

## **An overview of the salinization problem in the Berg river catchment (South Africa)**

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### **Abstract**

The Berg River and the salt load in it have been researched since the 1970s and various myths or misconceptions about the origin of salt in this catchment were gradually taken care of. The Berg River is a prominent river of the Western Cape Province of South Africa and also an important water supply system of this province. Equally important is the agricultural industry of this region that is totally dependent on water from this system. Therefore salinity that plagues the usefulness of this water is of increased importance to this community. Initially, research aimed at discovering the role irrigated agriculture played in the movement of salts toward the river. During the past 8 years, the role of dryland salinity was investigated. This was done through careful mapping of the region (geology, rainfall distribution, evapotranspiration, aridity index, vegetation, land use and groundwater quality), intensive monitoring at localized experimental sites and the application of hydrological modelling. From this research, a number of findings were documented that changed our perception about salinity in this landscape. Firstly, dryland salinity was identified as the major contributor to salinization in this landscape. Secondly, the source of salts occurs at the interface of an extensive, deeply weathered recharge zone, with silcrete remnants, overlying kaolinized Malmesbury shales with very low hydraulic conductivity. Thirdly, much of the salinity in the landscape could be derived from marine aerosols and rain, concentrated through evaporation, as salinity was related to climatic conditions, soils and geology. Follow-up research is currently under way to investigate the impacts of different land uses on salt discharge and water quality, and to recommend the most suitable land uses that would reduce salinization of the Berg River for regulatory purposes.

*Keywords: Berg river catchment, dryland salinity, regolith.*



## 1 Introduction

Dryland salinity is widespread throughout semi-arid regions of the world and its occurrence in some of the major catchments of the Western Cape (South Africa) is therefore not surprising. Wheat lands in the Swartland and Overberg regions are widely known to contain "brak kolle" (saline scalds) where the wheat will not germinate. Such saline soils are already recognized as a source of some of the salts affecting the quality of water in major Cape waterways such as the Berg River, where tributaries draining Malmesbury shale-derived soils are known to contribute disproportionately to the salt load [1, 2]. What does not seem to have been addressed yet in the numerous studies of salinization of major South African rivers is the possibility that changes in land use from extensive pastoral use to intensive cropping over the last century or more may have triggered the same process of salt decantation as that which is so widespread in Australia [3]. This is particularly likely in the semi-arid wheat lands of the Western Cape, which receive most of their rain during the winter months. The key question: is the dryland salinity in catchments such as that of the Berg river more intense now than it was several decades ago and is it still intensifying? The parallels with Australian climate, soils, natural salt levels in the regolith, topography and land use practices [4] are sufficiently striking to suggest that the answer is yes. If so, the consequences for the management of water quality could be enormous, because any current assessment of the salinity load, on the basis of which impoundment and canalisation schemes may be implemented, could be incorrect for planning purposes. The water in the Berg River is already seriously salinized and this affects not only irrigated agriculture but also water supply to the industrialized Saldanha region as well as the ecology of the river system itself. Any attempt to maintain water of suitable quality as the life-blood of this region could be doomed to failure if we do not know what the prognosis is for further decantation of salts from the catchment regolith into tributaries of the Berg River. The socio-economic and environmental consequences of underestimating the future salination potential of this river system could be vast.

## 2 Background

In 1997, a four-year Water Research Commission (WRC, Pretoria, South Africa) investigation entitled *Water and soil quality information for integrated water resource management: Berg river catchment* was initiated. The study identified a number of pressing research needs concerning the origin of salts, the mechanism of salinity recharge in fallowed soils and the potential contribution of dryland agriculture to total salt load in the Berg river basin, the location of which is shown in fig. 1. Hitherto, the focus on river salinity had invariably been linked to irrigation return flow. The study concluded that the salinity database should be expanded and integrated with other information relative to water management [5].

A WRC pilot study [6] on the contribution of dryland salinity to water quality was undertaken to assess whether a more detailed investigation was needed of



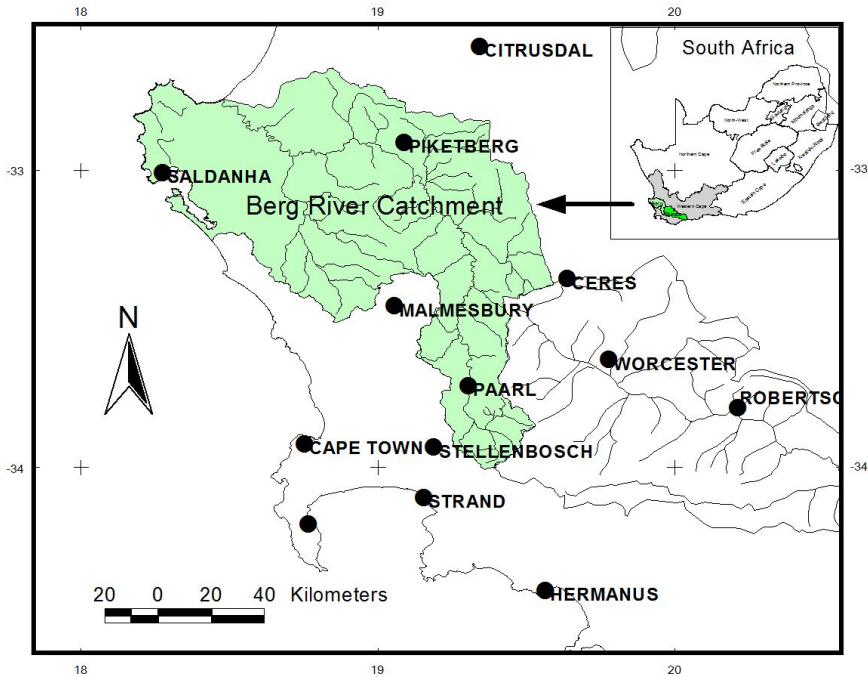


Figure 1: Location of the Berg river catchment in the Western Cape Province.

dryland agricultural impacts on river salinity similar to those being researched intensively in Australia. The Berg River basin was targeted because of its strategic importance to rural and industrial development in the Western Cape and its history of water quality research. The objectives were to obtain a preliminary estimate of the quantity of salts stored in the regolith of the Berg river catchment; calculate the current potential for decantation of these salts into the river; calculate the rate of change of salt discharge in response to changes in land use practices; and make a preliminary assessment of the applicability of the results to other major river systems in the region. The study involved field work at selected sites, remote sensing interpretation, laboratory analysis and synthesis of existing data. The evidence of dryland salinity impacts was convincing and resulted in the present study being initiated.

The central aim of this study was to develop a thorough understanding of water and salinity dynamics in the regolith (soil and vadose zone) of a small dryland catchment representative of semi-arid conditions in the Berg river basin. The perspective would include both salt sources and storage, and groundwater fluxes and catchment runoff, in order to inform future large-scale modelling and to guide the development of land use practices that would reduce the degradation of land and water resources. An additional aim was to spatially relate salt distribution to salinity generating factors (soils and soil forming processes,

geology, climate, topography, vegetation and land use) across the whole Berg river catchment.

### 3 Research approach and methodology

For the purpose of this study, the research approach included intensive monitoring of hydrosalinity fluxes in a small scale catchment (Goedertrou farm) representative of the mid-reaches of the Berg river basin, as well as an analysis of the available environmental records in the Berg river basin.

The small catchment at Goedertrou is about 20 ha in size and during the research period was either fallow or under wheat. Intensive pit excavation, core drilling and deep borehole augering were used to study the regolith, and samples of soil, saprolite and ground water were taken for physical and chemical analysis. Various soil, meteorological and hydrological monitoring devices were installed in the catchment and two pairs of Wischmeier plots were established to record solute and sediment migration in surface runoff. Other investigations included remote imaging; soil, groundwater and geological mapping; biological assessment and respirometry; infiltrometry; and hydrological modelling.

For the Berg River basin as a whole, a substantial database of historical salinity records for soil and groundwater was assembled and a GIS-based environmental interpretation was carried out. The geology of the Berg river basin (fig. 2) is dominated by the Malmesbury Group and the Table Mountain Group.

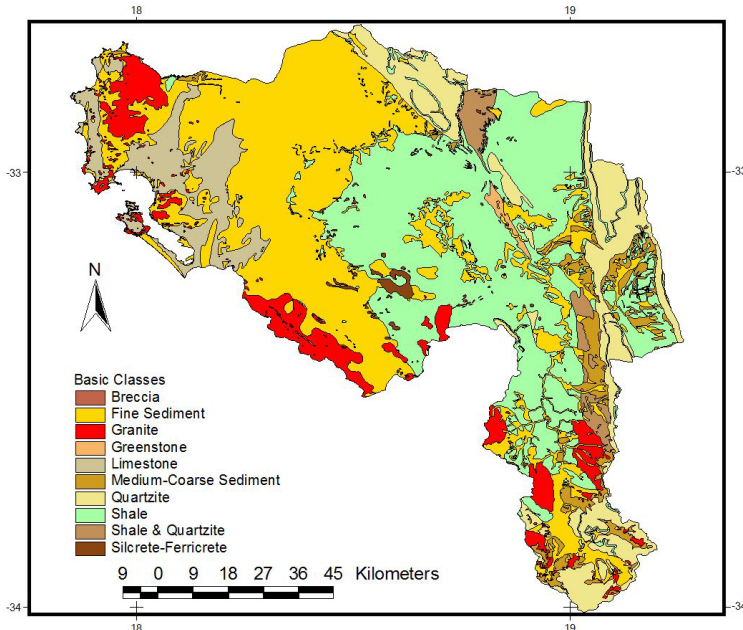


Figure 2: Geological map of the Berg river catchment.

The Table Mountain Group sandstone is common in the upper reaches (South-East in fig. 2). Sandstone formations precede the Malmesbury shales as one goes down the stratigraphy. Downstream, eastern bank tributaries drain areas that are dominated by the Table Mountain sandstone, whilst the saline Malmesbury shale is the dominant geological formation for tributaries draining the western bank.

The Berg river catchment is characterized by a Mediterranean climate with warm dry summers and cool wet winters. Mountainous areas in the southern parts of the catchment experience a mean annual precipitation (MAP) in excess of 2,600 mm a<sup>-1</sup>, whilst the MAP gradually decreases westwards to approximately 300 mm a<sup>-1</sup> along the West Coast.

## 4 Key findings

For the purpose of this study, we focus specifically on three key findings: the location (storage) of the salts, their nature (origin), and their relation to climatic conditions occurring in the Berg River basin. For the complete research study, the reader is referred to [7].

### 4.1 Location (storage) of salts

The location (storage) of salts was investigated through an intensive study in the Goedertrou small catchment. The Goedertrou catchment has a soil mantle that is generally more saline than similar (mainly Cambisol and Luvisol [8]) soils in the region, and this is possibly attributable to salt influx from an extensive recharge zone at the top of the catchment or to exposure of saline saprolite through natural erosion. Groundwater quality becomes increasingly saline towards the bottom end of the catchment.

The poorly structured, low carbon topsoil (with a clay fraction consisting mainly of kaolinite and mica), although lighter textured than the subsoil, exhibits strong crusting. Runoff during rain events is consequently intense. The more clayey subsoil represents a further barrier to recharge, and lateral migration of perched water through the surface horizon is common. First winter runoff was not markedly saline as might have been expected, since the earliest rain appears to wash in the evaporite (mainly halite) accumulated during summer, and first runoff only occurs after subsequent rain. Preferential flow through root channels and termite passages is likely to account for a high proportion of infiltrating water. Catchment water balance was not quantifiable because of complications associated with contour banks, but indications were that surface runoff, intercepted by a stock-watering pond at the base of the catchment, constitutes a very small fraction of precipitation. The hydrosalinity fluxes in the Goedertrou catchment were discussed in detail in [9].

A toposequence of soil pits revealed maximum soil salinity, including a bare, saline scald, where wheat fails to germinate, midway down a convex slope. Downslope leaching from the crest and down-valley leaching from the toe- and foot-slope soils could possibly account for this mid-slope salinity maximum. At depth, the regolith in boreholes showed a sharply peaking concentration of



soluble salts between about 5 and 15 m (fig. 3), on the edge of an extensive, deeply weathered recharge zone, with silcrete remnants overlying kaolinized Malmesbury shales with very low hydraulic conductivity. At this interface, groundwater is likely to occur. Salinity asymptotically declines below this peak to a value that might be expected after contact with underlying, slightly saline groundwater. In the Goedertrou catchment, the average salt storage in a roughly 20 m thick regolith (mainly saprolite) amounts to  $> 200 (\pm 50) \text{ Mg ha}^{-1}$ . It will be essential to investigate, however, whether the conditions in the Goedertrou small catchment occur elsewhere in the Berg River basin. The factors, related to the magnitude and shape of this deep salinity bulge in the vadose zone, need to be investigated since it may hold the key to estimating the quantity of stored salts in the drier regolith of the lower Berg River basin. Nevertheless, its study added considerably to our knowledge and understanding of salt and water dynamics in the region.

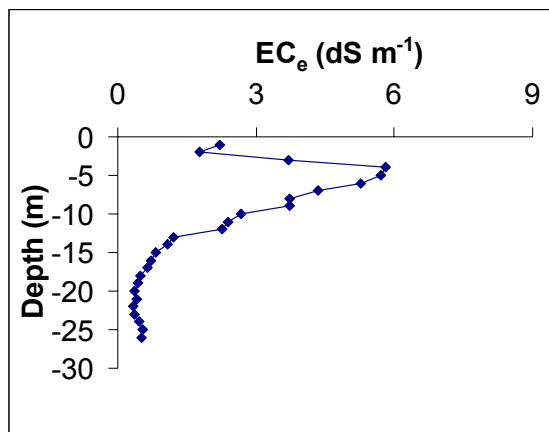


Figure 3: Regolith salinity profile (electrical conductivity of saturated paste extracts from samples collected to a depth of 25 m). The total salt storage at this site is equivalent to  $208 \text{ Mg ha}^{-1}$ .

The presence of a source of salts deep in the regolith profile causes atypical salinity profiles in the soil. An example is shown in fig. 4, where soil salinity measurements were carried out with Echo sensors (Decagon Devices Inc. Logan, Utah) at 10 and 40 cm depth on a hillslope. The results of these measurements suggested that salts are mainly mobilized during the rainy winter season (higher soil solution electrical conductivities), and that higher salinity levels occur deeper in the soil profile.

#### 4.2 Nature (origin) of salts

The nature and origin of the salt bulges identified in the Goedertrou small catchment were investigated. Table 1 reports typical chemical analyses of water

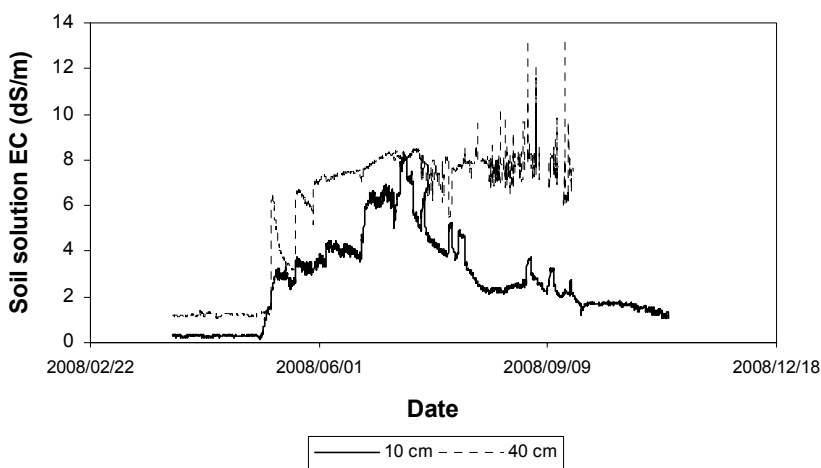


Figure 4: Soil solution electrical conductivity (EC) measured at 10 and 40 cm depth on a hillslope in the Goedertrou small catchment.

samples collected at Goedertrou (overland flow and groundwater), as well as chemical composition of aqueous extracts of powdered rock samples equilibrated at a solid:solution ratio of 1:5.

In Table 1, surface water analyses represent the average of 23 samples collected during the 2005 winter season, including overland flow intercepted at Wischmeier runoff plots, as well as runoff water collected in a stock-watering dam. Elevated Na and Cl were observed, as well as nitrogen levels due to grazing and fertilization activities on land.

Ground water quality becomes increasingly saline from the recharge area at the top of the catchment towards the bottom, predominantly due to increase in Na and Cl. In addition, increases in Ca, Mg and  $\text{SO}_4$  are also noticeable, mainly due to the mineralogy of the area, as well as in nitrogen level due to agricultural activities.

The powdered core samples of Malmesbury Group rocks represented major rock types of this group in the Western Cape. Many of the samples originated from areas in the vicinity of Goedertrou. The rock powders were equilibrated with distilled water overnight at a solid:solution ratio of 1:5. Filtered extracts were then analysed for salinity and dissolved ions and the results are presented in Table 1. The purpose of this work was to find out whether there are salts stored in these rocks that might, through release by weathering, account for salinity in soils of the Berg river basin. A cursory look at the data suggested that, except for two or three of the rock samples, the level of soluble salts is much lower than that is actually mobilized through catchment waters [10]. In the most saline of the rocks, the high salinity coincides with a quite elevated concentration of nitrate in addition to sodium chloride suggesting that this material may have been salinized by groundwater derived from recharge through the soil mantle.

Table 1: Typical chemical composition of water samples collected in the Goedertrou small scale catchment, and chemical composition of aqueous extracts of powdered rock samples equilibrated at a solid:solution ratio of 1:5.

Location	Water sample/rock type	pH	EC (dS/m)	Ca	Mg	Na	K	Cl	NO <sub>3</sub>	SO <sub>4</sub>
Goedertrou	Surface water	6.9	1.00	46.8	15.9	101.1	16.8	187.4	25.8	150.3
Goedertrou	Top of catchment	7.2	0.68	11.0	25.0	60.0	3.1	129.0	0.1	8.9
Goedertrou	Bottom of catchment	7.1	3.68	77.0	225.0	367.0	3.8	1127.5	1.2	137.5
Tulbagh	Phyllite	6.44	0.03	3.7	2.8	3.7	9.0	2.7	0.0	0.0
Voelvlei	Quartzite	5.25	0.03	3.8	0.9	2.4	7.2	5.7	0.1	0.6
Avontuur	Phyllite	6.46	0.07	4.0	3.4	5.0	15.6	3.0	1.2	5.7
Picketberg	Greywacke	5.05	1.24	6.9	10.3	193.6	37.8	389.9	8.6	38.7
Picketberg	Phyllite	7.25	0.39	7.6	5.7	45.8	23.5	116.0	1.0	12.0
Picketberg	Quartz vein	5.08	0.06	9.8	1.8	9.4	2.9	0.3	0.1	9.5
Zoutfontein	Sandstone	5.02	0.24	5.8	7.6	28.9	12.6	78.6	0.0	14.9
Zoutfontein	Quartz vein	4.52	0.09	3.7	2.6	11.4	2.0	23.6	0.0	4.8
Tontleberg	Phyllite	6.85	0.09	3.1	2.8	16.7	7.0	9.0	4.0	6.4
Ongegund quarry	Phyllite	6.44	0.04	3.3	2.2	6.0	1.6	3.6	1.0	5.2
Botmaskloof	Phyllite/sandstone	7.89	0.09	14.8	2.3	9.2	7.6	1.9	0.0	0.6
Botmaskloof	Phyllite/sandstone	7.24	0.03	2.9	2.8	6.2	9.0	2.8	0.1	0.6
Contermanskloof	Sandstone	7.22	0.06	2.3	0.5	7.0	7.4	3.7	0.4	4.4
Chavannesberg	Phyllite	7.02	0.07	2.4	1.1	2.4	15.9	3.1	0.5	0.7
Waihoek	Phyllite	6.93	0.05	1.8	0.7	1.8	15.6	2.1	0.2	0.7



The results reinforced the hypothesis that much of the salinity in the landscape of the Berg River basin could be derived from marine aerosols and rain, concentrated through evaporation and local redistribution through normal hydrological processes. This hypothesis needs, however, to be verified through more extensive sampling.

### 4.3 Relation between climate and groundwater salinity

Over the Berg river basin as a whole, collation of data from various sources into a GIS has made it possible to investigate relationships between a number of environmental variables (topography, climate, geology, land use) and the potential for salt discharge from various parts of the basin. Fig. 5 demonstrates the spatial correlation between an aridity index (precipitation minus evaporation, top map) and groundwater salinity based on borehole data (bottom map).

In previous work [6], a simple aridity index was calculated by subtracting rainfall from evaporation, with data obtained from the South African Weather Services. The resulting map is reproduced in fig. 5 (top map). The aridity index increases based on historic rainfall patterns and orographic conditions from the North-West (receiving about 300 mm rainfall  $a^{-1}$ ) towards the South-East (receiving up to 2600 mm rainfall  $a^{-1}$ ).

The groundwater salinity data were collated from existing reports and the National Groundwater Database of the South African Department of Water and Environmental Affairs. An interpolated map (fig. 5, bottom map) was generated showing that groundwater salinity increases from the South-Eastern upper, more rainy reaches of the Berg river to the North-Western mid- and lower, more arid reaches.

The comparison of an aridity index and groundwater salinity over the whole Berg River basin (fig. 5), shows a correlation exists between these two environmental variables, possibly driven by the concentrating effects of evaporation. A similar approach has proved useful [11] in relating soil chemical properties indicative of degree leaching to climatic indices. The relation between soil salinity and climatic conditions is currently being investigated.

## 5 Conclusions

It was traditionally believed that dryland salinity in the predominantly semi-arid Berg River basin originates from the weathering of sedimentary rocks that once formed under the ocean. In this research, some evidence was presented that the regolith in this semi-arid coastal region contains an abundance of stored salts of marine origin that have accumulated meteorically over a very long period. During this period, either the climate was drier than at present and/or a vegetation cover prevailed that allowed less water to be discharged from catchments than currently occurs under the prevailing land use (mainly winter wheat), because of greater water extraction and/or smaller surface runoff. In the present context, it seems increasingly likely that regolith salinity in the Berg river basin is primarily climate-driven and that the role of finer grained



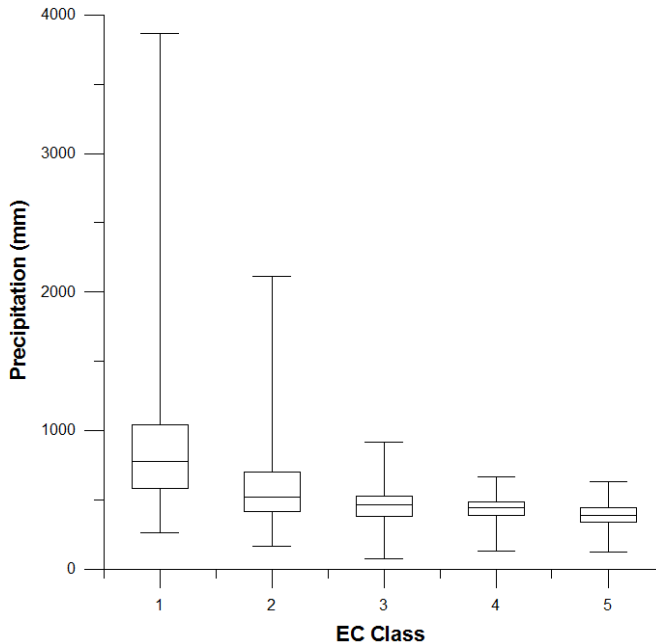


Figure 5: Comparison of aridity index (precipitation minus evaporation in mm, top map) and electrical conductivity in groundwater (bottom map).

Malmesbury shales is not mineralogical, but rather one of hydrological mediation. Further research is currently under way to confirm these findings.

The regolith typically contains in the region of 200 t of salt ha<sup>-1</sup>, stored mainly as a bulge in the unsaturated vadose zone above the water table and below the soil zone, discharging mainly through lateral leaching by groundwater from the phreatic zone. The impact of this salt discharge is lessened by the fact that most of it is released during periods of high flow so that considerable dilution occurs. The rate of salt discharge is sensitive to changes in both climate and agricultural practice, and the current rate has the potential to persist to the detriment of water users. Further research is currently under way to investigate the impacts of different land uses on salt discharge and water quality, and to recommend the most suitable land uses that would reduce salinization of the Berg River for regulatory purposes.

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