SALMOD, A SALINITY MANAGEMENT TOOL FOR IRRIGATED AGRICULTURE.[1]

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ABSTRACT

This paper presents an irrigation farm management tool, SALMOD (Salinity And Leaching Model for Optimal irrigation Development), that calculates the profit maximizing crop enterprise composition and irrigation management options for farm specific soil type, drainage status and irrigation system composition subject to various regional control measures and expected irrigation water salinities. After stating the water quality problem, and particularly salinisation in Southern Africa, the input data requirements and the results of SALMOD and their usefulness at farm level, are discussed. The impact of various possible regional or policy regulations are then discussed.

SALMOD was developed for irrigators in the lower Vaal and Riet Rivers in South Africa. These farmers have been experiencing rapidly fluctuating salinity levels in their irrigation water, resulting in soil salinisation, yield loss and subsequent financial instability. SALMOD calculates the profit maximizing crop choice and distribution over the farm, matching the crop choice with soil type, drainage status and irrigation system, indicating the optimal leaching vs. yield reduction seasonal management options as well as calculate long term management options such as underground drainage installation, a change in irrigation system or the construction of on farm storage dams.

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Leaching is necessary to maintain an acceptable salt balance in the root-zone of irrigated crops. This however contributes to point and non-point source water pollution externalities if not managed correctly. Results show valuable policy information regarding the interactions between artificial drainage subsidisation, return flow restrictions and on-farm storage.

Keywords: *Irrigation, water quality, return flows, salinisation, leaching, non-point source pollution, on-farm storage, SALMOD, linear programming, GAMS*

PROBLEM STATEMENT

Irrigation agriculture as a contributor to non-point-source water pollution externalities through nutrients, salts and chemicals in return flows is a global problem and one of growing concern in South Africa. Backeberg *et al* (1996:22), states "water quality is becoming of increasing concern to irrigation, both from a supply point of view and with respect to the environmental impacts of irrigation."

Leaching, the process of applying water over and above the requirements of the plants irrigated, is an irrigation management practice used to "flush" a certain amount of accumulated salts out of the root zone to maintain an acceptable salt balance. This practice is often considered by non-specialists as wasteful, especially as irrigation engineers and scientists appear to be in doubt about the required leaching rates and the efficiency of the leaching practice (Kijne *et al*, 1998).

Where no regulation exists, the seepage from leaching flows back into the river or groundwater carrying high concentrations of salts, further degrading the water source and creating secondary costs through externalities for downstream users and the environment. The paradox however is that without leaching the salts inherently found in soil, or those deposited by irrigating with poor water quality out of the soil, salts accumulate, degrading the soil to levels that can no longer support viable crop production.

SALINITY DEFINED

The concentration of total dissolved salts (TDS) (usually measured in mg/l) increases in static and slow moving water bodies subject to large scale evaporation, as well as according to Basson, (1997:57) in rivers and river reaches receiving large quantities of effluent, mainly due to salinity build-up which results from the addition of salts through most uses of water. Construction of dams and weirs in a river course for the purpose of water storage, often lead to the problem of salination because, except for increasing the susceptibility to evaporation, they also make the water available for use and reuse.

If the TDS concentration in water is high enough the negative effect of irrigating with such waters can be immediate through foliar damage from contact, alternatively salts accumulate in the soil over time. A high salt concentration in a soil body creates a physiological drought for the crops planted therein.

Electrical conductivity (EC) usually measured in milli-Siemens per meter (mS/m) is an indirect measure of the concentration of the total dissolved salts in solution. EC is related to TDS by multiplying by a factor of between 6 and 7 depending on the composition of dissolved salts (DWAF 1993:31-35).

DATA REQUIREMENTS

SALMOD has to be initially set up for a specific irrigation area or farm, entering the regional operating data such as the standard irrigation quota size, irrigation water tariffs, the water over-use fine structure, etc. Next average regional or farm level crop enterprise budgets need to be set up for the most important and possible alternative crops grown in the irrigation region. For these crops the regional crop water requirements and monthly usage have to be obtained and also entered into SALMOD, as well as the crop gradient and threshold tolerance to salinity as determined by Maas and Hoffmann (1977).

Due to the immense variability in biological/natural systems when dealing with grouped averages, acceptable average or representative values have to be determined for use in the model. The ECe (electrical conductivity of the saturated soil paste) variability within an irrigated field for example varies immensely, both across the surface area of the field and in soil depth. This variability could be captured if measured regularly and very intensively at a specific in field level, but would be far too time consuming and expensive to measure for a whole farm. A manageable level of standardisation and aggregation needs to be attained, thus the need for value judgements that are acceptable and widely applicable.

The value judgement data used in SALMOD include the following:

- The maximum leaching fraction ability of the irrigation systems used,
- The maximum leaching ability/infiltrability of the soil types and drainage classes,
- Irrigation drainage cost for the different soil types classified according to clay %,
- Aggregate irrigation system transfer costs,
- Irrigation system plant water uptake efficiencies and
- Irrigation water to soil saturation extract electrical conductivity conversions.

Once SALMOD has been set up for an irrigation region the data as set out in Text Box 1 is required for optimising cropping composition, resource use and management option combinations at farm level. This data comprises irrigable area, irrigation rights (the number of hectares a farmer is allowed to irrigate with a fixed water quota), water costs, pumping costs, monthly average or expected irrigation water electrical conductivity and the hectares of irrigable soil divided into soil type, irrigation system used and soil drainage class.

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SALMOD (FARM LEVEL & PARAMETRIC)       Date run: 26.02.02 Time: 09:12:50

SALMOD DRAFT Results (Leaching Fraction Methodology)
Model by the RAPIDS team, Dept.Ag.Econ.UFS for the WRC

GENERAL INPUT DATA   Olierivier   (1)
Irrigable area   (ha)       200.00
Irrigation rights(ha)       141.00
Water cost      (R/mm)        0.17
Pumping costs   (R/mm)        0.56

Electrical Conductivity of the irrigation water - ECiw (mS/m)
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC
   96     91     72     54    102    109     97     99    119    130    113     97

SOIL TYPE   : LMS  190.0  SNL   10.0  SNC    0.0  CLY    0.0
IRRIG.SYST.: FIS    35.0  CPI  165.0  DIS    0.0
DRAIN.CLASS: NDS  100.0  ADS   20.0  LDS   70.0  WLS   10.0

SOIL TYPE           (clay%)      IRRIGATION SYSTEM       DRAINAGE CLASS
LMS Loamy Sand soils  <15        FIS Flood irrigation    NDS Naturally drained soils
SNL Sandy Loam soils 15-25       CPI Center Pivot        ADS Artificially drained soils
SNC Sandy Clay soils 25-45       DIS Drip irrigation     LDS Limited drainage soils
CLY Clay soils        >45                                WLS Waterlogged soils
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Text Box 1. Data required for running SALMOD scenarios using Olierivier farm, 2000, as an example

SALMOD METHODOLOGY

SALMOD, developed in GAMS (General Algebraic Modelling System), uses a linear programming optimisation tool to model all farm level management options and possible crop combinations to find the profit maximising choice of crops and management options under different water quality and external policy scenarios.

The model consists of a simulation section in which, from a basic crop budget for each of the main crops grown in the study area, crop enterprise budgets are simulated for a range of soil types, irrigation technologies, water qualities, soil drainage abilities, leaching fractions and expected yield percentages. The resulting net returns from the various crop enterprise combinations are then incorporated into the linear programming optimisation section where the optimal crop enterprise combination is chosen, subject to various constraints such as land size, soil permeability, water price and availability and best management practice crop rotational constraints. The model makes provision for a farmer exceeding his water quota by charging for increasing increments at an increasing block rate tariff structure. Also where the annualised costs of artificial drainage installation and alternative irrigation systems are offset by the increased returns they generate, this is automatically accounted for in the model.

The simulation section determines a range of gross margins and water requirements for all possible combinations of six crops, four soil types, four soil drainage statuses and three irrigation system combinations for each of two methodologies, resulting in approximately 1700 crop combination activities for the optimisation section in SALMOD.

A limitation in previous methodologies for calculating the relative yield of a crop irrigated with saline irrigation water was that EC was assumed constant. From the various methodologies suggested on how the average EC can be determined over a season with fluctuating receiving water salinity, the most suitable method is to calculate the average EC weighted for irrigation water volume and quality and rainfall volume and quality. A worked example of the process followed in deriving the weighted average electrical conductivity (EC) of the water used by the plant (i.e. irrigation water and rainfall) is shown in Table 1.

Crop specific data required in this hypothetical example is the potential yield, total crop water requirement, threshold and gradient. For SALMOD the potential crop yields were verified in a technical meeting, the total crop water requirement obtained from the OVIB (Orange Vaal Irrigation Board) and the threshold and gradient values form Maas & Hoffmann (1977). The values used in this example are a potential yield of 1000 kg/ha, a total crop water requirement of 1000 mm/ha, an ECe threshold value of 200 mS/m and a yield decline with increasing ECe gradient value of 0.7 %/mS/m.

Other monthly data required are the salinity of the irrigation water, percentage requirements of the total crop water use and rainfall. As the salinity indication of the irrigation water is usually measured as TDS in ppm or mg/l, TDS of the irrigation water (iw) has to first be converted to ECiw by the following formula derived for the specific irrigation area:

$$ECiw = 0.1572 \, . TDSiw - 2.2295 \qquad (1)$$

ECe is then derived form ECiw by multiplying ECiw by a factor of 2. The TDSiw for the months of July to December, assuming these are the months that the hypothetical crop is in the ground, appear on the left in the table, together with the conversion to ECiw and ECe.

The monthly water requirement percentage (MW) is converted to a monthly water volume (MWV) required by the crop and multiplied by the monthly average ECe. The sum of the products of MWV and ECe over all months that the crop is in the ground is then divided by the total water requirement to give the average ECe weighted for irrigation water requirements alone.

Pure rainfall however also contributes to salinity dilution and leaching, but because of overlaps of irrigation events and rainfall, runoff and deep percolation, not all rainfall is utilised by the crop, or for leaching purposes. For this reason, only effective rainfall (ER) is accounted for. According to Van Heerden (2000), citing "*the Green book*", ER is calculated by subtracting 20 from the monthly average rainfall and dividing the result by 2. Monthly ER is then multiplied by the EC of rainwater (ECr) assumed to be 1mS/m, and added to the monthly ECe weighted for water to give the results in the right hand side of Table 1.

The sum of the products of MWV and ECe plus the sum of the products of ER and ECr over all months that the crop is in the ground is then divided by the sum of the total crop water requirement and effective rainfall to give the average ECe weighted for irrigation water requirements (MWV) and effective rainfall (ER).

Table 1. A hypothetical example of the determination of the average ECe to which a plant is subjected over its growing season, weighted according to monthly crop water requirements (MW) and effective rainfall (ER)

Crop yield (kg):	**1000**	Rainfall EC (ECr) (mS/m):	**1**
Crop water requirement (mm):	**1000**	ECiw to ECe conversion factor :	**2**
Threshold (mS/m):	**200**	TDSiw to ECiw conv. factor (CF):	**y = 0.1572x - 2.2295**
Gradient (%/mS/m):	**0.7**	Effective rainfall (ER) formula :	**= (Rainfall - 20) / 2**

	TDSiw (ppm or mg/l)	**ECiw (mS/m)**	**ECe (mS/m)**	**Mon-thly Water (%)**	**Monthly water volume (mm)**	**ECe weight -ed for water**	**Rainfall (mm)**	**Effective rainfall (mm)**	**Ave. ECe weighted for water & ER**
MONTH	**TDS**	**TDS x CF2**	**ECiw x 2**	**MW**	**MWV**	**ECe x WV**	**Rain**	**Rain - 20 / 2**	**ECe x (MWV+ (ER x ECr)**
Jul	**626**	96	192.2	**0.029**	29	5575	**1.8**	0	5574.8
Aug	**691**	106	212.7	**0.075**	75	15955	**7.5**	0	15954.5
Sep	**762**	118	235.2	**0.206**	206	48445	**12.3**	0	48444.9
Oct	**747**	115	230.3	**0.347**	347	79911	**28.4**	4.2	79915.0
Nov	**713**	110	219.6	**0.343**	343	75308	**29.6**	4.8	75312.9
Dec	**595**	91	182.5	**0.000**	0	0	**42.3**	11.15	11.2
TOTALS:				**1.000**	**1000**	**225193**	**121.9**	**20.15**	**225213.4**
Averages:	*689.7*	*106.0*	***212.1***		***Weighted:***	***225.2***		***Weighted:***	***220.8***
Rel.Yield:			***91.5%***			***82.4%***			***85.4%***

The average ECe weighted for irrigation water requirement and effective rainfall, calculated in Table 1 as 220.8 mS/m, is inputted into Equation 2, together with the crop threshold and gradient to give the percentage of maximum yield obtainable under the average ECe conditions.

$$RY = (100 - Gradient\,.\,(Ave.ECe - Threshold))/100 \qquad (2)$$

Where the relative yield percentage (RY) is the fraction of maximum yield obtainable for the average ECe (Ave.ECe). Gradient and Threshold are crop specific values as determined by Maas & Hoffmann (1977). The RY for each crop (c) is a function of the soil type(s), drainage status (ds) of the soil and leaching fraction (lf) implemented.

The RY calculated using average ECe weighted for monthly water requirements (MWV) alone (225.2 mS/m) is 0.82 resulting in a 823.6 kg/ha yield if the maximum yield is 1000kg/ha, while the RY calculated using average ECe weighted for MWV and effective rainfall (ER) (220.8 mS/m) is 0.85 resulting in a 854.6 kg/ha yield if the maximum yield is 1000kg/ha; this is a 3.6% improvement. Not accounting for monthly water use and rainfall results in a 6.7% over-estimation of the crop yield.

Table 2 lists the limitations and resulting assumptions for which the average ECe is calculated. Although very simple, this methodology is more applicable to conditions of rapidly fluctuation irrigation water salinities, as is the case in the study area, than simply using an average ECe value held constant over the growing season of the crop planted.

Table 2. The limitations and resulting assumptions for the methodology used to calculate average ECe

Data:	Limitation:	Assumptions:
TDSiw to ECiw conversion factor:	Different depending on origin	Same origin throughout season
ECiw to ECe conversion factor:	Depends on soil type & drainage status	Cropping unit homogeneous & stays the same for whole season
Effective rainfall values:	Monthly totals, doesn't take intensity / distribution into account	Equal distribution and intensity & runoff / wastage factor of 20mm (Van Heerden, 2001)
Threshold and Gradient values:	Don't make provision for different salt sensitivities at different physiological stages of growth.	Constant for whole season (Information limitation)

Once the relative yield percentage (RY) has been calculated as in equation 2, the final step of the simulation section is to set up the range of crop/resource combination gross margin above specified costs ($GMASC_{c,s,ds,lf}$) to be transferred as the decision variable coefficients (GM_i) into the optimisation section of SALMOD.

$$GMASC_{c,s,ds,lf}=PRICE_c * MEY_c * RY_{c,s,ds,lf} - FVC_c - HC_c * RY_{c,s,ds,lf} \qquad (3)$$

Where: $PRICE_c$ is a vector of selling prices for each crop ($_c$)

MEY_c is a vector of the maximum expected yield of each crop ($_c$)

FVC_c is a vector of the variable per hectare production costs for each crop ($_c$) excluding the water price and pumping costs

HC_c is a vector of the per ton harvesting costs of each crop ($_c$) dependent on the calculated relative yield (RY)

The structure of the linear programming problem in its most basic form is as follows (the complete mathematical model is available in a forthcoming WRC report by the same authors):

Maximize	$\pi = \sum^{n}_{i=1} GM_i . X_i$	$(i = 1, 2, \dots , n)$	**(4)**
Subject to	$\sum^{n}_{i=1} A_{ij} . X_i \geq , \leq or = R_j$	$(j = 1, 2, \dots , m)$	**(5)**
and	$X_i \geq 0$		**(6)**

where: π is net return / profit / total gross margin above specified costs

GM_i are the gross margins for activity i

X_i are the decision variables of activity i

A_{ij} is a m x n matrix of constraint coefficients

R_j are the constant constraint values of constraint j

The objective function (4) is to maximise farm net return (π) (or the TGMASC) by choosing the optimal level of activity (X) from the range of choice variables X_i $(i = 1$ *to* $n)$ multiplied by the objective function coefficients, GM_i $(i = 1$ *to* $n)$ which are a set of constants; which in SALMOD are calculated in the simulation section of the model. In equation line 5 the objective function is subject to j $(j = 1$ *to* $m)$ constraints. The levels of these constraints, R_j are also constants. The coefficients of the choice variables (X_i) in the constraints are denoted by A_{ij}. Since there are m constraints in n variables, the coefficients A_{ij} form a rectangular matrix with an m x n dimension. Equation line 6 is the non-negativity constraint of the choice variables.

MAIN RESULTS

The results generated by SALMOD provide the following:

- The maximum attainable farm level total gross margin above specified costs (TGMASC) under various water quality and management scenarios.
- The optimal combination of leaching fraction and yield reduction management options to implement to attain the maximum farm level TGMASC over a production year.
- The identification of the main factors of production constraining attainment of optimal TGMASC.

- What the farmers can indirectly afford to pay for irrigation water of various qualities (salinities) in a free market water system.
- What the impact of various management scenarios and constraints will be on the dual or shadow value of irrigation water.
- How a farmers crop composition is expected to change as water quality changes.
- What the impact of restricting irrigation return-flows would be on the TGMASC of the farmer.

Results show optimal enterprise composition under various water quality situations. Artificial drainage installation and leaching are financially justified under certain water/soil quality scenarios. The results are also a strong motivation for a change in the current water pricing and quota allocation system used in the study area in South Africa.

Useful data generated by SALMOD for use in environmental impact assessment are the estimated volumes of salt loaded return-flows that either leach into groundwater aquifers or are returned into the river system as a "diffuse pollution source". The model gives a good indication of a farmer's specific contribution to the diffuse or non-point source pollution problem. The economic effects of constraining return-flows and the effects of water pricing policy on the volume of return flows are also determined.

The shadow prices (dual values) calculated in the linear programming model indicate the price that resources should rise or decline to be incorporated into the optimal enterprise combination - for instance, the price that a farmer can afford to pay for water of a certain quality. Results clearly indicate that irrigation water resources of different qualities are different commodities for which different rates should be charged.

Text Box 2 in which the results calculated by SALMOD are displayed, is a continuation of Text Box 1 that lists the farm level set up data. The results show optimal crop/resource composition, water use, fines, financial returns and constraints. Looking at Maize in Text Box 2, the first crop included under optimal crop composition as an explanatory example, SALMOD calculates that 25.1 hectares are to be planted on the loamy sand soils (LMS) with limited drainage (LDS) under flood irrigation (FIS). The optimal crop management options calculated are to apply a 10% leaching fraction (LF10) and accept a 94% of the maximum attainable yield. The gross margin above specified costs (GMASC) for maize panted under these conditions is R3 154 per hectare and water usage will be 0 mm in the pre-year (winter growing season) and 19512 mm for the 25.1 hectares in the after-year (summer growing season).

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MODEL RESULTS
Optimal crop composition:
Crop      Soil Class Irrig LF     Yield HECTARES     GMASC  PYWater   AYWater
MAIZE     LMS  LDS   FIS   LF10   0.94      25.1      3154        0     19512
POTATO    LMS  NDS   CPI   LF0    1.00       6.0      6338        0      3663
LUCERNE   LMS  NDS   CPI   LF5    1.00      94.0      5339    49009     76655
LUCERNE   LMS  ADS   CPI   LF5    1.00      20.0      5339    10427     16309
LUCERNE   LMS  LDS   FIS   LF10   0.94       4.9      4985     2704      4230
LUCERNE   LMS  LDS   CPI   LF5    0.89       9.8      4683     5123      8013
LUCERNE   LMS  LDS   CPI   LF10   0.94      21.2      4985    11682     18272
Total water used               (mm):              225600    78946    146654
Unused trans. from Pre- to Aft-year :                                 28214
Water Usage Cost                (R):               38352    13421     24931
Water Pumping Cost              (R):              126336    44210     82126
Water overuse fines:    WF1     14100               3596  DUAL 1.4844
                        WF2     14100               4794  DUAL 1.3752
                        WF3     14100               5993  DUAL 1.2660
                        WF4     14100               7191  DUAL 1.1569
                        WFPY    14100              14100  DUAL 0.5276
    TOTAL WATER OVERUSE         70500  TOTAL FINE  35673
Estimated optimal net revenue (R):                662312
Pre-determined fixed costs    (R):                561000
FARM PROFIT                   (R):                101312
Production capital requirement(R):   (Max 300000)  300000  (DUAL= 0.2843)
Fixed capital loan requirement(R):   (Max 600000)       0  (DUAL= 0.0000)
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Text Box 2. An example of the farm level results generated by SALMOD using the Olierivier farm, 2000, as an example

Next the total water usage, cost and fines are displayed, showing a total water overuse of 70500 mm for the total irrigated area and a total water overuse fine of R35 673. The estimated farm total gross margin above specified costs (or optimal net revenue) is calculated as R662 312, and subtracting the pre-determined fixed costs of R561 000 from this gives the farm profit of R101 312. The production capital loan of R300 000 is fully utilised with the dual or shadow value 0.2843 indicating that for every R1 extra production loan the farmer could get, he could increase farm profits with an additional R0.28. This provides and indication to the farmer of the interest rate he could afford to loan additional money at. The fixed capital loan requirement of zero indicates that the farmer needn't implement any long term fixed capital improvements such as installing underground drainage, changing the irrigation system or building on farm storage for irrigation return flows.

Text Box 3 show the same basic information as Text Box 2, but for a parametric range of irrigation salinities. The results show the impact on farm level total gross margin (above specified costs), optimal crop composition and financial value of extra irrigation water (water fine shadow values) of changing irrigation water salinity.

Besides the farm level management option results generated by SALMOD, answers for the following questions/scenarios regarding the external operating environment can also be generated:

- What would be the impact on farm profitability if the price of water or electricity were to increase?
- What would the impact be of a policy limiting the volume of returnflows allowed off the farm?
- What would be the impact if the water quota volume allocated were to be reduced?
- What would the impact of different water quality scenarios be on all the questions above?

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SALMOD (FARM LEVEL & PARAMETRIC)      Date run: 26.02.02 Time: 09:12:50

SALMOD DRAFT Results (Leaching Fractions Methodology - PARAMETRIC ANALYSIS)
Model by the RAPIDS team, Dept.Ag.Econ.UFS for the WRC

PARAMETRIC MODEL RUN FOR:            Olierivier   (1)

                        MN3      MN2      MN1      PL1      PL2      PL3     EC98
                      -0.30    -0.20    -0.10     0.50     1.00     2.00     0.00
Total Gross Margin   686711   679686   670546   588276   509171   379816   662312
Total Water Fine      35673    35673    35673    35673    21573     3596    35673
Return Flows          12255    12255    14100    14100    14100    14100    14100
                       0.00     0.00     0.05     3.32     4.43     2.92     0.60

OPTIMAL CROP COMPOSITION
WHEAT                  0.00     0.00     0.00    18.98    26.66     0.00     0.00
MAIZE                 25.07    25.07    25.09     0.00     0.00     0.00    25.09
GRNDNUT                0.00     0.00     0.00     0.00     0.00     0.00     0.00
POTATO                 6.00     6.00     6.00     6.00     6.00     6.00     6.00
COTTON                 0.00     0.00     0.00     0.00     0.00     0.00     0.00
LUCERNE              151.43   151.43   149.97   153.93   138.84   119.39   149.97

WATER FINE SHADOW VALUES
WFPY                 0.7296   0.5648   0.5431   0.2093  -0.0304  -0.7354   0.5276
WF1                  1.7400   1.5921   1.5401   1.0429   0.6754   0.0096   1.4844
WF2                  1.6247   1.4749   1.4263   0.9478   0.5904  -0.0754   1.3752
WF3                  1.5094   1.3576   1.3126   0.8527   0.5054  -0.1604   1.2660
WF4                  1.3941   1.2404   1.1988   0.7575   0.4204  -0.2454   1.1569
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Text Box 3. An example of the parametric irrigation water sensitivity report results generated by SALMOD using the Olierivier farm, 2000, as an example

CONCLUSIONS

Salinisation has already reached critical proportions in many countries. With South Africa reaching the end of its available water resources within the next three decades, the volume of water use and reuse is expected to result in a rapid decline in water quality. With the successful quantification of the problem appropriate policy and management practices can be timeously implemented to minimize the effects and magnitude of the salinisation problem, guaranteeing the sustainability of the communities that are dependent on and the environment that is affected by this most valuable natural resource. The implementation of SALMOD for optimising farm and irrigation board management options for fluctuating salinity in the Lower Vaal and Riet Rivers in South Africa has proved the usefulness of SALMOD for assisting in managing salinisation in irrigated agriculture.

LIMITATIONS

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). According to Blackwell *et al* 2000, current USDA Salinity Laboratory evidence suggests these interactions are far more complex than originally thought, and that 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.

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."

These issues are proposed to be addressed in a follow up study by the same authors entitled "Multi-dimensional Models for the Sustainable Management of Water Quantity and Quality in the Orange-Vaal-Riet Convergence System" due for completion at the end of 2004.

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BIOGRAPHICAL SCETCH

Jack Armour (born February 1974) graduates in September 2002 with a master's degree in agricultural economics (M.Sc.Agric). His thesis is entitled "The Economic Effects of Poor and Fluctuating Irrigation Water Quality on Irrigated Agriculture in the Lower Vaal and Riet Rivers". He is employed by the University of the Free State where he assists in lecturing mathematical programming, environmental economics and farm management courses. Other interests are rural revitalisation and agritourism. Jack is married to Claire and they live in Ficksburg, where they are actively involved in the community and have farming and agritourism interests.