APPENDIX 2

IRRIGATION AGRICULTURE IN THE LOWER SWAKOP RIVER:

AN EVALUATION OF THE POTENTIAL IMPACT OF THE KARS PROJECT

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. BACKGROUND

The town of Swakopmund is reported to be experiencing unprecedented expansion and an increasing demand for high quality fresh produce. It is, however, far from the established vegetable growing areas. This creates opportunities for local production. With its extremely low rainfall and high evaporative demand, the climatic conditions on the Namibian west coast are such that no crop production is possible without irrigation.

Groundwater extracted from the alluvial aquifer of the lower Swakop River has since the early days of the town been used for the irrigation of a variety of crops on the alluvial terrace next to the dry river bed. Although water quality has always shown spatial and temporal variability, a deterioration has reportedly been observed since the construction of the Von Bach and Swakoppoort dams in the upper Swakop River catchment. Since the availability of sufficient water of an acceptable quality is a prerequisite for successful irrigation agriculture, irrigators within the municipal boundaries are concerned about the effect, which a further potential deterioration in water quality and quantity as a result of the KARS project, could have on their activities. The KARS project which is presently under consideration is expected to result in a decrease in the quantity of water and an increase in the salinity. This investigation was conducted in an effort to predict what the effect of these expected changes would be on present and planned irrigation activities.

2. INTRODUCTION

Irrigation is used by man to fill in the shortfall between crop water requirement and natural rainfall. The ability to sustain irrigated agriculture has been linked to the rise and fall of a number of past civilisations. The ultimate decline of these civilisations are mostly linked to their inability to control the salinization and degradation of their irrigated lands over the long term. Although our understanding of the factors controlling salinization and how they interact with one another have improved significantly in modern times, a large percentage of present day irrigation schemes fail because of inadequate attention to these factors. The most important factors controlling salinization of irrigation land are the quality (especially salinity) of the irrigation water and whether or not provision for drainage (either natural or artificial) is adequate.

The quality of irrigation water is not an inherent property, but is determined by the specific conditions under which it is used. Important factors to consider in the evaluation of water quality are the:

- water quality constituents of concern for a specific crop-soil-climate combination,
- properties of the soil which will be irrigated (such as its ability to leach salt). This determines whether the soil can be used on a sustainable basis with a specific water, crop, irrigation system combination,

- crop(s) to be grown (their sensitivity to water quality constituents, from which can be deduced their expected and economic yield under a given set of conditions),
- irrigation system (frequency of water application and whether applied overhead, at surface or subsurface).

3. APPROACH

As part of the broader KARS environmental impact assessment (EIA), water samples were taken from wells, boreholes and wellpoints in the farming area of the lower Swakop River. Hydrological modelling studies conducted as part of the EIA, made predictions of the increase in salinity which could be expected to occur in the lower Swakop River as a result of KARS. The assessment of the suitability of the present and the expected future water quality for irrigation, which are reported on in this report, are to a large extent based on the results of these two studies. Use was furthermore made of accepted relationships from the international literature to (firstly) link water salinity to soil salinity and (secondly) link soil salinity to crop yield. The present and expected water quality were further evaluated to assess their effect on soil permeability and to identify the preferred irrigation method.

4. RESULTS AND DISCUSSION

4.1 Soils

No soil survey was conducted as part of the investigations for the EIA. From superficial observations it is, however, clear that the soils used for irrigation are predominantly of an alluvial nature and belonging to the Dundee soil form of the South African binomial soil classification system (MacVicar et al, 1977). Layers of varying texture and thickness, typical of recent alluvial deposits have been observed. Since these layers have been deposited and redeposited over time, marked variability in texture and thickness is possible over relatively short distances.

Several farmers reported a silty layer (about 2 metres thick) which restricts vertical water percolation at a depth of 1 to 3 metres below the surface. Where the silt layer occurs close to surface localised water logging has been experienced. General water logging and elevated water tables as a result of over irrigation would, however, not appear to be a problem. Waterlogging would not be expected since only a relatively small portion of the area is being irrigated which allows for lateral dissipation of locally developed high water tables. Furthermore, irrigation water extraction for irrigation would lower, rather than raise, the local water table.

The surface soil layers are generally of a sandy nature, predominantly fine sand with approximately 10% silt plus clay. Some farmers experience surface crusting and some problems with soil wetting as a result of hydrophobic properties (*vet grond*).

4.2 Crops

A fairly wide range of mostly vegetable and fruit crops are grown on small scale. The impression was gained that present owners (specifically at the farms of Messrs Schreiber (Three Sisters) and Pohle (holding 185)) are temporarily irrigating smaller areas of land and a smaller variety of crops than previous owners. The range of crops grown tends to shift to the more salt-tolerant species from east to west in harmony with the increasing salinity of groundwater. Over time the range of crops that are grown have reportedly also shifted to the more salt-tolerant species and westernmost farmers are now no longer able to grow any crop. Vegetables that are reportedly grown include beetroot, melon, sweet melon, cabbage, tomatoes, onion, maize, lettuce and carrots. Beans and peas are no longer grown successfully. Lucerne is still grown successfully as a forage crop. Fruit trees which are grown include fig and citrus. Dates and Jojoba are being planted on an experimental basis at the western end of the presently irrigated area (Mr Hoppe, Farm 171). One farmer plans to plant 1,000 olive trees.

Asparagus has been grown very successfully in cultivar trials and on an experimental commercial basis by the Rössing Foundation for the past couple of years. Some farmers have followed their example so that it is presently probably the single most popular crop. Because of the warm climate farmers are able to produce fresh asparagus during December, which is out of season for other production areas, and are thus able to command premium prices on the South African and European markets. Against this background, several farmers plan to extend their production (Rössing Foundation is considering expansion of production to 100 hectares).

4.3 Irrigation method and quantity

Several variations of surface irrigation is the main irrigation method. Drip irrigation is being used by Rössing Foundation for the irrigation of asparagus. Their example is being followed by one or more other farmers and for planned expansions. Irrigation methods such as sprinkler irrigation which cause wetting of leaves have been found to be totally unacceptable because of the leaf scorch which results.

Irrigation scheduling appears to be fairly fixed and based on experience, rather than some independent soil, plant or atmospheric demand guideline. Precise control of water application with flood irrigation on sandy soils is difficult. It is unclear to which degree the present practice succeeds in supplying in crop water requirements without unnecessary over irrigation. The fact is that, through experience, crops are being produced with waters which would mostly be considered to be too saline for irrigation. The impression was gained that a fair degree of over irrigation takes place with the present flood irrigation and that water could possibly be saved by switching to drip irrigation.

4.4 Evaluation of present water quality

The two most important characteristics of water which need to be considered in the evaluation of its suitability for irrigation, are its:

- **salt content**, (measured as electrical conductivity, **EC**, or sometimes total dissolved solids, **TDS**) which determines the range of crops that can be grown successfully, and the degree to which their yields will be depressed relative to irrigation with non-saline water; and

- **sodium adsorption ratio (SAR)**, which provides an indication of the exchangeable sodium percentage (ESP) that will develop in the irrigated soil. Soil physical conditions are largely modified by a soil's ESP. Of great importance under irrigation is that permeability of the soil to water is largely determined by the combined effects of a soil's ESP and the salt content of the irrigation water.

4.4.1 Existing water quality

Water for irrigation is extracted from wells, boreholes, wellpoints and trenches sunk to below the water table in the alluvium. The water quality analyses from extraction points on farms in the lower Swakop River as sampled by the CSIR (**Table 4.4** of main report) are reproduced in **Table 1**. The order in which analyses are reported was re-arranged so that they follow a progression from east to west down the river. The change in salt content (EC) and SAR from east to west are displayed in **Figures 1 and 2**, respectively.

All the samples have EC (salt content) values in excess of the 500 mS/m limit of the highest salinity class (C4) of the USDA classification (USSL Staff, 1954) which is commonly used to evaluate irrigation water quality. The sodium adsorption ratio (SAR) of all samples falls in the highest sodicity risk class (S4). It is thus no wonder that water quality evaluation reports received by farmers invariably indicate that their water samples are unsuitable for irrigation. However, the fact remains that crops are presently being produced under irrigation. In the following paragraphs, the irrigation water's salt content and SAR will be assessed for the specific crop-soil combination which occur in the lower Swakop River.

Table 1: Chemical analyses of water from extraction points on farms in the Lower Swakop River. (Adapted from **Table 4.4** of the main CSIR report, to show an east-west progression).

Farm	Plot No	K	Na	Ca	Mg	SO4	Cl	Alk	NO_3	Sum of Ions*	TDS	EC	SAR
		mg/ℓ									mg/ℓ	mS/m	
Three Sisters	-	35	831	332	90	413	1667	192	6.5	3567	3840	600	10.4
Blakeway	185	40	1009	368	100	344	2139	167	7.2	4174	4608	720	12.0
Rössing Found	184	56	1697	559	170	647	3480	210	12.7	6832	7360	1150	16.1
De Kock	183	43	1233	473	126	539	2582	231	10.7	5238	5600	875	13.0
Jooste	181	50	1458	465	144	663	2970	222	5.7	5978	6368	995	15.1
Plot181	181	49	1568	512	144	636	3257	173	13.3	6352	6656	1040	15.8
Plot180	180	57	1811	588	165	748	3806	203	7.2	7385	7680	1200	17.0
Van Heerden	179	58	1811	594	167	718	3572	222	12.3	7154	7552	1180	16.9
Horse farm	178	64	2152	711	190	822	4346	269	8.3	8562	8768	1370	18.5
Pampel	178	75	2737	874	241	957	5665	175	20.4	10744	10880	1700	21.1
Erb	175	95	1932	670	194	835	3987	203	6.4	7922	8224	1285	16.9
Hoppe	171	74	2680	857	257	964	5712	202	15.6	10762	10816	1690	20.6
Hoppe well	171	87	2769	910	276	1194	5826	246	3.1	11311	11264	1760	20.6
Stiemert	167	58	1842	466	152	720	3626	166	11.4	7041	7397	1145	18.9
Nonidas	-	83	2745	788	228	1098	5604	274	5.1	10825	10816	1690	22.1
Mean		62	1885	611	176	753	3883	210	9.7	7590	7855	1227	17.0

* Sum of ions was obtained by adding the concentrations of K, Na, Ca, Mg, SO_4, Cl, Alk and NO_3

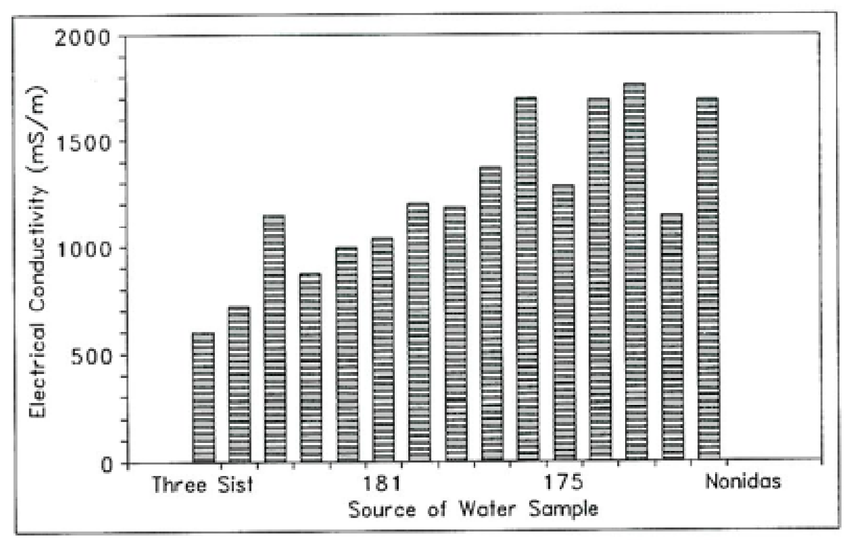

Figure 1: Change in electrical conductivity of water collected from extraction wells, from Three Sisters in the east to Nonidas in the west, in the farming area of the lower Swakop River.

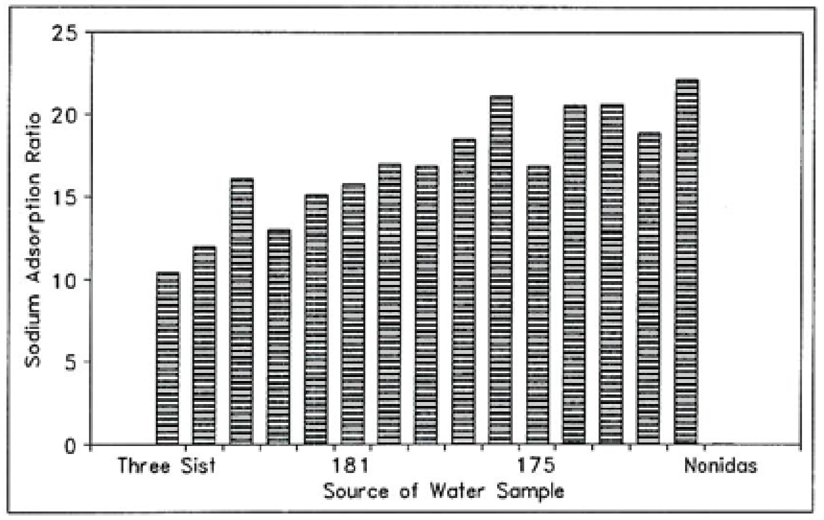

Figure 2: Change in Sodium Adsorption Ratio of water from extraction points, from Three Sisters in the west to Nonidas in the west, in the farming area of the lower Swakop River.

4.4.2 Salt content (EC)

The presence of salt makes it more difficult for plants to extract the water present in soils, thereby increasing the likelihood that plants will suffer water stress and yield decreases. Under experimental conditions crop yields were found to decrease only once a salinity threshold in the soil has been exceeded. Crop yields decrease approximately linearly once this threshold is exceeded. It is the convention to express yields of crops which are reduced by salinity not in absolute terms, but as the yield relative to that obtained under non-saline conditions. Several other factors influence the absolute yield, eg. water application management, fertilizer applications, pest control, etc. All of these variables need to be optimally managed. The salinity threshold as well as the rate at which yield decreases with increasing salinity, is specific for each crop.

Soil salinity is usually measured as the EC of the soil saturation extract. The soil salinity levels corresponding to relative yield levels of 40% to 100% for a number of crops which are presently cultivated (or were cultivated in the past) in the lower Swakop River are presented in **Table 2**. It is clear that these crops vary considerably with respect to their salinity thresholds (i.e. the salinity at 100% yield) and the rate at which yield is affected by increasing salinity. Crops consequently also vary considerably with respect to the relative yield which would be obtained at a specific soil salinity.

SPECIALIST REPORT - IRRIGATION AGRICULTURE IN THE LOWER SWAKOP RIVER

Table 2: Soil salinity (EC of the saturation extract, mS/m) at which different relative yields can be expected for a range of crops which have been or are presently being irrigated in the lower Swakop River (crop salinity tolerances as reported by Maas, 1990).

Crop	Relative Yield (%)						
	100	90	80	70	60	50	40
Asparagus	410	910	1410	1910	2410	2910	3410
Beans	100	153	205	258	311	363	416
Beetroot	400	511	622	733	844	956	1067
Broccoli	280	389	497	606	715	823	932
Cabbage	180	283	386	489	592	695	799
Carrots	100	171	243	314	386	457	529
Dates	400	678	956	1233	1511	1789	2067
Lettuce	130	207	284	361	438	515	592
Lucerne	200	337	474	611	748	885	1022
Maize	170	253	337	420	503	587	670
Onion	120	183	245	308	370	433	495
Tomato	250	351	452	553	654	755	856
Zucchini	470	576	683	789	896	1002	1108

The salt content of soil is determined predominantly by the salt content of the irrigation water and the degree to which leaching of excess salts from the soil is achieved. Leaching of salts is achieved by the application of water in excess of that required to satisfy crop transpiration and surface evaporation demand. The amount of leaching is described by the so-called leaching fraction (LF). The LF is defined as the amount of water passing to below the root zone expressed as a fraction of the total amount of water applied to the soil surface.

Under normal conditions soil salinity will be at its lowest in the topsoil (i.e. below the surface layer in which salts are concentrated because of surface evaporation) and at its highest at the bottom of the root zone. The smaller the LF (the less salt is leached from the soil) the higher the mean soil salinity and the bigger the difference between salinity in the topsoil and at the bottom of the root zone. Soil salinity will similarly increase with increasing salinity of the irrigation water. **Table 3** demonstrates the relative effect of these two variables in determining the mean salinity of the root zone. Note for example that it is possible to attain practically similar mean soil salinities under irrigation with water of 1,600 mS/m (at a LF of 0.5) as with a water of 600 mS/m (at a LF of 0.1).

Table 3: Mean soil salinity (EC of the saturation extract, mS/m) which will develop under steady state conditions in a soil irrigated to achieve a range of leaching fractions with water of various salt concentrations (EC, mS/m).

Leaching Fraction	EC of irrigation water (mS/m)							
	600	800	1000	1200	1400	1600	1800	2000
0.05	1949	2599	3249	3899	4549	5198	5848	6498
0.10	1232	1642	2053	2464	2874	3285	3695	4106
0.20	799	1065	1331	1597	1863	2130	2396	2662
0.30	623	831	1039	1247	1455	1662	1870	2078
0.40	523	697	871	1045	1219	1394	1568	1742
0.50	457	609	761	913	1065	1218	1370	1522

Several calculation procedures have been proposed to calculate the mean soil salinity which will develop under irrigation with water of a given salt content and LF. For this investigation the procedure used by Ayers and Westcott (1985) has been used to calculate the effective mean soil salinity to which crops have been found to respond under low frequency irrigation (**Table 3**). The procedure of Ayers and Westcott (1985) was preferred since it gives slightly higher soil salinity values than a procedure proposed by Rhoades and Merril (1976) and is thus more conservative. It is also the procedure which was used to derive the South African Water Quality Guidelines for Irrigation Agriculture (Department of Water Affairs and Forestry, 1993, 1996).

The crop yield which can be expected for a given irrigation water salinity - LF combination can be deduced from the information presented in **Tables 2 and 3**. First the mean soil salinity for a given irrigation water - LF combination has to be read from **Table 3**, after which the relative yield for a specific crop can be interpolated from the soil salinity - yield relationships presented in **Table 2**. **Table 4** presents such relative yield percentages for three LFs. (Similarly calculated relative yield figures for a wider range of LFs are presented in **Appendix 1**). It is deemed unlikely that the present flood irrigation will allow low LFs to be achieved. It is more likely that considerable over-irrigation takes place, i.e. LFs of about 0.5. The irrigation water EC range was selected to start with 600 m/Sm, which is the value measured at Three Sisters (the lowest of the samples in **Table 1**), and ends with 1400 mS/m.

Table 4: Relative crop yield (%) which can be expected under low frequency irrigation with increasingly saline waters (EC) at three leaching fractions.

Crop	EC of Irrigation water (mS/m)														
	600			800			1000			1200			1400		
	Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction		
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Asparagus	99	96	84	96	92	75	93	87	67	90	83	59	87	79	51
Beans	32	1	0	3	0	0	0	0	0	0	0	0	0	0	0
Beetroot	95	80	25	81	61	0	68	42	0	54	24	0	40	5	0
Broccoli	84	68	12	70	49	0	56	30	0	42	11	0	28	0	0
Cabbage	73	57	0	58	37	0	44	17	0	29	0	0	14	0	0
Carrots	50	27	0	29	0	0	7	0	0	0	0	0	0	0	0
Dates	98	92	70	92	84	55	87	77	40	82	70	26	76	62	11
Lettuce	58	36	0	38	9	0	18	0	0	0	0	0	0	0	0
Lucerne	81	69	25	70	54	0	59	39	0	48	24	0	37	8	0
Maize	66	46	0	47	21	0	29	0	0	11	0	0	0	0	0
Onion	46	19	0	22	0	0	0	0	0	0	0	0	0	0	0
Tomato	80	63	3	64	42	0	49	22	0	34	1	0	19	0	0
Zucchini	100	86	28	87	66	0	73	47	0	58	27	0	44	7	0

Upon closer inspection of the crop yields represented in **Table 4**, it was found that they agree at least qualitatively with the experience of irrigators in the lower Swakop River. The yield of beans (peas have a similar salt tolerance) are so low that even at Three Sisters it would be difficult to produce. Most irrigators are able to cultivate carrots only with low EC tap water obtained from the pipeline. Respectable yields are calculated for beetroot, broccoli, cabbage, lucerne, tomatoes and zucchini, while high relative yields are calculated for asparagus and dates.

Present understanding of the way in which irrigation water salinity affects soil salinity, which in turn determines crop yield, thus appear to agree with the experience of irrigators in the lower Swakop River, and should thus also be able to predict what the effect of increased salinity will be.

4.4.3 Sodium Adsorption Ratio (SAR)

The SAR of water is an index of its potential to induce sodic soil conditions. It is calculated from the sodium, calcium and magnesium concentrations in water. The higher the sodium the higher the SAR, and the higher the calcium and magnesium the lower the SAR. The negative effects associated with high soil sodicity are primarily impaired soil physical conditions, although it can also affect the yield of sensitive crops.

Impaired soil physical conditions are manifested as reduced soil permeability (infiltration rate and hydraulic conductivity) and an increased tendency for hard-setting. Both soil permeability and hard-setting are affected by the potential denseness of packing of soil particles (which is primarily a function of soil texture) and soil exchangeable sodium percentage (which is largely determined by irrigation water SAR). Under irrigation the inherent permeability and hard-setting characteristics of a soil are modified by the SAR and EC of the irrigation water.

While increasing SAR aggravates the situation, an increasing EC counteracts the negative effects of sodium. The relationship between SAR and EC of the water samples in **Table 1** are depicted in **Figure 3**. It is clear that there is a close and direct relationship between EC values and SAR.

Guidelines for the interpretation of the effect of SAR on soil permeability and hard-setting are presented in the South African Water Quality Guidelines for Irrigation (Department of Water Affairs and Forestry, 1996). No sodium-induced problems with infiltration rate are foreseen:

i. in the SAR range of 6 to 12, when EC exceeds 200 mS/m,
ii. in the SAR range of 12 to 20, when EC exceeds 310 mS/m, and
iii. for SAR values greater than 20, when EC exceeds 560 mS/m.

The EC of the present irrigation water is thus sufficiently high to counteract the negative effect that SAR could have on infiltration rate (**Figure 3**). Hydraulic conductivity and hard-setting are in general less sensitive to SAR than infiltration rate and thus even less likely to be affected by the present SAR levels.

Because of the high EC levels, it is thus unlikely that soil physical conditions along the lower Swakop River will be negatively affected by the present SAR levels of the irrigation water. The textural composition of the soil may, however, facilitate a dense packing of soil particles, which would be aggravated by the naturally low organic matter content of the soil.

The high exchangeable sodium content of the soil brought about by the high SAR values (in excess of 10) could also result in the formation of surface seals (crusts) when rain falls on bare soil surfaces. These seals form as a result of the disruptive effect of raindrop energy in combination with the chemical dispersion potential brought about by the low EC rainwater in combination with high soil sodium percentages. SAR values as low as 2 have been found to be dispersive and to promote seal forming under rainfall conditions (du Plessis and Shainberg, 1985). With the low incidence of rain in the area, it is not foreseen that this phenomenon will manifest itself often.

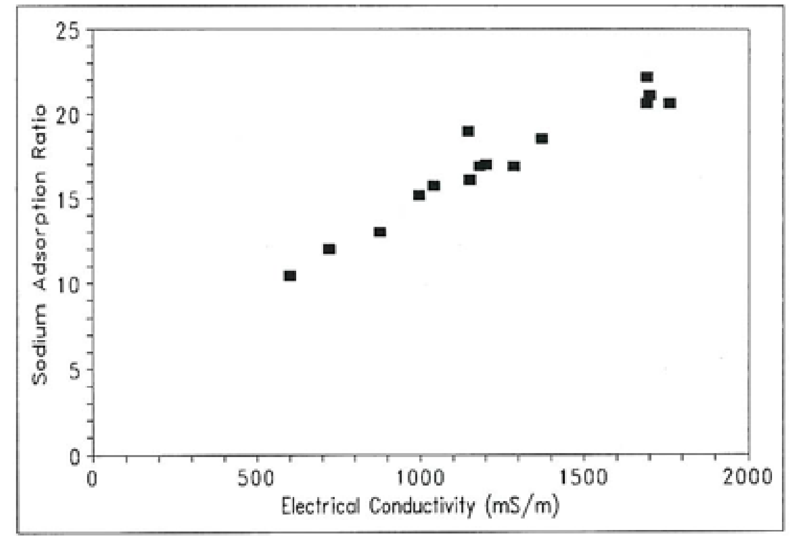

Figure 3. The relationship between SAR and EC of water samples collected from extraction points in the lower Swakop River

4.5 Evaluation of the effect of projected future water quality

4.5.1 Projected future water quality

Hydrological modelling studies undertaken as part of the EIA for the KARS project estimated that the average salinity in the farming area of the lower Swakop River, prior to the construction of the Swakoppoort and Van Bach dams (1925 to 1976), was 6,069 mg/ℓ. Reduced river flow as a result of the construction of these two dams caused a predicted increase in TDS to a mean of 9,911 mg/ℓ. The reduced river flow as a result of the KARS project is predicted to cause a further increase in TDS to a mean of 11,334 mg/ℓ (i.e. an increase of 1,423 mg/ℓ or 14.4 % above the 9 911 mg/ℓ prior to the KARS scheme).

From present TDS values of water samples from the farming area (**Table 1** and EC in **Figure 1**) it is clear that there are significant deviations from the mean TDS value of 9,911 mg/ℓ predicted for the present situation. It is to be expected that the same factors which cause the present variation in salinity, would also be effective in future, and that similar variations could be expected at higher salinity levels. It was therefore deemed inappropriate to use the predicted mean values for the farming area as a basis from which to predict the potential effect of KARS on irrigation activities. The appropriateness of using a concentration factor rather than a fixed increase in salinity was therefore investigated.

From **Figure 1** it would appear as if (with some exceptions) there is a progressive increase in salt content of water in a downstream direction. Such a concentration could be the result of evapotranspiration, by natural vegetation, from water in the alluvium as it slowly flows downstream. Evapotranspiration by crops of water used for irrigation will have the same effect. From **Table 5** it would appear as if the variation in salt content of the different samples can be largely explained by the progressive concentration of water with a similar initial ionic ratio. With the exception of nitrate, which is not a conservative ion, the ionic concentration as percentage of the sum of all ions are remarkably similar. It would thus appear reasonable to assume that for future high salinity scenarios, the water composition from any given point would be better described by concentrating it by a constant factor, rather than by a fixed amount of salt.

For the evaluation of the effect of KARS on the water quality of the farming area, it was consequently assumed that the water would be concentrated by 15 % (a rounding up of the projected 14.4 %) above present values, rather than by the addition of a universal 1,423 mg/ℓ to all samples.

The projected change to the present water composition is presented in **Table 6**. **Figures 4 and 5** compare the present and projected change, respectively, to the EC and SAR of water sources within the farming area.

Table 5: Ionic composition of water samples expressed as a percentage of the sum of ions.

Farm	Plot No	K	Na	Ca	Mg	SO4	Cl	Alk	NO3	TDS	EC	Sum of Ions
		Ionic concentration, TDS and EC as % of sum of ions										
Three Sisters	-	0.99	23.3	9.3	2.5	11.6	46.7	5.4	0.18	107.7	16.8	100.0
Blakeway	185	0.96	24.2	8.8	2.4	8.2	51.2	4.0	0.17	110.4	17.2	100.0
Rössing Found	184	0.82	24.8	8.2	2.5	9.5	50.9	3.1	0.19	107.7	16.8	100.0
De Kock	183	0.82	23.5	9.0	2.4	10.3	49.3	4.4	0.20	106.9	16.7	100.0
Jooste	181	0.84	24.4	7.8	2.4	11.1	49.7	3.7	0.10	106.5	16.6	100.0
Plot181	181	0.77	24.7	8.1	2.3	10.0	51.3	2.7	0.21	104.8	16.4	100.0
Plot180	180	0.77	24.5	8.0	2.2	10.1	51.5	2.7	0.10	104.0	16.2	100.0
Van Heerden	179	0.81	25.3	8.3	2.3	10.0	49.9	3.1	0.17	105.6	16.5	100.0
Horse farm	178	0.75	25.1	8.3	2.2	9.6	50.8	3.1	0.10	102.4	16.0	100.0
Pampel	178	0.70	25.5	8.1	2.2	8.9	52.7	1.6	0.19	101.3	15.8	100.0
Erb	175	1.20	24.4	8.5	2.4	10.5	50.3	2.6	0.08	103.8	16.2	100.0
Hoppe	171	0.69	24.9	8.0	2.4	9.0	53.1	1.9	0.14	100.5	15.7	100.0
Hoppe well	171	0.77	24.5	8.0	2.4	10.6	51.5	2.2	0.03	99.6	15.6	100.0
Stiemert	167	0.82	26.2	6.6	2.2	10.2	51.5	2.4	0.16	105.1	16.3	100.0
Nonidas	-	0.77	25.4	7.3	2.1	10.1	51.8	2.5	0.05	99.9	15.6	100.0
Mean		0.83	24.7	8.1	2.3	10.0	50.8	3.0	0.14	104.4	16.3	100.0

SPECIALIST REPORT - IRRIGATION AGRICULTURE IN THE LOWER SWAKOP RIVER

Table 6: Projected chemical composition of water from extraction points on farms in the lower Swakop River obtained by concentrating present composition by 15 %.

Farm	Plot No.	K	Na	Ca	Mg	SO4	Cl	Alk	NO3	TDS	EC	SAR
		mg/ℓ									mS/m	
Three Sisters	-	41	956	382	104	475	1917	221	7	4416	690	11.2
Blakeway	185	46	1160	423	115	396	2460	192	8	5299	828	12.9
Rössing Found	184	65	1952	643	196	744	4002	242	15	8464	1322	17.3
de Kock	183	49	1418	544	145	620	2969	266	12	6440	1006	13.9
Jooste	181	58	1677	535	166	762	3416	255	7	7323	1144	16.2
Plot181	181	56	1803	589	166	731	3746	199	15	7654	1196	16.9
Plot180	180	66	2083	676	190	860	4377	233	8	8832	1380	18.2
van Heerden	179	67	2083	683	192	826	4108	255	14	8685	1357	18.1
Horse farm	178	74	2475	818	218	945	4998	309	10	10083	1576	19.8
Pampel	178	86	3148	1005	277	1101	6515	201	23	12512	1955	22.6
Erb	175	109	2222	770	223	960	4585	233	7	9458	1478	18.1
Hoppe	171	85	3082	986	296	1109	6569	232	18	12438	1944	22.1
Hoppe well	171	100	3184	1046	317	1373	6700	283	4	12954	2024	22.1
Stiemert	167	67	2118	536	175	828	4170	191	13	8507	1317	20.3
Nonidas	-	95	3157	906	262	1263	6445	315	6	12438	1944	23.7
Mean		71	2168	703	203	866	4465	242	11.2	9034	1411	18.2

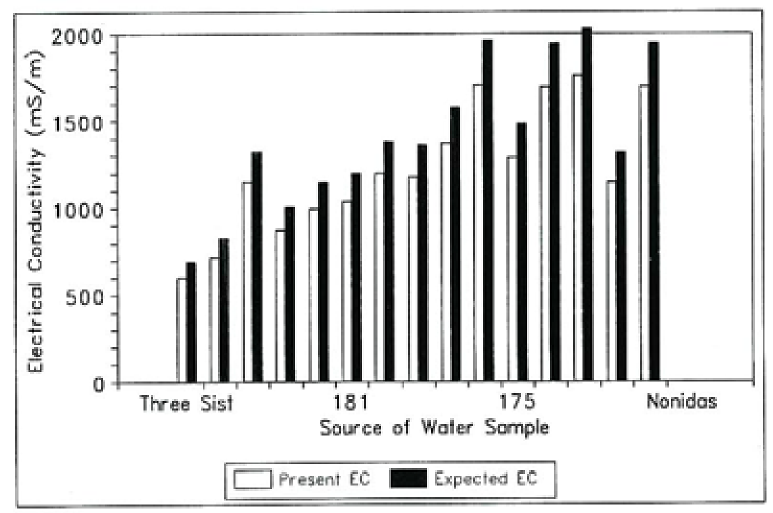

Figure 4: Present and projected change to the future electrical conductivity (mS/m), from Three Sisters in the east to Nonidas in the west, in the farming area of the lower Swakop River.

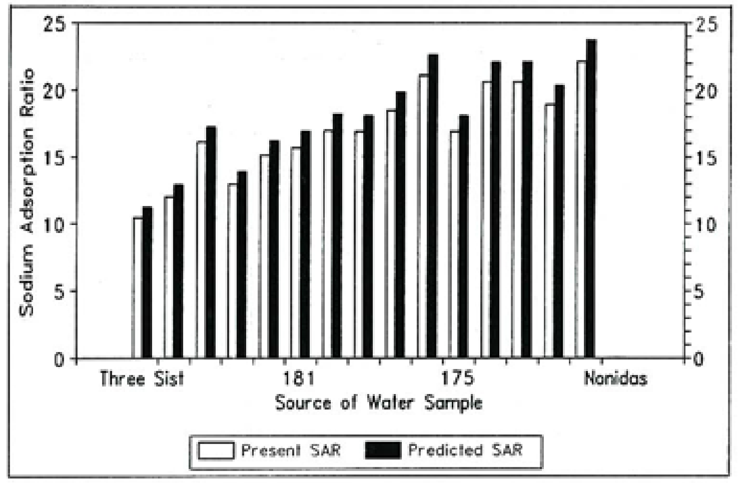

Figure 5: Present and projected change to the Sodium Adsorption Ratio, from Three Sisters in the east to Nonidas in the west, in the farming area of the lower Swakop River.

4.5.2 *Salt content (EC)*

Table 7 presents the relative crop yield which can be expected under irrigation with water of specific salt concentrations (similar to **Table 4**) which have been increased by 15 % in order to reflect projected future irrigation water salinities as a result of the KARS project. **Table 8** presents the calculated difference in yield as a result of this projected increase. From these two tables it is clear that:

i. Yield reductions will show considerable variation, but will mostly be less than 15 %, the increase in irrigation water salinity.

ii. The salt tolerant crops (asparagus, dates) will be less affected than the more sensitive crops.

iii. Yield reduction will be less at high leaching fractions (0.5) than at low leaching fractions (0.1). It is expected that present irrigation methods promote high leaching fractions and would thus be closer to 0.5 than to 0.1.

iv. The effect of the projected increase in water salinity will be more pronounced where present irrigation water salinities are already high. This is explained by the larger increase in absolute salinities they would undergo with a 15 % concentration, compared to waters with a lower salinity.

The main effects of the projected increase in irrigation water salinity for farming in the lower Swakop River are thus expected to be:

i. Minimal where crops with high salinity tolerance are already being cultivated.

ii. A continuation and acceleration of the trend to switch to more tolerant crops (or go out of production) as it becomes increasingly difficult to produce crops which are not very salt tolerant.

Table 7: Percentage relative crop yield which can be expected under low frequency irrigation with water of specific salt concentrations to reflect projected future salinities, i.e. a 15% increase in EC, at three leaching fractions.

Crop	EC of Irrigation water (mS/m)														
	600+15%			800+15%			1000+15%			1200+15%			1400+15%		
	Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction		
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Asparagus	98	94	80	94	89	70	91	84	61	87	80	52	84	75	42
Beans	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beetroot	89	71	9	73	50	0	57	28	0	41	7	0	26	0	0
Broccoli	77	60	0	61	38	0	45	16	0	29	0	0	13	0	0
Cabbage	67	48	0	50	25	0	33	2	0	16	0	0	0	0	0
Carrots	40	14	0	16	0	0	0	0	0	0	0	0	0	0	0
Dates	95	89	63	89	80	46	83	71	29	77	63	12	70	54	0
Lettuce	49	24	0	26	0	0	3	0	0	0	0	0	0	0	0
Lucerne	76	62	11	63	45	0	51	27	0	38	10	0	25	0	0
Maize	57	34	0	36	6	0	15	0	0	0	0	0	0	0	0
Onion	35	4	0	7	0	0	0	0	0	0	0	0	0	0	0
Tomato	73	54	0	55	30	0	38	6	0	21	0	0	3	0	0
Zucchini	95	77	11	78	54	0	62	32	0	45	9	0	29	0	0