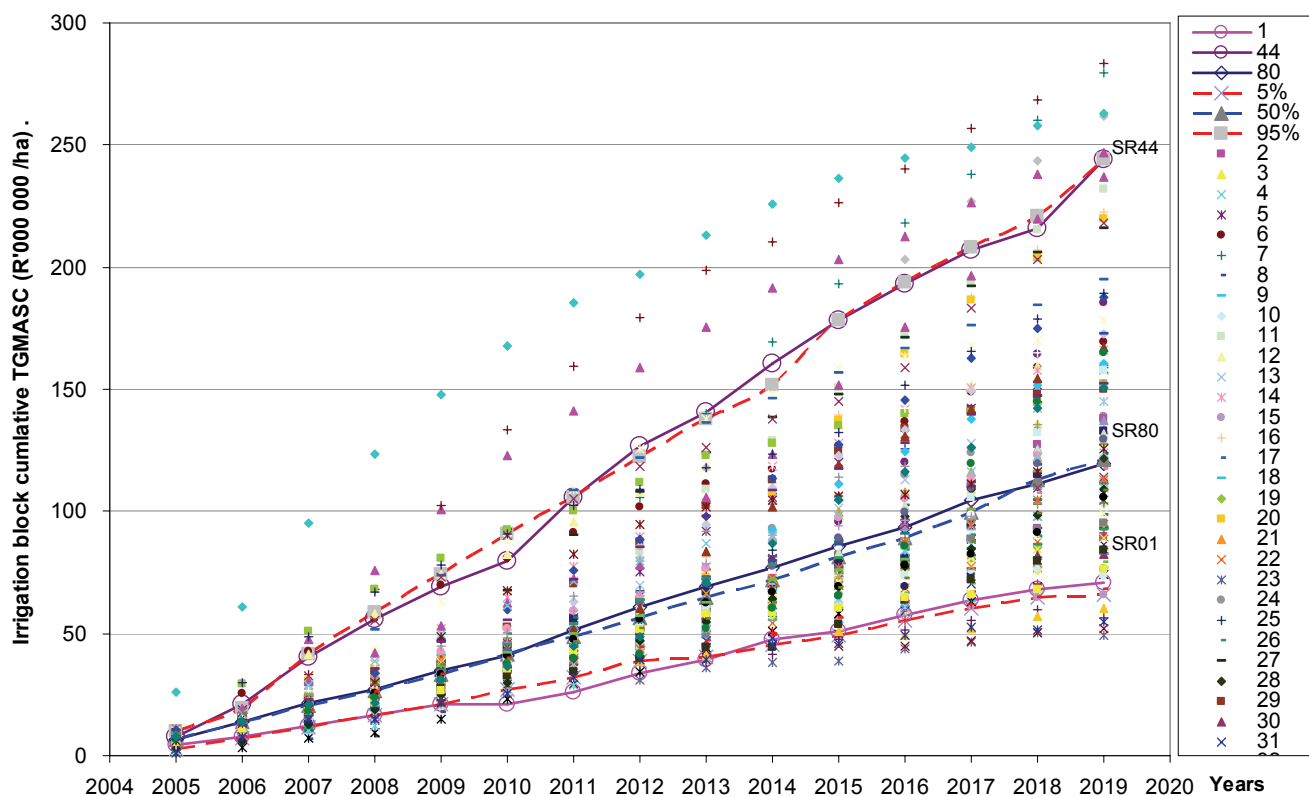


Figure 8.1. The selection of specific stochastic runs from the Base-Case scenario run for the Lower Riet Irrigation Block (*R/oR*) to analyse as “best-” “average-” and “worst case” hydrology sequences when comparing scenarios

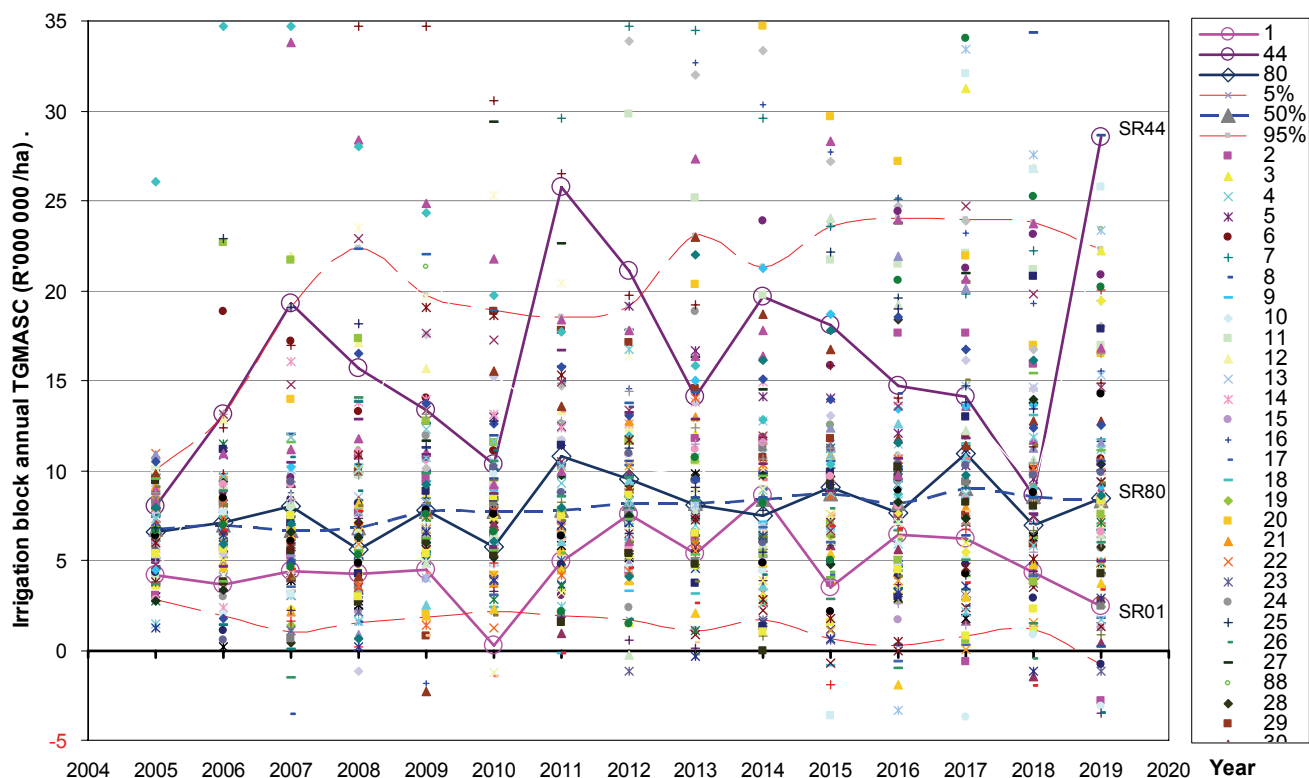
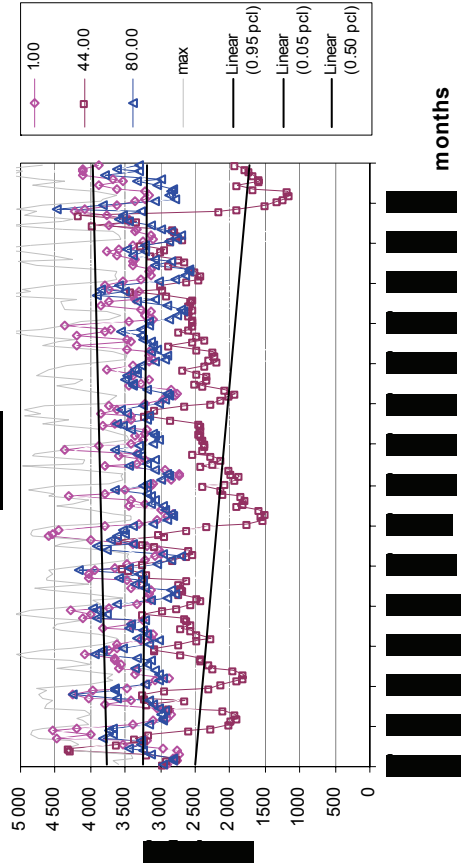
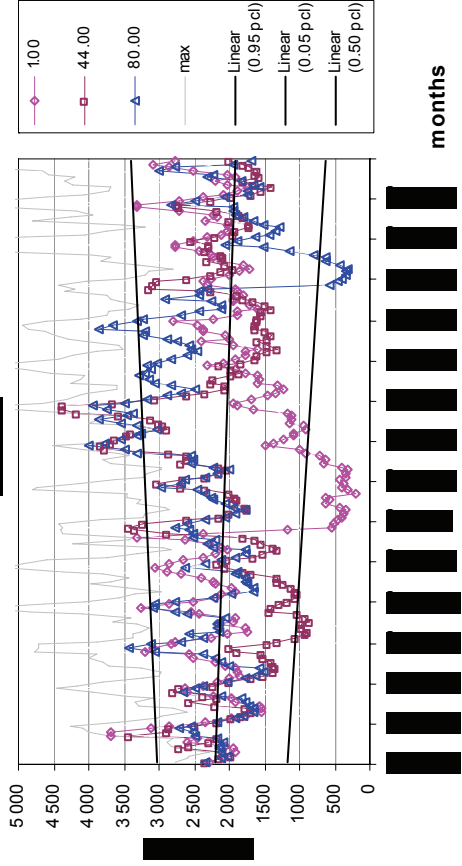


Figure 8.2. Annual TGMASC over 15 years for 100 stochastic runs for *R/oR* Base-Case scenario showing stochastic runs 1, 80 and 44 in relation to the 0.05, 0.50 and 0.95 percentiles

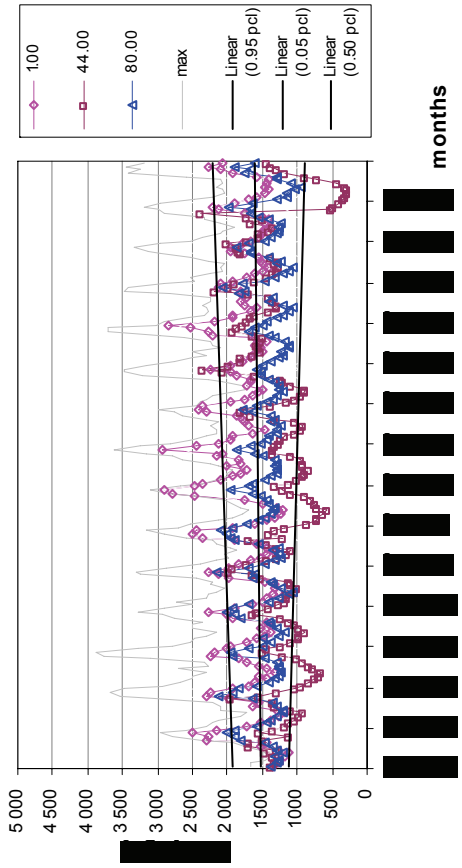
RloR Saturated soil salinity - C_{Ue} (mg/l) for stochastic runs



Vall Saturated soil salinity - C_{Ue} (mg/l) for stochastic runs



Rszg Saturated soil salinity - C_{Ue} (mg/l) for stochastic runs



Rscm Saturated soil salinity - C_{Ue} (mg/l) for stochastic runs

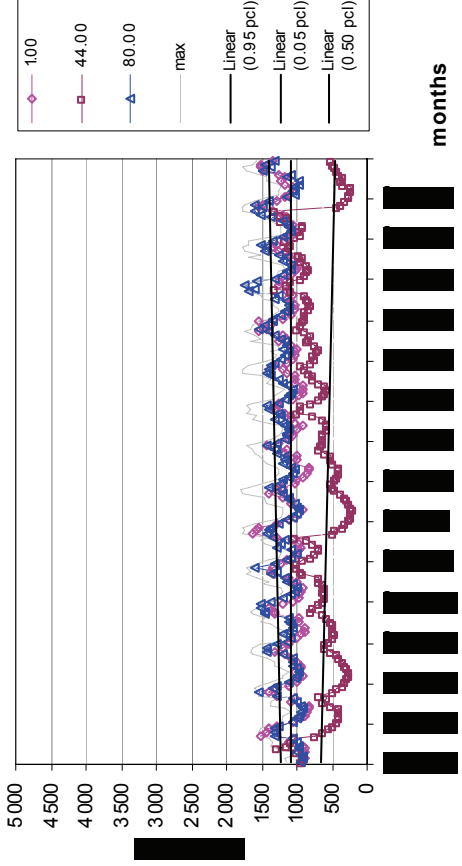


Figure 8.3. A comparison of saturated soil salinity concentrations - C_{Ue} (mg/l) - in different irrigation blocks for the Base Case stochastic runs analysed, with linear trends indicated

8.9. IRRIGATION BLOCKS COMPARED

Figure 8.3 consists of a comparison of the saturated salt concentration values in the upper zone (C_{Ue}) over 15 years in the Lower-Riet (**RloR**), Scholtzburg (**Rszg**), the Riet Scheme (**Rscm**) and the Orange Vaal WUA (**Vall**) Irrigation Blocks. The C_{Ue} values of stochastic runs 001, 044 and 080, as well as the linear trends of the 0.05, 0.50 and 0.95 percentile values are depicted in each of the four graphs to enable easy comparison and trend evaluation. Maximum C_{Ue} values for each irrigation block are also drawn in light grey to show the frequency over 15 years that certain thresholds are reached.

In the top left corner of Figure 8.3 **RloR** consistently has the highest C_{Ue} values for all three stochastic runs, with maximum values exceeding 5000 mg/l almost yearly. The 0.95 percentile trend line decreased at a sharper gradient than the other irrigation blocks, the 0.50 percentile trend line is very level and the 0.05 percentile trend line increases only slightly. Although in comparison, **Vall** in the top right corner of Figure 8.3 shows an average magnitude decrease in C_{Ue} of approximately 1000 mg/l, the **Vall** Irrigation Block displays a more dramatic fluctuation of C_{Ue} values for all three stochastic runs, with maximum values also reaching 5000 mg/l every few years. The 0.95 percentile trend line also decreases with a sharp gradient, but the 0.50 percentile trend line also decreases as opposed to all the other irrigation blocks, and at a steeper gradient, possibly indicating a sustainable improvement in the soil salinity status. This however counters the increase in the 0.05 percentile trend line, which is greater than the other irrigation blocks. The increase reflects the dramatic fluctuations, and therefore production risks, in the **Vall** Irrigation Block. At a magnitude decrease in C_{Ue} of approximately a further 1000 mg/l, is the **Rszg** Irrigation Block, and at approximately a further 500 mg/l decrease, the **Rscm** which gets its water predominantly from the Orange River. In the **Rszg** maximum values only exceed 3000 mg/l every few years and in the **Rscm** never exceed 2000 mg/l. Visible in especially the **Rszg** and **Rscm** Irrigation Blocks are the strong seasonal cycles of the C_{Ue}.

8.10. SUMMARY

The stochastic nature of the WRPM hydrology data generated for scenario analysis necessitates selecting 3 actual stochastic model runs from the 100 that reflect the 0.05, 0.50 and 0.95 percentiles instead of only using an average, so as to capture the stochastic/dynamic nature of the data for presentation. The micro-economic model is however run for all 100 runs and the resulting data also subsequently presented as described above.

The percentiles selected of the 100 stochastic runs are in themselves worst-, average- and best-case “scenarios” of each of the main scenarios discussed.

Extreme care was taken in the setting up of the scenarios in selecting the alternative cropping compositions so as not to exceed water delivery infrastructure, processing capacity and market demand constraints. Maize area was also reduced in both the salt tolerant and salt sensitive (yet high value) scenarios in the light of the apparent short-term maize over supply of 2005 (much publicised in the media) and long-term consumer trends.

The base-case scenario is essentially the first scenario, whereby the WRPM is updated, as described in the first section of this chapter, to reflect a chosen base year; 2005 for this study. The starting point salt concentration values used in the setup of the WRPM model are manually adjusted by the WRPM operators to take out any trend in the data. These starting points remain fixed for the other scenarios that follow.

Scenario 1 is set up using a more salt tolerant cropping combination of crops (i.e. greater area planted to wheat, barley, cotton, pastures and sunflowers) without increasing drainage and leaching from the base-case values. The objective of scenario 1 is to test the long term sustainability of this option.

For Scenario 2 and 3 a more salt sensitive, yet higher yielding cropping combination (i.e. greater area planted to fruit, vegetables, legumes and potatoes) is used without increasing drainage and leaching from the base-case values for Scenario 2. The objective of Scenario 2 is to test if the increased profits of higher value crops would not compensate for the yield losses due to salinity. Scenario 2 is run with 100% yield to calculate an indication of the maximum productivity of the irrigation blocks.

In Scenario 3 the same cropping combination is used as in Scenario 2, but artificial drainage and leaching is accounted for by increasing the return-flow factor by 15% to calculate the financial benefits of increased leaching and drainage. Scenario 3+ is also run whereby the additional costs of increased leaching and drainage are factored into the water costs, to test if the additional outlay could be justified by higher returns.

A scenario showing the impact of improved drainage and leaching in status quo crops would have provided interesting results, but due to the limitation in scenarios to run, the four selected and discussed in this chapter were the priority. The option of growing more higher value crops was chosen above the status quo to examine the impact of reduced maize production (all be it only 5% less) in the light of the much speculated overproduction of maize in 2005.

The chapter concludes with a comparison of the stochastic CUE values between the four irrigation blocks. **RloR** clearly displays the highest CUE values, followed respectively by **Vall**, **Rszg** and **Rscm** with the lowest values. Although **Vall** displays lower values than **RloR**, the fluctuation is more dramatic and very high CUE levels are also reached, though not as frequently as in the **RloR**.

CHAPTER 9. MICRO-ECONOMIC MODEL RESULTS

by R.J. Armour, and M.F. Viljoen - UFS

9.1. INTRODUCTION

The purpose of this chapter is to present the final results of the integrated suite of models up to the Micro-economic level, i.e. the economic impacts on irrigation block level as set up in the Water Resources Planning Model (WRPM).

The fifty-percentile value of 100 WRPM stochastic runs is used in presenting most of the results instead of the average, as the fifty percentile value gives a more realistic indication of the most predominant occurrence of a data series analysed than the average. Both the average and the fifty percentile however fail to account for the large variability in some cases that can be experienced and thus the five and ninety fifth percentiles were also calculated to present the data meaningfully.

The chapter starts with an explanation of the irrigation block level hydrology results for the various scenarios applicable to the economic modelling. With hydrology results showing that the Lower Riet Irrigation Block (**RioR**) (downstream in the Orange-Riet WUA) is the irrigation block worst affected by salinity, it is used in the results that follow as a case study example, where only one irrigation block is referred to. Results comparing all irrigation blocks are also presented.

Following the hydrology results, a worked example is used to present some of the results of the bio-physical model to show the linkage between the hydrology results and their impact on yield, which changes crop income in the economic model. An example using the per hectare crop enterprise budgets (CEBs) of the three main crops grown in the study area follows, which forms the basis for the micro-economic model. The results of the micro-economic model, the irrigation block level economic results, are then presented for 100 stochastic hydrology model runs for each scenario. Based mainly on these results, three actual stochastic runs are selected that most closely fit the 0.05, 0.50 and 0.95 percentile probability of occurrence of the fifteen year cumulative total gross margin above specified costs (TGMASC). Further analysis of the economic results proceeds using these stochastic run data sequences for each scenario.

The irrigation block level micro-economic model result linkages to the regional economic model are then discussed together with the social (change in employment patterns) and environmental (change in soil salt balance) linkages. The chapter concludes with a summary of the main results re-emphasising the significance of the results.

9.2. HYDROLOGY MODEL RESULTS ANALYSIS

The hydrology results consist of the processed WRPM data output. The main factor used as input in the bio-physical model is the monthly salt concentration (mg/l) in the irrigation block soil upper zone (CU). CU is converted to the monthly saturated soil concentration, CUE (mg/l) using monthly effective water volume data, HE (mm) and the maximum upper soil zone water volume capacity factor values used in the WRPM setup.

Irrigation water salinity, TDS (mg/l) changes are discussed in Paragraph 9.2.2 but as the impact of the irrigation water on the soil salinity is calculated internally in the WRPM, the irrigation water salinity is not explicitly used in the micro-economic model. As the only regular and tangible measure of the salinity status on the farm or WUA, that farmers and WUA managers respectively have, irrigation water salinity results are presented here for better clarity and understanding of the linkage to soil salinity and resulting reduced yields as shown in the sections to follow.

9.2.1. SOIL SALINITY CHANGES

Soil type is differentiated in the study in the setup of the WRPM model by varying the return-flow factors and proportion returnflows from the upper zone and lower zone factors, and by setting the water holding capacity of upper (HU) and lower zones (HL) and the target soil moisture.

Figure 9.1 is a comparison of the base-case scenario 0.50 percentile of the CUE of the various irrigation blocks, clearly showing similar definite seasonal trends for all irrigation blocks and a slight long-term trend of decreasing CUE. On the right-hand-side Y-axis, the corresponding ECe (mS/m) is listed as an indication of the TDS to EC conversion, a factor of 6.5 is used. The decreasing trend over the 15 years in Figure 9.1 is however deceiving as when one looks at the data over a longer period (25 years) there is a slightly increasing trend again. The period of analysis for this study is fifteen years and the first fifteen years as depicted in Figure 9.1 are used.

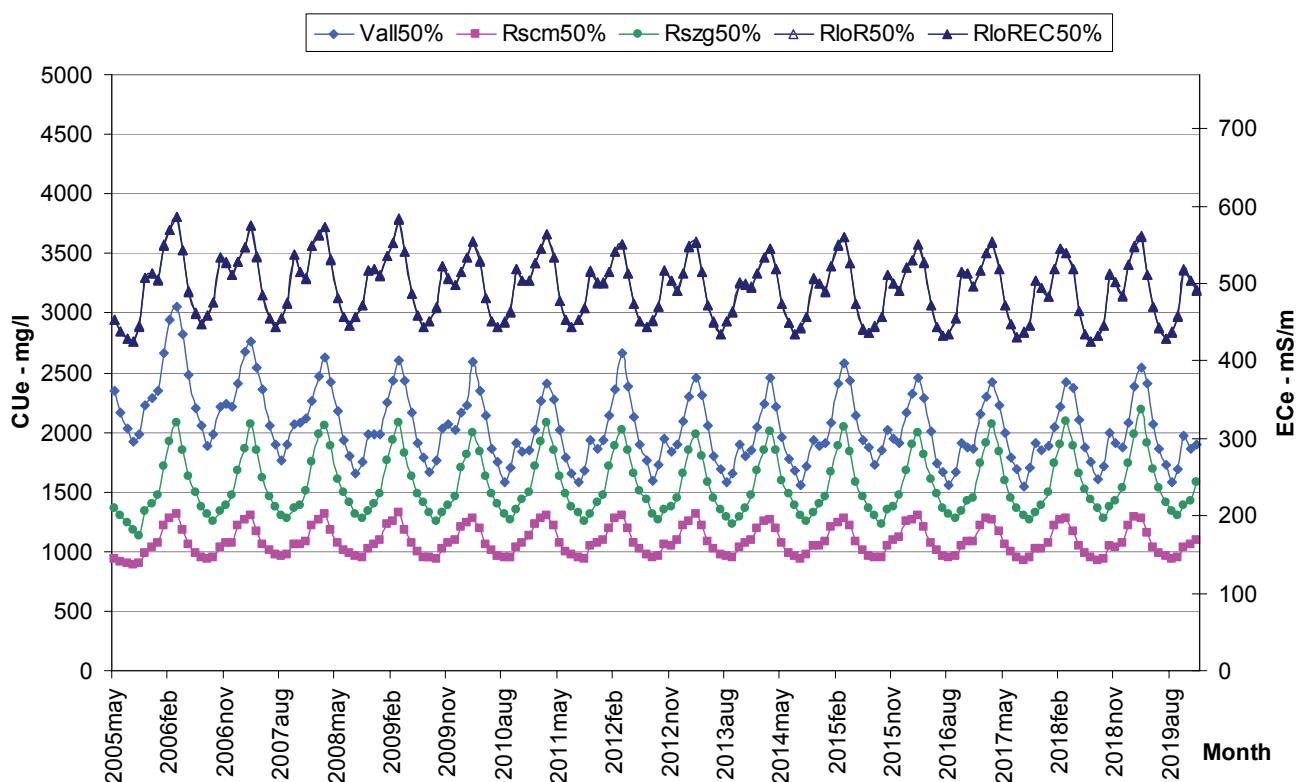


Figure 9.1. The 0.50 percentiles of 100 stochastic runs of the base-case scenario upper zone saturated soil salinity - CUE (mg/l) for all irrigation blocks

Of the scenarios tested, the largest impact on saturated extract salt concentration is clearly scenario 3 (see Figure 9.2 and Figure 9.3 for the Lower Riet and Vaal Irrigation Blocks respectively), where the WRPM return flow factor is increased by 15%, representing an effective increase of irrigation drainage and leaching of 15%.

Changing crop composition from status quo to tolerant to sensitive does have a very small impact on the hydrology as a whole, as shown by the very close correlation of lines Base-Case, Scen1 and Scen2 in Figure 9.2 and Figure 9.3, but increasing leaching (Scen3) clearly greatly improves soil salinity – i.e. reduced CUE.

It must be mentioned that all salts that accumulate in the study area are not only as a results of irrigation practices. Municipal, mining, stock watering, industry etc. are all users of water that contribute to the use and concentration of salts in the study area. There is also a salt wash-off module run in the WRPM explained in Chapter 4.

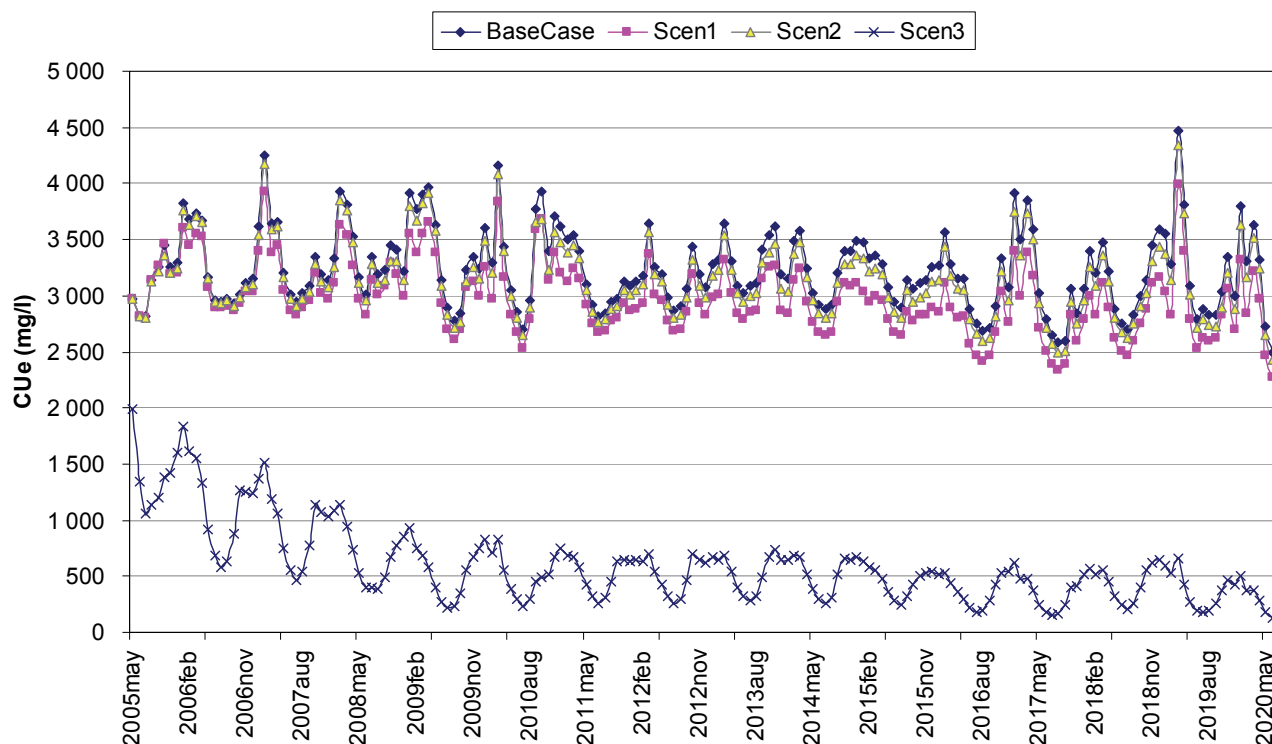


Figure 9.2. The impact of different scenarios on the saturated extract salt concentration - CUE (mg/l) for Stochastic run 080 in the Lower Riet Irrigation Block (*RloR*) for 15 years.

9.2.2. IRRIGATION WATER SALINITY DATA

Figure 9.4 shows the expected monthly irrigation water salinity concentration, TDS (mg/l) spread in WRPM channel number 490 which feeds into the Lower Riet Irrigation Block (*RloR*). The months of April to August have the largest variation and are also the months with the highest TDS values. Winter crops and crops germinating in these months therefore face the largest risk of salinity damage if sensitive to salinity.

Figure 9.5 shows the annual spread of irrigation water quality in the Lower-Riet Irrigation Block. The annual average irrigation water quality is stable at around 800 mg/l while the fifty percentile is around 500 mg/l, indicating that the maximum values (represented by the 0.95 percentile) fluctuate more widely. Looking only at the average irrigation water quality (mg/l) in Figure 9.5, one would conclude that the salinity is worse than it really is, if you do not also look at the 0.50 percentile. The 0.50 percentile indicates the level at which the irrigation water quality would be at 50% of the time, or put otherwise, there is a 50 / 50 (even) chance that irrigation water salinity could be more or less than the value indicated.

The flux of irrigation water salinity around the average and 0.50 percentiles are however very important as displayed by the micro-economic results in Figure 9.10.

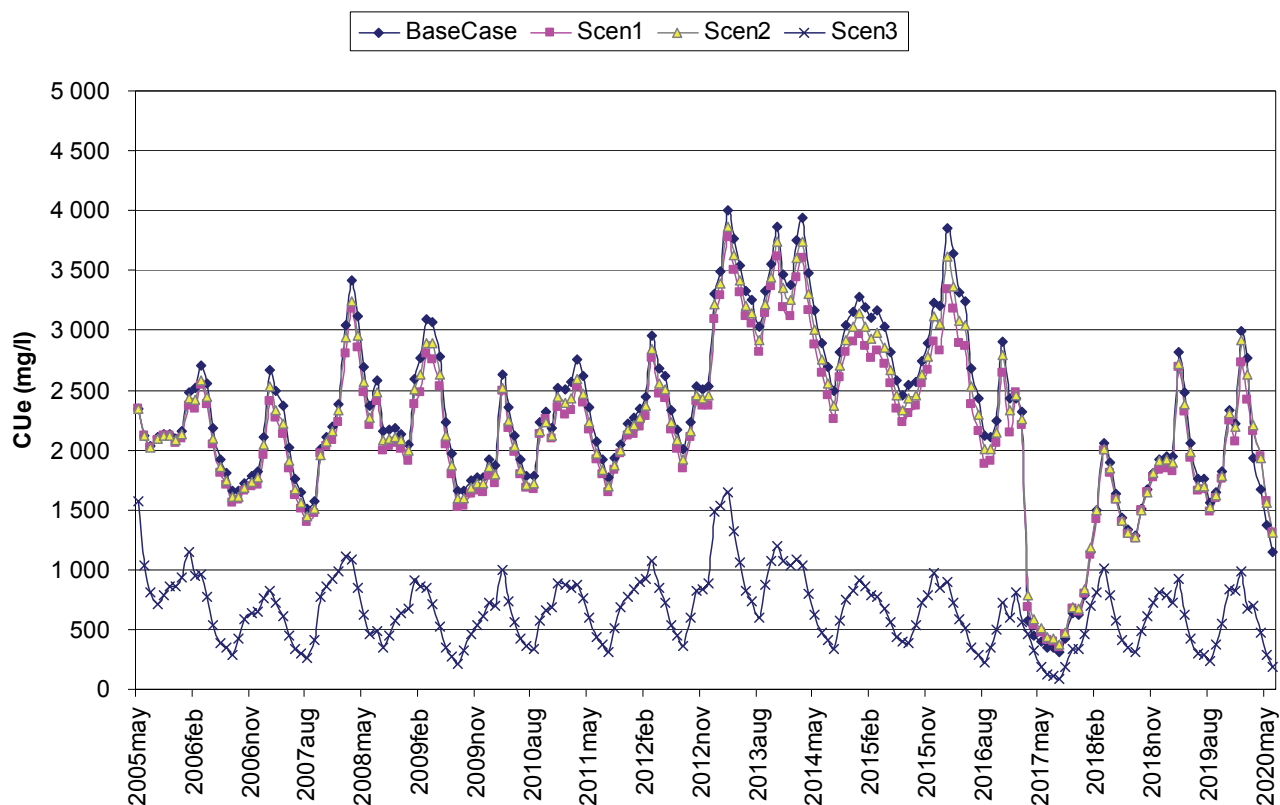


Figure 9.3. The impact of increased drainage in Scenario 3 on the saturated extract salt concentration - CUE (mg/l) for Stochastic run 080 in the Orange Vaal WUA block (Vall) for 15 years

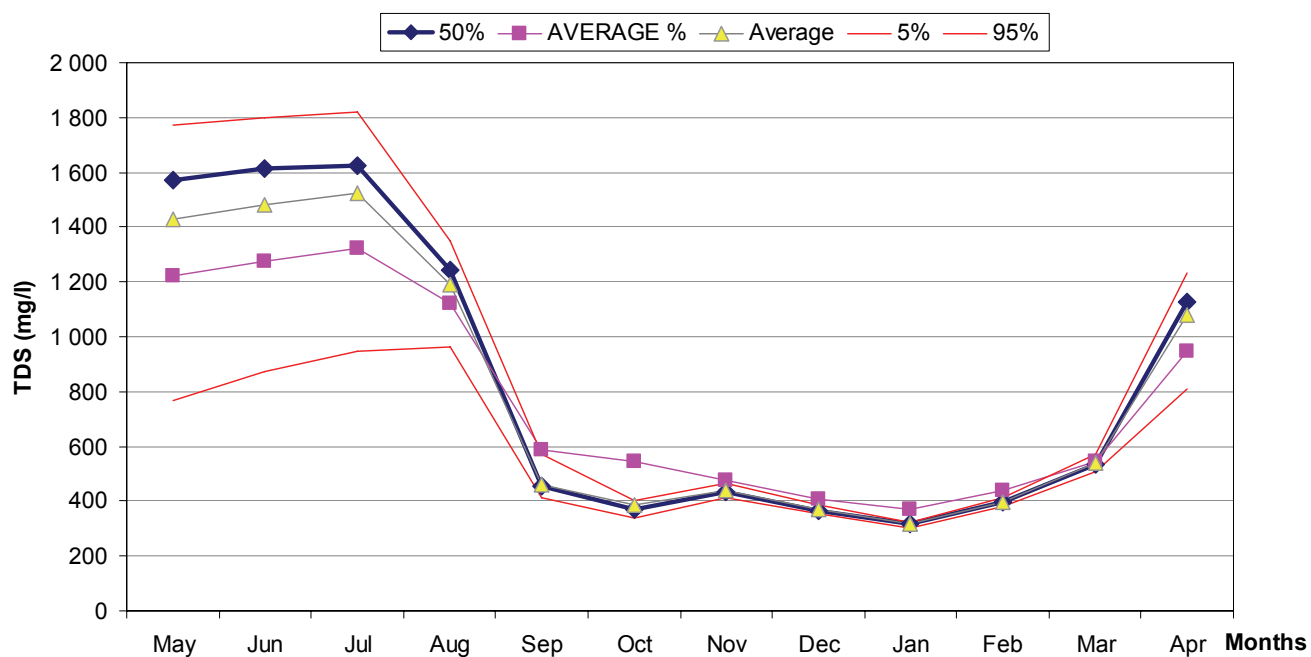


Figure 9.4. Monthly irrigation water salinity concentration, TDS (mg/l) spread in WRPM channel number 490 which feeds into the Lower Riet Irrigation Block (R/oR)

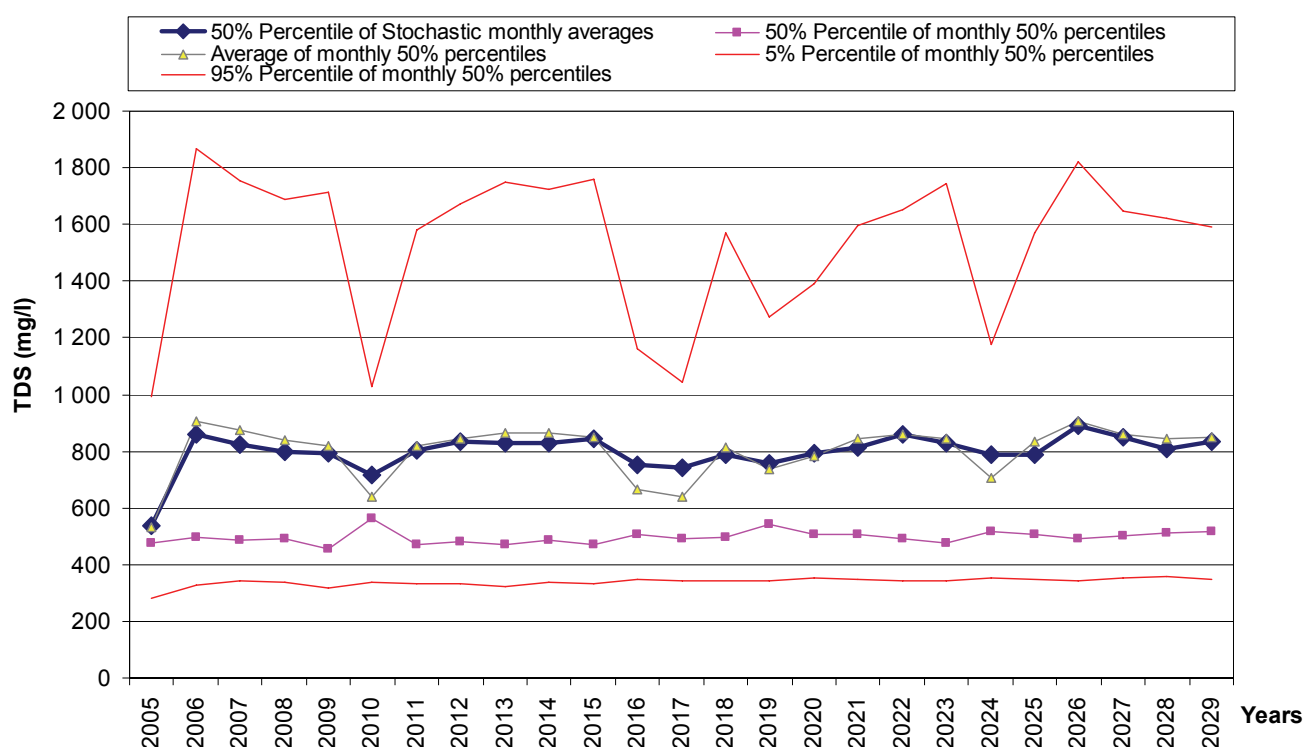


Figure 9.5. Annual irrigation water expected salinity, TDS (mg/l) spread in Channel 490, which feeds into the Lower Riet Irrigation Block (*R/oR*)

9.3. BIO-PHYSICAL EXAMPLE OF THE HYDROLOGY–ECONOMIC LINKAGE RESULTS

The key results of the bio-physical model are the conversion of the WRPM model soil salt concentration, CU (mg/l) results into saturated soil salt concentration, CUE (mg/l) and the subsequent conversion from salt concentration (mg/l) into electrical conductivity ECE (mS/m). The ECE is applied to the Maas and Hoffmann (1977) equation using crop threshold and gradients to determine the linear crop yield functions shown in Figure 9.6. The reduction in crop yield due to salinity is then used in the micro economic model as demonstrated in Table 9.2.

Figure 9.6 is a worked example of the Maas and Hoffmann equation (explained in full in Chapter 5). For this example the ECE of the saturated soil paste is set to 480 mS/m (3 120 mg/l) at which level maize gives an 8.85 ton yield (63% of the maximum yield of 14 ton/ha). Lucerne produces a yield of 16.29 ton/ha, only 80% of the maximum yield, and salt tolerant wheat yields 100% at this soil salinity level. The subsequent CEBs for these three crops are shown in Table 9.1 under Paragraph 9.4.1. Winter, summer and annual crops however will not be subject to the same annual average ECE because, depending on the months of production, monthly crop water requirements and the monthly ECE, a crop-specific weighted average ECE is calculated each year.

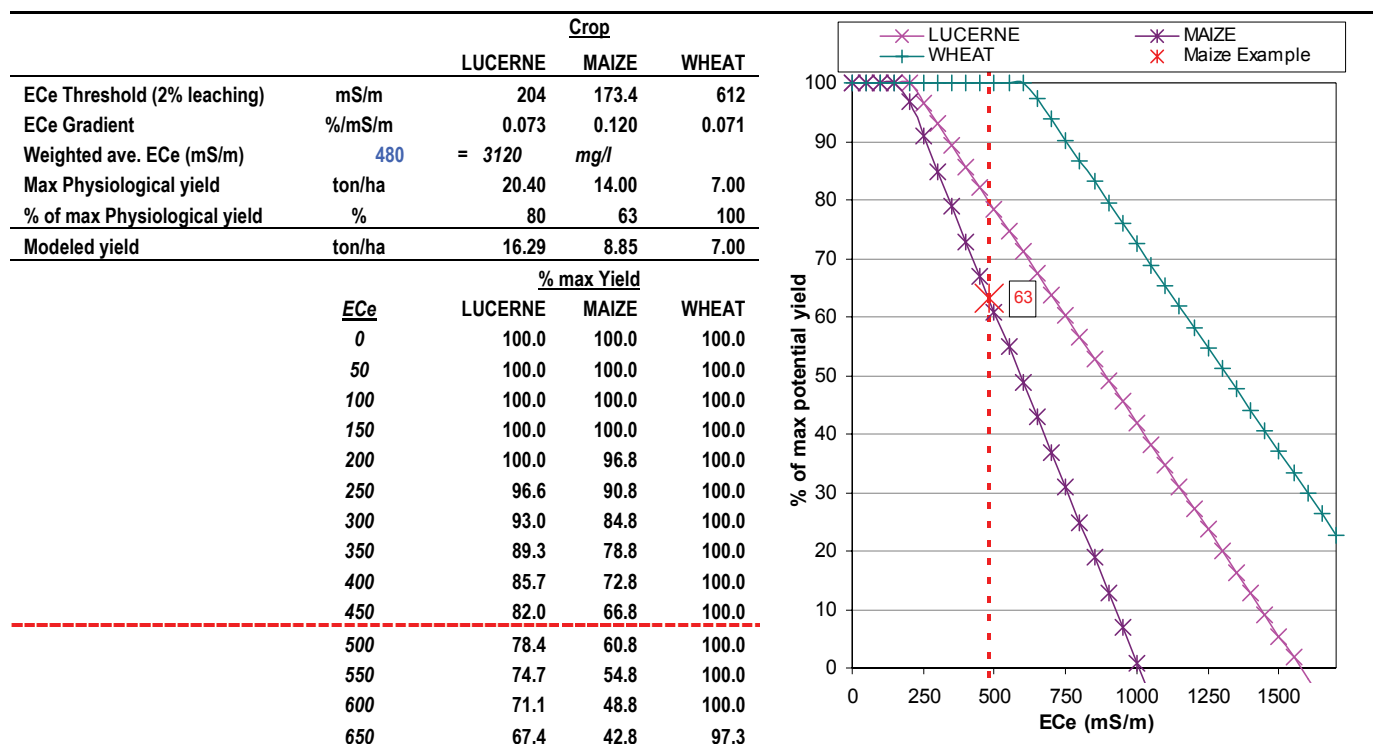


Figure 9.6 The working of the Maas and Hoffmann (1977) threshold and gradient graph for determining yield response to saturated soil salinity - ECe (mS/m) for the Lower Riet Irrigation Block, stochastic run 080 (closest fit to the 0.50 percentile)

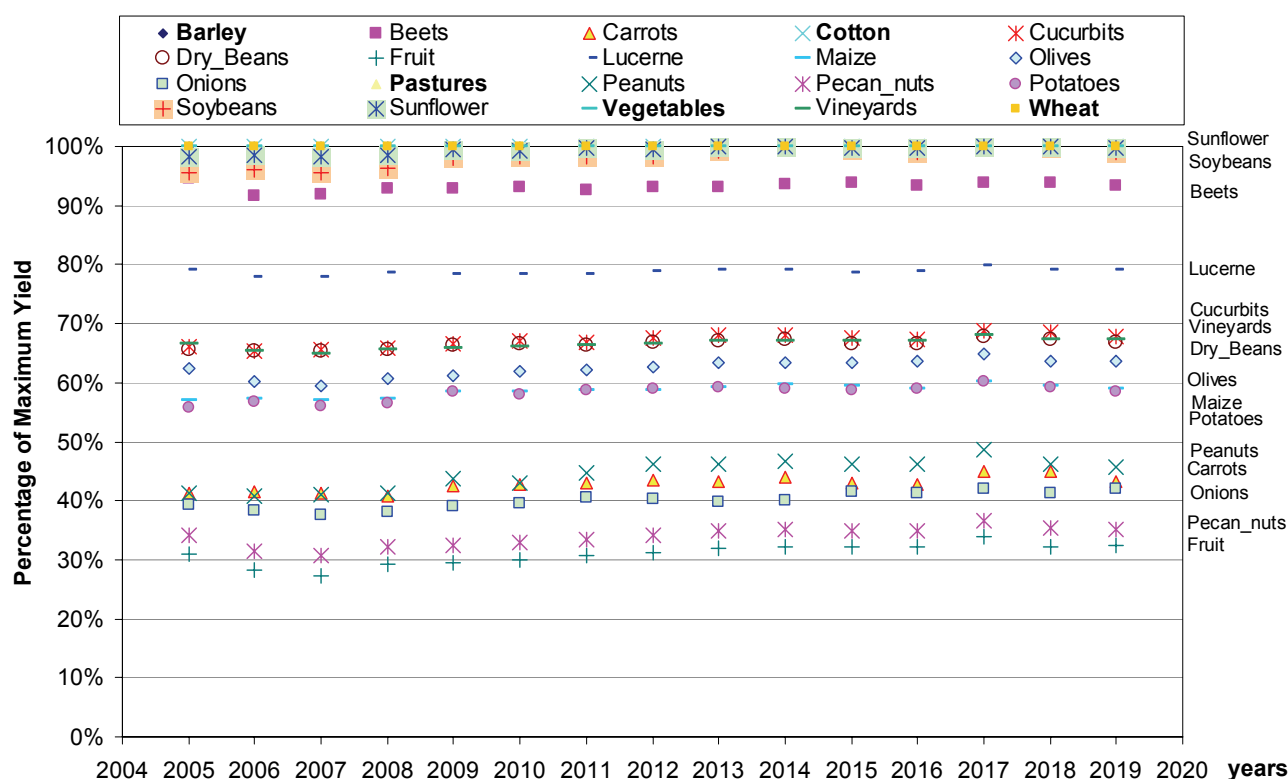


Figure 9.7. The fifty percentile (0.50) crop yield of the 20 main crops over 15 years in the Lower-Riet Irrigation Block (Crop names written in bold type achieve a 100% yield)

Expected crop yields (represented by the 0.50 percentile based on the 100 WRPM stochastic runs) for the base-case scenario (i.e. status quo) in the Lower Riet Irrigation Block are shown in Figure 9.7. The five crops that maintain 100% yield over the 15 years of analysis in this worst affected irrigation block are, wheat, barley, pastures, cotton and vegetables (more specifically, garlic and peas).

The average expected yield over the 15 years from Figure 9.7 of the other major crops grown in the Lower Riet Irrigation Block are as follows:

- Maize	59%	- Soybeans	99%
- Lucerne	78%	- Sunflowers	99%
- Potatoes	60%	- Peanuts	45%

Beets in the base-case scenario refer to beet root while in scenario 3 it refers to a combination of beetroots and sugar-beet that has a higher salt tolerance. The 95% yield for beets shown in Figure 9.7 would therefore be 100% when modelled in scenario 3.

The average maize yield in Figure 9.7 is 59%, but if one looks at Figure 9.8 the 0.50 percentile also varies around 59% yield, while stochastic run 080 shows a higher level of fluctuation around 59% of between 56% and 64%. In a “good case” hydrology sequence, i.e. stochastic run 044, yield fluctuates between 59% and 90% of potential maximum yield, while in a “bad case” hydrology sequence, i.e. stochastic run 001, yield only fluctuates between 50% and 60%. The extreme yield fluctuations shown by the 0.05 and 0.95 percentiles show that there is a 95% probability that maize yield in the Lower Riet Irrigation Block will not exceed 80% and a 5% probability that yield will be lower than 48% of maximum potential yield.

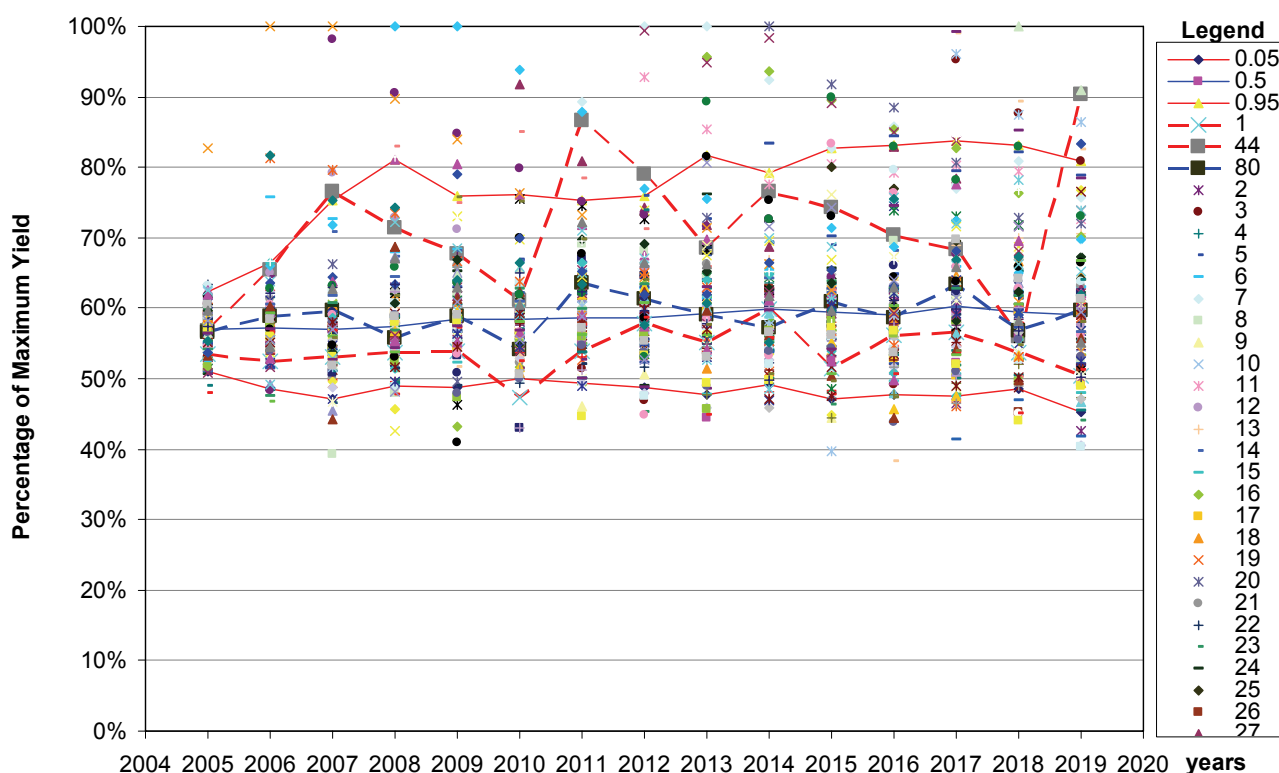


Figure 9.8. Stochastic spread of maize yield over 15 years in the Lower-Riet Irrigation Block

9.4. PER HECTARE LEVEL CROP ENTERPRISE BUDGET RESULTS

Crop enterprise budgets are set up for the 20 main irrigation crops in the study area on a per hectare basis with variation between irrigation blocks depending on:

- The average distance of the irrigation block from silos reflected in post harvest transport costs and influenced by crop yield
- The average distance of the irrigation block from an air field, factored into the aerial spraying costs of chemicals (GWK, 2005) influencing pre-harvest CEB costs
- The riskiness of crops grown in the different irrigation blocks as is reflected in the insurance costs supplied by GWK (2005)
- Water costs per irrigation block depend on the rates charged by the WUA and these are used in this study as supplied by GWK (2005)
- Electricity costs per irrigation block depend on the irrigation water volume pumped and are used in this study as supplied by GWK (2005)
- Yield variation between irrigation blocks are based on historical yields obtained from the OV- and OR-WUAs and GWK (2005) as well as expert opinion.

There are 80 (20 crops x 4 irrigation blocks) CEBs set up. For each of the 80 CEBs created there are a further 2 variations for Scenario 3 where 15% additional drainage is applied (reflected in increased irrigation water requirements), and scenario 3+ where the cost of the additional drainage is also factored into the cost of the irrigation water. The full set of these CEBs appear in Appendix 3. A simplified example, consisting of only 3 crops planted in the Lower Riet Irrigation Block follows.

9.4.1. PER HECTARE CROP GROSS MARGINS

In Table 9.1, the threshold values are adjusted according to the leaching percentages used in the WRPM setup. The corresponding increase in crop water requirements is updated accordingly. Where the cost of additional drainage is factored into the price of water as in Scenario 3+ the cost of water (R/mm/ha) is adjusted.

The yield reduction due to soil salinity as demonstrated in Figure 9.6 is factored into the CEB in Table 9.2 and the CEB re-calculated accordingly. At the average expected saturated soil salinity for the Lower Riet Irrigation Block, a TDS of 3120 mg/l (480 mS/m), direct returns to lucerne and maize are reduced from R5314 and R4312 to R3956 and R503 and wheat remains unchanged at R2177. The largest change in the CEB due to reduced yields is a reduction in gross income and also a reduction in harvesting costs. All other input costs remain unchanged as reflected in Figure 9.9.

Table 9.3 is a summary of the CEBs for different stochastic runs, leaching fractions and water costs in the RIoR, also showing the percentage change on a per hectare basis of the TGMASC of the Base-case versus Scenario 3 and Scenario 3+. Stochastic runs 001, 080 and 044 selected to represent the 0.05, 0.50 and 0.95 percentiles are compared to the 100% yield target. Lucerne shows a 25-, 36- and 41% and maize a 64-, 90- and 100% TGMASC reduction from the maximum TGMASC for stochastic runs 044, 080 and 001 respectively for the base-case where a return flow factor of 2% is applied.

Table 9.1. CEBs of 3 main crops, wheat, maize and lucerne in the Lower Riet Irrigation Block (RloR) calculated at maximum (target) yield using real 2005 data.

LOWER RIET	Unit	Lucerne	Maize	Wheat
ECe Threshold (BC, S1 and S2)	mS/m	204	173	612
ECe Gradient	%/mS/m	0.073	0.120	0.071
Crop water requirement	mm/ha	1 179	764	613
Crop Enterprise Budgets:		Lucerne	Maize	Wheat
PRICE	R/ton	552	832	1 208
Max Physiological yield	ton/ha	20.40	14.00	7.00
Modeled yield (max)	ton/ha	20.40	14.00	7.00
Gross income	R/ha	11 255	11 651	8 454
SEED	R/ha	375	1 080	756
FERT	R/ha	1 414	2 402	1 858
HERB	R/ha	165	277	84
PEST	R/ha	13	594	409
INSUR	R/ha	0	373	364
FUEL	R/ha	464	194	287
MAINT	R/ha	1 078	336	913
Temp LABOR	R/ha	0	0	0
WATER @ R 0.489 /mm	R/mm/ha	577	374	300
ELECT. @ R 0.677 /mm	R/mm/ha	798	517	415
HARVESTING COSTS	R/ton	44	71	103
HARVESTING COSTS	R/ha	899	996	723
Total expenses pre harvest	R/ha	4 883	6 147	5 386
Total expenses with max harvest	R/ha	5 783	7 143	6 109
Gross margin	R/ha	5 473	4 508	2 345
Co-op financed interest costs	R/ha	96	145	128
Bank financed interest costs	R/ha	63	52	40
<i>Total interest costs</i>	<i>R/ha</i>	<i>159</i>	<i>196</i>	<i>168</i>
TGMASC	R/ha	5 314	4 312	2 177

Table 9.2 CEBs of 3 main crops, wheat, maize and lucerne in the Lower Riet Irrigation Block (RloR) calculated at soil salinity EC_e = 480 mS/m (TDS = 3120 mg/l), using real 2005 data.

LOWER RIET	Unit	Lucerne	Maize	Wheat
ECe Threshold (BC, S1 and S2)	mS/m	204	173	612
ECe Gradient	%/mS/m	0.073	0.120	0.071
Crop water requirement	mm/ha	1 179	764	613
Crop Enterprise Budgets:		Lucerne	Maize	Wheat
PRICE	R/ton	552	832	1 208
Max Physiological yield	ton/ha	20.40	14.00	7.00
Modeled yield	ton/ha	16.29	8.85	7.00
Gross income	R/ha	8 988	7 364	8 454
SEED	R/ha	375	1 080	756
FERT	R/ha	1 414	2 402	1 858
HERB	R/ha	165	277	84
PEST	R/ha	13	594	409
INSUR	R/ha	0	373	364
FUEL	R/ha	464	194	287
MAINT	R/ha	1 078	336	913
Temp LABOR	R/ha	0	0	0
WATER @ R 0.489 /mm	R/mm/ha	577	374	300
ELECT. @ R 0.677 /mm	R/mm/ha	284	417	415
HARVESTING COSTS	R/ton	44	71	103
HARVESTING COSTS	R/ha	718	630	723
Total expenses pre harvest	R/ha	4 369	6 046	5 386
Total expenses with max harvest	R/ha	5 087	6 676	6 109
Gross margin	R/ha	3 901	688	2 345
Co-op financed interest costs	R/ha	96	145	128
Bank financed interest costs	R/ha	43	39	40
<i>Total interest costs</i>	<i>R/ha</i>	<i>140</i>	<i>184</i>	<i>168</i>
TGMASC	R/ha	3 761	504	2 177

Table 9.3. Base-Case (2% return-flow) vs. Scen3 (17% return-flow) vs. Scen3 + (water charge added) crop TGMASC for stochastic runs (SR) 001, 080 and 044 in the Lower Riet Irrigation Block (*RloR*) using real 2005 data

Scen.	Stochastic run	Lucerne TGMASC	Maize TGMASC	Wheat TGMASC	ECe (mS/m)	TDS (mg/l)	Leaching Return flow
S3 100%		6 224	4 789	2 177	170	1105	2%
BC,	SR 044	4 688	1 747	2 177	391	2542	2%
S1,	SR 080	3 956	503	2 177	480	3120	2%
S2	SR 001	3 669	14	2 177	515	3348	2%
	SR 044	4 465	1 973	2 132	391	2542	17%
S3	SR 080	3 734	728	2 132	480	3120	17%
	SR 001	3 446	239	2 132	515	3348	17%
	SR 044	3 407	1 287	1 582	391	2542	17%+WC
S3+	SR 080	2 676	43	1 582	480	3120	17%+WC
	SR 001	2 388	-447	1 582	515	3348	17%+WC
Percentage change from Scenario 3 (S3 100%)							
BC,	SR 044	-25%	-64%	0%	/ All 100%		2%
S1,	SR 080	-36%	-90%	0%	/ All 100%		2%
S2	SR 001	-41%	-100%	0%	/ All 100%		2%
	SR 044	-5%	13%	-2%	/ 2% leaching		17%
S3	SR 080	-6%	45%	-2%	/ 2% leaching		17%
	SR 001	-6%	1668%	-2%	/ 2% leaching		17%
	SR 044	-27%	-26%	-27%	/ 2% leaching		17%+WC
S3+	SR 080	-32%	-92%	-27%	/ 2% leaching		17%+WC
	SR 001	-35%	-3405%	-27%	/ 2% leaching		17%+WC

For Scenario 3, the return flow factor is increased by 0.15 to 17%. Compared to the Base-case scenario of 2% return flow, this results in a decrease in lucernes' TGMASC of 5% for stochastic run 044 and 6% for both stochastic runs 080 and 001. The cost of increased leaching for lucerne is not made up for by the resulting improved yield. For maize, the increased leaching however shows a 13-, 45- and 1668% increase from the base-case TGMASC for stochastic runs 044, 080 and 001 respectively. The increased water use for leaching results in the wheat TGMASC decreasing by 2%.

When factoring in the costs of additional drainage into the water charge, TGMASC for lucerne is decreased 27-, 32- and 35%, for maize decreased 26-, 92- and 3405% and for wheat by 27% for stochastic runs 044, 080 and 001 respectively, indicating a difficulty for farmers to afford the additional drainage costs, even though it may not be required by tolerant crops such as wheat. On a single crop, per ha basis the additional cost of drainage doesn't seem feasible, therefore it has to be calculated for a mix of crops over a series of years as appears in the following section.

9.5. IRRIGATION BLOCK LEVEL MICRO-ECONOMIC RESULTS

Figure 9.9 shows the sub-components of the base-case total annual CEB composition for the sum of all crops in the *RloR* Irrigation Block. These values are the sum of the CEB components over the areas planted to the specific crops. The breakdown of the CEBs at irrigation block level provides sectoral information to the macro model. As all crop input related factors that may impact yield are assumed optimum they remain constant, and only soil salinity impacts on yield. In Figure 9.9 it can clearly be seen that it is only harvesting costs and gross income that change as a result of yield changes, and subsequently impact on the total gross margin above specified costs (TGMASC).

Figure 9.10 shows the change in stochastic spread of annual TGMASC over 15 years, for all stochastic runs for the base case scenario for **RloR**. As time goes by, the possibility of a zero annual TGMASC increases, but also the probability of improved annual TGMASC. The trend in the 0.50 percentile TGMASC is slightly improving.

In Figure 9.11 the annual values of Figure 9.10 are added together to produce the cumulative TGMASC over 15 years. To use realistic data to fully capture the stochastic nature of the hydrology in the analyses that follow, stochastic runs 001, 080 and 044 were selected that most closely fitted the 0.05, 0.50 and 0.95 percentiles. Positive results stemming from Figure 9.11 are that even at the worst case sequence of hydrology events predicted for the Lower Riet Irrigation Block, the cumulative TGMASC still improves over time, although the annual TGMASC may only improve slightly. This shows that the system is in equilibrium and stabilised around the current farming and WUA management actions practised. The close fit of stochastic runs 001, 080 and 044 respectively to the 0.05, 0.50 and 0.95 percentiles in the cumulative TGMASC of Figure 9.11 is no longer as tight in Figure 9.12 (annual TGMASC), but provides more realistic dynamics in the results to be presented, than if the 0.05, 0.50 and 0.95 percentiles were used.

Stochastic run 044 in Figure 9.12 shows the massive changes that can be expected in TGMASC that a farmer will have to account for in his forward and cash flow planning. TGMASC can halve / double from one year to the next. Stochastic run 001 reflects a bad hydrology sequence that can result in zero TGMASC for some years (i.e. 1 in 15).

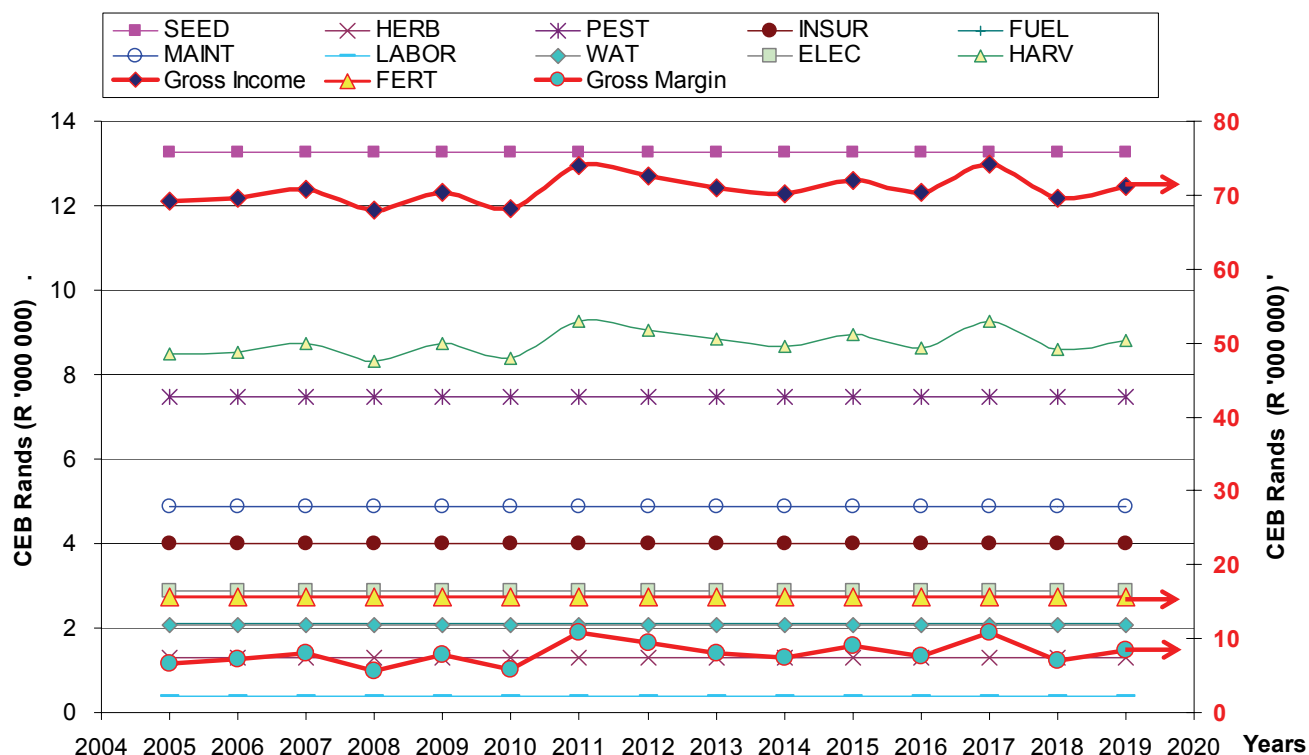


Figure 9.9. Base-case total annual CEB composition values for all crops in the RloR Irrigation Block for stochastic run 80 over 15 years

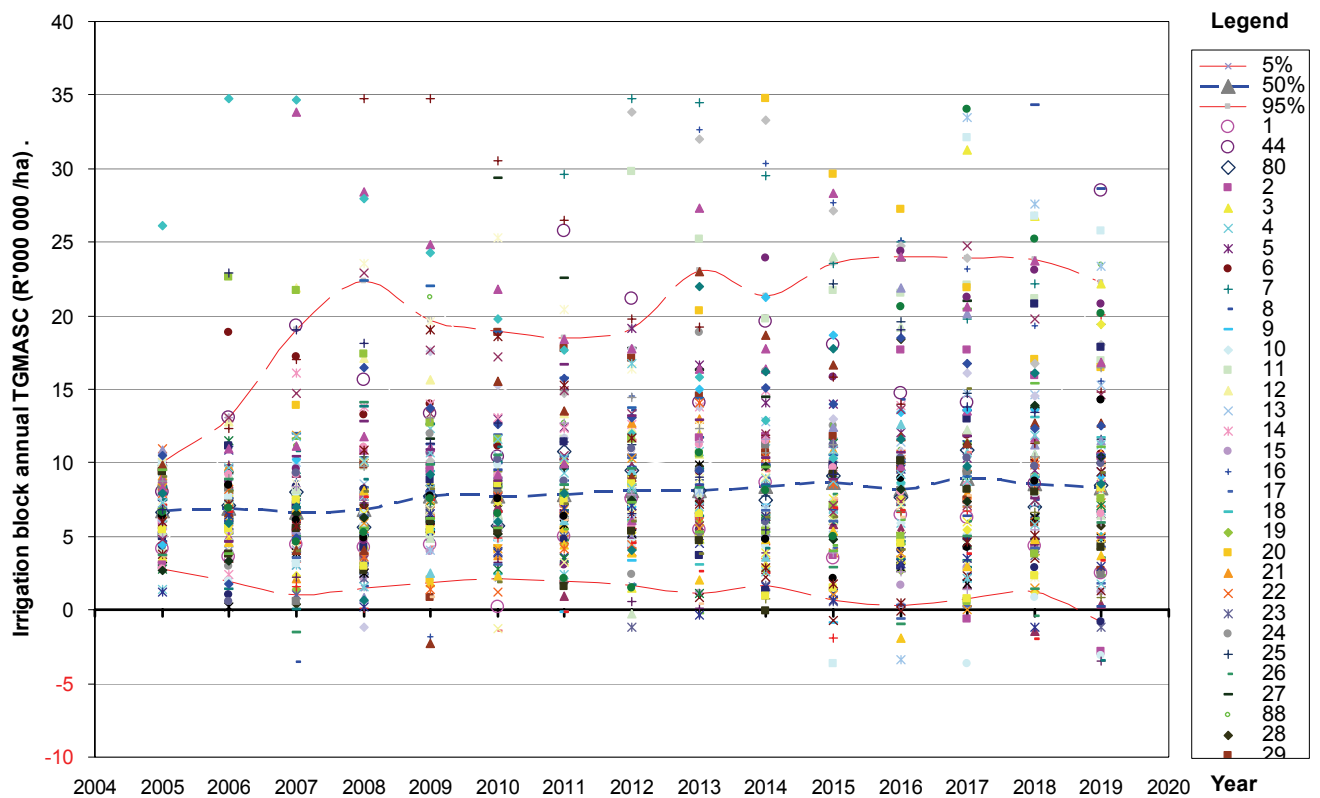


Figure 9.10. Base-case scenario annual TGMASCs (R' mil) for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles for 100 stochastic runs

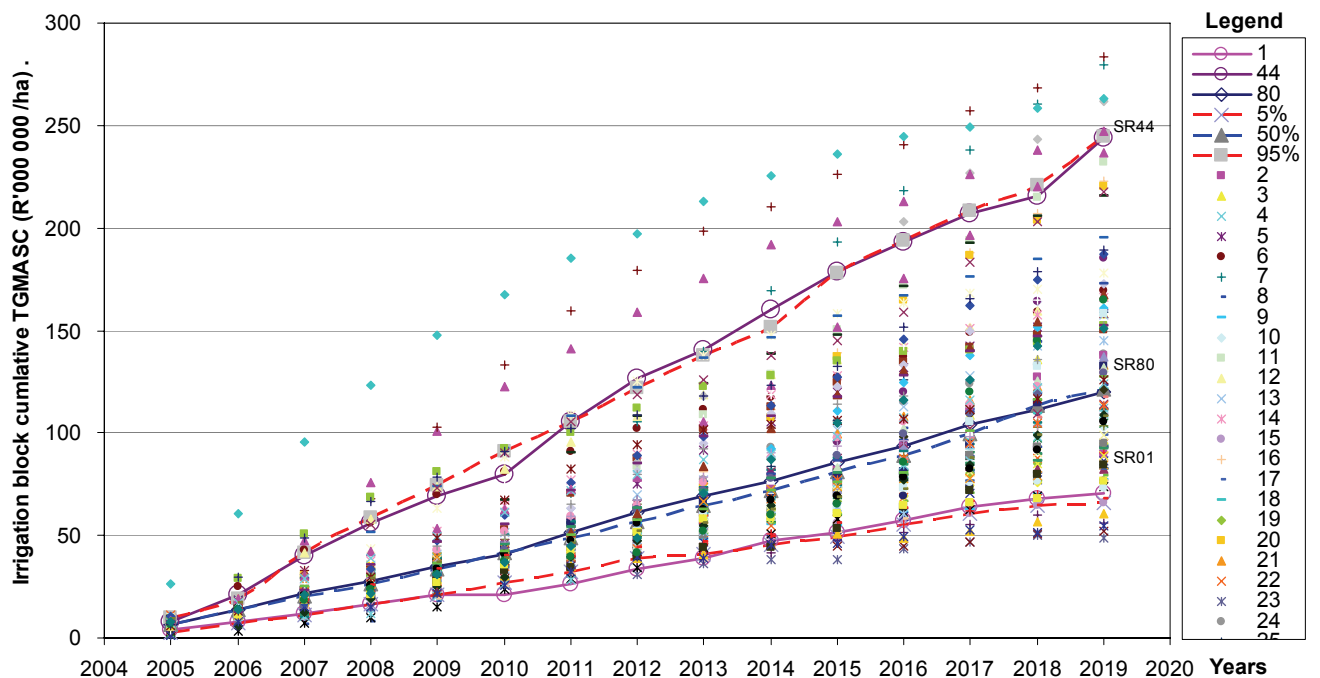


Figure 9.11. Base-case scenario cumulative annual TGMASCs (R'mil) for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles and most closely fitting stochastic runs 001, 080 and 044 respectively for 100 stochastic runs

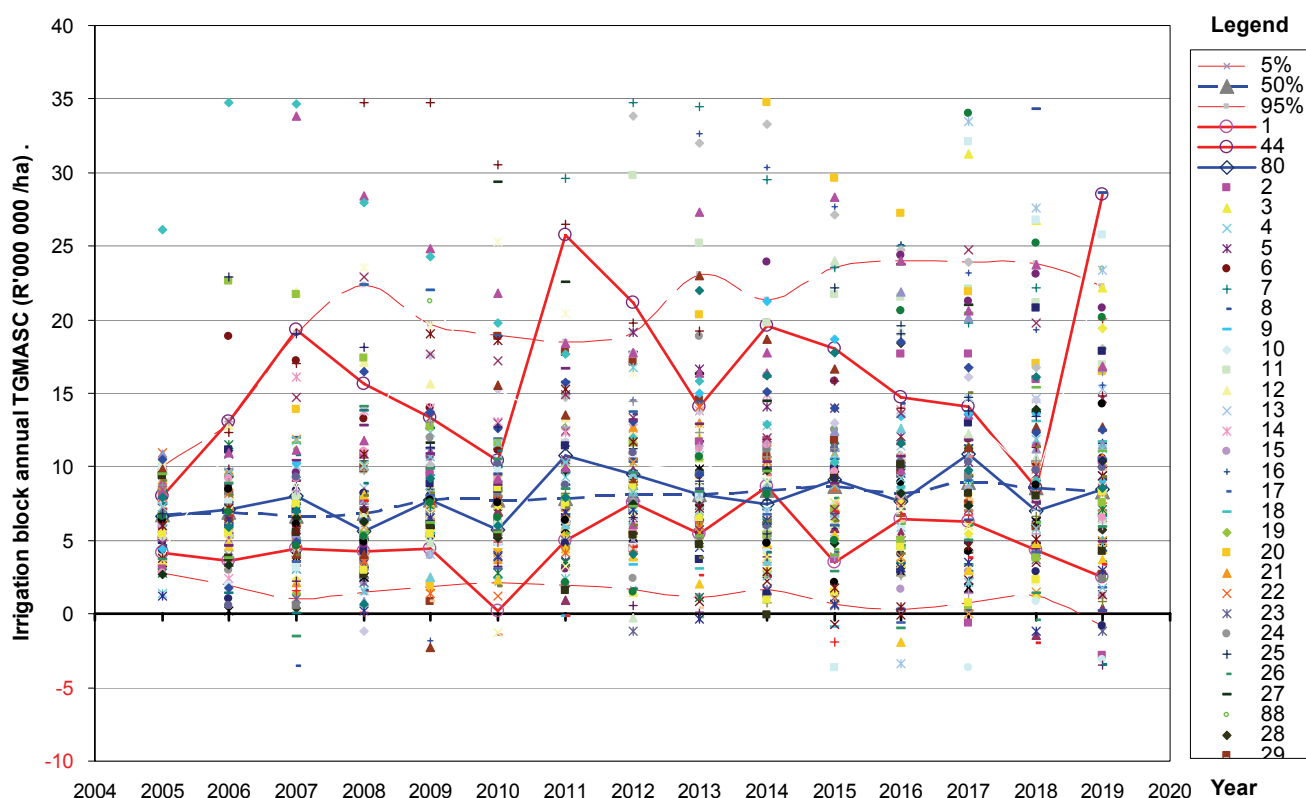


Figure 9.12 Base-case scenario annual TGMASCs (R' mil) at 2005 prices for the Lower Riet Irrigation Block showing the 0.05, 0.50 and 0.95 percentiles and corresponding selected stochastic runs 001, 080 and 044 respectively, for 100 stochastic runs.

9.6. WEIGHING UP THE SCENARIOS

9.6.1. IRRIGATION BLOCKS COMPARED

From the fifteen year cumulative TGMASCs presented In Table 9.4 for the base-case and scenarios 1 to 3, the total cost of salinity is calculated for each irrigation block. In Table 9.5 these costs are reduced to per hectare costs, by first dividing by 15 (the number of years) and then the number of hectares irrigated in the irrigation block, to make comparisons between irrigation blocks on an equal basis.

9.6.1.1. *Cost of salinisation*

Table 9.4 lists the fifteen-year cumulative TGMASC of each irrigation block for each scenario in millions of Rands (R'000 000). The base-case, representing the status quo, is subtracted from scenario 3 with yield forced to 100% (Scen3 100%Yield), representing a theoretical top level of productivity achievable without the constraint of salinity, to give an indication of the total cost of salinisation (net benefit forgone due to salinity). On a per hectare basis in Table 9.5 the greatest loss due to salinity is experienced in the Lower Riet Irrigation Block (**RloR**) to the value of R6962 per hectare per year, followed by Scholtzburg (**Rszg**) with R2596 and the Orange-Vaal Irrigation Block (**Vall**) with R2218. This can provide a farmer in the specific irrigation block with a good indication of the costs of poor drainage on his farm. At an average costs of drainage per ha on medium to heavy soils of R30 000 (Reinders, 2005 *personal communication*), a 15 year loan at 9% interest would cost R3722 per year to service – it would definitely be economical to spend in RloR, though not as convincing without

assistance grant in **Rszg** and **Vall**. Implemented for the whole study area (all irrigation blocks combined), the total real cost (2005 basis) of salinisation over a period of 15 years is R995 million, a good benchmark to use to leverage funds for remediation action.

Table 9.4. Cumulative 15 year annual average TGMASC (R'000 000) for all scenarios of all the irrigation blocks compared (real 2005 prices), based on 100 stochastic runs

	RloR	Rscm	Rszg	Vall	TOTAL	
<i>Ha</i>	3 853	12 335	641	7 390		
BaseCase	132.9	1 294.9	59.8	608.3	2 096	
Scen1	149.0	1 182.7	60.6	470.6	1 863	
Scen2	124.2	1 576.4	75.0	633.6	2 409	
Scen3	531.1	1 616.8	84.7	853.6	3 086	
Scen3+ drainage repay	476.4	1 576.5	82.5	815.8	2 951	
Scen3 100%Yield ¹	535.3	1 616.8	84.8	854.2	3 091	
Cost of salinity ('mil)	402.4	321.9	25.0	245.9	995	
% CHANGE from base						Change (R'mil)
Scen1	0.12	-0.09	0.01	-0.23	-0.11	-233
Scen2	-0.07	0.22	0.25	0.04	0.15	313
Scen3	3.00	0.25	0.42	0.40	0.47	990
Scen3+ drainage repay	2.58	0.22	0.38	0.34	0.41	855
Scen3 100%Yield ¹	3.03	0.25	0.42	0.40	0.47	995
Drainage repay impact	0.10	0.02	0.03	0.04	0.04	135

¹ The 100% yield scenario is a theoretical top benchmark used in calculating net benefit forgone

Table 9.5. Per hectare average annual TGMASC (R) for all scenarios of all the irrigation blocks compared (real 2005 prices), based on 100 stochastic runs

	RloR	Rscm	Rszg	Vall	TOTAL	
<i>Ha</i>	3853	12335	641	7390	24219	
BaseCase	2 299.9	6 998.3	6 215.6	5 488.2	5 769	
Scen1	2 577.4	6 391.9	6 295.7	4 246.0	5 128	
Scen2	2 148.8	8 520.1	7 793.7	5 716.3	6 632	
Scen3	9 190.4	8 738.1	8 811.0	7 701.2	8 496	
Scen3+ drainage repay	8 243.5	8 520.5	8 573.9	7 359.5	8 124	
Scen3 100%Yield ¹	9 262.3	8 738.1	8 812.0	7 706.7	8 509	
Cost of salinity (R / ha / yr)	6 962.4	1 739.8	2 596.3	2 218.4	2 739.3	
R/ha gain from leaching 15%	5 943.57	1 522.23	2 358.26	1 871.30	2 354.23	
Per ha annual cost of drainage (R/ha)	-946.97	-217.56	-237.13	-341.64	-371.97	
Soil Productivity gain (R/ha)	4 996.60	1 304.67	2 121.13	1 529.66	1 982.26	
% CHANGE from base case						Change (R/ha)
Scen1	0.12	-0.09	0.01	-0.23	-0.11	-642
Scen2	-0.07	0.22	0.25	0.04	0.15	862
Scen3	3.00	0.25	0.42	0.40	0.47	2 726
Scen3+ drainage repay	2.58	0.22	0.38	0.34	0.41	2 354
Scen3 100%Yield ¹	3.03	0.25	0.42	0.40	0.47	2 739
Drainage repay impact	0.10	0.02	0.03	0.04	0.04	371.97

¹ The 100% yield scenario is a theoretical top benchmark used in calculating net benefit forgone

9.6.1.2. Scenarios compared

In comparing the scenarios, the Base-Case is accepted as the status quo and percentage changes from the status quo are presented in the bottom half of Table 9.5 (these values are the same as in the bottom half of Table 9.4).

When planting the more salt tolerant cropping combination, as simulated in Scenario 1, it is only the **RloR** that shows a reasonable improvement from the Base-Case Scenario (12%). **Rszg** shows a minor improvement of 1%. The **Rscm** and **Vall** Irrigation Blocks show a 9% and 23% reduction in TGMASC (be it either the 15 year cumulative Table 9.4 or the per ha Table 9.5). Implemented for the whole study area (all irrigation blocks) the salt tolerant Scenario 1 results in a R233 million cumulative loss over the 15 years, and per hectare an average of R642 per year loss in Table 9.4 and Table 9.5 respectively, compared with the base-case scenario.

In Scenario 2, the implementation of a more salt sensitive yet higher value cropping combination, there is a 7% reduction for **RloR** from the Base-Case TGMASC to the Scen2 TGMASC, while for **Rscm** and **Rszg** there is a remarkable TGMASC improvement of 22% and 25% respectively, and a slight improvement of 4% for **Vall**. When implemented on the whole study area (all irrigation blocks) the salt sensitive yet higher value Scenario 2 results in a R313 million cumulative improvement over the 15 years, and per hectare an average of R862 per year improvement in Table 9.4 and Table 9.5 respectively, compared with the base-case scenario.

The implementation of the same more salt sensitive yet higher value cropping combination, but with 15% additional leaching and drainage in Scenario 3, results in a 300% improvement in the **RloR** TGMASC and a not as dramatic yet still marked improvement of 25%, 42% and 40% for the **Rscm**, **Rszg** and **Vall** respectively. This translates to a R990 million TGMASC cumulative improvement over the 15 years, and per hectare an average of R2726 per year improvement in Table 9.4 and Table 9.5 respectively, compared with the Base-Case Scenario. Internalising the cost of irrigation drainage in Scenario 3+ results in an 10% decrease in returns for the **RloR**, 2% for **Rscm**, 3% for **Rszg** and 4% for **Vall** when compared to Scenario 3 where the costs of additional drainage is not included.

A final scenario is run in the economic model (Scen3 100%Yield) where all yield is set at maximum (100%) yield levels (i.e. cancelling out the impact of salinity) to give maximum TGMASC values. These values are used to calculate the total cost of salinity (net benefit forgone), all other factors of production being optimal.

The deduction from this analysis is that each irrigation block is very sensitive to a specific salinity threshold level (dependant of cropping combination) and therefore not all irrigation blocks should be treated the same. Only **RloR** benefited slightly from planting crops that are more tolerant as its soil salinity threshold had been exceeded by the Base-Case cropping composition. Increased drainage and leaching however proved to be far more financially effective than planting tolerant crops. Furthermore, the return-flow externality effects of **RloR** on **Vall** downstream do not have a major impact when **Vall** is also drained, as indicated by far better results in **Vall** as well.

9.6.1.3. Water use changes

The cropping combinations selected for Scenarios 1 and 2 all result in a decrease in water use when compared to the Base-Case Scenario shown in Table 9.6, but with the additional leaching required in Scenario 3, which has the same cropping choice as Scenario 2, the total annual water requirements (m^3) exceed the Base-Case

water requirements. The additional water required for drainage however is a non-consumptive use and most of it ends up back in the river again, less wastage and loss. The impact of the increased salt load from additional leaching is factored into the whole hydrology system in the WRPM.

Table 9.6. Average annual irrigation water use and percentage changes (m³) across irrigation blocks for the different scenarios modelled, based on 100 stochastic runs

	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	Total
Base-case	4 881 786	14 836 968	762 149	8 506 028	28 986 931
Scen1	4 276 398	15 001 319	767 091	7 075 078	27 119 885
Scen2	4 664 869	14 734 871	758 668	7 933 108	28 091 516
Scen3	5 350 879	16 912 438	869 692	9 071 832	32 204 842¹
% CHANGE from Base-case in water use					
Scen1	-0.12	0.01	0.01	-0.17	-0.06
Scen2	-0.04	-0.01	-0.00	-0.07	-0.03
Scen3	0.10	0.14	0.14	0.07	0.11 ¹

¹Although there is an 11% increase in water use for Scenario 3, this is due to additional water required for leaching, and is a non consumptive use of the water – a large portion of this additional water returns to the river as a point source irrigation drainage return flow

9.6.1.4. Land and Water use productivity and risk between irrigation blocks

Land use and irrigation water use productivity is shown in Figure 9.13 and Figure 9.14 for all irrigation blocks and all scenarios. In both Figure 9.13 and Figure 9.14, the four graphs on the left are the land use productivity expressed as the TGMASC per hectare per year (R/ha/yr) and the four graphs on the right the water use productivity expressed as the TGMASC per millimetre water requirement per hectare per year (R/mm/ha/yr). To achieve these results, the irrigation water use productivity is calculated from the 15 year cumulative TGMASC per block (R), divided by the block area (ha), divided by 15 years (yr), divided by the weighted average crop water use (mm/ha). Land productivity is calculated the same except that the weighted average crop water use is not included.

In Figure 9.13 the slope of the cumulative probability function indicates the spread of possible results; the more horizontal the spread the more risky an option. Planting more salt tolerant crops in scenario 1 did reduce the risk slightly for all blocks, but only improved the results in **RloR**. Scenario 3, where additional drainage and leaching is implemented, clearly shows nearly vertical curves. In Figure 9.14, the greater the spread between the tops of the 0.05, 0.50 and 0.95 percentile bars, the greater the spread of risk. Once again, Scenario 3, where additional drainage and leaching is implemented, clearly shows almost level bar tops, indicating a very stable return per hectare and per millimetre water used. Figure 9.13 and Figure 9.14 clearly show that to reduce the risk of income loss due to irrigation salinity one has to install drainage and leach more.

For the Base-Case and Scenarios 1 and 2 in Figure 9.13 and Figure 9.14, the same pattern generally occurs and the irrigation blocks have the same order of riskiness. With the salt tolerant cropping choice, namely Scenario 2, **Rscm** and **Rszg** present very similar curves. **RloR** remains the block with the most risk and lowest results followed by **Vall**, then **Rszg** and least risky and highest yielding is **Rscm**. In Scenario 3 however, where additional drainage and leaching is implemented, **RloR**, moves from having the lowest land and water factor productivity (and greatest risk), to producing the best results. Even the 0.05 percentile yields better than the other irrigation blocks. The small spread in the **RloR** land factor productivity of Scenario 3 indicates a further small increase in drainage could still be implemented to further reduce risk and possibly improve results.

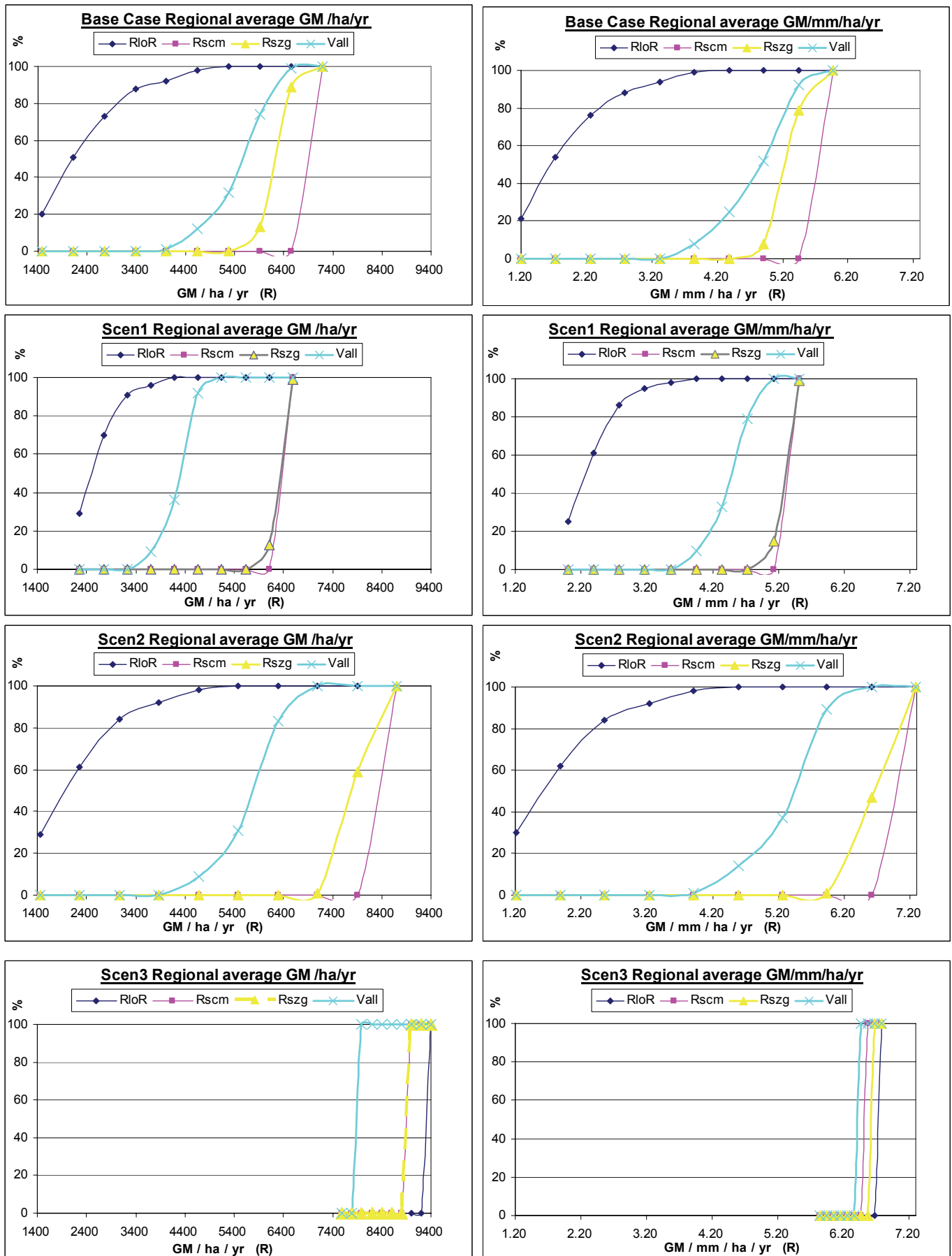


Figure 9.13. Land (R/ha/yr) and water (R/mm/ha/yr) productivity and cumulative probability functions based on 2005 prices (GM=TGMASC in this graph) for different scenarios based on 100 stochastic runs

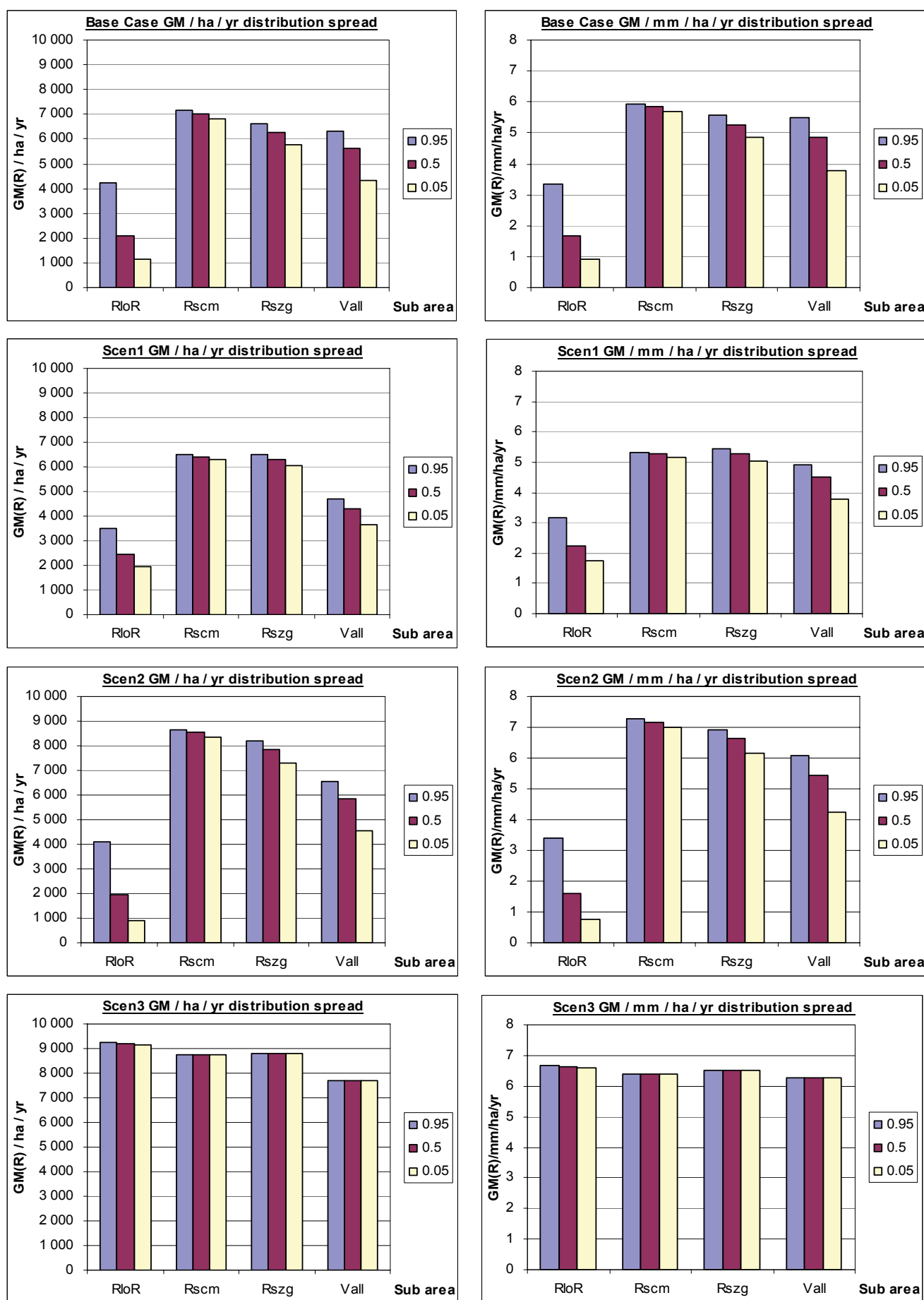


Figure 9.14. Land (R/ha/yr) and water (R/mm/ha/yr) productivity percentile spreads per irrigation block based on 2005 prices (GM=TGMASC in this graph) for different scenarios based on 100 stochastic runs

Table 9.7 is a summary of the results discussed in this chapter using the 0.50 percentile, with an elaboration using stochastic runs 001, 080 and 044 to represent realistic hydrology sequences most closely fitting the 0.05, 0.50 and 0.95 percentiles to try capture the whole spectrum of stochastic results using only 3 instead of 100 stochastic runs. Only the main results from Figure 9.7 are discussed further.

Interesting results from the Scenario 1 change from the base-case (Scen1 % CHANGE from base) is that for stochastic run 001 (5% probability), the planting of a more salt tolerant cropping combination leads to a 66% increase in TGMASC for **RloR**. Stochastic run 080 (50% probability) improves only 23% and run 044 (95% probability that it could be worse) results in a 24% decrease from the base-case results. In the other irrigation blocks it is only **Rszg** that shows a minor 1% improvement at 0.05 percentile level simulated by stochastic run 001. In the Scen2 % change from base, where more salt sensitive crops, yet higher values crops are planted (without additional leaching) **RloR** shows a TGMASC decrease, indicating that the crop combination salinity threshold has been exceeded and the increased returns do not make up for the reduced yields.

Table 9.7. A summary of various SMSim model results comparing stochastic runs 001, 080 and 044 and the 0.50 percentile value of the 100 stochastic runs (2005 prices)

Base Case 15yr cumulative TGMASC (R'000 000)						Scen1 % CHANGE from base						Change (R'mil)
	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>		<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>	
0.50%	133	1 295	60	608	2 096	0.50%	0.12	-0.09	0.01	-0.23	-0.11	-233
001	71	1 290	56	625	2 043	001	0.68	-0.08	0.06	-0.24	-0.10	-207
080	120	1 264	62	548	1 994	080	0.24	-0.08	-0.01	-0.20	-0.09	-183
044	244	1 329	64	615	2 252	044	-0.24	-0.09	-0.03	-0.23	-0.15	-327
Total Cost of salinity (R 'mil)						Scen2 % CHANGE from base						Change (R'mil)
	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>		<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>	
0.50%	402	322	25	246	995	0.50%	-0.07	0.22	0.25	0.04	0.15	313
001	465	326	29	229	1 048	001	-0.16	0.22	0.28	0.04	0.15	312
080	416	353	23	307	1 097	080	-0.05	0.22	0.24	0.05	0.16	313
044	291	288	21	239	839	044	-0.03	0.21	0.25	0.04	0.14	313
Cost of salinity (R / ha / yr)						Scen3 % CHANGE from base						Change (R'mil)
	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>		<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>	
0.50%	6 962	1 740	2 596	2 218	2 739	0.50%	3.01	0.25	0.42	0.41	0.48	999
001	8 040	1 764	2 968	2 065	2 886	001	6.53	0.26	0.51	0.37	0.51	1 052
080	7 190	1 905	2 364	2 766	3 021	080	3.44	0.28	0.37	0.56	0.55	1 101
044	5 036	1 557	2 132	2 158	2 309	044	1.18	0.22	0.32	0.39	0.37	844
R/ha gain from leaching 15%						Scen3+ % CHANGE from base						Change (R'mil)
	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>		<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>	
0.50%	5 944	1 522	2 358	1 871	2 354	0.50%	2.58	0.22	0.38	0.34	0.41	855
001	7 009	1 546	2 729	1 719	2 499	001	5.73	0.22	0.47	0.30	0.44	908
080	6 165	1 688	2 126	2 422	2 636	080	2.97	0.25	0.33	0.49	0.48	958
044	4 030	1 339	1 894	1 809	1 925	044	0.95	0.19	0.28	0.33	0.31	699
Soil Productivity gain (R/ha)						Scen3 100% CHANGE from base						Change (R'mil)
	<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>		<i>RloR</i>	<i>Rscm</i>	<i>Rszg</i>	<i>Vall</i>	<i>Ave.</i>	
0.50%	4 997	1 305	2 121	1 530	1 982	0.50%	3.03	0.25	0.42	0.40	0.47	995
001	6 060	1 328	2 492	1 378	2 127	001	6.58	0.25	0.51	0.37	0.51	1 048
080	5 222	1 470	1 888	2 080	2 264	080	3.47	0.28	0.37	0.56	0.55	1 097
044	3 081	1 122	1 657	1 467	1 553	044	1.19	0.22	0.32	0.39	0.37	839

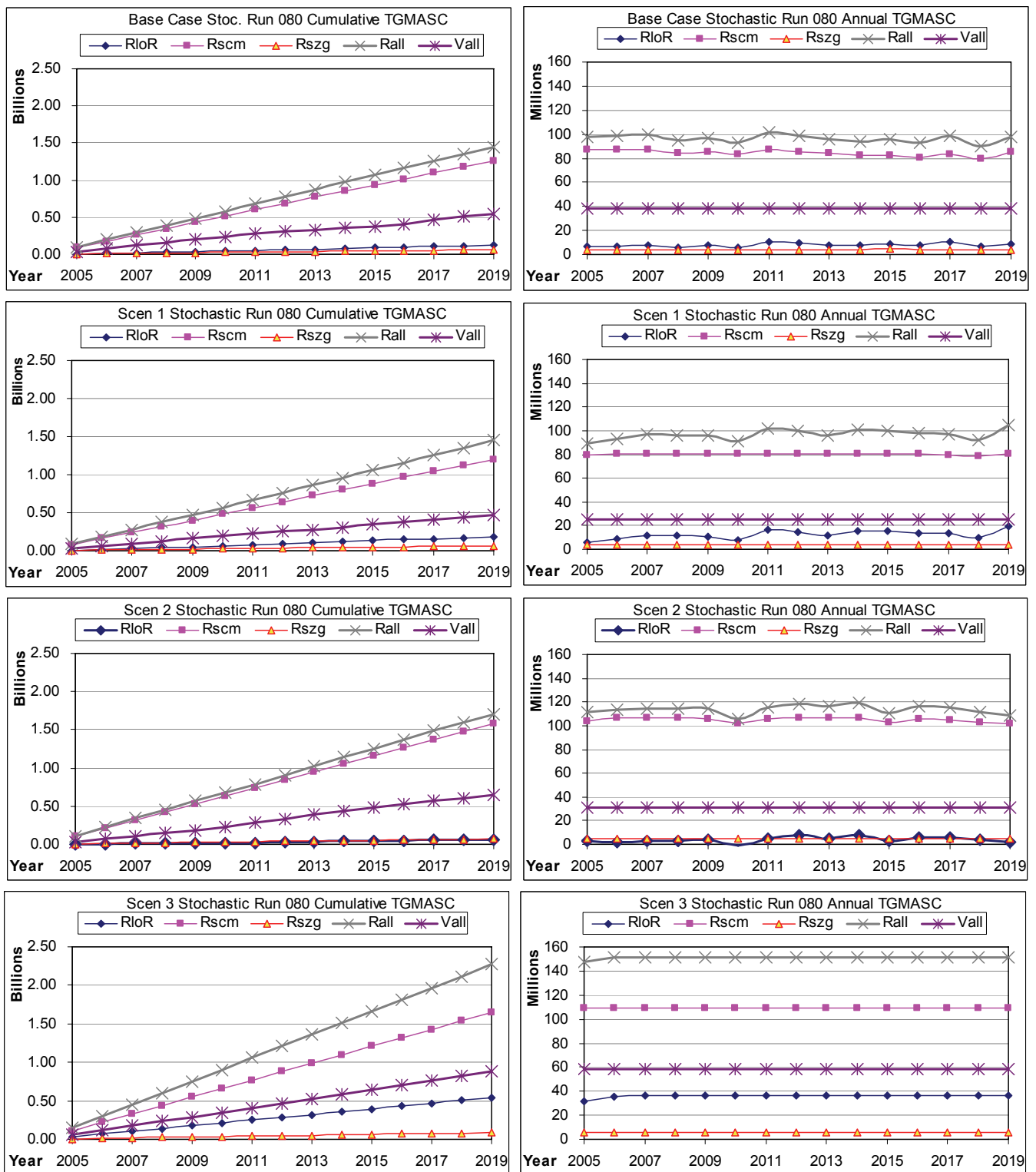


Figure 9.15. OV-WUA (*Vall*) versus OR-WUA (*Rall*) annual and 15 year cumulative average TGMASCs (2005 prices) for stochastic run 80

9.7. WUA LEVEL RESULTS

The Lower-Riet (**RloR**), Riet Scheme (**Rscm**) and Scholtzburg (**Rszg**) Irrigation Blocks together form the Orange-Riet WUA level results to compare directly with the Vaal Irrigation Block (**Vall**) that represents most of the Orange-Vaal WUA. Excluded in the Vaal Irrigation Block (**Vall**) from the Orange-Vaal WUA, due to the set-up in the Hydrology model WRPM, is the area irrigated directly from out of the Orange River, as from the Hydrology model perspective, this forms part of another irrigation block. **Vall** therefore only represents about 85% of the whole Orange-Vaal WUA.

Figure 9.15 shows the annual (right) and cumulative (left) TGMASC for the irrigation blocks **RloR**, **Rscm** and **Rszg** combined to make up the OR-WUA (**Rall**). This is compared to the **Vall** Irrigation Block, representing the OV-WUA. Results show that all the Orange-Riet WUA Irrigation Blocks together (**Rall**) and its main sub-block **Rscm** outperform **Vall** in total magnitude for all scenarios. Also evident from the graphs on the right is that for the **RloR** (and its impact in **Rall**) the Base-Case Scenario fluctuates the most, followed by Scenario 2, then Scenario 1, with Scenario 3 being the most stable (i.e. least risk). The other irrigation blocks are more stable, with the exception of **Rscm** that shows a decline for Scenarios 1 and 2. Important to note is that although the cumulative graph may be showing an increasing trend, the annual graph may be remaining constant or decreasing, as is the case with Scenario 2, showing possible diminishing marginal TGMASC.

9.8. LINKAGES TO THE REGIONAL ECONOMIC MODEL

9.8.1. MICRO-MACRO LINKAGES

This data linking the micro and macro (regional) models consists of the irrigation block level individual crop CEB breakdown data, such as the results data used to set up Figure 9.9. For the macro-economic model only the 0.50 percentile and stochastic runs 001, 080 and 044 are generated and saved as an output file [Scen...SR...SMmicro-out.xls](#) for use in the regional model.

9.8.2. INDEX FOR SOCIO ECONOMIC WELFARE (ISEW)

The index for socio economic welfare (ISEW) is explained in full in Chapter 7, but a brief description of the data required follows. The economic leg of the three pillars on which the sustainability of the scheme rests and as calculated in the ISEW is calculated from the year to year change in gross production value from the micro-economic model SMSim. The social leg is calculated from the year to year change in the value of temporary employment calculated in the micro-economic model SMSim, and the environmental leg is calculated from the year on year salt balance for each scenario.

9.8.2.1. Economic leg – change in gross production

The total value of production component (e.g. see Figure 9.9 – GROSS INCOME) of the per-hectare CEB combinations for the different scenarios is carried through from per hectare to irrigation block level changes and saved as inputs for the regional economic model.

9.8.2.2. Social leg – change in temporary employment

Changes in the temporary employment component (e.g. see Figure 9.9 - LABOUR) of the per hectare CEB combinations for the different scenarios are carried through from per hectare to irrigation block level changes and saved as inputs for the regional economic model.

9.8.2.3. Environmental leg – change in salt accumulation

Figure 9.16 is an example of the processed WRPM Salt abstraction, SA and return-flow, SR mass data (tonnes) that is saved as input for the regional economic model for use in the calculation of the Index for Social Economic Welfare, ISEW. Figure 9.16 shows that for the base-case scenario in **Vall** SA and SR slightly decline over 15 years resulting in a salt balance that increases over time, indicating increased salinisation for the status quo and therefore an un-sustainable situation.

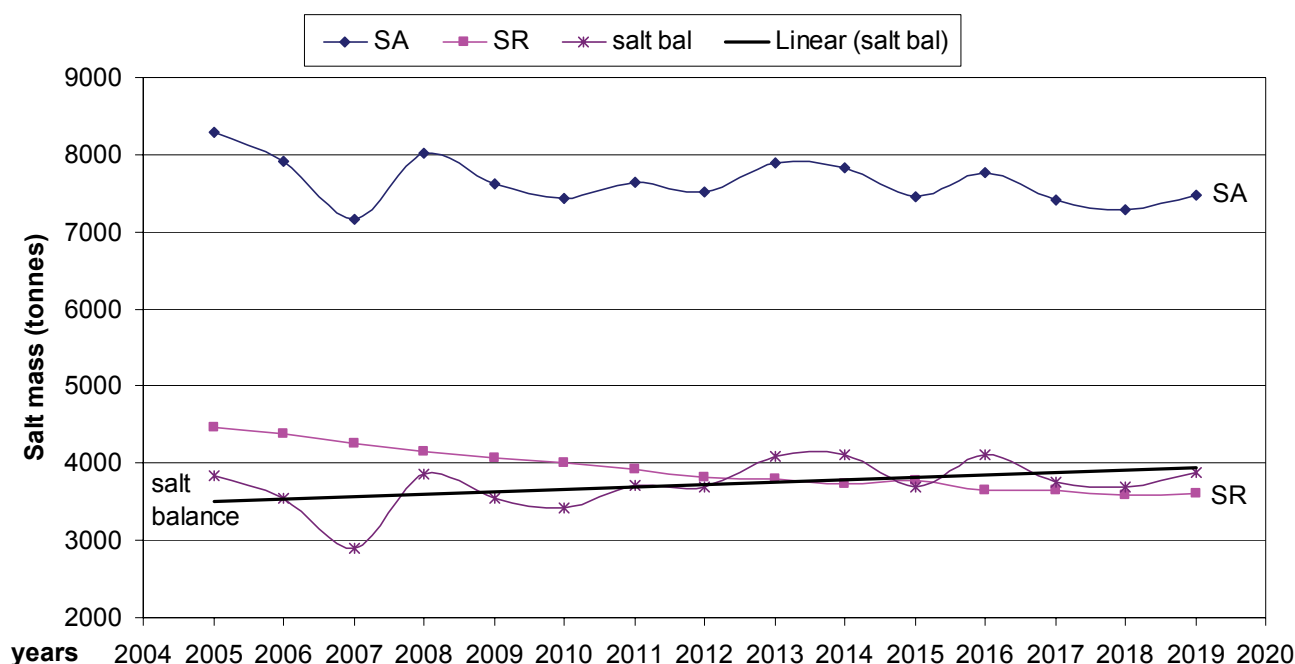


Figure 9.16. The salt mass balance (tonnes) calculated from the Vall base-case irrigation abstraction mass, SA(tonnes) minus the return-flow mass, SR (tonnes).

Figure 9.17 shows the resulting salt balance (tonnes) of the salt mass in the abstractions (**SA**) minus the salt mass in the returnflows (**SR**) of scenario 3 in the **RloR** Irrigation Block. With a greater mass of salts entering the **RloR** Irrigation Block than that leaving, there is an increase in the salt mass remaining in the soil in the irrigation block, even after 15 years when an equilibrium is reached, and is therefore not sustainable. The whole **Rscm** and **Rszg** is upstream from **RloR** and 15% increased drainage has also been implemented there, therefore possibly the reason for the prolonged salt accumulation. The declining salt balance values (Sbal) in the first 3 years indicate more salt are being washed out in the first three years after increasing returnflows by increasing drainage and leaching, but the salt balance returns to the initial levels after 15 years (2020 minus 2005) as equilibrium is reached again.

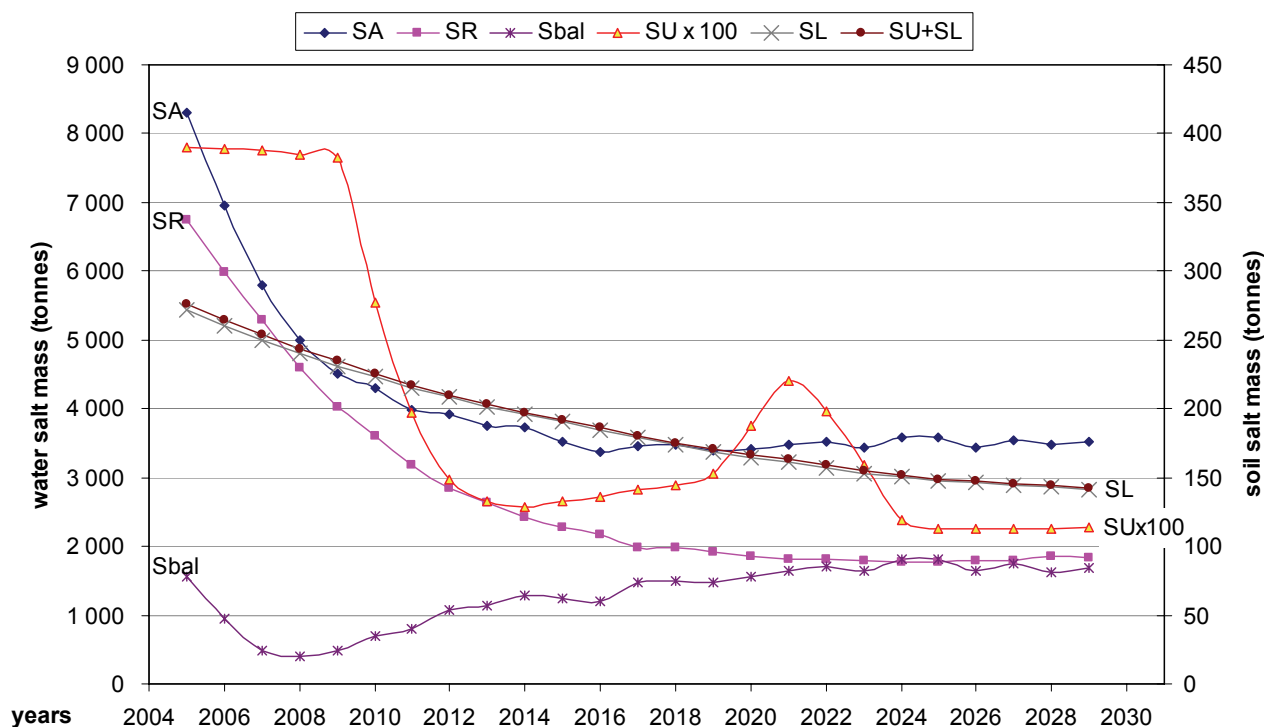


Figure 9.17. The salt mass balance (Sbal in tonnes) from irrigation abstraction (SA) minus returnflows (SR) for Scenario 3 in RLoR

With the change in the hydrology dynamics brought about by the 15% increased leaching and drainage as simulated in Scenario 3, a large mass of salts is initially drained from the soils and a new equilibrium reached at approximately 2000 tonnes of return-flow mass after 10 years (2015). The full 25 years of stochastic data generated by the WRPM model is used here to show the longer-term trends than the 15 years of analysis in this study to confirm that a new equilibrium is in fact reached after 15 years and that the decreasing trend doesn't continue.

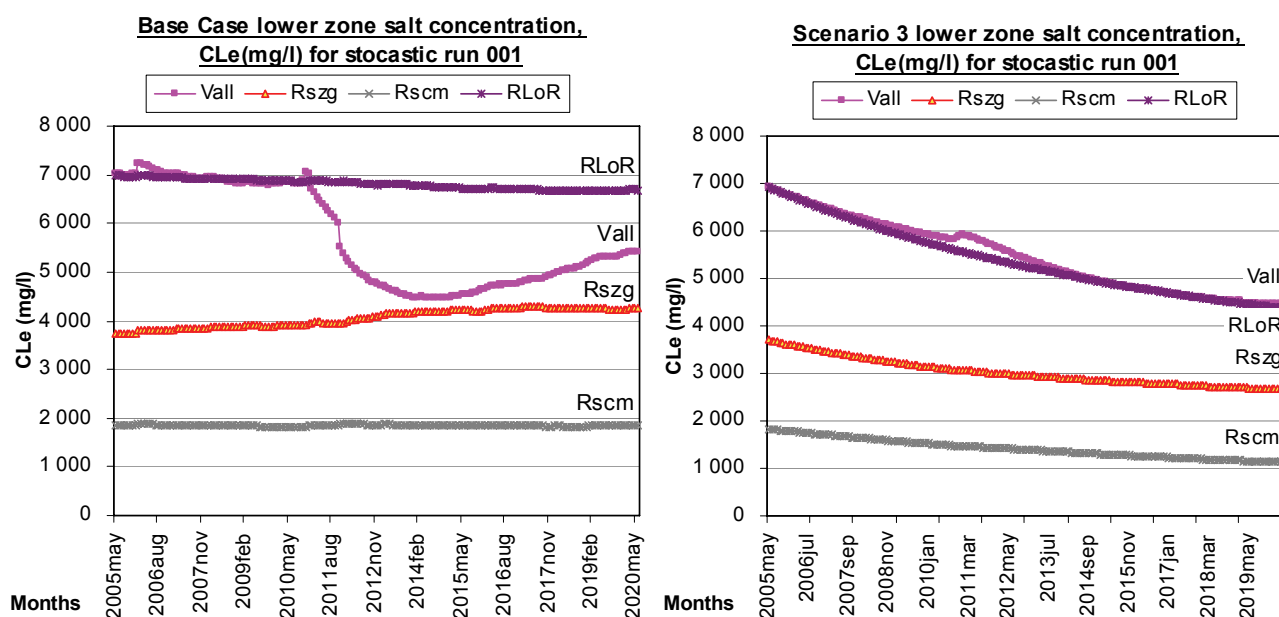


Figure 9.18. The impact of increased drainage on the lower zone salinity concentration, CLe(mg/l) – Base-case vs. Scenario 3.

To be analysed together with Figure 9.16 and Figure 9.17 is Figure 9.18 that shows the salinity concentration in the lower zone for the different irrigation blocks, and compares the Base-Case situation with 15% increased return-flow modelled in Scenario 3. Figure 9.18 shows that for the Base-Case, salt concentration in the lower zone remains fairly constant, except for drastic changes as with **Vall** triggered in year 2010 resulting in a sharp drop, but thereafter heading back towards the initial level at a relatively long lag-time. Scenario 3 on the right however shows a constant gradual washing out of salts over 15 year after which there seems to be a flattening out towards a new equilibrium level. These large masses of salts initially washing out with Scenario 3 explain the high returnflows in Figure 9.17.

9.9. SUMMARY

The hydrology results show that the Lower Riet Irrigation Block (**RloR**) has the highest soil salt concentration in the upper zone, CU (mg/l) followed by the Orange-Vaal Irrigation Block (**Vall**), The Scholtzburg Irrigation Block (**Rszg**) with the lowest soil salt concentration in the Orange-Riet Scheme Irrigation Block (**Rscm**).

In comparing the hydrology results from the different scenarios run, changing the cropping choice from the status quo (base-case scenario) to more tolerant crops (Scenario 1) to more salt sensitive yet higher value crops (Scenario 2) has very little impact on the hydrology results. Though changing the return flow factor by increasing leaching and drainage, has a major impact on the hydrology by bringing the CU (mg/l) down substantially in the irrigation blocks. Hydrology results also show that the greatest variation, and highest values, in monthly irrigation water salt concentration and TDS (mg/l) occur in the months from April to August being worst from May to July. This indicates that salt sensitive crops grown or germinating during these months will be worst off than crops grown and germinating in the other months, i.e. spring and summer month crops.

Running the hydrology results through the bio-physical model converts the soil salt concentration, CU (mg/l) to CUE (mg/l), the saturated soil salt concentration. CUE is multiplied by the electrical conductivity factor to produce ECE (mS/m) and this is run through the Maas and Hoffmann equation to give the impact of soil salinity on crop yield. Results showed that in the irrigation blocks where the CU is highest, there crop yields are worst affected.

These changes in crop yield are then run through the micro-economic model to first produce per hectare crop enterprise budgets (CEBs) which are then extrapolated to irrigation block level.

On a per hectare basis (as shown in Table 9.5) the greatest financial loss (2005 values) due to salinity is experienced in the Lower Riet Irrigation Block (**RloR**), to the value of R6962 per hectare per year, followed by Scholtzburg (**Rszg**) with R2596 and the Orange-Vaal Irrigation Block (**Vall**) with R2218. This provides the farmer in the specific irrigation block with a good indication of the per hectare costs (net benefit forgone) of poor drainage on his farm. At an average costs of drainage per ha on medium to heavy soils of R30 000¹⁶ (Reinders, 2005), a 15 year loan at 9% interest would cost R3722 per year to service – worth spending in **RloR**, though not as convincing without a funding grant in **Rszg** and **Vall**.

¹⁶ Note: drainage costs can range from R12000-R15000 on sandy soils (<15% clay), R20000-R25000 on medium soils (15-35% clay), and R30000-R50000 on heavy soils (>35% clay) – see Table 6.3.

Implemented for the whole study area (all irrigation blocks combined), the total real cumulative cost (2005 basis) of salinisation over a period of 15 years is R995 million, a good benchmark to use to leverage funds for remediation action.

Figure 9.13 and Figure 9.14 clearly show that to reduce the risk of income loss due to irrigation salinity one has to install drainage and leach more.

The conclusion is that an irrigation block is very sensitive to a specific salinity threshold level and therefore all irrigation blocks should not be treated the same. Only **RloR** benefited slightly from planting more tolerant crops as its soil salinity threshold is exceeded by the base-case cropping composition. Increased drainage and leaching however proved to be far more financially effective than planting tolerant crops, and the return-flow externality effects are more than compensated for as **Vall** downstream also achieved far better results when it is also drained.

Comparing the Orange-Vaal WUA (**Vall**) and Orange Riet-WUA (**Rall**), the **Rall** naturally did better in absolute terms as it is nearly twice the size of the **Vall**, but although the worst Irrigation Block (**RloR**) is part of **Rall**, its TGMASC improved at a better rate than **Vall** over the 15 years of analysis.

Results processed by the micro economic model SMSim, to be used in the macro model are also briefly discussed, but is overed in full in the chapter that follows.

CHAPTER 10. REGIONAL MODEL RESULTS

by Oberholzer J.L., Van der Merwe, B.J. and Pienaar, G.J – Urban-Econ: Development Economists

10.1. INTRODUCTION

The aim of this section is to determine the regional economic impacts of the five different scenarios developed for the study (described in Chapter 8) by applying the economic modelling techniques described in Chapter 7, being the Input-Output (I/O) Modelling techniques and the Index for Sustainable Economic Welfare (ISEW). More specifically, the following issues are addressed:

- Determination and evaluation of the direct effect of the different scenarios on the agricultural sector in the study area
- Assessment of the broader regional economic impacts of the scenarios and sectoral linkages
- Assessment of the regional impact in terms of employment creation
- Evaluation of the long-term effect that the scenarios will have on the sustainability of the region

The detailed analysis of the results explained in this section is provided in Appendix 5.

10.2. BASE CASE SCENARIO

The Base Case Scenario represents the current situation with regards to the salinisation of agricultural soil in the study area, with 2005 as the base case. The scenario considers the effects that these levels of salinity will have on the regional economy for the projection period of 2005 to 2019.

The following set of tables and figures depict the results of these projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80. These represent actual events that closely resemble the 0.05, 0.5 and 0.95 percentiles that were compiled over a total of 100 stochastic runs. The following results were obtained from the Micro Model and used as inputs in the ISIM.MACRO model (the Regional Economic Model).

10.2.1. MODEL INPUT DATA: BASE CASE SCENARIO

Table 10.1. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80 and 50% percentile)

Stochastic Run Number	
1	431 550 445 516 439 949 444 518 439 156 429 832 459 632 465 730 460 552 458 447 438 760 451 374 443 307 435 788 435 417
44	442 923 455 153 476 099 477 738 470 090 453 970 475 757 457 338 434 038 466 475 473 985 460 059 456 593 450 823 485 322
80	442 714 446 245 449 865 444 571 448 083 443 141 454 134 450 074 446 693 443 223 445 130 441 619 449 711 440 138 449 015
50% percentile	442 613 446 329 448 583 449 688 451 123 450 576 451 407 450 649 451 461 450 228 449 275 450 422 452 270 451 665 450 704

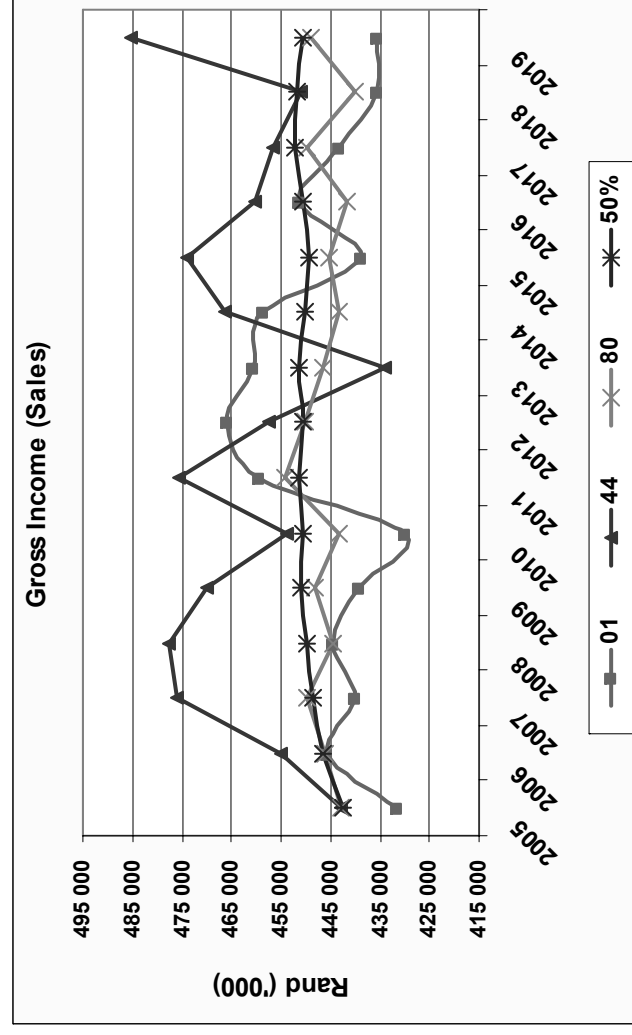


Figure 10.1. Gross Income per year, 2005 to 2019 (Stochastic runs 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

Table 10.2. Projected Gross Margins (R'000), 2005 – 2019

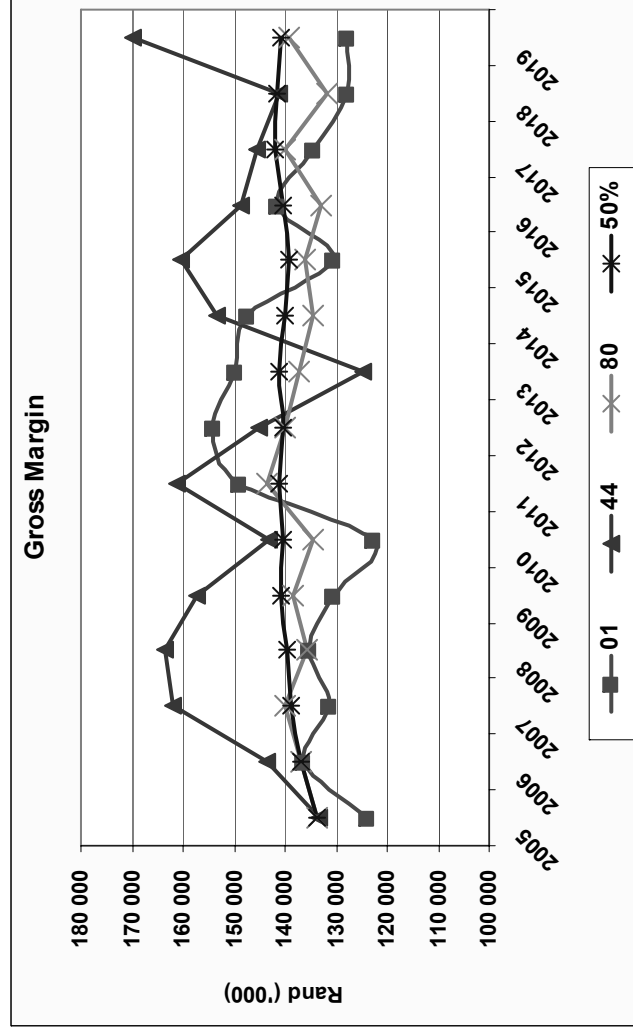
[illegible]

Figure 10.2. Gross margins, 2005 to 2019 (Stochastic runs 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

10.2.2. REGIONAL MODEL RESULTS

10.2.2.1. Regional Economic Impact

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GDP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table 10.3. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

Stochastic Run Number															
1	784 274	809 655	799 539	807 841	798 096	781 152	835 308	846 391	836 980	833 155	797 378	820 300	805 641	791 976	791 301
44	804 943	827 168	865 234	868 213	854 313	825 018	864 613	831 140	788 795	847 745	861 393	836 085	829 785	819 299	881 996
80	804 563	810 979	817 559	807 937	814 321	805 339	825 317	817 938	811 793	805 488	808 953	802 572	817 279	799 882	816 013
50% percentile	804 379	811 132	815 230	817 237	819 845	818 850	820 360	818 984	820 459	818 219	816 486	818 572	821 930	820 830	819 084

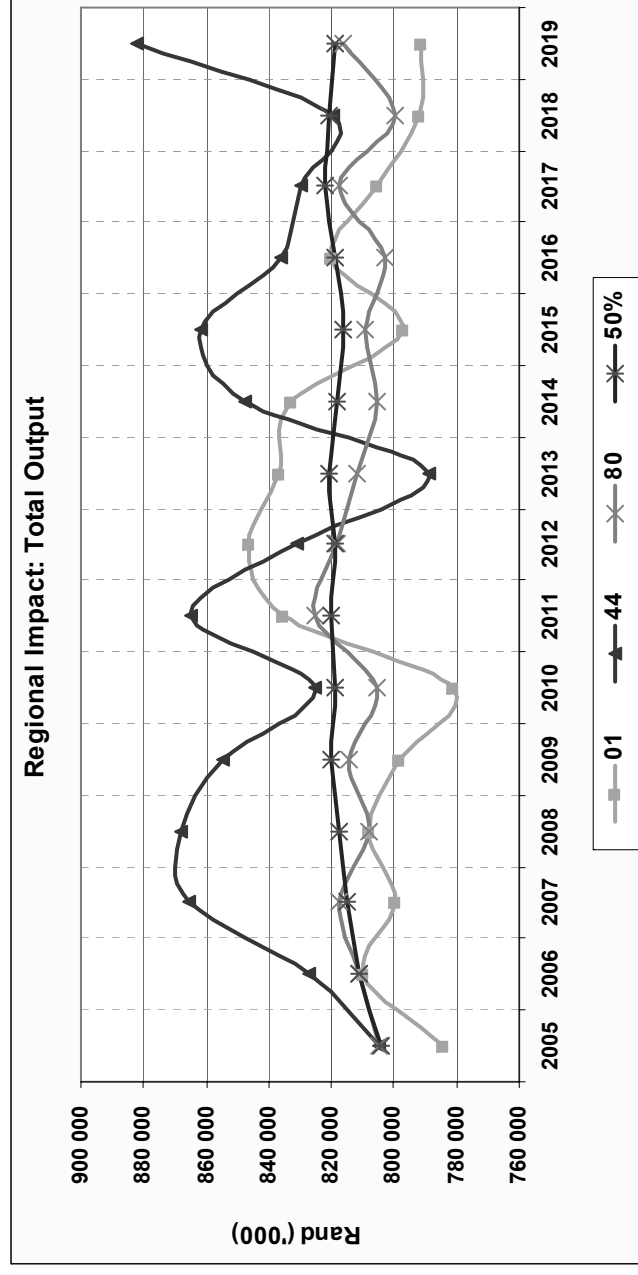


Figure 10.3. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO)

Table 10.4. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	134 583	147 000	141 792	145 821	141 159	133 234	159 580	164 533	160 236	158 049	140 965	151 887	144 806	138 290	138 158
44	143 984	154 051	172 436	174 089	167 576	153 613	171 720	155 504	135 317	164 002	170 929	158 947	155 897	151 487	180 109
80	144 150	147 319	150 467	146 037	149 064	144 869	154 211	150 686	147 886	144 939	146 506	143 623	150 424	142 450	149 878
50% percentile	144 056	147 280	149 289	150 236	151 447	151 044	151 727	151 034	151 728	150 661	149 822	150 820	152 403	151 920	151 105

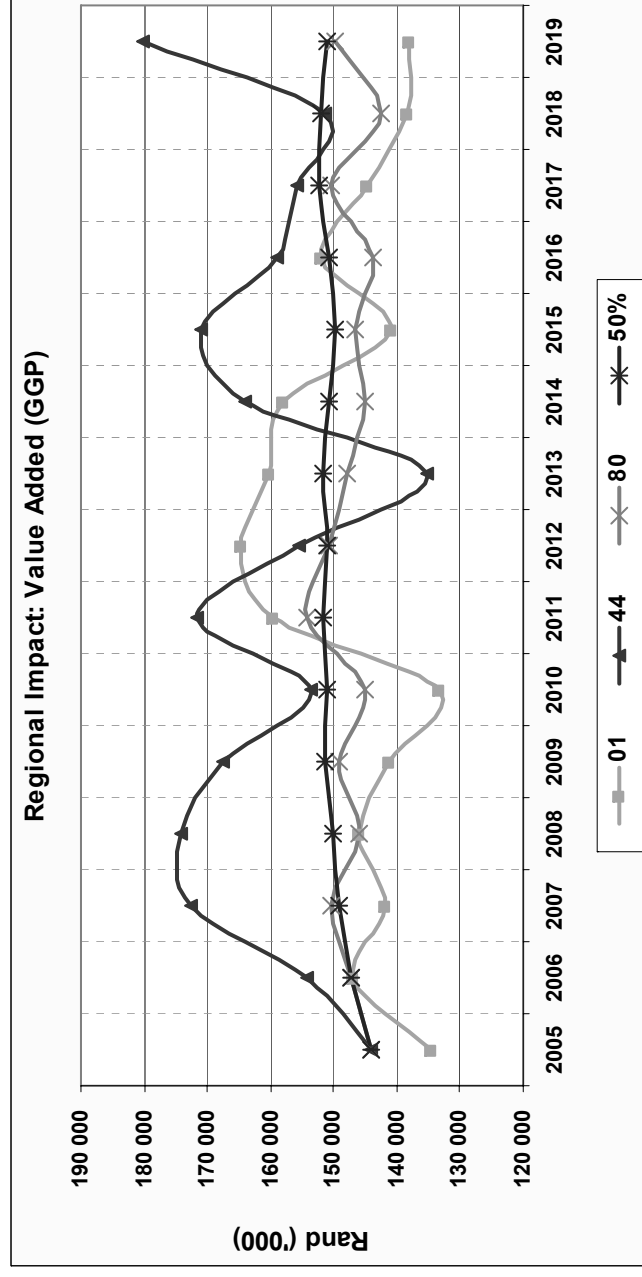


Figure 10.4. Regional Economic Impact in terms of generated GGP, 2005 to 2019 (Source: ISIM.MACRO)

Table 10.5. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	5 550	5 730	5 660	5 720	5 650	5 530	5 910	5 990	5 930	5 900	5 650	5 800	5 700	5 610	5 600
44	5 700	5 860	6 130	6 150	6 050	5 840	6 120	5 880	5 580	6 000	6 100	5 920	5 880	5 800	6 240
80	5 690	5 740	5 790	5 720	5 770	5 700	5 840	5 790	5 750	5 700	5 730	5 680	5 790	5 660	5 780
50% percentile	5 700	5 740	5 770	5 790	5 800	5 800	5 800	5 790	5 810	5 790	5 780	5 800	5 820	5 810	5 800

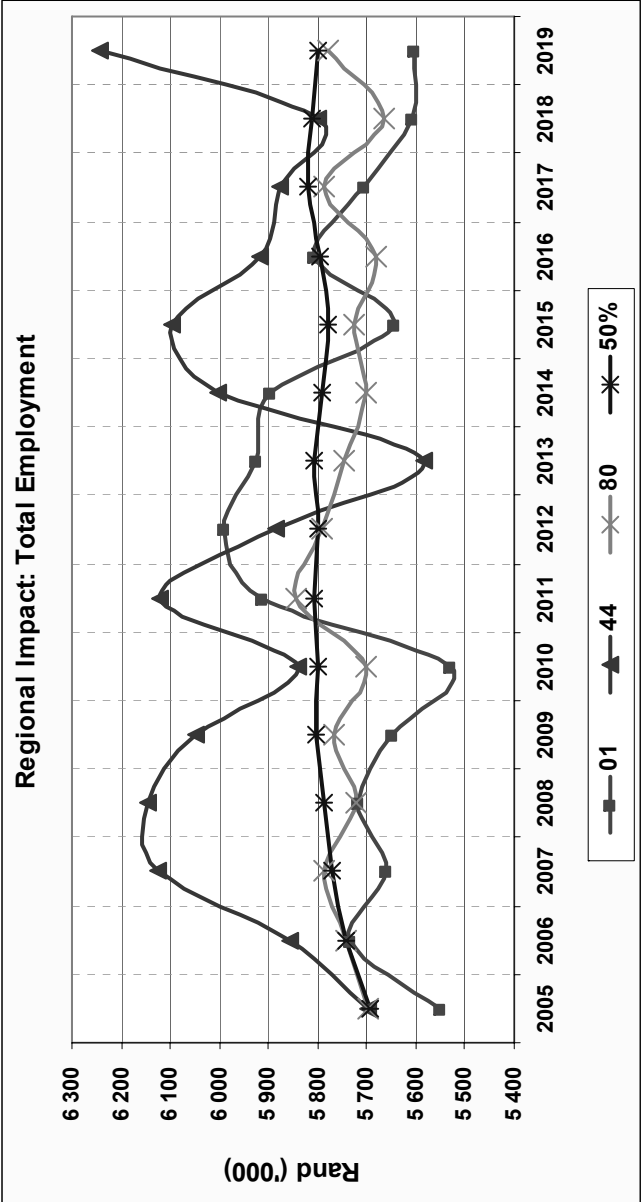


Figure 10.5. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

10.2.2.2. Total regional economic impact per economic sector

Table 10.6 indicates the range of regional impacts that could be experienced from 2005 to 2019 in the Base Case Scenario. The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

Table 10.6. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	464 231	479 255	473 266	478 180	472 412	462 382	494 439	500 999	495 429	493 164	471 987	485 556	476 878	468 789	468 390
	Max	476 465	489 621	512 153	513 916	505 689	488 348	511 785	491 972	466 907	501 801	509 879	494 899	491 170	484 963	522 075
Mining	Min	50 266	51 892	51 244	51 776	51 152	50 066	53 537	54 247	53 644	53 399	51 106	52 575	51 635	50 759	50 716
	Max	51 590	53 015	55 455	55 646	54 755	52 877	55 415	53 269	50 555	54 334	55 208	53 586	53 183	52 511	56 529
Manufacturing	Min	19 312	19 937	19 688	19 892	19 652	19 235	20 569	20 841	20 610	20 515	19 635	20 199	19 838	19 502	19 485
	Max	19 821	20 368	21 305	21 379	21 037	20 315	21 290	20 466	19 423	20 875	21 211	20 588	20 433	20 174	21 718
Energy	Min	4 318	4 457	4 402	4 447	4 394	4 300	4 598	4 659	4 608	4 587	4 390	4 516	4 435	4 360	4 356
	Max	4 431	4 554	4 763	4 780	4 703	4 542	4 760	4 576	4 342	4 667	4 742	4 603	4 568	4 510	4 856
Construction	Min	2 062	2 129	2 102	2 124	2 098	2 054	2 196	2 225	2 201	2 190	2 096	2 157	2 118	2 082	2 080
	Max	2 116	2 175	2 275	2 283	2 246	2 169	2 273	2 185	2 074	2 229	2 265	2 198	2 182	2 154	2 319
Trade	Min	27 555	28 446	28 091	28 383	28 040	27 445	29 348	29 737	29 406	29 272	28 015	28 820	28 305	27 825	27 802
	Max	28 281	29 062	30 399	30 504	30 015	28 986	30 377	29 201	27 713	29 785	30 264	29 375	29 154	28 785	30 988
Transport	Min	23 446	24 205	23 902	24 151	23 859	23 353	24 972	25 303	25 022	24 907	23 838	24 523	24 085	23 676	23 656
	Max	24 064	24 728	25 866	25 955	25 540	24 664	25 848	24 847	23 581	25 344	25 752	24 995	24 807	24 493	26 367
Finance	Min	19 340	19 966	19 716	19 921	19 681	19 263	20 599	20 872	20 640	20 545	19 663	20 228	19 867	19 530	19 513
	Max	19 850	20 398	21 337	21 410	21 067	20 345	21 321	20 496	19 452	20 905	21 242	20 618	20 462	20 204	21 750
Services	Min	43 562	44 972	44 410	44 871	44 330	43 389	46 397	47 013	46 490	46 277	44 290	45 563	44 749	43 990	43 953
	Max	44 710	45 945	48 059	48 225	47 453	45 825	48 025	46 165	43 813	47 088	47 846	46 440	46 090	45 508	48 990
Households	Min	130 183	134 396	132 717	134 095	132 478	129 665	138 655	140 494	138 932	138 297	132 358	136 163	133 730	131 462	131 350
	Max	133 614	137 303	143 622	144 116	141 809	136 946	143 519	137 963	130 934	140 719	142 984	138 783	137 738	135 997	146 404

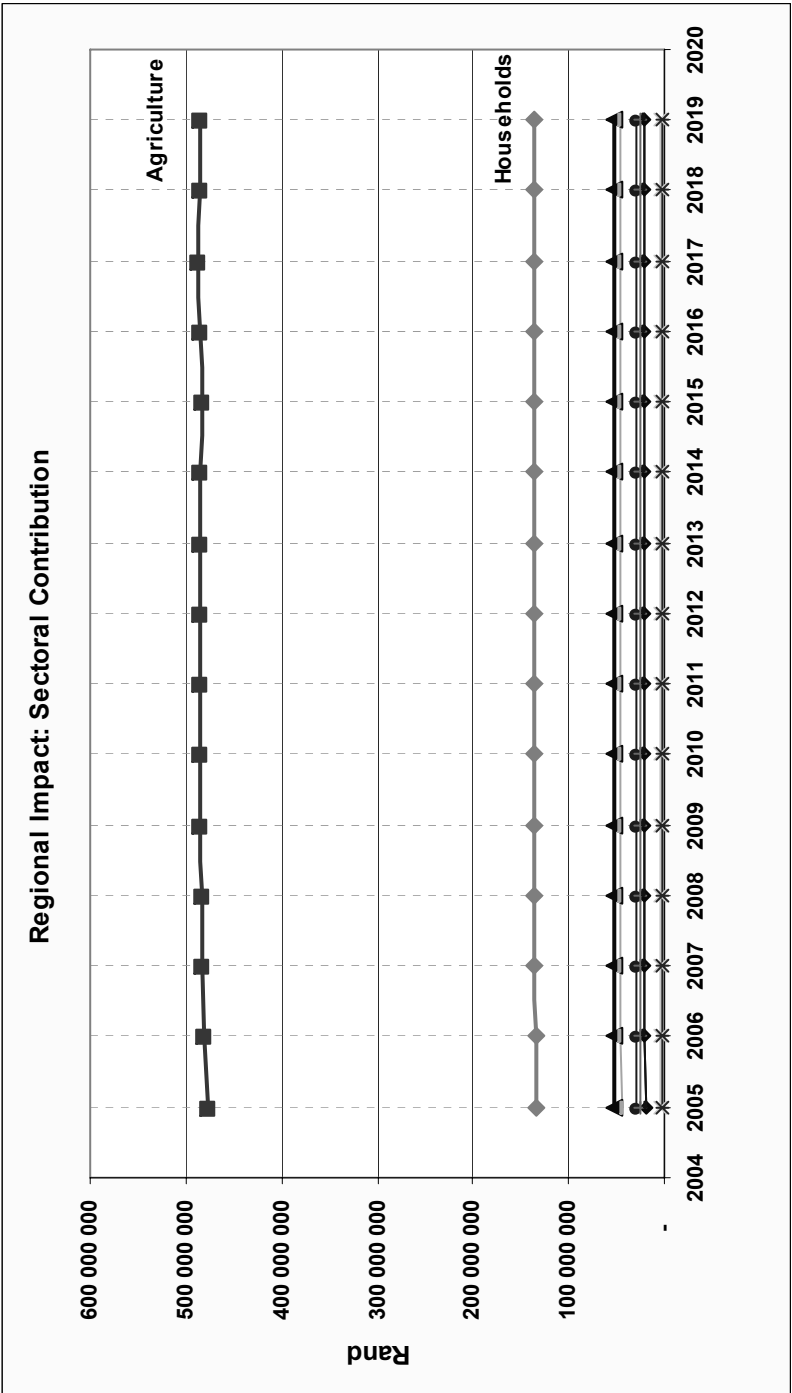


Figure 10.6. Total economic impact per economic sector (total output), 2005 to 2019 (50% percentile) (Source: ISIM-MACRO)

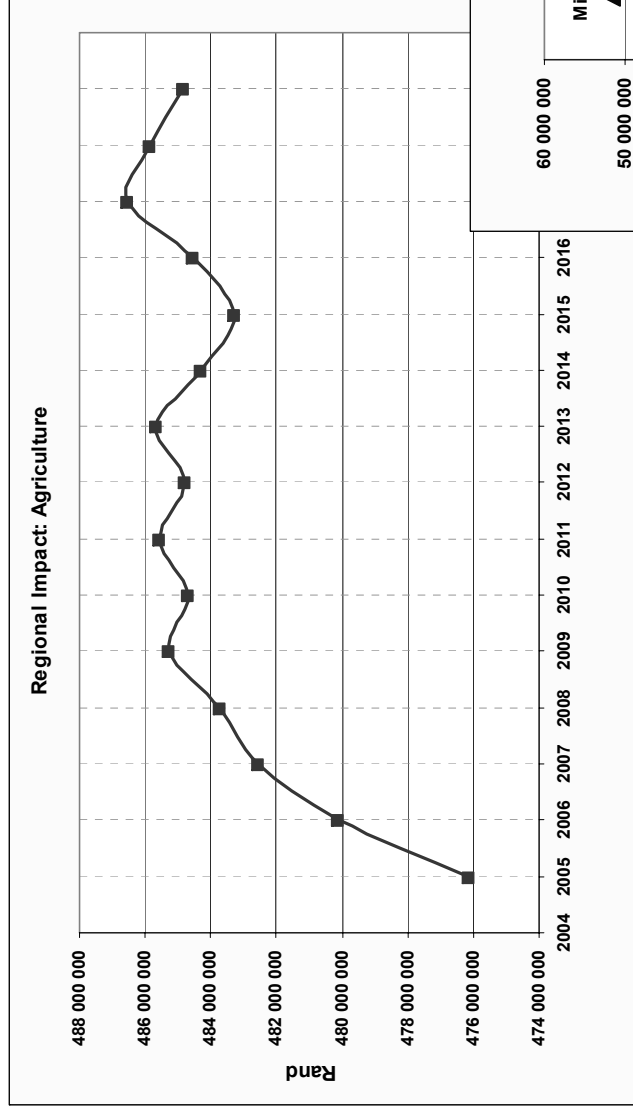


Figure 10.7. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

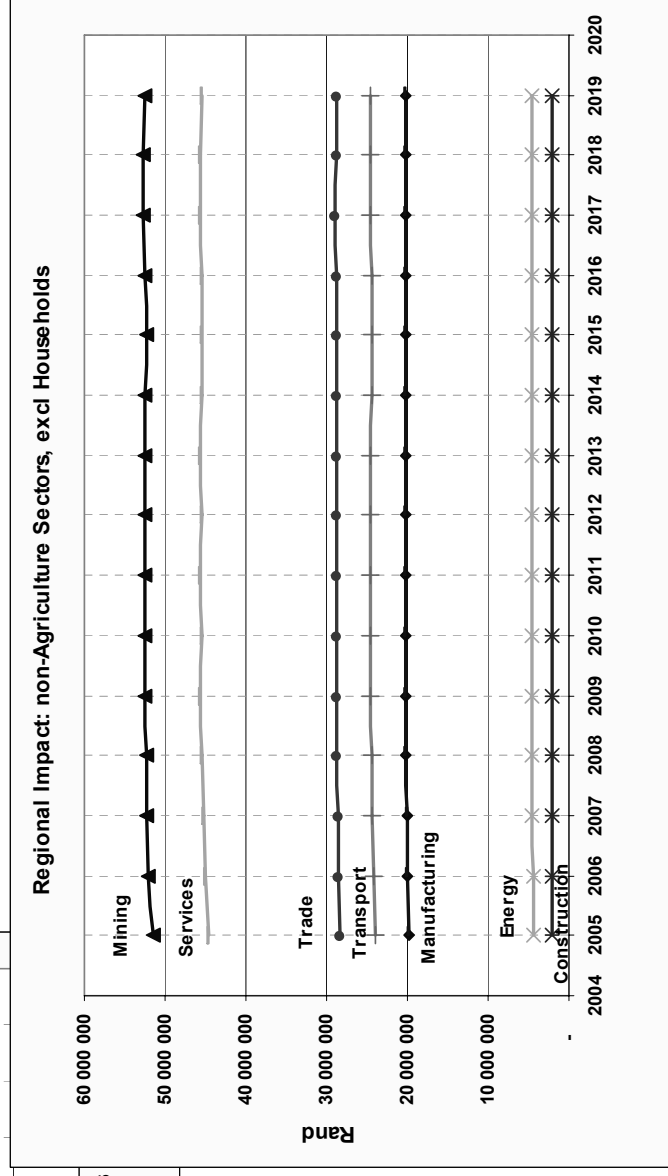


Figure 10.8. Total regional economic impact (output) for the non-agriculture sectors, excluding households, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

10.2.2.3. Index for Sustainable Economic Welfare (ISEW)

The ISEW is calculated, based on Equation 7.2.1. The following weights have been applied 25%:50%:25% to align the results with the national government's goal of decreasing unemployment and create sustainable jobs. Table 7.11 indicates the calculated indices for the 50% percentile values over the period 2005 to 2019:

Table 10.7. Index for Sustainable Economic Welfare, 2005 – 2019

$t =$	P_i P represents the economic pillar of sustainability	E_i E represents the social pillar of sustainability	S_i S represents the environmental pillar of sustainability	ISEW
2005				
w_i	0.25	0.50	0.25	0.421
2006	1.0156	0.9178	1.687	1.134
2007	1.0096	0.9246	1.624	1.121
2008	1.0044	0.9302	1.713	1.144
2009	1.0055	0.9375	1.677	1.139
2010	0.9984	0.9389	1.671	1.137
2011	1.0030	0.9465	1.703	1.150
2012	0.9968	0.9472	1.699	1.148
2013	1.0031	0.9540	1.744	1.164
2014	0.9952	0.9527	1.749	1.162
2015	0.9961	0.9559	1.709	1.154
2016	1.0046	0.9627	1.750	1.170
2017	1.0071	0.9662	1.714	1.164
2018	0.9979	0.9628	1.706	1.157
2019	0.9964	0.9637	1.733	1.164

Source: ISIM.MACRO [ISEW]

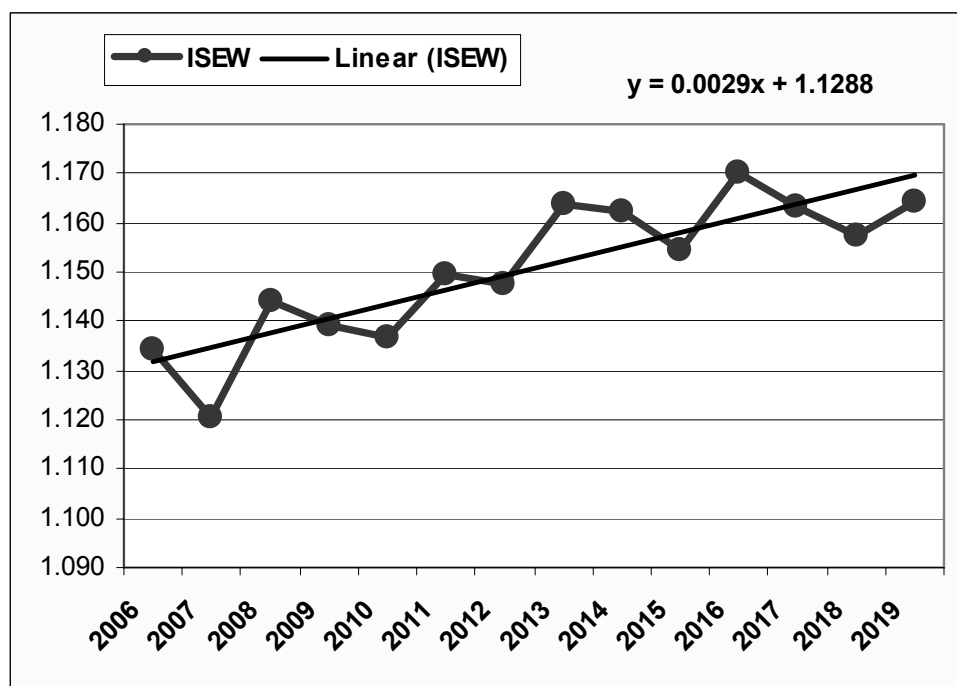


Figure 10.9. Index for Sustainable Economic Welfare, 2006 – 2019 (50% Percentile)

10.2.2.4. Comparative values for the ISEW of different stochastic runs

The ISEW results of the different stochastic runs performed on data projections are indicated in the following figures:

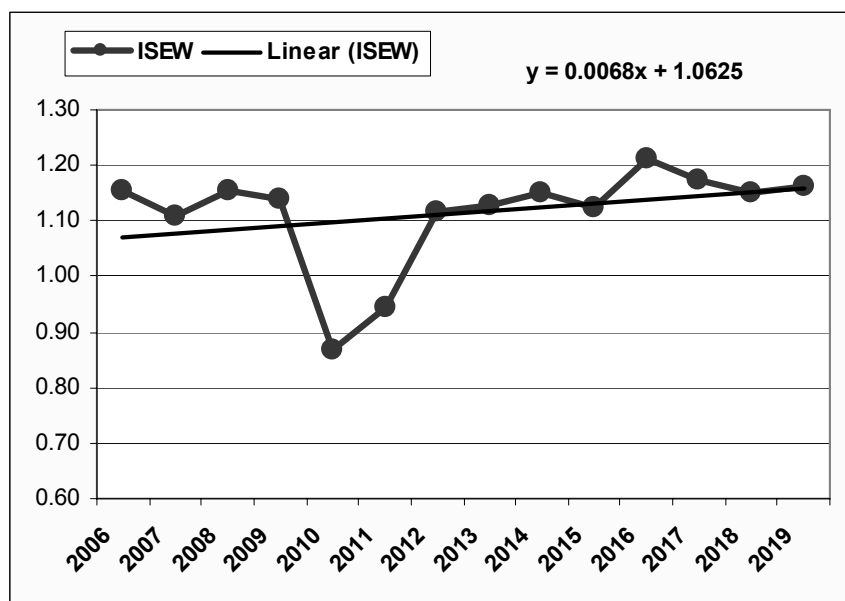


Figure 10.10. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic Run 01)

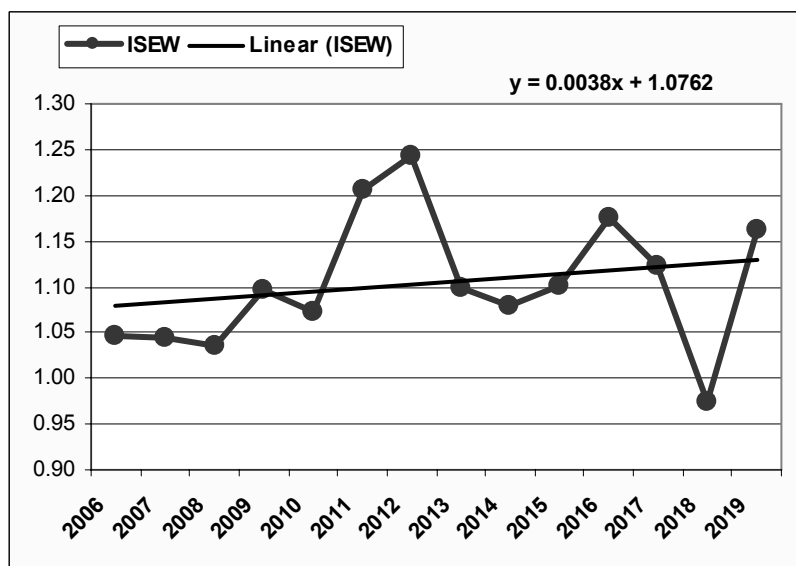


Figure 10.11. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic 44)

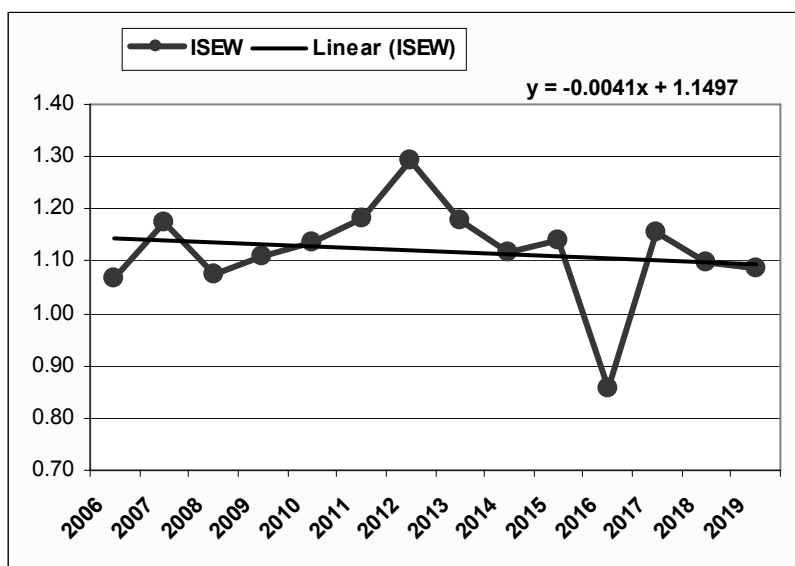


Figure 10.12. Index for Sustainable Economic Welfare, 2006 – 2019 (Stochastic Run 80)

An ISEW value of one (1) or larger represents a regional economic situation that can be considered as sustainable, while a value of lower than one represents unsustainable economic welfare or development. It is evident from the above indicators that the overall sustainability of the region could improve on the 50% probability over the next 15 years (Figure 10.9). This upward trend is mainly due to the average trends in soil salinity, as a measure of environmental sustainability. It should, however, be noted that for the same situation, the economic production and labour environment do not function optimally as individual indices indicate a situation of unsustainable economic welfare. This is due to consistent high levels of unemployment in the region. This also implies that the agriculture sector, whilst an important contributor to employment, will remain at current levels of labour absorption over the next 15 years, should current production- and salinity levels remain the same.

Data for stochastic run 80, which represents projections made from a real water cycle, indicates that the overall sustainable economic welfare of the region will decrease should this projection be followed. Both the 0.05 and 0.95 percentile projections indicate a positive trend, although detailed analysis has indicated that the economic production element will decline.

10.2.3. SUMMARY OF THE RESULTS FOR BASE CASE SCENARIO

Three categories of data were analysed during the base case scenario analysis described in this chapter, namely data for stochastic runs number 01, 44 and 80. To provide an indication of the probability of the results taking place, data obtained from the 50th percentile was also included.

The total direct impact over the period, due to salinisation in the Base Case Scenario can be expressed in terms of the net effect or incremental change over the total period of 2005 to 2019. These are as follows:

Table 10.8. Net effect and resulting composite annual growth rate for selected indicators, 2005 to 2019

<i>Gain (+) / Loss (-)</i>	<i>Value Added</i>	<i>Direct Output</i>	<i>Total Output</i>	<i>Employment</i>
<u>Stochastic Run 001</u>				
Rand	3 574 400	3 866 500	7 026 800	50
% annual growth	0.06	0.19	0.06	0.06
<u>Stochastic Run 044</u>				
Rand	36 125 000	42 398 800	77 053 100	550
% annual growth	0.66	1.61	0.66	0.66
<u>Stochastic Run 080</u>				
Rand	5 729 000	6 300 250	11 449 700	80
% annual growth	0.10	0.28	0.10	0.10
<u>0.5 Percentile (50%)</u>				
Rand	7 049 600	8 091 500	14 705 000	100
% annual growth	0.13	0.34	0.13	0.13

The total impact (direct and indirect) per economic sector over the period 2005 to 2019 can be summarised as indicated in Table 10.9.

Table 10.9. Net effect and resulting composite annual growth rate in terms of business output (Rand) per economic sector, 2005 to 2019

<i>Sector</i>	<i>SR01</i>	<i>SR44</i>	<i>SR80</i>	<i>50%</i>
Agriculture	4159 300	45 609 570	6 777 360	8 704 260
Mining	450 400	4 938 500	733 840	942 480
Manufacturing	173 030	1 897 350	281 940	362 100
Energy	38 680	424 190	63 030	80 950
Construction	18 470	202 580	30 100	38 660
Trade	246 880	2 707 180	402 270	516 650
Transport	210 070	2 303 520	342 290	439 610
Finance	173 280	1 900 110	282 350	362 620
Services	390 300	4 279 900	635 970	816 790
Households	1 166 390	12 790 200	1 900 560	2 440 920

The Index for Sustainable Economic Welfare was calculated by taking into consideration the production level (or value added to the irrigation sector), the employment structure of the area and the sector (as a social pillar) and the environmental changes brought on by changing salinity levels. This was done over the total period of 2005 to 2019.

The ISEW clearly indicates that, for the base case scenario, there are positive trends in the sustainable economic welfare of the study area. However, stochastic run number 80, which closely resembles the 50% average, indicates an overall decline in the sustainability of the economic welfare in the region.

10.3. SCENARIO 1

10.3.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE

The direct impact of the initiatives provided for in this scenario is achieved through direct spending in the agriculture sector and the resulting gross margins that are achieved. No provision has been made in this scenario for future price fluctuations or market changes. The direct impact in the agriculture sector is illustrated in Figure 10.13.

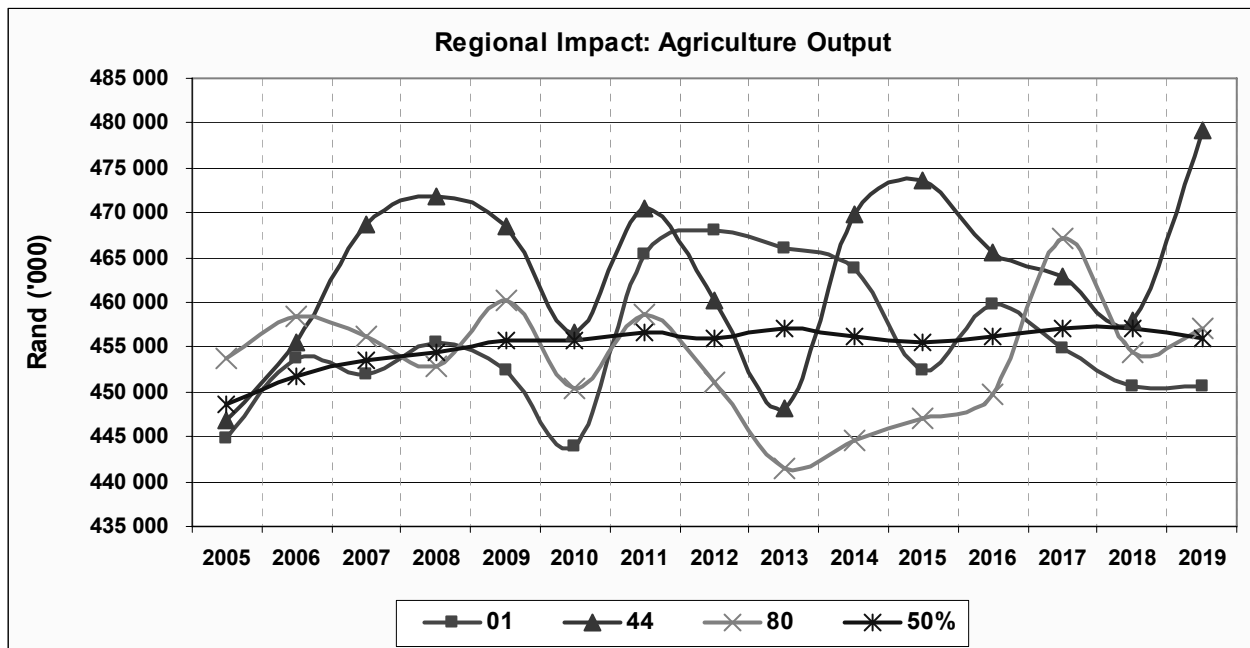


Figure 10.13. Direct output in the agriculture sector (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile

When compared to the output (in Rand terms) registered in the study area (as described in Chapter 7), this represents almost 70.1% of the total agriculture output and 71.3% of the output in the agriculture sector expected in 2019, should current growth trends prevail (this reflects the contribution of output in the irrigated crop production sectors). With the different multiplier effects being initiated by this investment or change in production, the total regional economy's output could be affected as indicated in Figure 10.14.

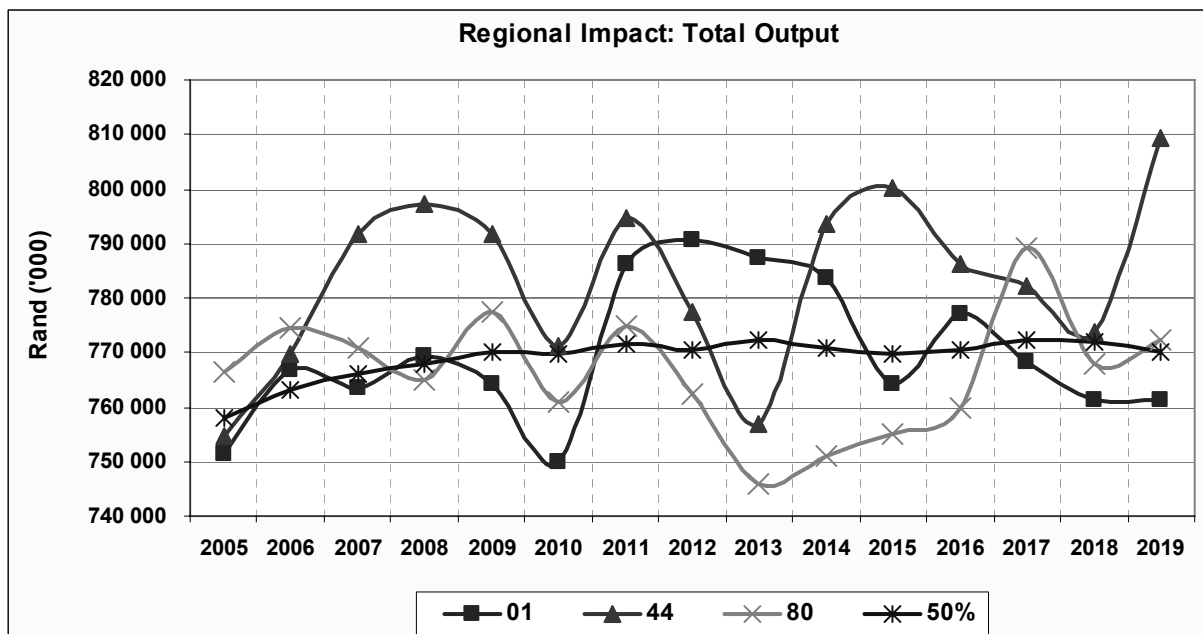


Figure 10.14. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile

When considering the 50th percentile values, which provides an average of the various indicators, it is evident that the regional economy could generate around R757.9 million worth of output in 2005 (5.0% of the total regional economic output) to about R770.2 million in 2019 (3.1% of the expected regional output in 2019). The calculated production outputs during this period could vary between R745.9 million to R810.0 million.

When compared to the results of the regional impact modelling of the Base Case Scenario, which represents the current situation, the total direct output is lower than the expected direct output, should current growth trends prevail. It is estimated that production output will be between 93.9% and 94.2% of the current production levels.

10.3.2. SECTORAL ECONOMIC IMPACTS

The impact of the scenario on the production output of the region per economic sector is indicated below.

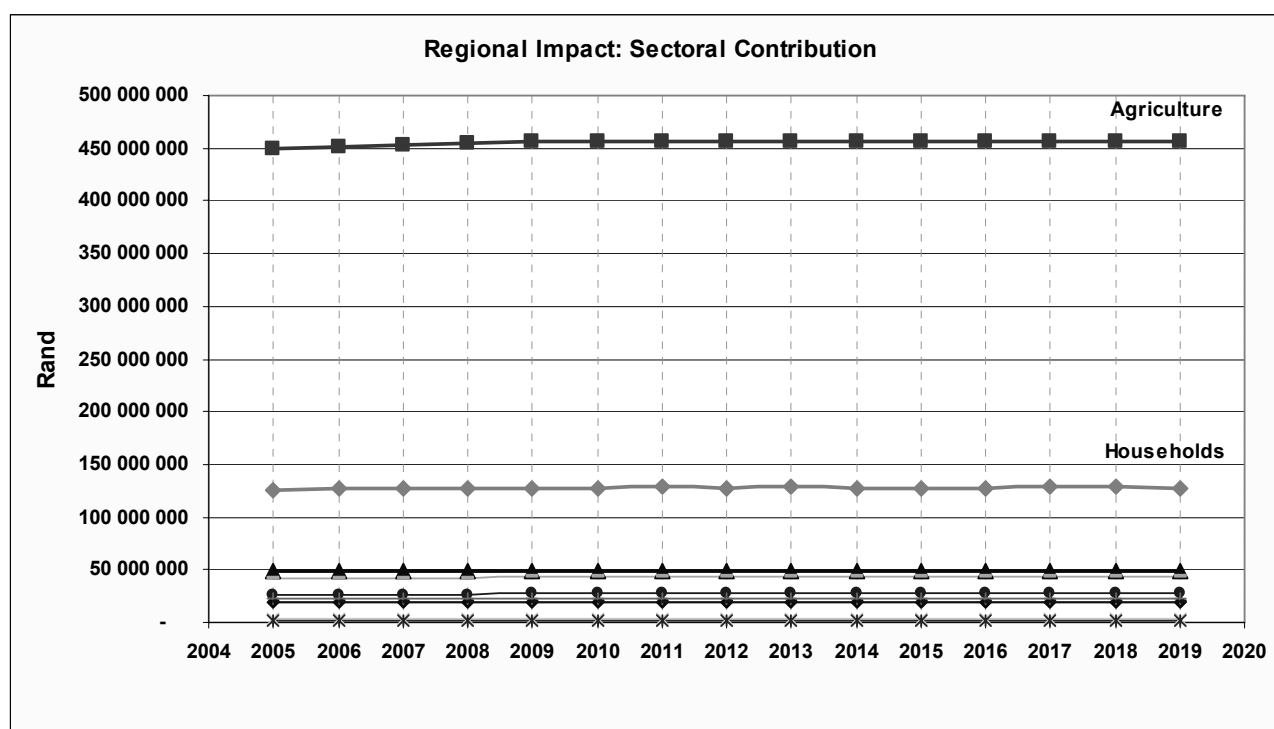


Figure 10.15. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)

The net effects in terms of sector business output is indicated in Table 10.10.

Table 10.10. Net effect on the production output (Rand) per economic sector (2005 to 2019)

Gain (+) / Loss (-)	SR 01	SR 44	SR 80	SR 50%
Agriculture	5 847 500	32 335 100	3 303 800	7 297 800
Mining	633 200	3,501 200	357 700	790 200
Manufacturing	243 250	1 345 100	137 400	303 600
Energy	54 400	300 700	30 700	67 900
Construction	26 000	143 600	14 700	32 400
Trade	347 100	1 919 300	196 100	433 200
Transport	295 300	1 633 100	166 900	368 600
Finance	243 600	1 347 100	137 600	304 030
Services	548 700	3 034 250	310 000	684 800
Households	1 639 800	9 067 700	926 500	2 046 500

10.3.3. EMPLOYMENT EFFECT

The impact of Scenario 1 on the employment in the region is indicated in Figure 10.16.

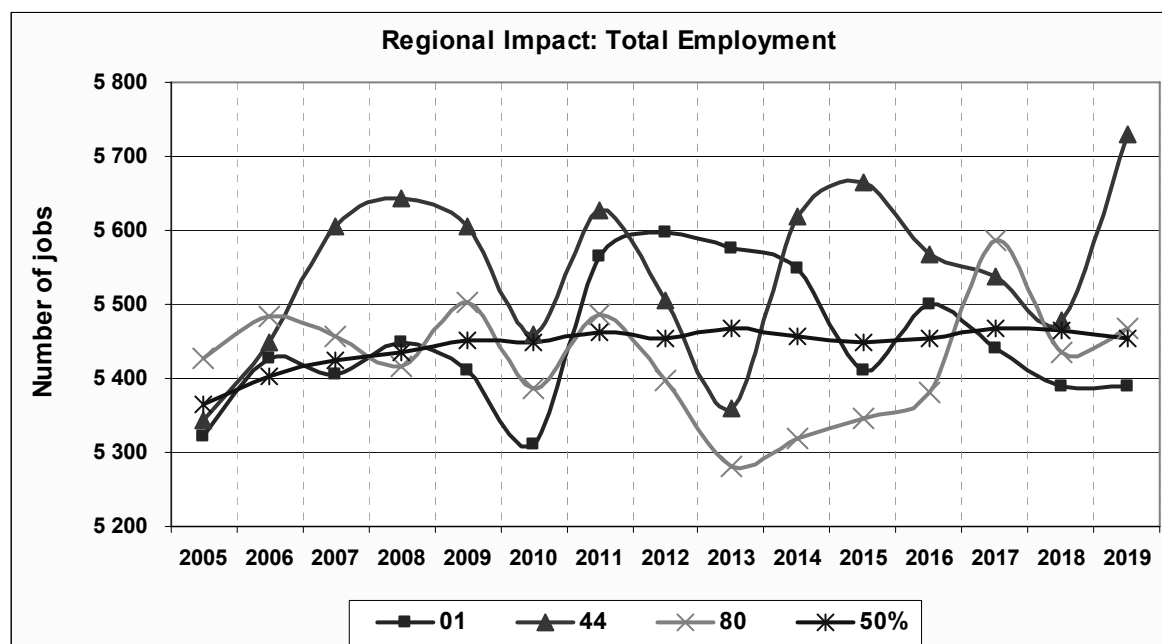


Figure 10.16. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile

With this scenario an average of about 5 370 jobs could be sustained in 2005 up to 5 450 in 2019 in the regional economy. This represents about 8.5% of the current labour force in the study area, but also 53.1 % of the agricultural labour force (2005). However, this is lower than the labour impact of the Base Case Scenario (about 94.0% of the total employment opportunities that could be sustained in the Base Case Scenario).

10.3.4. OTHER SECONDARY IMPACTS

The above impacts have direct implications on the creation of new GGP in the study area (that is, per definition, the value of intermediary goods and services provided within the borders of the study area for a given period). Figure 10.17 indicates the overall impact of the agriculture development on the rest of the regional economy.

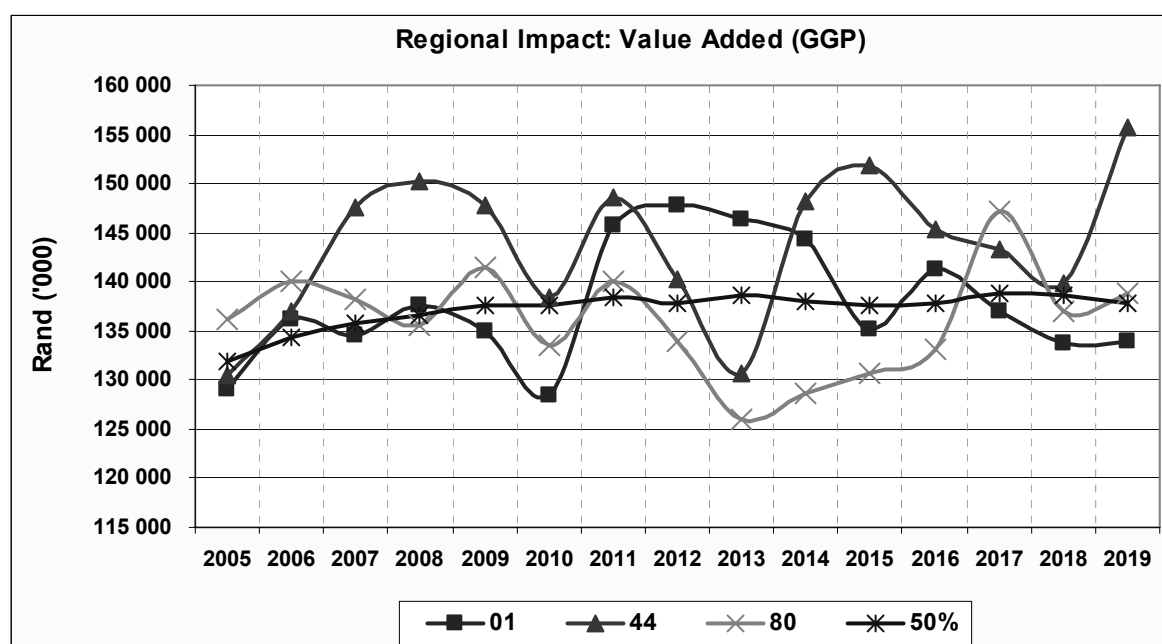


Figure 10.17. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile

It is evident that, when considering the 50th percentile run, the total GGP generated could increase from R132.0 million in 2005 to R137.7 million in 2019. The values calculated within this period range from a minimum of R128.4 million to R155.7 million. This represents around 54.3% of the total agriculture GGP in the region in 2005 (1.8% of the total GGP) and 64.2% of total agriculture GGP in 2019 (1.4% of total GGP). However, this amounts to about 91% of the total GGP that could be generated through the Base Case Scenario.

The net effects of the above indicators in Rand terms are indicated in Table 10.11.

Table 10.11. Net effect of Scenario 1 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019

Gain (+) / Loss (-)	Value Added	% growth	Direct output	% growth	Total output	% growth	Employment	% growth
SR 01	4 811 000	0.09	5 435 900	0.26	9 878 900	0.09	70	0.09
SR 44	25 154 700	0.50	30 058 800	1.27	54 627 100	0.50	390	0.50
SR 80	2 611 900	0.05	3 071 200	0.14	5 581 500	0.05	40	0.05
50%	5 795 600	0.12	6 784 100	0.31	12 329 000	0.12	90	0.12

Note: SR = Stochastic Run

10.4. SCENARIO 2

10.4.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE

As in Scenario 1, the direct impact of the initiatives provided for in this scenario is achieved through direct spending in the agriculture sector and the resulting net income or gross margins that are achieved. The direct impact in the agriculture sector is illustrated in Figure 10.18.

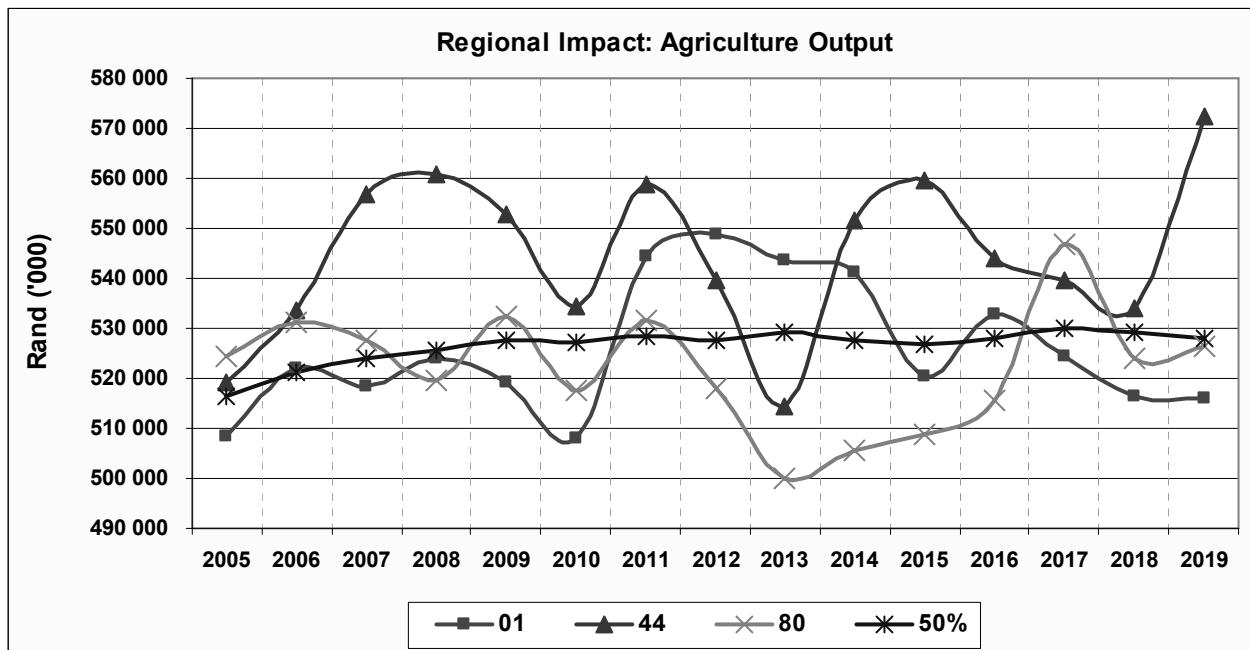


Figure 10.18. Direct output in the agriculture sector (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile

When compared to the total output registered in the study area in the agriculture sector, this represents almost 87.6% of the total agriculture output and 82.5.3% of the output expected in 2019, should current growth trends prevail. When compared to the Base Case Scenario, the impact on direct output is substantially higher. Economic production in this scenario could reach levels that are 8.5% to 10.1% higher than production levels in the Base Case Scenario.

With the different multiplier effects being initiated by this investment or change in production, the total regional economy's output could be affected as indicated in Figure 10.19.

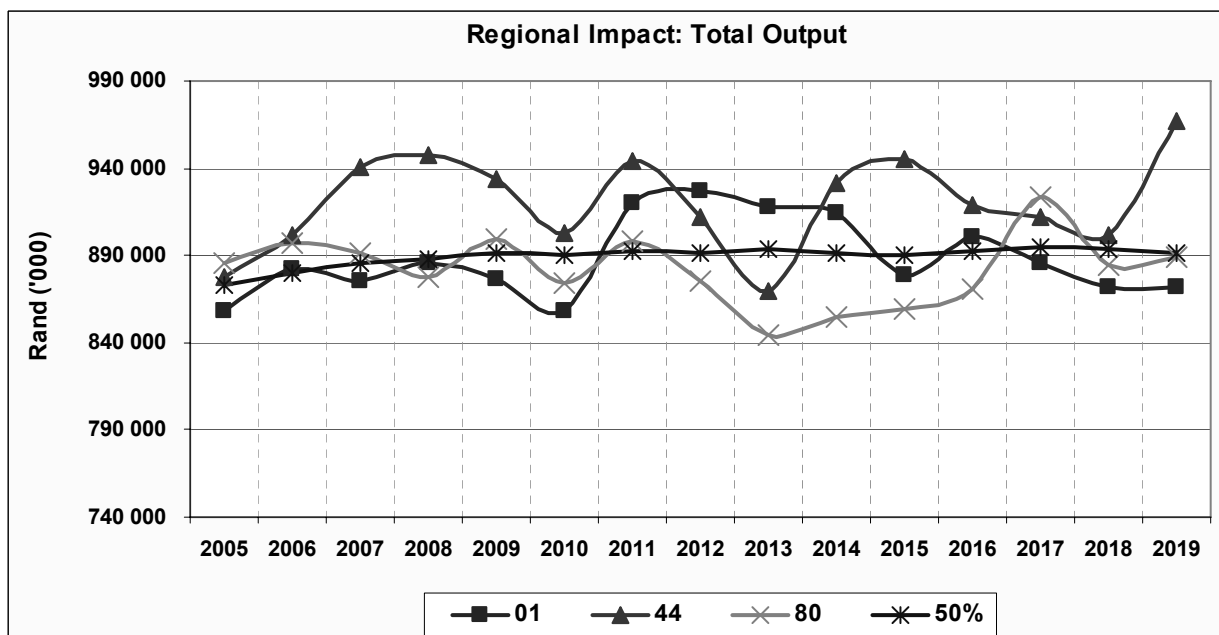


Figure 10.19. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80, as well as the 50th percentile

When considering the 50th percentile values, which provides an average of the various indicators, it is evident that the regional economy could generate around R872.7 million worth of output in 2005 (5.7% of the regional economic output) to about R891.8 million in 2019 (3.6% of the expected regional output in 2019). The calculated outputs during this period could vary between R751.5 million to R947.1 million.

10.4.2. SECTORAL ECONOMIC IMPACTS

The impact of the scenario on the production output of the region per economic sector is indicated in the next figure.

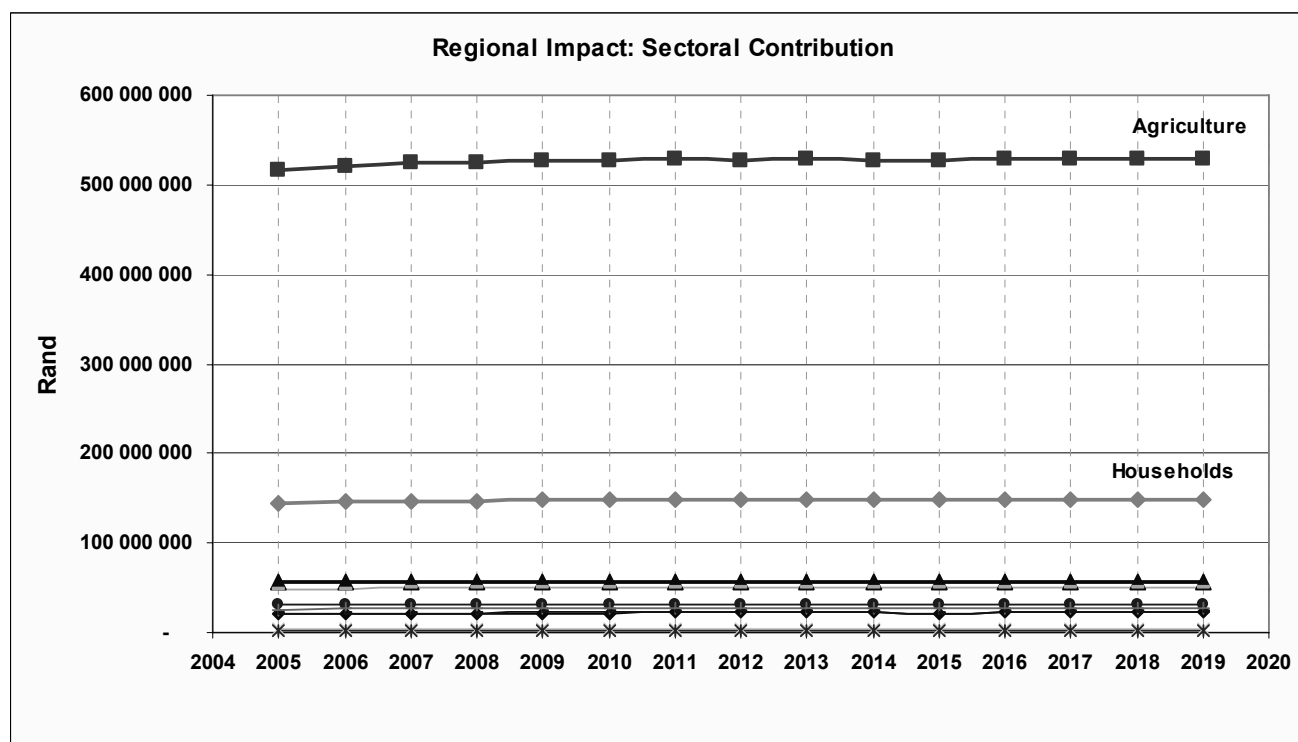


Figure 10.20. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)

The net effects in terms of per sector business output are as follows:

Table 10.12. Net effect on the production output (Rand) per economic sector (2005 to 2019)

<i>Gain (+) / Loss (-)</i>	<i>SR 01</i>	<i>SR 44</i>	<i>SR 80</i>	<i>SR 50%</i>
Agriculture	7 633 900	53 147 980	1 913 800	11 295 800
Mining	826 580	5 754 700	207 200	1 223 100
Manufacturing	317 570	2 210 900	79 600	469 900
Energy	71 000	494 300	17 800	105 060
Construction	33 900	236 100	8 500	50 200
Trade	453 100	3 154 650	113 600	670 500
Transport	385 550	2 684 250	96 660	570 500
Finance	318 030	2 214 200	79 700	470 600
Services	716 350	4 987 300	179 600	1 059 980
Households	2 140 760	14 904 180	536 700	3 167 700

10.4.3. EMPLOYMENT EFFECT

The impact of Scenario 2 on the employment in the region is indicated in Figure 10.21.

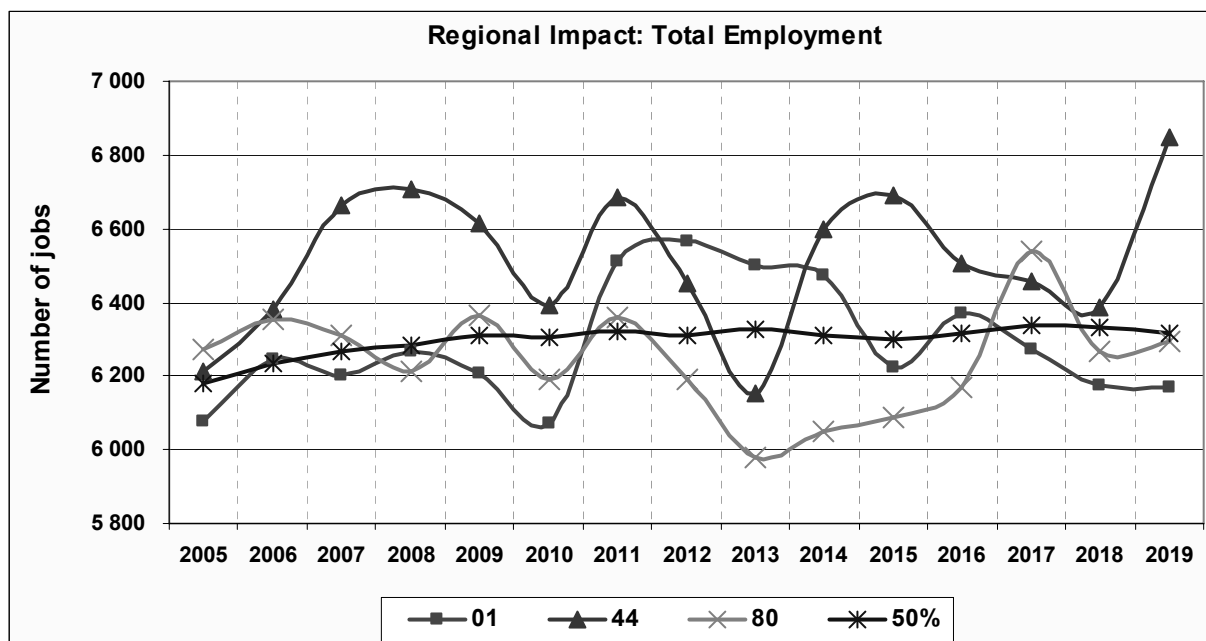


Figure 10.21. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile

With this scenario an average of about 6,180 could be sustained in 2005 up to 6,300 in 2019 in the regional economy. This represents about 10.0% of the current labour force in the study area, but also 61.2 % of the agricultural labour force (2005).

10.4.4. OTHER SECONDARY IMPACTS

The above impacts have direct implications on the creation of new GGP in the study area (that is, per definition, the value of intermediary goods and services provided within the borders of the study area for a given period). Figure 10.22 indicates the overall impact of the agriculture development on the rest of the regional economy.

When considering the 50th percentile run, the total GGP generated could increase from R166.8 million in 2005 to R175.8 million in 2019. The values calculated within this period range from a minimum of R155 million to R205 million. This represents around 68.7% of the total agriculture GGP in the region in 2005 (2.2% of the total GGP) and 82.0% of total agriculture GGP in 2019 (1.7% of total GGP). In comparison with the Base Case Scenario, this production is between 15.8% and 16.4% higher than the GGP generated in the current situation.

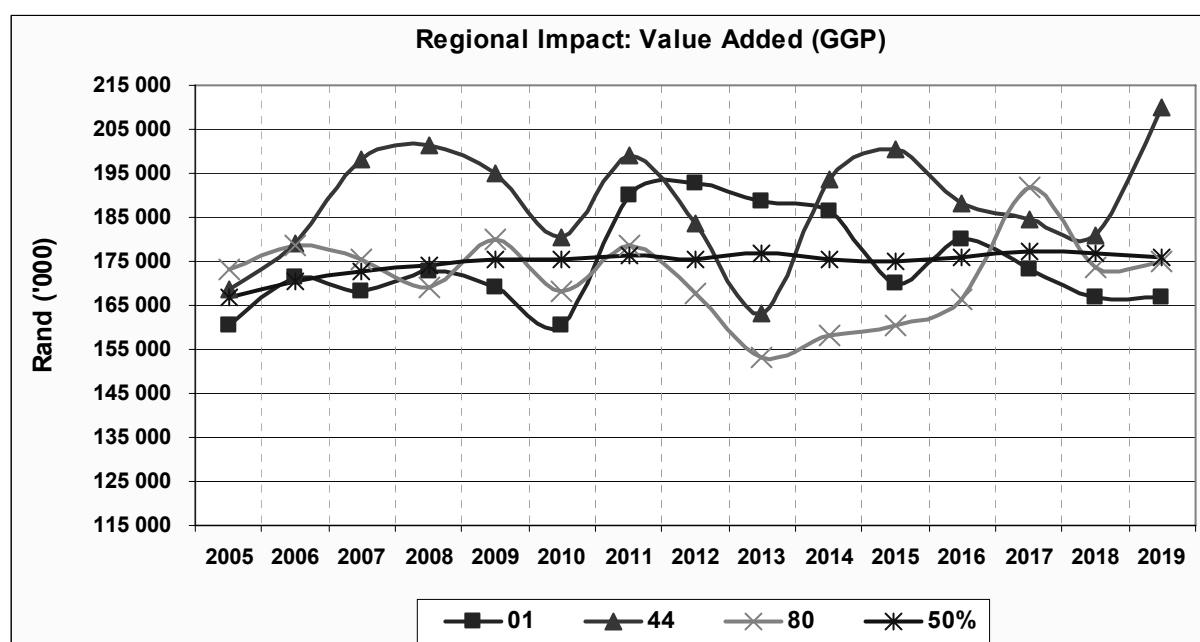


Figure 10.22. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80, as well as the 50th percentile

The net effects of the above indicators in Rand terms are as follows:

Table 10.13. Net effect of Scenario 2 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019

Gain (+) / Loss (-)	Value Added	% growth	Direct output	% growth	Total output	% growth	Employment	% growth
SR 01	6 338 300	0.11	7 096 500	0.28	12 896 700	0.11	90	0.11
SR 44	41 392 800	0.70	49 406 500	1.58	89 788 500	0.70	640	0.70
SR 80	1 580 300	0.03	1 779 100	0.06	3 233 200	0.03	20	0.03
50%	8 949 500	0.15	10 500 600	0.37	19 083 200	0.15	140	0.15

Note: SR = Stochastic Run

10.5. SCENARIOS 3 AND 3(+)

10.5.1. CHANGE IN CONTRIBUTION OF IRRIGATION AGRICULTURE

As in Scenario 1 and 2, the direct impact of the initiatives provided for in this scenario is achieved through direct spending in the agriculture sector and the resulting net income or gross margins that are achieved. No provision has been made in this scenario for future price fluctuations or market changes. The direct impact in the agriculture sector is illustrated in Figure 10.23.

When compared to the total output registered in the study area, this represents almost 98.1% of the total agriculture output (3.5% of the regional output in all sectors) and 91.2% of the output expected in 2019 (2.2% of the total regional output), should current growth trends prevail. With the different multiplier effects being initiated by this investment or change in production, the total regional economy's output could be affected as indicated in Figure 10.24.

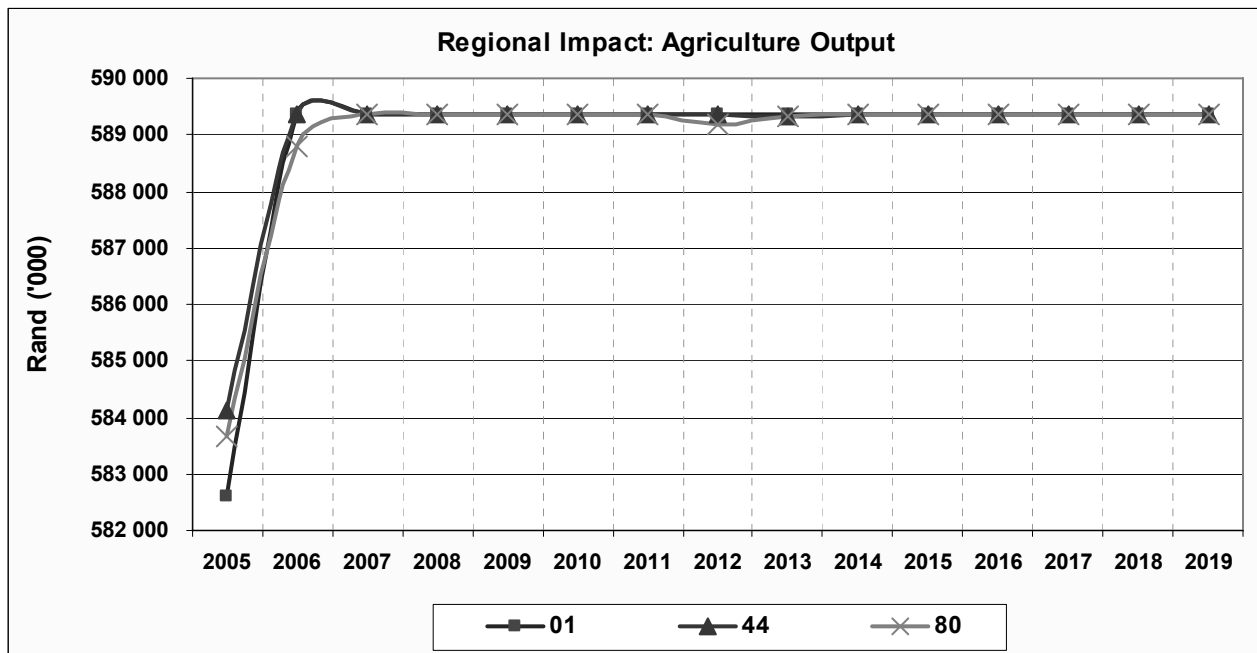


Figure 10.23. Direct output in the agriculture sector (R'000), 2005-2019 for stochastic runs 01, 44 and 80

When compared to the Base Case Scenario, this scenario have the largest increase in direct, as well as total economic production output (in Rand terms) in the study area. This output is expected to be between 21.5% and 22.6% higher than for the Base Case Scenario.

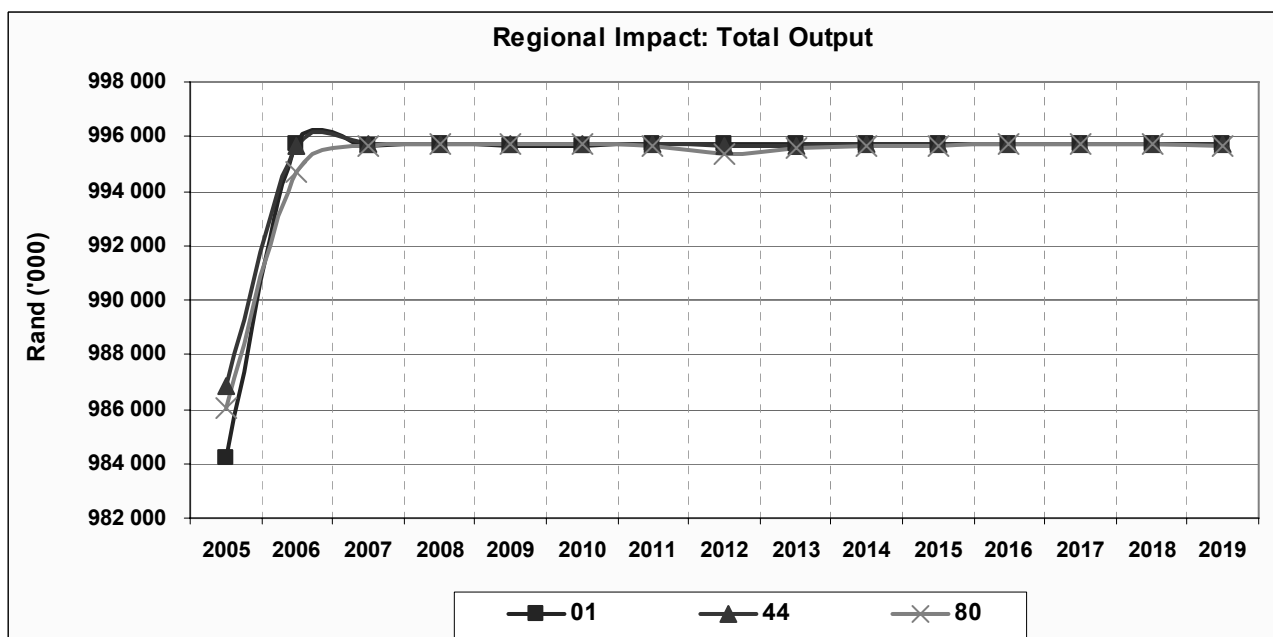


Figure 10.24. Total output in the regional economy (R'000), 2005 to 2019 for stochastic runs 01, 44 and 80

When considering the 50th percentile values, which provides an average of the various indicators, it is evident that the regional economy could generate around R977 million worth of output in 2005 (6.4% of the regional economic output) to about R985.8 million in 2019 (4.0% of the expected regional output in 2019). The calculated outputs during this period could vary between R985 million to R995 million.

10.5.2. SECTORAL ECONOMIC IMPACTS

The impact of the scenario on the production output of the region per economic sector is indicated in the next figures.

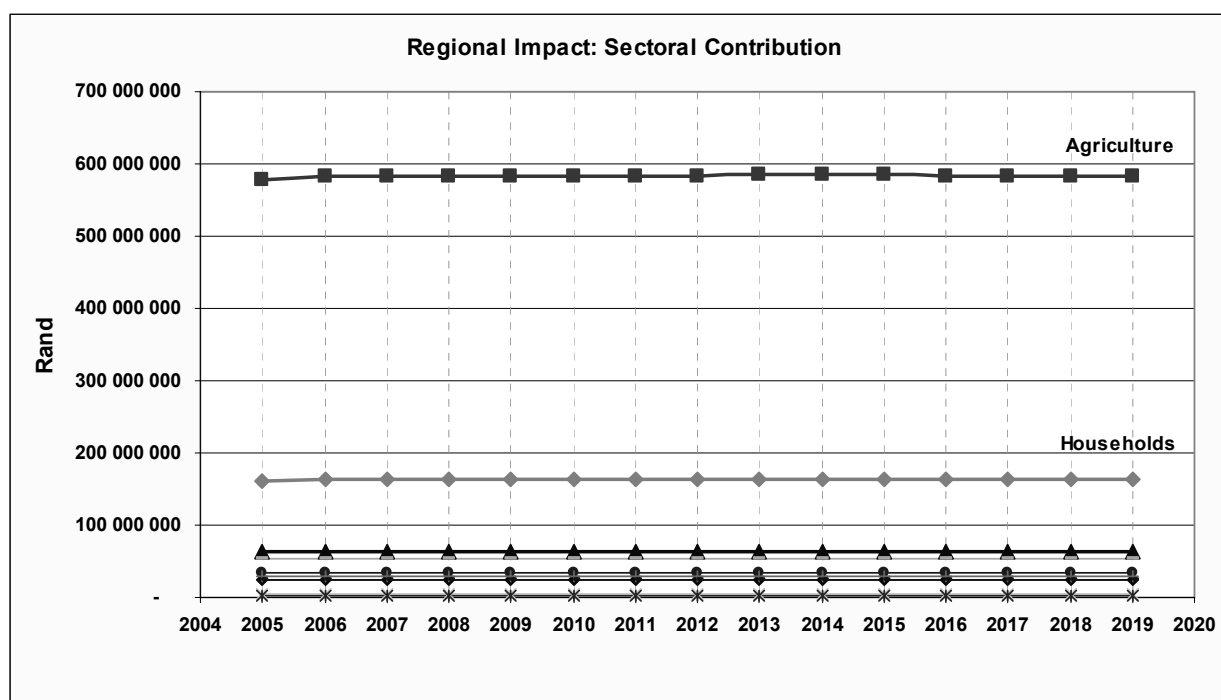


Figure 10.25. Total output in the regional economy (R'000), per economic sector for the period 2005 to 2019 (50th percentile)

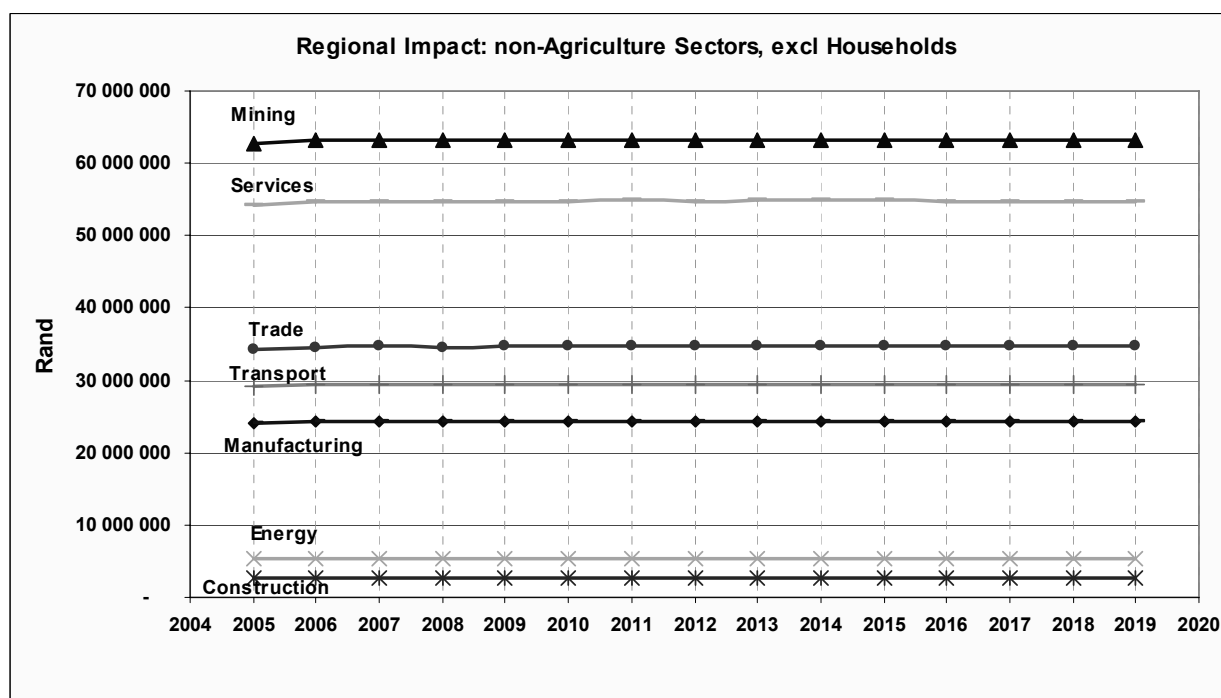


Figure 10.26. Total output in the regional economy (R'000), per economic sector excluding agriculture and households for the period 2005 to 2019 (50th percentile)

The net effects in terms of per sector business output are as follows:

Table 10.14. Net effect on the production output (Rand) per economic sector (2005 to 2019)

<i>Gain (+) / Loss (-)</i>	<i>SR 01</i>	<i>SR 44</i>	<i>SR 80</i>	<i>SR 50%</i>
Agriculture	6 791 410	5 254 340	5 705 390	5 246 740
Mining	735 360	568 930	617 770	568 100
Manufacturing	282 520	218 580	237 340	218 260
Energy	63 160	48 870	53 060	48 800
Construction	30 170	23 340	25 340	23 300
Trade	403 110	311 870	338 650	311 420
Transport	343 000	265 370	288 150	264 990
Finance	282 930	218 900	237 690	218 580
Services	637 290	493 060	535 380	492 340
Households	1 904 500	1 473 460	1 599 950	1 471 330

10.5.3. EMPLOYMENT EFFECT

The impact of Scenarios 3 and 3(+) on the employment in the region is indicated in Figure 10.27.

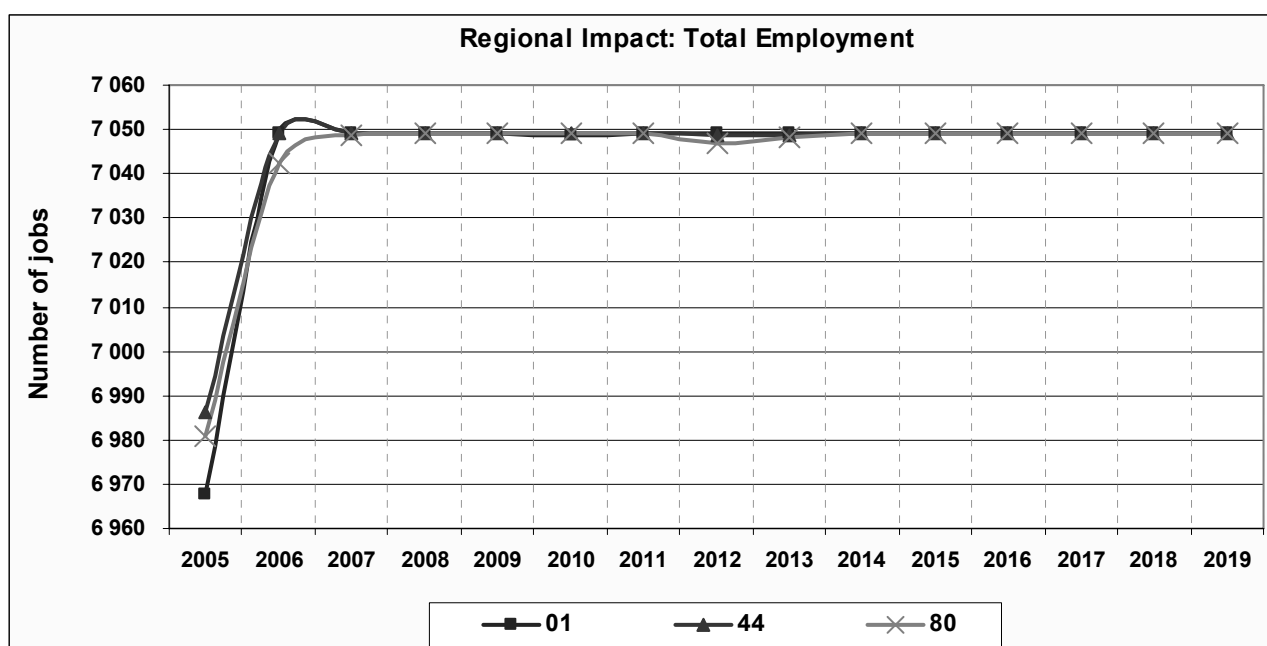


Figure 10.27. New sustained employment opportunities in the regional economy (number of jobs), for the period 2005 to 2019, for stochastic runs 01, 44 and 80

With this scenario an average of about 6 920 jobs could be sustained in 2005 up to 6 990 jobs by 2019 in the regional economy. This represents about 11.2% of the current labour force in the study area, but also 68.5 % of the agricultural labour force (2005).

10.5.4. OTHER SECONDARY IMPACTS

The above impacts have direct implications on the creation of new GGP in the study area (that is, per definition, the value of intermediary goods and services provided within the borders of the study area for a given period). Figure 10.28 indicates the overall impact of the agriculture development on the rest of the regional economy in Scenario 3, while Figure 10.29 indicates the expected impact on GGP per Scenario 3(+). The different impact values are a result of the different margins being experienced between the two Scenarios, which, in turn, is influenced by varying input costs due to the two irrigation options.

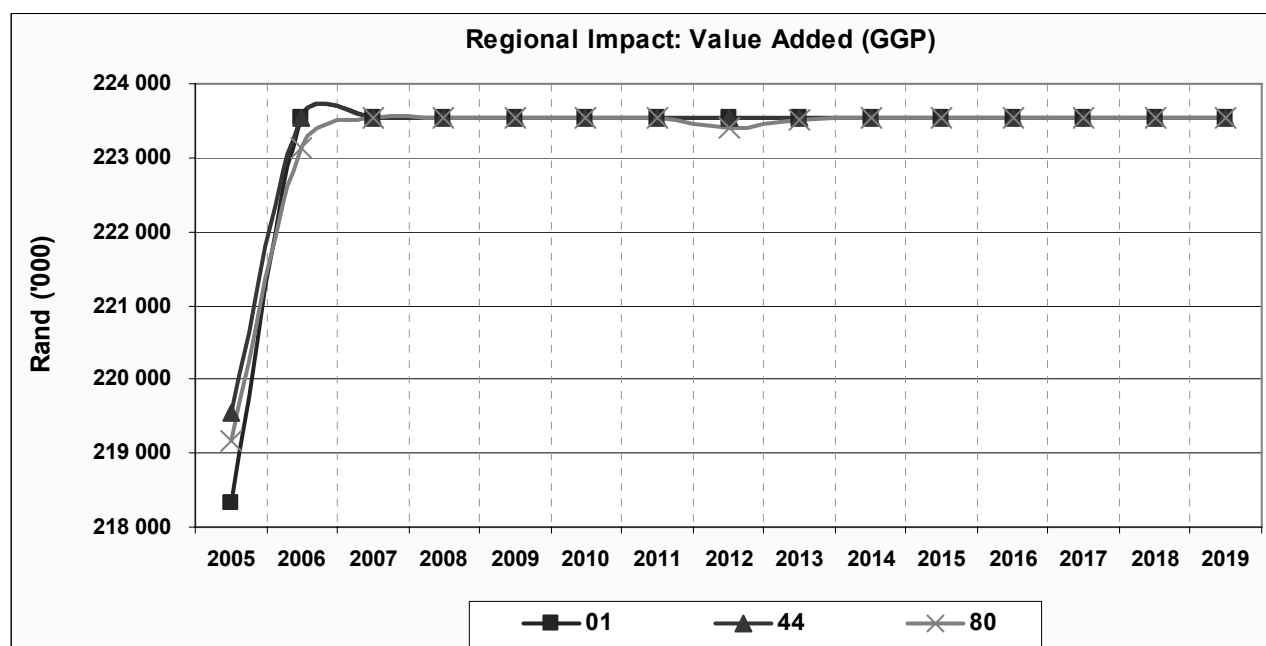


Figure 10.28. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80 for Scenario 3

It is evident that the total GGP generated could increase from R219.5 million in 2005 to R223.5 million in 2019. The values calculated within this period range from a minimum of R218 million to R223.5 million. This represents around 88.4% of the total agriculture GGP in the region in 2005 (2.9% of the total GGP) and 102.0% of total agriculture GGP in 2019 (2.2% of total GGP).

Comparing to the Base Case Scenario, this represents on average an increase of between 35.1% and 45.6% of current GGP production.

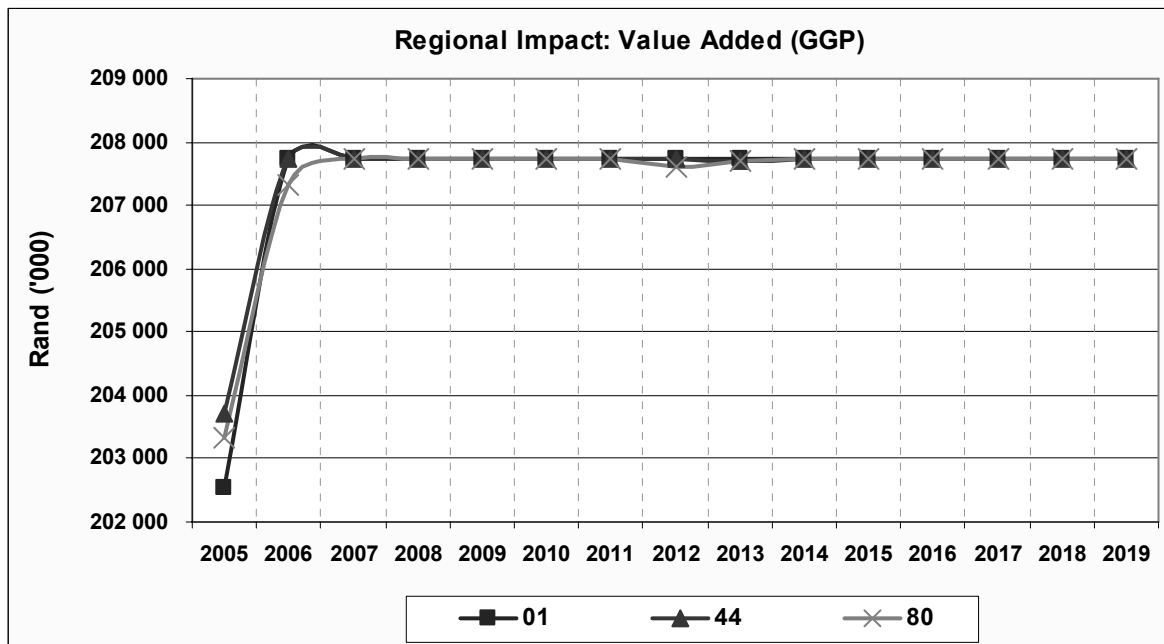


Figure 10.29. New GGP generated in the regional economy (R'000), for the period 2005 to 2019, for stochastic runs 01, 44 and 80 for Scenario 3+

The total GGP generated could increase from R203.3 million in 2005 to R207.7 million in 2019. The values calculated within this period range from a minimum of R202.5 million to R207.7 million. This represents around 81.9% of the total agriculture GGP in the region in 2005 (2.6% of the total GGP) and 94.7% of total agriculture GGP in 2019 (2.0% of total GGP).

The net effects of the above indicators in Rand terms are as follows:

Table 10.15. Net effect of Scenarios 3 on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019

Gain (+) / Loss (-)	Value Added	% growth	Direct output	% growth	Total output	% growth	Employment	% growth
SR 01	5 209 450	0.08	6 313 300	0.17	11 473 450	0.08	80	0.08
SR 44	4 008 030	0.06	4 884 450	0.13	8 876 700	0.06	60	0.06
SR 80	4 383 040	0.07	5 303 750	0.14	9 638 700	0.07	70	0.07

Note: SR = Stochastic Run

Table 10.16. Net effect of Scenarios 3(+) on value added and output (Rand) and employment and the resulting annual growth rate from 2005 to 2019

Gain (+) / Loss (-)	Value Added	% growth	Direct output	% growth	Total output	% growth	Employment	% growth
SR 01	5 209 450	0.08	6 313 300	0.17	11 473 450	0.08	80	0.08
SR 44	4 008 030	0.06	4 884 450	0.13	8 876 700	0.06	60	0.06
SR 80	4 383 040	0.07	5 303 750	0.14	9 638 700	0.07	70	0.07

Note: SR = Stochastic Run

10.6. SCENARIO COMPARISON

The impact results of the five analysed scenarios are compared by means of Figures 10.30 to 10.33. This comparison is done for the following indicators:

- Output in the agriculture sector (direct output) measured in Rand
- Total output in the regional economy, measured in Rand
- Gross Geographic Product for the region, measured in Rand
- Total employment for the region, measured in number of sustainable employment opportunities or jobs.

Each of the figures depicts:

- A comparison based on the results measured through the 50th percentile done on the stochastic runs
- A comparison of the “best case scenario”, namely stochastic sun number 44
- A comparison of the “worst case scenario”, namely stochastic sun number 01

Figure 10.30. Comparative output (R'000)
in the agriculture sector,
2005 to 2019

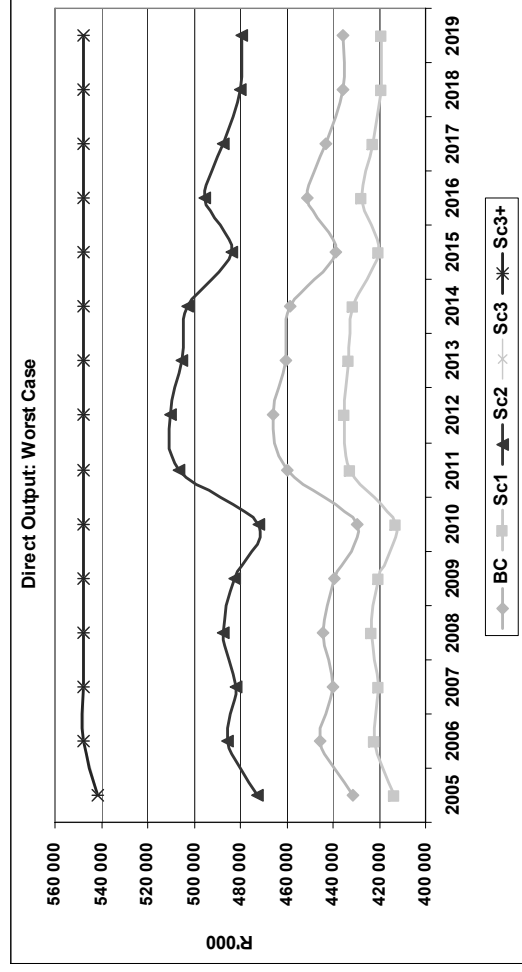
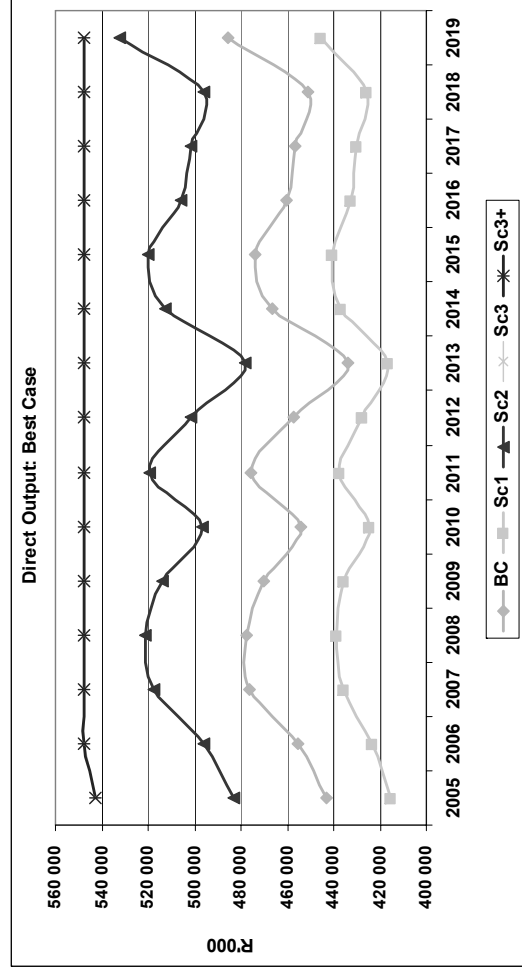
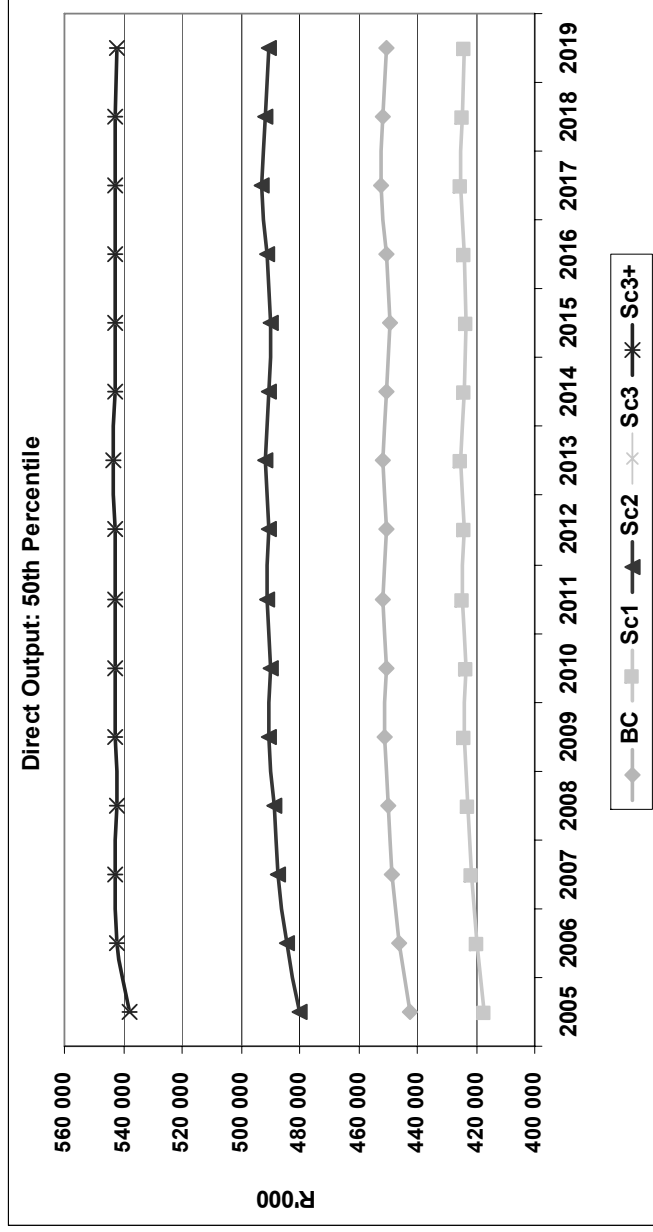


Figure 10.31. Comparative total output (R'000)
in the regional economy,
2005 to 2019

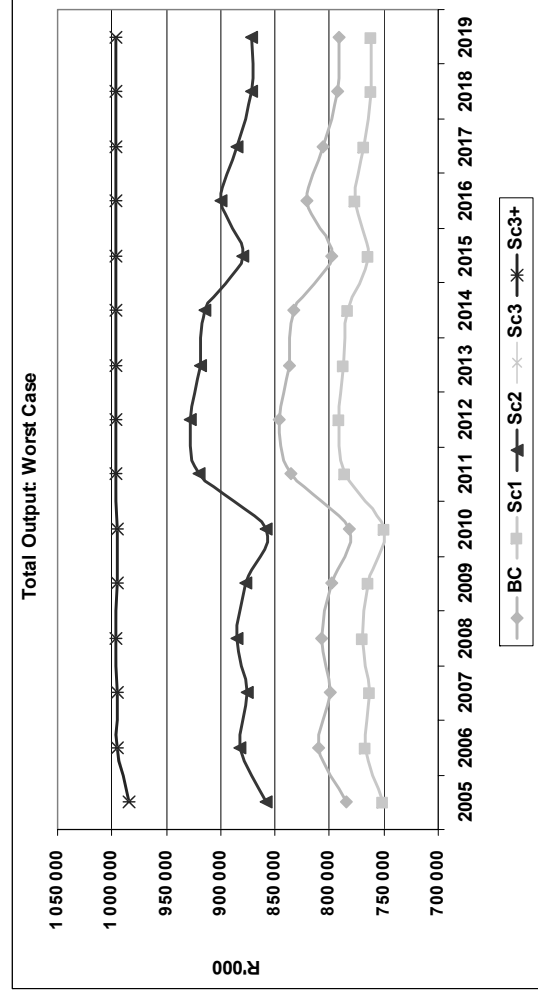
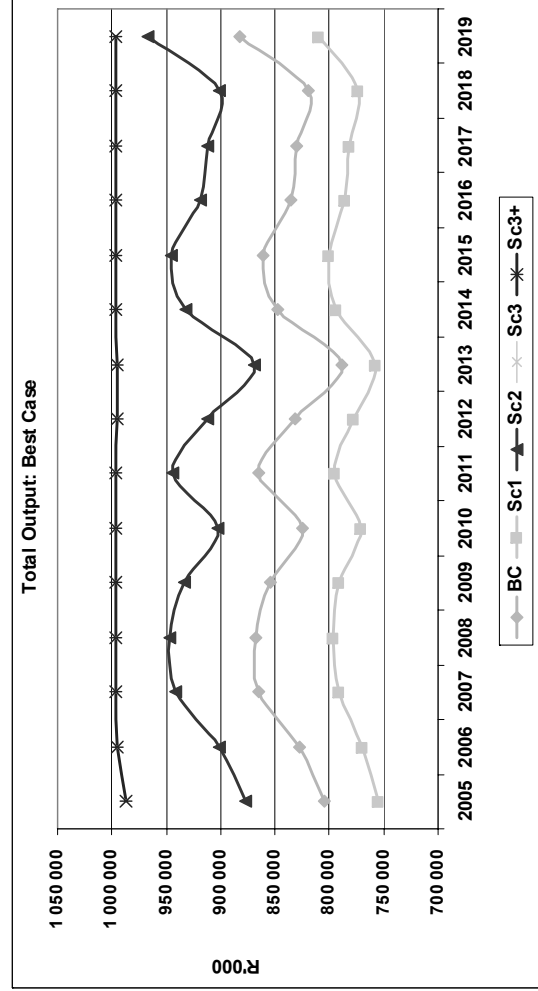
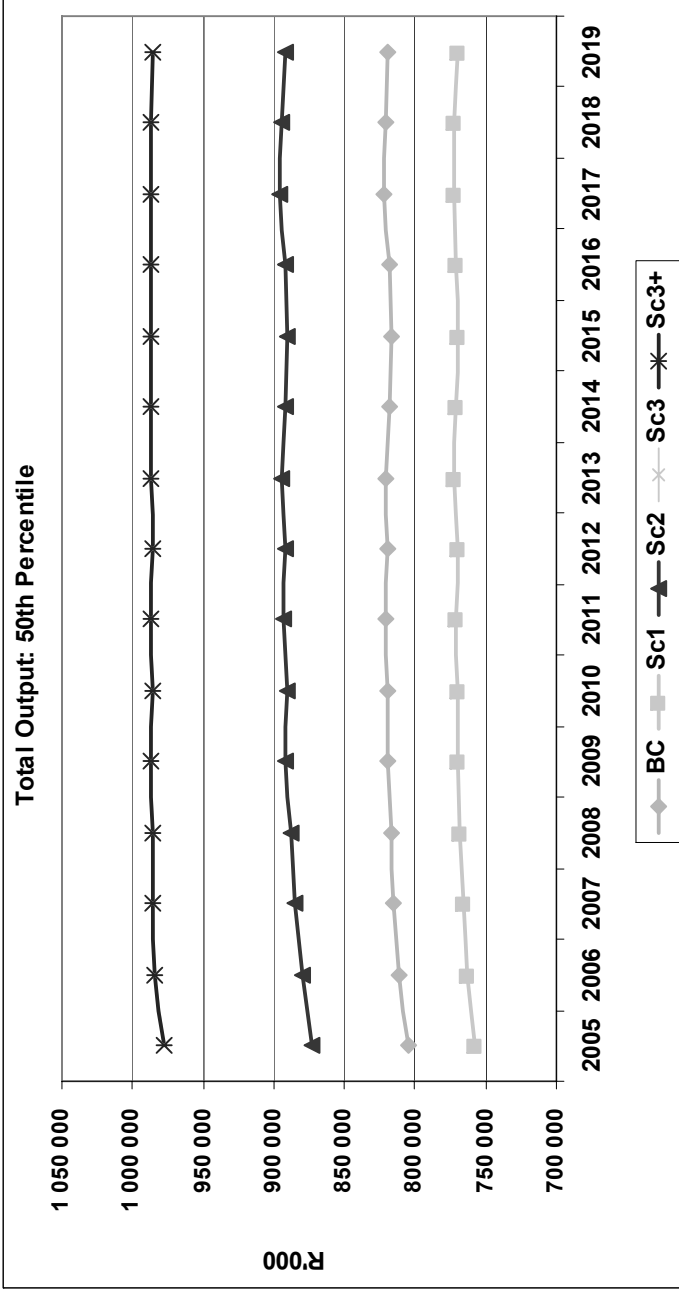


Figure 10.32. Comparative GGP (R'000)
in the regional economy,
2005 to 2019

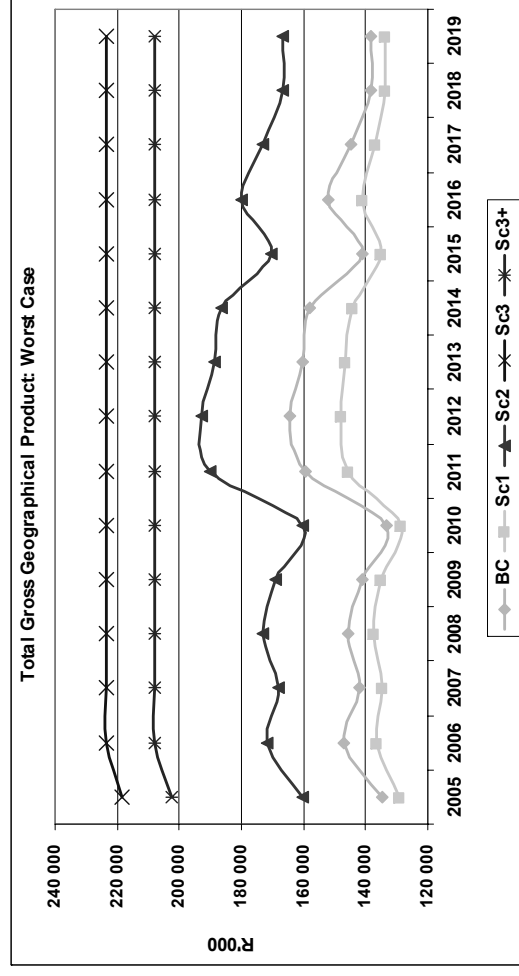
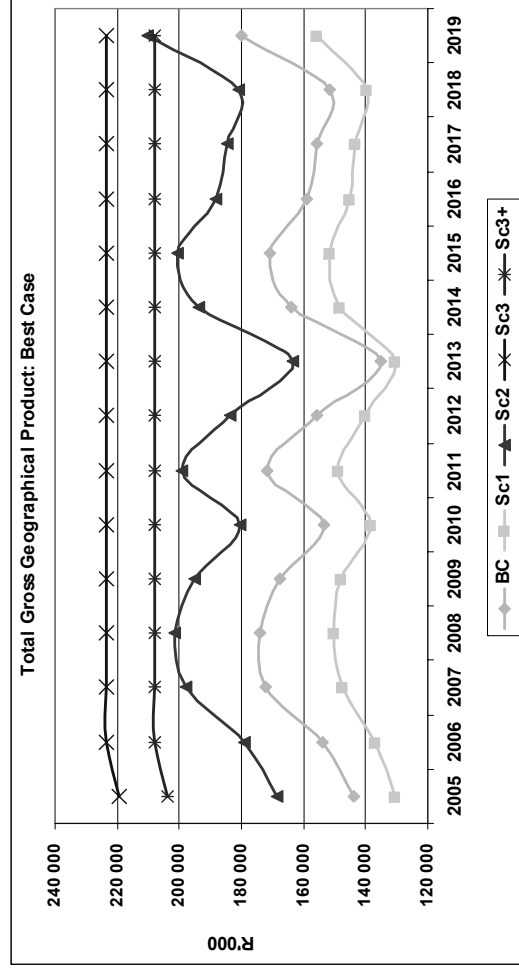
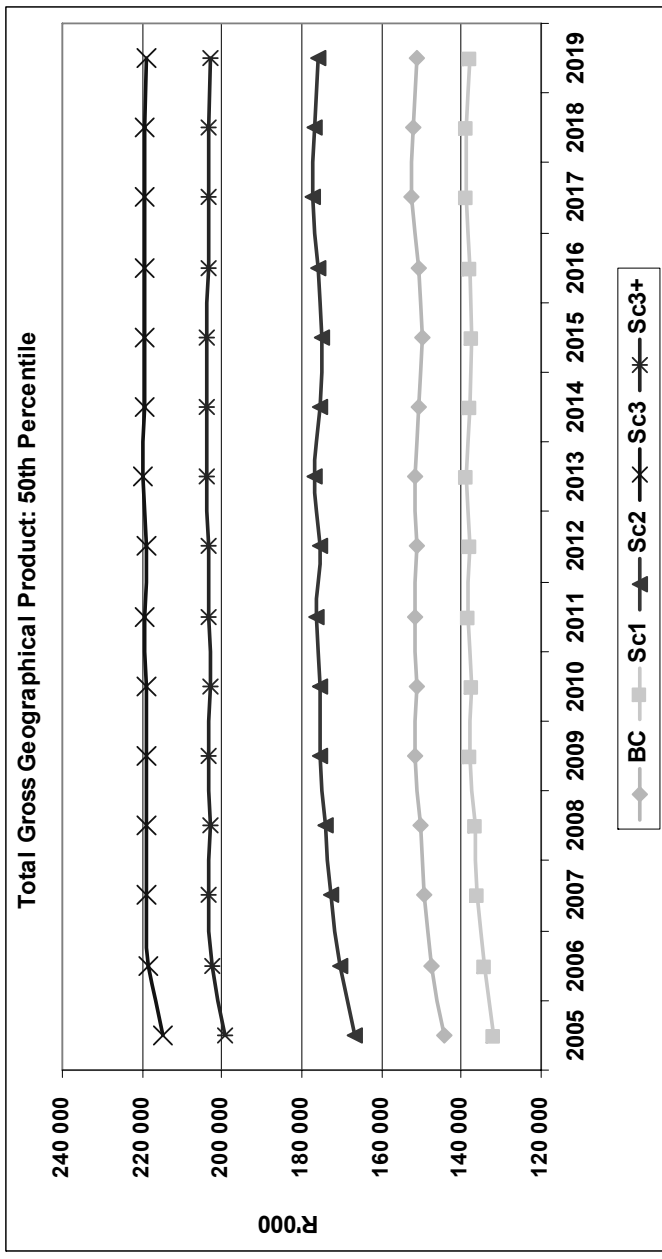
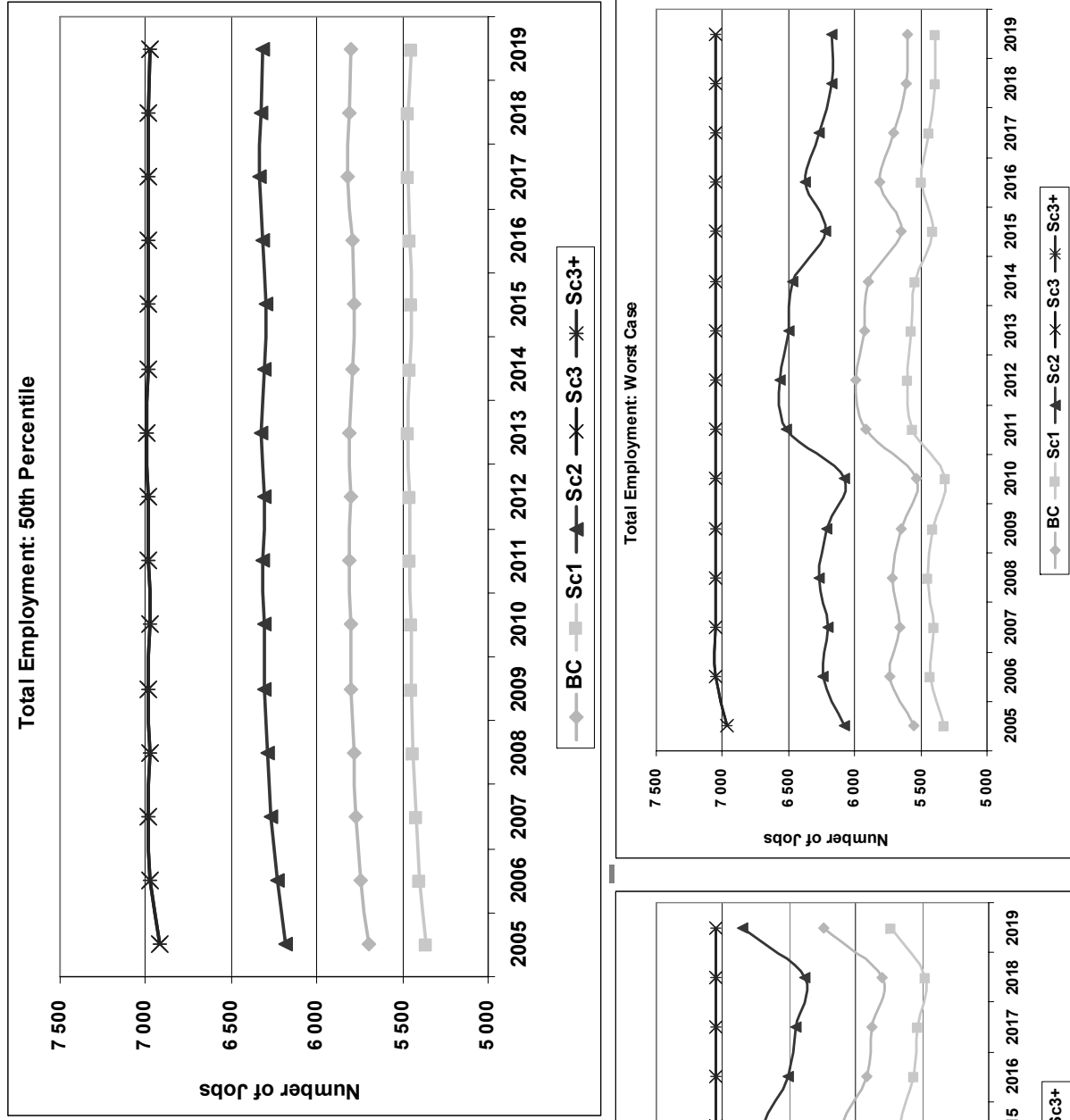


Figure 10.33. Comparative employment (R'000)
in the regional economy,
2005 to 2019



10.7. LONG TERM SUSTAINABILITY OF IRRIGATION

10.7.1. INDEX FOR SOCIO-ECONOMIC WELFARE

As indicated in Chapter 7, the ISEW is calculated by taking into account the following elements of sustainable development:

- An *economic pillar* which takes into account the incremental change in production value adding in the regional economy, which is calculated by the sum of the net profit generated in the study area and labour remuneration.
- A *social pillar*, which takes into account an assessment of the number of persons being employed as a direct result of the project (as determined by increased labour costs) as a proportion of the total economically active population in the study area.
- An *environmental or resource aspect*, which considered soil salinity. Soil salinity in this case is a function of the balance between abstraction channel salt and return flow salts (therefore the build up of salt levels).

An ISEW value of one (1) or higher represents a situation that can be considered as sustainable, while an ISEW value of less than one represents a potentially unsustainable economic welfare environment. Details with regards to the results calculated for each of the scenarios are indicated in Appendix 5.

The main ISEW results for the three scenarios (with the four stochastic runs) are indicated in the following figures.

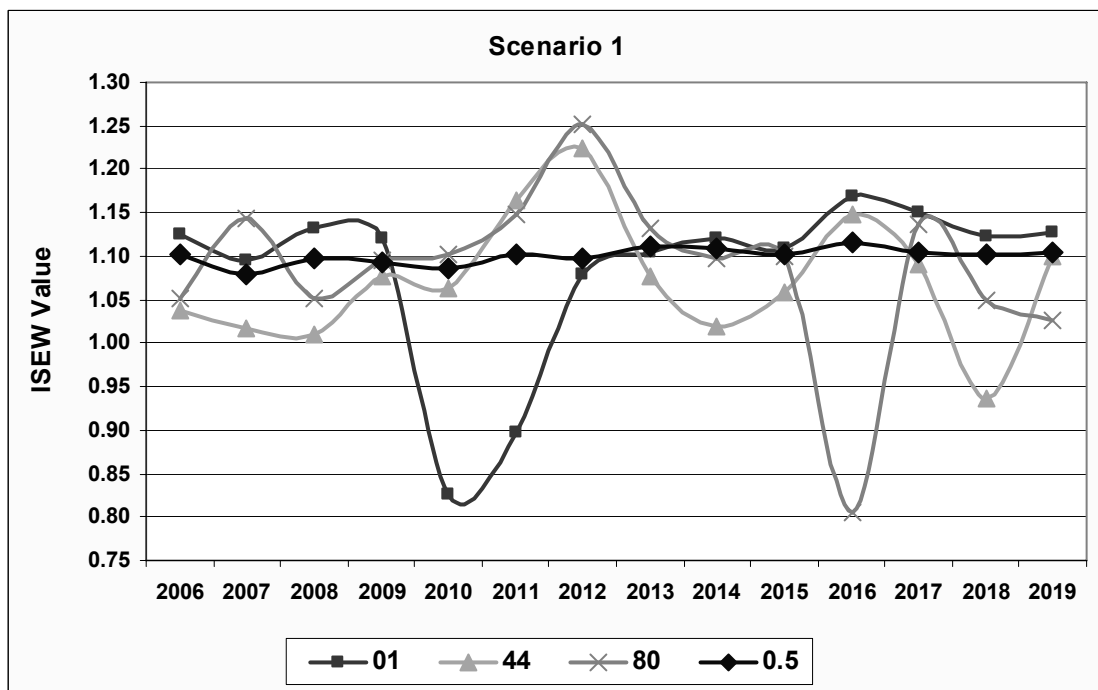


Figure 10.34. Scenario 1: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)

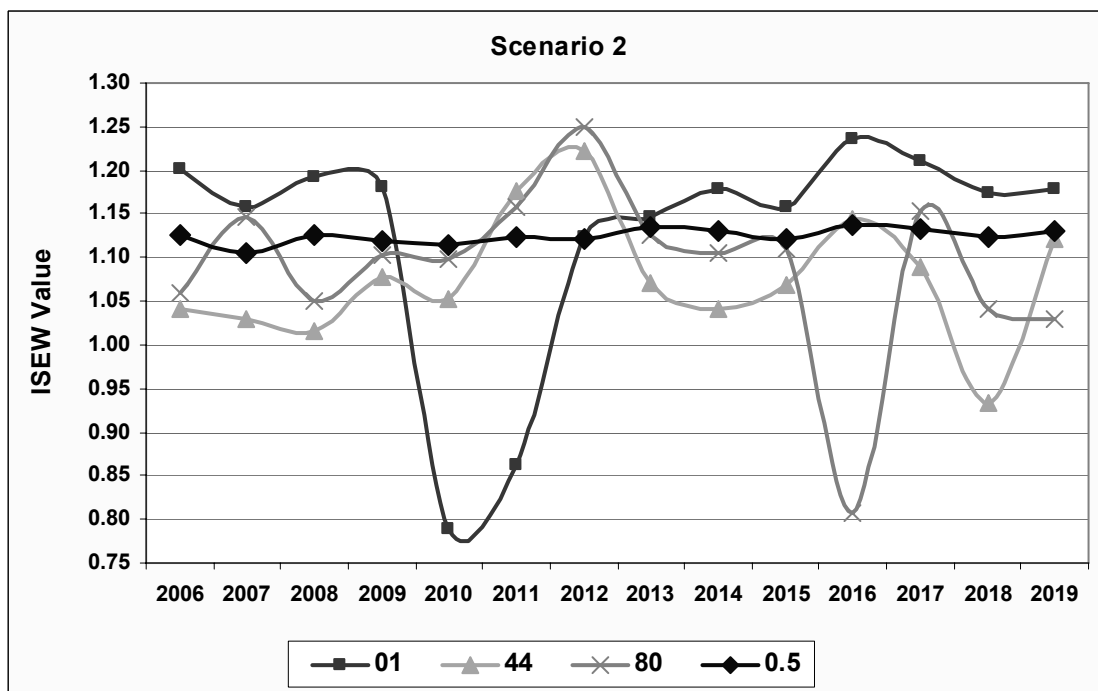


Figure 10.35. Scenario 2: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)

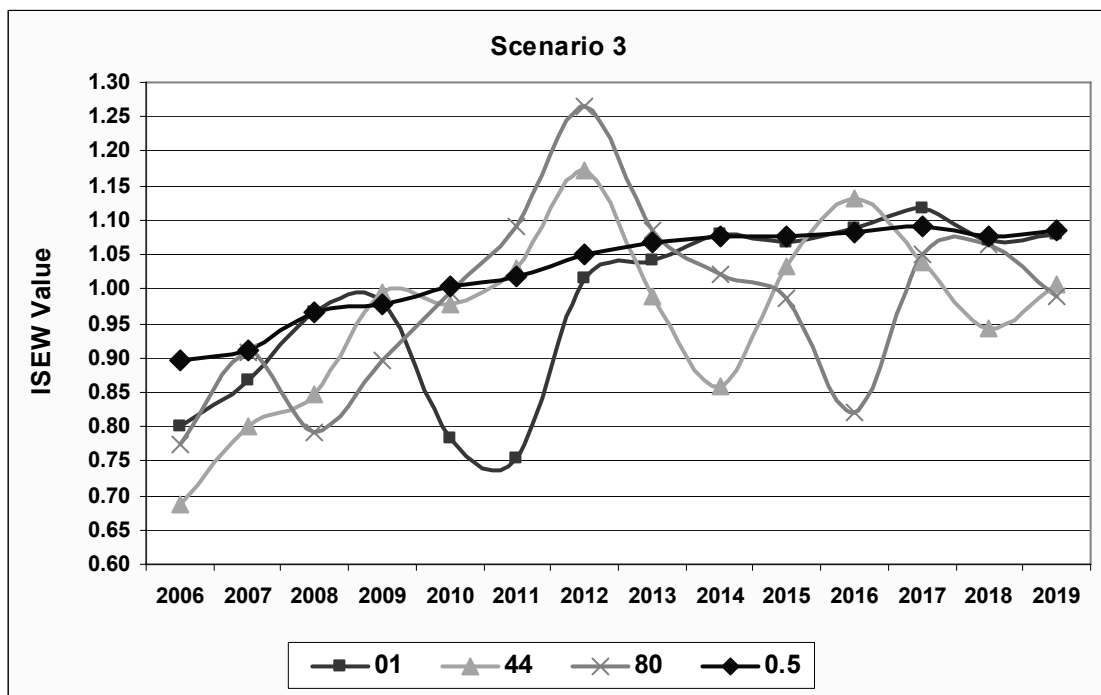


Figure 10.36. Scenario 3: ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)

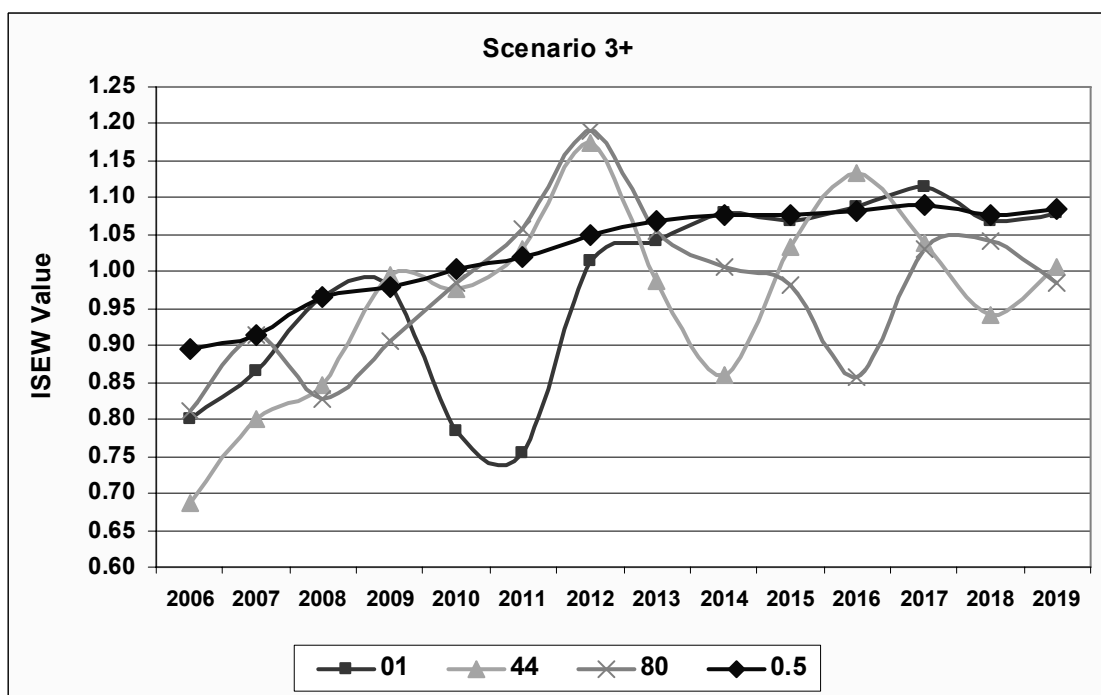


Figure 10.37. Scenario 3(+): ISEW for the period 2005 to 2019 (stochastic runs 01, 44 and 80, as well as the 50th percentile)

10.8. SUMMARY

The impact analysis results described in this Chapter, with the supplement of Appendix 5, indicates the following:

a) SCENARIO 1

The regional economy could generate around R757.9 million worth of output in 2005 (5.0% of the regional economic output) to about R770.2 million in 2019 (3.1% of the expected regional output in 2019). The calculated outputs during this period could vary between R745.9 million to R810.0 million. With this scenario an average of about 5 370 job opportunities could be sustained in 2005 up to 5 450 in 2019 in the regional economy. This represents about 8.5% of the current labour force in the study area, but also 53.1 % of the agricultural labour force (2005). The total GGP generated could increase from R132.0 million in 2005 to R137.7 million in 2019. The values calculated within this period range from a minimum of R128.4 million to R155.7 million. This represents around 54.3% of the total agriculture GGP in the region in 2005 (1.8% of the total GGP) and 64.2% of total agriculture GGP in 2019 (1.4% of total GGP).

Net effect calculations indicate that between R2.6 million and R25.2 million of GGP could additionally be created, with new total output between R5.6 million and R54.6 million and between 40 and 387 job opportunities.

b) SCENARIO 2

The regional economy could generate around R872.7 million worth of output in 2005 (5.7% of the regional economic output) to about R891.8 million in 2019 (3.6% of the expected regional output in 2019). The calculated outputs during this period could vary between R751.5 million to R947.1 million. With this scenario an average of about 6 180 job opportunities could be sustained in 2005 up to 6 300 in 2019 in the regional economy. This represents about 10.0% of the current labour force in the study area, but also 61.2 % of the agricultural labour force (2005). The total GGP generated could increase from R166.8 million in 2005 to R175.8 million in 2019. The values calculated within this period range from a minimum of R128.4 million to R155.7 million. This represents around 68.7% of the total agriculture GGP in the region in 2005 (2.2% of the total GGP) and 82.0% of total agriculture GGP in 2019 (1.7% of total GGP).

Net effect calculations indicate that between R1.6 million and R41.4 million of GGP could additionally be created, with new total output between R3.2 million and R89.8 million and up to 640 job opportunities.

c) SCENARIO 3 and 3(+)

The regional economy could generate around R977.0 million worth of output in 2005 (6.4% of the regional economic output) to about R985.8 million in 2019 (4.0% of the expected regional output in 2019). The calculated outputs during this period could vary between R985 million to R995 million.

With this scenario an average of about 6 920 jobs could be sustained in 2005 up to 6 990 by 2019 in the regional economy. This represents about 11.2% of the current labour force in the study area, but also 68.5 % of the agricultural labour force (2005).

The total GGP generated could increase from R214.8 million in 2005 to R218.9 million in 2019 for Scenario 3. The values calculated within this period range from a minimum of R214 million to R223.5 million. This represents around 88.4% of the total agriculture GGP in the region in 2005 (2.9% of the total GGP) and 102.0% of total agriculture GGP in 2019 (2.2% of total GGP).

GGP generated in Scenario 3(+) range from R203.3 million in 2005 to R207.7 million in 2019. this is mainly due to increased costs to the farmers that affects the gross margins of the agricultural production. The values calculated within this period range from a minimum of R202.5 million to R207.7 million. This represents around 81.9% of the total agriculture GGP in the region in 2005 (2.6% of the total GGP) and 94.7% of total agriculture GGP in 2019 (2.0% of total GGP).

Net effect calculations for both scenarios indicate that between R4.0 million and R5.2 million of GGP could additionally be created, with new total output between R8.9 million and R11.4 million and up to 80 job opportunities.

d) **SCENARIOS COMPARED TO BASE CASE SCENARIO**

Table 10.17. Comparison of regional economic impact results in Scenarios 1, 2, 3 and 3+ with Base Case Scenario, 2005 to 2019

	<u>Scenario</u>				
	Base Case	Sc 1	Sc 2	Sc 3	Sc 3+
Average direct output (2005-2019)	449 800	423 126	489 390	542 406	542 406
% of Base Case Scenario Results	-	94.1	108.8	120.6	120.6
Average GGP (2005-2019)	150 305	137 161	174 626	218 855	203 040
% of Base Case Scenario Results	-	91.3	116.2	145.6	135.1
Average Employment (2005-2019)	5 787	5 444	6 297	6 979	6 979
% of Base Case Scenario Results	-	94.1	108.8	120.6	120.6

It is evident that the overall level of impact on the regional economy of the study area increases as alternative scenarios are considered. Scenario 2 produces higher values in total output, GGP and jobs than Scenario 1. Similarly, Scenario 3 and 3(+) results in higher values than Scenarios 1 and 2. Scenarios 1 and 2 are also very cyclical in nature due to varying gross income levels, which in turn is linked to varying salinity levels and yield. Scenarios 3 and 3(+) is considered to have a more stable regional impact. These impacts did not consider price fluctuations or market volatility. Scenario 1 is the only scenario in which the overall regional economic impacts are lower than those assessed for the Base Case Scenario. It is also evident that Scenarios 3 and 3+ results in a substantial improvement in terms of production output, GGP generation and job creation.

e) **ISEW**

When considering the indices for sustainable economic welfare, it is also evident that all three scenarios will contribute towards increased economic welfare, based on the indicators measured, but that Scenarios 3 and 3(+) will have a steeper improvement in the overall sustainability levels.

CHAPTER 11. POLICY IMPLICATIONS AND RECOMMENDATIONS

by R.J. Armour, and M.F. Viljoen - UFS

11.1. INTRODUCTION

In this chapter some policy options for the management of salinity are discussed, together with the applicability of the various options on per hectare, irrigation block, WUA and regional levels.

The first section of this chapter deals with the various policy options available for implementation at the various levels. Specifically, a sensitivity analysis of scenario 3+, whereby farmers' ability to pay for increased drainage and various cross subsidisation options is analysed. The next section of this chapter reviews the conclusions from the results of policy options and discusses their policy implications for various spatial levels of modelling.

The final section of this chapter deals with the regional impacts of salinisation and various possible policy implications at regional level, stressing the regional importance of irrigation agriculture and the impact that improved agricultural production due to better salinity management and control can have on the region as a whole.

11.2. POLICY OPTIONS

The following policy options to manage salinity are discussed in this section:

- Leaching incentives
- Drainage grant assistance
- Return-flow management options
- Efficient and effective water usage charges
- Farmers' willingness to pay for drainage: a sensitivity analysis and cross subsidisation options
- Changes in crops grown
- Correct institutional framework for salinity management
- Salinity awareness program

A holistic approach incorporating most / all of the above options needs to be implemented to optimally manage salinity. Leaching cannot be practiced if there is not sufficient drainage. Once drainage has been installed, irrigation returnflows become a point source of pollution and needs to be managed, through either on-farm or irrigation block / sub-WUA level drainage collection canals and storage dams. These drainage and return-flow infrastructure costs have to be recouped through efficient and effective water charges, where the farmers' willingness to pay has been properly considered. Where drainage and return-flow management are not an option and soil has become salinised, all that remains is to change to more salt tolerant crops. Where a whole WUA, or irrigation block is salinised then the WUA and / or the local agricultural co-operative / company (e.g. GWK) may need to facilitate the change to more tolerant crops by providing enough water at the right price or the processing capacity for the new crops. For all of the above to happen the correct institutional framework has to be in place, and irrigators need to be made aware of the risks and management options for effective sustainable salinity management.

11.2.1. SALINITY LEACHING INCENTIVES

Increasing the cost of irrigation water results in irrigators being more careful with their water, leading to less unintentional leaching and an increase in salinisation, hence the leaching paradox (Armour and Viljoen, 2002). This paradox is prevented if the increased water costs are used at WUA level to improve the irrigation water quality through dilution with more Orange River water pumped into the system. Dilution however, does not facilitate the leaching of the salts already accumulated in the soils. Free or reduced cost irrigation water could be made available during periods of high river flow (see Figure 9.4 in Chapter 9) or in periods of low distribution canal usage (Table 8.8 in Chapter 8) to provide an incentive for farmers to flush the salts out of their soils.

The farmers also need to know that they do have a salinity problem, or potential salinity problem before they will be convinced to leach. Encouraging regular soil salinity measurement, through either subsidising it or further developing easy infield measurement techniques (see Figure 11.1) will help promote leaching. Fertilizer companies should also include soil salinity testing in their soil test at the beginning of each season before cropping choice and cultivar is decided on by the farmer.

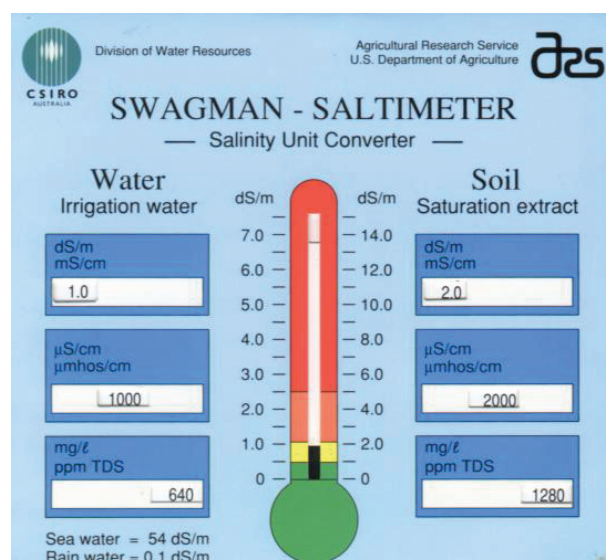


Figure 11.1. A possible infield Ece testing kit comprising of a soil bore, vacuum pump and filter (far left), salt meter (left) and a conversion chart (top)

The current water tariff charge system in the study area is based on the hectares of crops planted, and therefore a derived water use, and not on an exact measured water use. Therefore, if farmers pump themselves and are not dependent on the canal infrastructure to deliver water to their farms, and they are irrigating on fallow land, or in-between crops, they do not necessarily pay the WUA for the water used. These irrigators do however pay for the electricity to pump the water, and face possible constraints in time before they can get their tractors back onto the land for preparation and planting of the following crop.

11.2.2. DRAINAGE GRANT ASSISTANCE

Figure 11.2 clearly shows the significant impact of increasing the return-flow factor by 15% on the saturated soil salinity in the upper zone. In the first month already, there is a salt concentration reduction of 1000 mg/l, with a declining trend over the following 5 years to stabilize at a safe new equilibrium of just under 500 mg/l. Below a saturated soil salinity of 600 mg/l there is very little impact on crop yield.

Table 11.1. The determination of the increased water charge to pay for 15% additional underground leaching for Scenario 3

Scenario 3+ additional leaching costs					
Sub Irrigation Block	Vall	RloR	Rscm	Rszg	ALL
Base Case return-flow factor	4.5%	2.0%	1.5%	2.5%	2.5%
Scenario 3 return-flow factor	19.5%	17.0%	16.5%	17.5%	17.5%
Area (ha) per sub- block	7389.6	3852.8	12335.1	641.2	24218.7
WRPM modeled drainage increase					
	15.0%	15.0%	15.0%	15.0%	15.0%
Drainage increase (ha)	1108.4	577.9	1850.3	96.2	3632.8
Total additional drainage Costs	33 253 200	17 337 600	55 508 040	2 885 400	108 984 240
Minus subsidised deposit (10%)	29 927 880	15 603 840	49 957 236	2 596 860	98 085 816
Amortised annual payments	3 712 819	1 935 795	6 197 639	322 164	12 168 417
Value of assistance	3 325 320	1 733 760	5 550 804	288 540	10 898 424
Water use cost (R/m³)	Vall	RloR	Rscm	Rszg	ALL
Water cost (R/m ³ /ha)	0.35	0.49	0.82	0.45	0.61
Water quota (m ³ /ha)	1 100	1 100	1 100	1 100	1 100
Water quota use (m ³)	8 128 560	4 238 080	13 568 632	705 320	26 640 592
Water Charge (R/block)	2 844 996	2 072 652	11 144 288	319 645	16 381 580
TOTAL WUA/block obligations (R)	6 557 815	5 298 977	17 341 926	641 808	31 335 966
Water Cost with drainage (R/m ³ /ha)	0.81	1.25	1.28	0.91	1.18
Percentage increase in water costs	57%	61%	36%	50%	48%
Actual water use (m³)					
Base-Case	8 506 028	4 881 786	14 836 968	762 149	28 986 931
Scen1	7 075 078	4 276 398	15 001 319	767 091	27 119 885
Scen2	7 933 108	4 664 869	14 734 871	758 668	28 091 516
Scen3 and Scen3+	9 071 832	5 350 879	16 912 438	869 692	32 204 842
Change in Water revenue (%)					
Base-Case	0.04	0.13	0.09	0.07	0.08
Scen1	-0.15	0.01	0.10	0.08	0.02
Scen2	-0.02	0.09	0.08	0.07	0.05
Scen3 and Scen3+	0.10	0.21	0.20	0.19	0.17

At the bad case stochastic run 001, a saturated soil salinity level of around 3 350 mg/l results in significant yield losses from sensitive and medium tolerant crops. The increased installation of artificial drainage should therefore clearly have a dramatic effect on the saturated soil salinity levels in the soil and hence on crop yields, farm profit and regional socio-economic welfare.

The factors used in calculating the annual repayments in scenario 3+ in Table 11.1 are as follows:

- Installation of artificial drainage at **R 30 000¹** per ha (in-between the cost of drainage for medium and heavy soils – see Table 6.3, and slightly inflated for the average soil types irrigated in the study area, to include in the costs of drainage other secondary / hidden costs),
- A fully subsidised deposit of **10%** of the total drainage costs,
- repaid over a period of **15** years,
- and at a **9%** interest rate (subsidised)

Table 11.1 demonstrated the calculations required to internalise the costs of irrigation drainage into the water charge. Modelled in the WRPM scenario is a 15% increase to the existing irrigation and drainage return flow factors for each irrigation block. With the additional costs of drainage factored into the water charge, using the factors listed above, an increase in water charge of between 36% for the **Rscm** and 61% for **RloR** result. From existing water costs, water quotas and irrigated area the change in the current actual water use and revenue is determined.

11.2.3. RETURN-FLOW MANAGEMENT OPTIONS

11.2.3.1. Implementing the Polluter Pays Principle for salinity

A definition of the Polluter Pays Principle (PPP) from the MSN Encarta web dictionary is “**principle that causer of pollution pays**: the principle that a company that causes pollution should pay for the cost of removing it, or provide compensation to those who have been affected by it”

(http://encarta.msn.com/dictionary_561547833/polluter-pays_principle.html.)

The installation of artificial drainage creates a point source for irrigation water pollution. A point source facilitates collection, management and disposal of returnflows, for which a management fee, as opposed to a fine should be paid in accordance with the polluter pays principle. Introducing the additional cost as a management fee, instead of as a fine, has a positive connotation and therefore better willingness to pay by irrigators.

11.2.3.2. Waste Discharge Charge System

Research conducted by DWAF (2003) to determine the rates to charge for waste discharge into rivers in accordance with the PPP provides guidelines for a Waste Discharge Charge System. However irrigation salinisation is an interesting problem as it receives salt from the river source and concentrates it before returning it back to the river. It doesn't generate waste, it just concentrates it, or mobilizes it. Charges for salinisation still need to be formulated.

Where drainage collection dams are built, a stepwise scaled discharge charge could be levied, based on the dilution capacity of the river. During periods of high river flow, lower rates should be charged for saline wastage discharged. The capacity sharing concept has been applied to wastage discharge (Dudley 1992), whereby

¹ Note: drainage costs can range from R12000-R15000 on sandy soils (<15% clay), R20000-R25000 on medium soils (15-35% clay), and R30000-R50000 on heavy soils (>35% clay) – see Table 6.3.

shareholders hold a proportionate share of the dilution capacity of a body of water. Shareholders can either use their dilution capacity share or trade it if not required at a particular time.

Where the damage or impact due to salinity is high and high rates charged, the high opportunity cost of water will lead to other uses for the salinised drain water. An example of the reuse of such drainage water is applied in the concept of Sequential Biological Concentration (SBC) (Blackwell, 2002).

11.2.3.3. Regional return-flow capture by WUAs

Due to limited on-farm space, limited financial resources and a lower water use productivity of farm level storage dams, sub-WUA level collection, storage and management of irrigation returnflows would be financially a more sustainable option. The externality prevented in this way should be internalized into the irrigation water tariff for the sub-WUA. Downstream irrigators benefiting from the return-flow management intervention, could also be charged more for better water quality to subsidize the drainage management costs upstream.

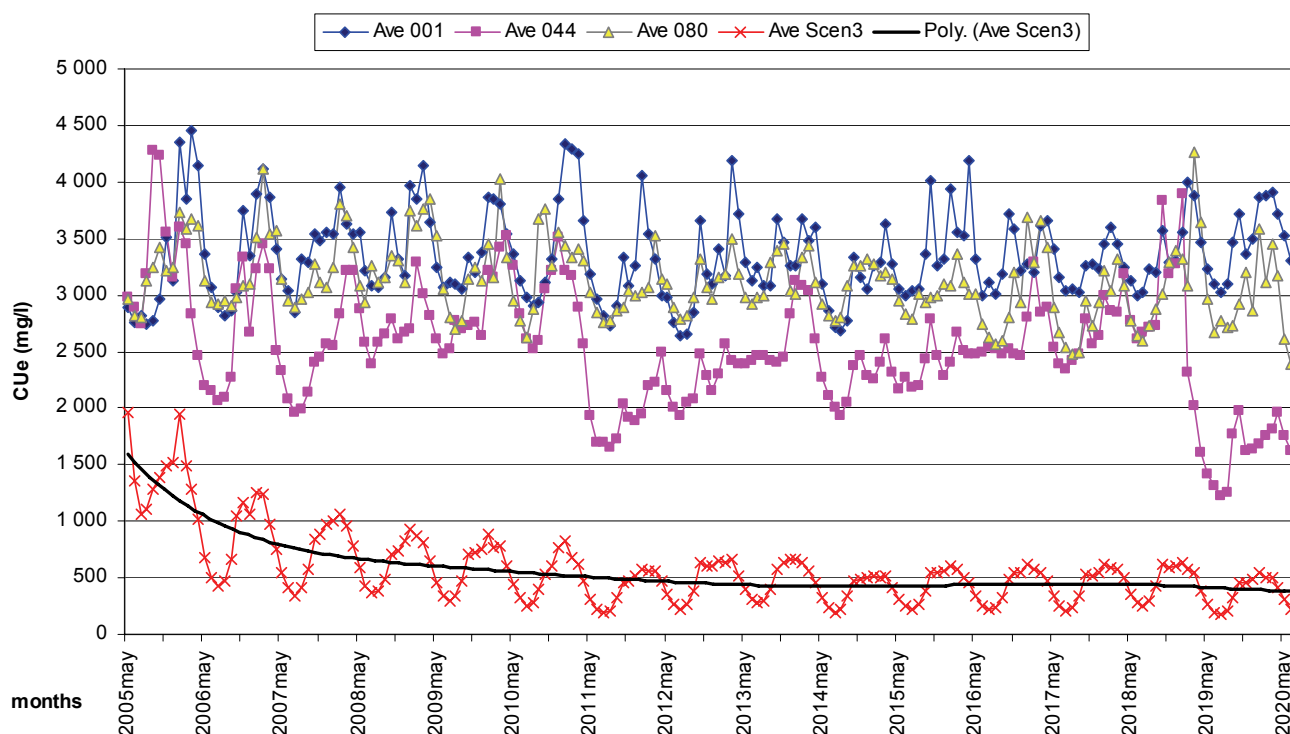


Figure 11.2. CUe for the 3 stochastic runs under analysis averaged for the Base-Case, Scenario 1 and Scenario 2 and the average of the 3 stochastic runs for Scenario 3 for all irrigation blocks

Financial results show that after the first 2 years of increasing drainage by 15% stable maximum returns are obtained, indicating that the CUe has gone below levels that impact crop yield in the **RloR** Irrigation Block (+/- 700 mg/l). Figure 11.2 shows how the CUe for Scenario 3 stabilises (with steady seasonal cycles) after 5 years from drainage installation, way below levels affecting crop yields.

11.2.4. EFFICIENT AND EFFECTIVE WATER CHARGING

11.2.4.1. Willingness to pay for water of different qualities

The marginal willingness to pay for water quality (i.e price to pay for one additional unit improvement in water quality) determines the demand curve for water of a specific water quality. Within a season, a farmer may only

need a certain water quality for germination when a plant is particularly vulnerable to salinity, but thereafter crop growth may no longer be sensitive to salinity. The marginal willingness to pay for water of a specific quality is therefore crop and time specific. With many farmers all using the same water delivery canal or river, it is very difficult for a WUA to meet all their individual requirements.

11.2.5. FARMERS' WILLINGNESS TO PAY FOR DRAINAGE: A SENSITIVITY ANALYSIS AND CROSS SUBSIDISATION OPTIONS

The hydrology basis at which this analysis is conducted, is for scenarios 3 and 3+ whereby a 15% increase in irrigation returnflows is simulated in the WRP model. The financial analysis of scenarios 3 and 3+ revealed that the **Rscm** and **Rszg** Irrigation Blocks didn't require as much drainage as 15%, and that the **RloR** was in need of more, proportional to the respective irrigated areas. By parametrically changing the return flow factor (leaching and drainage percentage) by factors of 5%, the best irrigation block TGMASC results were obtained where return flow percentage was increased from 15% to 20% in **RloR**, reduced to 10% in **Vall** and reduced to 5% for both the **Rscm** and **Rszg**, by evaluating the resulting economic impact. The results of this analysis are shown in Table 11.2 to Table 11.5 and discussed in Paragraph 11.3 and 11.4.

11.2.5.1. *Regional cost benefit analysis*

Two cost benefit analyses are conducted, one with 15% drainage throughout all irrigation blocks (the setup on which the WRPM hydrology results are based) and one with the drainage percentages changed, so that **RloR** is drained 20%, **Vall** 10% and both **Rscm** and **Rszg** only drained 5%. Discount rates of 0%, 5%, 8% and 10% are used to determine the net present value (NPV) of the sequence of increased TGMASC as a result of increased drainage over 15, 20, 25 and 30 years, depending on the effective lifespan of the drainage system. Although occasional maintenance is acknowledged for optimal functioning of the drains (ARC-ILI ,1997, for care and maintenance of irrigation drains) these costs have been left out of the calculation of the NPV in the costs benefit analysis as these costs are highly variable and are generally borne by the farmer and not government who is assumed to initially subsidising the drains. The results of this analysis are shown in Table 11.6 and Table 11.7 and discussed in Paragraph 11.4.

11.2.5.2. *Cross-subsidisation options*

Irrigation blocks receiving Orange River water directly (**Rscm** and parts of **Vall**) do not display yield losses due to salinisation for most crops, yet the returnflows from these irrigation blocks do affect irrigation blocks downstream. A higher water charge for the upstream farmers to compensate / remediate water quality for affected downstream farmers may be a viable policy option.

The percentage change in TGMASC between scenario 3, where the standard water charge is levied, and scenario 3+, where a proportional 43% increase in water charges across the study area are levied, results in a minimal change in TGMASC of only between 5.7 and 7.6% as shown in the last column of Table 11.4 (% change between 3 and 3+). TGMASC is therefore relatively inelastic to changes in water charges.

11.2.6. CHANGES IN CROPS GROWN

The farmers choice of crops to grow is not based purely on the most profitable crop as depicted in Table 11.3, but on the alignment of the most profitable crops with the physical, resource, capital, financial and managerial capacity of the farming operation.

At the WUA level, cropping choice influences water use consumption patterns and volumes (Figure 9.4, Chapter 9). Internal WUA policy to alleviate possible water delivery constraints can be made whereby incentives are given to plant more of certain crops that will help alleviate constraints. The OV-WUA has an internal policy in place whereby pre-year and after-year water is charged at different rates to discourage farmers from using more expensive, scarce pre-year water in the low rainfall winter months.

11.2.7. CORRECT INSTITUTIONAL FRAMEWORK FOR SALINITY MANAGEMENT

11.2.7.1. *Water trading*

The WUAs have implemented a system of water trading, but only on a very small scale and only for a season in advance at a time. The correct institutional framework for effective and efficient water trading between farmers within and in-between WUAs could automatically divert water from less efficient to more efficient water users.

11.2.7.2. *Fractional water allocation (capacity sharing)*

The concept of a fractional water allocation, or a capacity share of a water resource (or body) only accounts for a specific quantity of the water, and doesn't specifically guarantee a certain quality. The whole concept would have to be revised to account for a quality dimension. One option is to have an effective water market whereby the irrigators with highly elastic demand curves for water quality (bulk commodity, salt tolerant, low value products) can sell their water capacity share to irrigators with more inelastic water quality demand curves (long term and high value crops). Generally, the higher value the crop (e.g. fruit trees), the smaller the percentage of total production costs are attributed to water costs. Permanent crops are also generally more inelastic in their demand for water than annual crops.

11.2.8. SALINITY AWARENESS PROGRAM

The following programmes are recommended for implementation or initiation by the Department of Agriculture, WUAs, GWK, etc. in the irrigation areas:

- Agricultural extension to regularly measure soil salinity on a cost recovery basis
- Promote soil salinity status readings by fertilizer companies when conducting soil analyses and making fertilization recommendation
- Promote inquiring about the salinity status of soils when purchasing irrigation land
- Increase awareness to insurance companies of the potential increased risk of salinised soils if not managed properly.

These salinity awareness programmes must be coupled with a centralised soil salinity database to facilitate the accumulation of soil salinity data for better policy analysis and research in the future, as one of the limitation identified in this study is a shortage of historical soil salinity data.

11.3. FARM LEVEL POLICY IMPLICATIONS

Farm level policy impact is derived from analysis of the resulting total gross margin above specified costs (TGMASC) of per hectare crop enterprise budgets (CEBs) as displayed in Table 11.3. The TGMASCs of the

CEBs in Table 11.3 are derived from the crop specific weighted average saturated soil salinity values shown in Table 11.2. Among others, the change in the TGMASC for the increased water charge initiated in scenario 3+ is shown for a 15% increase in drainage and leaching, and also for different leaching fraction changes for different irrigation blocks. To prevent the installation of unnecessary drainage and to install additional drains where most needed, the uniform installation increase of 15% from scenario 3 is adjusted to the following:

- RloR increased from the base case level of 2% to 17% (+15) and increased by a further 5% to 22%
- Rscm increased from the base case level of 1.5% to 16.5% (+15), but decreased by 10% to 6.5%
- Rszg increased from the base case level of 2.5% to 17.5% (+15), but decreased by 10% to 7.5%
- Vall increased from the base case level of 4.5% to 19.5% (+15) but decreased by 5% to 14.5%

The decrease in soil salinity as a result of increased drainage and leaching is clearly evident from Table 11.2. When comparing the base-case crop specific weighted average ECe (mS/m) with the scenario 3 ECe, ECe is reduced by between 68% and 86%. The very low ECe values for **Rscm** and **Rszg** are unnecessarily low at 15% leaching and drainage and it was therefore decided to only increase drainage in **Rscm** and **Rszg** by 5%.

Where a percentage more area of drainage is installed, a corresponding equal percentage leaching fraction is applied, resulting in additional water and electricity costs over and above the physical drainage costs. It is this increase in the costs of additional leaching and drainage that are being weighed up against the financial benefits to determine the farmers ability to pay for drainage.

Irrigation farmers know what cropping combination they are able to plant on their particular farm. Table 11.3 gives an indication of the potential per hectare TGMASC attainable from different crops in the various irrigation blocks. For policy analysis at farm level, these crop specific values can be multiplied by the hectares planted / planned to plant overall to determine the potential / expected annual marginal income above fixed / operational costs.

Table 11.2. Corresponding weighted average ECe (mS/m) with 15% increased drainage area and a 15% leaching fraction

	Irrigation Block										Average	WQ improve- ment %											
	Barley	Beets	Carrots	Cotton	Cucurbits	Dry- Beans	Fruit	Lucerne	Maize	Olives			Onions	Pastures	Peanuts	Pecan- nuts	Potatoes	Soybeans	Sunflower	Vege- tables	Vineyards	Wheat	
Base Case	RloR	471	510	519	496	505	512	498	491	515	499	497	503	513	497	521	515	519	472	497	456	500	
Scenario 3 and 3+	RloR	184	194	240	103	111	118	100	97	117	101	84	99	116	98	118	117	120	79	98	63	118	0.76
Base Case	Rscm	148	152	166	173	186	192	182	177	193	183	192	188	190	182	200	193	197	167	182	165	180	0.86
Scenario 3 and 3+	Rscm	53	47	46	18	22	25	20	19	24	21	21	21	24	20	26	24	26	15	20	14	25	0.86
Base Case	Rszg	195	194	227	196	216	224	214	204	226	214	240	223	222	214	237	226	231	193	214	194	215	0.75
Scenario 3 and 3+	Rszg	61	49	125	30	54	65	47	40	63	47	59	52	58	46	71	63	70	24	46	24	55	0.75
Base Case	Vall	324	327	337	335	354	364	347	335	367	347	369	354	364	346	377	367	369	315	346	305	347	0.68
Scenario 3 and 3+	Vall	127	124	144	102	116	126	105	99	125	106	100	106	122	104	130	125	130	78	104	65	112	0.68

Table 11.3. Average annual TGMASC (R/ha) with different leaching fractions (2005 input costs and average 10yr real average crop prices)

	Irrigation Block										Average										change from BC %		
	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat			
Base Case	RloR	1533	5272	-4969	3431	9678	-3823	4190	481	3687	11286	2157	-2324	5976	-8163	6019	2353	11669	998	2345	2576	4.13	
Scenario 3 LF17%	RloR	1428	6886	6088	3299	18381	37540	6287	4825	9218	50008	2013	2164	22724	11147	6122	2354	11564	5646	2240	10626	4.13	
Scenario 3+LF17%	RloR	1107	6677	5886	2896	18109	2411	36905	6067	4502	49880	1571	1848	22389	10855	5784	2135	11241	5312	1919	10321	4.01	
Scenario 3+LF22%	RloR	946	6572	5975	2695	17973	2333	36661	5958	4350	49899	1350	1690	22247	10767	5615	2025	11080	5152	1758	10191	3.96	
Base Case	Rscm	1334	6825	8268	4317	22081	3000	36038	6223	3918	9133	44074	1883	2049	21941	10789	6023	2174	13725	6075	2146	10601	1.06
Scenario 3 LF16.5%	Rscm	1199	6737	10619	4148	21967	3174	37272	6130	4050	9010	51354	1698	1916	23276	12189	5881	2082	13589	6351	2011	11233	1.06
Scenario 3+LF06.5%	Rscm	1191	6732	10614	4139	21960	3170	37257	6125	4042	9003	51351	1687	1908	23268	12182	5873	2077	13582	6343	2003	11226	1.06
Scenario 3+LF16.5%	Rscm	879	6528	10418	3747	21696	3000	36640	5912	3728	8719	51225	1258	1601	22943	11899	5544	1863	13268	6018	1691	10929	1.03
Base Case	Rszg	1551	6967	6133	4590	22261	2856	32896	5478	3550	9331	39192	2183	2263	20683	8962	6252	2323	13944	5883	2364	9983	1.14
Scenario 3 LF17.5%	Rszg	1450	6901	10483	4463	22179	3311	37768	5312	4109	9238	51454	2043	2163	23537	12416	6145	2254	13842	6612	2262	11397	1.14
Scenario 3+LF07.5%	Rszg	1419	6881	10084	4425	22154	3295	37708	5254	4071	9211	51442	2001	2133	23506	12389	6113	2233	13811	6580	2231	11347	1.14
Scenario 3+LF17.5%	Rszg	1127	6690	10280	4058	21906	3135	37130	4692	3707	8945	51325	1599	1845	23201	12124	5805	2033	13517	6276	1939	11067	1.11
Base Case	Vall	1603	7001	2065	3572	14944	1029	15785	5399	2528	7818	25156	2253	1045	14187	179	6271	2469	11758	3187	2421	6533	1.68
Scenario 3 LF19.5%	Vall	1510	6940	9882	3456	18451	2672	37888	6343	4956	9293	50559	2126	2245	23601	11447	6209	2411	11664	5773	2328	10988	1.68
Scenario 3+LF14.5%	Vall	1331	6824	9581	3232	18299	2574	37535	6221	4776	9131	50378	1880	2069	23414	11285	6020	2289	11485	5588	2150	10803	1.65
Scenario 3+LF19.5%	Vall	1182	6726	9677	3045	18173	2493	37239	6119	4626	8995	50427	1675	1922	23259	11149	5863	2186	11335	5432	2000	10676	1.63

* all based on stochastic run number 80 for all scenarios and all irrigation blocks, with a 10% grant on the increased drainage in Scenario 3 and 3+

11.4. IRRIGATION BLOCK (/SUB-WUA) LEVEL POLICY IMPLICATIONS

Table 11.4 and Table 11.5 are an extension of Table 11.3, taking the average cropping composition for the base-case (upper half of tables) and the salt sensitive, yet higher value (lower half of tables) scenario values and working out the total annual per hectare productivity (TGMASC / ha / year). As irrigation blocks utilize land for more than one crop per year (>100%) at different rates, crop composition is standardised to 150% for all irrigation blocks (i.e. all plant 1.5 crops per year per hectare), to enable equal comparison between irrigation blocks (the bottom halves of the two scenario crop composition sub-tables in Table 11.4).

Table 11.4 is an annual TGMASC (R/ha/year) analysis of the scenarios run through the WRPM (hydrology model) where 15% additional leaching and drainage is applied to all irrigation blocks, and Table 11.5 an annual TGMASC (R/ha/year) analysis of irrigation blocks with the following additional leaching and drainage implemented: **Vall** 10%, **RloR** 20%, **Rscm** 5% and **Rszg** 5%.

Table 11.4. Annual TGMASC (R/ha/year) for different scenarios with a 15% increase in leaching and drainage implemented in all irrigation blocks (for actual and standardized crop composition percentages)

<u>Irrigation Block cropping composition</u>		SCENARIO			<u>% CHANGE</u>		
Base-case average cropping composition (% area)		Base Case	Scenario 3	Scenario 3+	<i>BCand3</i>	<i>BCand3+</i>	<i>3and3+</i>
Vall	151%	4953	7351	6884	148%	139%	-6.36%
RloR	185%	2075	8750	8175	422%	394%	-6.57%
Rscm	166%	6889	7025	6510	102%	94%	-7.34%
Rszg	114%	4456	5329	4923	120%	110%	-7.62%
<i>Vall</i>	<i>150%</i>	4929	7317	6851	<i>148%</i>	<i>139%</i>	<i>-6.36%</i>
<i>RloR</i>	<i>150%</i>	1685	7108	6641	422%	394%	-6.57%
<i>Rscm</i>	<i>150%</i>	6236	6359	5892	102%	94%	-7.34%
<i>Rszg</i>	<i>150%</i>	5879	7031	6495	120%	110%	-7.62%
Scenario 3 average cropping composition		Base Case	Scenario 3	Scenario 3+	<i>BCand3</i>	<i>BCand3+</i>	<i>3and3+</i>
Vall	142%	5070	7606	7168	150%	141%	-5.77%
RloR	180%	1612	9004	8448	558%	524%	-6.17%
Rscm	172%	8416	8588	8064	102%	96%	-6.09%
Rszg	117%	4846	5872	5484	121%	113%	-6.60%
<i>Vall</i>	<i>150%</i>	5363	8046	7582	<i>150%</i>	<i>141%</i>	<i>-5.77%</i>
<i>RloR</i>	<i>150%</i>	1347	7519	7055	558%	524%	-6.17%
<i>Rscm</i>	<i>150%</i>	7357	7507	7050	102%	96%	-6.09%
<i>Rszg</i>	<i>150%</i>	6236	7556	7057	121%	113%	-6.60%

The shaded areas in the Table 11.4 and Table 11.5 show the irrigation blocks with the greatest comparative advantage. When looking at the current cropping composition in both tables, **RloR** has the greatest TGMASC per hectare per year for scenarios 3 and 3+ because it plants 185% of the cropping area each year (1.85 crops per hectare per year), but with readjustment of the leaching and drainage percentage the **Rscm** has the greatest comparative advantage for Scenario 3+ (Table 11.4).

At base-case scenario levels (i.e. no additional leaching and drainage) the **Rscm** consistently has the greatest comparative advantage, with very poor TGMASC per hectare per year results from the **RloR**.

When equalising irrigation blocks to 150% (1.5 crops per hectare per year) **Vall** proves to be the irrigation block with the greatest comparative advantage for all scenarios and leaching and drainage combinations.

Table 11.5. Change in annual TGMASC (R/ha/year) for different scenarios with adjusted additional leaching and drainage implemented for the different irrigation blocks (for actual and standardized crop composition percentages)

<u>Irrigation Block cropping composition</u>		SCENARIO						<u>% CHANGE</u>		<i>Change due to leaching area</i>
Base-case average cropping composition (% area)		Base Case	Scenario 3	Scenario 3+	BCand3	BCand3+	3and3+	Scenario 3	Scenario 3+	
Vall	151%	4953	7393	7095	149%	143%	4.04%	0.01	0.03	
RloR	185%	2075	8703	7904	419%	381%	9.18%	-0.01	-0.03	
Rscm	166%	6889	7171	7013	104%	102%	2.19%	0.02	0.07	
Rszg	114%	4456	5414	5291	122%	119%	2.29%	0.02	0.07	
<i>Vall</i>	<i>150%</i>	<i>4929</i>	<i>7358</i>	<i>7061</i>	<i>149%</i>	<i>143%</i>	<i>4.04%</i>	<i>0.01</i>	<i>0.03</i>	
<i>RloR</i>	<i>150%</i>	<i>1685</i>	<i>7070</i>	<i>6420</i>	<i>419%</i>	<i>381%</i>	<i>9.18%</i>	<i>-0.01</i>	<i>-0.03</i>	
<i>Rscm</i>	<i>150%</i>	<i>6236</i>	<i>6491</i>	<i>6348</i>	<i>104%</i>	<i>102%</i>	<i>2.19%</i>	<i>0.02</i>	<i>0.07</i>	
<i>Rszg</i>	<i>150%</i>	<i>5879</i>	<i>7144</i>	<i>6980</i>	<i>122%</i>	<i>119%</i>	<i>2.29%</i>	<i>0.02</i>	<i>0.07</i>	
Scenario 3 average cropping composition		Base Case	Scenario 3	Scenario 3+	BCand3	BCand3+	3and3+	Scenario 3	Scenario 3+	
Vall	142%	5070	7645	7365	151%	145%	3.67%	0.01	0.03	
RloR	180%	1612	8961	8188	556%	508%	8.63%	-0.00	-0.03	
Rscm	172%	8416	8735	8576	104%	102%	1.83%	0.02	0.06	
Rszg	117%	4846	5954	5835	123%	120%	1.99%	0.01	0.06	
<i>Vall</i>	<i>150%</i>	<i>5363</i>	<i>8087</i>	<i>7791</i>	<i>151%</i>	<i>145%</i>	<i>3.67%</i>	<i>0.01</i>	<i>0.03</i>	
<i>RloR</i>	<i>150%</i>	<i>1347</i>	<i>7483</i>	<i>6838</i>	<i>556%</i>	<i>508%</i>	<i>8.63%</i>	<i>-0.00</i>	<i>-0.03</i>	
<i>Rscm</i>	<i>150%</i>	<i>7357</i>	<i>7636</i>	<i>7497</i>	<i>104%</i>	<i>102%</i>	<i>1.83%</i>	<i>0.02</i>	<i>0.06</i>	
<i>Rszg</i>	<i>150%</i>	<i>6236</i>	<i>7661</i>	<i>7509</i>	<i>123%</i>	<i>120%</i>	<i>1.99%</i>	<i>0.01</i>	<i>0.06</i>	

Table 11.5 includes an additional two columns for the comparison of results where 15% drainage is implemented throughout (Table 11.4) versus the adjusted levels of additional leaching and drainage (Table 11.5). Results show that at the per hectare level annual TGMASC (R/ha/year) is very slightly affected, -3% to +6%, by the changes in the leaching and drainage percentage between Table 11.4 and Table 11.5. However, to take a hypothetical example, a 6% change on R5000 per hectare is R300, multiplied by the 12 335 hectares that the Riet Scheme, Canal and Ritchie (**Rscm**) occupy, gives an irrigation block level financial improvement of R3.7 million per year.

Increasing drainage in the **RloR** from 15% to 20% results in a less than 1% reduction in annual TGMASC per hectare if fully subsidised, and a 3% reduction in annual TGMASC per hectare if only subsidised 10% and the farmers, through increased water tariffs have to repay the rest. This indicates that 20% leaching in the **RloR** is too much and that 15% yielded better financial results. It is expected that optimising the leaching and drainage percentage for maximum TGMASC, a result closer to 20% than 15% leaching and drainage will result. Increasing the irrigation and drainage percentage has a smaller impact on scenario 3 where the cost of the drainage isn't factored into the water charge than in scenario 3+, indicating sensitivity to the cost of water.

In Table 11.6 and Table 11.7 the irrigation block level cost of grant assistance of additional artificial drainage installation at levels of 10%, 50% and 100% are compared for **Vall** and **RloR** respectively. As **RloR** has positive net returns for all discount rates, a full discussion for **Vall** follows as it is a “border-line” block (i.e. positive to negative net returns for different discounts rates). Net returns are less (more negative) for the **Rszg** and **Rscm** as their levels of salinisation are not as bad as **Vall** and **RloR**.

As the choice of discount rate depends on *inter alia* the following economic and social factors: the opportunity cost of capital, the cost of borrowing money and the social rate of time preference, the results are presented at four different discount rates, 0%, 5%, 8% and 10%. Zero percent is included to give an idea of the direct net returns when not factoring in the time value of money. The greater the discount rate used, the less favourable the results. Drainage maintenance costs are assumed zero in all analyses, and the positive secondary impacts on job creation and the environment have also not been factored in to the annual costs and benefits calculations, as these amounts are very subjective.

11.5. WUA LEVEL POLICY IMPLICATIONS

11.5.1. CROP CHOICE IMPACT ON THE SHORT-TERM VERSUS. LONG-TERM DEMAND FOR WATER

The short-term versus the long-term demand for water is determined by:

- the factors that influence the decision to plant a long-term crop,
- what the stability of water supply (quantity) is, and
- the probability that the quality over the long term will be acceptable.

At farm level these factors will influence the decision to make a large capital investment in a long term crop. From a WUA perspective, if only a few farmers demand a certain quantity and quality it will be far more difficult than if many demand it, however if the WUA can guarantee a certain water quality and quantity then more farmers may change their cropping choice. This may however subject the WUA to litigation and great expense if the guaranteed standards can not be met once farmers have implemented large capital investments in long-term, high value crops.

Table 11.6 Vall net returns of subsidised drainage costs (2005 constant prices - R'000 000)

		Cost	Marginal Income *	NPV	Net Return (Cost+NPV)
Year	real	1	1-15		
Assistance costs	10%	-3.33			
Maintenance costs		0.00			
discount rate	0%	-3.33	0.36	5.40	2.08
discount rate	5%	-3.33	0.36	3.74	0.41
discount rate	8%	-3.33	0.36	3.08	-0.24
discount rate	10%	-3.33	0.36	2.74	-0.59
Year		1	1-20		
discount rate	0%	-3.33	0.36	7.20	3.88
discount rate	5%	-3.33	0.36	4.49	1.16
discount rate	8%	-3.33	0.36	3.54	0.21
discount rate	10%	-3.33	0.36	3.07	-0.26

		Cost	Marginal Income	NPV	Net Return (Cost+NPV)
Year	real	1	1-15		
Assistance costs	50%	-16.63			
Maintenance costs		0.00			
discount rate	0%	-16.63	1.80	27.02	10.39
discount rate	5%	-16.63	1.80	18.70	2.07
discount rate	8%	-16.63	1.80	15.42	-1.21
discount rate	10%	-16.63	1.80	13.70	-2.93
Year		1	1-20		
discount rate	0%	-16.63	1.80	36.02	19.40
discount rate	5%	-16.63	1.80	22.45	5.82
discount rate	8%	-16.63	1.80	17.68	1.06
discount rate	10%	-16.63	1.80	15.33	-1.29

		Cost	Marginal Income	NPV	Net Return (Cost+NPV)
Year	real	1	1-15		
Assistance costs	100%	-33.25			
Maintenance costs		0.00			
discount rate	0%	-33.25	3.60	54.03	20.78
discount rate	5%	-33.25	3.60	37.39	4.14
discount rate	8%	-33.25	3.60	30.83	-2.42
discount rate	10%	-33.25	3.60	27.40	-5.85
Year		1	1-20		
discount rate	0%	-33.25	3.60	72.05	38.79
discount rate	5%	-33.25	3.60	44.89	11.64
discount rate	8%	-33.25	3.60	35.37	2.11
discount rate	10%	-33.25	3.60	30.67	-2.58
Year		1	1-25		
discount rate	0%	-33.25	3.60	90.06	56.80
discount rate	5%	-33.25	3.60	50.77	17.52
discount rate	8%	-33.25	3.60	38.45	5.20
discount rate	10%	-33.25	3.60	32.70	-0.56
Year		1	1-30		
discount rate	0%	-33.25	3.60	108.07	74.82
discount rate	5%	-33.25	3.60	55.38	22.12
discount rate	8%	-33.25	3.60	40.55	7.30
discount rate	10%	-33.25	3.60	33.96	0.71

* Marginal income = change in gross margin between drainage and no drainage

Table 11.6 shows the Net Returns (NR) of the different assistance levels at different discount rates for **Vall**. At a 10% assistance grant, the total costs to government for only one year will be R3.33 mil (million). At a discount rate of 0%, i.e. the time value of money not factored in, the increased (marginal) value to the farmers of the assistance grant over 15 years is R0.36 mil x 15 = R5.40 mil (= the net present value (NPV)). The net return (NR), which is the assistance grant costs minus the NPV = R2.08mil.

At a 5% discount rate the NPV = R3.74mil and the NR = R0.41mil.

At a 8% discount rate the NPV = R3.08mil and the NR = R-0.24mil., a relative loss.

If the NPV is calculated over 20 years, then at an 8% discount rate the NPV = R3.54 mil and the NR = R0.21 mil. Over 20 years at a discount rate of 10% the NR = R-0.26 mil.

At a government assistance grant rate of both 50% and 100% a similar pattern in positive and negative NR's is presented for the same respective discount rates.

For the 100% assistance grant rate the life span of marginal returns is extended to 25 and 30 years. At a lifespan of only over 30 years can a positive NR be attained at a 10% discount rate.

Table 11.7 *RloR* net returns of subsidised drainage costs (2005 constant prices - R'000 000)

		Cost	Marginal	NPV	Net Return
	Year	real	Income *		(Cost+NPV)
		1	1-15		
Assistance costs	10%	-1.73			
Maintenance costs		0.00			
discount rate	0%	-1.73	0.24	3.57	1.84
discount rate	5%	-1.73	0.24	2.47	0.74
discount rate	8%	-1.73	0.24	2.04	0.30
discount rate	10%	-1.73	0.24	1.81	0.08
Year		1	1-20		
discount rate	0%	-1.73	0.24	4.76	3.03
discount rate	5%	-1.73	0.24	2.97	1.23
discount rate	8%	-1.73	0.24	2.34	0.60
discount rate	10%	-1.73	0.24	2.03	0.29
		Cost	Marginal	NPV	Net Return
	Year	real	Income		(Cost+NPV)
		1	1-15		
Assistance costs	50%	-8.67			
Maintenance costs		0.00			
discount rate	0%	-8.67	1.19	17.85	9.18
discount rate	5%	-8.67	1.19	12.35	3.68
discount rate	8%	-8.67	1.19	10.19	1.52
discount rate	10%	-8.67	1.19	9.05	0.38
Year		1	1-20		
discount rate	0%	-8.67	1.19	23.80	15.13
discount rate	5%	-8.67	1.19	14.83	6.16
discount rate	8%	-8.67	1.19	11.68	3.02
discount rate	10%	-8.67	1.19	10.13	1.46
		Cost	Marginal	NPV	Net Return
	Year	real	Income		(Cost+NPV)
		1	1-15		
Assistance costs	100%	-17.34			
Maintenance costs		0.00			
discount rate	0%	-17.34	2.38	35.70	18.36
discount rate	5%	-17.34	2.38	24.70	7.37
discount rate	8%	-17.34	2.38	20.37	3.03
discount rate	10%	-17.34	2.38	18.10	0.77
Year		1	1-20		
discount rate	0%	-17.34	2.38	47.60	30.26
discount rate	5%	-17.34	2.38	29.66	12.32
discount rate	8%	-17.34	2.38	23.37	6.03
discount rate	10%	-17.34	2.38	20.26	2.93

* Marginal income = change in gross margin between drainage and no drainage

Table 11.7 shows the Net Returns (NR) of the different assistance grant levels at different discount rates for *RloR*.

As opposed to drainage grant assistance investment in the *Vall* where a positive net return is only realised at low discount rates and over longer periods of time, for all discount rates, all assistance grant levels and for 15 and 20 year repayment terms, the net return of assistance grant investment for the *RloR* is positive, indicating a very favourable return to subsidised drainage investment over a range of possible circumstances and conditions.

11.6. REGIONAL LEVEL POLICY IMPLICATIONS

The regional level policy implications are deduced from the regional economy model results presented in chapter 10. The regional level results include *inter alia* the combined economic output from all the irrigation blocks within both WUAs.

Scenarios 3 and 3+ results in Chapter 10 show a positive affect on the economy over the period of analysis, yet far less than the positive impacts of scenarios 1 and 2, but still considered far more stable. Furthermore, Scenarios 3 and Scenario 3+ have a steeper improvement in the overall sustainability levels than the other

scenarios, proving that increased leaching and drainage does improve the long-term sustainability of an irrigation scheme.

Scenario 3 and 3+ as compared to scenarios 1 and 2 results show the regional economic impact that increased leaching and drainage has on a regional economy. Results in Chapter 10 indicate that the regional economy for Scenario 1 could generate a gross geographical product (GGP) around R757 to R770 million and sustain 5370 to 5450 jobs from year 1 to 15 respectively.

Scenario 2 could generate a GGP of around R872 to R891 million and sustain 6180 to 6300 jobs from year 1 to 15 respectively. Scenario 3 and 3+ could generate a GGP of around R977 to R985 million and sustain 6920 to 6990 jobs from year 1 to 15 respectively.

These results clearly show that Scenario 2 yields approximately a R100 million GGP improvement from scenario 1 and Scenarios 3 and 3+ a further R100 million improvement from Scenario 2. The total jobs sustained by the regional economy rises by 700 with scenario 2 and a further 800 with scenario 3 and 3+.

These dramatic improvements in the regional economy further motivate the case for the full grant assistance of additional leaching and drainage where required. From an environmental perspective, leaching and drainage is also a more sustainable option (ISEW results converge closer to 1) than planting more salt resistant crops (scenario 1) or planting higher value crops without sufficient drainage (scenario 2). Result from the last option also proving the least stable economic results.

11.7. OPTIMAL TIMING OF THE INSTALLATION OF IRRIGATION DRAINAGE IN THE LIFE CYCLE OF A SCHEME: DISCUSSION

There are various examples from the literature that arid area irrigation schemes or more temperate irrigation schemes receiving poor water quality are unsustainable over the long term unless suitable leaching and drainage practices are implemented to wash out the salts that build up insidiously over time.

Bristow *et al.* (2005) referred to an irrigation scheme in Northern Australia that was badly salinised within 5 years of inception due to a decision to only install drainage at a later stage once it became a problem. This decision resulted in large financial losses and a legal battle between the farmers, who had invested in the land, and the state, for compensation and for losses in expected / projected revenues.

Based on the magnitude of the improvement in TGMASC demonstrated by scenario 3 in Chapter 10, and demonstrated in Figure 11.2, the installation of drainage at the implementation phase of a new scheme can be justified.

Remedial action only taken when the salinity reaches harmful proportions can be unsustainable as:

- by this time the irrigators' financial position may already be weakened,
- the installation of the drainage will further result in the loss of one seasons production, further affecting cash-flow
- the total cost of grant assistance would have to be greater as the farmers' are in a poorer off position to pay

- if done through the WUAs, increasing of water tariffs at this stage to cover the drainage costs, may be difficult for already struggling irrigators to accept
- if irrigators need to pay for the drainage themselves, finance may be difficult to acquire due to recent declining profit margins from salinity build-up

If drains are installed at inception of a scheme:

- unnecessary financial losses as salinity builds up over time in the scheme will be eliminated,
- irrigators will start off paying a higher water tariff, but major adjustments will not need to be made later on when drainage becomes necessary,
- there are the financial advantages of economies of scale in constructing all the drains and planning the return-flow drains and return-flow management options at inception, instead of haphazardly during the lifecycle of the scheme as emergency operations.

Although not applicable to the existing irrigation blocks in the study area analysed, it is highly recommended that irrigation drainage be installed with conception of any new irrigation scheme.

Within the study area there are plans to develop the Oppermansgronde area into a new sub-irrigation block within the OR-WUA. Although the area does have deep red sandy soil to facilitate natural drainage, it is speculated that artificial drainage, if required following an in-depth investigation, should be installed right from the beginning in the new scheme.

11.8. SUMMARY

Briefly, the conclusions from the analysis of the results can be summed up with resulting policy implications as follows:

- **Farm level** – drainage is a better management option than changing to more tolerant crops, but only where needed and depending on assistance grant and cash flow.
- **Irrigation Block level** – grant assistance is necessary to drain before salinity levels become too high in areas not too badly affected yet.
- **WUA level** – cross subsidisation / grant assistance of downstream return-flow users from upstream Orange River water users is possibly a viable option.
- **Regional level** – the improvement of agricultural productivity from increased investment in irrigation drainage far outweighs the costs and has a positive ripple effect through the economy. In calculating the secondary effects to the economy the returns to investment are great. Agricultural water use productivity is also far better with the secondary impacts accounted for.

Drainage installation for facilitation of leaching is a more financially and environmentally sustainable option than the planting of tolerant crops. Factoring in the costs of drainage into irrigators' water tariffs, is less than the additional financial benefits derived from the drainage and should therefore be acceptable to farmers. Although **Rscm** and **Rszg** Irrigation Blocks do not require immediate remediation action they should possibly be charged more for water by internalizing the downstream externality they produce on the **RloR** and some **Vall** farmers.

Cross-subsidising a portion of the **RloR** and the **Vall** farmers drainage with increased **Rscm** and **Rszg** water tariffs may be a plausible policy option.

At base-case scenario levels (i.e. no additional leaching and drainage) the **Rscm** consistently has the greatest comparative advantage, with very poor TGMASC per hectare per year results from the **RloR**.

When equalising irrigation blocks to 150% (1.5 crops per hectare per year) **Vall** proves to be the irrigation block with the greatest comparative advantage for all scenarios and leaching and drainage combinations.

Having identified the **RloR** as the most critical irrigation block requiring additional artificial leaching and drainage, over a range for discount rates, assistance grant levels and repayment terms, the net return of assistance grant investment for the **RloR** is positive, indicating a very favourable return to subsidised drainage investment over a range of possible circumstances and conditions.

11.9. RECOMMENDATIONS

Drainage installation for facilitation of leaching needs to be promoted in the Orange-Vaal WUA (**Vall**) and especially in the Lower Riet (**RloR**) Irrigation Blocks in the study area. Results from the research indicate that 10% and 20% of the **Vall** and **RloR** Irrigation Blocks' irrigable area respectively need to be considered for addition drainage for efficiency and sustainability benefits to the area and region.

If the **Rscm** and **Rszg** Irrigation Blocks are to be drained, before salinity builds up to levels which result in financial losses, at least a 50% assistance grant of the total drainage costs may be needed to make the offer financially viable and acceptable by the irrigators. Just as in an environmental management plan, remedial action for possible environmental and unsustainable practises have to be planned and budgeted for at initialization. There is definite need for the planning and budgeting for installation of drainage before the settlement of a new irrigation area.

CHAPTER 12. SYNTHESIS, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

by R.J. Armour, and M.F. Viljoen - UFS

12.1. INTRODUCTION

The aims of this chapter are:

- to provide a synthesis of the process followed during the course of this research,
- to give a brief summary of each of the chapters of this report ,
- to list the conclusions deduced from this study, and
- to provide recommendations stemming from this work, and for new research to be conducted.

12.2. SYNTHESIS

In the course of this study the following tasks were undertaken:

- Background research and a literature study was conducted
- An integrated model framework was developed and applied
- A research method was followed and a model was designed
- Data was accumulated and analysed
- Results were generated and interpreted, and
- Findings were reported at various levels.

The purpose of this synthesis is to briefly highlight the most important aspects of each of these various tasks.

12.2.1. BACKGROUND RESEARCH

A broad literature study, including an interdisciplinary evaluation of the multi-dimensional components underlying the integrated modelling was undertaken. A better understanding of the interdisciplinary nature of the problem was achieved and the following relevant applicable models / methodologies identified, together with their set-up data and manpower requirements:

- WRPM to simulate stochastic hydrology sequences and importantly, linked soil salinity values,
- The Maas and Hoffmann equation to translate saturated soil salinity values into reduced crop yield,
- CEB simulation analysis to interpret the reduced yield in economic terms, and
- Input / output analysis to interpret the economic changes in agriculture at regional level.
- During this phase, profiles, trends and the main problem areas were identified and formulated.

A combination of study area specific information gleaned from existing reports and documents was used in compiling Chapter 2 and discipline specific information was used for Chapters 4 (Hydrology), 5 (Bio-physical) and 7 and 10 (Macro-economic) formulation.

12.2.2. INTEGRATED CONCEPTUAL FRAMEWORK

The development of the integrated conceptual framework provided a vital reference framework to combine the applicable models / methodologies identified into an integrated salinity modelling process, guiding the design, organisation, runs and output of the model. A series of workshops was held with key role-players and technical experts to finalise the conceptual and generic modelling approach of the study. The resulting final integrated model framework is displayed in Figure 3.1.

12.2.3. METHOD AND MODEL DESIGN

The aim of the model is to integrate holistically the bio-physical and hydrology components involved in irrigation salinisation, into a long-term economic model to improve the financial sustainability of irrigation agriculture.

The method followed for the model development process to achieve this consisted of the following:

- The setup of the base-case and subsequent scenario for analysis
- The collection of input data and data processing
- The setting up, integrating and running the sub-disciplinary models:
 - *Hydrology model (WRPM)*
 - *Bio-physical sub-components (Maas and Hoffmann equation)*
 - *Micro economic model (CEB simulation)*
 - *Regional economic model (input/output analysis)*
- The interpretation of output data and results files for report writing.

12.2.4. DATA ACCUMULATION AND ANALYSIS

Study area surveys were conducted in the study area for the collection of primary data used to:

- identify the problem areas and the magnitude and scope of the salinity problem, to sensibly divide the study area into logically grouped sub-WUAs
- identify key role players for expert panel opinion and data verification
- locate sources of secondary data for model inputs and analysis

Secondary data was mainly used as model inputs, mainly provided by WUA water management plans (Ninham Shand , 2004 and CSIR, 2004), GWK Pty. Ltd. (CEBs) and expert panel opinion gleaned for meetings and technical workshops.

12.2.5. RESULTS INTERPRETATION

Recommendations are formulated based on the integrated economic, biophysical and hydrologic modelling results. Strategic guidelines for micro and regional level management are also suggested and policy formulated.

A most valuable model output not initially planned for, is an economic interpretation of DWAF's hydrology model (WRPM), with particular reference to the salinity component.

12.2.6. REPORTING

With the eventual client in mind, the different levels of reporting are as follows:

- For the WRC and policy planners, policy guidelines, an indication of the nature and extent of the problem at regional level and a better integration of various disciplines
- For the WUA managers, an indication of the source of the cause of the salinity problem, the financial extent of the problem, the potential gains of remedying the problem and cost effective options to manage irrigation salinity
- For farmers, practical per hectare benchmarks of the impact and extent of salinity, and a simple method of calculating the per hectare reduction in yield and subsequent impact of crop profitability.

12.3. SUMMARY

The purpose of this paragraph is to summarise the chapters of this report, namely the chapters on:

- The study area
- The integrated model design
- The hydrology model
- The biophysical linkage components
- The micro-economic model description
- The regional model description
- The scenarios modelled
- Micro-economic model results
- Regional economic results
- Policy implications and recommendations

12.3.1. THE STUDY AREA

A detailed discussion on the study area is presented in Chapter 2. In short, the area is not suited to dryland agriculture except extensive grazing, and is reliant on the stability that irrigated agriculture brings. However, increasing pressure on the use of water for irrigation, together with degrading irrigated soils due to salinity, is placing increasing financial pressure on farmers, and hence on the regional economy.

Hydrologically , the study area falls within these boundaries;

- Vaal River, downstream of the Bloemhof Dam to the confluence with the Orange River
- Orange River, the Orange-Riet and Orange-Vaal Canal extraction points downstream of the Vanderkloof Dam to the Orange-Vaal Confluence where the returnflows of the study area re-enter the Orange River

- Riet River, downstream of the Kalkfontein Dam to the confluence with the Vaal River

This encompasses the Orange-Vaal (OV-WUA) and Orange-Riet (OR-WUA) Water Users Associations (WUAs).

At micro hydrology level, four irrigation blocks in the two WUAs, represent the main receiving water quality areas within the Orange-Vaal-Riet-Modder confluence area, namely:

- the Riet River Scheme, Orange Riet Canal and Ritchie sub-WUA of the OR-WUA combined, **Rscm**, all receiving Orange river water directly from the Orange Riet Canal,
- the Schotzburg sub-WUA of the OR-WUA, **Rszg**, lying mainly at the confluence of the Modder and Riet Rivers, but receiving a large portion of Orange River water diluting the tail ends of the Riet and Modder Rivers upstream,
- the Lower Riet River sub-WUA of the OR-WUA, **RloR**, from Ritchie to Soutpansdrift, mainly receiving Riet Scheme and Scholtzburg returnflows, and
- the whole Orange Vaal WUA, **Vall**, receiving Vaal River system excess spillage and a large portion of Orange River water pumped via the Orange-Vaal and Orange-Riet Canals, with the latter carrying the returnflows of the whole OR-WUA.

The main characteristics of the study identified of particular importance for integrated salinity modelling are:

- The spatial dimensions and boundaries spanning two provinces, various municipal management areas (see Figure 7.3), the confluence of the two major rivers in South Africa, various quaternary catchments and different water management areas (Figure 7.4) that influence the anthropogenic (social, political, economic) and natural (bio-physical, hydrology, environment) dynamics over time in the study area.
- According to Van Veele (2004), “the Riet-Modder catchment is a “feast or famine” catchment with only 8 years in 50 being ‘average’ years”.

Realising these dynamics in the study area led to using actual stochastic sequence data as basis for the modelling (and not aggregated data), selected to represent the full spectrum of possible sequences, to try capture the true dynamics of salinity in the study area.

12.3.2. INTEGRATED MODEL STRUCTURE

See Figure 3.1 for a diagrammatic representation of the integrated conceptual framework. In short, a hydrology model, WRPM, simulates stochastic hydrology sequences and corresponding soil salinity values (CU in mg/l), CU is converted to saturated soil salinity values (ECe in mS/m), the Maas and Hoffmann equation translates ECe into reduced crop yield (ton/ha), and CEB simulation is used to interpret the reduced yield in economic terms (TGMASC in R/ha), that are used in an input / output analysis to interpret the economic changes in agriculture at regional level (GGP in Rands and employment).

12.3.2.1. Critical Linkages – assumptions and limitations

Hydrology to Economic (and back) - The main limitation of the integrated model presented is the uncoupled, static, virtually mono-directional linkage between the hydrology and economic models. A feedback loop is possible as was used to set up the base-case scenario, but due to the nature of WRPM (ownership and complexity) many more scenarios could not be run.

Per hectare to Irrigation Block level – The assumption made when converting per hectare CEB data to irrigation block level data is that the irrigation block is representative of the farmers within that irrigation block. The WRPM model setup however has constrained the number of representative irrigation sub-WUAs to the irrigation blocks in the WRPM. Ideally the Orange-Vaal WUA irrigation block should have been split into the 5 representative sub-WUA blocks as discussed in Chapter 2.

The Orange-Riet WUA sub-WUAs fit the WRPM irrigation block split relatively well. Further differentiation could however have been made for the Irrigation Block (**Rscm**) combining the Orange-Riet canal, Scheme and Ritchie, to have them each as a separate irrigation block, and the Scheme further divided to reflect the sandy soil sub-WUA and heavy clay soil sub-WUAs. Their water source however is very similar and representative of the farmers in the subsequent WRPM irrigation blocks.

12.3.3. HYDROLOGY MODEL

The investigation of irrigation practices undertaken as part of this study is focused in Chapter 4 on the analysis of the salinity contents of the water supply as well as the modelling of the salinity balance in the soil profiles of the irrigated areas using the WRPM. Since monthly water supply time series data (both volumes and TDS concentrations) were required for the modelling of the irrigation activities within the study area, the WRPM as configured for the IVRS was identified as the best source of information. A further advantage of the WRPM model is its capability to generate and analyse alternative stochastic stream-flow sequences, providing 100 possible water quantity and quality outcomes for risk analysis.

12.3.4. BIOPHYSICAL MODEL

The biophysical sub-models discussed in Chapter 5 refer to a group of biophysical-hydrology, hydrology-biophysical and biophysical-economic linkages, assumptions and procedures, using recognized existing models and algorithms to integrate the hydrology and economic models. Paragraph 5.2 shows how SAPWAT is used to determine crop coefficients for setting up the hydrology model (WRPM). From the results of the WRPM, the saturated soil salinity, EC_e (mS/m) it derived (see Paragraph 5.3) for the setting up of salinity-yield functions using the Maas and Hoffmann equation discussed in Paragraph 5.4.

The biophysical model generates the important linkage between the hydrology results and yield which form the basis of the economic models, as well as an important component of the final output in the regional economic model as the environmental component of the Index for Socio-Economic Welfare (ISEW). The biophysical model doesn't produce results of its own, but is an important linkage in transferring data from one disciplinary model to another.

12.3.5. MICRO ECONOMIC MODEL

The spatial dimensions of the model are delineated to build from per hectare level CEBs to irrigation block level and higher up. Irrigation blocks are combined into WUAs, and WUAs are combined to form the regional economic model. The temporal dimensions of the model are delineated to monthly, annual and 15 year cumulative results. The model further simulates for a range of 100 stochastic runs, the per hectare financial impacts and possible range of financial results subject to salinisation, for different irrigation blocks per year, and over 15 years.

Data requirements are discussed with particular reference to the primary data collected through mainly expert panel opinion and the secondary data obtained predominantly from GWK, the WUA WMPs and expert opinion panels and workshops. The mathematical specification of the model is an expansion of per hectare level CEBs that produce TGMASC to irrigation block and WUA level TGMASC results for use in micro-level analysis and as input into the regional economic model.

12.3.6. REGIONAL MODEL

In defining the regional model, the macro economic project team first sketch the regional economy and use the description of the base case scenario to illustrate the processes and development if the ISIM model, consisting basically of input / output tables and multipliers.

The following can be concluded from the results of the base case scenario model:

- The total population in the study area (municipal boundaries) is estimated at 317 610 people in 2005. Approximately 60.5% of the population is considered to be *Potentially Economically Active*. Approximately 33.7% of the 2005 population can be considered Economically Active, leaving, approximately 45 402 are unemployed.
- The mining sector and the tertiary economic sectors are the largest contributors to the local economy of the study area. The mining sector contributed 19.0% to the total GGP, followed by financial services (17.1%), government (16.3%) and transport (15.0%). The agriculture sector contributed 4.5% to total GGP in the area, 4.8% to production output, 16.6% to employment and only 2.8% to total labour compensation.
- The agriculture sector registered a negative growth rate of -0.9 percentage points during the period 2000 to 2004. Municipal areas where a positive annual growth rate was experienced include Tembelihle (6.5%), Siyancuma (0.9%) and Diamondfields (0.4%). Sol Plaatje Municipal Area and Letsemeng Municipal Area both registered high negative growth rates of -5.1% and -5.9% respectively. This growth is measured in terms of constant prices with 2000 as base year. Given the above rates, it can be expected that the study area's GGP contribution in the agriculture sector in 2019 will amount to R10.1 billion (at constant price values).
- Total output in the agriculture sector grew by 0.6% during the period 2000 to 2004, while total output in the regional economy grew with 3.2 percentage points. Agriculture output in the Siyancuma Local Municipal Area was the highest at 29.1% contribution to the total agricultural output in the study area by the start of 2005.

Three categories of data were analysed during the base case scenario analysis described in this chapter, namely data for stochastic runs number 01, 44 and 80. To provide an indication of the probability of the results taking place, data obtained from the 50th percentile was also included.

The Index for Sustainable Economic Welfare was calculated by taking into consideration the production level (or value added to the irrigation sector), the employment structure of the area and the sector (as a social pillar) and the environmental changes brought on by changing salinity levels. This was done over the total period of 2005 to 2019. The ISEW clearly indicates that, for the base case scenario, there are positive trends in the sustainable economic welfare of the study area. However, stochastic run number 80, which closely resembles the 50% average, indicates an overall decline in the sustainability of the economic welfare in the region.

12.3.7. SCENARIOS MODELLED

The stochastic nature of the WRPM hydrology data generated for scenario analysis necessitates selecting 3 actual stochastic model runs from the 100 that reflect the 0.05, 0.50 and 0.95 percentiles instead of only using and average, so as to capture the stochastic/dynamic nature of the data for presentation. The micro-economic model is however run for all 100 runs and the resulting data also subsequently presented as described above. The percentiles selected of the 100 stochastic runs are in themselves worst-, average- and best-case “scenarios” of each of the main scenarios discussed.

Extreme care was taken in the setting up of the scenarios in selecting the alternative cropping compositions so as not to exceed water delivery infrastructure, processing capacity and market demand constraints. Maize area was also reduced in both the salt tolerant and salt sensitive, yet high value crop scenarios in light of the apparent maize oversupply of 2005 much publicised in the media.

The base-case scenario is essentially the first scenario, whereby the WRPM is updated, as described in the first section of this chapter, to reflect a chosen base year; 2005 for this study. The starting point salt concentration values used in the setup of the WRPM model are manually adjusted by the WRPM operators to take out any trend in the data. These starting points remain fixed for the other scenarios that follow.

Scenario 1 is set up using a more salt tolerant combination of crops (i.e. greater area planted to wheat, barley, cotton, pastures and sunflowers) without increasing drainage and leaching from the base-case values. The objective of Scenario 1 is to test the long term sustainability of this option.

For Scenario 2 and 3 a more salt sensitive, yet higher yielding combination of crops (i.e. greater area planted to fruit, vegetables, legumes and potatoes) without increasing drainage and leaching from the base-case values for Scenario 2. The objective of Scenario 2 is to test if the increased profits of higher value crops would not compensate for the yield losses due to salinity. Scenario 2 is run with 100% yield to calculate an indication of the maximum productivity of the irrigation blocks.

In Scenario 3 the same cropping combination is used as in Scenario 2, but artificial drainage and leaching is accounted for by increasing the return-flow factor by 15% to calculate the financial benefits of increased leaching and drainage. A Scenario 3+ is also run whereby the additional costs of increased leaching and drainage are factored into the water costs, to test if the additional outlay could be justified by higher returns.

A scenario showing the impact of improved drainage and leaching in status quo crops would have provided interesting results, but due to the limitation in scenarios to run, the four selected and discussed in this chapter

were the priority. The option of growing more higher value crops was chosen above the status quo to examine the impact of reduced maize production (all be it only 5% less) in the light of the much speculated overproduction of maize in 2005.

12.3.8. MICRO-ECONOMIC RESULTS

The hydrology results show that the Lower Riet Irrigation Block (**RloR**) has the highest soil salt concentration in the upper zone, CU (mg/l) followed by the Orange-Vaal Irrigation Block (**Vall**), The Scholtzburg Irrigation Block (**Rszg**) and with the lowest soil salt concentration, the Orange-Riet Scheme Irrigation Block (**Rscm**).

In comparing the hydrology results from the different scenarios run, changing the cropping choice from the status quo (base-case scenario) to more tolerant crops (scenario 1) to more salt sensitive yet higher value crops (scenario 2) has very little impact on the hydrology results. Though changing the return flow factor by increasing leaching and drainage, has a major impact on the hydrology by bringing the CU (mg/l) down substantially in the irrigation blocks. Hydrology results also show that the greatest variation, and highest values, in monthly irrigation water salt concentration, TDS (mg/l) occur in the months from April to August being worst from May to July. This indicates that salt sensitive crops grown or germinating during these months will be worst off than crops grown and germinating in the other months, i.e. spring and summer month crops.

Running the hydrology results through the bio-physical model converts the soil salt concentration, CU (mg/l) to CUE (mg/l), the saturated soil salt concentration. CUE is multiplied by the electrical conductivity factor to produce ECE (ms/m) and this is run through the Maas and Hoffmann equation to give the impact of soil salinity on crop yield. Results showed that in the irrigation blocks where the CU is highest, there crop yields are worst affected.

These changes in crop yield are then run through the micro-economic model to first produce per hectare crop enterprise budgets (CEBs) which are then extrapolated to irrigation block level. On a per hectare basis (as shown in Table 9.5) the greatest financial loss (2005 values) due to salinity is experienced in the Lower Riet Irrigation Block (**RloR**), to the value of R6962 per hectare per year, followed by Scholtzburg (**Rszg**) with R2596 and the Orange-Vaal Irrigation Block (**Vall**) with R2218. This provides the farmer in the specific irrigation block with a good indication of the per hectare costs (net benefit forgone) of poor drainage on his farm. At an average costs of drainage per ha on medium to heavy soils of R30 000¹⁸ (Reinders, 2005), a 15 year loan at 9% interest would cost R3722 per year to service – worth spending in **RloR**, though not as convincing without a funding grant in **Rszg** and **Vall**. Implemented for the whole study area (all irrigation blocks combined), the total real cumulative cost (2005 basis) of salinisation over a period of 15 years is R995 million, a good benchmark to use to leverage funds for remediation action.

Figure 9.13 and Figure 9.14 clearly show that to reduce the risk of income loss due to irrigation salinity one has to install drainage and leach more.

The conclusion is that an irrigation block is very sensitive to a specific salinity threshold level and therefore all irrigation blocks should not be treated the same. Only **RloR** benefited slightly from planting more tolerant crops

¹⁸ Note: drainage costs can range from R12000-R15000 on sandy soils (<15% clay), R20000-R25000 on medium soils (15-35% clay), and R30000-R50000 on heavy soils (>35% clay) – see Table 6.3.

as its soil salinity threshold is exceeded by the base-case cropping composition. Increased drainage and leaching however proved to be far more financially effective than planting tolerant crops, and the return-flow externality effects are more than compensated for as **Vall** downstream also achieved far better results when it is also drained.

Comparing the Orange-Vaal WUA (**Vall**) and Orange Riet-WUA (**Rall**), the **Rall** naturally did better in absolute terms as it is nearly twice the size of the **Vall**, but although the worst Irrigation Block (**RloR**) is part of **Rall**, its TGMASC improved at a better rate than **Vall** over the 15 years of analysis. Results data further processed by the micro economic model SMSim, to be used in the macro model is also briefly discussed, but is covered in full in the chapter that follows.

12.3.9. REGIONAL MODEL RESULTS

It is evident that the overall level of impact on the regional economy of the study area increases as alternative scenarios are considered. Scenario 2 produces higher values in total output, GGP and jobs than Scenario 1. Similarly, Scenario 3 and 3+ results in higher values than Scenarios 1 and 2. Scenarios 1 and 2 are also very cyclical in nature due to varying gross income levels, which in turn is linked to varying salinity levels and yield. Scenarios 3 and 3+ are considered to have a more stable regional impact. These impacts did not consider price fluctuations or market volatility.

The overall GGP value lost to the regional economy for farmers having to pay 90% of the additional drainage costs themselves (10% is subsidised in the calculations) at a loan repayment rate of 9% over 15 years is in excess of R10 million per year.

When considering the indices for sustainable economic welfare (ISEW), it is also evident that all three scenarios will contribute towards increased economic welfare, based on the indicators measured, but that Scenarios 3 and 3+ will have a steepest improvement in the overall sustainability levels.

12.3.10. POLICY IMPLICATIONS

Briefly, the conclusions from the analysis of the results can be summed up with resulting policy implications as follows:

- Farm level – drainage is a better management option than changing to more tolerant crops, but only where needed and depending on assistance grant and cash flow.
- Irrigation Block level – grant assistance is necessary to drain before salinity levels become too high in areas not too badly affected yet.
- WUA level – cross subsidisation of downstream return-flow users from upstream Orange river water users is a viable option as the price elasticity of water quantity is relatively small. However due to the large price elasticity of water quality, affected farmer can almost afford to pay for the drainage themselves.
- Regional level – the improvement of agricultural productivity from increased investment in irrigation drainage far outweighs the costs and has a positive ripple effect through the economy. In calculating the secondary effects to the economy the returns to investment are great. Agricultural water use productivity is also far better with the secondary impacts accounted for.

Drainage installation for facilitation of leaching is a more financially and environmentally sustainable option than the planting tolerant crops. Factoring in the costs of drainage into irrigators' tariffs is acceptable payable by farmers. Although **Rscm** and **Rszg** Irrigation Blocks do not require immediate remediation action they should pay more for water as they produce a downstream externality on the **RloR** and some **Vall** farmers. Cross-subsidising a portion of the **RloR** and the **Vall** farmers drainage with increased **Rscm** and **Rszg** water tariffs is a feasible option.

At base-case scenario levels (i.e. no additional leaching and drainage) the **Rscm** consistently has the greatest comparative advantage, with very poor TGMASC per hectare per year results from the **RloR**. When equalising irrigation blocks to 150% (1.5 crops per hectare per year) **Vall** proves to be the irrigation block with the greatest comparative advantage for all scenarios and leaching and drainage combinations.

Having identified the **RloR** as the most critical irrigation block requiring additional artificial leaching and drainage, over a range for discount rates, assistance grant levels and repayment terms, the net return of assistance grant investment for the **RloR** is positive, indicating a very favourable return to subsidised drainage investment over a range of possible circumstances and conditions.

12.4. CONCLUSIONS

The most compelling results from this research are:

- a total GGP value lost to the regional economy of R10 million per year as a result of farmers having to pay for the additional drainage costs themselves (difference between Scenario 3 and scenario 3+ results)
- the total once off costs of additionally leaching 20% more in RloR, 10% more in Vall and 5% more in both Rscm and Rszg only amounts to R 64.75 million.
- The full grant assistance of these costs can be justified in just 7 years if not taking the time value of money into account. This is not even taking into account the improvement from the base case situation to Scenario 3 level.
- Over 15 years R 995 million in agricultural TGMASC is cumulatively lost in the study area due to salinity alone (with all other factors of production optimal)
- The total region output generated under base-case conditions in 2005 amounts to R 804.37 million. With increased drainage this total regional economic output can be increased to R977 million, an improvement of R173.63 million in one year alone.
- When considering the indices for sustainable economic welfare, it is also evident that Scenarios 3 has a steeper improvement in the overall sustainability levels.

This presents an overwhelming case for the full grant assistance of additional irrigation drainage in the interest of increased regional socio-economic welfare.

12.4.1. CRITICAL MODEL EVALUATION AND USEFULNESS

Sometimes advancement in a science is made by an in-depth enquiry into a very small aspect thereof, but sometimes advancement in the sciences is made by a superficial inquiry into a lot of sciences and through the identification of critical linking factors, the binding of them into a better understood whole. (inspired from Smuts, 1925 – Holism and Evolution)

Table 12.1. A table summarising the level to which original objectives have been met

Initial project aims	New model	Improvements / achievements	Limitations / shortcomings
Development and integration of multi-dimensional models	√	Hydrology, Agronomy, micro- and regional economic models linked	Groundwater, unsaturated root zone chemistry and climate models lacking. Feedback loops lacking.
Sustainable management of water quantity and quality	√	Drainage & leaching proved more sustainable than planting salt resistant crops. water use efficiency modelled	Water distribution infrastructure and blending options not analysed
a. Better understand the polluting chemical processes and interactions	√	A better understanding of the spatial variability and fluctuation of salts	Only salinity impacts modelled and not those of other salts (e.g. Cl, Br) and trace elements
b. Develop new models -			
i. Micro	√	SMSim + linkages	Not Farm Level – excluded fixed and capital expenses, Tax etc. – Purely a TGMASC model
- Dynamic	√	Used stochastic model data over time to capture dynamics	Decision variable interaction from linear programming
- Optimisation	×	identified that biophysical problems contain too many decision variables to easily optimize	No shadow prices and optimal crop combinations can be calculated
ii. Macro	√	Full regional dynamic Input/Output model + Index for Social Economic Welfare (ISEW)	National input/output matrix data is used for regional interpretation
c. Economic integration		Hydrology -> bio -> micro-econ. -> macro-econ.	Only direct costs are taken into consideration
i. Hydrology / hydraulic	√	WRPM model	The WRPM is not “open source” and not user friendly for own adaptation / use
ii. Chemical balance	√ / ×	Only salt balance in WRPM model	Other chemical balances not incorporated
iii. Groundwater	√ / ×	Lower layer in WRPM model linked to ISEW	Impact on deep groundwater not investigated
iv. Crop growth	√ / ×	The Maas and Hoffmann (1977) equation & SAPWAT crop growth coefficients used as plant growth factors	More sophisticated plant growth in salts models could be used (e.g. SATLMED by Ragab, 2000)
d. Best management practices		Drainage and leaching identified	Optimal distribution infrastructure not identified
i. Micro (Field and Farm)	√ / ×	Risk distribution (stochastic analysis)	Manual scenario selection (objective not optimisation)
ii. Macro (policy, catchment, WUA)	√	Mainly provincial (and municipal) + ISEW	Agricultural secondary impact on the economy not indicated
e. Enhance water use efficiency	√	Temporal redistribution and better crop selection by scenario	Spatial redistribution of water not modelled
f. Policy guidelines	√	A spatial relative comparison is made and scenarios are used	4 Sub-WUA in the OV-WUA rather than 1 Irrigation Block (Vall) would have improved results
g. Robust method used	√ / ×	The method used is robust if other more user friendly and adaptable hydrology models are used	WRPM is not robust (though can be applied almost anywhere in SA – but must make use of WRP consultants)

The main limitation of the integrated model presented in this chapter is the uncoupled, static, virtually mono-directional linkage between the hydrology and economic models, although a full loop is modelled in this study.

Further refinement through the addition of additional irrigation blocks in the hydrology model would have also been more representative of the sub-WUA level irrigation water quality and soil salinity status of the Orange Vaal WUA study area in particular.

Further hydrology model irrigation block refinement and feedback loops between the hydrology and economic models are possible, but because of the separate and professional human resources required to do the modelling at the different levels, time and cost is prohibitive. Very careful planning, data checks and co-ordination are therefore essential to guarantee the desired results.

Although far less elaborate than initially proposed, this project has succeeded in refining and identifying critical obstacles towards fully integrated salinity economics modelling, and to a certain degree in coming up with plausible results suitable for meaningful farm, sub-WUA, WUA, CMA and national policy interventions and strategic decision making.

12.4.1.1. Industry specific usefulness of this work

For GWK, the impact of cropping choice changes on regional crop input component value, processing capacity and storage can be determined that will help GWK plan strategically and aid the transition process.

For the insurance industry, the question of “what percentage of loss is due to a natural disaster, and what would have taken place anyway due to salinisation?” could be attempted using this work.

12.4.1.2. Applicability for expansion to other irrigation areas

A main constraint to the expansion and adaptation of the integrated models to other irrigation areas is the WRPM. If however recent WRPM hydrology set up data can be transferred to a more user friendly model (e.g DHI's Mike Basin, or ACRUSalinity) or any other hydrology model that calculates the EC in the soil, the micro-economic model could be applied with ease. The ease of application of the regional economic model will depend on the availability of suitable input / output tables and multipliers for the area under consideration.

12.4.2. LESSONS LEARNED IN WORKING IN A MULTI-DISCIPLINARY TEAM

Lessons learned in this project, observing the course of other projects and from the literature, are as follows:

- In-house specialist, dedicated teams (as in an institute) are logistically better and easier to work in and with than spatially diverse and segmented teams to conduct integrated / multidisciplinary research.
- Choose the sub-disciplinary teams well and obtain definite buy-in (almost contractual) at the project proposal phase already.
- Choose sub-disciplinary teams whom you know well and have previously worked with as far as possible.

A challenge of a project requiring long-term inter-disciplinary co-operation is the possibility of team members resigning where contractual obligation is not required (as in the academic setting), and of them dying, of which one cannot do much about. Good backup specialist staff (depth in research knowledge and ability of the sub-discipline team appointed) and a good grasp by the sub-discipline team leader of the team members direction and thinking throughout the study is important and necessary.

12.5. RECOMMENDATIONS

Drainage installation for facilitation of leaching needs to be promoted in the Orange-Vaal WUA (**Vall**) and especially in the Lower Riet (**RloR**) Irrigation Blocks in the study area. 10% and 20% of **RloR** and **Vall** Irrigation Blocks irrigable area respectively are indicated to be drained. This should however be evaluated with a detailed feasibility study.

If the **Rscm** and **Rszg** Irrigation Blocks are to be drained, before salinity builds up to levels which result in financial losses, at least a 50% assistance grant of the total drainage costs is recommended to make the offer financially viable and acceptable by the irrigators.

Just as in an environmental management plan, remedial action for possible environmental and unsustainable practises have to be planned and budgeted for at initialization, there is a strong recommendation for the planning and budgeting for installation of drainage before the implementation of any new scheme.

12.5.1. PROPOSED FARM LEVEL MANAGEMENT STRATEGY

On a per hectare basis in Table 9.5 (row 10) the greatest loss due to salinity is experienced in the Lower Riet Irrigation Block (**RloR**) to the value of R7100 per hectare per year, followed by Scholtzburg (**Rszg**) with R2748 and the Orange-Vaal Irrigation Block (**Vall**) with R2415. This can provide a farmer in the specific irrigation block with a good indication of the costs of poor drainage on his farm. At an average costs of drainage per ha on medium to heavy soils of R30 000 (Reinders, 2005), a 15 year loan at 9% interest would cost R3722 per year to service – it would definitely be economical to spend in **RloR**, though not as convincing without assistance grant in **Rszg** and **Vall**.

12.5.2. IRRIGATION BLOCK (/SUB-WUA) LEVEL OPTIONS

Positive results stemming from Figure 9.11 are that even at the worst case sequence of hydrology events predicted for the Lower Riet Irrigation Block, the cumulative TGMASC still improves over time, although the annual TGMASC may only improve slightly. This shows that the system is in equilibrium and stabilised around the current farming and WUA management actions practised.

Stochastic run 044 in Figure 9.12 shows the massive changes that can be expected in TGMASC that a farmer in the **RloR** will have to account for in his forward and cash flow planning. TGMASC can halve / double from one year to the next. Stochastic run 001 reflects a “bad case” hydrology sequence and can result in zero TGMASC for some years (1 in 15).

In Table 11.6 and Table 11.7 the irrigation block level cost of grant assistance of additional artificial drainage installation at levels of 10%, 50% and 100% are compared for **Vall** and **RloR** respectively. As **RloR** has positive net returns for all discount rates, as opposed to drainage grant assistance investment in the **Vall** where a positive net return is only realised at low discount rates and over longer periods of time, for all discount rates, all assistance grant levels and for 15 and 20 year repayment terms, the net return of assistance grant investment for the **RloR** is positive, indicating a very favourable return to subsidised drainage investment over a range of possible circumstances and conditions. At base-case scenario levels (i.e. no additional leaching and drainage) the **Rscm** consistently has the greatest comparative advantage, with very poor TGMASC per hectare per year results from the **RloR**

12.5.3. PROPOSED WUA LEVEL MANAGEMENT STRATEGY

Figure 9.15 shows the annual) TGMASC for the irrigation blocks **RloR**, **Rscm** and **Rszg** combined to make up the OR-WUA (**Rall**). This is compared to the **Vall** Irrigation Block, representing the OV-WUA. Results show that all the Orange-Riet WUA Irrigation Blocks together (**Rall**) and its main sub-block **Rscm** outperform **Vall** in total magnitude for all scenarios indicating that OR-WUA has a comparative advantage over the OV-WUA economically because of the source of its irrigation water being mainly from the Orange River.

From a WUA perspective, if only a few farmers demand a certain quantity and quality it will be far more difficult than if many demand it, however if the WUA can guarantee a certain water quality and quantity then more farmers may change their cropping choice. This may however subject the WUA to litigation and great expense if the guaranteed standards can not be met once farmers have implemented large capital investments in long-term, high value crops

12.5.4. PROPOSED REGIONAL MANAGEMENT STRATEGY

Johnston (1994) warns “most of the irrigation schemes in South Africa are affected to some degree by soil salinity. This accumulation of salts in the soil is normally associated with water-logging that occurs primarily in the poorly- drained regions of the landscape. Salinisation usually develops insidiously over many years, and can present a serious threat to the long-term viability of an irrigation scheme. There is a need therefore to monitor trends in soil salinity levels on irrigation schemes.” Not heading to this warning by Johnston (1994) made over 10 years ago, there is still currently no reliable data on soil salinity trends. This study therefore reinforces this recommendation made by Johnston (1994), to set in place a soil salinity monitoring programme at national level on all irrigation schemes.

Implemented for the whole study area (all irrigation blocks combined), the total real cumulative cost (2005 basis) of salinisation over a period of 15 years is R995 million, a good benchmark to use to leverage funds for remediation action.. See in Table 9.4 (Chapter 9)

12.5.5. PROPOSED POLICY RECOMMENDATIONS

The following policy implications and suggestions were identified in Chapter 11:

- **Farm level** – drainage is a better management option than changing to more tolerant crops, but only where needed and depending on assistance grant and cash flow.
- **Irrigation Block level** – grant assistance is necessary to drain before salinity levels become too high in areas not too badly affected yet.
- **WUA level** – cross subsidisation of downstream return-flow users from upstream Orange river water users is possibly a viable option.
- **Regional level** – the improvement of agricultural productivity from increased investment in irrigation drainage far outweighs the costs and has a positive ripple effect through the economy. In calculating the secondary effects to the economy the returns to investment are great. Agricultural water use productivity is also far better with the secondary impacts accounted for.

Drainage installation for facilitation of leaching is a more financially and environmentally sustainable option than the planting of tolerant crops. Factoring in the costs of drainage into irrigators' water tariffs is less than the

additional financial benefits derived from the drainage and should therefore be acceptable to farmers. Although **Rscm** and **Rszg** Irrigation Blocks do not require immediate remediation action they should possibly be charged more for water to internalize the downstream externality they produce on the **RloR** and some **Vall** farmers. Cross-subsidising a portion of the **RloR** and the **Vall** farmers drainage with increased **Rscm** and **Rszg** water tariffs may be a plausible policy option.

At base-case scenario levels (i.e. no additional leaching and drainage) the **Rscm** consistently has the greatest comparative advantage, with very poor TGMASC per hectare per year results from the **RloR**. When equalising irrigation blocks to 150% (1.5 crops per hectare per year) **Vall** proves to be the irrigation block with the greatest comparative advantage for all scenarios and leaching and drainage combinations.

Having identified the **RloR** as the most critical Irrigation Block requiring additional artificial leaching and drainage, over a range for discount rates, assistance grant levels and repayment terms, the net return of assistance grant investment for the **RloR** is positive, indicating a very favourable return to subsidised drainage investment over a range of possible circumstances and conditions.

Drainage installation for facilitation of leaching needs to be promoted in the Orange-Vaal WUA (**Vall**) and especially in the Lower Riet (**RloR**) Irrigation Blocks in the study area. 10% and 20% of the **Vall** and **RloR** Irrigation Blocks' irrigable area respectively are indicated to be drained. If the **Rscm** and **Rszg** Irrigation Blocks are to be drained, before salinity builds up to levels which result in financial losses, at least a 50% assistance grant of the total drainage costs may be needed to make the offer financially viable and acceptable by the irrigators.

The following programmes (author's opinion) could be implemented or initiated by the Department of Agriculture, WUAs, GWK, etc. in the irrigation areas:

- Subsidise agricultural extension to regularly measure soil salinity
- Promote soil salinity status readings by fertilizer companies when conducting soil analyses and making fertilization recommendation
- Promote inquiring about the salinity status of soils when purchasing irrigation land
- Increase awareness to insurance companies of the potential increased risk of salinised soils if not managed properly.

These salinity awareness programmes must be coupled with a centralised soil salinity database to facilitate the accumulation of soil salinity data for better policy analysis and research in the future, as one of the limitation identified in this study is a shortage of historical soil salinity data.

12.6. FUTURE RESEARCH NEEDS

12.6.1. WHOLE FARM LEVEL ECONOMIC MODEL REFINEMENT (OPTIMISATION)

The externalities need to be internalised to determine the best way and the acceptability to internalise the costs of salinisation created by farmers at different locations along the river. Separate optimisation models at farm

level and all along a river reach are proposed if the limitations of optimising bio-physical interactions with too many decision variables can be overcome.

12.6.2. HYDROLOGY REFINEMENT

The refinement of the WRPM to include the sub-WUAs identified in Chapter 3 as irrigation blocks will provide better results especially for the Orange-Vaal WUA (**Vall**) Irrigation Block. A more user friendly version of the WRPM model needs to be developed that other operators can use. A suggestion would be to transfer the existing data bases and set up information from the out dated model coding into a GIS based model already developed, for instance MIKE Basin from the Danish Hydraulic Institute (DHI).

12.6.3. LOCAL SALINITY YIELD RESPONSE

Research conducted at the UFS Department of Soil Science, not completed at the time of this report on crop response to infield salinity should be incorporated into similar studies as this research. More up to date and locally applicable measures of crop salinity threshold and gradient values, provided by this research may be more applicable and relevant as those used in this study, mostly calculated in laboratory situations in California.

12.6.4. SOIL SALINITY DATA BASE

One of the limitations identified in this study was a shortage of historical soil salinity data. Salinity awareness programmes must be coupled with a centralised soil salinity database to facilitate the accumulation of soil salinity data for better policy analysis and research in future.

12.6.5. GIS LINKAGES

McKinney *et al.* (2000, ix) state that “*the future direction of modelling will lie in GIS-based decision support systems that integrate economic, agronomic, institutional and hydraulic components*”. The authors fully agree with this statement and recognise the need for multidisciplinary teams to conduct this type of research.

LIST OF REFERENCES

- ALLEN, R.B. AND HEROLD, C. DWAF (1988) Vaal River System Analysis: Water Quality Modelling (Volume A: Water Quality Calibration Model). March 1988. Report No. C000/00/7086 compiled by BKS Consulting Engineers (Pty) Ltd for the Department of Water Affairs and Forestry, Directorate: Planning, Pretoria, South Africa
- ANNANDALE, J.G., STEYN, J.M., BENADE, N., JOVANOVIC, N.Z. AND SOUNDY, P. (2005) Irrigation scheduling using the Soil Water Balance (SWB) model as a user-friendly irrigation scheduling tool. WRC Report Number: TT 251/05, Pretoria
- ARC-ILI (1997) ILI Irrigation Design Manual. Published by the Institute of Agricultural Engineering, and Institute of the Agricultural Research Council, Silverton. ISBN 1-919685-11-1
- ARMOUR, R.J. AND VILJOEN, M.F. (2002) The Leaching Paradox and Return Flow Management Options for Sustainable Irrigated Agriculture. *South African Journal of Economic and Management Sciences, Special Environmental Issue*, NS 5:2 430-451
- ARMOUR, R.J. and VILJOEN, M.F. (2002b) *The Economic Impact of Changing Water Quality on Irrigated Agriculture in the Lower Vaal and Riet Rivers*. Water Research Commission Report No.947/1/02, ISBN No. 1-86845-951-9
- BENADE, N., ANNANDALE, J.G., JOVANOVIC, N.Z., MEIRING, J.A., AND CROUS, C.L. (2002) The development of an integrated information system for irrigation water management using the WAS SWB and RiskMan computer models. WRC Report Number: 946/1/02, Pretoria
- BRISTOW, K.L., ANNANDALE, J.G., DU PLESSIS, H.M. AND ARMOUR, R.J. (2005, personal discussion) Discussion meeting on 3 March 2005, WRC offices, Pretoria
- BLACKWELL, J. (2002) [Research project information Sheet No. 18](http://www.clw.csiro.au/publications/projects/projects18.pdf) July 2002 (PDF, 253 kB), CSIRO, Australia. <http://www.clw.csiro.au/publications/projects/projects18.pdf>
- BLACKWELL, J., BISWAS, T.K., JAYAWARDANE, N.S. AND TOWNSEND, J.T. (2000). Irrigation—getting the edge. CSIRO Land and Water, PMB No 3, Griffith, NSW
- CARDON, G.E. AND LETEY, J. (1992a). Plant water uptake terms evaluated for soil water and solute movement models. *Soil Sci. Soc. Am. J.* **32**: 1876-1880.
- CARDON, G.E. AND LETEY, J. (1992b). Soil-based irrigation and salinity management model: I. Plant water uptake calculations. *Soil Sci. Soc. Am. J.* **56**: 1881-1887.
- CSIR (2004) Orange-Vaal Water User Association - Water Management Plan, 2004. Draft, January 2004.
- DoA (2005) Abstract of Agricultural Statistics 2005. Department of Agriculture (DoA), Directorate of Agricultural Statistics. Pretoria
- DUDLEY, N.J. (1992). Water allocation by markets, common property and capacity sharing – companions or competitors. *Natural Resources Journal* 32(4), 757-778.

- DU PREEZ, C.C., STRYDOM, M.G., LE ROUX, P.A.L., PRETORIUS, J.P., VAN RENSBURG. L.D. AND BENNIE, A.T.P.(2000) Effects of Water Quality on Irrigation Farming Along the Lower Vaal River: The Influence on Soils and Crops. WRC Report No. 740/1/00, Pretoria.
- DWAF (DEPARTMENT OF WATER AFFAIRS AND FORESTRY). (1996) South African Water Quality Guidelines, (2nd edn.). Volume 4 Agricultural use . The Government printer: Pretoria
- DWAF (2003) Towards a Strategy for a Waste Discharge Charge System [[Portable document format \(PDF\)](#) (2.60 MB) | [Zipped](#) (1.20 MB)] http://www.dwaf.gov.za/Dir_WQM/docs/Waste/default.htm
- ELLINGTON, R.G., USHER, B.H. AND VAN TONDER, G.J. (2004) Quantification of the impact of irrigation on the aquifer underlying the Vaalharts Irrigation Scheme. [WRC report \(South Africa. Water Research Commission\) ; no. 1322/1/04](#). Pretoria
- ELLINGTON, R.G. (2003) Quantification of the impact of irrigation on the aquifer underlying the Vaalharts irrigation scheme. Thesis (M.Sc. (Groundwater Studies))-University of the Free State. Bloemfontein
- GREEN, G.C. (1985) Estimated Irrigation Requirements of Crops in South Africa. Part 2, Highveld Region, Free State Region Transvaal Region. Memoirs on the Agricultural Natural Resources of South Africa, No.2. Soil and Irrigation Research Institute. Department of Agriculture and Water Supply. Pretoria
- GREENGROWTH STRATEGIES CC (2003) The Value of Water as an Economic Resource in the Vaal River Catchment. WRC report 990/1/03, Pretoria
- HEROLD and BAILEY (1996) Long-term salt balance of the Vaal-Harts Irrigation Scheme. WRC report 420/1/96, Pretoria
- JOHNSON, M.A.(1994) An Evaluation of the Four-Electrode and electromagnetic induction techniques of soil salinity measurement. Water Research Commission Report No. 269/1/94. South Africa
- KIJNE, J.W., PRATHAPAR, S.A., WOPEREIS, M.C.S and SAHARAWAT, K.L. (1998) How to manage salinity in irrigated lands: A selective review with particular reference to irrigation in developing countries. SWIM PAPER 2, International Irrigation Management Institute System-Wide Initiative on water Management, Colombo: Sri Lanka.
- MAAS, E.V., HOFFMANN, G.J. (1977) Crop salt tolerance - current assessment. ASCE J.Irrig.Drain.Div, 103 (2), Pages 115-134
- MCKINNEY, D.C., CAI, X., ROEGRAANT, M.W., RINGLER, C. AND SCOTT, C.A.(2000). Modelling Water Resource Management at the Basin Level: Review and Future Directions. SWIM Paper 6, International Irrigation Management Institute System-Wide Initiative on water Management, Colombo: Sri Lanka.
- NATIONAL WATER ACT, THE (39 of 1998)
- NINHAM SHAND (2004) Orange-Riet Water User Association Water Management Plan 2004. Final Draft, January 2004. Ninham Shand report No: 094930/3070/R/1 for the Department of Water Affairs and Forestry, Directorate water conservation.

- PRATHAPAR, S.A., MEYER, W.S., MADDEN, J.C. and ALOCILJ, E. (1997) SWAGMAN Options: A Hierarchical Multi-Criteria Framework to Identify Profitable Land Uses that Minimize Water Table Rise and Salinisation. *Applied Mathematics and Computation* 83:217-240 May 1997. Elsevier Science Inc., NY.
- QUADDUS and SIDDIQUE (2004) *Handbook of Sustainable Development Planning: Studies in Modeling and Decision Support*
- RAGAB, R. (2000) An Integrated Modelling Approach for Irrigation Water Management Using Saline and Non-Saline Water: The SALTMed Model. Conference paper, sixth international Micro-Irrigation Congress, 22-27 October 2000. South Africa: Cape Town
- REINDERS, F. (2005) Personal communication via e-mail on the costs of artificial drainage installation.
- TEWELDEBRHAN, A.T. (2003) The Hydro-salinity module ACRU Agro-hydrological Modelling System (ACRUSalinity): Module Development and Evaluation. M.Sc. Dissertation, University of KwaZulu-Natal, Pietermaritzburg, June 2003.
- THOMAS J.F. (2001) Valuing the costs and benefits of water use. [The Resource Economics Unit. Perth.
http://www.nlwra.gov.au/archive/minimal/30_themes_and_projects/
50_scoping_projects/04_methods_papers/30_Thomas/Costs_and_Benefits.html](http://www.nlwra.gov.au/archive/minimal/30_themes_and_projects/50_scoping_projects/04_methods_papers/30_Thomas/Costs_and_Benefits.html)
- SECKLER, D.; BARKER, R.; AMARASINGHE, U. (1999) Water scarcity in the twenty-first century. *International Journal of Water Resources Development*, 15(1/2):29- 42.
- SMUTS, J.C (1926) *Holism and Evolution: The Original Source of the Holistic Approach to Life*. Edited and reprinted by Sanford Holst (1999) [UNABRIDGED]
- STIRZAKER RJ, SUNASSEE S AND WILKIE J (2004). Monitoring water, nitrate and salt on-farm: a comparison of methods. Irrigation Australia 2004 conference, 11-13 May, Adelaide.
- VAN DER MERWE, J. (2005) Personal communication via telephone on the costs of artificial drainage installation.
- VAN HEERDEN, P.S, CROSBY, C.T. AND CROSBY, C.P. (2001) Using SAPWAT to estimate the water requirements of crops in selected irrigation areas managed by the Orange-Vaal and Orange-Riet Water Users Associations. WRC report no. TT 163/01, October 2001. Water Research Commission, Pretoria.
- VOLSCHEK, T., FEY, M.V. AND ZIETSMAN, H.L. (2005) Situation Analysis of Problems for Water Quality Management in the Lower Orange River Region with Special Reference to the Contribution of the Foothills to Salinisation. WRC Report Number: 1358/1/05, Pretoria.
- WINPENNY, J.T. (2002) *Managing Water Scarcity for Water Security*. Prepared for the FAO and edited to suit an e-mail conference. (last accessed 22-06-06)
<http://www.fao.org/waicent/Faoinfo/Agricult/AGL/AGLW/webpub/scarcit1.htm>

WRP consultants – Chapter 4

- ALLEN, R.B. AND HEROLD, C. (1988) Vaal River System Analysis: Water Quality Modelling (Volume A: Water Quality Calibration Model). March 1988. Report No. C000/00/7086 compiled by BKS Consulting Engineers (Pty) Ltd for the Department of Water Affairs and Forestry, Directorate: Planning, Pretoria, South Africa
- HEROLD, C.E. (1981) A Model to Simulate the Daily Water and Salt Balance in the Vaal River Water Supply System. Report No 5/81, Hydrological Research Unit, University of the Witwatersrand, Johannesburg
- MIDGLEY DC, PITMAN WV AND MIDDLETON BJ. (1994) Surface Water Resources of South Africa 1990: User's Manual. WRC Report No. 298/1/94
- PITMAN WV AND KAKEBEEKE JP. (1997) WRSM90 Water Resources Simulation Model: User Guide Version 4.2 Compiled by Steward Scott Incorporated Consulting Engineers.
- PEGRAM, G.G.S. (1997) Patching Rainfall Data (A guide). August 1997. Compiled by BKS Consulting Engineers (Pty) Ltd for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning, Pretoria, South Africa
- MCKENZIE, R.S. AND MARÉ, H.G. (1998) Orange River Development Project Replanning Study: Hydrology and Systems Analysis: Orange Basin. April 1998. DWAF Report No. PD 00/00/4697 compiled by BKS (PTY) LTD/Ninham Shand (PTY) LTD for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning, Pretoria, South Africa.
- BKS (1999) Water Resources Yield Model User Guide Release 4.1.1 June 1999. Report No. P000/00/001/98 compiled by BKS Consulting Engineers (Pty) Ltd for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning, Pretoria, South Africa
- MARÉ, H.G. (2001) Vaal River System Analysis Update: Summary Report. July 2001. DWAF Report No. PC000/00/19496 compiled by BKS (Pty) Ltd/Steward Scott Inc/Ninham Shand (Pty) Ltd Consortium for the Department of Water Affairs and Forestry, Directorate: Water Resources Planning, Pretoria, South Africa
- MOOLMAN, J. and QUIBELL, G. (1995). Salinity problems at the Douglas Weir and Lower Riet River. Institute for Water Quality Studies ? DWAF. Report Number N/C900/29/DIQ1495
- WRC (2003) Monthly Multi-Site Stochastic Stream-flow Model, STOMSA USER GUIDE. November 2003. WRC Report No. TT/99, ISBN.
- MARÉ, H.G., HATTINGH, L.C. AND KAMISH, W. (2004a) Pre-Feasibility Study into Measures to Improve The Management of The Lower Orange River and to Provide for Future Developments Along the Border Between Namibia and South Africa: Hydrology, Water Quality and Systems Analysis Volume A. July 2004. DWAF Report No. PB D000/00/4303 compiled by Lower Orange River Consultants for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning, Pretoria, South Africa

VAN ROOYEN, P.G., SWART, H.S., AND RADEMEYER, J.I. (2004b) Annual Operating Analysis for the Total Integrated Vaal River System (2003/2004). October 2004. Report No. P RSA C000/00/0204 compiled by WRP Consulting Engineers (Pty) Ltd as part of the Vaal River Continuous Investigations (Phase 2) for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning, Pretoria, South Africa

Urban-Econ – Chapters 7 and 10

CONNINGARTH CONSULTING ECONOMISTS. (1999) The theory and practice of input-output analysis.

ICLEI. (1996) Local Governments for Sustainability: the Local Agenda 21 Planning Guide: an introduction to sustainable development planning. <http://www.iclei.org>

O'CONNOR, R AND HENRY, EW. (1975) Input-output analysis and its applications. London

QUANTEC RESEARCH PTY (LTD). (2006) Beyond 20/20 Regions Databases.

REPUBLIC OF SOUTH AFRICA. DEPARTMENT OF PROVINCIAL and LOCAL GOVERNMENT (n.d.) National Policy for Local Economic Development in South Africa (Version 3- DRAFT). DPLG: pp. 1-32.

STATISTICS SOUTH AFRICA. (2001) Population census statistics.

STATISTICS SOUTH AFRICA. (2001) National Accounting Matrix.

URBAN-ECON: DEVELOPMENT ECONOMISTS. (2006) Input-Output Table at Basic Values, 2004 (R million) derived for the Free State Water Quality Models ISIM. Reference: P/02/53

WIKIPEDIA. (2006) Wikipedia: the free encyclopaedia. Available online at <http://en.wikipedia.org/>

LITERATURE REVIEWED

- ALLEN R.B., AND HEROLD, C. (BKS Inc.) (1988) Water quality Modelling. Volume A: Water Quality Calibration Model. DWAF Vaal River System Analysis. Report 4161/30 March 1988.
- BATH, A.J. and QUIBELL, G. (1997). Application of a hydrodynamic model to examine the hydro-salinity response of the Vaal Barrage to selected operating rules. Paper presented at the Eighth South African National Hydrology Symposium, 17 - 19 November 1997, Sanlam Conference Centre, University of Pretoria, South Africa.
- BATH, A.J., DE SMIDT, K.O., GÖRGENS, A.H.M. and LARSEN, E.J. (1997). The applicability of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa: Application of DYRESM and CE-QUAL-W2. WCR Report No 304/2/97. Ninham Shand (Pty) Ltd.
- BELL, R. and KLINJE, N (2000) Basin Scale Models for Assessing Salinity Management Options. Paper presented at the 2000 World Water Conference, Melbourne, Australia.
- BEUSTER, J., GÖRGENS, A.H.M. and GREYLING, A.J.(1990a) Development of a Daily Hydrosalinity Model (DISA). Report No, H000/00/0790. Department of Water Affairs and Forestry. Pretoria
- BRADY, N.C. AND WEIL, R.R. (1996) The nature and properties of soils. Eleventh edition. Prentice Hall International 4Editions, New Jersey.
- CHAKRAVORTY, J. AND UMETSU, C. (2003) Basinwide Water Management: A Spatial Model. *Journal of Environmental Economics and Management* (45), January 2003, 1-23, Lead Article.
- DU PLESSIS, H.M. (1982) Die uitwerking van verswakkende waterkwaliteit op die opbrengs van gewasse langs die Benede-Vaalrivier. Department of Agriculture. Confidential Report No. 987/174/82. Research Institute for Soil and Irrigation, Pretoria.
- DU PLESSIS, M.C.F. and Van Der Merwe, A.J. (1970) Herwinning van sout-alkalie gronde van die Rietrivierbesproeiingskeme. Department of Agriculture, Technical Report No. 95.
- DWAF (1998) Water quality aspects: Orange River. Volume 1: Expected water quality changes. Orange River Development Project Preplanning study, PD000/00/5997
- DWAF Report No. P C000/00/7086 (Water Quality Modelling Appendix A: Water Quality Calibration Model)
- GÖRGENS, A.H.M., BATH, A.J., VENTER, A., DE SMIDT, K. and MARAIS, G v R (1993) The applicability of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa. WRC Report No. 304/1/93 ISBN 1 86845 004 X. Pretoria
- GOUWS, J.A. , NEL, P. and BROODRYK, S.W. (1998) Quantifying the impact of salinisation of South Africa's water resources with special reference to economic effects. Volume 3: Agricultural sector. Draft document for the WRC by Urban Econ.
- HEROLD, C.E. AND RADEMEYER, J.J. (2000) Water utilisation in the Vaal River system: the current situation, influences and expected trends. Paper presented at Vaal 2000 Conference. 13 pp

- HEYNIKE, J. J. C. (1987). Salination of Vaal River Water: Economic Effects. (A Desk Study). A Water Research Commission Report.
- JANMAAT, J. (2004) *Calculating the cost of irrigation induced soil salinisation in the Tungabhadra Project*. Agricultural Economics 31 pp 81-96
- KLINTWORTH, H. (1949) Riet River Irrigation Scheme. Survey of certain waterlogged areas on the settlement. SIRI Report No. 275, Pretoria.
- MARÈ, H.G. (BKS Inc.) (1995) Marico-Bosveld Staatswaterskema: Stogastiese waterbronnontledings gekoppel aan ekonomiese evaluasie. DWAF project P542501
- MEYER, W.S., BORLAND, A-M, AND REUTER. D. (2004 – current) Irrigation salinity as an integrator between soil and water and land use practice. Land and Water Audit irrigation salinity assessment. http://www.nlwra.gov.au/minimal/30_themes_and_projects/50_scoping_projects/04_methods_papers/19_Meyer/Irrigation_Salinity.html
- MURRAY, G. (1956) 'n Ondersoek na die versuiping en verbrakking van gronde op die Rietrivier nedersetting. NIGB Report No. 482/259/56, Pretoria.
- NEL, J. P. (1995). Kriteria vir besproeiingswater van gronde in die Rietrivier en Laer Vaalrivier wat deur die Oranje-Rietkanaal bedien word. Instituut vir Grond, Klimaat en Water. Verslag Nr. GW/A/95/5
- NELL, J.P. AND LEA, I. (2004) The effect of the Blesbokspruit wetland system and gold mine effluent water use on Irrigated Agriculture. SANCID [Symposium](#) on "Integrated Water Resource Management: Challenges for Irrigated Agriculture", Fish River Sun, 17-19 November 2004.
- TSUR, Y., SHANI, U AND ZEMEL, A. (2004) Optimal Dynamic Irrigation Schemes. Recent Discussion Papers. The Hebrew University of Jerusalem. <http://www.agri.huji.ac.il/~tsury/optirrocarn.pdf>
- VAN DYK, G.S., NEL, J.M. AND VAN WYK, E. (1997) *Rietrivier Staatswaterskema: Grondwater dreinerings Ondersoek*. DWAF report GH 3894
- WOLFF-PIGGOTT, B. (1994) Coupling Geographical Information systems and Catchment Hydrological Models. M.Sc. Thesis, University of Stellenbosch.

APPENDIX 1. **SMsim MODELLING SEQUENCE AND FILES**

by R.J. Armour, and M.F. Viljoen – UFS

i.) Set up scenario inputs for WRPM

To edit the scenarios to be run through WRPM open file [C:\SALMOD\SMsim\SMscenarioSetup.xls](#). Once the scenarios setup for the WRPM are correct, run the macro “SaveScenarios” saved in “SMscenarioSetup” to get the WRPM setup data required into the correct form for easy input into the WRPM. The macro saves the text (.txt – space delimited) files under the following: “C:\SALMOD\WRPM scenarios” “-Base Case”, “-Scen1”, “-Scen2” and “-Scen3”

To edit the input data used in setting up the “SMscenarioSetup” file open [C:\SALMOD\SMsim\SMsubWUA.xls](#), edit the input data and rerun the macro.

ii.) Receive and save WRPM results data

WRP consultants returns the files zippered per irrigation block and channel flows zippered.

Save the zipped files to “C:\WRPMdata\WRPM output data raw” taking care to place the respective files in the “BaseCase”, “Scen1”, “Scen2” and “Scen3” sub-folders.

Systematically unzip each folder copying only the CL..., CU... and HE... files to the same folder.

iii.) Process WRPM data

Run the macro, “TSRR_Fix” saved in [C:\WRPMdata\WRPM read coding\ GAMS CU CL HE.xls](#) to resize the column widths. The output from this Macro is saved in “C:\WRPMdata\Resize” “-Base Case”, “-Scen1”, “-Scen2” and “-Scen3” sub-folders

Run the GAMS sub-routines [“C:\WRPMdata\WRPM read coding\060130 WRPM read CuClHe”](#) “-BaseCase”, “-Scen1”, “-Scen2” and “-Scen3” “.gms” to open, edit, rearrange and save the data to the files: “C:\SALMOD\SMsim\Scenario input data” “-Base Case”, “-Scen1”, “-Scen2” and “-Scen3” for use in SMsim.xls.

In each folder “-Base Case”, “-Scen1”, “-Scen2” and “-Scen3” update the CU-, CE- and [HE-AllScen.xls](#) files checking links.

The [CeAll.xls](#) file is subsequently linked to these and feeds [CeAllScens.xls](#), which is the final hydrology link, to SMsim.

iv.) Use processed WRPM data as inputs to SMsim

The WRPM data is processed through the biophysical models for use in the economic models.

v.) Bio-physical data as inputs in SMsim

Open and run the model SAPWAT (van Heerden *et al.* 2001) and fill in the data fill in the required data fields to calculate crop coefficients to be used as input in the WRPM setup.

Convert the WRPM output factor CU from each irrigation block to CUe for each irrigation block using HE and the constant HSU saving a separate CUe file for each scenario.

Other WRPM output for the macro model biophysical calculation are the SA and SR data that are used to calculate the ISEWe.

vi.) Study area set up data as inputs to SMsim

Open [C:\SALMOD\SMsim\SMsubWUA.xls](#) to edit the Irrigation block level data used as input into SMsim

vii.) Crop Enterprise Budget (CEB) data as input to SMsim

Open [C:\SALMOD\SMsim\SMCEBs.xls](#) to set up / update / edit the CEBs.

APPENDIX 2. HYDROLOGY SETUP DATA

Main authors: HS. Swart and P.G. van Rooyen – WRP Consultants

Table A2.1: Summary of irrigation water requirements, canal losses and returnflows (Based on the LORMS and ORRS Studies)

Description	WRPM Ref	Irrigation Area		Annual Allocation		Net canal loss		Gross Irrigation		Total Return Flow		Net Irrigation	
		WRPM Ref	Area (km ²)	(ha)	Quota (m ³ /ha/a)	Water Volume (million m ³ /a)	(million m ³ /a)	% Gross Dem	(million m ³ /a)	(Including tailwater) (million m ³ /a)	% Gross Dem	(million m ³ /a)	Demand (million m ³ /a)
1 Orange-Riet Canal	RR239	RR239	121.12	12112	11014	133.4	22.3	14.2	156.9	4.5	2.9	130.0	
2 Kalkfontein Canals	RR342	RR342	30.46	3046	10998	33.5	2.4	6.1	39.4	6.9	17.5	32.5	
3 Scholtzburg	RR479	RR479	6.46	646	10991	7.1	1.2	14.3	8.4	0.4	4.8	7.9	
4 Lower Riet	RR482	RR482	39.38	3938	10995	43.3	7.3	14.3	51.0	2.5	4.9	41.2	
5 Douglas (weir&river)	RR5	RR5	70.25	7025	9139	64.2	12.6	16.7	75.5	9.8	13.0	65.7	
6 Douglas Canal	Ch 450	Ch 450	15.83	1583	9160	14.5	1.0	5.9	17.0	1.9	11.2	15.1	

Table A2.2: Summary of Base Case (status quo) irrigation water requirements (Based on the Historic Analysis results - 68 year period - of the WRC Salinity Study)

Description	WRPM Ref	Area		Annual Allocation		Canal loss		Gross Irrigation		Return Flow		Net Irrigation	
		WRPM Ref	Area (km ²)	(ha)	Quota (m ³ /ha/a)	Water Volume (million m ³ /a)	(million m ³ /a)	% Gross Dem	(million m ³ /a)	(million m ³ /a)	% Gross Dem	(million m ³ /a)	Demand (million m ³ /a)
1 Orange-Riet Canal	RR239	RR239	123.351	12335	11000	135.7	22.1	14.0	157.77	5.71	3.6	130.0	
2 Kalkfontein Canals	RR342	RR342	35.818	3582	11000	39.4	14.6	27.0	53.97	9.13	16.9	30.3	
3 Scholtzburg	RR479	RR479	6.412	641	11000	7.1	1.2	15.0	8.30	0.56	6.7	6.5	
4 Lower Riet	RR482	RR482	38.528	3853	11000	42.4	22.8	35.0	65.20	2.05	3.1	40.3	
5 Douglas (weir&river)	RR5	RR5	73.896	7390	11000	81.3	47.7	37.0	129.02	9.52	7.4	71.8	
6 Douglas Canal	Ch 450	Ch 450	26.200	2620	11000	28.8	3.2	10.0	32.02	0.0	0.0	28.8	

Table A2.3: Summary of Scenario 1 (more salt tolerant crops) irrigation water requirements (Based on the Historic Analysis results - 68 year period - of the WRC Salinity Study)

<u>Description</u>	<u>WRPM</u>	<u>Area</u>		<u>Annual Allocation</u>		<u>Canal loss</u>		<u>Gross Irrigation Demand</u>		<u>Return Flow</u>		<u>Net Irrigation Demand</u>	
		<u>Ref</u>	<u>(km²)</u>	<u>(ha)</u>	<u>(m³/ha/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>
1	Orange-Riet Canal	RR239	123.351	12335	11000	135.7	22.1	14.0	157.77	5.79	3.7	129.9	129.9
2	Kalkfontein Canals	RR342	35.818	3582	11000	39.4	14.6	27.0	53.97	9.13	16.9	30.3	30.3
3	Scholtzburg	RR479	6.412	641	11000	7.1	1.2	15.0	8.30	0.66	8.0	6.4	6.4
4	Lower Riet	RR482	38.528	3853	11000	42.4	22.8	35.0	65.20	2.14	3.3	40.2	40.2
5	Douglas (weir&river)	RR5	73.896	7390	11000	81.3	47.7	37.0	129.02	9.89	7.7	71.4	71.4
6	Douglas Canal	Ch 450	26.200	2620	11000	28.8	3.2	10.0	32.02		0.0	15.1	15.1

Table A2.4: Summary of Scenario 2 (salt sensitive crops) irrigation water requirements, (Based on the Historic Analysis results - 68 year period - of the WRC Salinity Study)

<u>Description</u>	<u>WRPM</u>	<u>Area</u>		<u>Annual Allocation</u>		<u>Canal loss</u>		<u>Gross Irrigation Demand</u>		<u>Return Flow</u>		<u>Net Irrigation Demand</u>	
		<u>Ref</u>	<u>(km²)</u>	<u>(ha)</u>	<u>(m³/ha/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>
1	Orange-Riet Canal	RR239	123.351	12335	11000	135.7	22.1	14.0	157.77	5.94	3.8	129.7	129.7
2	Kalkfontein Canals	RR342	35.818	3582	11000	39.4	14.6	27.0	53.97	9.13	16.9	30.3	30.3
3	Scholtzburg	RR479	6.412	641	11000	7.1	1.2	15.0	8.30	0.58	7.0	6.5	6.5
4	Lower Riet	RR482	38.528	3853	11000	42.4	22.8	35.0	65.20	2.09	3.2	40.3	40.3
5	Douglas (weir&river)	RR5	73.896	7390	11000	81.3	47.7	37.0	129.02	9.61	7.4	71.7	71.7
6	Douglas Canal	Ch 450	26.200	2620	11000	28.8	3.2	10.0	32.02		0.0	15.1	15.1

Table A2.5: Summary of Scenario 3 (increased drainage and leaching) irrigation water requirements, (Based on the Historic Analysis results - 68 year period - of the WRC Salinity Study) Based on old scenario 3 and not scenario 3A

<u>Description</u>	<u>WRPM</u>	<u>Area</u>		<u>Annual Allocation</u>		<u>Canal loss</u>		<u>Gross Irrigation Demand</u>		<u>Return Flow</u>		<u>Net Irrigation Demand</u>	
		<u>Ref</u>	<u>(km²)</u>	<u>(ha)</u>	<u>(m³/ha/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>	<u>% Gross Dem</u>	<u>(million m³/a)</u>	<u>(million m³/a)</u>
1	Orange-Riet Canal	RR239	123.351	12335	11000	135.7	22.1	14.0	157.77	6.53	4.1	129.2	129.2
2	Kalkfontein Canals	RR342	35.818	3582	11000	39.4	14.6	27.0	53.97	10.21	18.9	29.2	29.2
3	Scholtzburg	RR479	6.412	641	11000	7.1	1.2	15.0	8.30	0.64	7.7	6.4	6.4
4	Lower Riet	RR482	38.528	3853	11000	42.4	22.8	35.0	65.20	2.35	3.6	40.0	40.0
5	Douglas (weir&river)	RR5	73.896	7390	11000	81.3	47.7	37.0	129.02	10.74	8.3	70.5	70.5
6	Douglas Canal	Ch 450	26.200	2620	11000	28.8	3.2	10.0	32.02		0.0	15.1	15.1

A2.1. ADDITIONAL BASE-CASE SCENARIO SETUP DATA FOR THE WRPM

The original data used to set up WRPM as given under VRSAU (2002) in Table A2.2 to Table A2.12 are updated considerably using new data discussed in Chapter 6. point 6.5 and expert opinion to better reflect the status quo of the base year 2005, as the Base-Case Scenario. This new data has been of great value to the DWAF for their continual refinement and updating of the WRPM.

The main values used to setup the base case scenario are accepted or modified as follows:

- **Max water allocation per year (million m³/a)** – set at the 2004/5 actual annual water quota allocations for the sub-WUAs making up the WRPM irrigation blocks, given in hectares (ha), multiplied by an irrigation quota of 1100m³/ha and divided by 1million.

Table A2.6. A comparison of the maximum annual water allocations (mm³/a)

		Max Annual Allocation (Mm ³ /a)		
Description	WRPM Ref	VRSAU (2002) A	UFS (2005) B	Difference (mm ³ /a) B - A
1 Orange-Riet Canal	RR239	156.90	157.77	0.87
2 Kalkfontein Canals	RR342	39.40	53.97	14.57
3 Scholtzburg	RR479	8.40	8.30	-0.10
4 Lower Riet	RR482	51.00	65.20	14.20
5 Douglas (weir and river)	RR5	75.50	129.02	53.52
6 Douglas Canal	Ch 450	17.00	32.02	15.02

Table A2.7. Division of WUAs into Irrigation Blocks

Irrigation block			Irrigation Block (WRPM code)	Water allocations (ha)	Rights (m ³ /ha)	Annual Quota (mil.m ³)
1	Orange-Vaal WUA	1.1	Vall RR5	10 014	11 000	110.15
	Orange-Vaal WUA	TOTAL		10 014		110.15
		2.1	Rscm RR239	12 335	11 000	135.69
		2.2	Rszg RR479	641	11 000	7.05
2	Orange-Riet WUA	2.3	RloR RR482	3 853	11 000	42.38
	Orange-Riet WUA	TOTAL		16 829		185.12
	Study area total			26 843		295.27

- **Flow loss proportion in transfer canal** – Based on the WUA WMAs (OV-WMP 2004, OR-WMP 2004) these were in the WRPM hydrology to better reflect the latest canal transfer losses

Table A2.8. Comparison of canal loss factors

		Canal losses (%)		
Description	WRPM Ref	VRSAU (2002) A	UFS (2005) B	Difference (%) B - A
1 Orange-Riet Canal	RR239	12.00	14.00	2.00
2 Kalkfontein Canals	RR342	15.00	27.00	12.00
3 Scholtzburg	RR479	15.00	15.00	0.00
4 Lower Riet	RR482	15.00	35.00	20.00
5 Douglas (weir and river)	RR5	15.00	37.00	22.00
6 Douglas Canal	Ch 450	11.00	10.00	-1.00

- **Salt loss proportion in transfer canal** – was adjusted in the WRPM hydrology setup proportionally to the canal transfer losses.
- **Irrigation efficiency factor** – these were updated from the Lower Vaal Irrigation Study (Herold ... 1992?) values of 60-65% to values of 80-85% as shown in Table A, calculated as weighted averages for each irrigation block depending on the irrigation system composition in 2003/4 as reported in the WUA WMPs (Water Management Plans) (OV-WMP, 2004 and OR-WMP 2004).
Table 8.8. Comparison of irrigation efficiencies in the irrigation blocks

Table A2.9. A comparison of the irrigation efficiency factors used in the irrigation blocks

Description	WRPM Ref	Irrigation Efficiencies (%)		
		VRSAU A	UFS B	Difference (%) B - A
1 Orange-Riet Canal	RR239	65	85	20
2 Kalkfontein Canals	RR342	65	80	15
3 Scholtzburg	RR479	65	84	19
4 Lower Riet	RR482	65	84	19
5 Douglas(weir and river)	RR5	69	80	11
6 Douglas Canal	Ch 450			

An assumption is made, and verified by expert opinion (WUA managers), that the irrigation system composition changed only very slightly from 2003/4 to the project base year, 2004/5 production year.

- **Return Flow factor** - for the base case and scenarios 1 and 2 the return flow factor is accepted as initially set up in the WRPM hydrology at 4,5% for Vall, 2% for RloR, 1,5% Rscm and 2,5% for Rszg, and verified in the Vaal River Study (Herold, 1981). For scenarios 3 and 3+, however, the original values are increased by 15% to reflect a 15% increase in the area of artificial drainage installed and subsequent 15% increase in irrigation leaching.
- **Return flow proportion from Upper zone** - for all scenarios the return flow proportion from the upper zone is accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981)
- **Return flow proportion from Lower zone** - for all scenarios the return flow proportion from the lower zone is accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981). A WRPM model trial was run with the return-flow proportions from the upper zone and lower zones swapped to reflect a larger proportion of returnflows from the upper zone with the increase in artificial irrigation drainage. The results were found very unrealistic, concluding that the division between the upper and lower zone was not related to and increase in irrigation drainage.
- **Deep percolation salt [] Factor** - for all scenarios the deep percolation salt concentration factor is accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981)
- **Salt loss proportion to deep storage** – the value of 0.004 was accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981) for all scenarios.

- **The initial salt storage (mg/l) in the upper and lower zones** – these values are manually adjusted by the WRPM operators to level-out all trends in the base case model runs, so as to reflect an irrigation block at equilibrium (i.e. no trends).

Table A2.10. Initial Salt Storage Values used for all the scenarios (WRP Consultants, 2006)

	Description	WRPM Ref	Initial Salt Storage (mg/l) Final for Base Case	
			RRSSUI	RRSSLI
1	Orange-Riet Canal	RR239	1300	1700
2	Kalkfontein Canals	RR342	900	2150
3	Scholtzburg	RR479	2250	3750
4	Lower Riet	RR482	6500	9500
5	Douglas (weir and river)	RR5	4000	7000

- **Monthly effective rainfall factors** – are accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981) for all scenarios – zero rainfall efficiency is assumed.
- **Monthly mean pan evaporation (mm)** – is accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981) for all scenarios.
- **Monthly mean pan factors - fraction-** accepted as initially set up in the WRPM hydrology and verified in the Vaal River Study (Herold, 1981) for all scenarios.
- **The irrigation area % (% area in crop)** – is presented in Table A2.11 as updated.
- **Monthly crop water usage factors** – are derived using SAPWAT from Green (1985) and explained in full in Chapter 5.
- **Allocated area (sq.km) where NPA <=> 0** – the simplification of the formula used to derive allocated area is the Max water allocation per year (million m³/a) / 1.1, as the irrigation quota is 1100m³/ha for each hectare of water entitlements allocated. These values (Table A2.11) have been updated to reflect the latest changes in quota allocations in the study area.

Table A2.11. A comparison of irrigation areas (km²)

Irrigation Areas (km ²)					
	Description	WRPM Ref	VRSAU (1992)	UFS (2005)	Difference
			A	B	(km ²) B - A
1	Orange-Riet Canal	RR239	121.12	123.35	2.23
2	Kalkfontein Canals	RR342	30.46	35.82	5.36
3	Scholtzburg	RR479	6.46	6.41	-0.05
4	Lower Riet	RR482	39.38	38.53	-0.85
5	Douglas (weir and river)	RR5	70.25	73.90	3.65
6	Douglas Canal *	Ch 450	15.83	26.20	10.37

* The VRSAU information was used for all the UOFS runs

APPENDIX 3. IRRIGATION BLOCK CEBs

by R.J. Armour, and M.F. Viljoen – UFS

Table A3.1. The CEBs (2005 prices) of the Riet Scheme irrigation block of the OR-WUA

RIET SCHEME	Unit	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
ECe Threshold without leaching	mS/mt	800	400	100	770	250	160	170	200	170	300	120	600	320	150	170	500	170	170	150	600
ECe Threshold (BC, S1 and S2)	mS/m	812	406	102	782	254	162	173	203	173	305	122	609	325	152	173	508	508	711	152	609
ECe Gradient	%mS/m	0.071	0.090	0.140	0.052	0.130	0.096	0.210	0.073	0.120	0.190	0.160	0.071	0.290	0.190	0.120	0.200	0.087	0.090	0.096	0.071
Crop water requirement	mm/ha	610	398	383	765	517	333	1206	1173	761	555	245	839	601	635	553	642	417	613	634	610
Crop Enterprise Budgets:																					
PRICE	R/ton	1030	1061	1142	3016	550	2782	3000	552	832	5400	1378	800	2591	16500	1412	1693	1451	750	725	1208
Max Physiological yield	ton/ha	6.00	35.00	50.00	5.00	50.00	3.50	21.00	20.40	14.00	6.40	55.00	8.00	4.00	1.60	45.00	6.00	4.00	40.00	20.38	7.00
Gross income	R/ha	6 180	37 133	57 091	15 079	28 000	9 739	63 000	11 255	11 651	34 560	75 774	6 400	10 364	26 400	63 557	10 160	5 805	30 000	14 778	8 454
SEED	R/ha	504	2 680	3 900	1 114	224	1 120	7 683	375	1 080	578	2 742	1 175	1 040	373	16 000	475	61	585	2 349	756
FERTILIZER	R/ha	1 424	2 881	3 162	2 145	2 389	1 218	1 535	1 414	2 402	1 754	3 372	1 153	1 120	1 149	4 718	1 070	1 167	1 754	756	1 858
HERBICIDES	R/ha	84	368	334	85	103	204	506	165	277	539	537	0	94	25	117	233	140	270	2 204	84
PESTICIDES	R/ha	157	40	309	1 792	257	1 021	4	13	594	830	1 156	0	754	0	9 574	159	188	612	0	409
INSURANCE	R/ha	341	0	2 376	1 080	0	360	11 201	0	960	0	4 950	0	344	0	1 200	0	307	384	0	364
FUEL	R/ha	206	281	426	444	271	225	43	464	194	127	426	233	295	82	828	171	274	233	146	287
MAINTENANCE	R/ha	481	0	0	567	0	418	66	1 078	336	1 000	223	698	811	29	1 154	145	418	406	207	913
Temp LABOUR	R/ha	0	4 597	5 307	988	1 900	554	900	0	0	567	491	0	1 070	0	268	160	0	300	1 434	0
ELEC. @ R 0.82 /mm	R/mm/ha	501	327	314	628	425	273	990	343	504	456	201	689	494	522	454	527	343	504	521	501
WATER@ R 0.68 /mm	R/mm/ha	413	269	259	518	350	225	817	282	415	376	166	568	407	430	375	435	282	415	430	413
HARVESTING COSTS	R/ton	122	539	600	280	20	249	82	44	50	3 000	184	0	471	233	368	127	113	270	12	103
Total expenses pre harvest	R/ha	734	18 865	30 000	1400	1 000	873	1 716	899	704	19 200	10 104	0	1 886	373	16 557	760	450	10 812	240	723
Total expenses with max harvest	R/ha	4 112	11 443	16 388	9 362	4 919	5 618	23 745	4 133	6 761	6 227	14 263	4 517	6 429	2 610	34 688	3 377	3 180	5 463	8 047	5 585
Total expenses with max harvest	R/ha	4 846	30 308	46 388	10 762	6 919	6 491	25 461	5 033	7 465	25 427	24 366	4 517	8 315	2 983	51 245	4 137	3 630	16 275	8 287	6 308
Gross Margin	R/ha	1 334	6 825	10 704	4 317	21 081	3 248	37 539	6 223	4 186	9 133	51 408	1 893	2 049	23 417	12 311	6 023	2 174	13 725	6 491	2 146
Co-op financed	R/ha	88	0	725	226	236	0	0	96	161	593	382	359	152	0	931	66	70	125	781	128
Bank financed	R/ha	45	0	1 401	70	81	0	0	42	45	2 204	288	138	77	0	478	47	30	323	131	45
Total Interest	R/ha	133	0	2 126	296	317	0	0	138	205	2 797	670	497	229	0	1 409	114	100	448	912	173
TGMASC	R/ha	1 200	6 825	8 578	4 022	20 764	3 248	37 539	6 084	3 980	6 336	50 738	1 387	1 820	23 417	10 902	5 909	2 075	13 278	5 580	1 972

Table A3.2. The CEBs (2005 prices) of the Scholtzburg irrigation block of the OR-WUA

SCHOLTZBURG	Unit	Barley	Beets	Carrots	Cotton	Cucurbits	Dry Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
ECe Threshold without leaching	mS/m	800	400	100	770	250	160	170	200	170	300	120	600	320	150	170	500	170	170	150	600
ECe Threshold (BC, S1 and S2)	mS/m	820	410	103	789	256	164	174	205	174	308	123	615	328	154	174	513	513	718	154	615
ECe Gradient	%/mS/m	0.071	0.090	0.140	0.052	0.130	0.096	0.210	0.073	0.120	0.190	0.160	0.071	0.290	0.190	0.120	0.200	0.087	0.090	0.096	0.071
Crop water requirement	mm/ha	616	402	386	772	522	336	1218	1185	768	561	247	847	607	642	559	648	421	619	641	616
Crop Enterprise Budgets:																					
PRICE	R/ton	1030	1061	1142	3016	560	2782	3000	552	832	5400	1378	800	2591	16500	1412	1693	1451	750	725	1208
Max Physiological yield	ton/ha	6.00	35.00	50.00	5.00	50.00	3.50	21.00	20.40	14.00	6.40	55.00	8.00	4.00	1.60	45.00	6.00	4.00	40.00	20.38	7.00
Gross income	R/ha	6 180	37 133	57 091	15 079	28 000	9 739	63 000	11 255	11 651	34 560	75 774	6 400	10 364	26 400	63 557	10 160	5 805	30 000	14 778	8 454
SEED	R/ha	504	2 680	3 900	1 114	224	1 120	7 683	375	1 080	578	2 742	1 175	1 040	373	16 000	475	61	585	2 349	756
FERTILIZER	R/ha	1 424	2 881	3 162	2 145	2 389	1 218	1 535	1 414	2 402	1 754	3 372	1 153	1 120	1 149	4 718	1 070	1 167	1 754	756	1 858
HERBICIDES	R/ha	84	368	334	85	103	204	506	165	277	539	537	0	94	25	117	233	140	270	2 204	84
PESTICIDES	R/ha	157	40	309	1 792	257	1 021	4	13	594	830	1 156	0	754	0	9 574	159	188	612	0	409
INSURANCE	R/ha	341	0	2 376	1 080	0	360	11 201	0	960	0	4 950	0	344	0	1 200	0	307	384	0	364
FUEL	R/ha	206	281	426	444	271	225	43	464	194	127	426	233	295	82	828	171	274	233	146	287
MAINTENANCE	R/ha	481	0	0	567	0	418	66	1 078	336	1 000	223	698	811	29	1 154	145	418	406	207	913
Temp LABOUR	R/ha	0	4 597	5 307	988	1 900	554	900	0	0	567	491	0	1 070	0	268	160	0	300	1 434	0
ELEC. @ R 0.45 /mm	R/mm/ha	279	182	175	350	237	152	552	191	281	254	112	384	275	291	253	294	191	281	290	279
WATER@ R 0.68 /mm	R/mm/ha	417	272	262	523	354	228	825	285	419	380	167	574	411	435	378	439	285	419	434	417
HARVESTING COSTS	R/ton	122	539	600	280	20	249	82	44	50	3 000	184	0	471	233	368	127	113	270	12	103
	R/ha	734	18 865	30 000	1 400	1 000	873	1 716	899	704	19 200	10 104	0	1 886	373	16 557	760	450	10 812	240	723
Total expenses pre harvest	R/ha	3 894	11 301	16 251	9 089	4 734	5 499	23 314	3 985	6 543	6 029	14 175	4 217	6 215	2 383	34 490	3 148	3 031	5 244	7 820	5 367
Total expenses with max harvest	R/ha	4 628	30 166	46 251	10 489	6 734	6 372	25 030	4 884	7 246	25 229	24 279	4 217	8 100	2 756	51 048	3 908	3 481	16 056	8 060	6 090
Gross margin	R/ha	1 551	6 967	10 840	4 590	21 266	3 367	37 970	6 372	4 404	9 331	51 495	2 183	2 263	23 644	12 509	6 252	2 323	13 944	6 718	2 364
Co-op financed	R/ha	88	0	725	226	236	0	0	96	161	593	382	359	152	0	931	66	70	125	781	128
Bank financed	R/ha	39	0	1 395	63	73	0	0	62	43	2 182	286	105	71	0	473	41	25	317	106	39
Total Interest	R/ha	127	0	2 120	288	309	0	0	158	204	2 775	668	464	223	0	1 404	107	96	442	887	167
TGMASC	R/ha	1 424	6 967	8 720	4 302	20 957	3 367	37 970	6 214	4 201	6 556	50 827	1 719	2 041	23 644	11 105	6 145	2 228	13 503	5 831	2 196

Table A3.3. The CEBs (2005 prices) of the Vaal All Irrigation Block of the OV-WUA

VAAL ALL	Unit	Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
ECe Threshold without leaching	mS/m	800	400	100	770	250	160	170	200	170	300	120	600	320	150	170	500	170	170	150	600
ECe Threshold (BC, S1 and S2)	mS/m	836	418	105	805	261	167	178	209	178	314	125	627	334	157	178	523	523	732	157	627
ECe Gradient	%/mS/m	0.071	0.090	0.140	0.052	0.130	0.096	0.210	0.073	0.120	0.190	0.160	0.071	0.290	0.190	0.120	0.200	0.087	0.090	0.096	0.071
Crop water requirement	mm/ha	628	410	394	787	532	343	1241	1208	783	572	252	864	619	654	570	661	429	631	653	628
Crop Enterprise Budgets:																					
PRICE	R/ton	1030	1061	1142	3016	560	2782	3000	552	832	5400	1378	800	2591	16500	1412	1693	1451	750	725	1208
Max Physiological yield	ton/ha	6.00	35.00	50.00	5.00	50.00	3.50	21.00	20.40	14.00	6.40	55.00	8.00	4.00	1.60	45.00	6.00	4.00	40.00	20.38	7.00
Gross income	R/ha	6180	37133	57091	15079	28000	9739	63000	11255	11651	34560	75774	6400	10364	26400	63557	10160	5805	30000	14778	8454
SEED	R/ha	504	2680	3900	1114	224	1120	7683	375	1080	578	2742	1175	1040	373	16000	475	61	585	2349	756
FERTILIZER	R/ha	1424	2881	3162	2145	2389	1218	1535	1414	2402	1754	3372	1153	1120	1149	4718	1070	1167	1754	756	1858
HERBICIDES	R/ha	84	368	334	85	103	204	506	165	277	539	537	0	94	25	117	233	140	270	2204	84
PESTICIDES	R/ha	157	40	309	1738	257	1021	4	13	588	830	1156	0	754	0	9574	159	188	594	0	403
INSURANCE	R/ha	341	0	2376	2217	3780	1032	11201	0	373	0	5759	0	321	0	2224	0	192	2640	901	364
FUEL	R/ha	206	281	426	444	271	225	43	464	194	127	426	233	295	82	828	171	274	233	146	287
MAINTENANCE	R/ha	481	0	0	567	0	418	66	1078	336	1000	223	698	811	29	1154	145	418	406	207	913
Temp LABOUR	R/ha	0	4597	5307	988	1900	554	900	0	0	567	491	0	1070	0	268	160	0	300	1434	0
ELEC. @ R 0.35 /mm	R/mm/ha	220	143	138	276	186	120	435	150	221	200	88	302	217	229	199	231	150	221	229	220
WATER@ R 0.68 /mm	R/mm/ha	425	277	267	533	360	232	841	291	427	387	170	585	419	443	386	448	291	427	442	425
HARVESTING COSTS	R/ton	122	539	600	280	20	249	82	44	50	3000	184	0	471	233	368	127	113	270	12	103
	R/ha	734	18865	30000	1400	1000	873	1716	899	704	19200	10104	0	1886	373	16557	760	450	10812	240	723
Total expenses pre harvest	R/ha	3843	11268	16219	10107	8471	6143	23213	3949	5898	5982	14964	4147	6141	2330	35468	3094	2880	7430	8669	5310
Total expenses with max harvest	R/ha	4577	30133	46219	11507	10471	7016	24929	4849	6601	25182	25067	4147	8027	2703	52026	3854	3330	18242	8909	6033
Gross margin	R/ha	1603	7001	10872	3572	17529	2722	38071	6407	5049	9378	50707	2253	2337	23697	11531	6306	2474	11758	5870	2421
Co-op financed	R/ha	88	0	725	256	409	0	0	96	144	593	404	359	151	0	959	66	67	187	880	128
Bank financed	R/ha	38	0	1394	61	71	0	0	37	37	2177	285	98	69	0	471	40	25	315	100	38
Total Interest	R/ha	126	0	2118	316	480	0	0	133	182	2770	689	456	221	0	1431	106	92	502	980	166
TGMASC	R/ha	1477	7001	8754	3256	17049	2722	38071	6273	4868	6608	50017	1797	2116	23697	10100	6200	2383	11256	4890	2255

Table A3.4. Irrigation Block comparison of the Crop TGMASC less interest values (2005 prices)

TGMASC																						
Irrigation Blocks compared			Barley	Beets	Carrots	Cotton	Cucurbits	Dry_Beans	Fruit	Lucerne	Maize	Olives	Onions	Pastures	Peanuts	Pecan_nuts	Potatoes	Soybeans	Sunflower	Vegetables	Vineyards	Wheat
LOWER RIET	R/ha		1 405	6 125	10 056	3 110	16 987	2 490	37 243	6 224	4 789	6 537	49 989	1 691	2 045	22 887	10 035	6 125	2 333	11 165	4 809	2 177
RIET SCHEME	R/ha		1 200	6 825	8 578	4 022	20 764	3 248	37 539	6 084	3 980	6 336	50 738	1 387	1 820	23 417	10 902	5 909	2 075	13 278	5 580	1 972
SCHOLTZBURG	R/ha		1 424	6 967	8 720	4 302	20 957	3 367	37 970	6 214	4 201	6 556	50 827	1 719	2 041	23 644	11 105	6 145	2 228	13 503	5 831	2 196
VAAAL ALL	R/ha		1 477	7 001	8 754	3 256	17 049	2 722	38 071	6 273	4 868	6 608	50 017	1 797	2 116	23 697	10 100	6 200	2 383	11 256	4 890	2 255
Average			1 377	6 729	9 027	3 672	18 939	2 957	37 706	6 199	4 459	6 509	50 393	1 648	2 005	23 411	10 535	6 095	2 255	12 300	5 277	2 150
Min			1 200	6 125	8 578	3 110	16 987	2 490	37 243	6 084	3 980	6 336	49 989	1 387	1 820	22 887	10 035	5 909	2 075	11 165	4 809	1 972
Max			1 477	7 001	10 056	4 302	20 957	3 367	38 071	6 273	4 868	6 608	50 827	1 797	2 116	23 697	11 105	6 200	2 383	13 503	5 831	2 255
Change from average.			rank	sum																		
LOWER RIET	4	-5 421	28	-604	1 029	-562	-1 952	-467	-462	25	330	28	-404	42	40	-524	-501	30	79	-1 135	-468	27
RIET SCHEME	2	2 008	-176	96	-449	349	1 825	291	-167	-115	-479	-173	345	-262	-185	6	367	-185	-180	977	302	-178
SCHOLTZBURG	1	6 270	48	238	-307	630	2 018	410	264	15	-259	47	435	71	35	233	569	50	-27	1 202	554	46
VAAAL ALL	3	-2 856	100	271	-273	-417	-1 890	-234	365	74	408	99	-375	149	110	286	-435	105	128	-1 044	-388	105

APPENDIX 4. MATHEMATICAL FORMULATION OF SMsim

by Equations 5. and 6. – Armour and Viljoen – UFS, and

Equations 7. – Grosskopf, Pienaar, Van Der Merwe and Oberholzer – Urban-Econ

The sets, sub-sets, scalars and input data codes are listed here, together with a complete list of all the Equations used in this study with reference to the page numbers where the formulae are defined.

SETS:

t	=	monthly (m) time step of the model over a number of years (y)	
t	=	f (m, y)	
m	=	months in the model as follows:	
		in the hydrology model, rainfall	$m = \{\text{Oct, Nov, ... Sep.}\}$
		in WRPM output	$m = \{\text{May, Jun, ... Apr.}\}$
		in financial model Tax year	$m = \{\text{Mar, Apr, ... Feb.}\}$
		in SMsim an agricultural season	$m = \{\text{Jul, Aug, ... Jun.}\}$
y	=	years in the model as follows	
		in WRPM (25 Years)	$y = \{\text{yr1, yr2, ... yr25}\}$
		in SMsim (15 years)	$y = \{\text{2005, 2003, ... 2019}\}$
t	=	1,2, ... 180. (12 months x 15 years)	
s	=	irrigation blocks in the model	$\{RloR, Rscm, Rszg, Vall\}$
r	=	stochastic model runs	$\{1, 2, ... 100\}$
c	=	all crops modelled in SMsim	$\{\text{wheat, maize, lucerne}\}$
i	=	a set of all inputs / direct production costs	$\{\text{seed, fertilizer, ... transport}\}$

SUB-SETS

sr of s	=	irrigation blocks of the OR-WUA	$\{RloR, Rscm, Rszg\}$
sv of s	=	irrigation blocks of the OV-WUA	$\{Vall\}$
fi of i	=	are all the fixed inputs (R/ha)	$\{\text{seed, fertilizer, chemicals, etc.}\}$
yi of i	=	are all the yield dependant production costs (R/ton)	$\{\text{harvesting, packaging, transport, etc.}\}$

SCALARS / CONSTANTS:

SCF	TDS to EC salinity conversion factor	=	6.5

INPUT DATA:

$TDS_{cu,t,s,r}$	is a data set of the salt concentration (mg/l) in the upper layer calculated in the WRPM as output data used as input for SMsim. The data set $TDS_{cu,t,s,r}$ comprises monthly data for all years (t) in all irrigation blocks (s) for 100 stochastic runs (r).
$CWR_{c,m}$	is the crop water requirement percentage for each month (m) for all crops (c). The sum over m for each c gives a result 1 = 100%.
$Thrsh_c$	is the crop (c) specific salinity yield reduction threshold value (mS/m) (assumed constant for all irrigation blocks)
$Grad_c$	is the crop (c) specific salinity yield reduction gradient value (ton/ mS/m) (assumed constant for all irrigation blocks)

GradLF	is the crop (c) specific salinity yield reduction gradient value adjusted for leaching
P_{c,y,s}	is an array of different crop (c) prices (R/ton) in each year (y) and in each irrigation block (s). An assumption of the model is constant prices over the 15 years therefore y remains unchanged, however the price P _{c,y,s} can change between irrigation blocks.
I_{fi,c,y,s}	are the fixed input costs (fi) i.e. seed, fertilizer, chemicals, etc. (R/ha), for the different crops (c) which remain unchanged in each year (y), but which can change between irrigation blocks (s).
I_{yi,c,y,s}	are the yield dependant production costs (yi) i.e. harvesting, packaging, transport, etc. (R/ton), for the different crops (c) in each year (y) and in each irrigation block (s).

SUMMARY OF EQUATIONS:

Page Number:

Equation 5.1:	$CUe_{t,s} = (CU_{t,s} \cdot HE_t) / HSU$	58
Equation 5.2:	$ECE_{t,s} = CUe_{t,s} / SCF$	58
Equation 5.3:	$ECC_{c,y,s} = \sum_{t,m} ECE_{t,s} * CWR_{c,m}$	59
Equation 5.4:	$ThrshLF_c = Thrsh_c * (1 + LF_s)$	60
Equation 5.5:	$Yf_{c,y,s} = \{100 - Grad_c * (ECC_{c,y,s} - ThrshLF_c)\} / 100$	60
Equation 5.6:	$Ys_{c,y,s} = Yf_{c,y,s} * Ym_c$	60
Equation 5.7:	$ISEWe_y = 1 + ((\sum_m SA_{y,m} - \sum_m SR_{y,m}) / 10\ 000)$	62
Equation 6.1:	$TGMASCh_{c,y,s,r} = Ys_{c,y,s,r} * P_{c,y} - \sum I_{fi,c,y,s} - \sum I_{yi,c,y,s} * Ys_{c,y,s,r}$	77
Equation 6.2:	$TGMASCs_{y,s,r} = \sum_c TGMASCh_{c,y,s,r} * SA_s * CP_{c,s}$	78
Equation 6.3:	$TGMASCwr_{y,sf,r} = \sum_{sr} TGMASCs_{y,sf,r}$	78
Equation 6.4:	$TGMASCwv_{y,sv,r} = \sum_{sv} TGMASCs_{y,sv,r}$	78
Equation 6.5:	$TGMASCr_{y,r} = \sum_s TGMASCs_{y,s,r}$	78
Equation 6.6:	$TGMASCrc_r = \sum_y TGMASCr_{y,r}$	78
Equation 7.1:	$ISEW_y = w_i(P_y/P_{y-1}) + w_i(E_y/E_{y-1}) + w_i(S_y/S_{y-1})$	88
Equation 7.2:	$P = (Pa + Pfl + Pbl) + (ERa + ERfl + ERbl)$	88
Equation 7.3:	$EMP = (ERa + ERbl + ERfl)/wr$	88
Equation 7.4:	$E = EMP / (PEA_i - NEA_i) \times 100$	88
Equation 7.5:	$S = \Sigma(EC_s \times ha_s) / \Sigma ha_s$	89
Equation 7.6:	$ISE_y = 1 + ((SA_y - SR_y)/1000)$	89
Equation 7.7:	$m_i = CI_i / Pa$	89
Equation 7.8:	$Net\ Benefit_y = (P_y - P_{y-1}) - \Sigma WI_i$	89

APPENDIX 5. REGIONAL MODEL RESULTS

by Pienaar, G., Van Der Merwe, B.J. and Oberholzer J.L. – Urban-Econ: Development Economists

A5.1. BASE CASE SCENARIO

A5.1.1. MODEL INPUT DATA

The following set of tables and figures depict the results of the Base Case Scenario-projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80.

Table A5.1. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80 and 50% percentile)

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	431 550	445 516	439 949	444 518	439 156	429 832	459 632	465 730	460 552	458 447	438 760	451 374	443 307	435 788	435 417
44	442 923	455 153	476 099	477 738	470 090	453 970	475 757	457 338	434 038	466 475	473 985	460 059	456 593	450 823	485 322
80	442 714	446 245	449 865	444 571	448 083	443 141	454 134	450 074	446 693	443 223	445 130	441 619	449 711	440 138	449 015
50% percentile	442 613	446 329	448 583	449 688	451 123	450 576	451 407	450 649	451 461	450 228	449 275	450 422	452 270	451 665	450 704

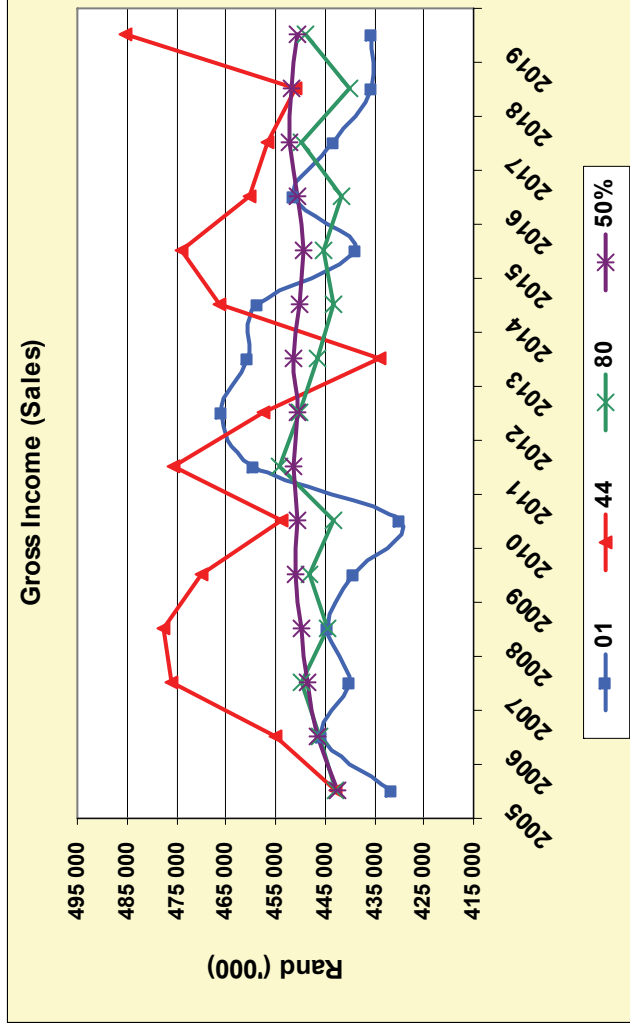


Figure A5.1. Gross Income per year, 2005 to 2019 (Stochastic run 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

Table A5.2. Projected Gross Margins (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	124 092	136 509	131 301	135 330	130 668	122 743	149 089	154 042	149 745	147 558	130 474	141 396	134 315	127 799	127 667
44	133 493	143 560	161 945	163 598	157 084	143 122	161 229	145 013	124 826	153 511	160 438	148 456	145 406	140 996	169 618
80	133 659	136 828	139 976	135 546	138 573	134 378	143 719	140 195	137 394	134 448	136 015	133 132	139 933	131 959	139 387
50% percentile	133 564	136 789	138 798	139 745	140 956	140 553	141 235	140 543	141 237	140 170	139 331	140 329	141 912	141 429	140 614

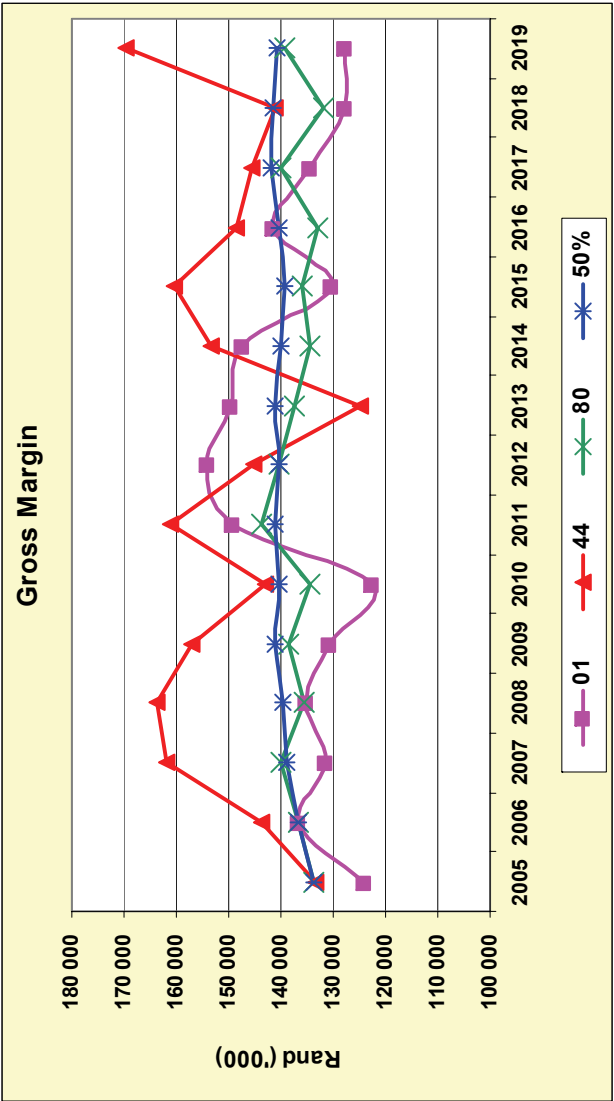


Figure A5.2. Gross margins, 2005 to 2019 (Stochastic run 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

A5.1.2. REGIONAL MODEL RESULTS

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GDP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table A5.3. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	784 274	809 655	799 539	807 841	798 096	781 152	835 308	846 391	836 980	833 155	797 378	820 300	805 641	791 976	791 301
44	804 943	827 168	865 234	868 213	854 313	825 018	864 613	831 140	788 795	847 745	861 393	836 085	829 785	819 299	881 996
80	804 563	810 979	817 559	807 937	814 321	805 339	825 317	817 938	811 793	805 488	808 953	802 572	817 279	799 882	816 013
50% percentile	804 379	811 132	815 230	817 237	819 845	818 850	820 360	818 984	820 459	818 219	816 486	818 572	821 930	820 830	819 084

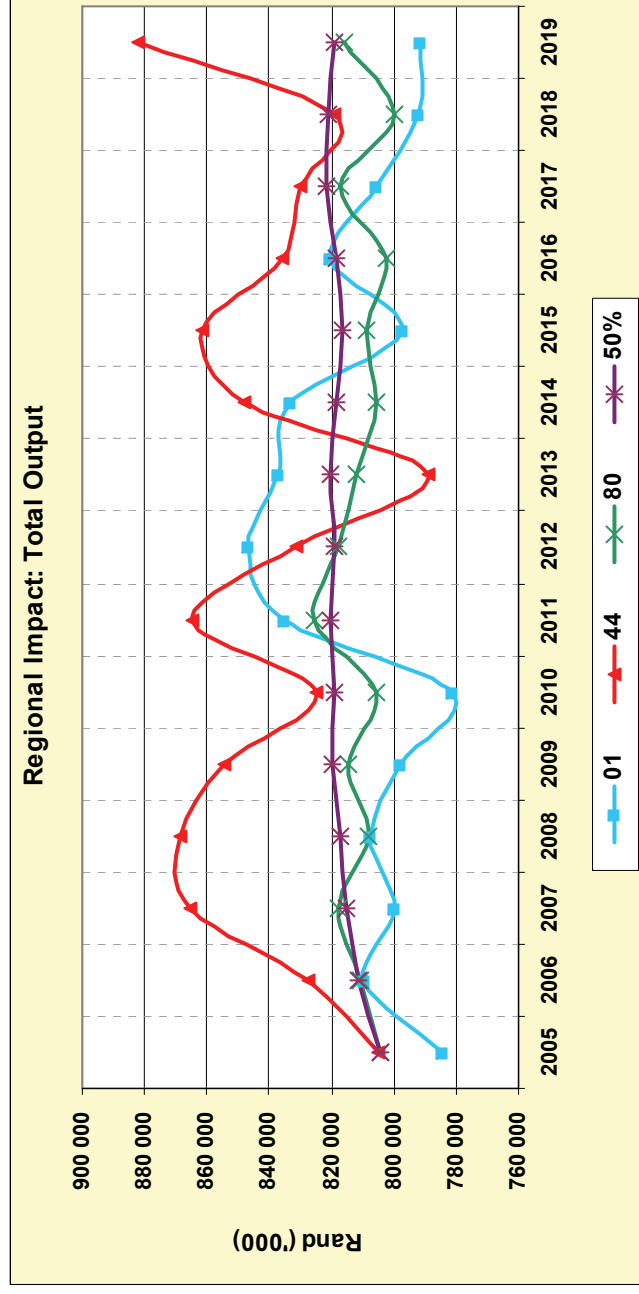


Figure A5.3. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.4. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	134 583	147 000	141 792	145 821	141 159	133 234	159 580	164 533	160 236	158 049	140 965	151 887	144 806	138 290	138 158
44	143 984	154 051	172 436	174 089	167 576	153 613	171 720	155 504	135 317	164 002	170 929	158 947	155 897	151 487	180 109
80	144 150	147 319	150 467	146 037	149 064	144 869	154 211	150 686	147 886	144 939	146 506	143 623	150 424	142 450	149 878
50% percentile	144 056	147 280	149 289	150 236	151 447	151 044	151 727	151 034	151 728	150 661	149 822	150 820	152 403	151 920	151 105

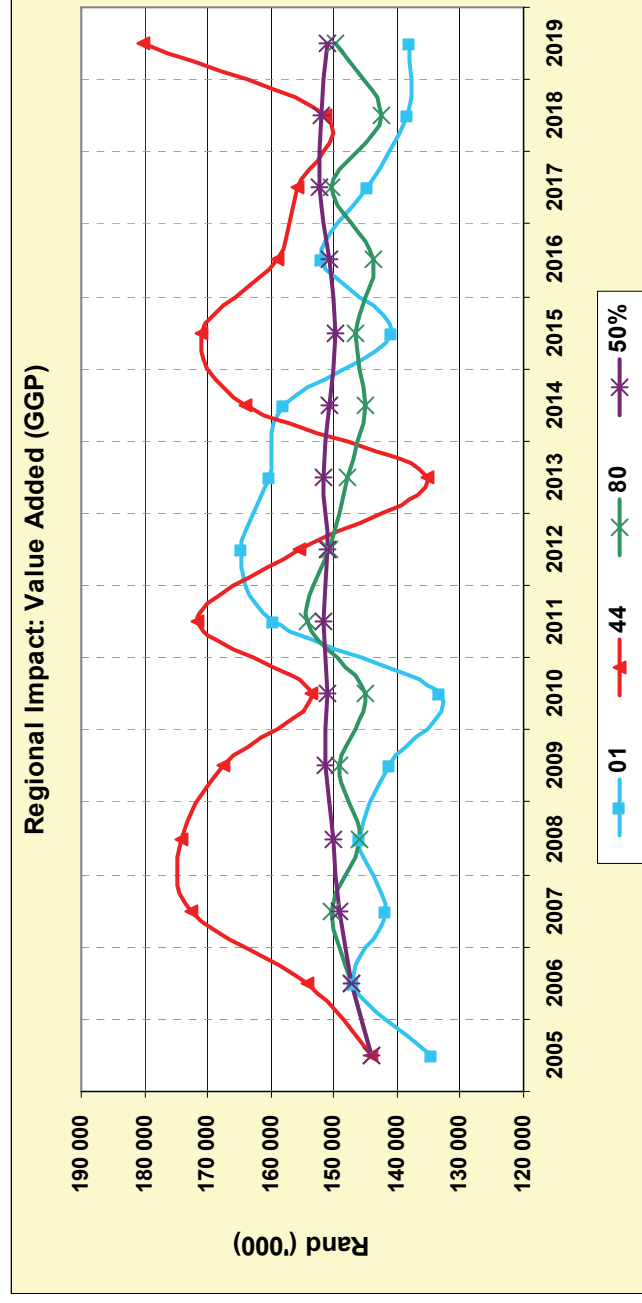


Figure A5.4. Regional Economic Impact in terms of generated GDP, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.5. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	5 552	5 732	5 660	5 719	5 650	5 530	5 914	5 992	5 925	5 898	5 645	5 807	5 704	5 607	5 602
44	5 699	5 856	6 126	6 147	6 048	5 841	6 121	5 884	5 584	6 002	6 098	5 919	5 875	5 800	6 244
80	5 696	5 741	5 788	5 720	5 765	5 701	5 843	5 791	5 747	5 703	5 727	5 682	5 786	5 663	5 777
50% percentile	5 695	5 742	5 771	5 786	5 804	5 797	5 808	5 798	5 809	5 793	5 780	5 795	5 819	5 811	5 799

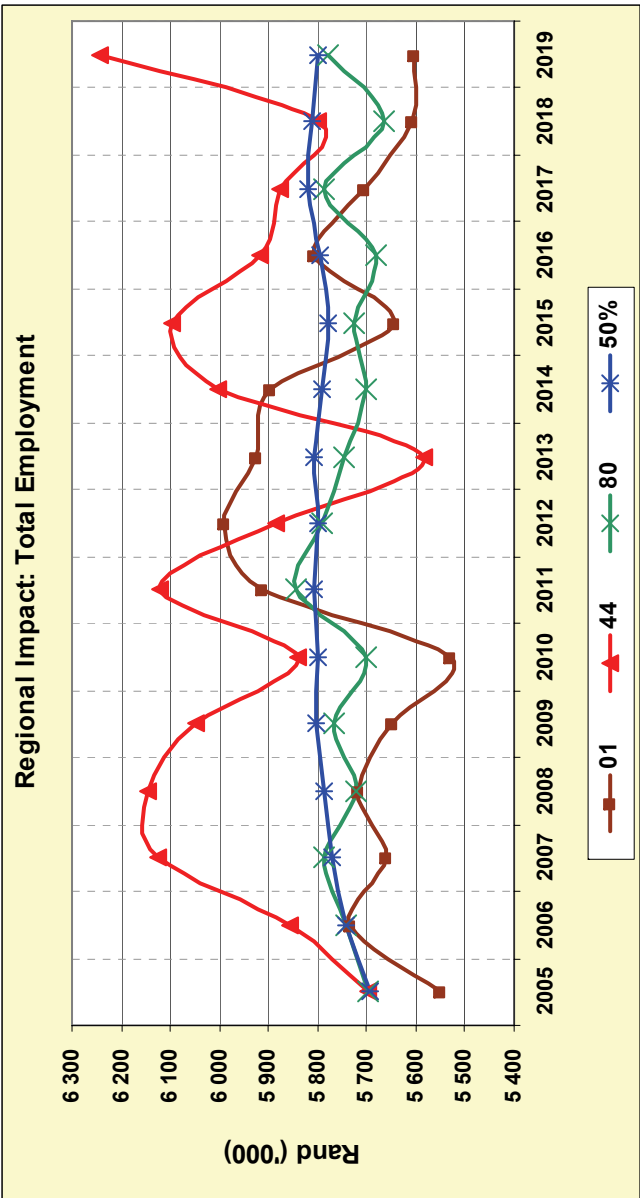


Figure A5.5. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.6 indicates the range of regional impacts that could be experienced from 2005 to 2019 in the Base Case Scenario. The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

Table A5.6. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	464 231	479 255	473 266	478 180	472 412	462 382	494 439	500 999	495 429	493 164	471 987	485 556	476 878	468 789	468 390
	Max	476 465	489 621	512 153	513 916	505 689	488 348	511 785	491 972	466 907	501 801	509 879	494 899	491 170	484 963	522 075
Mining	Min	50 266	51 892	51 244	51 776	51 152	50 066	53 537	54 247	53 644	53 399	51 106	52 575	51 635	50 759	50 716
	Max	51 590	53 015	55 455	55 646	54 755	52 877	55 415	53 269	50 555	54 334	55 208	53 586	53 183	52 511	56 529
Manufacturing	Min	19 312	19 937	19 688	19 892	19 652	19 235	20 569	20 841	20 610	20 515	19 635	20 199	19 838	19 502	19 485
	Max	19 821	20 368	21 305	21 379	21 037	20 315	21 290	20 466	19 423	20 875	21 211	20 588	20 433	20 174	21 718
Energy	Min	4 318	4 457	4 402	4 447	4 394	4 300	4 598	4 659	4 608	4 587	4 390	4 516	4 435	4 360	4 356
	Max	4 431	4 554	4 763	4 780	4 703	4 542	4 760	4 576	4 342	4 667	4 742	4 603	4 568	4 510	4 856
Construction	Min	2 062	2 129	2 102	2 124	2 098	2 054	2 196	2 225	2 201	2 190	2 096	2 157	2 118	2 082	2 080
	Max	2 116	2 175	2 275	2 283	2 246	2 169	2 273	2 185	2 074	2 229	2 265	2 198	2 182	2 154	2 319
Trade	Min	27 555	28 446	28 091	28 383	28 040	27 445	29 348	29 737	29 406	29 272	28 015	28 820	28 305	27 825	27 802
	Max	28 281	29 062	30 399	30 504	30 015	28 986	30 377	29 201	27 713	29 785	30 264	29 375	29 154	28 785	30 988
Transport	Min	23 446	24 205	23 902	24 151	23 859	23 353	24 972	25 303	25 022	24 907	23 838	24 523	24 085	23 676	23 656
	Max	24 064	24 728	25 866	25 955	25 540	24 664	25 848	24 847	23 581	25 344	25 752	24 995	24 807	24 493	26 367
Finance	Min	19 340	19 966	19 716	19 921	19 681	19 263	20 599	20 872	20 640	20 545	19 663	20 228	19 867	19 530	19 513
	Max	19 850	20 398	21 337	21 410	21 067	20 345	21 321	20 496	19 452	20 905	21 242	20 618	20 462	20 204	21 750
Services	Min	43 562	44 972	44 410	44 871	44 330	43 389	46 397	47 013	46 490	46 277	44 290	45 563	44 749	43 990	43 953
	Max	44 710	45 945	48 059	48 225	47 453	45 825	48 025	46 165	43 813	47 088	47 846	46 440	46 090	45 508	48 990
Households	Min	130 183	134 396	132 717	134 095	132 478	129 665	138 655	140 494	138 932	138 297	132 358	136 163	133 730	131 462	131 350
	Max	133 614	137 303	143 622	144 116	141 809	136 946	143 519	137 963	130 934	140 719	142 984	138 783	137 738	135 997	146 404

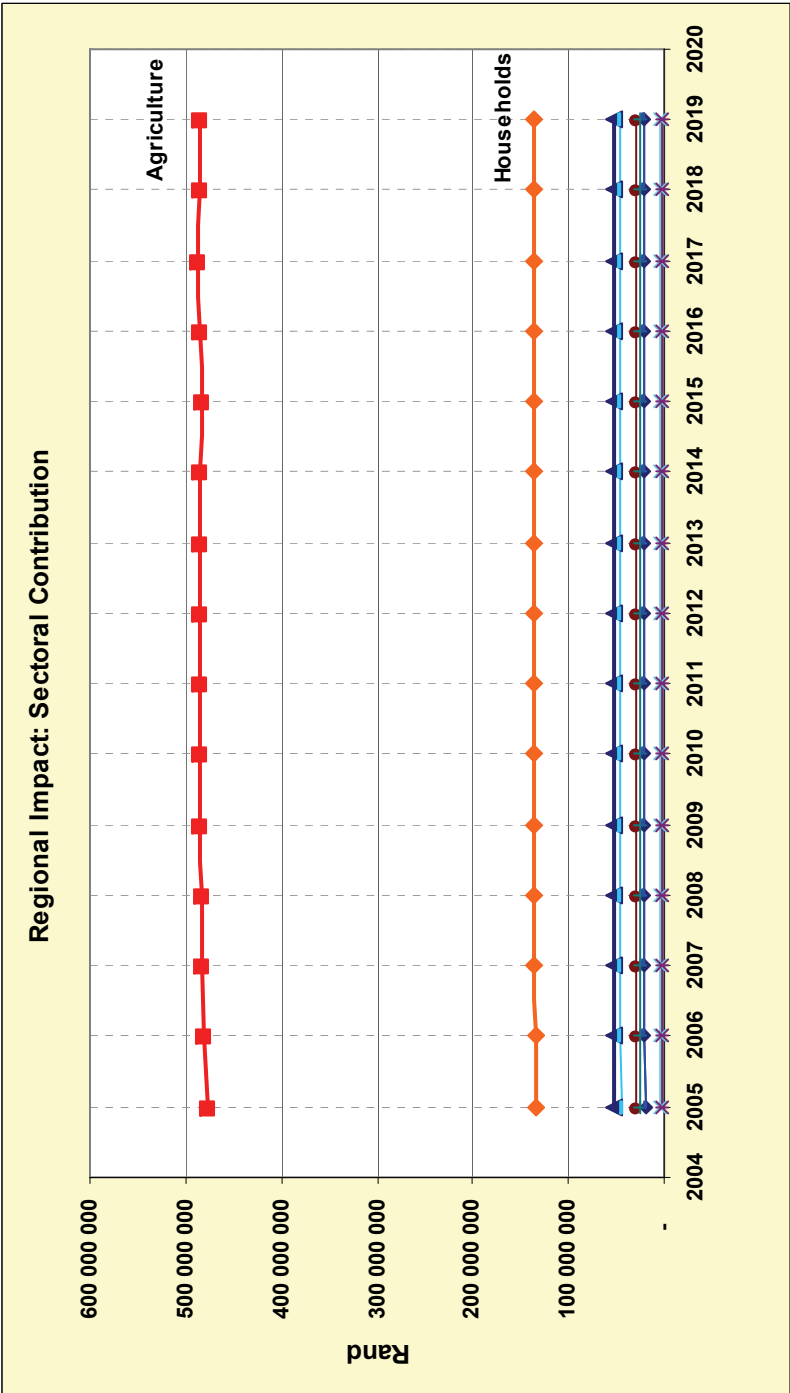


Figure A5.6. Total economic impact per economic sector (total output), 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

A5.2. SCENARIO 1

A5.2.1. MODEL INPUT DATA

The following set of tables and figures depict the results of the Scenario 1-projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80.

Table A5.7. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80 and 50% percentile)

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	413 518	421 856	420 096	423 423	420 479	412 729	432 563	435 127	433 295	431 220	420 525	427 483	422 760	418 857	418 954
44	415 361	423 535	435 717	438 660	435 595	424 422	437 306	427 805	416 558	436 668	440 377	432 719	430 407	425 783	445 419
80	421 818	426 120	424 059	420 943	427 770	418 716	426 414	419 405	410 411	413 317	415 498	418 155	434 196	422 447	424 890
50% percentile	417 029	419 877	421 568	422 509	423 714	423 578	424 517	423 880	424 943	424 057	423 556	423 996	425 021	424 838	423 813

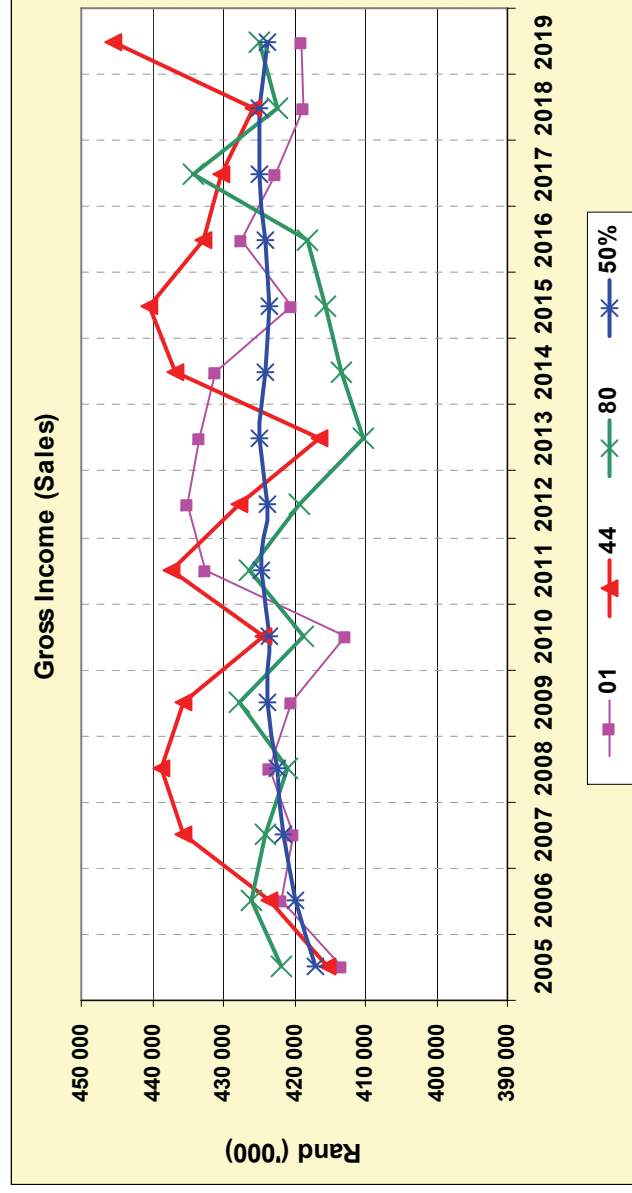


Figure A5.7. Gross Income per year, 2005 to 2019 (Stochastic run 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

Table A5.8. Projected Gross Margins (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	113 769	120 919	119 265	22 191	119 683	113 129	130 445	132 481	131 038	129 021	119 823	125 818	121 701	118 359	118 580
44	115 159	121 681	132 252	134 936	132 390	122 983	133 297	124 974	115 373	132 900	136 419	129 929	127 914	124 459	140 313
80	120 833	124 709	122 780	120 161	126 153	118 221	124 761	118 614	110 711	113 395	115 261	117 799	131 804	121 740	123 444
50% percentile	116 594	119 039	120 511	121 306	122 301	122 243	123 011	122 458	123 362	122 606	122 166	122 543	123 391	123 262	122 390

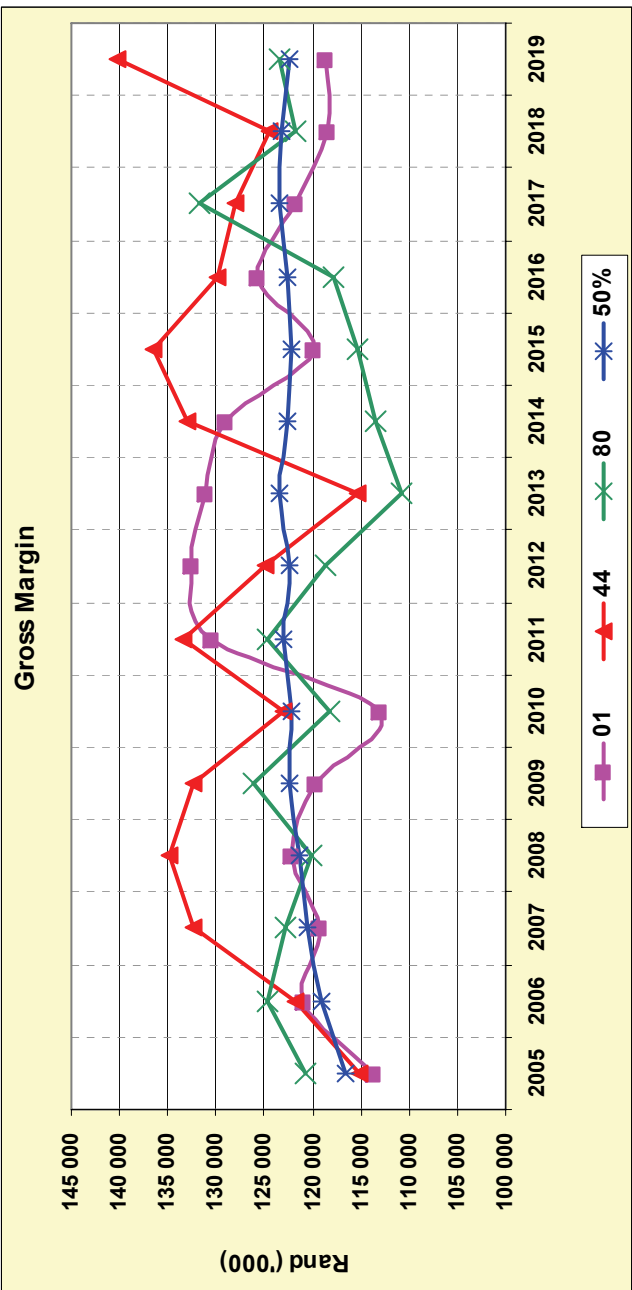


Figure A5.8. Gross margins, 2005 to 2019 (Stochastic run 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

A5.2.2. REGIONAL MODEL RESULTS

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GGP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table A5.9. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	751 505	766 657	763 459	769 505	764 155	750 070	786 114	790 775	787 444	783 674	764 238	776 883	768 300	761 206	761 383
44	754 853	769 707	791 847	797 195	791 625	771 320	794 735	777 467	757 028	793 576	800 315	786 399	782 197	773 794	809 480
80	766 588	774 406	770 660	764 997	777 404	760 949	774 939	762 203	745 858	751 138	755 101	759 930	789 082	767 730	772 170
50% percentile	757 884	763 061	766 134	767 844	770 033	769 785	771 492	770 336	772 268	770 656	769 746	770 546	772 409	772 076	770 213

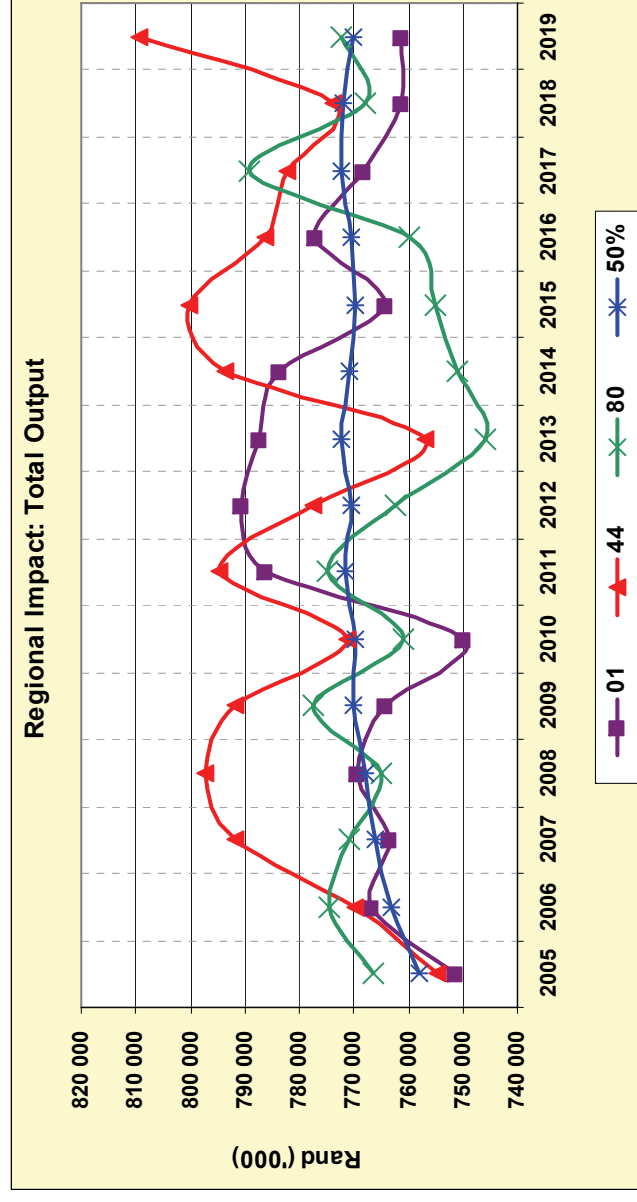


Figure A5.9. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.10. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	129 117	136 268	134 614	137 539	135 031	128 477	145 794	147 830	146 386	144 369	135 172	141 166	137 049	133 707	133 928
44	130 507	137 030	147 600	150 284	147 738	138 331	148 646	140 323	130 721	148 249	151 767	145 277	143 263	139 808	155 662
80	136 181	140 058	138 129	135 509	141 502	133 570	140 110	133 962	126 059	128 743	130 610	133 148	147 152	137 088	138 793
50% percentile	131 943	134 388	135 860	136 655	137 650	137 592	138 359	137 807	138 710	137 955	137 514	137 891	138 739	138 610	137 738

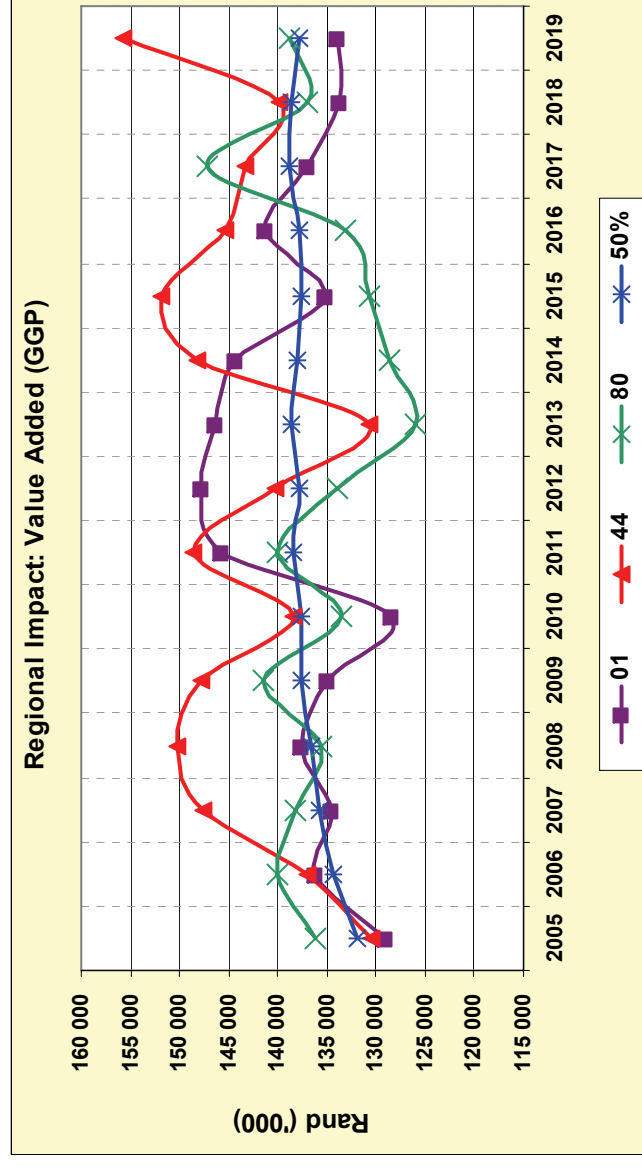


Figure A5.10. Regional Economic Impact in terms of generated GDP, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.11. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	5 320	5 428	5 405	5 448	5 410	5 310	5 565	5 598	5 575	5 548	5 410	5 500	5 439	5 389	5 390
44	5 344	5 449	5 606	5 644	5 604	5 461	5 626	5 504	5 359	5 618	5 666	5 567	5 538	5 478	5 731
80	5 427	5 482	5 456	5 416	5 504	5 387	5 486	5 396	5 280	5 318	5 346	5 380	5 586	5 435	5 467
50% percentile	5 366	5 402	5 424	5 436	5 452	5 450	5 462	5 454	5 467	5 456	5 449	5 455	5 468	5 466	5 453

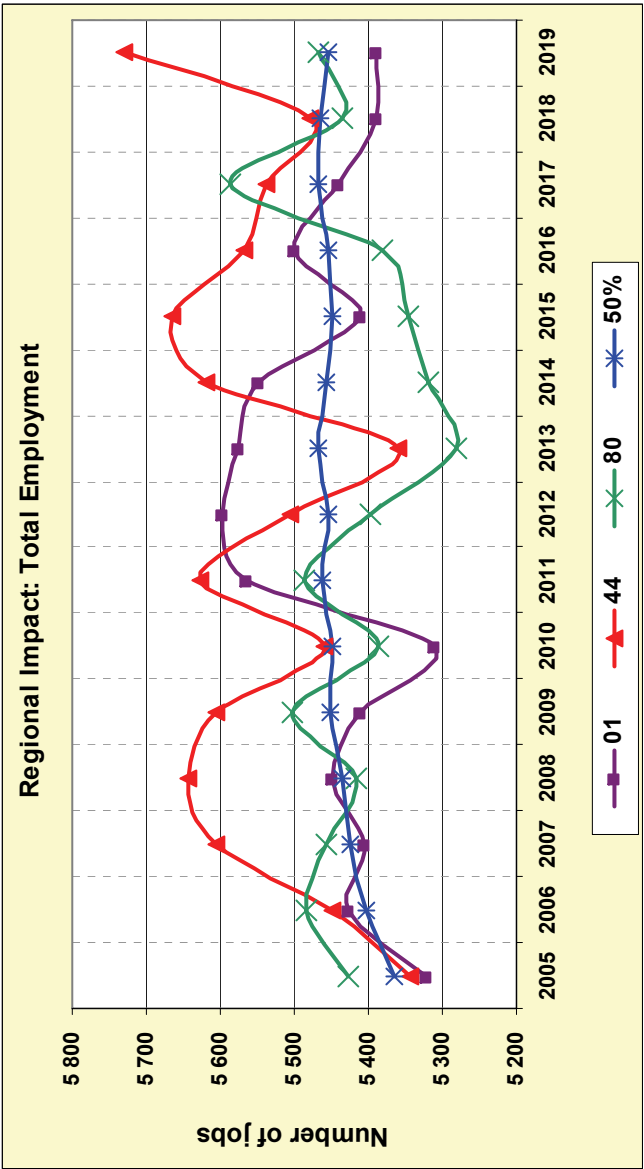


Figure A5.11. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.12 indicates the range of regional impacts that could be experienced from 2005 to 2019 in Scenario 1. The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

Table A5.12. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	444 834	453 803	451 910	455 489	452 322	443 984	485 320	488 079	466 107	463 875	452 371	459 866	454 775	450 576	450 681
	Max	453 762	458 389	456 172	452 820	460 164	450 424	458 705	451 166	441 491	444 617	446 963	449 821	467 077	454 438	457 066
Mining	Min	48 165	49 137	48 932	49 319	48 976	48 073	50 384	50 682	50 469	50 227	48 982	49 792	49 242	48 787	48 799
	Max	49 132	49 633	49 393	49 030	49 825	48 771	49 667	48 851	47 804	48 142	48 396	48 705	50 574	49 205	49 490
Manufacturing	Min	18 505	18 878	18 799	18 948	18 816	18 470	19 357	19 472	19 390	19 297	18 819	19 130	18 919	18 744	18 748
	Max	18 876	19 069	18 977	18 837	19 143	18 738	19 082	18 768	18 366	18 496	18 594	18 712	19 430	18 904	19 014
Energy	Min	4 137	4 221	4 203	4 236	4 207	4 129	4 328	4 353	4 335	4 314	4 207	4 277	4 230	4 191	4 192
	Max	4 220	4 263	4 243	4 211	4 280	4 189	4 266	4 196	4 106	4 135	4 157	4 184	4 344	4 226	4 251
Construction	Min	1 976	2 016	2 007	2 023	2 009	1 972	2 067	2 079	2 070	2 060	2 009	2 043	2 020	2 001	2 002
	Max	2 015	2 036	2 026	2 011	2 044	2 001	2 037	2 004	1 961	1 975	1 985	1 998	2 075	2 018	2 030
Trade	Min	26 403	26 936	26 823	27 036	26 848	26 353	27 619	27 783	27 666	27 534	26 851	27 295	26 993	26 744	26 750
	Max	26 933	27 208	27 076	26 877	27 313	26 735	27 227	26 779	26 205	26 390	26 530	26 699	27 724	26 973	27 129
Transport	Min	22 466	22 919	22 824	23 005	22 845	22 424	23 501	23 640	23 541	23 428	22 847	23 225	22 969	22 756	22 762
	Max	22 917	23 151	23 039	22 870	23 241	22 749	23 167	22 786	22 298	22 455	22 574	22 718	23 590	22 951	23 084
Finance	Min	18 532	18 906	18 827	18 976	18 844	18 497	19 385	19 500	19 418	19 325	18 846	19 158	18 946	18 771	18 776
	Max	18 904	19 097	19 004	18 865	19 171	18 765	19 110	18 796	18 393	18 523	18 621	18 740	19 459	18 932	19 042
Services	Min	41 742	42 584	42 406	42 742	42 445	41 662	43 665	43 923	43 738	43 529	42 449	43 152	42 675	42 281	42 291
	Max	42 580	43 014	42 806	42 492	43 181	42 267	43 044	42 336	41 429	41 722	41 942	42 210	43 829	42 643	42 890
Households	Min	124 744	127 259	126 728	127 732	126 844	124 506	130 489	131 262	130 710	130 084	126 857	128 956	127 532	126 354	126 384
	Max	127 248	128 545	127 923	126 983	129 043	126 312	128 634	126 520	123 806	124 683	125 341	126 142	130 981	127 437	128 174

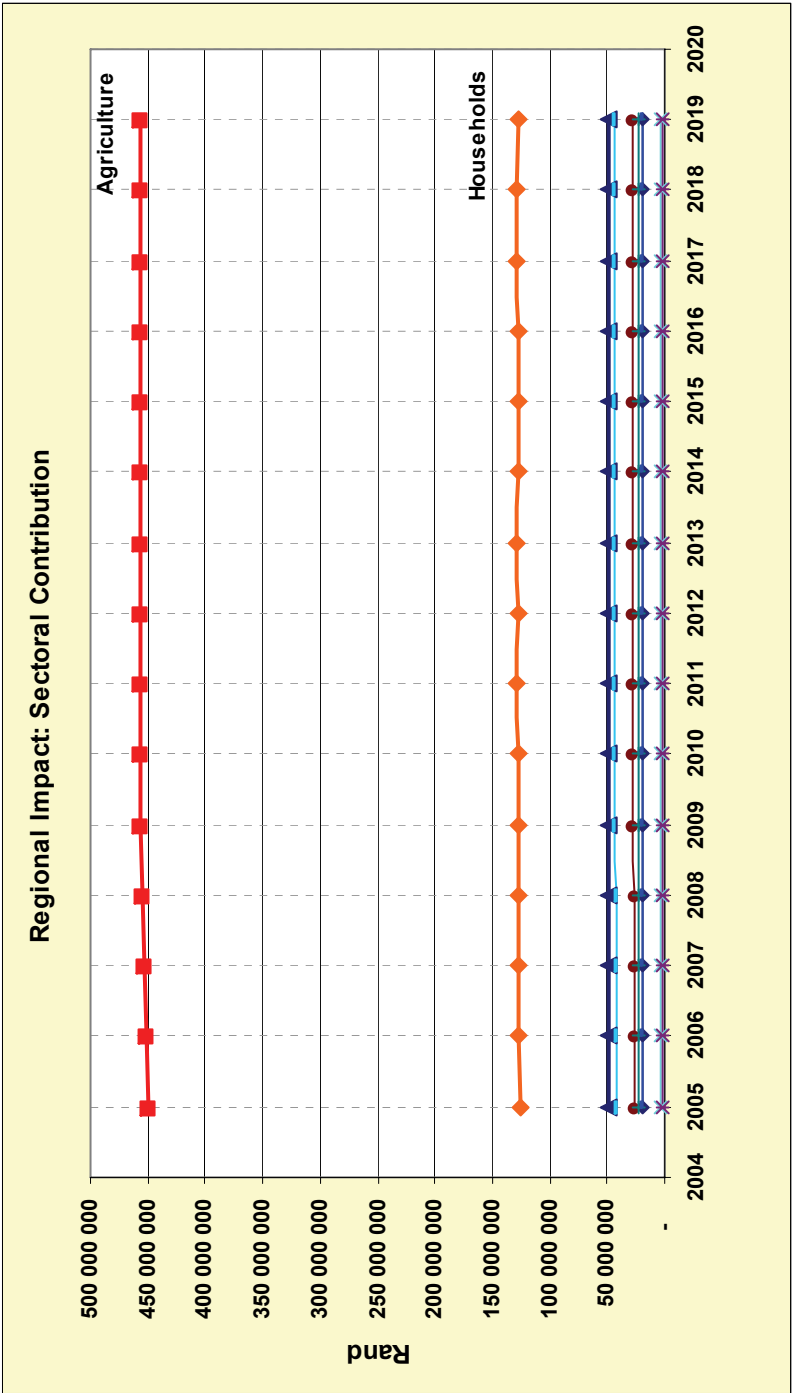


Figure A5.12. Total economic impact per economic sector (total output), 2005 to 2019 (50% percentile) (Source: ISIM-MACRO)

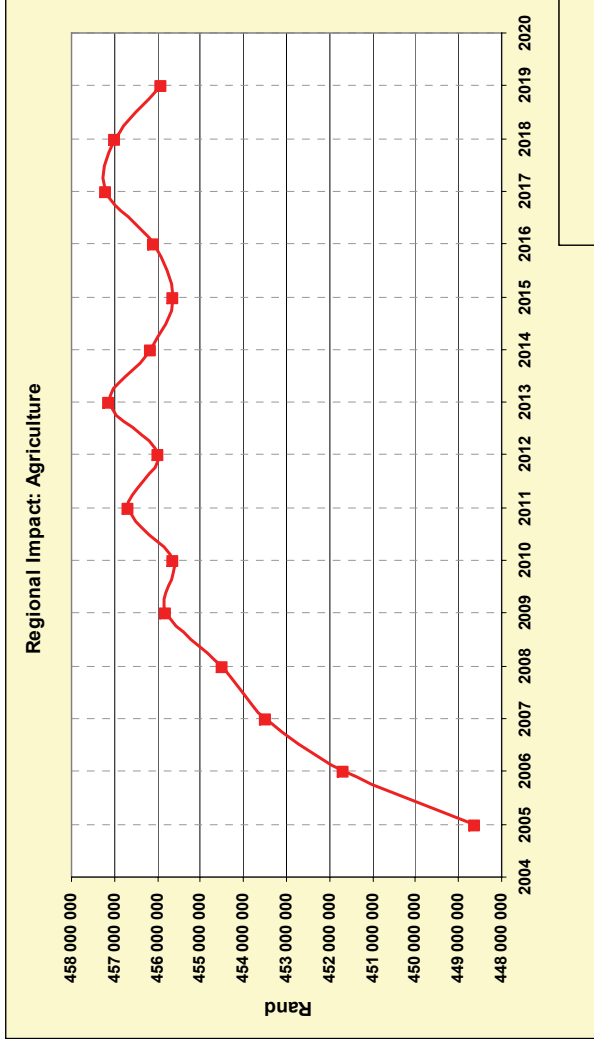


Figure A5.13. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

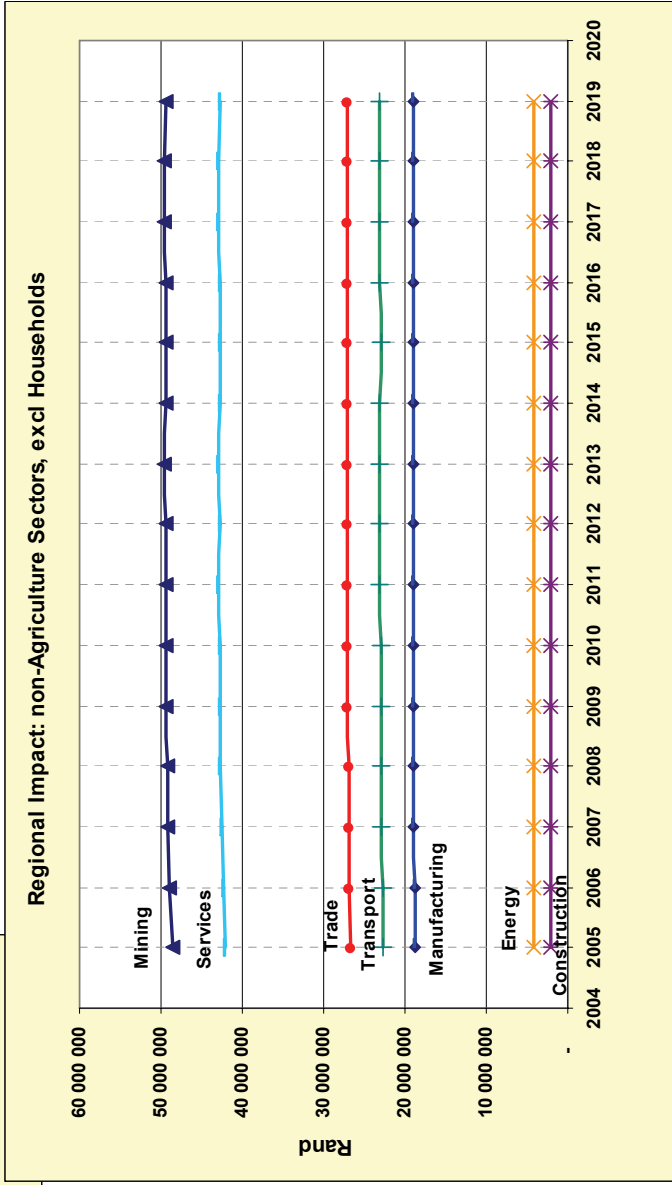


Figure A5.14. Total regional economic impact (output) for the non-agriculture sectors, excluding households, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

A5.3. SCENARIO 2

A5.3.1. MODEL INPUT DATA

The following set of tables and figures depict the results of the Scenario 2-projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80.

Table A5.13. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80 and 50% percentile)

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	472 465	485 373	481 916	487 293	482 540	472 088	506 204	510 256	505 223	502 953	483 756	495 318	487 327	479 917	479 561
44	482 820	495 937	517 733	521 194	513 927	496 661	519 618	501 640	478 185	512 778	520 172	505 624	501 668	496 226	532 227
80	487 618	493 658	490 342	482 866	494 823	481 327	494 067	481 376	464 852	470 049	472 978	479 363	508 403	486 990	489 397
50% percentile	480 218	484 401	487 112	488 488	490 391	490 018	491 305	490 571	491 875	490 553	489 785	490 800	492 641	491 976	490 719

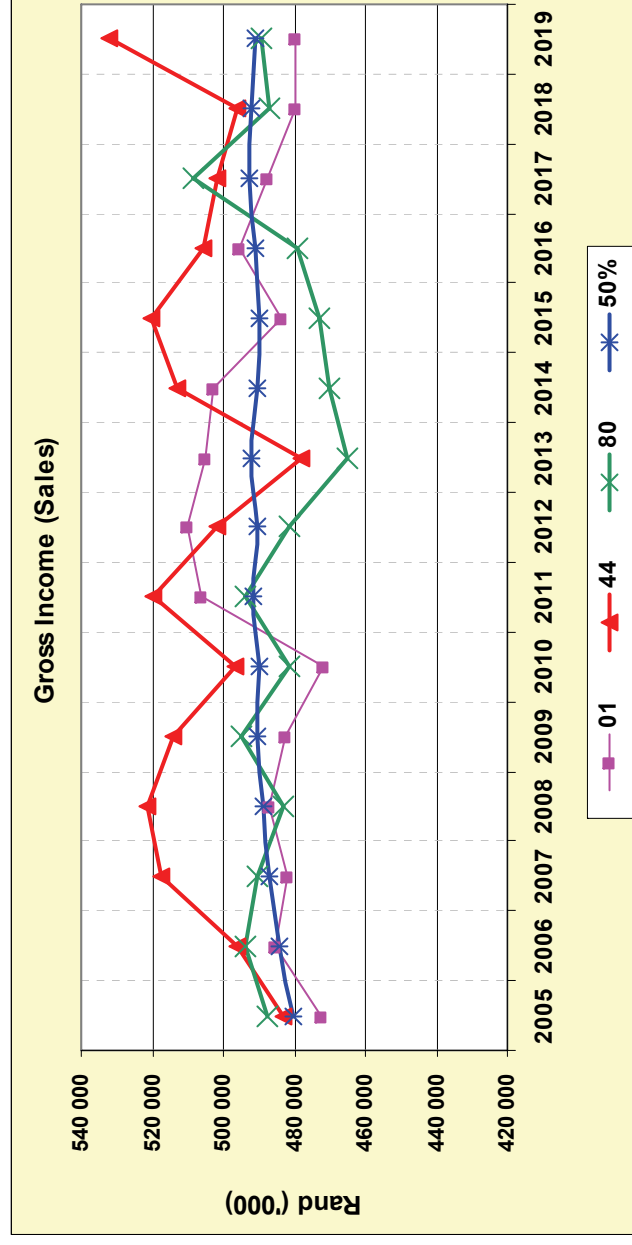


Figure A5.15. Gross Income per year, 2005 to 2019 (Stochastic run 01, 44, 80, 50% percentile) (Source: ISIM.MACRO)

Table A5.14. Projected Gross Margins (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	142 925	154 062	150 755	155 456	151 456	142 808	172 415	175 400	171 351	169 054	152 702	162 515	155 630	149 316	149 263
44	151 199	161 707	180 557	183 849	177 735	163 089	181 619	165 986	145 923	176 077	182 986	170 719	167 279	163 481	192 592
80	155 785	161 238	158 140	151 835	162 326	150 562	161 260	150 161	135 593	140 484	142 976	148 963	174 240	156 015	157 366
50% percentile	149 331	152 882	155 257	156 417	157 982	157 758	158 803	158 148	159 254	158 128	157 459	158 321	159 865	159 338	158 281

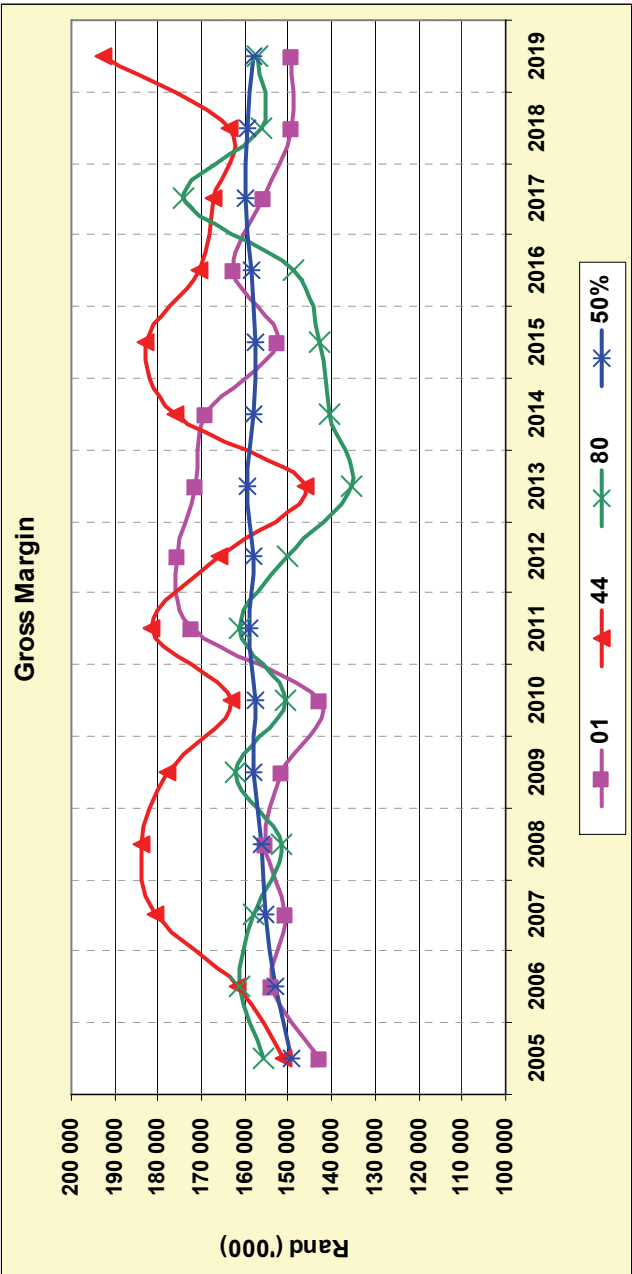


Figure A5.16. Gross margins, 2005 to 2019 (Stochastic run 01, 44, 80 and 50th Percentile) (Source: ISIM.MACRO)

A5.3.2. REGIONAL MODEL RESULTS

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GDP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table A5.15. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	858 630	882 090	875 806	885 579	876 940	857 946	919 946	927 310	918 163	914 037	879 150	900 162	885 640	872 174	871 527
44	877 450	901 288	940 899	947 188	933 981	902 604	944 323	911 651	869 025	931 893	945 330	918 892	911 703	901 813	967 238
80	886 169	897 146	891 119	877 532	899 262	874 737	897 888	874 825	844 795	854 240	859 562	871 167	923 941	885 028	889 402
50% percentile	872 721	880 322	885 248	887 751	891 208	890 530	892 870	891 536	893 905	891 502	890 107	891 951	895 297	894 089	891 804

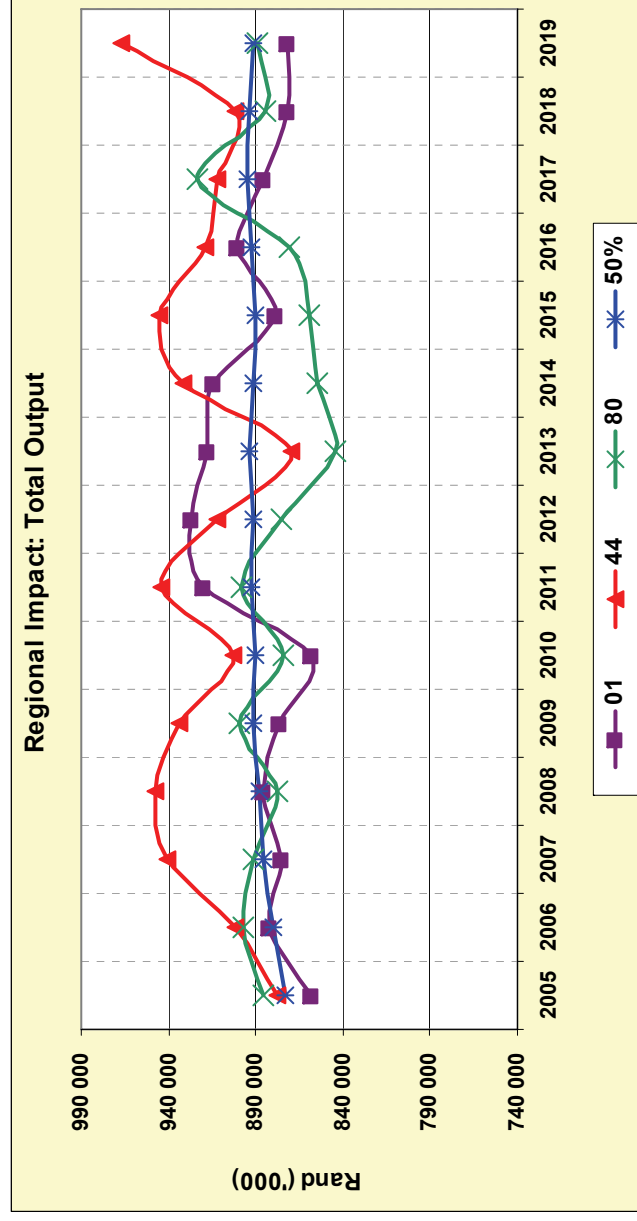


Figure A5.17. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.16. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

STOCHASTIC RUN UMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	160 402	171 539	168 233	172 933	168 933	160 285	189 892	192 877	188 828	186 531	170 179	179 992	173 107	166 793	166,741
44	168 676	179 184	198 035	201 326	195 212	180 567	199 097	183 464	163 400	193 554	200 464	188 196	184 756	180 958	210,069
80	173 263	178 715	175 617	169 313	179 803	168 040	178 738	167 639	153 070	157 961	160 453	166 441	191 717	173 492	174,843
50% percentile	166 809	170 359	172 735	173 895	175 459	175 235	176 280	175 625	176 731	175 605	174 937	175 798	177 342	176 815	175,758

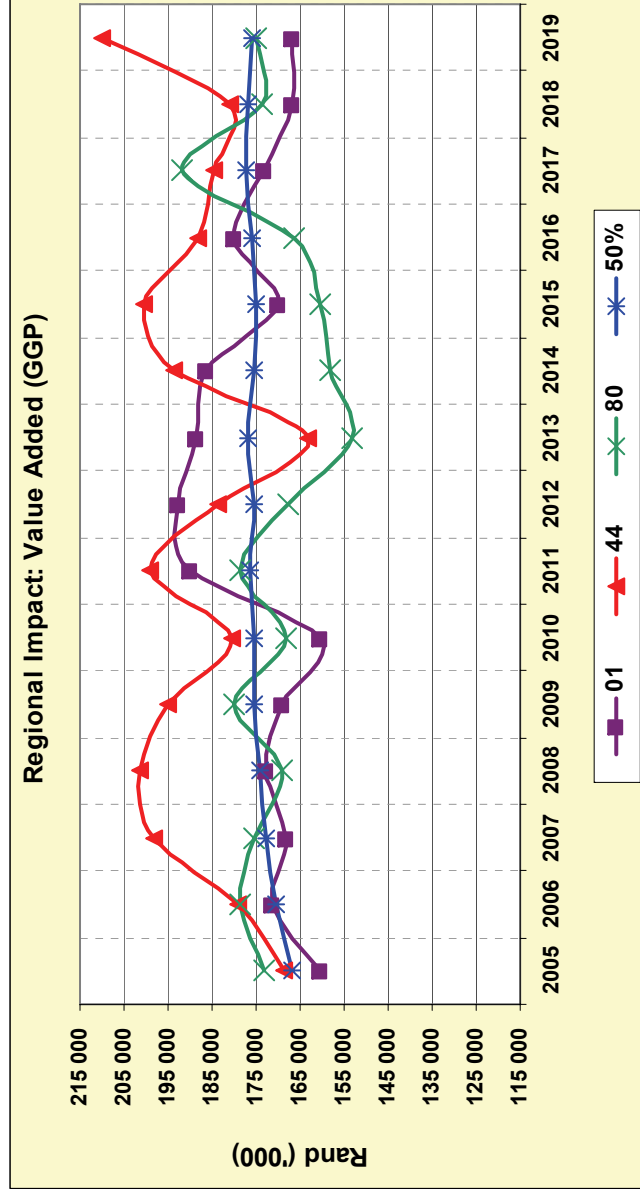


Figure A5.18. Regional Economic Impact in terms of generated GGP, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.17. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	6 079	6 245	6 200	6 270	6 208	6 074	6 513	6 565	6 500	6 471	6 224	6 373	6 270	6 175	6 170
44	6 212	6 381	6 661	6 706	6 612	6 390	6 685	6 454	6 152	6 597	6 693	6 505	6 454	6 384	6 848
80	6 274	6 351	6 309	6 213	6 366	6 193	6 357	6 193	5 981	6 048	6 085	6 168	6 541	6 266	6 297
50% percentile	6 179	6 232	6 267	6 285	6 309	6 305	6 321	6 312	6 328	6 311	6 302	6 315	6 338	6 330	6 314

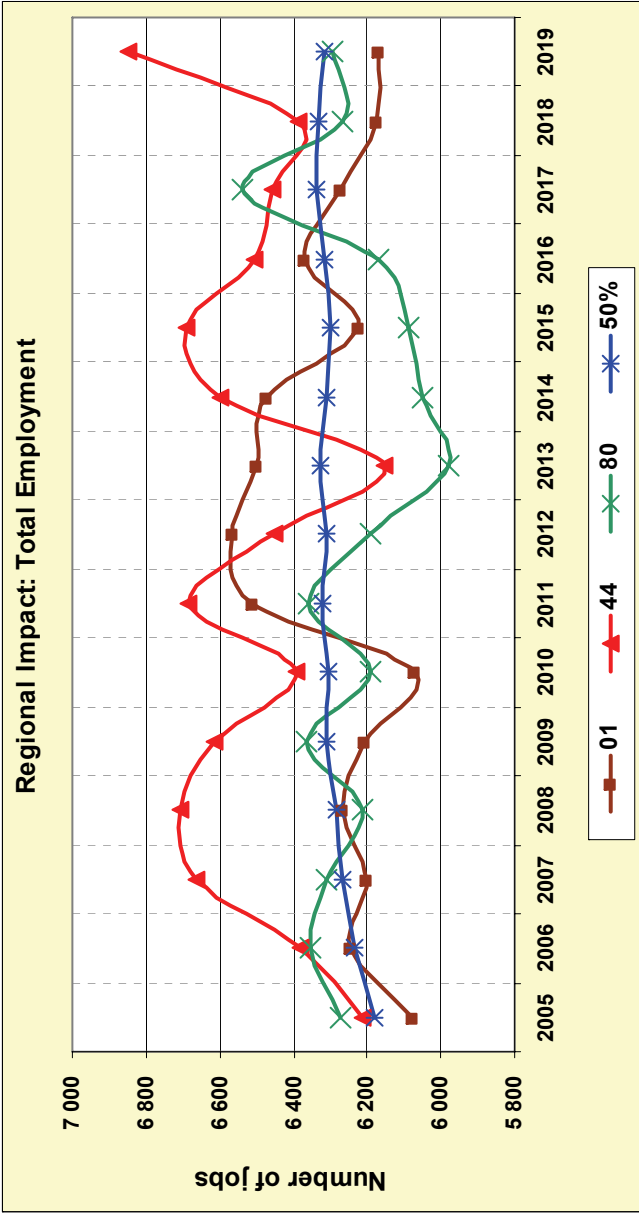


Figure A5.19. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.18 indicates the range of regional impacts that could be experienced from 2005 to 2019 in Scenario 2. The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

Table A5.18. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	508 244	522 130	518 411	524 195	519 082	507 839	544 538	548 897	543 483	541 041	520 390	532 828	524 232	516 261	515 878
	Max	524 545	531 042	527 475	519 432	532 295	517 778	531 482	517 830	500 055	505 645	508 796	515 664	546 903	523 869	526 458
Mining	Min	55 031	56 535	56 132	56 759	56 205	54 988	58 961	59 433	58 847	58 583	56 347	57 693	56 763	55 899	55 858
	Max	56 796	57 500	57 114	56 243	57 636	56 064	57 547	56 069	54 145	54 750	55 091	55 835	59 217	56 723	57 004
Manufacturing	Min	21 143	21 720	21 566	21 806	21 594	21 126	22 653	22 834	22 609	22 507	21 648	22 165	21 808	21 476	21 460
	Max	21 821	22 091	21 943	21 608	22 143	21 539	22 109	21 542	20 802	21 035	21 166	21 451	22 751	21 793	21 901
Energy	Min	4 727	4 856	4 821	4 875	4 828	4 723	5 064	5 105	5 055	5 032	4 840	4 956	4 876	4 801	4 798
	Max	4 878	4 939	4 906	4 831	4 951	4 816	4 943	4 816	4 651	4 703	4 732	4 796	5 086	4 872	4 896
Construction	Min	2 257	2 319	2 303	2 328	2 306	2 256	2 419	2 438	2 414	2 403	2 311	2 367	2 328	2 293	2 291
	Max	2 330	2 359	2 343	2 307	2 364	2 300	2 361	2 300	2 221	2 246	2 260	2 290	2 429	2 327	2 338
Trade	Min	30 167	30 991	30 771	31 114	30 810	30 143	32 321	32 580	32 259	32 114	30 888	31 626	31 116	30 643	30 620
	Max	31 135	31 520	31 309	30 831	31 595	30 733	31 546	30 736	29 681	30 013	30 200	30 608	32 462	31 095	31 248
Transport	Min	25 669	26 370	26 182	26 475	26 216	25 648	27 502	27 722	27 449	27 325	26 282	26 911	26 476	26 074	26 054
	Max	26 492	26 820	26 640	26 234	26 884	26 150	26 843	26 153	25 255	25 538	25 697	26 044	27 621	26 458	26 589
Finance	Min	21 174	21 752	21 597	21 838	21 625	21 157	22 686	22 867	22 642	22 540	21 680	22 198	21 840	21 508	21 492
	Max	21 853	22 123	21 975	21 640	22 176	21 571	22 142	21 573	20 832	21 065	21 197	21 483	22 784	21 825	21 932
Services	Min	47 692	48 995	48 646	49 189	48 709	47 654	51 098	51 507	50 999	50 770	48 832	49 999	49 193	48 445	48 409
	Max	49 222	49 832	49 497	48 742	49 949	48 587	49 873	48 592	46 924	47 449	47 744	48 389	51 320	49 159	49 402
Households	Min	142 526	146 420	145 377	146 999	145 565	142 412	152 704	153 926	152 408	151 723	145 932	149 420	147 009	144 774	144 666
	Max	147 097	148 919	147 919	145 663	149 270	145 199	149 042	145 214	140 229	141 797	142 680	144 607	153 367	146 908	147 634

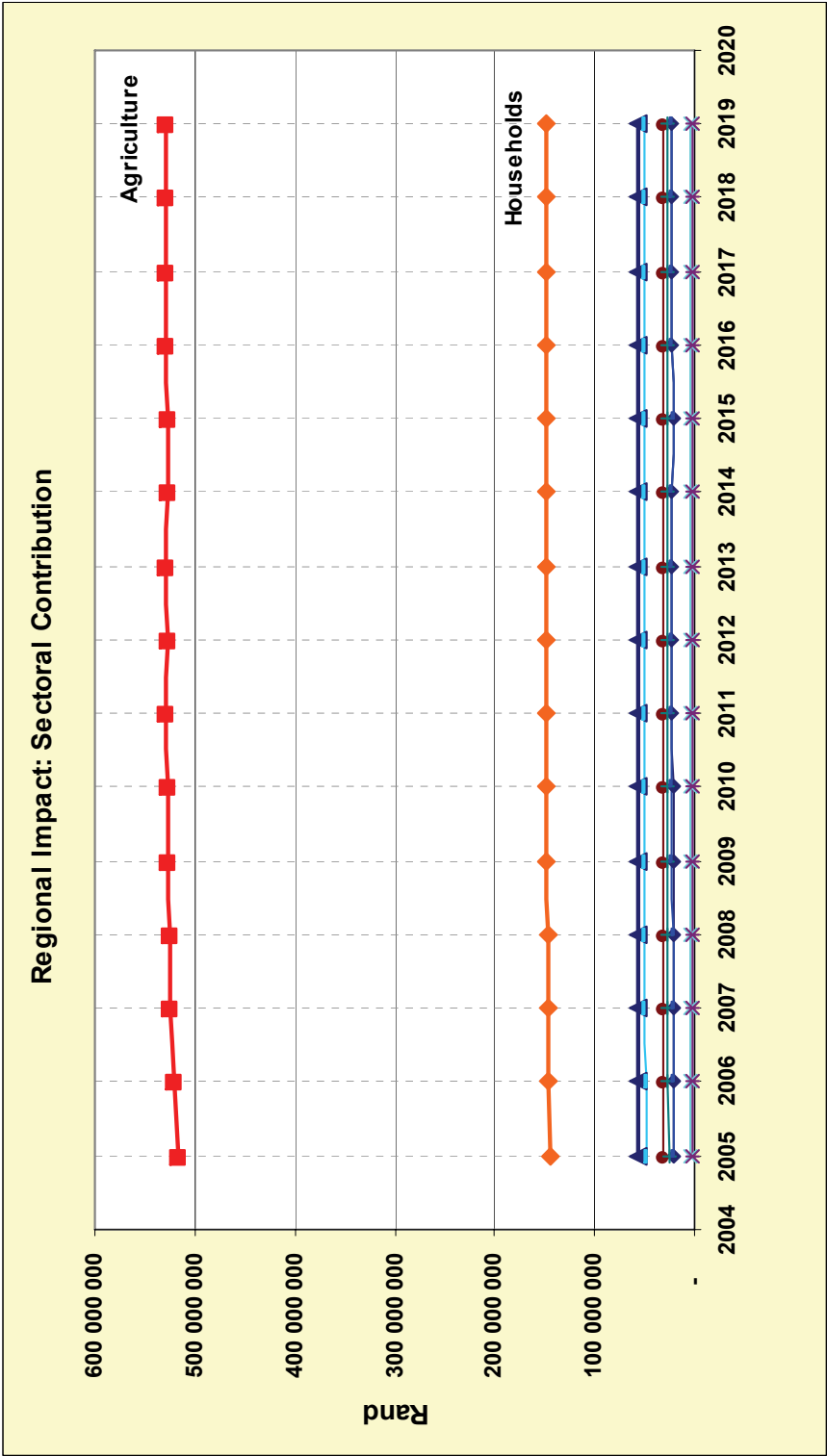


Figure A5.20. Total economic impact per economic sector (total output), 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

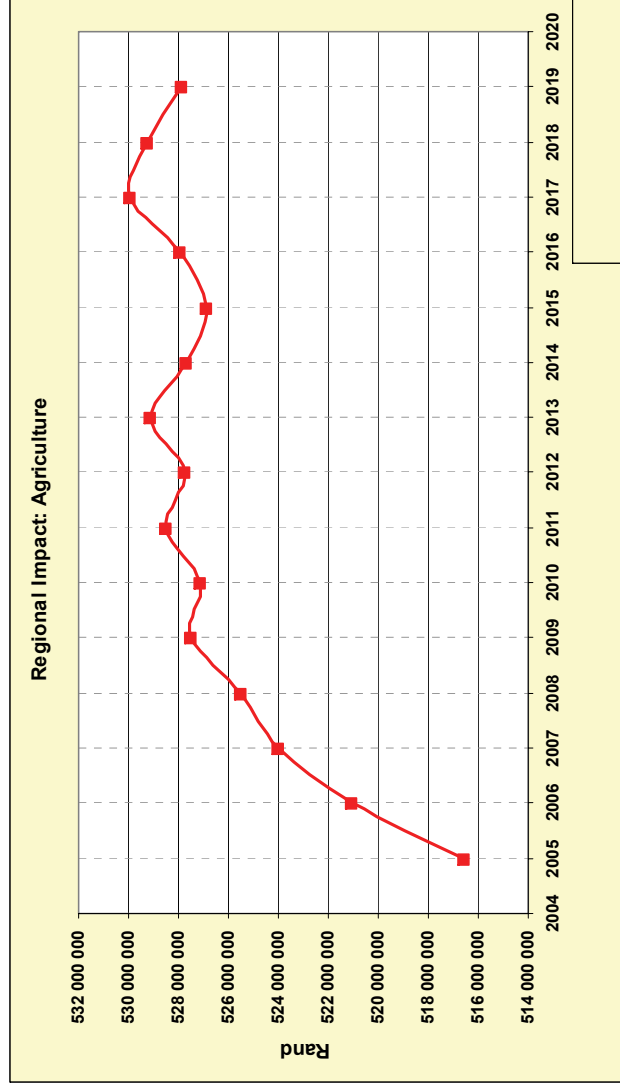


Figure A5.21. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

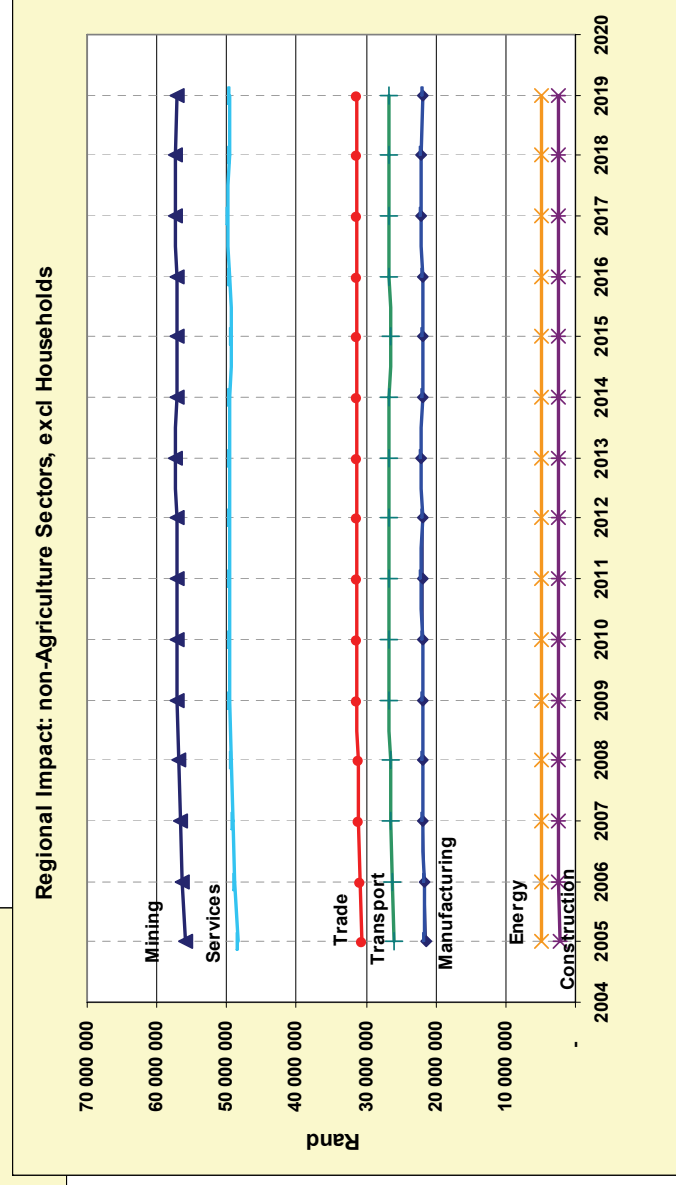


Figure A5.22. Total regional economic impact (output) for the non-agriculture sectors, excluding households, 2005 to 2019 (50% percentile) (Source: ISIM.MACRO)

A5.4. SCENARIO 3

A5.4.1. MODEL INPUT DATA

The following set of tables and figures depict the results of the Scenario 3-projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80.

Table A5.19. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44 and 80)

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	541 574	547 882	547 876	547 887	547 871	547 861	547 887	547 887	547 887	547 887	547 887	547 887	547 887	547 887	547 887
44	543 002	547 875	547 887	547 887	547 887	547 886	547 887	547 862	547 843	547 887	547 887	547 887	547 887	547 887	547 887
80	542 571	547 356	547 866	547 887	547 887	547 884	547 881	547 715	547 831	547 873	547 872	547 887	547 887	547 887	547 875

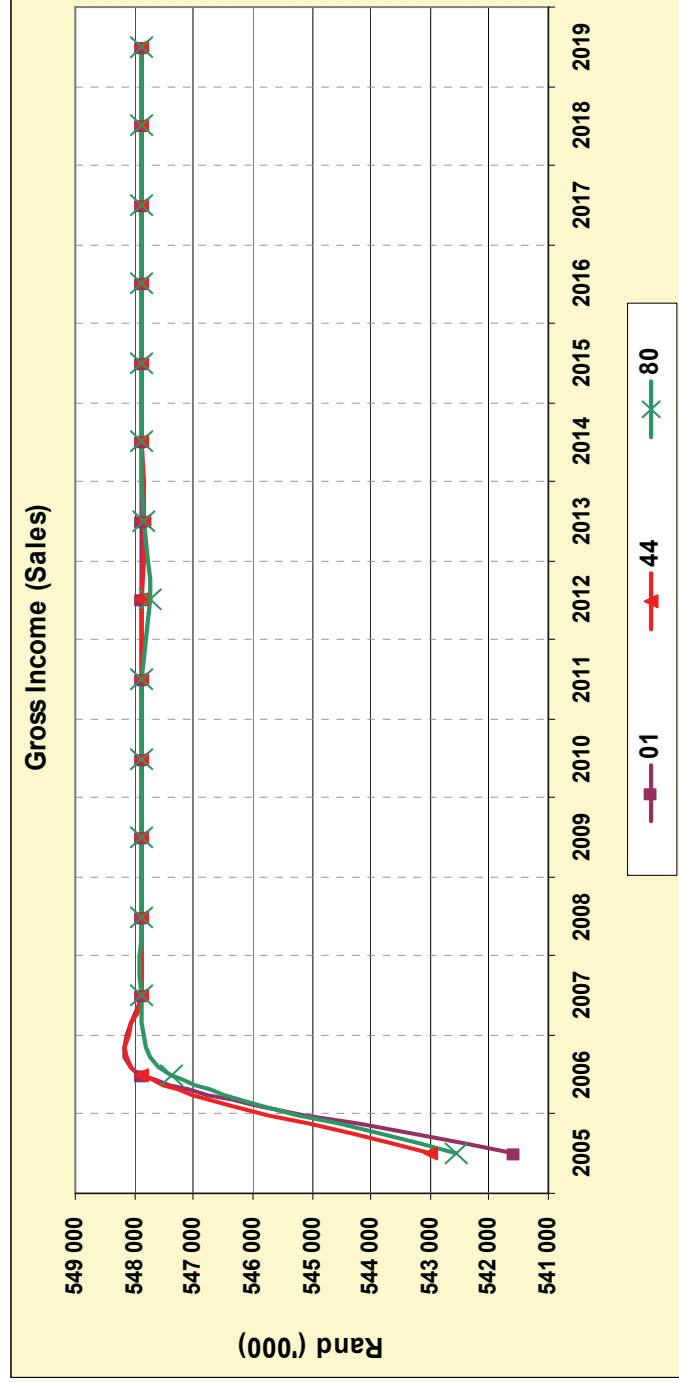


Figure A5.23. Gross Income per year, 2005 to 2019 (Stochastic run 01, 44, 80) (Source: ISIM.MACRO)

Table A5.20. Projected Gross Margins (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	200 861	206 068	206 065	206 070	206 063	206 058	206 070	206 070	206 070	206 070	206 070	206 070	206 070	206 070	206 070
44	202 062	206 065	206 070	206 070	206 070	206 070	206 070	206 059	206 049	206 070	206 070	206 070	206 070	206 070	206 070
80	201 682	205 645	206 060	206 070	206 070	206 069	206 067	205 934	206 044	206 064	206 063	206 070	206 070	206 070	206 065

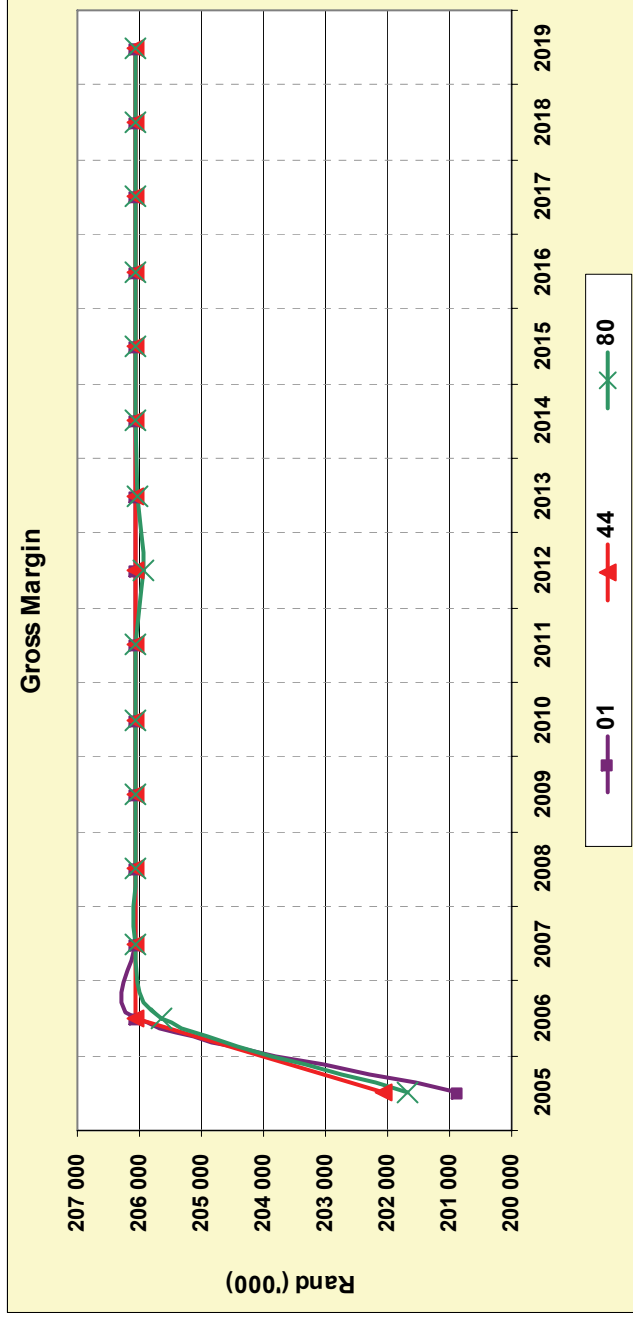


Figure A5.24. Gross margins, 2005 to 2019 (Stochastic runs 01, 44 and 80) (Source: ISIM.MACRO)

A5.4.2. REGIONAL MODEL RESULTS

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GGP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table A5.21. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	984 225	995 689	995 678	995 698	995 669	995 650	995 698	995 698	995 698	995 698	995 698	995 698	995 698	995 698	995 698
44	986 821	995 677	995 698	995 698	995 698	995 697	995 698	995 653	995 618	995 698	995 698	995 698	995 698	995 698	995 698
80	986 037	994 733	995 659	995 698	995 698	995 693	995 687	995 386	995 596	995 673	995 671	995 698	995 698	995 698	995 675
50% percentile	976 954	984 890	986 098	985 736	986 397	985 911	986 789	986 155	987 639	986 939	986 956	986 595	986 475	986 705	985 818

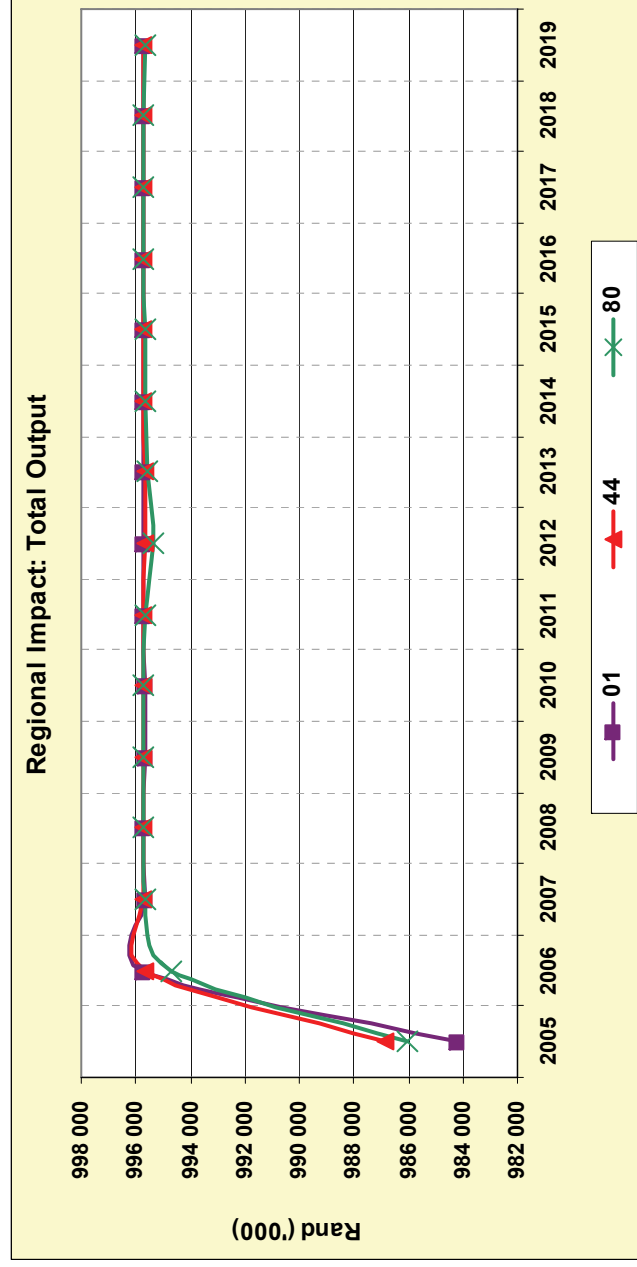


Figure A5.25. Regional Economic Impact, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.22. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	218 338	223 545	223 543	223 548	223 540	223 535	223 548	223 548	223 548	223 548	223 548	223 548	223 548	223 548	223 548
44	219 540	223 542	223 548	223 548	223 548	223 548	223 548	223 536	223 527	223 548	223 548	223 548	223 548	223 548	223 548
80	219 159	223 123	223 538	223 548	223 548	223 546	223 545	223 411	223 521	223 541	223 541	223 548	223 548	223 548	223 542

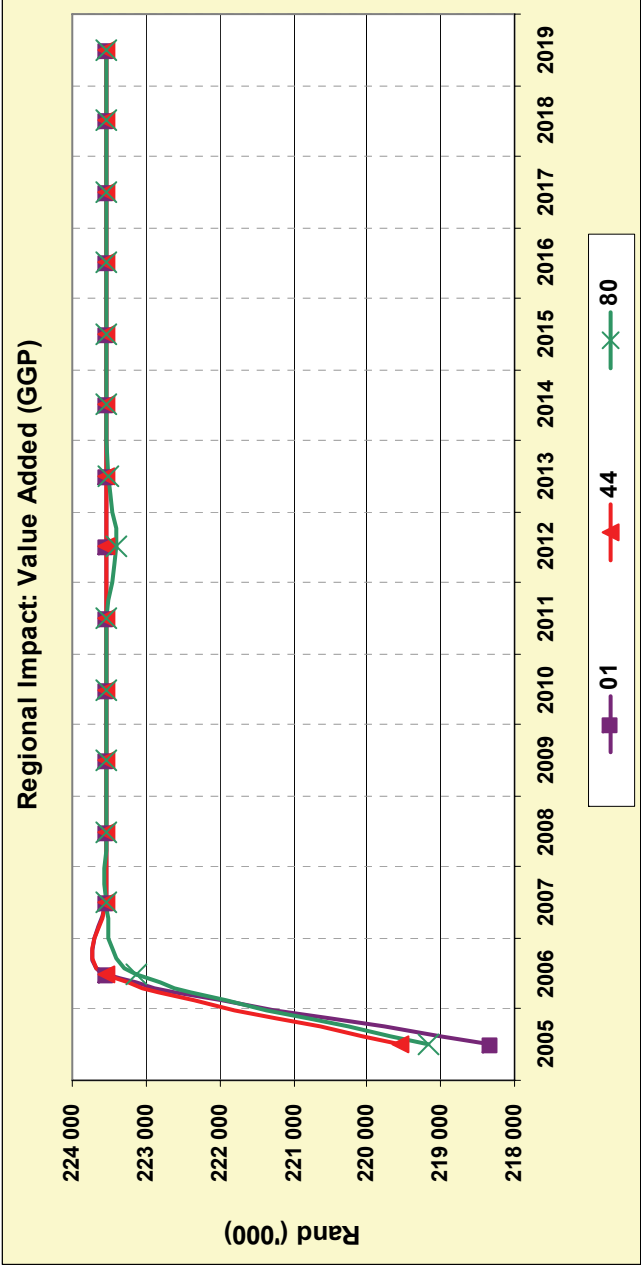


Figure A5.26. Regional Economic Impact in terms of generated GDP, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.23. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	6 968	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049
44	6 986	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049
80	6 981	7 042	7 049	7 049	7 049	7 049	7 049	7 047	7 048	7 049	7 049	7 049	7 049	7 049	7 049

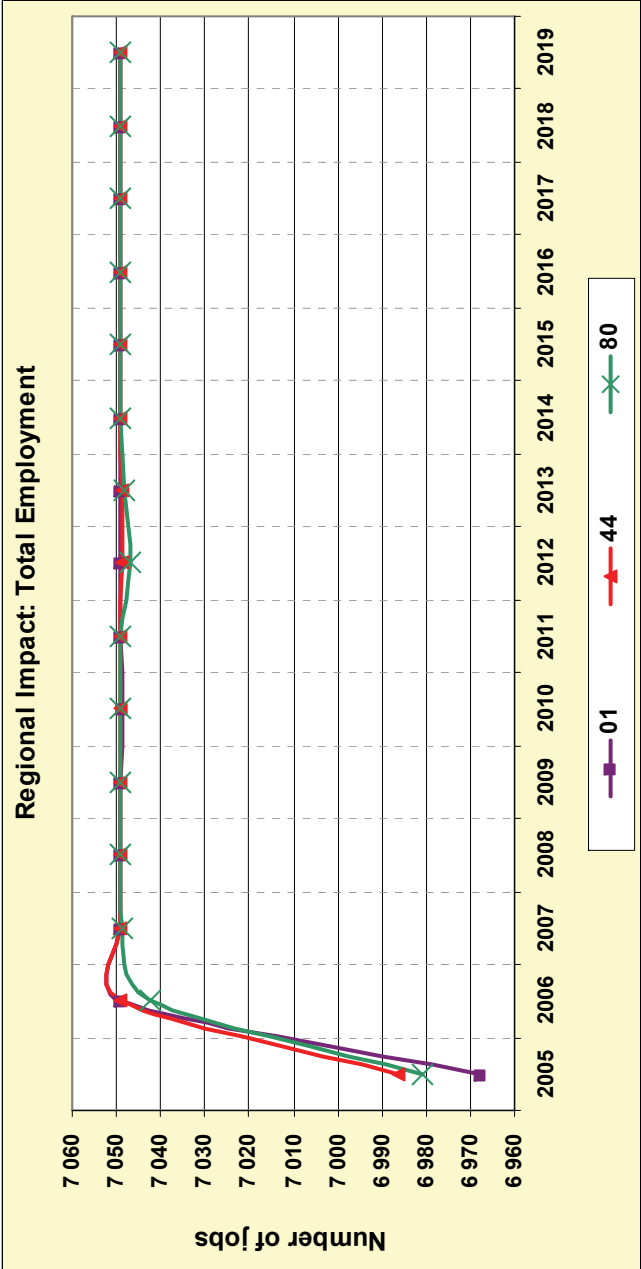


Figure A5.27. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.24 indicates the range of regional impacts that could be experienced from 2005 to 2019 in Scenario 3. The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

Table A5.24. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	582 586	589 372	589 366	589 378	589 360	589 349	589 378	589 378	589 378	589 378	589 378	589 378	589 378	589 378	589 378
	Max	583 659	588 806	589 355	589 378	589 378	589 374	589 371	589 193	589 317	589 363	589 362	589 378	589 378	589 378	589 364
Mining	Min	63 081	63 816	63 815	63 816	63 814	63 813	63 816	63 816	63 816	63 816	63 816	63 816	63 816	63 816	63 816
	Max	63 197	63 754	63 814	63 816	63 816	63 816	63 816	63 796	63 810	63 815	63 815	63 816	63 816	63 816	63 815
Manufacturing	Min	24 235	24 518	24 517	24 518	24 517	24 517	24 518	24 518	24 518	24 518	24 518	24 518	24 518	24 518	24 518
	Max	24 280	24 494	24 517	24 518	24 518	24 518	24 518	24 510	24 515	24 517	24 517	24 518	24 518	24 518	24 517
Energy	Min	5 418	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481
	Max	5 428	5 476	5 481	5 481	5 481	5 481	5 481	5 480	5 481	5 481	5 481	5 481	5 481	5 481	5 481
Construction	Min	2 588	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618
	Max	2 592	2 615	2 618	2 618	2 618	2 618	2 618	2 617	2 618	2 618	2 618	2 618	2 618	2 618	2 618
Trade	Min	34 580	34 982	34 982	34 983	34 982	34 981	34 983	34 983	34 983	34 983	34 983	34 983	34 983	34 983	34 983
	Max	34 643	34 949	34 981	34 983	34 983	34 983	34 982	34 972	34 979	34 982	34 982	34 983	34 983	34 983	34 982
Transport	Min	29 424	29 766	29 766	29 767	29 766	29 765	29 767	29 767	29 767	29 767	29 767	29 767	29 767	29 767	29 767
	Max	29 478	29 738	29 765	29 767	29 767	29 766	29 766	29 757	29 764	29 766	29 766	29 767	29 767	29 767	29 766
Finance	Min	24 271	24 553	24 553	24 554	24 553	24 553	24 554	24 554	24 554	24 554	24 554	24 554	24 554	24 554	24 554
	Max	24 315	24 530	24 553	24 554	24 554	24 554	24 553	24 546	24 551	24 553	24 553	24 554	24 554	24 554	24 553
Services	Min	54 669	55 305	55 305	55 306	55 304	55 303	55 306	55 306	55 306	55 306	55 306	55 306	55 306	55 306	55 306
	Max	54 769	55 252	55 304	55 306	55 306	55 306	55 305	55 289	55 300	55 304	55 304	55 306	55 306	55 306	55 305
Households	Min	163 373	165 276	165 275	165 278	165 273	165 270	165 278	165 278	165 278	165 278	165 278	165 278	165 278	165 278	165 278
	Max	163 674	165 118	165 272	165 278	165 278	165 277	165 276	165 226	165 261	165 274	165 273	165 278	165 278	165 278	165 274

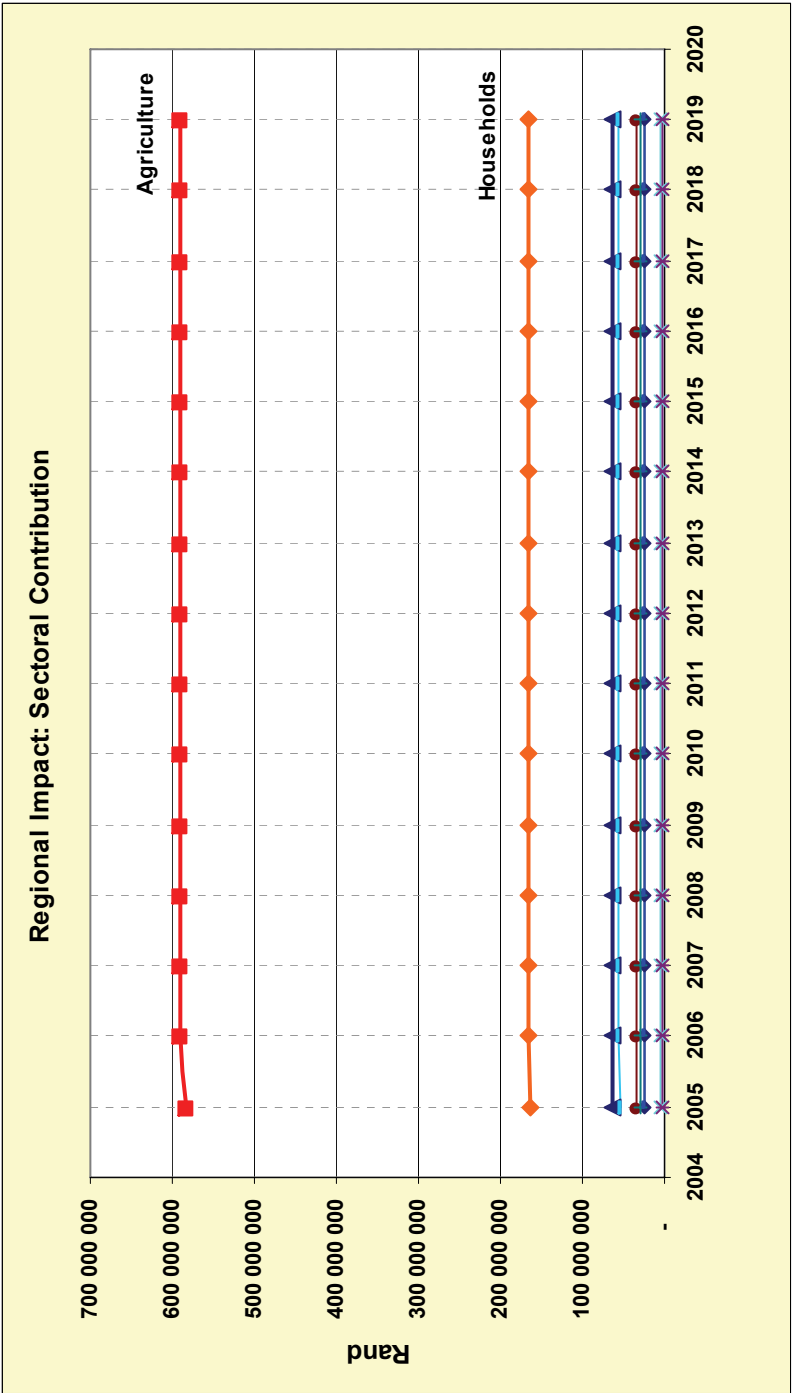


Figure A5.28. Total economic impact per economic sector (total output), 2005 to 2019 (Source: ISIM.MACRO)

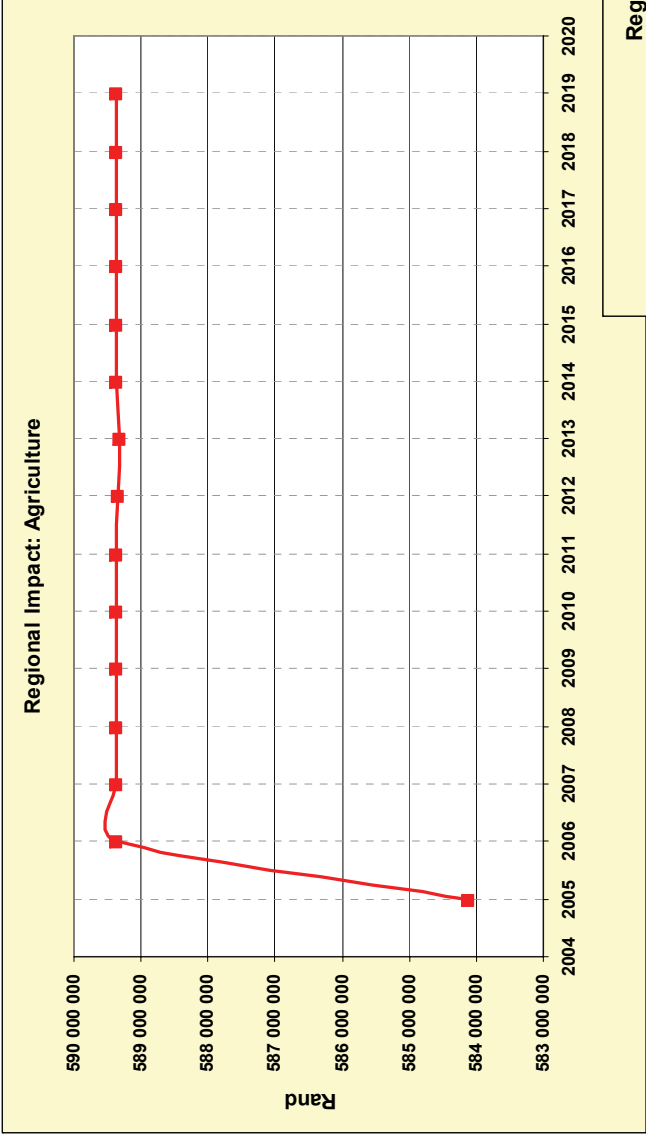


Figure A5.29. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (Source: ISIM.MACRO)

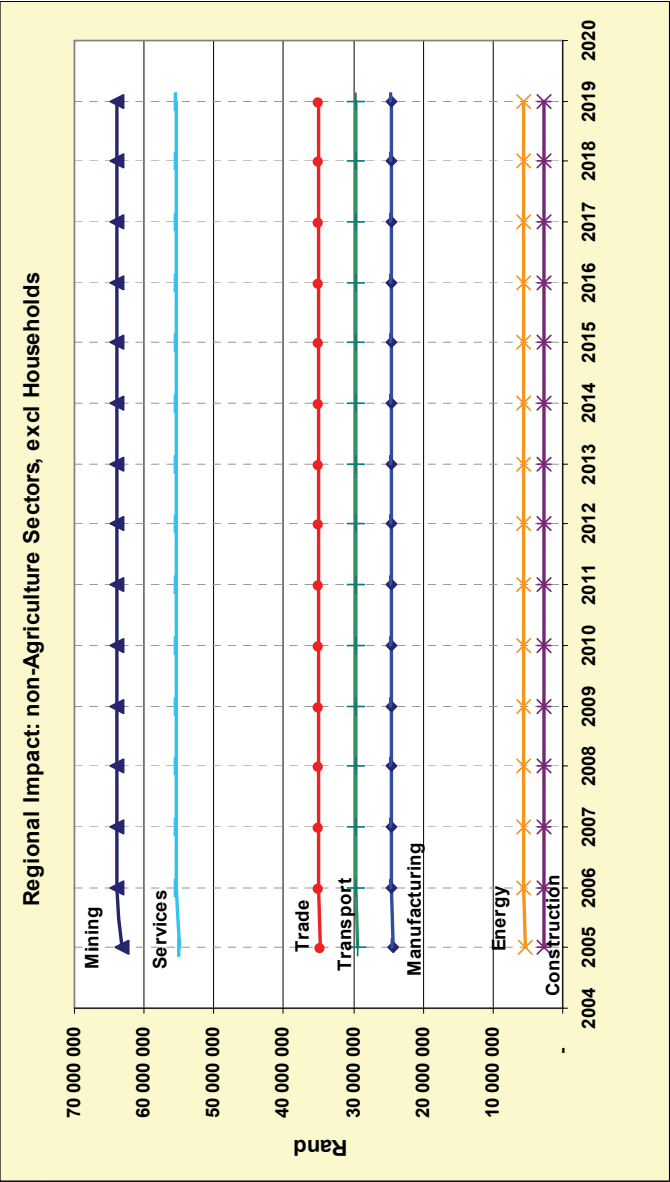


Figure A5.30. Total regional economic impact (output) for the non-agriculture sectors, excluding households, 2005 to 2019 (Source: ISIM.MACRO)

A5.5. SCENARIO 3 (+)

A5.5.1. MODEL INPUT DATA

The following set of tables and figures depict the results of the Scenario 3(+) -projections in terms of three stochastic runs that were done on the data, namely stochastic runs 01, 44 and 80.

Table A5.25. Projected Gross Income (Sales R'000), 2005 – 2019 (Stochastic Run 01, 44, 80)

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	541 574	547 882	547 876	547 887	547 871	547 861	547 887	547 887	547 887	547 887	547 887	547 887	547 887	547 887	547 887
44	543 002	547 875	547 887	547 887	547 887	547 886	547 887	547 862	547 843	547 887	547 887	547 887	547 887	547 887	547 887
80	542 571	547 356	547 866	547 887	547 887	547 884	547 881	547 715	547 831	547 873	547 872	547 887	547 887	547 887	547 875

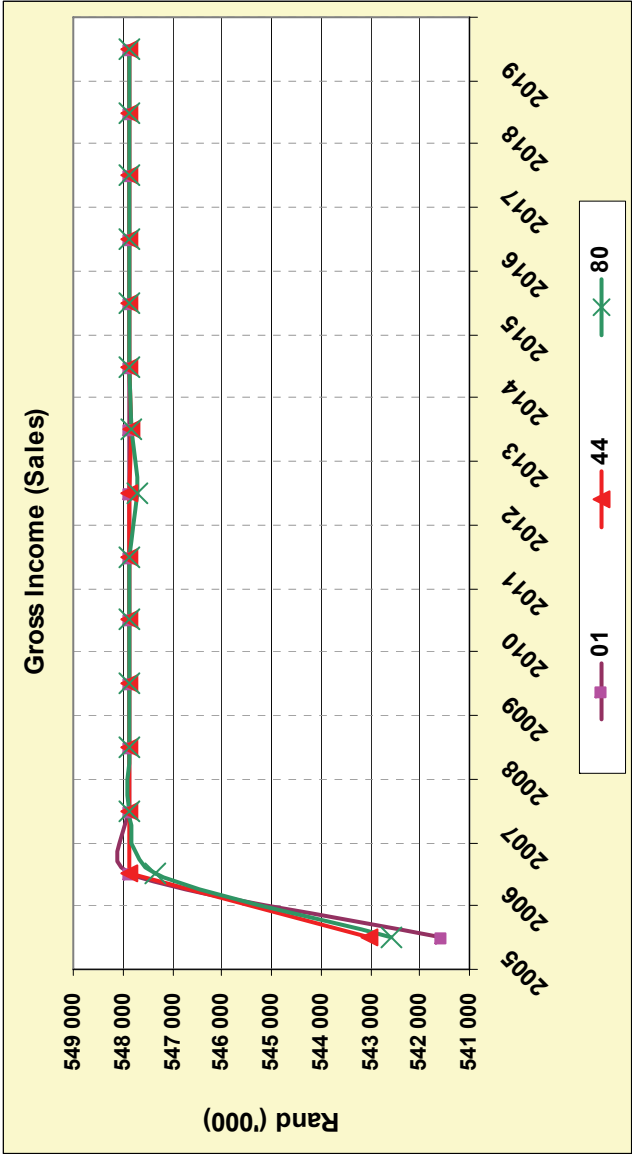


Figure A5.31. Gross Income per year, 2005 to 2019 (Stochastic run 01, 44, 80) (Source: ISIM:MACRO)

Table A5.26. Projected Gross Margins (R'000), 2005 – 2019

Stochastic Run Number	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	185 046	190 253	190 250	190 256	190 248	190 243	190 256	190 256	190 256	190 256	190 256	190 256	190 256	190 256	190 256
44	186 248	190 250	190 256	190 256	190 256	190 255	190 256	190 244	190 235	190 256	190 256	190 256	190 256	190 256	190 256
80	185 867	189 830	190 246	190 256	190 256	190 254	190 253	190 119	190 229	190 249	190 249	190 256	190 256	190 256	190 250

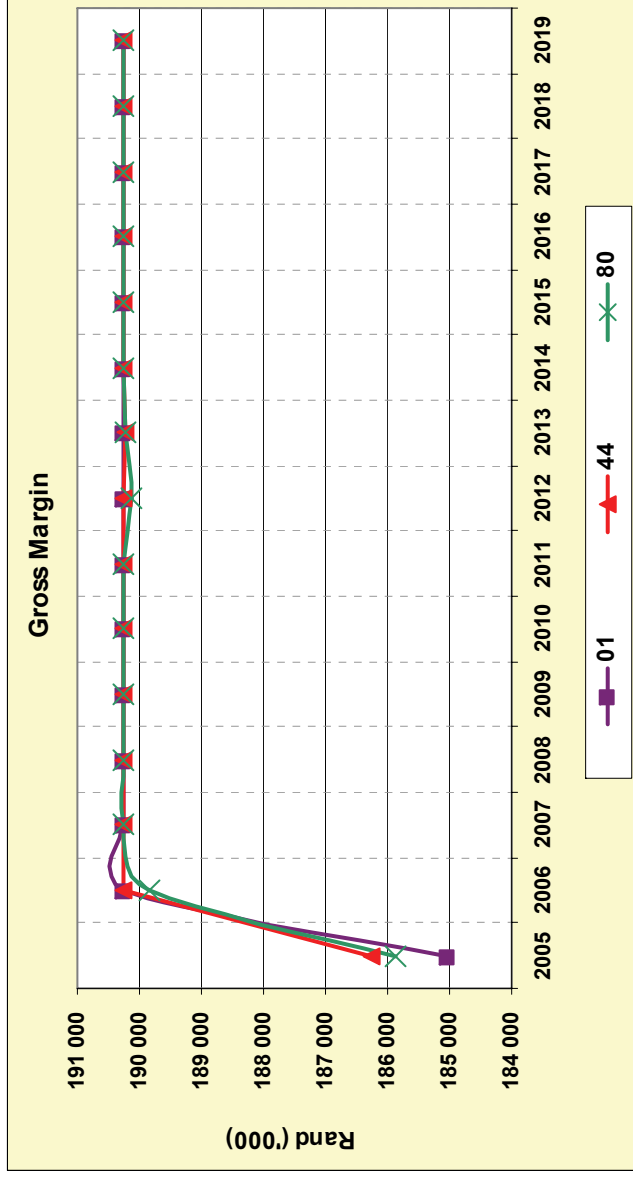


Figure A5.32. Gross margins, 2005 to 2019 (Source: ISIM.MACRO)

A5.5.2. REGIONAL MODEL RESULTS

By applying the relevant multipliers obtained from the Input/Output Model, the following impacts are calculated:

- Regional impact in terms of output or business sales
- Impact in terms of value added (GDP)
- Impact in terms of employment created

The results per stochastic run analysed are indicated by means of the following sets of tables and figures.

Table A5.27. Regional economic impact in terms of total (direct and indirect) output (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	984 225	995 689	995 678	995 698	995 669	995 650	995 698	995 698	995 698	995 698	995 698	995 698	995 698	995 698	995 698
44	986 821	995 677	995 698	995 698	995 698	995 697	995 698	995 653	995 618	995 698	995 698	995 698	995 698	995 698	995 698
80	986 037	994 733	995 659	995 698	995 698	995 693	995 687	995 386	995 596	995 673	995 671	995 698	995 698	995 698	995 675

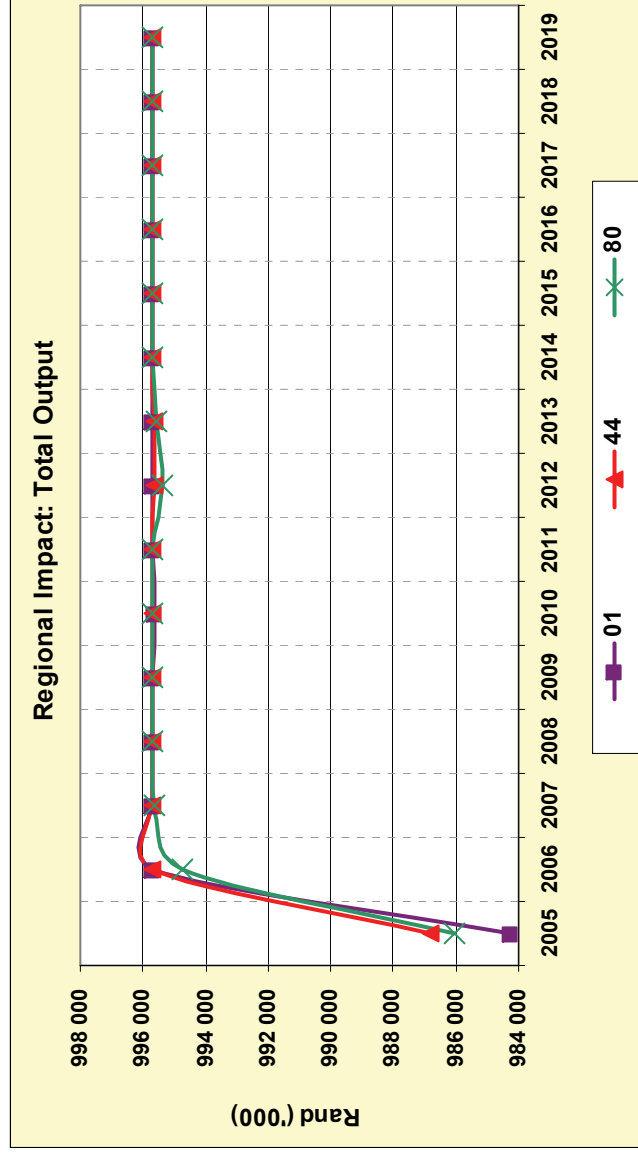


Figure A5.33. Regional Economic Impact in terms of total output, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.28. Regional economic impact in terms of value added (GGP) (R'000), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	202 523	207 731	207 728	207 733	207 725	207 720	207 733	207 733	207 733	207 733	207 733	207 733	207 733	207 733	207 733
44	203 725	207 727	207 733	207 733	207 733	207 733	207 733	207 721	207 712	207 733	207 733	207 733	207 733	207 733	207 733
80	203 344	207 308	207 723	207 733	207 733	207 732	207 730	207 596	207 706	207 726	207 726	207 733	207 733	207 733	207 727

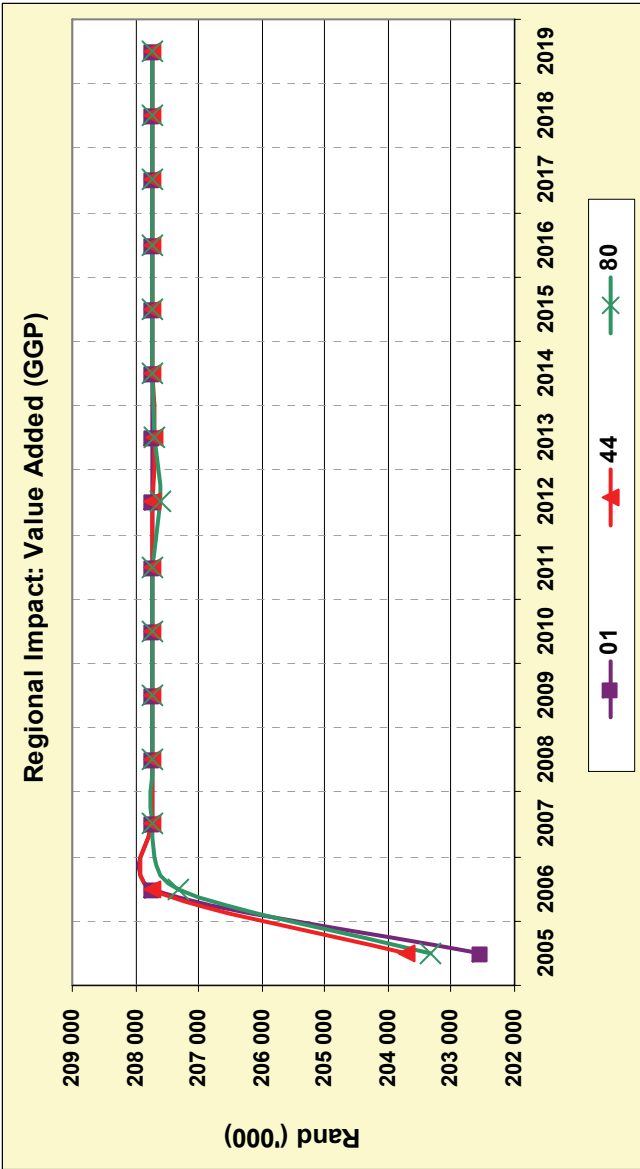


Figure A5.34. Regional Economic Impact in terms of generated GGP, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.29. Regional economic impact in terms of employment created (number of jobs), 2005 – 2019

STOCHASTIC RUN NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
01	6 968	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049
44	6 986	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049	7 049
80	6 981	7 042	7 049	7 049	7 049	7 049	7 049	7 047	7 048	7 049	7 049	7 049	7 049	7 049	7 049

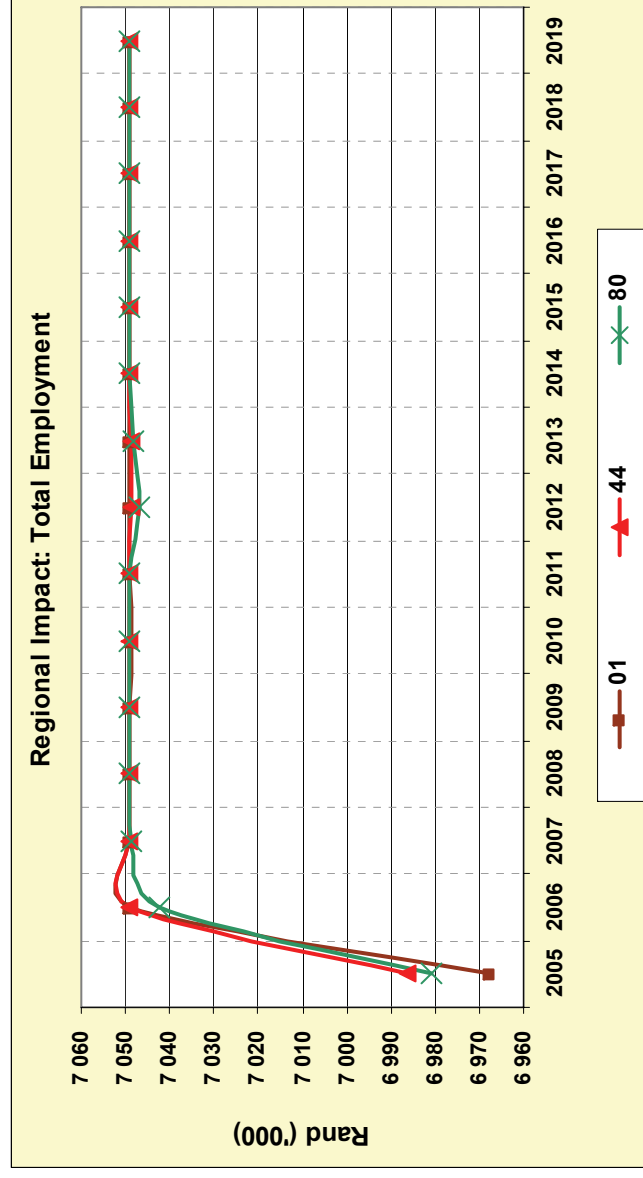


Figure A5.35. Regional Economic Impact in terms of generated employment, 2005 to 2019 (Source: ISIM.MACRO)

Table A5.30. Total economic impact per economic sector in terms of total direct and indirect output, 2005 – 2019 (R'000)

Sector	Range	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture	Min	582 586	589 372	589 366	589 378	589 360	589 349	589 378	589 378	589 378	589 378	589 378	589 378	589 378	589 378	589 378
	Max	583 659	588 806	589 355	589 378	589 378	589 374	589 371	589 193	589 317	589 363	589 362	589 378	589 378	589 378	589 364
Mining	Min	63 081	63 816	63 815	63 816	63 814	63 813	63 816	63 816	63 816	63 816	63 816	63 816	63 816	63 816	63 816
	Max	63 197	63 754	63 814	63 816	63 816	63 816	63 816	63 796	63 810	63 815	63 815	63 816	63 816	63 816	63 815
Manufacturing	Min	24 235	24 518	24 517	24 518	24 517	24 517	24 518	24 518	24 518	24 518	24 518	24 518	24 518	24 518	24 518
	Max	24 280	24 494	24 517	24 518	24 518	24 518	24 518	24 510	24 515	24 517	24 517	24 518	24 518	24 518	24 517
Energy	Min	5 418	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481	5 481
	Max	5 428	5 476	5 481	5 481	5 481	5 481	5 481	5 480	5 481	5 481	5 481	5 481	5 481	5 481	5 481
Construction	Min	2 588	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618	2 618
	Max	2 592	2 615	2 618	2 618	2 618	2 618	2 618	2 617	2 618	2 618	2 618	2 618	2 618	2 618	2 618
Trade	Min	34 580	34 982	34 982	34 983	34 982	34 981	34 983	34 983	34 983	34 983	34 983	34 983	34 983	34 983	34 983
	Max	34 643	34 949	34 981	34 983	34 983	34 983	34 982	34 972	34 979	34 982	34 982	34 983	34 983	34 983	34 982
Transport	Min	29 424	29 766	29 766	29 767	29 766	29 765	29 767	29 767	29 767	29 767	29 767	29 767	29 767	29 767	29 767
	Max	29 478	29 738	29 765	29 767	29 767	29 766	29 766	29 757	29 764	29 766	29 766	29 767	29 767	29 767	29 766
Finance	Min	24 271	24 553	24 553	24 554	24 553	24 553	24 554	24 554	24 554	24 554	24 554	24 554	24 554	24 554	24 554
	Max	24 315	24 530	24 553	24 554	24 554	24 554	24 553	24 546	24 551	24 553	24 553	24 554	24 554	24 554	24 553
Services	Min	54 669	55 305	55 305	55 306	55 304	55 303	55 306	55 306	55 306	55 306	55 306	55 306	55 306	55 306	55 306
	Max	54 769	55 252	55 304	55 306	55 306	55 306	55 305	55 289	55 300	55 304	55 304	55 306	55 306	55 306	55 305
Households	Min	163 373	165 276	165 275	165 278	165 273	165 270	165 278	165 278	165 278	165 278	165 278	165 278	165 278	165 278	165 278
	Max	163 674	165 118	165 272	165 278	165 278	165 277	165 276	165 226	165 261	165 274	165 273	165 278	165 278	165 278	165 274

Table A5.30 indicates the range of regional impacts that could be experienced from 2005 to 2019 in Scenario 3(+). The minimum and maximum values incorporate the possible range of values obtained from stochastic runs 01, 44, 80 and the 50% percentile of the data.

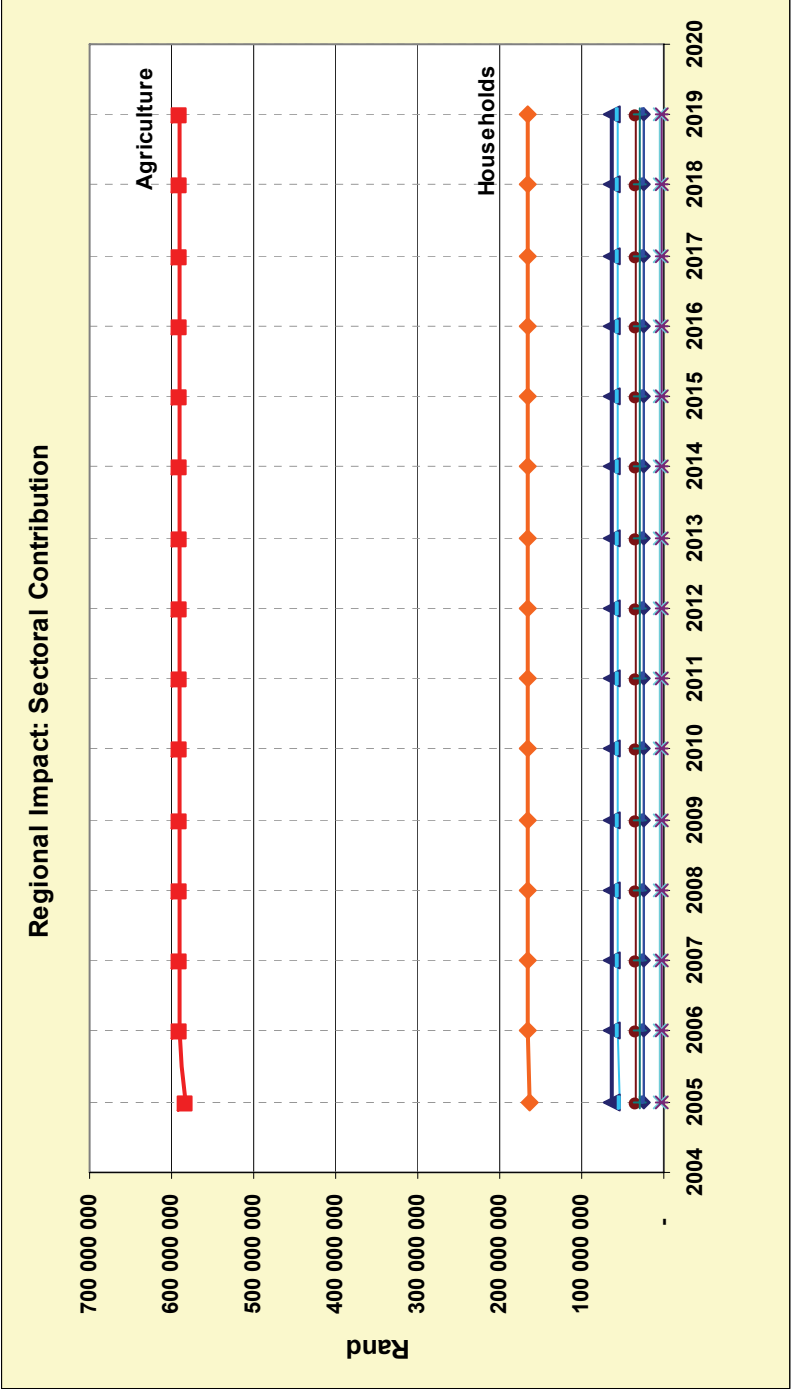


Figure A5.36. Total economic impact per economic sector (total output), 2005 to 2019 (Source: ISIM.MACRO)

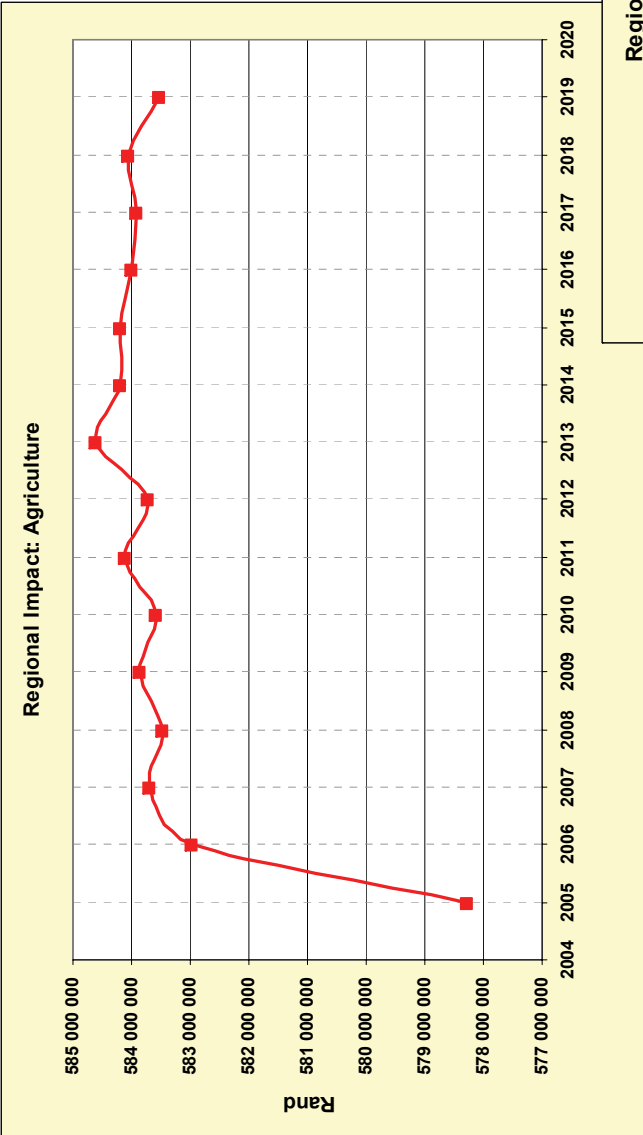


Figure A5.37. Total regional economic impact (output) for the agriculture sector, 2005 to 2019 (Source: ISIM.MACRO)

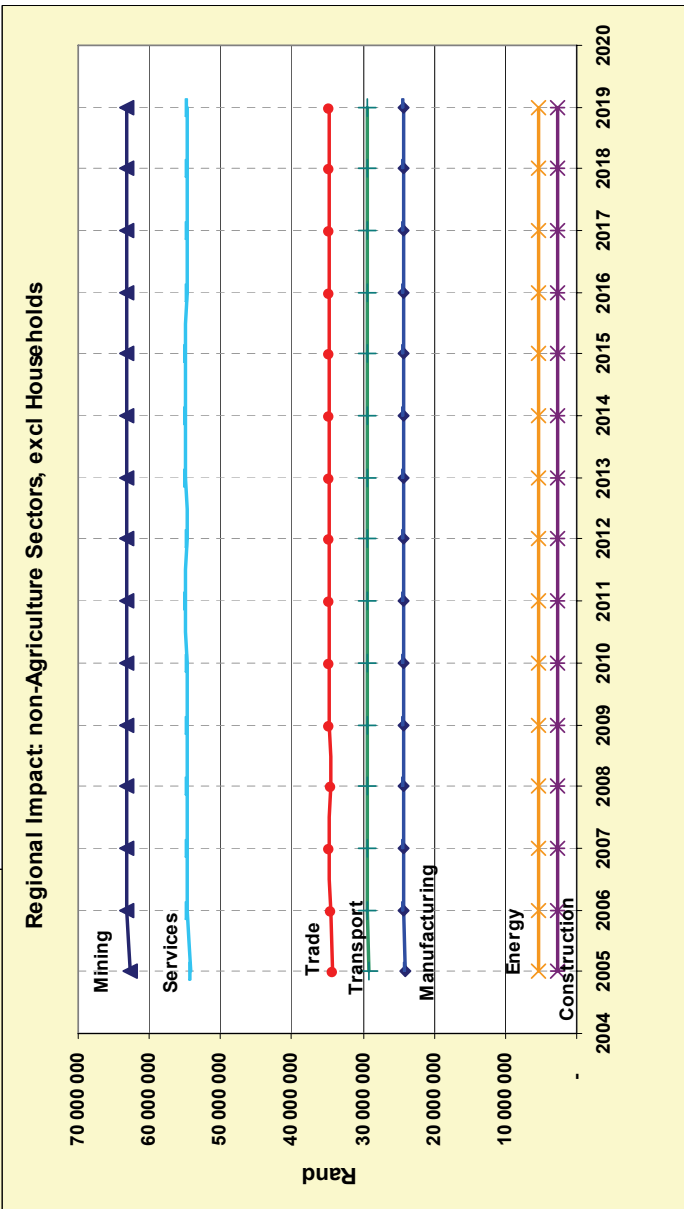


Figure A5.38. Total regional economic impact (output) for the non-agriculture sectors, excluding households, 2005 to 2019 (Source: ISIM.MACRO)

A5.6. INDEX FOR SUSTAINABLE ECONOMIC WELFARE

A5.6.1. BASE CASE SCENARIO

The resulting ISEW values for Base Case Scenario are indicated below, as well as the trends experienced in each of the three elements measured, namely production (Pi), employment (Ei) and Salinity (Si) for the 50% percentile.

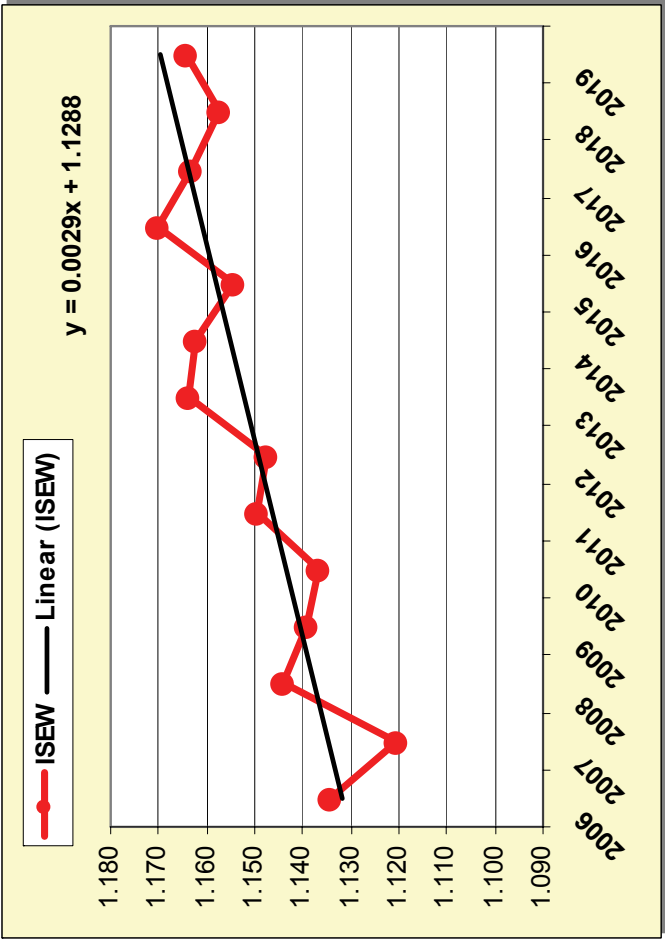
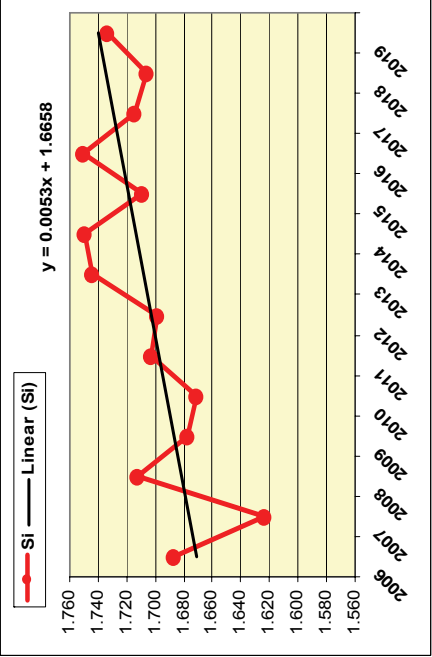
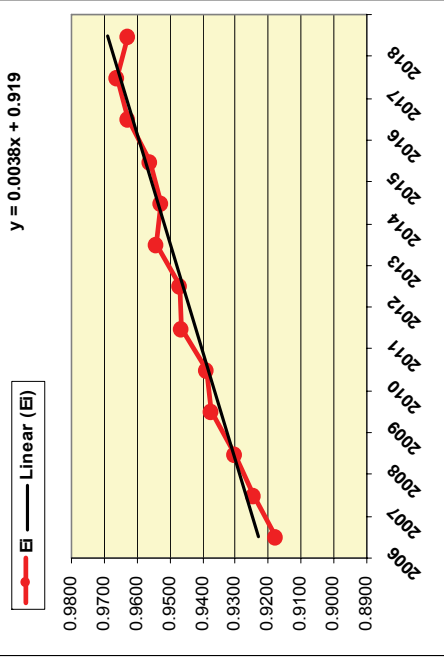
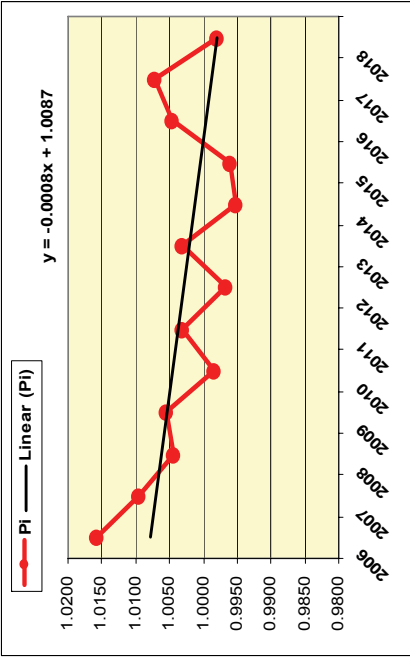


Figure A5.39. ISEW for Base Case Scenario, 2005 - 2019



A5.6.2. SCENARIO 1

The resulting ISEW values for Scenario 1 are indicated below, as well as the trends experienced in each of the three elements measured, namely production (Pi), employment (Ei) and Salinity (Si) for the 50% percentile.

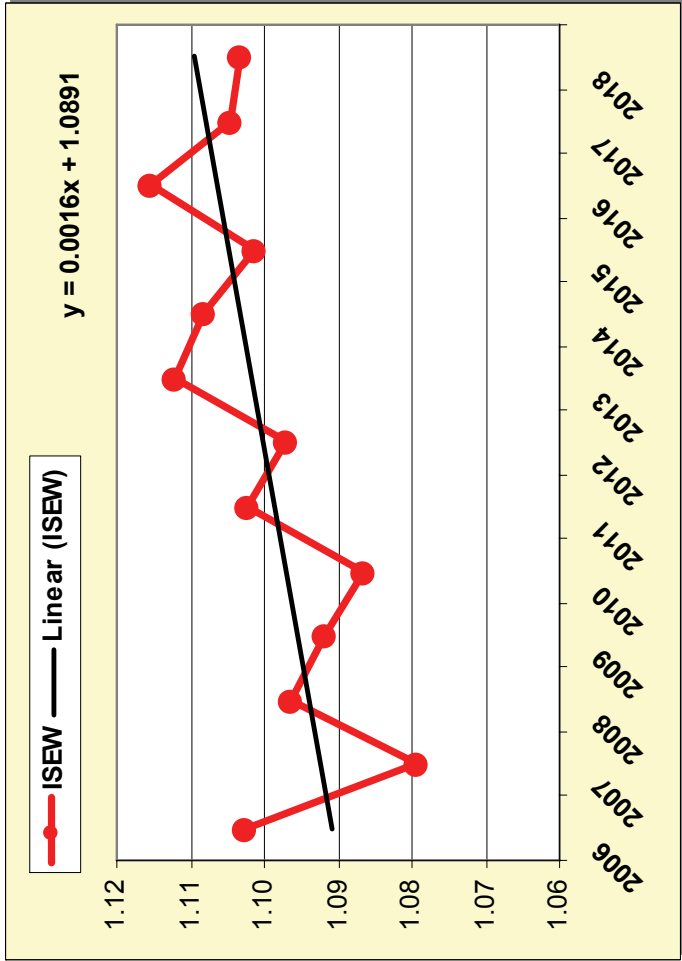
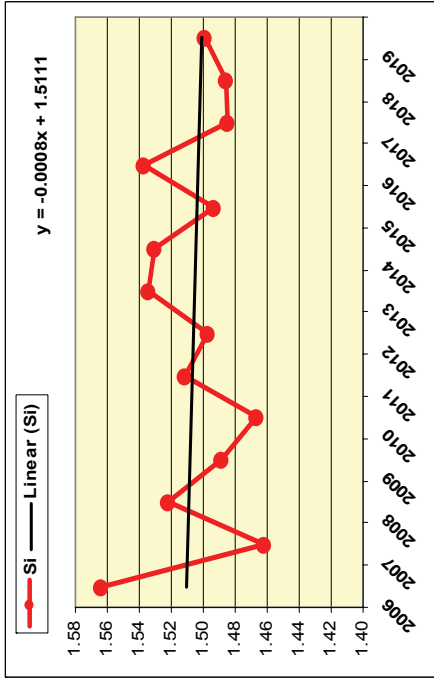
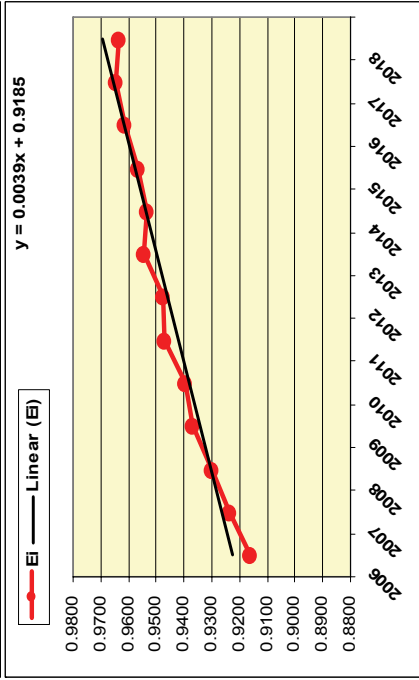
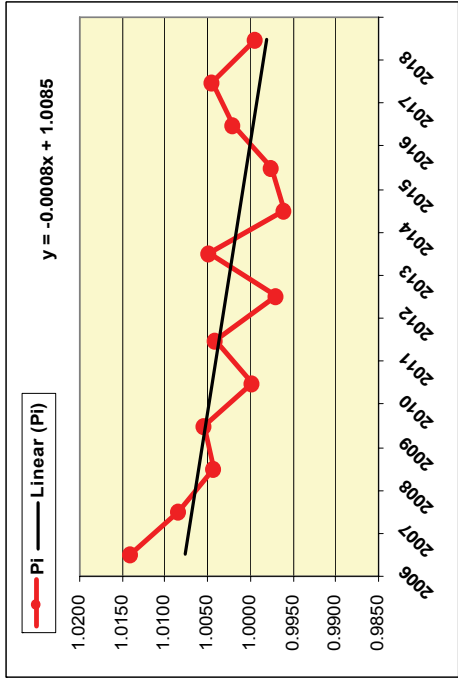


Figure A5.40. ISEW for Scenario 1, 2005 – 2019



A5.6.3. SCENARIO 2

The resulting ISEW values for Scenario 2 are indicated below, as well as the trends experienced in each of the three elements measured, namely production (Pi), employment (Ei) and Salinity (Si) for the 50% percentile.

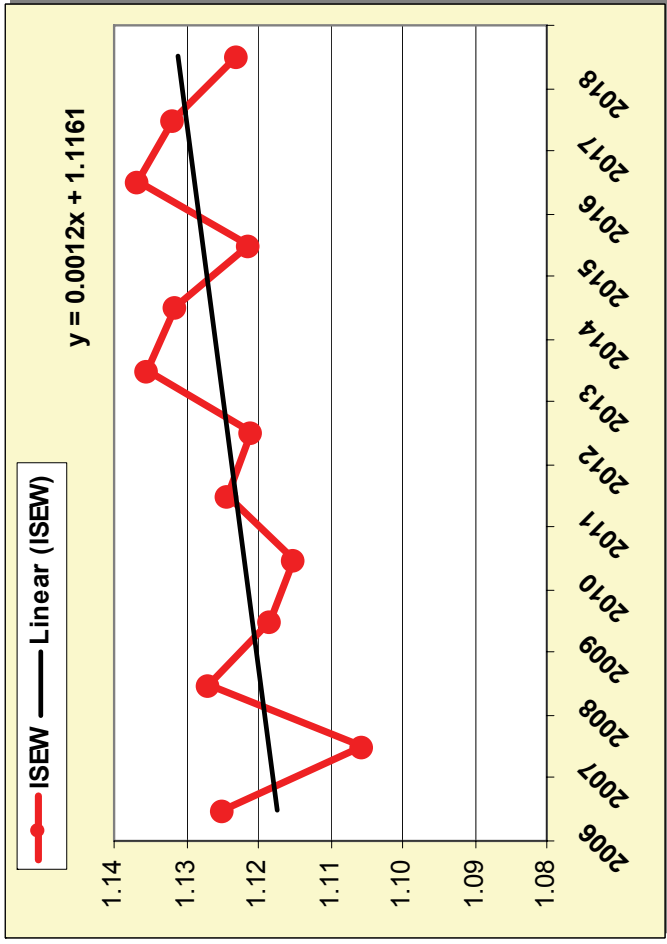
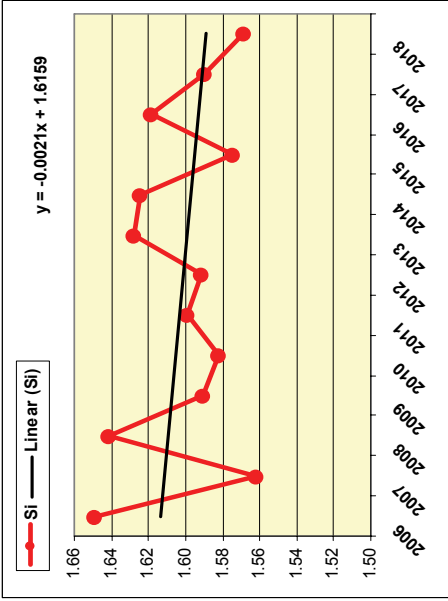
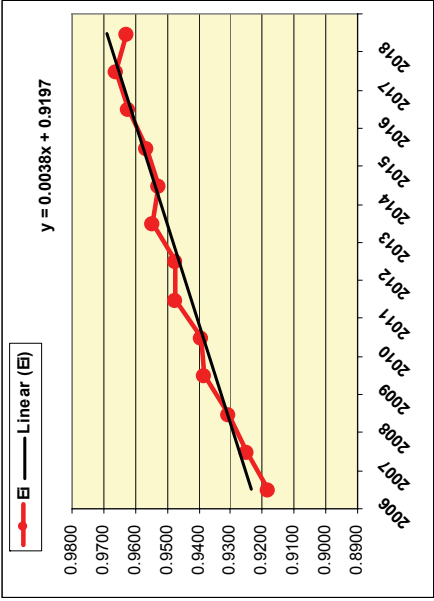
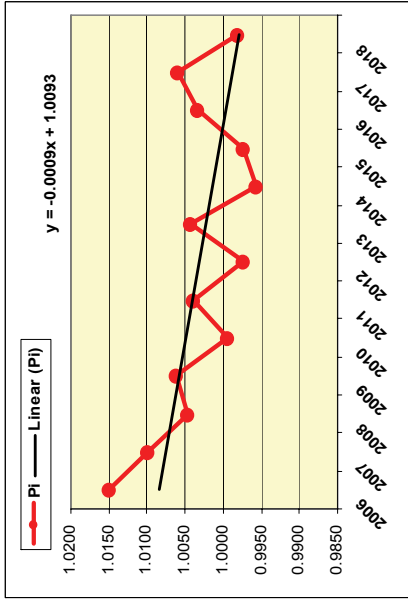


Figure A5.41. ISEW for Scenario 2, 2005 - 2019



A5.6.4. SCENARIO 3

The resulting ISEW values for Scenario 3 are indicated below, as well as the trends experienced in each of the three elements measured, namely production (Pi), employment (Ei) and Salinity (Si) for the 50th percentile.

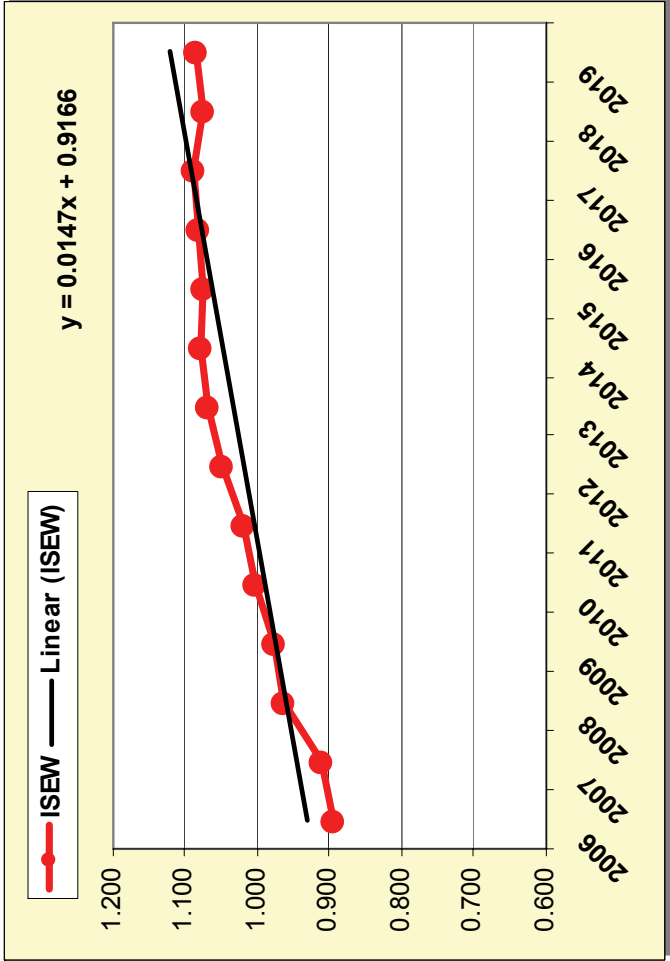
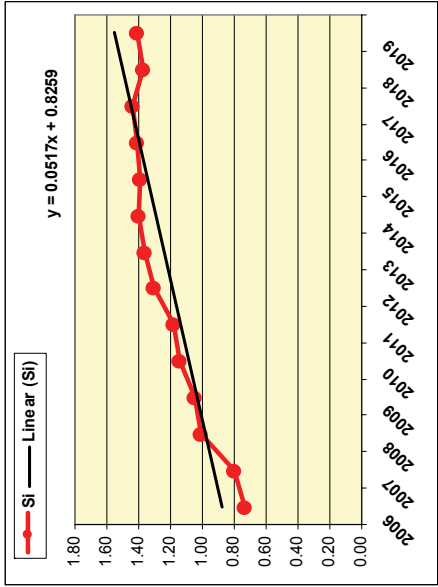
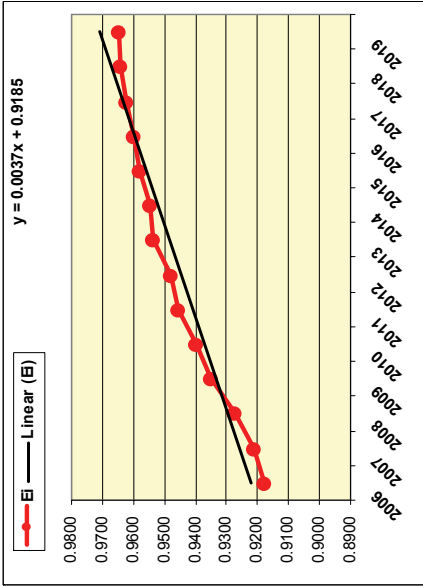
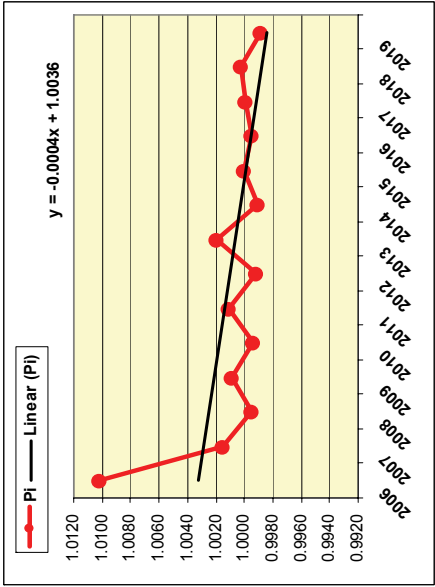


Figure A5.42. ISEW for Scenario 3, 2005 - 2019



A5.6.5. SCENARIO 3(+)

The resulting ISEW values for Scenario 3(+) are indicated below, as well as the trends experienced in each of the three elements measured, namely production (Pi), employment (Ei) and Salinity (Si).

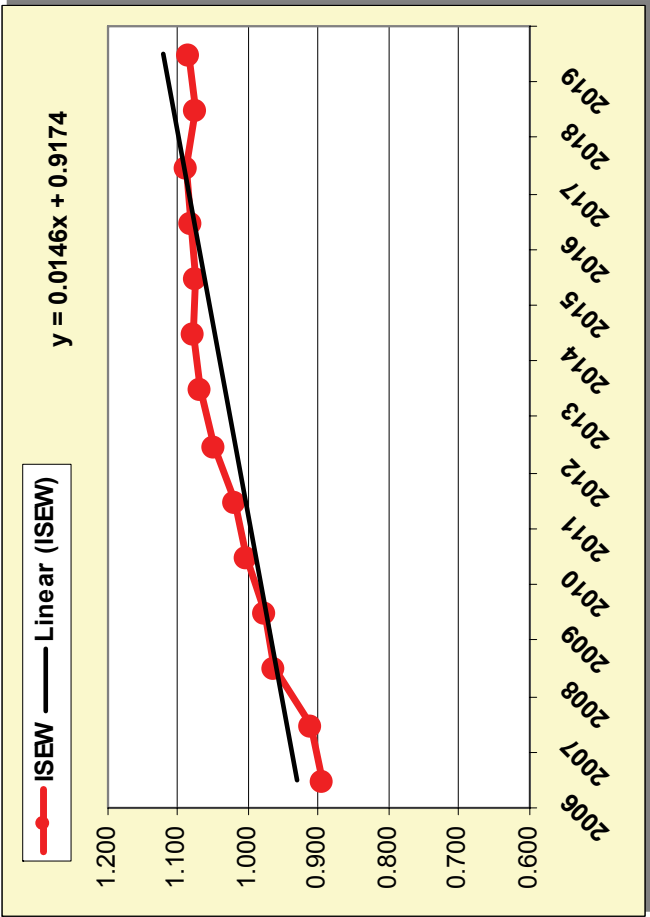


Figure A5.43. ISEW for Scenario 3(+), 2005 – 2019

