USE OF SATELLITE REMOTE SENSING IN MAPPING IRRIGATED LAND-USE

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ABSTRACT

Irrigated agriculture is and probably always will be the major consumer of our natural water resources Irrigation takes place during different times of the year in a widely scattered area. Updating our information on growth in this field by conventional field surveys is rapidly becoming impractical and extremely costly. Remote sensing is a real alternative.

1. INTRODUCTION

Irrigated land use covers roughly 1.000 000 ha of land in South Africa and consumes about 70 percent of our bulk water supplies largely from surface run-off. Vegter (1983) estimates that based on 1978 data approximately 17 percent of our irrigated land is supplied from boreholes, wells and springs.

Three institutional categories of irrigation can be separated: State Water Schemes, Irrigation Boards and Private. The estimated distribution and the observed growth between 1965 and 1978 are given in Table 1 (Van Robbroeck, 1983)

TABLE 1 Distribution of irrigated land use over three institutional categories and the observed growth rate during 1965-1978.

		Annual growth rate
State Water Schemes	19%	1,55%
Irrigation Boards	22%	1,47%
Private	59%	3,34%

Total water consumption is presently estimated at 9000 x $10^6 m^3$ per annum which is expected to increase to 16 000 x $10^6 m^3$ by the year 2010.

The two largest single State Water Schemes are Vaalhartz (33 000 ha) and Loskop (16 500 ha) comprising 5% of the total irrigated area. Although irrigation on Schemes and Boards is fairly well known and controlled there are large areas where irrigated land use is not so well known.

In a recent analysis of the Vaal water supply system our Directorate of Planning concluded that there could be a possible 65 000 ha of irrigated land use not presently on record.

As our planning options are becoming more urgent and sophisticated it should be obvious that a good base of factual knowledge about who is irrigating where and when is a prerequisite for the future development of our water resources.

2. COMPETITION FOR WATER

Planning requirements are not the only consideration for wanting to monitor our irrigated land use. Water supply for irrigation must compete with other users and because industrial and domestic supplies require a high degree of assurance, the assurance for agricultural supplies will probably decrease in future. Therefore it will become necessary to monitor the degree of soil moisture stress on scheduled irrigation land in order to assess the effects of imposed water restrictions during droughts.

3. LEVELS OF MONITORING

For the purpose of this paper three levels of land cover mapping will be considered:

LEVEL 1: Separating irrigated from non-irrigated land use.

LEVEL 2: Distinguish between different crop types within the irrigated land.

LEVEL 3: Assessment of water stress, yield prospects and water use.

4. FUNDAMENTAL BACKGROUND

Green, healthy vegetation with a high degree of ground cover reflects more radiation in band 7 and less in band 5. The successful separation between irrigated and non-irrigated land therefore hinges strongly on the contrast between the greeness of its cover and that of its surrounding environment (see Plate 1). Fortunately we may assume that irrigation is practised to raise the vigour of the vegetation above that of the natural surroundings in order to produce more photosynthetic products.

Level 1 mapping can therefore be expected to yield good results if one can use imagery taken in a time of maximum contrast between irrigated and dryland crops. However, South Africa is characterised by the highly variable nature of its rainy season. In areas where supplementary irrigation is practised during the rainy season one may expect that during wet years it will be more difficult to distinguish between irrigated and non-irrigated land. In the more arid parts of South Africa this problem will seldomly occur. The same principle applies to crops such as vine and sugar cane where irrigated and non-irrigated versions occur intermingled. This problem is presently researched by Zietsman (1982) in the Western Cape.

Another problem is encountered with vines and orchards where the canopy cover is not full and spectral signature is largely polluted by that of the bare soil or undergrowth. In such cases it may be difficult to distinguish between orchards and other incomplete cover types. In such conditions the reflective properties of the soil become an important consideration.

Level 2 mapping of crop types cannot immediately be based on one single image. For this kind of mapping one must use multitemporal imagery. The selection of imagery must be based on a sound knowledge of individual crop calenders including planting dates, various development stadia and harvesting times. Much information on a general basis can be obtained from Green (1985) the famous new "Green book" of the Department of Agriculture and Water Supply.

Level 3 mapping is largely based on the fact that actual evapotranspiration of vegetation covers can be related to the temperature difference between the vegetation surface and the ambient air temperature. Jackson, Reginato and Idso (1977) used the following equation:

$$ET = R_N - B\,(T_s - T_a)$$

where:

ET	= evapotranspiration (mm d^{-1})
R_N	= the net radiation equivalent
B	= a local empirical factor
T_s, T_a	= the temperature of the vegetation surface and the ambient air.

Plants evaporate water mainly as a precaution to overheating. Radiactive temperatures can be measured in the thermal infra-red waveband and this data is provided on the Landsat thematic mapper in a 120 m resolution. The spectral resolution is such that temperature differences of 0,3°C can be observed (Nieuwenhuis, 1980).

5. METHODOLOGY

Two basic techniques can be used:

- Visual, manual or eyeball techniques
- Image processing techniques

Because the human brain has a very strong capability for pattern recognition a combination of the two techniques usually gives the best results. One can manually cut out riparian vegetation or certain vleis which are obviously not irrigated. Generally, more complex methods result in more accurate results but accrue a higher overall cost (Kolm and Case, 1984).

At the Hydrological Research Institute we have obtained first hand experience with these techniques but before results will be discussed a brief summary will be given of each technique tested.

5.1. Eyeball technique

Stickler (1985) carried out various manual techniques using false colour prints. He concluded that for various reasons a scale of 1:100 000 is recommended. He evaluated four techniques for measuring areas on such images:

- dot-count using special dot-count transparents
- grid square filling on transparent overlays using a 3 mm spacing.
- video image analyser, using prints from the 1:100 000 transparencies using different filters. The method is expensive and not reliable.
- computer digitising using a large Tectronix system.

5.2 Image processing techniques

Two methods have been used so far:

- digital classification using all four bands
- greeness ratios using band 5 and band 7.

The main problem with supervised classifications is the ground reference data. This can either be obtained from ground or field surveys or it can be selected from the

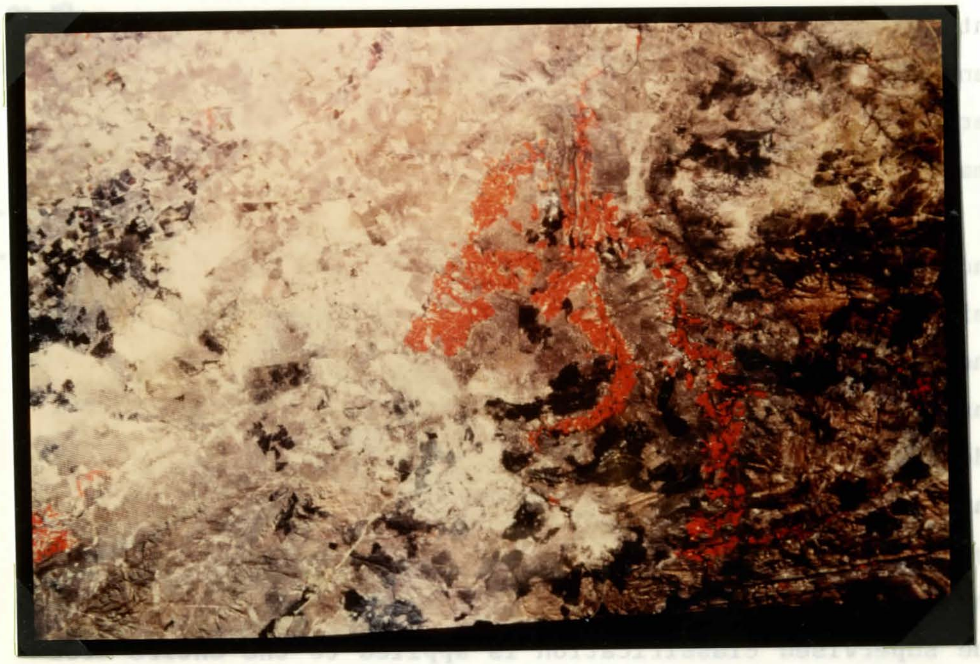

PLATE 1: THE LOSKOP SWS ON 10 SEPTEMBER 1972

PLATE 2: CENTRAL PIVOT IRRIGATION, TUGELA, SEPTEMBER 1983

image to be classified, provided there is little doubt about the validity of the training area. If we are only interested in level 1 mapping of irrigated areas the central pivot system of irrigation has provided us with a very useful ground reference point (Plate 2, September 1983 image).

Another method used was the CWIC method (Classification by Weighted Interative Clustering) formulated by the NPRL of the CSIR. This is a combination of the better parts of unsupervised and supervised clustering. Training areas are identified, concentrated and then subjected to an unsupervised classification in order to obtain a representative signature for our area of interest. When the analyst is satisfied with the classification result, the supervised classification is applied to the entire area using maximum likelihood techniques.

The vegetation index or even simple band 7/band 5 ratios can be used to distinguish between different degrees of green cover. The basic concept is illustrated in Figure 2 after Flavel (1980). The method is based on a certain cut-off threshold ratio that will differentiate between irrigated and non-irrigated land use. Turner (1984) also showed that the ratio can be used to separate winter wheat from other vegetation on the Highveld. This is illustrated in Figure 1.

The technique is presently being used to determine the irrigated area in the Vaal system by Brunette, Kruger and Stoffberg in consultation with the HRI.

6. SUMMARY OF EXPERIENCE GAINED SO FAR

Level 1 mapping has been carried out on various areas in South Africa using both manual and image processing techniques. A summary of the areas covered is given in Table 2.

TEMPORAL PLOT OF VEGETATION RATIO FOR WHEAT 1981, 1982, 1983

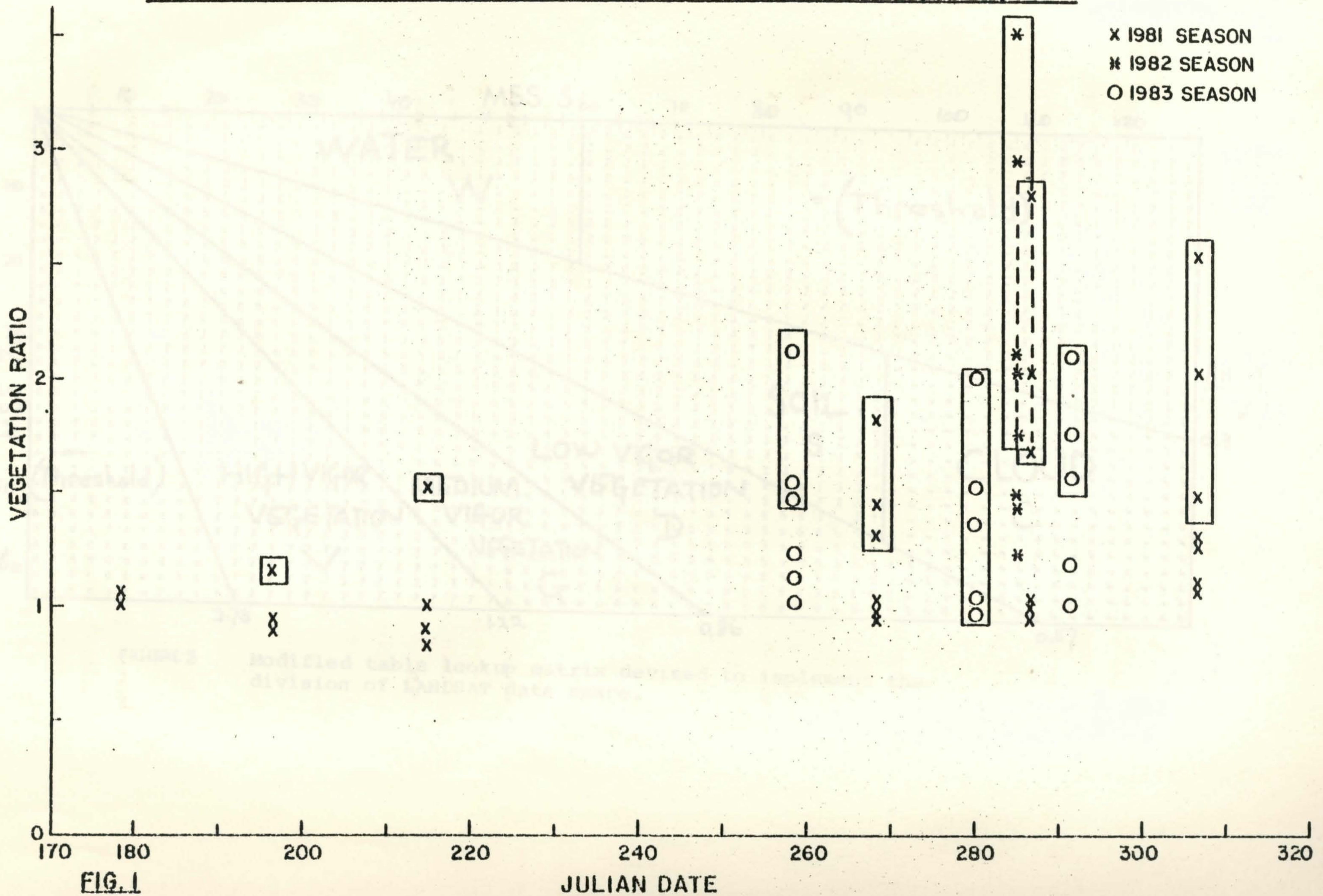

FIG. 1

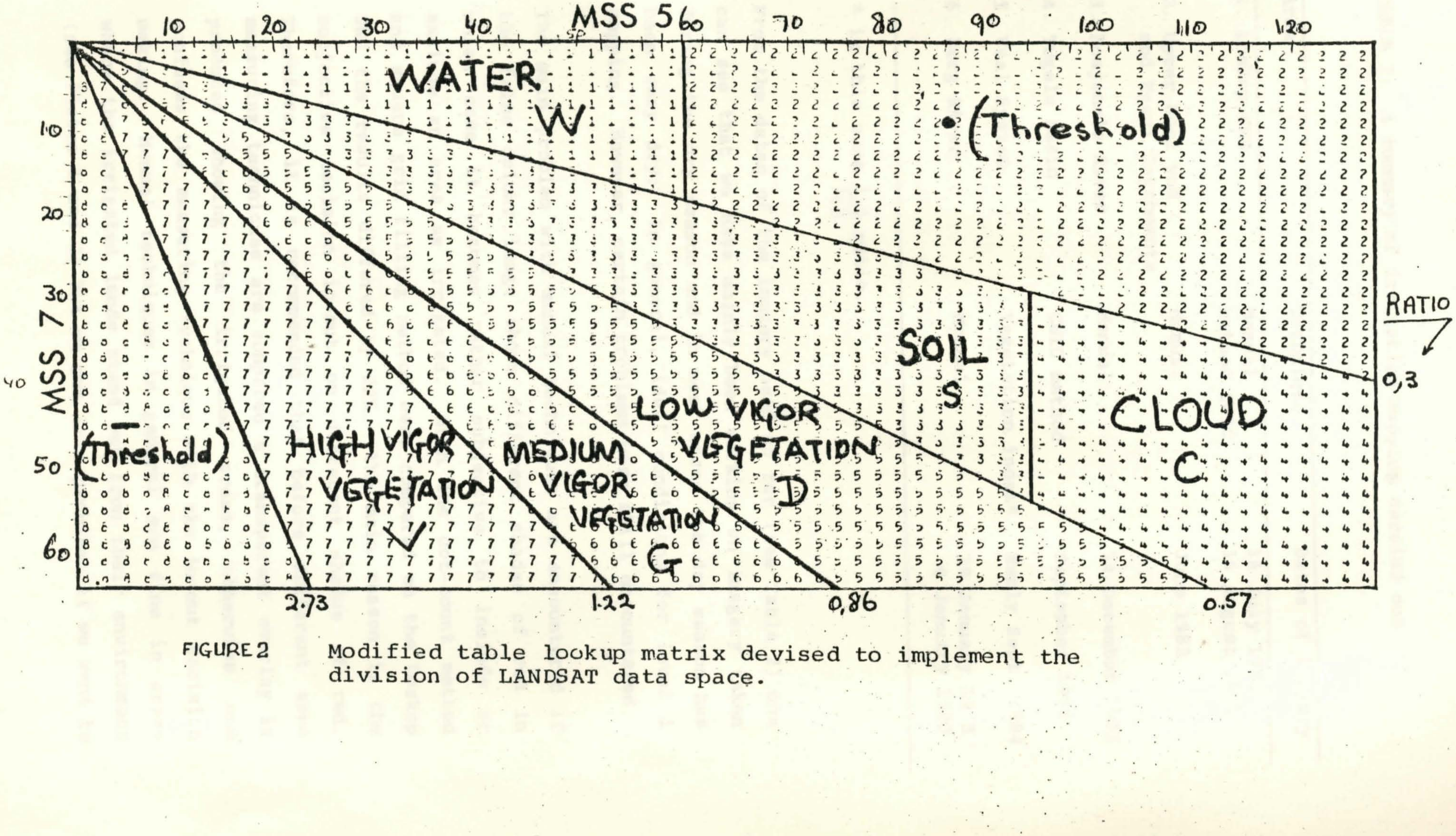

FIGURE 2 Modified table lookup matrix devised to implement the division of LANDSAT data space.

TABLE 2: A summary of irrigation mapping carried out

Area	Technique	Dates of imagery
1. Loskop SWS	Manual Method CWIC	16 July 1981 16 August 1981
2. Upper Mooi and and Mgeni Catchments	Manual	June 1983
3. Posjenels River	Manual	14 December 1982
4. Tugela Basin	CWIC method	September 1983
5. Vaal System	Vegetation index*	Early Sept. 1984
6. Berg River	Manual	19 January 1973 6 January 1983

* in this case $\frac{7-5}{7+5}$ ratio.

From the dates of the imagery used so far (see Table 2) one can see that we have mainly been working on imagery taken during the dry season and in most cases the dry season has been very dry: In general, ideal conditions for level 1 mapping. However, certain problems were still encountered.

The main problem with manual techniques are encountered if the false colour image shows different shades of red in which case it becomes rather subjective to include or exclude an area as irrigated. When the dot-count method and square grid filling method were compared on the Loskop SWS the results differed by 22%. The main reason is the subjective decision in-out on different shades of red. Therefore, it is recommended that before different area measuring techniques are compared a transparent overlay is produced showing the irrigated areas, otherwise one confuses the measuring technique with the in-out decision making. Manual techniques in general are fine in areas where the irrigated lands stand out from their environment (see Plates 1 and 2) but we run into problems if we want to separate irrigated crops from winter wheat in the Highveld or the winter rainfall region. In these cases image processing techniques must be used.

But even with image processing techniques some minor problems were encountered. Sticker (1984) found in the Tugela survey that signatures generated from local training areas did not "travel". It became necessary to constantly "retrain" in the immediate vicinity of the area of interest. The term "locational supervised" classification was used for this phenomenon. Henning (1985) also found that the cut-off limit of the vegetation index did not "travel" from north to south in the Vaal system. It is believed that the reason lies in differences in planting dates and general agrometeorological conditions.

6.1 Cost aspects

The costs of various surveys compare very favourably with conventional field survey methods. The Mooi-Mgeni area is 4420 Km^2. The Landsat survey comprised 5 images costing R2700 and the manual analyses cost 40 hydrologist hours. The Tugela survey included the major portion of drainage region V, approximately 26175 Km^2 in total and the total cost of the survey was in the order of R6000 - and took three weeks to complete. The costs of this kind of information gathering is a fraction of the field survey methods. The only unresolved issue is the one of accuracy. But here it must be realised that we are only on the lowest steps of the learning curve. If a programme of regular monitoring is persued with the aid of image processing techniques there is no dount that accuracies well above 90% for level 1 mapping can be obtained.

7. THE FUTURE PROGRAMME

In the near future the Hydrological Research Institute hopes to enter the era of image processing. In the field of irrigated land use the following programme is provisionally envisaged.

1. A level 1 survey once every five years of the entire country on a tertiary catchment basis to establish general trends for long term planning. The comparison of the 1973 and 1983 images for the Berg river has clearly shown that official records do not reflect the true world. In certain key regions this survey may take place more frequently.

2. A survey four times a year of all State Water Schemes.

3. A survey four times a year of certain key catchments eg.,

   - Vaal river system
   - Berg river
   - Breë river
   - Mgeni river
   - Fish-Sundays river system

   The level of survey will probably be extended to level 2: crop identification. During periods of water restrictions level 3 surveys may become desirable.

4. Ad hoc analyses of catchments pending proclamation as Government Water Control areas. Level 1 mapping may be sufficient.

5. Continuous research to improve accuracy on crop identification and water use estimation. With high resolution imagery even methods of irrigation and subsequently general water use efficiency may be monitored.

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