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RIVER SALINATION DUE TO DRYLAND AGRICULTURE IN THE WESTERN CAPE PROVINCE, REPUBLIC OF SOUTH AFRICA

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ABSTRACT River salination due to dryland agriculture was studied in 1985 and 1986 in the 152 km^2 catchment of the Sandspruit River, a tributary to the Berg River in the semi-arid Western Cape Province of South Africa. The study included investigations of all major water bodies within the catchment and aimed to identify and quantify their salinity dynamics. The mean annual rainfall is about 400 mm, and has a mean ocean-derived salt input of 37 mg l^{-1} TDS. Groundwater recharge of the shale aquifer occurred only during the winter season when salts from the soil and the weathered shale were transported into the groundwater. Salt transport occurred predominantly during floods from July to September. Measured water levels were used in a regression model to estimate salt output from the catchment. The total salt output in 1986 was 8052 t, but atmospheric deposition accounted for only a third of the total. The remaining source of the salt was contributed by groundwater and interflow from the weathered shale and the soil within the catchment.

INTRODUCTION

River salination due to dryland agriculture is a worldwide known process responding to land clearing with a time delay of at least ten years and was first reported from Australia by Wood (1924). Heavy losses of productive farm land induced intensive research about the phenomenon of "dryland salinity" in Australia (Downes, 1954; Peck, 1978) and North America (Miller *et. al.*, 1981; Sommerfeldt & McKay, 1982). A figure of 0.4260 x 10^6 ha of salinized farm land is given for Australia by Williams (1987), and Miller et. al. (1981) estimated 0.8 x 10^6 ha taken out of production in North America. Dryland salinity was also reported from Argentina (Lavado & Taboada, 1987), India (Choudhari & Sharma, 1984), and South Africa (Flügel, 1987). The dynamics of dryland salinity initiated by clearing the deep rooting natural vegetation and rising groundwater table are fairly well understood (Jenkin, 1981; Talsma, 1981; Schofield, 1989) and reclamation strategies are already established (van Schilfgaarde, 1981; Schofield, 1989). However, there are considerable differences regarding the sources of salts leaching into the rivers. In Australia, they mainly were transported from the ocean through the atmosphere and were deposited as wet and dry deposition (Downes, 1954; Peck, 1978). In North America, weathering and leaching from shale and glacial deposits are considered the major salt sources (Miller et. al., 1981). There is still a lack of detailed studies investigating the interactive hydro-saline dynamics of a catchment which would be relevant to the phenomenon of dryland salinity in South Africa. The results presented in this paper are for the Sandspruit River catchment and they contribute to filling this research gap.

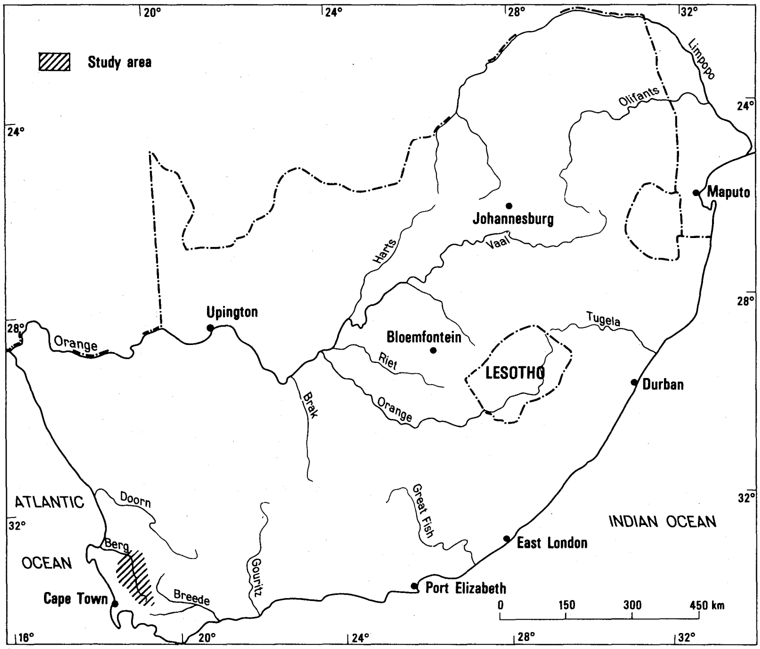

FIG. 1 Study area in the Berg river catchment, Western Cape Province.

OBJECTIVES

The Berg River is one of the major river systems in the Western Cape Province (Fig. 1). It originates in the Franschoek valley northeast of Cape Town and flows north towards the Atlantic Ocean. Agriculture in the upper part of the catchment is characterized by irrigation of vines and orchards, and in the middle part by dryland wheat cropping with summer fallowing. The salinity of the Berg River increases as it passes through the wheat region. A research project in the Sandspruit River, a representative tributary to the Berg River began in 1984 with the following objectives:

(a) Determine the distribution of soils and their characteristics.
(b) Quantify the salinity of precipitation, soil water, and groundwater.
(c) Identify the relief dependent salt distribution in the catchment.
(d) Balance the water and salt output to the Berg river.
(e) Characterize the seasonal hydro-saline dynamics of the catchment.

SANDSPRUIT RIVER CATCHMENT

Regarding its climate, geology, soils, and relief the catchment of the Sandspruit River can be considered as representative for the middle part of the Berg River catchment between Paarl and Moorreesburg. The climate is semi-arid and the mean annual rainfall which only occurs in winter is about 400 mm. Consequently, the Sandspruit River flows only periodically from May to October. The underlying geology is Precambrian Malmesbury Shale which is deeply weathered. The area was flooded by the sea during the late Tertiary when the sea level was about 120 m higher than today (Haughton, 1933).

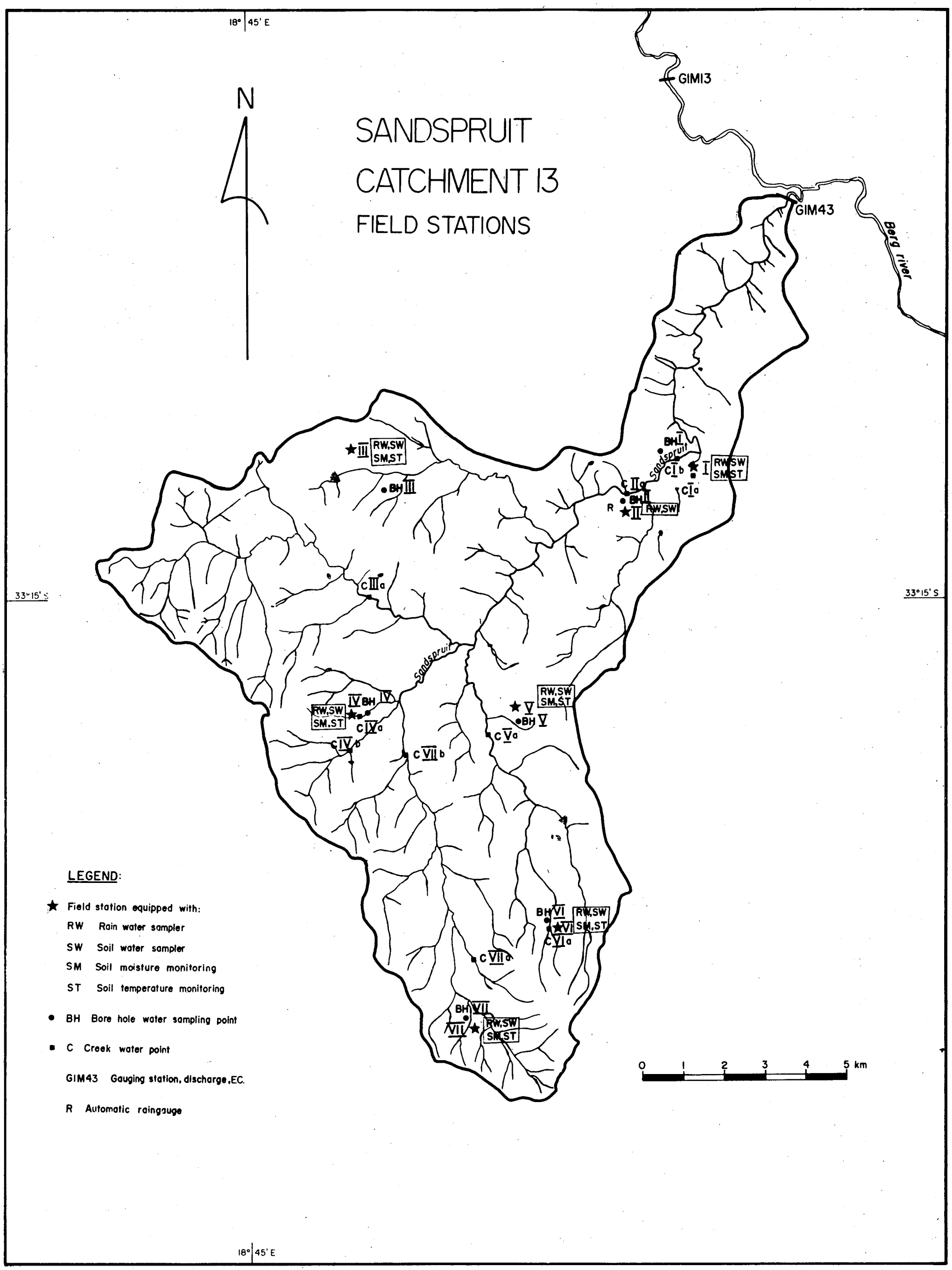

FIG. 2 Distribution of field stations in the Sandspruit River catchment.

The shape of the catchment is similar to a hand axe having an area of 152 km^2. It has a gentle hilly relief with 0-4° inclination occurring in 61% of the catchment and 4-7° occurring in 27%.

The valleys have a shallow groundwater table during the winter rain season. Only halophytic vegetation grows in the valley bottoms and it is used to feed sheep. Saline seeps occur in depressions spread all over the catchment and these seeps have no vegetation cover but are characterized by crystallized salt patches during the hot summer from November to March. The groundwater in these seeps is shallow and very saline.

METHODS

Seven field stations were installed (Fig. 2), at which rainfall, soil water, and groundwater were sampled every three days. Just above the confluence of the Sandspruit and Berg Rivers, a weir was installed and instrumented with an electrical conductivity (EC) meter. The meter was connected to a datalogger which calculated and recorded hourly average EC, in $\mu S\ cm^{-1}$, from 1-min readings. Water samples were analyzed in the chemical lab of the Hydrological Research Institute in Pretoria.

In order to identify the time and relief dependent salt distribution in representative relief sections cross profiles were drilled by hammer augering and soil salts were leached out of the samples.

TABLE 1 Chemical and physical soil parameters of the field stations.

		Chemical parameter			Physical Parameter		
Stat. no.	Location	CEC (meq $100g^{-1}$)	ESP (%)	salts (g kg^{-1})	PV (Vol.%)	FC (Vol.%)	k (cm day^{-1})
1	valley	15.1	27.2	9.8	38.3	20.3	118
2	slope	40.9	3.6	1.8	37.4	14.0	108
3	slope	56.1	18.8	5.3	37.8	n.d.	3
4	valley	30.4	13.7	n.d.	40.5	25.4	3
5	slope	9.9	18.4	1.2	33.3	12.3	402
6	slope	14.7	12.4	0.7	33.4	12.0	55
7	slope	19.3	8.6	1.3	37.1	11.4	105

SOILS

Five dominant soil types were identified: solonetz soils in the valley bottoms and saline seeps; solonetzic Latosols, Luvisols, and regosols at the slopes; and ranker on top of the hills. A summary of the chemical and physical properties of the soils is as follows (Table 1):

(a) Cation exchange capacity CEC vary but, in general, is highest in the clayey soils of station 2, 3 and 4.

(b) Except for station 2 and 7, the exchangeable sodium percentages (ESP) are consistent with the solonetzic characteristics.

(c) All stations show a fairly high soluble salt content.
(d) Total pore volume (PV) and field capacity (FC) are low.
(e) Saturated permeability k is related to the sand and clay content.

The precipitation depth which can be stored in the soil is given by the field capacity FC. Using the soils of the slope stations 2, 5, 6 and 7, the estimated mean precipitation depth was 350 mm for which the soils had an average FC of 12.5%. The total precipitation storage for these regions (88%) is about 44 mm which is only a fraction of the winter rainfall. The excess rain saturates the soil and generates surface runoff, erosion, and interflow which were observed frequently during rainfall events in 1986.

SOIL WATER, GROUNDWATER, AND PRECIPITATION

During the winter and spring when the soil contained sufficient water, soil water was collected from 15, 30, and 45 cm depths using ceramic vacuum samplers. Salt concentrations increased with depth. Groundwater was sampled from boreholes drilled for stock watering. Water from these wells was supplied to the livestock using wind mills which prevented continuous monitoring of groundwater levels. However, groundwater levels were measured periodically during the winter season and these measurements indicate that considerable recharge occurs to the fractured shale aquifer. A summary of the salt content of soil water and groundwater is as follows (Table 2):

(a) The TDS of soil water and groundwater were highly variable which is consistent with evaporation and the variable infiltration of less concentrated precipitation.
(b) Stations at the valley bottom had a higher salt content in the soil water and groundwater than those on the slopes. The maximum salt concentration of the soil water was observed in a saline seep at station 1.
(c) Soils with higher clay content like the Latosol in station 4 also had higher salt concentrations in the soil water than the sandy Regosols at stations 6 and 7.
(d) Except for station 6, stations with higher salt concentrations in the soil water also were underlain by more saline groundwater suggesting that groundwater recharge occurs during winter.

TABLE 2 Total dissolved salts (TDS, mg l^{-1}) of soil water and groundwater at stations 1 through 7.

	Soil water TDS				Groundwater TDS			
Station	Mean	Min.	Max.	No. of Samples	Mean	Min.	Max.	No. of Samples
1	17 038	1768	30 565	73	2639	414	3277	22
2	257	108	556	27	547	496	649	22
3	274	129	9703	47	4718	4379	5094	23
4	1324	210	5005	43	3775	968	4293	21
5	260	85	950	25	1337	829	1526	29
6	111	27	227	26	3295	3041	3504	17
7	458	58	1500	31	1495	1249	1656	11

Sixty seven samples of bulk atmospheric deposition were collected in plastic samplers. The salt concentrations in precipitation ranged from 14 to 125 mg l^{-1} and averaged 37 mg l^{-1}. The average concentration was used to compute atmospheric contribution to the salt balance. The dominant solutes in precipitation were sodium and chloride.

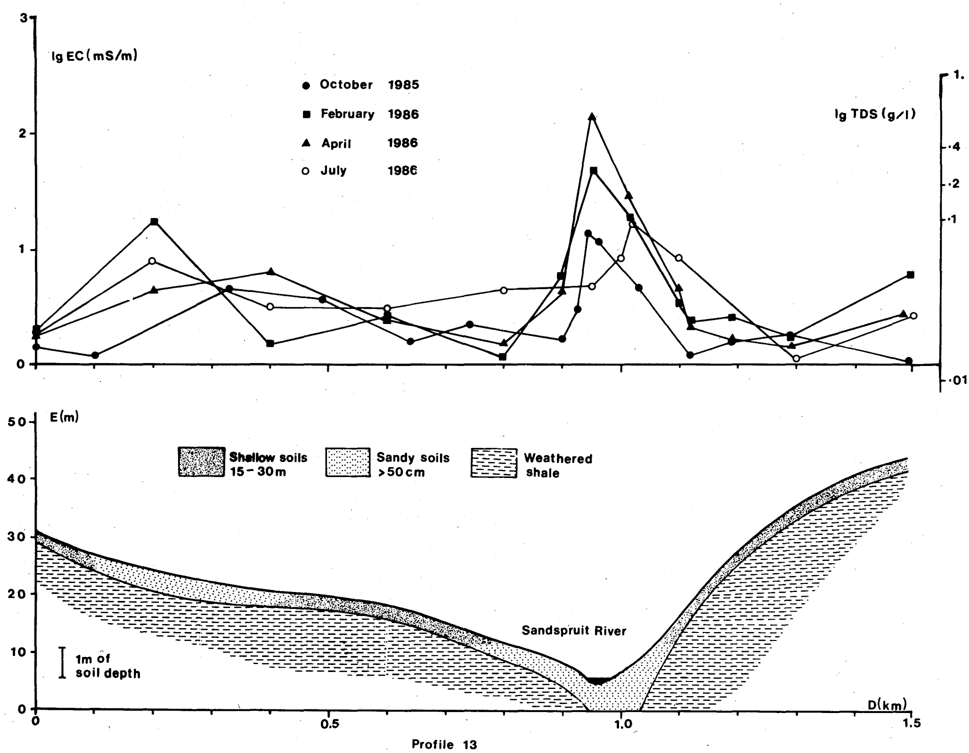

FIG. 3 Cross section salinity profile of the Sandspruit catchment.

RELIEF DEPENDENT SALT DISTRIBUTION

The results of the soil and groundwater investigations reflect the variability of the salinity within the catchment. They also indicate that the salt distribution is associated with the slope position. Therefore, the salt dynamics of representative profiles were investigated by hammer augering from October 1985 to July 1986. Salts were leached out from samples covering the complete profile. The results are shown for cross section 13 in Fig. 3, and can be summarized as follows:

(a) Soil salinity on both slopes of the cross section was similar and varies from 2000 to 10000 µS cm^{-1} corresponding to a salt content of about 12 000 mg l^{-1} of soil. Sandy patches obviously act as salt traps.

(b) A considerably salinity increase was found in the sandy alluvial deposits in the valley bottom of the Sandspruit River. Maximum values were measured nearby the river bed.

(c) A monthly trend of salinity is not evident for the slopes but can be seen very clearly for the alluvial deposits in the valley bottom. Here soil salinity increased continuously from October 1985 to April 1986 to about 45 000 mg l^{-1} of soil as capillary rise of saline groundwater during the hot summer months transported salts from the saturated zone into the unsaturated soil.

(d) The winter rainfall leached out salts to the river and the groundwater and consequently soil salinity dropped down to a similar level as it was measured at the beginning in October 1985. The results from this drilling program clearly demonstrate the active seasonal dynamics of upwards and downwards salt transport and leaching which is obvious in the alluvial soils but also takes place in the soils of the slopes.

SANDSPRUIT RIVER

Total dissolved salts (TDS) were computed from the hourly recorded EC of the Sandspruit River at the gage upstream of the confluence with the Berg River and a relation between EC and TDS. Total salt loads were computed from the TDS estimate and continuous discharge.

The Sandspruit flows only periodically from May to October and salt transport mainly occurs from July to September. The interactive hydrological and salinity dynamics of the river can be described by using data from August 1986 as an example (Fig. 4):

(a) Two separate rainfall events occurred during the first half of August for which each generated a flood. Each flood was characterized by a steep linear discharge increase from about 20 to 7000 l s^{-1} followed by a more gentle exponential decrease. The floods were generated by surface runoff and interflow from the slopes because the shallow soils were saturated quickly during the rain.

(b) Corresponding to the rapid increase in flow, the EC of the discharging water decreased from 10 000 to 2000 µS cm^{-1} as surface runoff from the slopes diluted the saline base flow between the rainfall events.

(c) After surface runoff from the slopes had ceased, the relative contribution of interflow and groundwater increased causing the EC of the discharging water to increase approaching the 10 000 µS cm^{-1} pre-event base-flow concentration in about 14 days after the second flood.

(d) Although the EC dropped considerably during the floods, the salt load was controlled primarily by the discharge and peaked during the second flood at about 25 kg s^{-1}.

The salt load (kg s^{-1}) and stage level (m) of 3600 hourly cases were analyzed and a regression model was derived to calculate salt load (SL) from stage level (STL) by:

$$SL = e^{2.2263 * \ln STL + 3.7206} \quad (1)$$

The model has a coefficient of determination of 0.97 and was used to calculate the salt input from the Sandspruit into the Berg River.

WATER AND SALT BALANCE

The water and salt balance was computed for the 1986 water year from October 1985 through September 1986. Rainfall in this period was 325 mm which is 19% below the long-

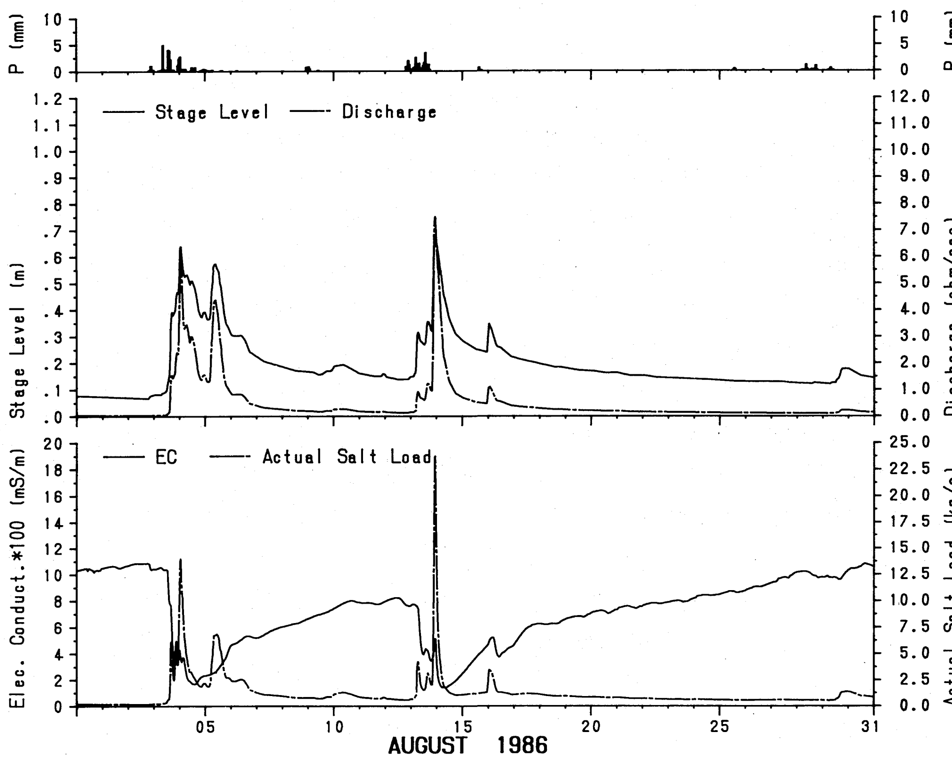

FIG. 4 Discharge, EC and salt load of the Sandspruit River in August 1986.

TABLE 3 Water and salt balance of the Sandspruit catchment between October 1985 and October 1986.

Parameter	Oct. 85 to May 86	1986 June	July	August	September	October	Total
Rainfall (mm)	93.0	62.6	65.8	70.8	29.3	3.2	324.7
Salt input (t)	523	353	371	399	165	18	1829
Discharge(mm)	0.02	0.05	1.99	8.23	0.99	0.02	11.30
River TDS ($g\ l^{-1}$)	5.5	5.3	4.5	4.5	6.6	9.0	—
Salt Output (t)	11	39	1371	5627	988	16	8052
Salt balance (t)	512	314	-1000	-5228	-823	2	-6223

term annual mean but within the annual variability. Therefore, this period can be considered as representative for a hydrological year in this region. The results of the salt balance are listed in Table 3 and summarized below.

(a) Atmospheric input from rainfall concentrated in the three months from June to August 1986, but it never exceeded 400 t month^{-1}.

(b) Flow started in May and peaked in August. Runoff never exceeded 12% of the monthly rainfall input and only 11 mm or 3.5% of the total rainfall discharged from the catchment. The remainder of 314 mm evaporated or recharged groundwater.

(c) The major salt transport from the catchment occurred during floods in July and August.

(d The total salt output was 8052 t of which the atmospheric input accounts for only 1829 t or 23% of the total salt transport.

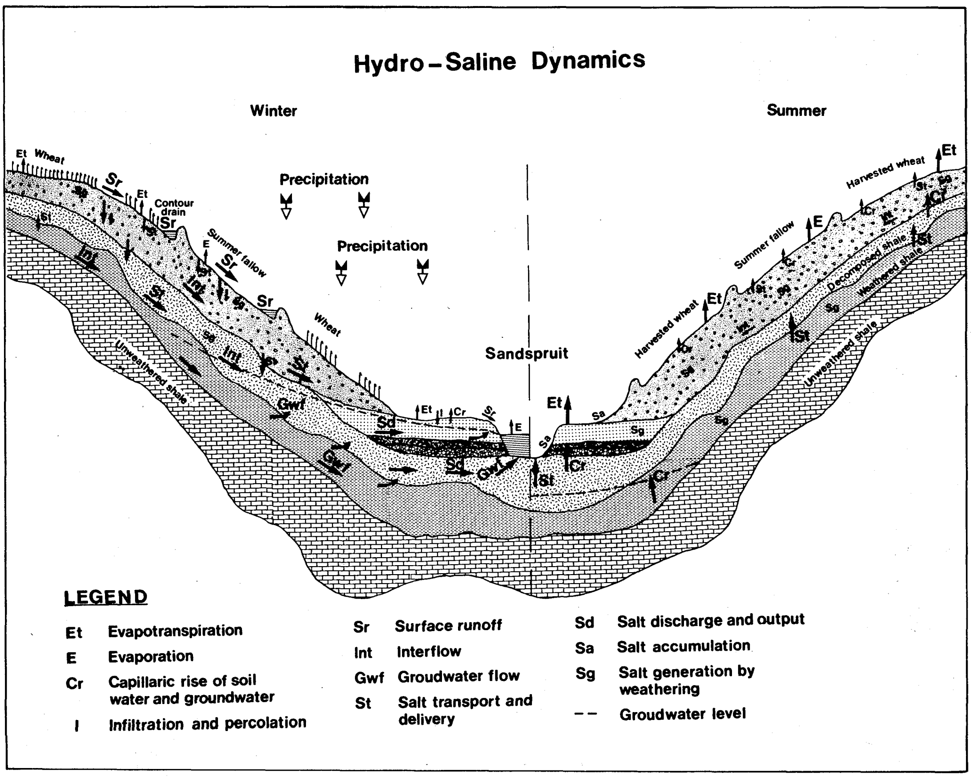

FIG. 5 Seasonal hydro-saline dynamics of the Sandspruit catchment.

CONCLUSIONS AND HYDRO-SALINE DYNAMICS

The seasonal hydro-saline dynamics within the Sandspruit catchment in Fig. 5 is based on the results and field observations discussed earlier. The conclusions about the hydro-saline catchment dynamics are:

(1) Due to the seasonal rainfall distribution there is a distinct difference between summer and winter. The first rains of May and June fill up the shallow soils on the slopes. Rain events in July and August then saturate the soils and create surface runoff and interflow which generate the rapid increases in discharge on the rising limbs. Infiltrating rainfall at the slopes also recharges the fractured shale aquifer and the groundwater table rises in the valley bottom. The groundwater provides flow after rainfall has ceased.
(2) Salts from these recharge areas on the slopes are leached out of the soils and the weathered shale into the underlying groundwater. They are transported to the valley bottom where seep into the river.
(3) In the summer season, the salt in the soil and groundwater is concentrated by evapotranspiration. In the valley bottom, salts are transported by capillary rise from the saline groundwater upwards, and are concentrated in the soil water or crystallize on the soil surface. The groundwater level beneath the river bed decreases and flow in the river eventually ceases as occurred in October 1986.
(4) The soil distribution within the catchment is a result of the hydro-saline dynamics. Because the salts are leached during winter, soil on the slopes is less saline and consequently is only moderate to medium solonetzic. In the valley bottom, where salt is transported both upwards due to capillary rise and downwards due to infiltration, salts are concentrated and characteristic solonetz soils develop there.

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