ON THE ORIGIN AND ACCUMULATION
OF SALTS
IN GROUNDWATER AND IN SOILS
OF ISRAEL

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DEPARTMENT OF GEOLOGY

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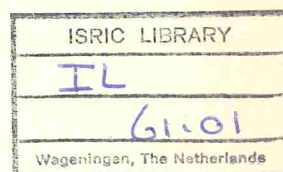Department of Geology, The Hebrew University of Jerusalem

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ABSTRACT

The problem of the source of soluble salts in groundwater and in soils of Israel is examined and analysed.

Both igneous and sedimentary rocks are generally poor in Cl and S, so that the salts released by weathering cannot alone explain the process of salinization. Fossil salt accumulations are a major factor only in certain regions. Oceanogenic airborne salts, being continuously blown inland and precipitated by rain, are the main source of soluble salts in coastal areas. In Israel the concentration of chloride in the precipitation is highest in a narrow coastal belt and decreases inland to about 10 ppm Cl, resulting in an average annual addition of about 8 kg NaCl per dunam. In the arid region the dry salt deposition probably amounts to less than 0.2 kg NaCl per dunam annually. For the country as a whole the annual accession of airborne salts is estimated to be about 100,000 tons NaCl.

Before reaching the underground aquifer, the airborne salts dissolved in the rainwater are concentrated in the soil by evaporation. On passing through the soil the composition of the salts changes due to ion exchange processes, and through increment from weathering and from dissolution of fossil salt accumulations o from connate waters of former sea inundations. The relativ contribution of airborne salts can be estimated from the knowledge of groundwater recharge and the salinity of precipitation.

Geomorphic conditions favourable to salt accumulation in soils occur generally in areas of basin shaped topography, particularly when imported saline groundwater reaches close to the surface and if evapotranspiration exceeds precipitation, as in the marshy plains of the Coastal Plain and the Arava Valley. Weathering contributes only small amounts of soluble salts, with local exceptions as in parts of the Jordan Rift Valley where the soils are formed from gypseous lake deposits. All saline soils in Israel are of the solonchak type. The position of the horizon of maximum salt accumulation is a function of the height of the water table and of the seasonal balance between precipitation and evaporation.

It is suggested that the desert dust which originally formed the loess deposits in the Beersheba basin was non-saline, but that a simultaneous deposition of airborne salts accompanied its accumulation. Similarly the salinity of the desert gravel pavement soils is postulated to be mainly derived from airborne salts, which have accumulated over a longtime arid period. In both cases the accumulated salts represent the balance between the amount of imported atmospheric salts and losses due to leaching.

The accession of soluble salts in rain has also affected the Hamra sandy soil of the Coastal Plain, though soluble salts have here not accumulated because of adequate leaching. The effect manifests itself in an increase in the adsorbed Na percentage and a decrease in the exchangeable Ca/Mg ratio.

The accession of airborne salts as a significant factor in soil formation has not been generally recognized in the past, but its evaluation is necessary for the proper understanding of soil development in coastal regions, for areas with depositional surfaces and for arid regions in general.

INTRODUCTION

Salinity is one of the major problems of arid and semi-arid regions and concerns many aspects of their development. The subject of the origin and circulation of the soluble salts in soils and waters has not received sufficient attention in the past, as efforts were first concentrated on the determination of the general distribution of salt accumulation. However, an understanding of the natural processes leading to salinization is necessarily of importance for the evaluation of the salt balance of any region.

In the present paper we shall endeavour to analyse the process of salinization in Israel and the distribution of the soluble salts among soils and groundwater in relation to the environmental factors, and with particular reference to the effect and contribution of atmospheric salts. The suggestion that the composition of groundwater is closely related to the natural conditions of the land was made in Palestine already by Menchikovsky (1929), who also made a few measurements of airborne salt precipitation (Menchikovsky 1925). The problem of the origin and circulation of soluble salts has recently attained a new urgency as the result of the increased exploitation of our waters, and has received impetus from the work of Löwengart (1958 and present volume) and through kindred work abroad (Eriksson 1952 and 1958).

The present exposition is an integrated analysis of available data, supplemented by own observations. In addition to the effect of atmospheric salts, it pays attention to the contribution of salts released by weathering, and especially to the process of salinization of soils in the arid regions of Israel. Published data are not necessarily the best suitable for such an analysis, but they provide sufficient material for some generalized conclusions of interest. Additional data, which are constantly being accumulated, will in the future enable a refinement of the present interpretation.

ACKNOWLEDGEMENTS

Scope of the Study

The relative contribution of the primary sources of salinity from weathering and from airborne sea spray is assessed on the basis of known mean data, corroborated in several ways, and by some new analyses. The factors controlling salt accumulation in groundwater and in soils is evaluated first in general, without undertaking, in this study, a separate detailed analysis of the groundwater sources for each hydrologic region. Finally the processes of soluble salt accumulation in the soils of Israel is examined. The process of soil salinization as a result of past or present irrigation is beyond the scope of the present study.

The analysis is largely restricted to the assessment of the chloride and partly of the sulphate circulation, because most data are available with respect to these ions. Due to the high solubility and mobility of all chloride salts, Cl is a most convenient representative and indicator of the accumulation process. Often we shall for the sake of brevity speak of soluble salts, even though the evidence relates to Cl only. Since NaCl, followed by $CaSO_4$, is the most important and common salt in saline soils of Israel the approximation is largely justified. In groundwater Cl is usually accompanied by a close to or higher than equivalent amount of Na, but the proportion of other ions is very variable. It is of course recognized that Cl is neither the only nor necessarily the best indicator of the damage being caused by salts to soils or to plant-soil-water relationships. It is hoped to extend

the analysis in the future to a similar examination of the cor-
responding cationic circulation.

PRIMARY SOURCES OF SALINITY

Disregarding the insignificant meteoritic (outer space)
supply, for which there are no reliable measurements or estimates,
and nucleotides formed in the atmosphere as a result of cosmic
indication, then the primary source of soluble salts now present
in soils or groundwater can only be the elements found either in
the rocks or in the sea. We shall examine the relative importance
of both these primary sources.

The Abundance of Cl and S in Nature

The main mass of chlorine is todayfound in the oceans.
The average content of Cl in igneous rocks is very low (Table 1)
and there is general agreement that the main part of the Cl which
has accumulated through the ages in the sea is of volcanic origin.
Volcanic production of Cl and also of S is even today a fairly
significant factor in the geochemical cycle of these elements.

The main mass of sulphur in nature is also of volcanic
origin, but while about half of the sulphur has been absorbed by
sediments, very little of chlorine is being absorbed or retained
by sedimentary rocks. This is reflected in the average abundance
of these elements in nature, which shows that sedimentary rocks

are usually somewhat richer in S than the average igneous rocks, whereas the amount of Cl in sedimentary rocks is usually slight and on the average less than that of igneous rocks (Table 1).

Among the various groups of sedimentary rocks sandstones are expectedly poorest in Cl content. Carbonate rocks seem to be richer than shales both in Cl and S. While it is difficult to obtain meaningful average figures for soils, the data in Table 1 (quoted from Vinogradov, 1954) reflect well the normally leached nature of soils, having an average content of Cl and S lower than that in shales.

Data of Cl and S content in carbonate rocks, which are of special interest for Israel, are surprisingly scarce, possibly because in many cases their amount is below the limits of detection and has thus not been recorded. Some new and unpublished data, together with data from abroad have been assembled in Table 2.

Except for the Middle Eocene limestones all the data for Cl fall close to the average of Table 1. There is, however, a significant difference between carbonate rocks of different age and origin. Where rocks from same formations and age have been analysed it appears that dolomite is richer in Cl than limestone. Data for sulphate are more varied. The data seem to indicate that the S content in Israel limestones is significantly lower than the world averages calculated by Green (1959) on the basis of sediments of the Russian platform, but that they are comparable to Russian samples of similar age.

The mode of occurrence of the Cl and S in carbonate rocks is of some interest, since post-depositional contamination from saline solutions might be suspected. Behne (1953) found that in marine limestones about 40% of the Cl present was leachable with water, the remainder presumably being bound to the crystal lattice of calcite or to the accessory minerals (apatite, micas). Dolomites contained more Cl, but only 20% of it was water-leachable. Graf (1952) found that a large part of the leachable salts in dolomite must be present as alkaline earth chlorides, which might indicate that the salts have been trapped during diagenesis. Lamar and Shrode (1953) found the soluble salts in limestones occurring as intra-crystal liquid inclusions and to be mostly NaCl and $CaSO_4$ in limestones, and NaCl and Mg-salts in dolomites. The data of Goldberg (1958) do not show any difference in Cl and S content of limestones and accompanying recrystallized nari (caliche) and would also seem to indicate that in marine limestones the salts are largely trapped in intra-crystal liquid inclusions and would not be accessible to percolating waters. S is bound in limestones mainly to pyrite, FeS_2, and in shales it occurs principally in the oxidized form as sulphate, in gypsum.

Shales and clays play a rather subordinate role in the sedimentary sections in Israel and are rarely exposed in the northern or central parts of Israel. The marine and lacustrine clays of Jurassic, Lower Cretaceous and Neogene age in the Negev are known to be both saline and gypseous and similar facies are

not exposed in northern Israel. The average of 55 chemical analyses assembled by Landsberg (1955) gives 0.42% Cl and 0.07% S. Since the obviously gypseous samples were <u>a priori</u> excluded, the average S content is close to that quoted in Table 1, whereas the Cl content (mainly present as NaCl) is many times greater than that of average shales.

Contribution from Weathering

Rates of rock weathering vary considerably from area to area. The average rate of denudation for given regions can be calculated from the transport and total discharge of solids per catchment area. Corbel (1959) has recently assembled a large body of such data for various climatic regions from which we take the figure of 12 mm per 1000 years for flatlands in Mediterranean climates, and considerably higher rates in steeply sloping mountain areas. The writer (Yaalon, 1959b) has arrived by two different approaches at the figure of 10 mm per 1000 years as the rate of weathering of limestone in Israel, which is in agreement with Corbel's figures for 6 to 10 mm per millenium for limestone weathering in Southern France and North Africa, whereas the rate rises to 60 mm per 1000 years in the humid karst landscape of Yugoslavia.

If we assume 10 and 50 mm per millenium as representing the average and maximal rates of weathering in Israel (which is equal respectively to 25 and 125 kg of weathered rock per dunam

annually), and the figures for the average Cl and S content as quoted above, the amount of salts released by weathering can be calculated (Table 3). For 0.04% Cl it ranges from 16 to 80 gr NaCl per dunam annually, for average and maximal rates respectively, while at average sulphur content the maximum values may be about 10x higher. Under any circumstance the amount of Cl and S salts released by weathering is so extremely small that it alone cannot give rise to salinization of soils or explain the accumulation of salts in groundwater.

Airborne Spray as a Source of Soluble Salts

It has long been known that precipitation contains small amounts of dissolved salts, and geochemists have inferred from data of rock composition that oceanogenic airborne salts are practically the only source of chloride in the precipitation and in turn usually the main source of chloride salts in river waters (Conway, 1942, Anderson, 1945). The amount and composition of salts in the precipitation has been measured in numerous places all over the world, and the data have been tabulated and appraised by Eriksson (1952). Presently regular measurements of salts in the precipitation are being carried out in several countries. A similar net of measurements in Israel has been organized by the writer to start operating with the rainy season in 1960/61.

The accretion of airborne salts is largest close to the coast and decreases rapidly, generally exponentially, going inland. Eriksson (1958) estimates the characteristic inland accre-

tion of Cl to be 10 kg / ha (1 kg Cl per dunam) for rainfall of the order of hundreds of mm per year, and the variations show the influence of inflow of maritime air masses. The average value for annual S accretion is also about 10 kg / ha but shows a much smaller range of variation, no doubt because it is present in the atmosphere largely as gaseous SO_2 and thus more easily distributed and spread by winds, whereas Cl is carried principally in small aerosol droplets or dry NaCl crystals.

So far the only published determinations of salts in the precipitation in Israel were made over 35 years ago by Menchikov-sky (1925) who obtained for several stations at a distance great-er than 6 km from the sea shore an average concentration of about 10 ppm Cl, which for an annual precipitation of 500 mm becomes 5 kg Cl or 8 kg NaCl per dunam annually. Near the shore in Tel Aviv the concentration was $3^{1/2}$ times higher (Figure 1).

Some direct effects of airborne salts can be observed on the damage caused to coastal vegetation, which is particularly noticeable on the wind-shorn flag-shaped eucalyptus trees planted along the Herzlia-Tel Aviv highroad (1-2 km from the coast). As Karschon (1958) has shown this deformation is due to the injury inflicted by absorption of air-borne salts by the leaves, which results in their scorching and fall, and is not merely due to the physical action of the wind. The higher corrosion rate of buildings and materials near the coast is also due to airborne salts.

The sea salts are carried in the air in the form of aerosols consisting of minute droplets or dry salt nuclei. Their distribution over the continents is governed by the general circulation of the atmosphere, especially by the maritime air masses. The average residence time of sea salt particles in the atmosphere is only a few days (Junge, 1952). The annual precipitation is thus not necessarily proportional to the quantity of salts precipitated by rain, as long as rainfall exceeds a certain frequency and intensity. The amount of airborne salts brought down in arid regions is likely to be small and largely restricted to the deposition of dry salts. The composition of the deposited salts usually varies somewhat from that of sea water because a certain fractionation takes place by nucleation and reaction with the air, so that the ionic proportions, especially of SO_4/Cl, become altered. The Na/Cl ratio remains more constant. Supplemental salts of industrial, volcanic or biogenic origin are important in certain regions but very likely insignificant in Israel, except possibly around Haifa (cf. Loewengart 1958).

According to Eriksson (1958) this region lies within the latitudes of near maximal oceanic production of sea salt particles (40 kg salt per ha annually). Most of the blown in salts are likely to fall in the coastal plain and foothill region because of the mountain barrier effect, thus supporting the relatively high values obtained by Menchikovsky. The arid regions are shielded from the maritime air masses and the amount of precipitated salt will be mainly by deposition of dry salts and may be as low as 1 - 2 kg Cl / ha (1.5 - 3 kg NaCl) annually. Since

other evidence (cf. Fig. 1) also supports the concentration of 10 ppm Cl or about 8 kg NaCl per dunam annually for the subhumid parts of the country (considerably more close to the coast and somewhat less far inland), this value will be used in the subsequent calculations together with the above low value for the arid parts.

For the country as a whole the annual airborne accession comes to about 100,000 tons NaCl.[x] This may be compared to the estimated maximal release by weathering of about 500 tons NaCl per year, and to the annual industrial production of NaCl in Israel which amounts to ca 20,000 tons. It can thus be seen that from all the quantities of salts which now enter annually the geochemical cycle in Israel waters and soils the contribution of atmospheric salts is by far the most important one.

The Composition of Storm Runoff Waters

Indirect evidence of oceanogenic salts in the precipitation can be obtained from the composition of storm runoff waters, if we assume that these rapidly flowing waters would be unable to exsolve large amounts of salt from the surface soil.

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[x] This is equivalent to the amount of NaCl contained in about 3 mill. m^3 of sea water.

The writer has assembled all published analyses for the
concentration of Cl in storm runoff waters of Israel and calculated
the average concentration at each point of measurement (Table 4).
The data are plotted on Figure 1, as a function of distance from
the sea at the point of measurements.[*] The average value for the
wadis flowing westward is 17 ± 4 ppm Cl, which obviously is higher
than the original concentration in rain water, but is comparable
to the 10 ppm value of Menchikovsky in the precipitation. There
necessarily is some dissolution of salts which have accumulated
on the surface and some concentration by evaporation, but it seems
that these effects are not very pronounced.

Minimum values of storm runoff concentrations represent
rather well the concentration of salts in the precipitation. Thus
the minimum values in the storm waters of Nahal Hadera and Nahal
Alexander, which during normal dry weather flow are rather saline
(over 100 ppm Cl), were found to be 6 and 8 ppm Cl respectively.[**]
The values for Nahal Soreq show an increase on its passage from
Motza to Gedera, and probably reflect not only the effect of
larger salt supply nearer to the shore, but also the increased
dissolution and leaching on its way towards the sea. The highest
values for storm runoff waters are found in a number of wadis

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[*] Obviously for the westward flowing wadis this represents the
minimum distance of the waters from the shore rather than
the true distance.

[**] If such minimum values are to indicate the average salinity
of precipitation, it is imperative that they be judiciously
scrutinized, since it is known that during persistent rains
the Cl concentration in the precipitation decreases with time.

draining the Cenomanian limestones of the Western Galilee. However, these wadis are partly fed by perennial springs and the data are therefore not strictly comparable with the data from rapid surface runoff from other wadis.

Similar conditions are found in the wadis of the Eastern Galilee draining eastward. The average storm runoff concentration of four Jordan river tributaries is 20 ppm Cl, and the concentration of the generally saline Nahal Tabor decreased during floods to 11 ppm Cl, in close agreement with the values obtained in the west. In the humid Upper Galilee, the concentration of Cl in perennial springs feeding the Jordan is quite constant with averages ranging from 8 to 16 ppm Cl, or similar to the minimum values of runoff (Table 4).

A plot of the average runoff concentrations against average annual precipitation shows a clear trend for decreased concentrations with decrease in precipitation, with some of the lowest values found in the semiarid regions of the Shephelat Pleshet (P = 300 to 400 mm) which is in agreement with the expected smaller annual accretion in the arid parts of the country.

At first sight an exception to these rules seem to be the wadis draining the Eocene limestones of the Meggido syncline. These limestones absorb large quantities of water, but owing to the low permeability release it more slowly than the fissured Cenomanian limestones. As a result, there is in these wadis a considerable dry weather runoff. The relatively high and persis-

tent salinity of the runoff might seem to be in contradiction to the generally good quality of waters from Eocene springs, but is apparently related to the higher content of chloride in these limestones (cf. Table 2). The question is being studied further.

FACTORS CONTROLLING THE CONCENTRATION OF SALTS IN GROUNDWATER

Of the sea salts continuously brought inland by wind and precipitated onto the soil by rain, only a small portion is rapidly returned to the sea by surface storm runoff. The remaining salts become concentrated by evaporation and accumulate in groundwater and in soils.

The average concentration of Cl in groundwater (C_w) of a given drainage area with precipitation P and average concentration of Cl in the precipitation (C_p) is dependent on the amount of evaporation (E) and the quantity of storm runoff (R_{st}, and can be predicted according to the following general formula (where P, R_{st} and E are expressed in mm):

$$C_w = C_p \left(\frac{P - R_{st}}{P - R_{st} - E} \right) \qquad (1)$$

Since groundwater recharge varies from less than 1% of precipitation in arid regions to over 50% in humid areas, it can be seen from the formula that the concentration of groundwater may

vary from 2 times to over 100 times the concentration of rain.[*]
Additional concentration by evaporation is possible only under
specific geomorphic conditions, when the groundwater reaches near
surface and evaporation exceeds precipitation. This is collateral
to salt accumulation in lakes or in soils (cf. next chapter), and
the formula becomes then non-applicable.

The formula also implies that for natural areas a dynamic
equilibrium becomes established with a steady salt concentration
level in groundwater and in soils, the annual increment of salts
from rain being balanced by a similar amount of surface and sub-
surface outflow to the sea.

Using the appropriate data for each region (Table 5)
and the concentration of 10 ppm Cl in the precipitation as re-
presenting an acceptable general average valid for the subhumid
and humid parts of Israel, we obtain by inserting into the above
equation, the expected minimal concentration of Cl in ground-
water as shown in the last column of Table 5. The data used
for P and E are those calculated by the Meteorological Service
(Neumann 1955), whereas the values for storm runoff are based
on figures of total storm runoff to the Mediterranean collected
by the Hydrological Service and estimated to be 200 - 250 mill
m^3 (e.g. Goldschmidt, 1955) and divided by the appropriate

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[*] In very rigorous calculations a slight correction is required
     for the additional salinity in storm runoff water which is in
     excess of that of the original precipitation.

catchment area. For eastern drainage the storm runoff data are based on measurements by the Hydrological Service (cf. Yearbooks).

The above relations are best applicable to relatively simple drainage basins and stable conditions in time and in space. Fluctuations or a periodic variation in precipitation or evaporation (such as may be caused by a radical change in the vegetational cover) and the accompanying changes in the runoff regime, may cause great variations in the concentration of salts in groundwater and a temporary accumulation and precipitation of salts in the sunsoil. In semiarid and arid regions groundwater becomes highly saline during the infrequent wetter periods as a result of leading of the previously accumulated salts.

Such fluctuations do not, however, disqualify the applicability of the equation, nor disprove that a substantial part of the soluble salts in the groundwaters of Israel can be attributed to airborne sea salts. By evaluating the limits of the superimposed fluctuations, we obtain an excellent tool for estimating the airborne sea salt component in groundwater.

The predicted concentrations of Table 5 reflect well the general quality of groundwater sources in the various regions of Israel (Löwengart, 1958). The value for the eastern drainage appears somewhat too high, as Jordan head waters and springs with perennial flow have usually lower concentrations, and it seems that a concentration of 7 to 8 ppm Cl in rain might be more correct for this catchment area.

For the areas of western drainage, the data are in good agreement with values observed in many wells of the Coastal Plain, and this has already led Löwengart (1958) to conclude that the salts of the Pleistocene aquifers of the Coastal Plain are of cyclic origin. Wherever the Cl concentration of the groundwater comes within reasonable limits of these predicted values and the proportion of other ionic species is compatible with that of sea spray, we may safely agree that the salts have been concentrated from recent atmospheric accession. A statistical analysis of the quality of groundwater sources in Israel (Yaalon, in preparation) shows that the median concentration of Cl in the Coastal Plain waters is close to 3 meq/l (105 ppm Cl). Considered in relation to the predicted value we conclude preliminarily on the basis of Table 5 that the increment from recent atmospheric salts is substantial, and mostly approaching 50% with respect to chlorides.

Any amount of Cl salinity above the predicted accession from recent atmospheric salts must be attributed to additions from other sources, especially to incomplete flushing out of sea salts contained in the sediments from past sea inundation and ancient salt accumulations, to weathering, and more rarely, to infiltration of sea water. Applying the above formula, the relative contribution of airborne salts and other sources can be evaluated both for large and small catchment areas.

It must be remembered that the above calculations are made with respect to Cl only, though a similar derivation can be made for SO_4 and other ions when acceptable data for average

accession from precipitation become available. It has been ob-
served that the SO_4/Cl ratio in the groundwaters of the Coastal
Plain increases southward (Löwengart, 1958, and Taussig, written
communication) and this is likely to be a function of increased
relative increment of airborne S, which is carried in the atmos-
phere in gaseous form and is thus more evenly distributed and
deposited also in the drier parts of the country, whereas the
amount of deposited airborne chloride salt decreases in the more
arid regions. Present knowledge enables us thus to conclude that
a substantial part of SO_4 in groundwater is of airborne origin,
and that its relative importance increases in the more arid parts
of the country. Of the remaining anions, practically all the
HCO_3 is in solution equilibrium with calcite as determined by the
CO_2 pressure of the air, while a substantial part of the generally
small quantities of nitrates may be of bio-atmospheric origin.

Since all the common cations (Ca, Mg, Na and K) which may
be present in rain water, besides being supplemented by release
from weathering, undergo ion exchange during their passage through
the soil and subsoil, the cationic proportions reaching the aquifer
are variable and usually very different from those in the precipita-
tion. Statistical analysis by the author (in preparation) of
numerous water analyses indicates that about 70 - 80% of Ca + Mg
and about 10% of Na present in groundwaters of Israel have been
derived from weathering. Other conclusions in this respect have
been arrived at by Löwengart (1958).

Contribution from Fossil Salt Accumulations

While, as we have shown, atmospheric salts supply a sub-stantial part of the soluble salts to the groundwaters of Israel, they are generally supplemented by additional salts from fossil salt accumulations in soils and sediments. Sea salts may have become trapped during past sea inundations and only incompletely flushed out following the emergence of the land or they have ac-cumulated in soils and sedimentary basins during past drier periods and now become redissolved as the water passes through the rocks.

There are relatively few regions in Israel with highly saline groundwater whose salts are derived almost wholly from highly saline residual brines, connate sea water and similar. The regions include Emeq Beth Shean, the Carmel Coast, Emeq Zevulun, Sdom and the Northern Negev, and they are generally also those regions in which there occurs excessive accumulation of salts in soils. According to calculations by Tahal,[*] the total amount of harmfully saline waters represents about 10 - 12% of the total amount of exploitable waters in Israel. In all other regions, the supplement by fossil salts is of lesser significance.

In the arid regions of the country, with its large vari-ability in climatic conditions, occasional wetter periods may have leached out large quantities of accumulated salts into the groundwater, thereby largely suppressing the possibility of dis-tinguishing between fossil and recent atmospheric salts.

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[*] Lecture by A. Melamed at Symposium on Problems of Salinity in Israel, held in Rehovot, April 1960.

FACTORS AFFECTING SALT ACCUMULATION IN SOIL

The accumulation of soluble salts in soils is only rarely due to salts derived from the weathering of the underlying rock. In Israel, this factor is significant only in certain areas of the Jordan Rift Valley, where Pleistocene Lisan lake beds are occasionally somewhat saline and often gypseous. As a result of inadequate leaching under the prevalent arid and semiarid climatic conditions the salts have been inherited by the derived soils.

In all other cases the soluble salts which are accumulating in soils are being imported by groundwater or precipitation. The main cause for excessive accumulation can generally be traced to the hydrologic condition of the drainage basin, which in turn is governed by climate and the morphogenetic configuration of the landscape. The mobility and distribution of the soluble salts imported in the soil is in turn largely determined by the prevailing moisture regime and the position of the water table in relation to the soil profile. The principal types of moisture regimes and their relationship to salt accumulation in soils are shown in Fig. 2. A normal leached profile is added for comparison.

Salinity in relation to Topography and Water Table

Numerous investigations, both here and abroad, have shown that there is a direct relationship between the depth to the saline groundwater and the salt content of the soil above. In a normal

leached profile and where the groundwater is at least 3 metres below the surface, no soluble salts will accumulate. But as the groundwater level rises closer to the surface, and when evaporation exceeds precipitation, the imported salts will accumulate i. the profile. As long as the evaporated moisture is lost mainly by plant transpiration and there is a rainy season in which precipitation exceeds evaporation, the salts will accumulate in the subsoil, often in definite horizons, and the topsoil may remain relatively salt free. Only when the groundwater reaches a level less than 1 metre, and the loss of moisture is mainly by direct evaporation from the soil surface, will the salts accumulate in the top layer. There may then develop a characteristic salt efflorescence and salt crust. The often encountered spotty and unequal soil salinization is caused by uneven microrelief, which results in excessive evaporation and accumulation in certain spots, dissolution and leaching in others.

Salinity in relation to Climate

There is a general belief that high salinity is a normal feature of arid soils. This is not necessarily so. The majority of the soils in the central arid interior of Australia, for example, are non-saline (Jackson, 1957). Since the average concentration of Cl and S in rocks is very low (Table 1), sedentary soils formed from weathering of such rocks could not become saline unless supplemented by salts from outside sources. A significant addition from groundwater is generally implausible in

desert regions and we are thus led to suggest that the main
supplemental source of salts in these regions is the accretion
of airborne salts. Though this amount may not be more than
about 2 kg NaCl per hectar annually, even under favourable con-
ditions close to the sea (Eriksson, 1958), the lack of effective
leaching coupled with the factor of time, may eventually produce
highly saline soils. Interior continental deserts, e.g. in
Australia, shielded and distant from any source of airborne
salts, may on the other hand remain salt-free.

As a rule, all of the limited moisture which precipit-
ates in arid regions again rapidly evaporates, leaving all the
salts behind in the soil. There is no regular water table and
only a shallow layer of soil is being wetted. The salts, both
airborne and those released by weathering, will accumulate at
the depth of wetting, and only very occasionally will there be
an opportunity for a more thorough redistribution of the salts
during floods. In the course of time all soils, except those
in wadis which are more frequently wetted, will become saline.

The Effect of Vegetation

Finally, it must be mentioned that vegetation may con-
tribute to the process of soil salinization and redistribution
of salts. Certain halophytic plants selectively absorb salts,
often from the deeper soil layers, which are subsequently re-
leased from the plant litter to the surface horizon of the soils.
The soluble salt content under the canopy of _Tamarix_ trees in

the Northern Negev was thus found to be two to three times as high as in the open areas (Litwak, 1957). In coastal regions the vegetation serves as a significant interceptor of sea spray and passes the salts into the soil.

The continuous biologically induced circulation of salts and nutrients undoubtedly retards large quantities of salts from being washed into the deeper layers of the soil, and likewise in forested regions the high evapotranspiration rates will leave smaller amounts of water for leaching and result in the retention of a larger portion of the atmospheric salts in the soil.

SALINE SOILS OF ISRAEL

The occurrence of saline soils in Israel and previously Palestine has been noted by many investigators. Their properties have been studied for over 30 years, beginning with the researches of Menchikovsky and followed by those of Puffeles, Ravikovitch and collaborators at the Agric. Research Station, Rehovot. Zohary, Orshan, Karschon and others have studied their botanical and ecological aspects. The danger of secondary salinization by irrigation was also considered and the effect of saline water on soils has been investigated by Reifenberg, Ravikovitch et al. and Yaalon. Altogether, close to 20 papers[*] deal with the subject of saline soils and salinization in Israel, but so far none has discussed in detail the primary cause of salinization.

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[*] It is not attempted in this article to give a bibliography or a review of these papers.

All the saline soils found in this country are of the solonchak type, with NaCl as the dominant electrolyte salt, followed by $CaSO_4$ as the next most abundant. In the desert soils, gypsum is usually more abundant than NaCl. This fact is closely connected with the mode of accumulation of the salts and with the prevalence in them of atmospheric salts, which abound in NaCl and $CaSO_4$, whereas solonetz type of soils, in which carbonate salinity is dominant, usually are products of leaching and alteration of solonchaks, a stage which has not taken place in Israel (Yaalon, 1959a).

In the northern subhumid parts of Israel there are now less than 50,000 dunam of saline soils (mainly in Emeq Zevulun) but at least another 20,000 dunam (excluding the Hule area) suffer from a high water table and the attendant dangers of salinization. About 100 - 200,000 dunam of high water table salines (sebhas) are found in the Arava Valley (Wadi Araba). In the Negev about 2 million dunam of desert gravel pavement soils are highly saline, and some 400,000 dunam of loessial soils are salt affected. About 150,000 dunam of fairly saline and gypseous lake sediment soils are in the Arava Valley and a similar size area in the Lower Jordan Valley is now outside Israel territory (see Fig. 3).

Saline Soils of Marshy Plains and Basins

The saline soils of the Coastal Plain are a good example of salinization from inflow of saline groundwater (Menchikovsky, 1927, Ravikovitch and Bidner-Barhava, 1948, Orshan and D. Zohary,

1955). Wherever on the Coastal Plain runoff water was prevented
by some obstacle from reaching the sea rapidly, for example, by
dune sand encroachment into the wadi outlet or because of the
resistance of the kurkar sandstone ridge, swamps and marshes
formed in their wake. Largest among them are the inundation
areas of the lower reaches of the Kishon and Na'aman river and
the Kabbara swamps. Excessive evaporation of the brackish ground-
water in these deficiently drained areas eventually led to the
salinization of the soils. As no correlation exists between
the occurrence of saline soils on the Coastal Plain and Pleis-
tocene shorelines (Itzhaki, 1959), the salts left behind by these
inundations do not seem to have affected the soil salinization
process, though they have contributed significant amounts of
salts to the groundwater of the deeper layers.

As a result of the pronounced seasonal precipitation,
both salinity and water table are fluctuating. During the winter
the water table often reaches close to the surface and the sali-
nity decreases by dilution with rainfall, whereas during the
summer the water table is lowered as a result of reduced inflow
and by evaporation, leading to an increase in salinity. Salinity
of the soil solution may reach 40%, or up to 5% of the dry soil.
Salt movement is upward during the dry summer and downward during
winter (precipitation 500 - 600 mm). The layer of maximum salt
accumulation depends on the balance between these two processes.
Sterile, vegetation-free spots generally indicate maximum con-
centration in the upper layer; in other cases, the highest con-
centration occurs at some depth in the profile.

In the extremely arid Arava Valley (precipitation less than 50 mm), large stretches of salines are found in the Dead Sea region (the Sdom saline), near the Gulf of Akaba (the Eilat and Evrona salines) and at Yotvata (the Yotvata saline) (Zohary, 1945, Ravikovitch, Pines and Dan, 1956). These are terminal drainage salt marshes (playas) fed by ephemeral streams and by saline springs. The water table is all the year 1 to 4 metres below the surface, and only a few metres above the level of the adjacent seas. The alluvial material of the salines is generally arranged according to texture in concentric belts along the stream channels and at its termination. The heaviest and most saline soils accumulate in the lowest parts of the basins. The levees along the channels are coarse textured and less saline, while the marshes of the lower lying flood plain beyond them offer the best conditions for salt accumulation. Vegetation is also usually arranged in distinct belts and is a good indicator of the depth of the water table and of maximum salinity. Salt movement is practically only upward, and the highest concentrations are therefore found in the upper layer of the soils, decreasing to that of the groundwater in the subsoil.

Similar salt flats have developed on the periphery of seepage areas of major saline springs, e.g. Ein Husb, etc.

Salt Accumulation in the Loessial Soils

Airborne salts, which have accumulated as a result of high evaporation rates, are the main source of soluble salts in the loessial sierozem soils of the Beersheba basin and the Northern Negev. Evaporation in this region is 90% or more of total precipitation, so that precipitation rarely wets the soil sufficiently to leach the salts out of the subsoil. The small amount of runoff is the result of occasional heavy torrential rains which exceed the low infiltration capacity of the soils. Groundwater recharge is very limited and only from wadi beds, so that the runoff only triggers a redistribution rather than a removal of the salts. Maximum salinity is thus found in the lower lying areas and at the lower depth of moisture penetration in the soil profile.

The dust which originally formed the deep loess deposits of the Negev originated from the weathering of calcareous rocks in the inland deserts, and was presumably like other calcareous rocks (Table 2 and 3) originally non-saline. Since the present salt concentration is far above that of the average source rock, the excess salts must have been supplied from other sources. If we accept as reasonable a rate of deposition (maximal) of about 0.1 mm per year (Rim, 1952) - which would account for the accumulation of the 20 - 15 metres layer of loess in about 200 - 150,000 years - and a simultaneous rate of addition of airborne salts of 1 - 2 kg Cl / ha / year (cf. p. 13), then the deposited loess would contain an average salinity of about

0.1% Cl. At slower rates of deposition of higher rates of air-
borne salt accretion, the salinity content would be proportion-
ally higher, while superimposed leaching would cause a loss of
salts.

The present day salinity distribution in the loess - both
areal and vertical - lends considerable evidence supporting the
above hypothesis. Most of the loessial soils have a salinity
close to or slightly lower than 0.1% Cl (Ravikovitch, 1953),
which includes all the areas of heavier rainfall (ca 300 mm) in
the northwestern part and would suggest a reasonable loss by
leaching. Also, the more easily leached coarser soils are usu-
ally less saline than the neighbouring finer loess. Along the
200 mm isohyet in the Beersheba basin the salinity increases
eastward and is at maximum in the southeastern part of the basin
(Fig. 4). This seems only explicable in terms of the prevailing
eastern wind which would bring a larger amount of dry salt, and
the decreased rainfall intensity per rainy day at greater dist-
ance from the sea (Katznelson, 1955), as a result of which there
would be a minimal removal of the accumulated salts. Higher
salinities (0.5 - 1% Cl) are only met with in the synclinal val-
leys and loessial plains of the Negev, which have collected from
runoff all the airborne salts deposited on the adjoining bare
mountains.

Though the dust which today settles in the Negev is usu-
ally saline, this cannot be accepted as sufficient evidence for
the saline character of the original loess. Today's dust repre-

sents, for the largest part, a redistribution of already salin-
ized local loess or desert dust rather than new increment. The
large vertical and areal variability in the salinity of the
deposits is in striking contrast to the very uniform textural
composition of the loess, and cannot, in the author's opinion,
be explained otherwise than by considering two different, but
simultaneous, sources of loess and salts. Climatic conditions
are variable in desert fringe areas, and as we have shown deter-
mine the salinity distribution.

The Salinity of the Desert Pavement Soils

Characteristic soils of the Southern Negev desert are
the gravel pavement soils (called 'hammada' in this country)
which cover vast plateaux and broad plains between the bare
rocky highlands and the Arava Valley. They are shallow and
always saline, with several percent gypsum and smaller amounts
of chlorides (Karshon, 1953, Ravikovitch et al., 1956, Dan, 1959).
It is postulated that the high content of soluble salts is also
here predominantly due to the accumulation of atmospheric salts,
made possible by the considerable age of the soils.

Practically all post-Oligocene deposits in the Negev are
of continental or lacustrine origin, and consist of debris from
the underlying older non-saline rocks. They are occasionally
saline and usually gypseous, and show evidence that they have
been accumulated without any very large transport from the point
of origin. As a result of the predominantly arid conditions

which have prevailed in the Negev since at least the early part
of the Miocene period, and due to the relative closeness to the
coast which has served as a steady supply source, atmospheric
salts have become accumulated in these deposits over the ages.

Even if it is assumed that the low value of annual incre-
ment of 1 kg salt per hectar (cf. p. 13), over a period of 25
million years (Neogene age), this would amount to (without any
losses) a layer of 1.0 metre of salts. Thus, even if we assume
very large losses by leaching during wetter periods, the salts
now present in the profile of the desert pavement soils could
have accumulated in a much shorter time, possibly of the order
of a few million years.

The predominance of gypsum over NaCl in the desert pave-
ment soils may be due to a number of possible processes. Since
sulphur is present in the atmosphere mainly in gaseous form,
partly originating from the reduction of sulphates in the propor-
tion of sulphur to chloride unloaded from the air is very much
different from that of the sea, and in arid deserts the deposition
favours sulphate over chloride salts. Some evidence for this is
the previously mentioned increase in the SO_4/Cl ratio in the
groundwater towards the south. Another reason for the predomin-
ance of gypsum is the higher solubility and geochemical mobility
of chlorides, which would tend to separate the salts in the course
of time and leave gypsum behind. Evidence of leaching and mobi-
lity of salts even in the desert pavement soils is the fact that
salinity generally increases sharply with depth, and that it very

much depends on topography (Fig. 5.). The high salinity content
of the meagre groundwater sources in the Negev is also support-
ing evidence.

The sparse vegetation of these soils is confined entirely
to the small depressions marking the course of runoff. These
rivulets and small gullies receive a fair amount of runoff from
the surroundings and are consequently relatively well watered
and practically free of soluble salts (Karschon, 1953), thus
enabling the growth of vegetation. This is a striking example
of the effect of microrelief on salt distribution (Fig. 5), and
would seem to indicate a high stability of these gravel pavement
surfaces.

THE EFFECT OF AIRBORNE SALTS ON COASTAL PLAIN SOILS

While the retention of airborne salts in the soil de-
pends largely on the amount of evaporation in relation to pre-
cipitation, the mere passage of slightly saline water through
the soil induces cation exchange reactions between the clay
phase and the saline solution. The main cation present in sea
salts is Na^+ together with appreciable amounts of Mg^{++} (equiva-
lent ratio 4.3:1), which in their passage through the soil may
become absorbed and exchanged especially for Ca^{++}. Slightly
saline solution would be of little effect on soils possessing a
high concentration of exchangeable Ca^{++}, because the replacing
power of Na^+ is low compared to Ca^{++}. But with increasing con-

centration of the soluble salts as a result of evaporation, and on sandy soils with low exchangeable Ca^{++} content, some replacement does take place, the effect being cumulative with time, until a steady state is established. Such conditions are found in Hamra soils of the Coastal Plain and have resulted in a considerable increased exchangeable Na percentage and a decrease in the exchangeable Ca/Mg ratio. The exchangeable Na percentage has in many places reached 15% or more, and even considered as proof of solonization (Ravikovitch, 1956). However, in this case, because of the sandy texture of the soils, the chemical adjustment was not accompanied by a decrease in permeability or other morphological changes characteristic of solonetzic soils, and the soils have retained their excellent agricultural properties (Yaalon, 1959a).

GENERAL DISCUSSION

The occurrence of saline groundwater and soils in arid and semiarid regions is a significant impediment in their economic development, and the understanding of the natural processes leading to salinization would seem to be of great value in the design for the beneficial exploitation of these resources. In order to assess long range effects, the ultimate aim must be the calculation of a detailed salt balance and the annual circulation for each major region.

The circulation of salts in the geochemical cycle of elements and their distribution and differentiation between soil and

groundwater is governed by a large number of factors. Besides
the factors mentioned in this exposition, the industrial produc-
tion and consumption of salt and its return in sewage water must
be taken in account. In Israel, the production of NaCl is about
20,000 tons annually, corresponding to a consumption of about 10
kg per capita. It has been estimated that town effluent in
Israel - which might be used for groundwater recharge or for
irrigation - is enriched through human consumption by about 100
ppm NaCl.

But of course the largest concentration of salts in
groundwater is effected through irrigation. Taking a hypothetic
example of a water containing 100 ppm Cl, which is used in such
a way that only 10% of it will drain into the underground, the
drainage water will reach a concentration of 1000 ppm Cl. The
overall effect on the quality of groundwater may be small if the
body of groundwater reserve is very large, but it may be signi-
ficant when the quantity of groundwater is comparatively small.
No doubt the increase in salinity observed during the last 30
years in Israel is due to the expansion of irrigation. As we
already exploit some 60% of all available water sources in this
country and the quantity is rapidly growing, the question deserves
serious consideration and evaluation.

The effect of a radical change in vegetation must also be
considered. As a result of afforestation of the hills evapo-
transpiration will increase, which may result in less efficient

leaching of the soil and in more concentrated drainage solutions, similar to the effect of irrigation.[*])

The process of soil salinization from saline groundwater in areas of basin shaped topography has long been recognized as the main cause of salt accumulation in soils. Airborne sea salts as a source of salinity in regions with a non-existent or low water table, which is postulated to be the main cause of salinization in the arid parts of Israel has not been considered as a factor in soil development in such regions, though it is gradually being recognized that the accession of atmospheric salts is an important factor in soil formation in coastal areas (in Australia-Prescott, 1931, and Downes, 1954; in New Zealand, Gibbs, 1949; in California, Ulrich et al., 1959). More and detailed measurements of atmospheric salt precipitation are necessary for the correct evaluation of this factor. However, it seems clear that we can state already now that the accumulation of atmospheric salt must have been an important factor in all areas which can be classed geomorphologically as depositional surfaces (as opposed to erosional surfaces) and where evaporation attains high values in relation to precipitation.

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[*]) It may well be that the reverse effect, namely the flushing out of accumulated salts as a result of the destruction of vegetation and soil erosion during the last few centuries, has taken place and that it is partially responsible for the higher than expected salinity in some wells and springs. The salt increase in the streams of Western Australia was for example considered to be due to the destruction of native vegetation (cf. Eriksson, 1958).

The amount of atmospheric salts deposited in a certain region depends mainly on climatic and geographic conditions such as the proximity to the coast, the direction and intensity of the winds, the intensity and distribution of rains and the presence of topographic barriers. Since the amount retained by the soil represents the balance between the amount unloaded from the air and that lost by leaching, the maximum accumulation will not necessarily occur near the coast where the annual increment is largest, but at some distance inland where the higher evaporative power and lowest rainfall intensity result in less effective leaching. Even when not retained by the soil, a significant effect of atmospheric salt on soils is their inducement of cation exchange reactions within the soil, generally resulting in an increase of absorbed Na and Mg. As additional data bearing on the matter are being collected, the effect of atmospheric salt in soil formation will no doubt be more widely recognized.

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TABLE 1. The average abundance of chlorine and sulphur in nature

(after Green, 1959)

Rock type	Cl %	S %	Source of data
Igneous rocks	0.0230	0.090	(1)
Shale	0.0160	0.110	(2) and (3)
Sandstone	0.0020	0.220	(2) and (3)
Limestone	0.0370		(2) and (3)
		0.800	
Dolomite	0.0500		(2) and (3)
Soils	0.0100	0.085	(1)
Ocean	1.9000	0.088	

(1) Vinogradov, A.P., 1956, Geokhimiya, No. 1, 6-52.

(2) Chlorine data mainly from Behne, W., 1953, Geochim. Cosmochim. Acta, 3, 186-215.

(3) Sulphur averages computed by Green (1959) from analyses of Russian platform sediments.

TABLE 2. Chlorine and sulphur in carbonate rocks of Israel and some other countries

Location	Lithology	Stratigraphic division	Number of samples	Cl Average %	Cl Range %	S Average %	S Range %	Remarks and reference
ISRAEL								
Beersheba basin	Marls and flinty lst.	Lower and Upper Eocene	8	.019	.010-.045	-	-	(1)
Emeq Jezreel	Hard limest. and chalk	Middle Eocene	7	.24	.06 -.45	.074	.040-.110	(2)
- " -	Hard chalk	Lower Eocene	1	.19	-	.080	-	(2)
- " -	Soft chalk	Campanian	5	.07	.05 -.10	.270	.140-.360	(2)
- " -	Hard limest.	Cenomanian	1	.12	-	.092	-	(2)
Judean mountains	Hard limest.	Cenomanian	5	.0012	.0007-.0030	.0024	.0017-.0044	(8)
- " -	Dolomite, calcitic, non-purous	Cenomanian	11	.0028	.0015-.0044	.0033	.0017-.0064	(8)
- " -	Dolomite, porous	Cenomanian	6	.0016	.0012-.0018	.0017	.0013-.0026	(8)
Other countries								
Illinois, USA	Limestone	Paleozoic group	12	.012	.003-.030	.013	.0003-.061	(3)
- " -	Dolomite	Paleozoic group	7	.045	.023-.063	.009	.002 -.026	(3)
North America	Dolomite	-	4	.029	.000-.055	.0006	.0003-.0008	(4)
Germany	Marine limestone	Mesozoic group	4	.015	.005-.024		-	(5)
- " -	Dolomite	Mesozoic group	2	.075	.061-.088		-	(5)
- " -	Travertine	Recent	1	.002	-		-	(5)

(cont.)

Table 2. (continuation)

Russia	Limestone	Upper Cretaceous	54	–	.10	–	(6)
_ " _	Limestone	Tertiary	71	–	.08	–	(6)
_ " _	Limestone	Quarternary	7	–	.10	–	(6)
North America	Lake marl	Recent	9	–	.27	.16–.45	(7)

(1) Core samples from water well. Blake and Goldschmidt (1947, p. 371-2).

(2) Near surface samples. Eocene samples are compact non-porous, whereas Campanian chalk is highly porous. No significant difference in Cl and S content with overlying nari. Eocene samples include one chalk from Judean Mountains; Goldberg (1955).

(3) Water leachable salts from fine powders; Lamar and Shrode (1953).

(4)   _ " _   ; Graf (1952).

(5) Total content, whereof about 40% is water leachable in limestone and 20% in dolomite; Behne (1953).

(6) From analyses of Russian platform sediments used by Green (1959) in computing world averages.

(7) Minnesota lake deposits; Goldich et al. (1959, Econ. Geol. 54 , 283-300).

(8) Water leachable salts from powdered samples; Yaalon and Katz (in preparation).

TABLE 3. Quantity of Cl and S released by weathering at different rates of weathering and content of element in rock

Rate of rock weathering	Annual release by weathering per dunam, when average content of element in rock is				
	0.02 %	0.04 %	0.1 %	0.2 %	0.4 %
Average rate 10 mm / 1000 years (25 kg/dunam/year)	5g Cl 8g NaCl	10 g Cl 16g NaCl	25g Cl 40g NaCl	50g S 210g $CaSO_4$	100g S 425g $CaSO_4$
Maximal rate 50 mm / 1000 years (125kg/dunam/year)	25g Cl 40g NaCl	50g Cl 80g NaCl	125g Cl 200g NaCl	250g S 1050g $CaSO_4$	500g S 2100g $CaSO_4$

Note: Density of rock taken as 2.5. The computed NaCl and $CaSO_4$ values are slightly rounded off.

No.	Name of Wadi (Old Arab name in brackets)	Sampling site [1]			Samples [2]		Concentration of chloride [3]		Surface geology of catchment [4]	Remarks
		Distance from sea km	Catchment area km^2	Precipitation range mm	Number of analyses	Number of seasons	Average ppm	Minimum ppm		

WESTERN DRAINAGE

1	Betset (Karkara)	11	71	800–900	15	8	26.5 ± 2.0	24	Cen.lst.	(5)
2	Keziv (Qarn)	1.5	137	800–900	10	4	22.0 ± 3.8	12	Cen.Tur.lst.	(5)
3	Hilazon (Halazun)	9.5	158	600–700	10	4	15.8 ± 6.2	8	Sen.lst.& All.	
4	Hashofet (Fureir)	18	13	600–700	5	3	46.6 ± 9.1	38	Eoc.lst.	(6)
5	Daliya (Fureidis)	3	68	550–650	2	2	40.0 ± 5.0	35	Eoc.lst.	(6)
6	Ada (Marah)	5.5	22	550–650	6	6	86.3 ± 25.6	35	Eoc.lst.	(6)
7	Senunit (Sindijana)	7	68	550–650	4	2	51.9 ± 11.8	35	Eoc.lst.	(6)
8	Hadera	6	593	550–650	1	–	–	6	All.	(7) (8)
9	Aleksander (Iskandaruna)	5	497	550–650	1	–	–	9	All.	(7) (8)
10	Shilo (Lajja)	11	400	550–650	9	3	16.2 ± 6.9	3	Cen.Tur.lst.	
11	Ayalon (Salama)	3	802	550–650	15	5	20.1 ± 6.0	8	All.& Hamra	
12	Natuf (Sarar)	16	251	600–700	3	2	12.0 ± 2.7	10	Tur.lst.,All.	
13a	Soreq	46	74	600–700	14	5	14.9 ± 4.5	8	Cen.lst.	At Motza
13b	Soreq	33	245	500–600	4	2	19.8 ± 2.9	14	Paleoc.lst.	At Har–Tuv
13c	Soreq	20	407	500–600	11	4	23.0 ± 7.0	13	Eoc.lst.	At Rlw.Bridge
13d	Soreq	12	492	500–600	18	6	23.1 ± 8.1	10	All.	At Gedera
14	Lakhish (Qureqi)	11	281	400–500	11	4	16.3 ± 4.9	8	Eoc. & All.	
15	Haela (Ajjur)	14	328	400–500	5	3	16.9 ± 3.1	10	Eoc. & All.	
16	Guvrin (Jaladiya)	12	204	350–450	7	3	17.6 ± 4.4	12	Eoc. & All.	
17	Shikhma (Hesi)	13.5	382	300–400	6	3	14.7 ± 5.6	5	Loess	

(cont.)

Table 4. (continuation)

| 18 | Beersheba | 47 | 1090 | 200-300 | 4 | 2 | $8.8^{-}4.8$ | 4 | Loess | |
| - | Average of 15 sites | 1.5-47 | - | - | 142 | - | $16.9^{-}3.6$ | $10.1^{-}3.6$ | | (9) |

EASTERN DRAINAGE

1	Iyon (Bureighit)	35	30	850-950	12	5	$21.3^{\pm}7.9$	8	Lst.,Basalt	(6)
2	Dishon (Hindaj)	38	91	600-700	10	4	$21.1^{\pm}2.8$	16	Eoc.&Cen.lst	(6)
3	Hatzor (Waqqas)	41	31	600-700	5	3	$20.4^{\pm}4.1$	15	Eoc.&Cen.lst	(6)
4	Amud	43	124	650-750	8	4	$18.4^{\pm}3.4$	15	Eoc.&Cen.lst	(6)
5	Tabor (Bira)	57	214	450-550	1	-	ca.100	11	Neogene	(8)
-	Average of 4 sites	35-43	-	-	35	-	$20.3^{\pm}1.0$	$13.5^{\pm}2.8$		

Source of data: Hydrologic Yearbooks of Israel, 1946/47 to 1955/56.

Notes:

(1) For coordinates and details of samplings cf. Hydrologic Yearbooks; distance from sea measured at point of sampling.

(2) Sampling seasons used were 1946/47 to 1955/56; in no case were samples analysed during all 10 seasons; occasionally some older data have also been included.

(3) Arithmetic average and arithmetic mean deviation. Mean deviation is average of differences from average. For small number of samples arithmetic mean deviation is a better expression of variability than standard deviation, as it is less sensitive to extreme values.

(4) Cen. - Cenomanian; Tur. - Turonian; Sen. - Senonian; Eoc.- Eocene; All. - Alluvium; lst. - limestone.

(5) Flow largely fed by perennial springs which respond rapidly to rains.

(6) Includes measurements during periods with considerable dry weather flow. Note high minimum values for wadis 4 to 7 draining Eocene limestone of the Meggido syncline.

(7) Dry weather flow is generally of high and variable salinity.

(8) Minimum concentrations measured during stormflood of 21.12.1951.

(9) Without sites 4 to 7; cf. Note 6.

TABLE 5. <u>Computed concentration of chloride in groundwater for the main catchments of Israel</u>[*]

Description of catchment area	Area of surface catchment	Annual precipitation	Annual evapo-transpiration	Storm water runoff	Computed mean groundwater concentration of chloride
	km^2	P, mm	E, mm(%)	R_{st}, mm	C_w, ppm
Western drainage catchment; North of coordinate 100 (N31°30'); Subhumid coastal plain and uplands; Precipitation above 400 mm.	8260	580	380(65%)	20	31
Western drainage catchment between coordinates 100 to 70 (N31°15'); Mediterranean steppe region; Precipitation 200 to 400 mm.	2310	290	250(86%)	12	100
Catchment of Jordan river North of Huliot; Subhumid to humid mountain region; Precipitation above 500 mm.	841	1100	420(38%)	70	17
Catchment of Jordan and lake area between Huliot and Dagania; Subhumid hilly region; Precipitation above 400 mm.	1685	600	450(75%)	15	44
Catchment of Jordan river between Dagania and Allenby bridge; Semiarid Jordan Valley and arid eastern slopes of Samaria and Judea	13700	370	330(89%)	5	104

[*] <u>Source of data.</u> Precipitation is mean for years 1901–50. Evaporation after Neumann (1955) – in western catchment it was computed by reduction of Piche evaporimeter data, for Jordan catchment from river flow. Storm runoff from measurements by Hydrological Service (Hydrologic Yearbooks and Goldschmidt, 1955). The catchment area between Huliot and Dagania does not include the lake and swamp areas in which evaporation exceeds precipitation. The catchment area of the Jordan river includes only its western side.

<u>Reliability.</u> The reliability of the hydrologic quantities is estimated to be $\pm$ 20% (Neumann, 1955). Due to their interdependence the reliability of the recharge quotient in equation 1, i.e. $(P-R_{st}/P-R_{st}-E)$, will not be any different, and thus the reliability of the predicted groundwater concentration as obtained from equation 1 depends largely on the uncertainties attached to the estimate of the concentration of Cl in rain water taken her as 10 ppm. Its variability is as yet difficult to asses, but considering that ground water flow and storage will level out short range variations, the precision of the computed groundwater concentration is estimated to be within $\pm$ 40%.

Figure 1

The relation of chloride concentration in storm runoff water and in precipitation to distance from sea shore. Numbers at each point refer to wadis listed in Table 4.

Though a decrease in salinity with distance from the shore is clearly evident, the data are too scant to fit them to an exponential equation (cf. Eriksson, 1952). The value of 10 ppm Cl was therefore chosen and used in the subsequent calculations as being representative for most parts of the inland region.
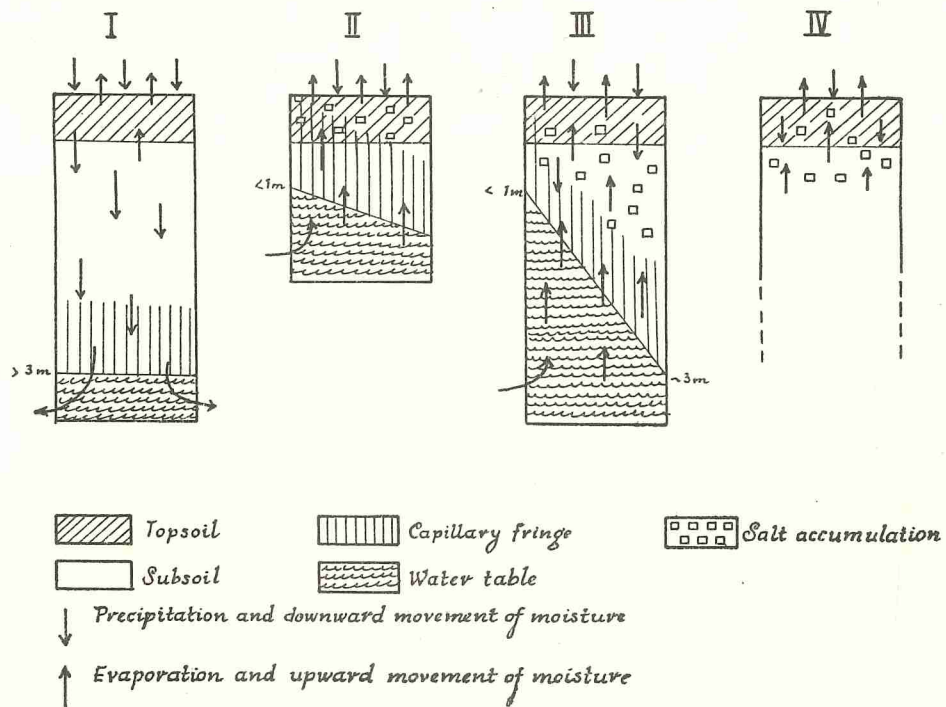
Figure 2

Schematic diagram of characteristic soil moisture regimes showing their relation to salt accumulation.

Figure 2. (Legend)

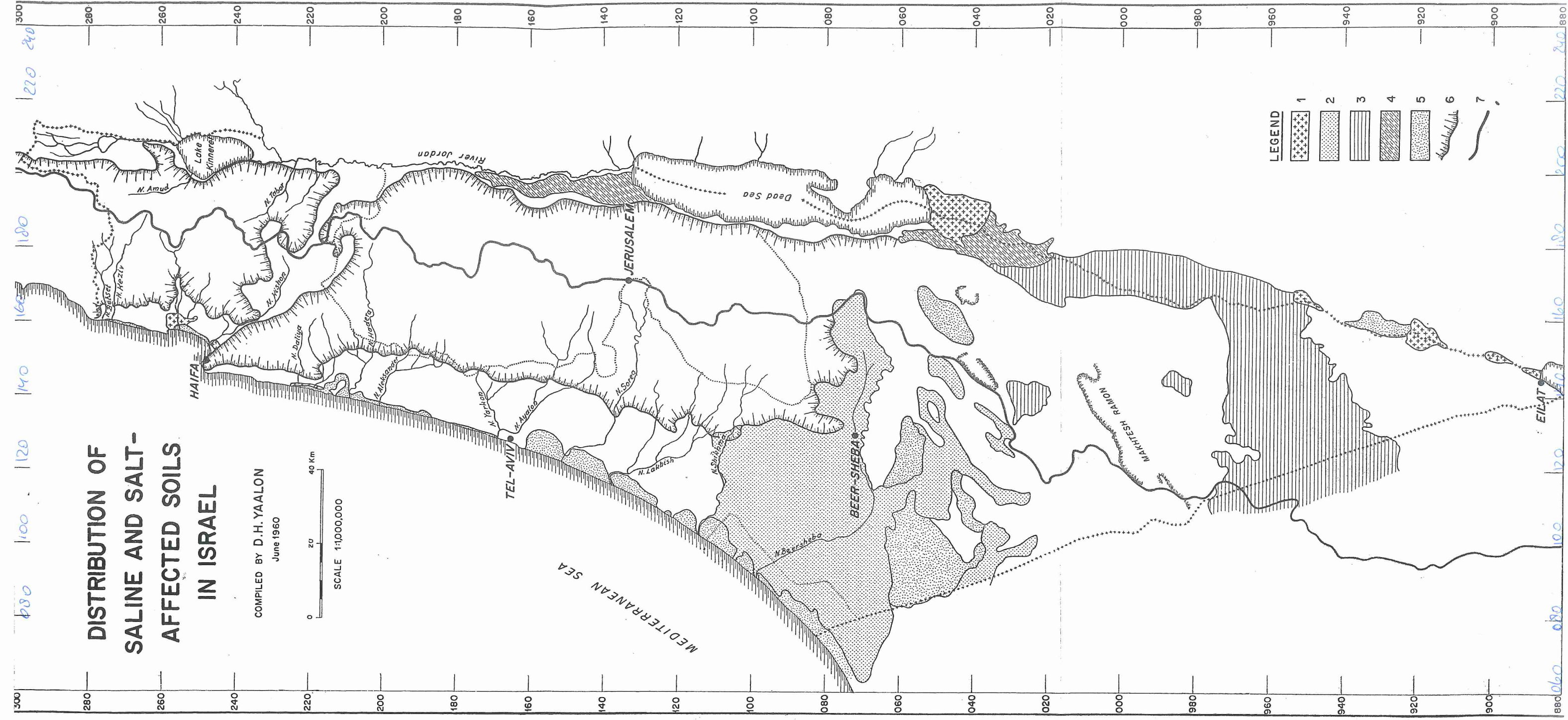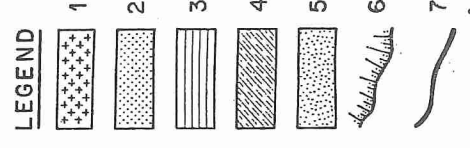|	I	II	III	IV
Type of moisture regime	Normal (percolative)	Epipercolative	Amphipercolative	Subpercolative
Precipitation evaporation ratio	P ≫ E most of the year	E ≫ P most of the year	Variable with season	E ≫ P except for very short periods
Topography	Flat or sloping lowland	Flat bottomland	Flat bottomland	Mostly flat
Permeability of subsoil	Good to moderate	Poor	Poor to fair	Usually good
Water table	Low	Constantly high	Fluctuating with season	None; dry subsoil
Moisture movement	Outflow of excess moisture	Evaporation and ascending movement of imported water	Alternating downward and upward movement of imported water	Evaporation of 'suspended' water
Origin of salts	Weathered and airborne sea salts leached through the soil profile	Imported by inflowing water	Imported by inflowing water and by precipitation	Imported by precipitation and released by weathering
Mode of accumulation	Adsorption of Na during leaching possible	At surface if water table 1m, in subsoil if deeper	In subsoil at balance between evaporation and leaching	At depth of wetting
Example in Israel (Soil type)	Coastal plain soils (Hamra)	Marshy basins (playa) (Sebha)	Littoral marshes (Solonchak)	Desert soils (Desert pavement and loessial sierozem)

Figure 3

Geographical distribution of saline and salt affected soils in Israel, according to source of salts and mode of their accumulation.

Legend:
1. Littoral salt marshes and desert salines (playas).
2. Area of loess deposition (cf. Figure 4), Middle Pleistocene age.
3. Soil region with dominant occurrence of desert pavement soils (Hammada), mainly Neogene age.
4. Saline soils developed from Lisan Lake marl deposits, Middle Pleistocene age.
5. Coastal sand dunes and inland shifting sands.
6. Morphologic divide, indicating border between depositional and erosional surfaces in the subhumid parts of Israel.
7. Watershed divide.

DISTRIBUTION OF SALINE AND SALT-AFFECTED SOILS IN ISRAEL

COMPILED BY D.H.YAALON

June 1960

SCALE 1:1,000,000

40 Km

LEGEND

1
2
3
4
5
6
7

MEDITERRANEAN SEA

Dead Sea

River Jordan

Lake Kinnereth

HAIFA

TEL-AVIV

JERUSALEM

BEER-SHEBA

EILAT

MAKHTESH RAMON

N. Amud
N. Tabor
N. Meziv
N. Yizfon
N. Daliya
N. Hadera
N. Alekkanoth
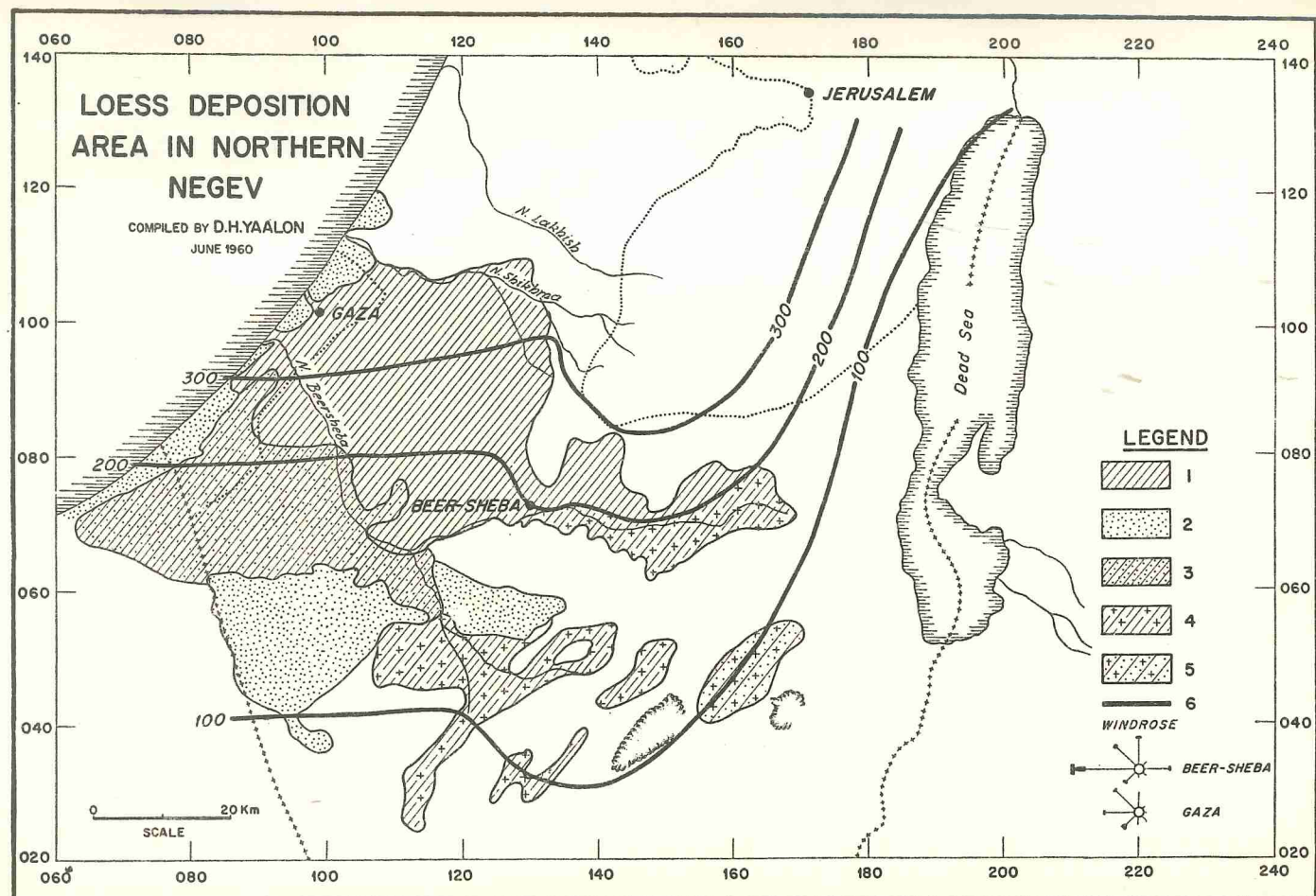N. Yarkon
N. Ayalon
N. Soreq
N. Lakhish
N. Shikma
N. Beersheba

Figure 4

Distribution of chloride salts in the loess deposition area of the Northern Negev.

Legend: 1. Eolian loess, partly redistributed; chloride content less than 0.1%.
2. Dune sand, non-saline.
3. Loess intermixed with shifting sand, non-saline.
4. Loess, chloride content above 0.1%
5. Sands of Neogene age (Rotem basin), somewhat saline in lower layers.
6. Precipitation isohyets (1921-50).

Salinity mainly after Ravikovitch, 1953, with additional data by Yaalon. Precipitation and windrose from Meteorological Service. Northern border of loess deposition area is tentatively drawn.
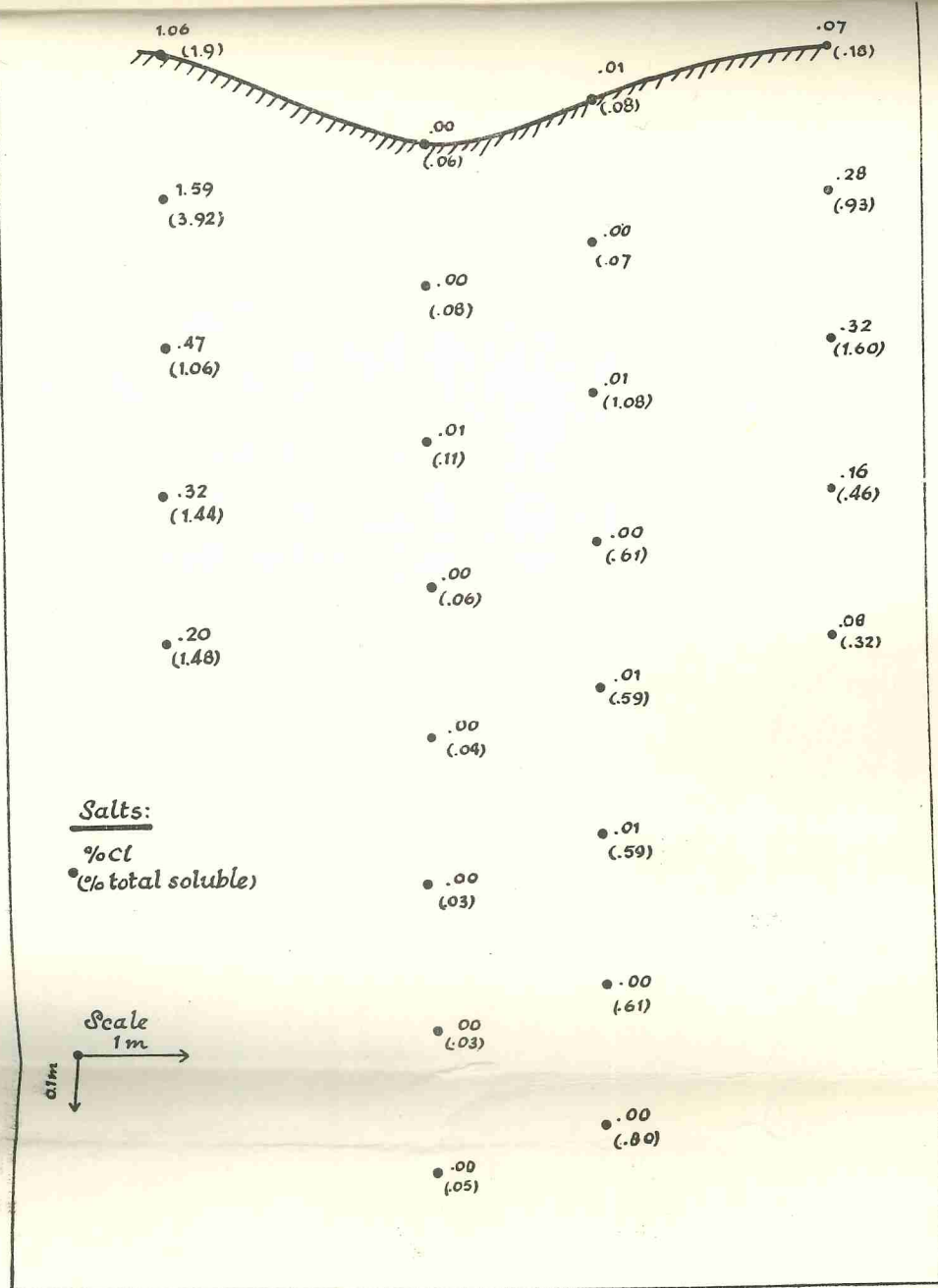
Salts:

% Cl
(% total soluble)

Scale
1 m →

0.1 m ↓

Figure 5

Diagrammatic section of rivulet in desert pavement soil, showing effect of microrelief on salinity distribution (after Karschon, 1953). Width 5.60 m; profile sampled at 25 cm intervals. Data indicate chloride and total soluble salt concentration. Note that in the depression the salts are leached out to a depth of at least 2 m and that on the shoulders maximum salinity occurs at some depth below the surface. Texture of the soils is fairly uniformly sandy, with less than 7% clay and large percentages of gravel (40 – 60%).

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