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MAPPING AREAS OF RECHARGE AND EVAPORATION IN DESERTS BY MEANS OF THEMATIC MAPPER DATA

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C O N T E N T S

MAPPING AREAS OF RECHARGE AND EVAPORATION IN DESERTS

BY MEANS OF THEMATIC MAPPER DATA

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1. INVESTIGATION AND TECHNICAL PLAN

1.1. Summary

The groundwater reservoir of the great basins of North-Africa and Arabia is currently estimated as being 8.10^{14} m^3 (BURDON, 1977). A widespread opinion is that the last relevant recharge took place some 11,000 years ago. There is evidence that some recharge may still take place, but there is no definitive proof and no overall estimation of its extent. Evaporation of this fossil groundwater takes place in depressions with a shallow groundwater table (playas). The first direct estimation of such losses has been given by MENENTI (1984) for the West-Libyan aquifer.

On the basis of literature data one may guess that total losses of groundwater amount to some 10^{10} $m^3 \cdot a^{-1}$ for the North-African basins. Groundwater extraction by pumping probably amounts to some 10^9 $m^3 \cdot a^{-1}$.

From the preceding guesses about the terms of the groundwater balance one may conclude that current development of groundwater resources in deserts is even too conservative, although the inaccuracy of these figures does not allow for a definitive development policy to be chosen.

A second relevant consequence of the figures as given above relates to the current understanding and numerical modelling of the global atmospheric circulation. To this respect it has always been assumed that evaporation from the desert surface is low and equal to the amount of rainfall. As mentioned above such assumption does not hold true.

The goal of the proposed research project is two-fold:

a. to work out an estimate of total groundwater losses by evaporation from the great basins of North-Africa;
b. to establish whether recharge takes place by mapping those areas where rainfall is concentrated by run-off and infiltration is taking place.

Three streams of activity are foreseen:

1) Collection, revision and synthesis of existing studies and data about the aquifer systems of North Africa. A short list of representative literature items is enclosed. The goal of this part of the project is two-fold. From one side a comprehensive picture must be drawn of the structure of these aquifer systems for the entire North-African belt. Secondly the assumptions made within each single study, especially about groundwater exchanges between contiguous aquifer systems, should be critically compared.
2) Estimation of regional groundwater losses by evaporation from playas. To this end the approach presented by MENENTI (1984) will be applied. Remotely sensed areal data, i.e. maps of surface reflectance and surface temperature, will be combined with point ground reference measurements. A test site will be established in the Qattara depression, Western desert of Egypt.
3) Mapping areas of recharge and evaporation in deserts by means of Thematic Mapper data. It is expected that the enhanced multispectral capability of the TM sensor, with special regard to Band 5 and Band 6 will greatly facilitate the distinction of clayey sediments from salt mineral crusts. The occurrence of evaporation is indicated by the presence of dried clayey mud, while the occurrence of evaporation by the presence of salt crusts of varying mineral composition.

1.2. Experimental objectives

As pointed out in the previous paragraph, the here described research program is a component of a wider effort to study the interaction between aquifers and atmosphere in the Saharan belt. The overall scientific goal of the research is to estimate the net groundwater losses from Saharan aquifers.

As regards the investigation involving Thematic Mapper data, the hypothesis to be tested relates to the relationship between the spectral reflectance of bare soils in arid areas and the hydrological regime, via the mineral composition of soil surface. From one side a clear-cut difference in spectral reflectance exists between the dry-lake type of playa surfaces and the salty crust type. In the former case (dry-lake type) light-brown to grey clay sediments remain on the soil surface after ponding and infiltration have taken place. In the latter case (salt crust type) salty crusts of varying composition and structure grow on the soil surface, because of evaporation of groundwater being present at shallow depths.

In the evaporation case many sub-cases should be considered, as relating to the crust mineral composition. This issue will be adressed in Section 1.3.

According to the above the first objective of the present Thematic Mapper research is to assess whether the TM-data allow for accurate discrimination of clayey and salty crusts, which are considered to be reliable indicators of groundwater recharge respectively evaporation. When this first step is successful, it will be investigated whether different hydrous minerals can be discriminated.

1.3. Scientific background

In this section the specific scientific background of the proposed Thematic Mapper research will be discussed. In the following Section 1.4 the expected contribution of TM-data analysis to the overall goal of the investigation into the hydrological regime of Saharan aquifers will be described.

Spectral reflectance of desert terrain in the infrared region (0.5 µm to 6.0 µm) has been studied by HOVIS (1966). This author presented a number of reflectance spectra, as relating to pure and natural minerals. Those data can be considered to show that the TM-Band 5 and TM-Band 6 do indeed enhance our capability of discriminating between different kinds of bare soils. In Table 1 the indices $[(B5-B1)/(B5-B1)]$ and $[(B6-B1)/(B6+B1)]$ are presented, as calculated from the data given by HOVIS (1966); here B1, B5, B6 are reflectances in the TM-Bands 1, 5 respectively 6. The Rosamond dry lake is a typical example of the clayey type of playa crusts, with a 70.7% fraction of particles smaller than 1 µm (KERR and LANGER, 1965). The Death Valley is typical of the salt crust type, with portions of it where the soluble saline content may be as high as 100%, dry weight percentage (KERR and LANGER, 1965).

Table 1. Reflectances (%) of the dry-lake type (Rosamond dry lake) respectively of the salt-crust type (Salt Pool, Death Valley) of playa surface; Thematic Mapper Band 1, Band 5 respectively Band 6 are considered; values of two combinations of such reflectances are shown

	Band 1	Band 5	Band 6	$\frac{(B6-B1)}{(B6+B1)}$	$\frac{(B5-B1)}{(B5+B1)}$
	(5)	(%)	(%)	(-)	(-)
Rosamond dry lake	18	33	27.5	0.21	0.29
Salt Pool, Death Valley	53.5	70	57	0.03	0.13

It appears that the data in Table 1 do support the concept that the multi-spectral Thematic Mapper data will allow discrimination of different kinds of playa surface types. The Thematic Mapper capability to discriminate rock and soil types has been discussed by GOETZ et al. (1983) and ABRAMS et al. (1983), although no specific comments dealing with playa mineralogy and desert hydrology have been given by these authors. A review about spectral features of arid lands has been recently presented by KAHLE (1984).

The intimate relationship between the hydrological regime and the soil mineral composition has been discussed in detail by NEAL (1965a,b, 1969, 1972), with special regard to playas in the USA. A detailed hydrological study of playas in the Libyan desert has been presented by MENENTI (1984), who presented surface reflectance measurements of playa soils with greatly different surface crust characteristics. The occurrence of small, grey clay pan in the dunes of the Idehan Awbari, Fezzan, Libya has been noticed by this author. Similar clayey pans are a widespread occurrence in the Kalahari desert. It seems quite likely that the presence of such sediments relates to ponding and infiltration of the scarce rainfall, after concentration by runoff.

Rainfall, albeit scarce, and dew can modify by re-solution the mineral composition of salty crusts and make it dependent on the weather pattern. Such dynamic character of mineral composition and, therefore, of surface reflectance require that regular and quantitative observations of surface properties are available. Because of the rare occurrence of clouds and of the low rate of change of surface properties, the relatively low temporal resolution of the Thematic Mapper data is not a serious hindrance. Spatial resolution seems to be a major improvement, according to experience gathered in the Libyan Desert (MENENTI, 1984).

A few additional comments will now be given about mineral equilibria in relation to drying - wetting cycles. A fundamental analysis of these topics has been presented by GARRELS and CHRIST (1965), while properties of crusts in playas have explicitly been considered by EUGSTER and SMITH (1965), LANGER and KERR (1966) and VERGOUWEN (1981). The interrelation between the chemical evolution of brines and the hydrological regime of the Lake Magadi basin, Kenya has been modelled by JONES et al. (1977). The issue of cyclic wetting and drying in arid terrain in connection with groundwater has been studied, by means of experiments, by DREVER and SMITH (1978). On the basis of the literature mentioned above, it can be concluded that sufficient scientific knowledge is available about the relationship between the mineralogy of playas, its dynamic nature and the hydrological regime of shallow groundwater bodies. So also this aspect of the present research plan rests on a relatively firm scientific ground.

The present analysis of Thematic Mapper data, as regards their capability to increase our understanding of desert hydrology, has so far been restricted to TM Bands 1 through 6. The TM Thermal Infrared channel (10.42 μm to 11.66 μm) has been intentionally left out of consideration. This band can be useful for surface discrimination, when applied in combination with Bands 1 through 6. The overpass time of the LANDSAT satellites, however, is not suitable for estimations of either the surface temperature amplitude or of representative values of energy fluxes at the surface. This notwithstanding, there may be an enticing perspective for the analysis of these TM-Thermal Infrared data, just because of the early overpass time. Namely, under desert conditions, clay soils and soils with very high salt content may behave in a thermally anomalous way during the first few hours after sunrise, when the air relative humidity decreases rapidly. Such anomalous thermal behaviour relates to the varying nature of the binding between water molecules and the surface of soil particles, when the relative humidity of the air surrounding these particles decreases from say 0.8 to 0.3.

A peculiarity of very dry soils is the possible influence of adsorbed water on the exchange of heat. The adsorbed phase may have an enthalpic content varying with the relative humidity of soil air. This property implies that the adsorbed phase can either store or release heat when the relative humidity of the soil air decreases. The magnitude of this phenomenon can be evaluated for any soil, when its adsorption isotherm and the proper relationship between enthalpy and relative humidity are known. This effect is likely to be relevant in playa soils, because of the particle size and the chemical interactions at the surface of particles and salt crystals. The basic thermodynamic quantities that relate to the process can be determined by laboratory experiments.

To give an impression of the relevance of such enthalpic variations in comparison with the soil heat capacity which would be expected on the basis of soil constituents only, the data presented by SHARMA et al. (1969) for a Molokai clay and by CARY et al. (1964) for a Millville loam will be used. The adsorption isotherms and the curves giving enthalpy in $J.mol^{-1}$ vs. air relative humidity have been combined to obtain a curve for each soil depicting the enthalpy in $J.cm_s^{-3}$, i.e. per unit soil volume, vs. air relative humidity. These curves are presented in Fig. 1.

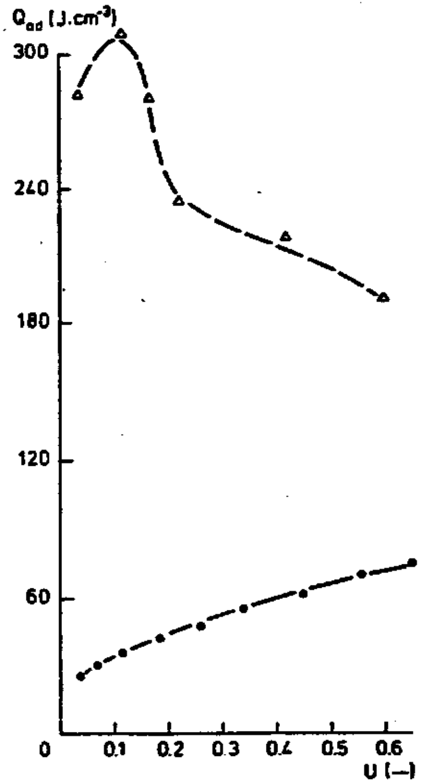

Fig. 1. Enthalpy of adsorbed soil water Q_{ad} per unit soil volume, as calculated for Molokai clay (Δ) with the data given by SHARMA et al. (1969) and for Millville loam (.) with data by CARY et al. (1964), plotted versus relative humidity

It can be assumed that in an upper thin dry soil layer of 1 mm, say, the moisture content and temperature remain in equilibrium with surrounding air of varying relative humidity and temperature. Thus the enthalpy Q_{ad} of the adsorbed phase will change according to Fig. 1. A reasonable daily range of relative humidity for desert climates is between 0.2 and 0.6. Accordingly over this range in Molokai clay an enthalpy amount $\delta Q_{ad} = 7.5 \cdot 10^{4}\ J \cdot m^{-2}$ is released, while in Milville loam $\delta Q_{ad} = 2.9 \cdot 10^{4}\ J \cdot m^{-2}$ is stored. To assess the effect of such heat amounts on soil surface temperature, in first instance the soil heat capacity is determined without taking the rôle of adsorbed water into account. Accordingly the soil heat capacity of both soils is estimated as being $\rho_s c_s = 1.05 \cdot 10^{6}\ J \cdot m^{-3} \cdot K^{-1}$ with U = 0.2, and $\rho_s c_s = 1.2 \cdot 10^{6}\ J \cdot m^{-3} \cdot K^{-1}$ with U = 0.6. Thus some average value $\rho_s c_s = 1.1 \cdot 10^{6}\ J \cdot m^{3} \cdot K^{-1}$ can be applied. A representative daily amplitude for the surface temperature can be chosen as being 30°C. Hence the heat amount released from the storage is $\delta Q = \rho_s c_s \cdot T = -3.3 \cdot 10^{4}\ J \cdot m^{-2}$, which figure must be compared with the $-7.5 \cdot 10^{4}\ J \cdot m^{-2}$ and $+2.9 \cdot 10^{4}\ J \cdot m^{-2}$ given above.

The thermal behaviour of dry clay soils, as described above can be an explanation of the seemingly unreasonable outcome of a thermal infrared survey, carried out at Harper Lake (California) in 1967 (NEAL, 1972). According to Neal the first airborne infrared (4.5 to 5.5 μm) survey of a playa was carried out at Harper Lake (California) in 1967. Large daily amplitudes of surface temperature were observed in soft, friable surfaces where groundwater discharge occurred. Small amplitudes were observed in hard, dry, clayey crusts. It has been pointed out by MENENTI (1984) that the observed behaviour of the clayey crust of Harper Lake can be explained by the heat of wetting being air humidity dependent for that particular soils.

Similar effects, as described above in relation with clay soils, may occur in playas, because of the presence of unstable, hydrous salt minerals. For example, it has been shown by VERGOUWEN (1981) that at Lake Turkana (Kenya) burkeite, $Na_6CO_3(SO_4)_2$, is unstable in the assemblage with thenardite, Na_2SO_4, and trona, $NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O$. It is understood that thermal effects, as due to the difference in enthalpy between possible mineral equilibria, will occur upon re-solution due to rainfall and, to a lesser extent, upon wetting by dew.

It can be concluded that the TM capabilities of discriminating soil mineral composition of playa surface types, in comibnation with estimations of surface temperature (TM Band 7) may prove very useful on behalf of our current understanding of the intèrrelation between soil mineral composition and thermal behaviour.

1.4. Experimental plan

The here described research program, as focussed on the analysis of multitemporal Thematic Mapper data, is a contribution to a wider investigation into the groundwater resources of the Saharan belt, as planned by the Institute for Land and Water Management Research. So, to explain how the Thematic Mapper research fits into this wider program, the main steps of the latter will be mentioned.

1.4.1. Groundwater resources of the Saharan belt

A detailed list of the successive steps involved in the wider research program can be given as specified below:

- A map with location of playas will be prepared on the basis of existing and available geohydrological maps and reports and of photographic satellite imagery. METEOSAT and NOAA digital satellite data will also be collected.
- A geohydrological synthesis about the aquifer systems of the Saharan belt will be worked out in the form of reports and maps.
- Remote sensing techniques will be applied to various locations in North-Africa. Satellite data with different resolution (METEOSAT, DMSP, NOAA, LANDSAT, SHUTTLE) will be applied to map playa basins, to estimate water depth (where open free water is present) and to estimate shallow groundwater table depths. The approaches presented by AKHAVI (1980) and MENENTI (1984) will be applied.
- The soil water regime in unsaturated - saturated soil will be studied for steady and unsteady state conditions, with the help of numerical simulation models developed at the Institute for Land and Water Management Research (ICW), e.g. see FEDDES et al. (1978). The relevant soil hydrological properties will be determined on undisturbed soil cores and the results of calculations tested against measurements of soil water content and of shallow groundwater table depth, as collected on a few locations in the Sahara belt (Egypt, Lybia).
- Collection of field data. Field data about the soil water and energy

balance of playas are already available for a few sites in the Libian desert (MENENTI, 1984). A test site will be established in the Qattara depression, Western Desert of Egypt. Relevant groundwater discharge takes place in this area, and its role in the water balance of groundwater reservoirs has been underscored by EZZAT (1977, 1983) and AMER et al. (1981).

The following data collection program is foreseen:

1st year: 2 field trips (15 days each) to choose the test sites, to organize the operational details of the data collection program, to collect data and reports specifically dealing with the selected test site.

2nd year: 4 data collection trips (20 days each): undisturbed soil cores will be collected of the top soil (upper 20 cm) and of the lower soil layers (close to shallow water tables); groundwater table depth and soil moisture content will be measured. At the selected test site some 30 sampling points will be considered.

1.4.2. Analysis of Thematic Mapper data

As described in Section 1.3, the objective of the analysis of Thematic Mapper data is the discrimination of different types of bare soil surfaces, as relating to the occurrence of salt minerals and clayey sediments.

The characteristics of such surficial encrustations are greatly modified by rainfall and evaporation. Multitemporal data, therefore, will have to be applied. The selection of suitable periods has to be made on the basis of rainfall data. As an example, in Table 2 rainfall data as collected at Hun, Libya are presented. A first-hand selection of suitable periods is: March, beginning of June, end of August, November. Additional rainfall data will be considered, especially in relation with the test-

Table 2. Monthly maximum (R_X) and average (R) rainfall (mm) at weather station Hun, Libya (1935-1978)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
R_X	34.4	21.8	13.7	34.4	42.2	4.7	0.0	1.3	20.1	47.3	19.9	22.3
R	2.9	2.9	2.2	2.8	4.7	0.5	0.0	0.1	3.4	6.2	2.1	2.3

sites (see Paragraph 1.4.4). It can, however, be concluded that Thematic Mapper data will be needed on four dates during two yearly cycles. Photographic products will be needed for the first yearly cycle and digital data for the second one. A two-fold use of TM data is foreseen:

- photographic products will be used to prepare a map of the test sites (see Paragraph 1.4.4);
- digital data products will be applied to determine surface reflectances and surface temperatures.

An overview of the required Thematic Mapper data is given in Table 3. It should be noted that the acquisition of photographic products must not necessarily match a very strict schedule, since data of 1983 and 1984 also are suitable for this preliminary mapping of the test sites. Moreover, these photographic data must not coincide with field-data collection activities. These data should be delivered prior to the second field trip in 1985. The schedule of data acquisition in 1986 is somewhat strict, because of the field-data collection activities. Delivery of digital data, however, is not so strict, since the analysis effort will be initiated in 1986 and concentrated in 1987. The test sites (Paragraph 1.4.4) will be chosen so as to fall within a single TM-quarter scene, thus limiting the total data requirement to 56 items of photographic imagery and 8 CCT-s.

Photographic imagery will be applied to work out a map of the test sites depicting the physiographic units relevant to the scope of the investigation. It is expected that this photo-interpretation effort will give a first qualitative impression about the relationship between spectral features and soil mineral composition, as envisaged in Section 1.2. It is also expected that the field data collection program will be more effectively planned and carried out, by combining the analysis of the photographic data with the findings of the field reconnaissance trips, as being planned during 1985.

Digital TM data products will be applied to determine surface reflectances in the relevant spectral bands. To this end a number of pre-processing stages will have to be gone through:

Table 3. Conspectus of Thematic Mapper data required on behalf of the here described investigation (ICW, Wageningen, The Netherlands)

Product	Amount	Acquisition	Delivery	Remarks
480 mm positive film; full scene; all the bands	2 sites x 4 passes x 7 bands = 56	March; 1 to 15 June; 15 to 31 August; November	July 1985	LANDSAT 4 and 5 data during 1983 and 1984 also are suitable
CCT; quarter scene; system corrected data	2 sites x 4 passes = 8	March; 1 to 15 June; 15 to 31 August; November; during 1986	three months after acquisition	two suitable dates will be indicated before each field data collection trip in 1986

- calibration;
- correction for sun zenith angle and surface exposure (dip and azimuth);
- correction for atmospheric effects;
- correction of the multitemporal data set for the varying intensity of incoming solar radiation;
- co-registration of the multitemporal data set with a ground reference grid.

The corrected data will then be correlated with:

- ground reference data on spectral reflectance and soil composition;
- hydrogeological features of the area;
- soil water balance measurements.

For the analysis of digital data to be successful a number of ancillary data are needed and they are described in Paragraph 1.4.3.

Assuming that all the preceding steps have been successful, maps depicting surface units with a similar mineral composition of the soil surface will be prepared.

1.4.3. Ancillary data

The following list of ancillary data can be given, as corresponding with the successive stages of analysis, as described in the previous Paragraph 1.4.2.

A. Pre-processing of digital data products:

- topographic maps of test sites to obtain a ground elevation model for proper calculation of surface reflectance;
- solar radiation for determination of atmospheric transmittance, as needed to correct for atmospheric effects and to normalize the multitemporal data set for the varying intensity of incoming solar radiation.

B. Correlation of TM data with ground reference data:

- spectral reflectance measurements;
- literature dealing with groundwater quality and salt minerals in the Qattara depression;
- mineralogical analyses of soil, brine and crust samples;

- chemical composition of groundwater;
- soil water fluxes as determined by the soil water balance method and by means of soil water flow simulation models, on the basis of field measurements (see Paragraph 1.4.1).

1.4.4. Selection of test sites

As anticipated in Paragraph 1.4.1 an important feature of the here described investigation is that the TM data will be combined with ground reference data, to be collected in the Qattara depression, Western Desert of Egypt. The reason for this choice is two-fold:

A. The Qattara depression itself is an important natural discharge area of the Nubian sandstone aquifer system of the Western Desert of Egypt. Furthermore the fresh water bearing formation crops out to the East of the depression and, according to EZZAT (1983), recharge may take place some 100 km to the East of the depression. This circumstance would simplify the logistical aspects of the field data collection program.

B. A numerical simulation model has been established for the Nubian sandstone aquifer of the Western Desert, Egypt (AMER et al., 1981). It will, therefore, be possible to evaluate the estimations of evaporation and recharge by applying them as boundary conditions for the above mentioned simulation model.

The test sites will actually be some 100 km^2 in extent and they will be selected to fall within a single TM-quarter scene. Accordingly it is expected that a final selection will be made prior to the second reconnaissance trip (November 1985). As regards the test site for the recharge experiments, an alternative selection might be in the southern portion of the regional aquifer system. The latter, however, would be a logistically awkward solution. The scope of the first reconnaissance trip (May - June 1985) is, inter alia, to assess the logistical difficulties of the on-site field activities.

1.4.5. Chronological sequence of investigation phases

A description of the organizational aspects of the investigation will be presented in Chapter 2. Here the sequence of the main steps foreseen by the investigation will be summarized.

1st project-year (1985):

- January through March: collection of literature items; request for Thematic Mapper photographic data products is filed;
- May - June: first reconnaissance trip in Egypt (see also Paragraph 1.4.1);
- July through October: interpretation of TM photographic imagery to work out the maps of the test-site area; definitive selection of test sites; integrative analysis of literature;
- November: second reconnaissance trip to the chosen test sites;
- December: planning of the field data collection program is initiated.

2nd project-year (1986):

- January and February: planning of the field data collection program continues; the first results of the analysis of digital satellite data with a coarser resolution (NOAA/AVHRR, METEOSAT) become available (see also Paragraph 1.4.1); first request for TM digital data product is filed (see Table 3);
- March: first field data collection trip;
- April and May: first analysis of field data; second request for TM digital data (see Table 3);
- June: second field data collection trip;
- July: analysis of field data; analysis digital TM data, first pass (March); third request for TM digital data;
- August: third field data collection trip;
- September and October: analysis of field data; analysis of digital TM data, second pass (June); fourth and last request for TM digital data;
- November: fourth and last field data collection trip;
- December: analysis of field data; analysis of digital TM data, third pass (August).

3rd project-year (1987)

- January through March: analysis and processing of field data and TM digital data products are completed;
- April through October: comparative and integrative analysis of TM and field data is completed; estimations of evaporation and recharge applying to the Nubian sandstone aquifer of the Western Desert of Egypt are worked out and evaluated by means of the aquifer simulation model;
- November and December: preparation of the Final Report in draft form.

1.5. Anticipated results

Many details about the expected results of the investigation, as it has been described in the preceding sections, have already been given. Here the results, as expected from the research program dealing with the groundwater resources of the Saharan belt (see Sections 1.1, 1.2 and Paragraph 1.4.1), will be mentioned. It is understood that a more complete picture of the expected outcome of the here described investigation will be thus obtained.

Besides of what has already been mentioned in the preceding pages, it is expected that the proposed research will give:

- a hydro-geological synthesis about the North-African aquifers;
- satellite-based maps of playas in the Saharan belt;
- detailed experimental data and modelling results about the soil water balance of a portion of the Qattara depression, Western Desert of Egypt;
- a theoretical approach, as based upon analytical solutions of the heat and water diffusion equations, to translate the available geological and environmental knowledge into the patterns which are expected to appear in thermal infrared satellite images;
- a procedure to use the LANDSAT Thematic Mapper data to map recharge respectively evaporation areas.

1.6. Significance of the investigation

The rationale for undertaking the research project which is herewith described is that an overall picture of the interaction between aquifers and atmosphere is needed for the Saharan belt. It can be expected that such a picture will suggest a re-assessment of management and development of groundwater reservoirs at a more detailed scale. It can also be expected that the entity of the difference between evaporation and rainfall in the Sahara will trigger additional research and computer based experiments to assess the sensitivity of the global atmospheric circulation to the net water loss of the Sahara. It should be recalled that the net water loss of the Sahara is usually assumed to be zero in numerical models of the global atmospheric circulation.

In many arid and desert areas of the world irrigated agricultural land has been augmented by mining groundwater. In some cases the risks

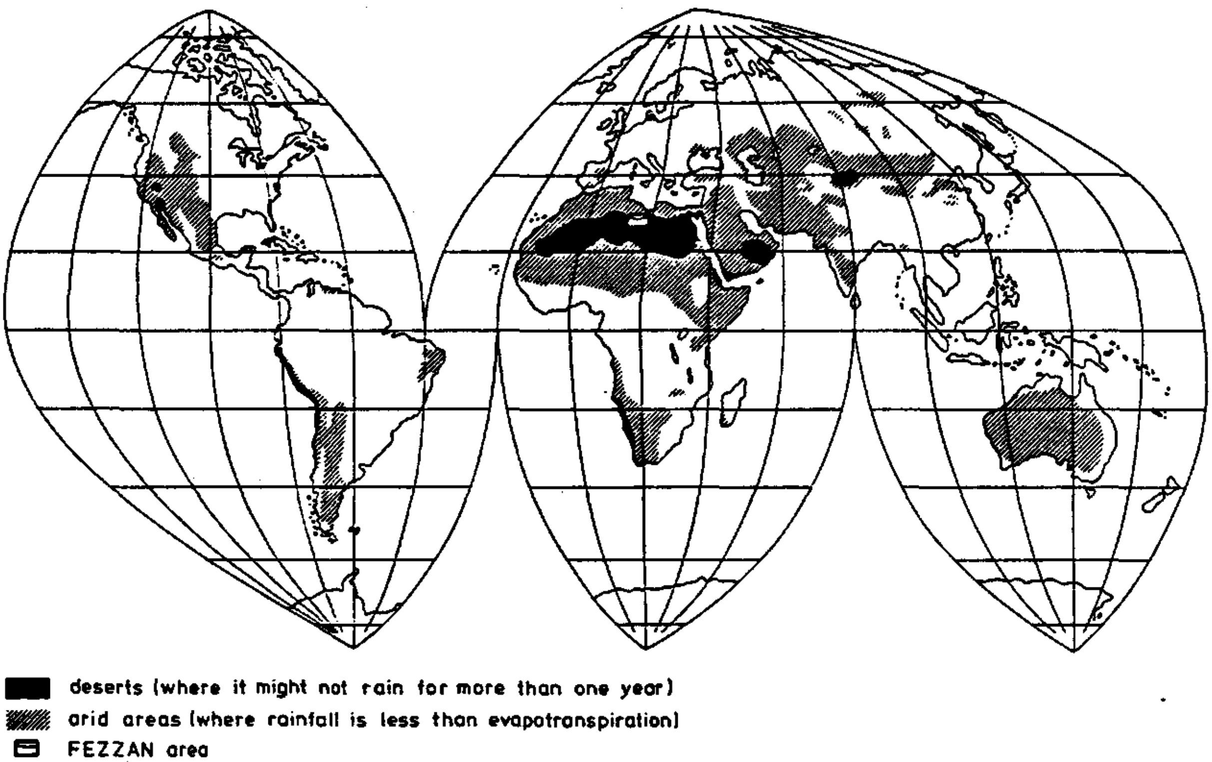

Fig. 2. Deserts and arid areas of the world

involved have already become hard facts. In some of the states where groundwater is being mined from the Ogalalla aquifer (USA), the forced re-conversion to dry farming is expected to begin soon.

Groundwater mining in North-Africa nowadays might be at so an early stage, that proper assessment of the future availability of groundwater resources may significantly improve the perspectives of irrigated agriculture.

To underscore the relevance of the issues discussed so far, in Fig. 2 a map of desert and arid areas in the world is presented. The expected outcome of the here described investigation would improve our knowledge of groundwater hydrology in these regions. The first attempt to combine ground reference measurements with satellite data to map regional evaporation from playas relates to the Fezzan area, which also is indicated in Fig. 2 (see MENENTI, 1984).

From a strictly practical point of view, the most relevant applications of the results of the proposed research are to be expected for regional hydrogeological studies, such as being undertaken by North-African and Arabian countries. Exploitation of groundwater reservoirs, e.g. to supply the irrigated areas of Sahara, is comparable or smaller than the groundwater losses by evaporation. It is, therefore, clear that no reliable long term estimate of groundwater availability and cost can be made without proper knowledge of groundwater losses by evaporation. Both present losses and their relation with the expected groundwater drawdown have to be assessed.

A relevant consequence of the above is that the feasibility of new irrigated areas can only be assessed when the groundwater losses by evaporation are known. These difficulties have been emphasized in UNESCO (1972) and MENENTI (1984).

Recent research proved that the major part of evaporation losses occurs in places with very shallow groundwater tables (playas). Moreover, knowledge of the hydrological regime of playas is required in establishing water management policies to avoid the salinization hazard due to groundwater flow from playas towards the oases.

The mechanism of evaporation in nearly dry, hot soils, with the additional complication of having a complex structure and a very large salt content, is a poorly understood process. New concepts concerning evaporation from bare soil have been worked out and tested with real data on evaporation from playas in a part of the Libyan desert (MENENTI, 1984).

It must be stressed once more that our present knowledge of desert hydrology is very scarce. As an example it may be mentioned that MARGAT and SAAD (1984) tried to give an overview of the water balance of deserts' aquifers. The occurrence of groundwater losses by evaporation was completely overlooked by these authors. Furthermore it must be pointed out that the current estimations of evaporation from and recharge of groundwater reservoirs in deserts have usually been established by means of numerical simulation models only. The latter implies that no direct experimental determination of these two terms of the reservoir water balance is available. As regards evaporation only, the first attempt to do so has been presented by MENENTI (1984).

2. MANAGEMENT PLAN

A reasonably detailed list of the successive steps to be undertaken on behalf of the successful conclusion of the here described research program has already been given in Paragraph 1.4.5. The present Management Plan, however, may be reviewed and evaluated independently of the Investigation Plan. So the schedule, as already given in Paragraph 1.4.5, is re-presented below.

2.1. Schedule of operations

The sequence of the main steps foreseen by the investigation can be summarized as follows:

1st project-year (1985):
- January through March: collection of literature items; request for Thematic Mapper photographic data products is filed;
- May - June: first reconnaissance trip in Egypt (see also Paragraph 1.4.1);
- July through October: interpretation of TM photographic imagery to work out the maps of the test-site area; definitive selection of test sites; integrative analysis of literature;
- November: second reconnaissance trip to the chosen test sites;
- December: planning of the field data collection program is initiated.

2nd project-year (1986):
- January and February: planning of the field data collection program continues; the first results of the analysis of digital satellite data with a coarser resolution (NOAA/AVHRR, METEOSAT) become available (see also Paragraph 1.4.1); first request for TM digital data product is filed (see Table 3);
- March: first field data collection trip;
- April and May: first analysis of field data; second request for TM digital data (see Table 3);
- June: second field data collection trip;
- July: analysis of field data; analysis digital TM data, first pass (March); third request for TM digital data;
- August: third field data collection trip;

- September and October: analysis of field data; analysis of digital TM data, second pass (June); fourth and last request for TM digital data;
- November: fourth and last field data collection trip;
- December: analysis of field data; analysis of digital TM data, third pass (August).

3rd project-year (1987):

- January through March: analysis and processing of field data and TM digital data products are completed;
- April through October: comparative and integrative analysis of TM and field data is completed; estimations of evaporation and recharge applying to the Nubian sandstone aquifer of the Western Desert of Egypt are worked out and evaluated by means of the aquifer simulation model;
- November and December: preparation of the Final Report in draft form.

2.2. Organization of project activities

The investigation will be carried out by three institutions:

- Institute for Land and Water Management Research (ICW), Wageningen, The Netherlands
- Water Research Centre, Cairo, Egypt
- National Aerospace Laboratory (NLR), Amsterdam, The Netherlands

The tasks of each institution will be briefly described.

Institute for Land and Water Management Research (ICW)

The ICW will carry out the following tasks:

- project management; satellite data analysis; field data collection; preparation of Final Report. Personnel: Dr. M. Menenti, Principal Investigator (3 man-years) and a research assistant (1 man-year);
- hydrogeological synthesis. Personnel: Dr. J. Wesseling (0.6 man-year) and Ing. E. van Rees Vellinga (2.3 man-years);
- modelling of soil water flow and analysis of soil water balance measurements. Personnel: Dr. R.A. Feddes (0.5 man-year) and Ing. W.A.J.M. Kroonen (1.6 man-year);
- laboratory analyses of soil and water samples. The analyses will be

done by the staff of the Laboratory of Soil Physics and of the Laboratory of Soil and Water Quality, both belonging to the ICW.

Water Research Centre

An agreement has already been reached with the Water Research Centre, Ministry of Irrigation, Cairo, Egypt as regards the here described research project. This Water Research Centre will participate to the field activities and to the research at ICW, and will apply the there available simulation model of the Nubian sandstone aquifer (Western Desert of Egypt) to compare with the satellite based estimations of total evaporation losses. Personnel: 1 scientist (1 man-year)

National Aerospace Laboratory (NLR)

The NLR is the Dutch National POint of Contact (NPOC) of ESA/ EARTHNET and a major image processing facility is available at NLR. Accordingly NLR will be responsible for satellite data procurement and will make the image processing system freely available for the needs of the investigation. The NLR will also contribute by modifying, improving en eventually enlarging the presently available image processing software.

2.3. Interinstitutional aspects and lines of authority

The Water Research Centre will operate as a subcontractor of ICW. The NLR will also operate as a subcontractor of ICW as regards satellite data procurement and (partly) data processing. Moreover the NLR will function as an interface with NASA and ESA/EARTHNET as regards satellite data procurement. As regards the ICW it is pointed out that all the tasks, with the exception of the analyses at the Laboratory of Soil and Water Quality, will be performed by personnel of the Department of Water Management, with Dr. J. Wesseling being the Head and Dr. R.A. Feddes being the Deputy Head of this Department. The successful conclusion of the here described investigation, therefore, will be a responsibility of the Department as a whole. It is believed that such an organizational configuration will greatly enhance the effectiveness of the investigation.

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4. BIOGRAPHICAL INFORMATION ABOUT THE PROJECT TEAM

Principal investigator: Dr. M. Menenti

Dr. Massimo Menenti was born in Rome on 9 July, 1949, where he attended High School from 1963 to 1968. In 1972 he obtained (cum laude) the degree of Dottore in Fisica at the University of Rome with, in partial fulfillment, a thesis on the water balance of the river Po watershed. From 1973 to 1974 he attended a post graduate school on Physics of the Solid and Liquid State, while working at the Office of Agricultural Ecology of the Italian Ministry of Agriculture and Fisheries. He then joined TECNECO, a state-owned engineering company dealing with management of water resources and environment. There he contributed to a number of projects, both in Italy and abroad, among which an experimental study on the water requirements of natural vegetation (1975-1976), an advisory mission to the Venezuelan Ministry of Environment at Caracas (1979) and an Italo - Argentinian joint research project (1977-1982) on the optimization of irrigation water use. In 1977 he became involved under contract from the state-owned engineering company Aquater in the study of the West-Libyan aquifer system. His tasks were:

a) the development of an approach to estimate regional evaporation of desert groundwater;
b) planning and on-site management of field experiments in the Libyan desert.

In 1979, in the framework of this study, he was seconded for nine months to the Institute for Land and Water Management Research (ICW). From 1 September 1980 he is Senior Scientist in the Department of Water Management of the ICW. In 1984 he obtained the Doctor of Science degree at the Agricultural University of Wageningen. He is a member of the Steering Committee of the International Satellite Land Surface Climatology Project (ISLSCP), as carried out by COSPAR, IAMAP and UNEP.

List of some significant papers:

MENENTI, M., 1980. Defining relationships between surface characteristics and actual evaporation rate. Tellus Newsl. 15, JRC Ispra. 21 p.

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Investigator: Dr. R.A. Feddes

Dr. Reinder Auke Feddes was born on 2 November 1939 in Gramsbergen, The Netherlands. He obtained the Master of Science degree of the Agricultural University in Wageningen with honours in 1966 with as main subjects: agro-hydrology, irrigation, soil survey investigations and land development. In 1971 he obtained the Doctor of Science degree at the same university on the subject 'Water, heat and crop growth'. From 1966 to present he is employed by the Ministry of Agriculture at the Institute for Land and Water Management Research (ICW), at present being Deputy Head of the Department of Water Management. His work includes:

- modeling unsaturated flow in soils - transpiration of crops - production of crops;
- agro-meteorological and agro-hydrological problem solving (irrigation, drainage, groundwater extraction, etc.), application of remote sensing techniques;
- lectures for post-graduate students in international courses;
- representation of Institute in national and international working groups (e.g. EC, WMO, Euratom);
- consultancies for Dutch International Technical Assistance Department (e.g. Pakistan, Israel, Saudi-Arabia);

- participation, as advisor, to the Rain Harvesting project, as carried out at the Institute for Desert Research, Sede Boger, Israel

List of some significant papers:

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Investigator: Ing. E. van Rees Vellinga

Ing. E. van Rees Vellinga, born in 1923, obtained the degree of B.Sc. from the Agricultural College in Boskoop (The Netherlands). From 1945 till 1951 he was a manager of various large agricultural holdings (plantations) in Indonesia. Upon his return in 1951 he got a training in geology at the Dutch Geological Service. Working under supervision of Dr. de Ridder, Professor in Geohydrology of the Free University of Amsterdam he got an additional training in geohydrology. Since 1958 he is working at the Institute for Land and Water Management Research in Wageningen, where he is responsible for the geohydrological research. A list of publications from his hand is attached.

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