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The Effect of Thornthwaite Moisture Index Changes on Ground Movement Predictions in Australian Soils

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Summary The Australian Standards, Residential slabs and Footings-Construction (AS 2870) contains a number of standard footing designs to cope with expansive soil conditions that are common in Australia. The choice of designs depends on a site classification method, which is based on the "Characteristic Surface Movement" which can be calculated from a triangular model of soil suctions and moisture variation depth (Hs) supplied in this standard. The climate zone classification, which determines the Hs depth, is based on an Australian map of Thornthwaite isopleths published in 1964. Anecdotal evidence suggests that the Australian climate has undergone changes, which may affect the performance of these designs. This paper presents a new calculation and maps of these isopleths and discusses the consequences to engineering structures.

INTRODUCTION

The "Atlas of Australian Soils", Northcote (1962) shows that about half of the soils in the Eastern Australian states are significantly expansive. Designing footings for light structures on such soils has created problems for engineers. The approach adopted in Australia has involved the selection of published "standard" footing designs on the basis of past knowledge, soil profile identification or by the calculation of the "Characteristic Surface Movement" (CSM). Soil properties and climate are important considerations in this calculation.

Climate Zones were determined based on Thornthwaite Moisture Index (TMI) isopleths calculated by Stephens (1964) from Australian Weather Bureau data averaged between 1940-1960 and published in 1964. In 1996 a Victorian Climate Zone map, based on this C.S.I.R.O. map, was included in AS 2870 to give guidance to designing engineers. In future reviews similar maps for other states are proposed. Walsh *et a2* (1998) have examined the effect of climate on the design depth of moisture change in clay soils of the Hunter Valley. A change of design suction for South Western Australia and South Eastern Queensland was also assessed by Walsh *et al* (1998). Fox (2000). has recently published a new map for Queensland calculated from more recent climate data. The writers have re-calculated the TMI isopleths for Australia using Weather Bureau data from 1960-1991. More recent rainfall and evapotranspiration data has also been noted. (not presented here), to establish whether the boundaries of the previously established Climate Zones are still applicable in an environment of suspected climate change. The effect on the CSM and its engineering significance is also discussed.

RELATIONSHIP OF TMI TO SOIL MOISTURE STATE

Australian researchers agree that the surface suction change (Au) is approximately 1.0-1.5 pF where it is not affected by trees, flooding or man-made water sources. AS 2870 suggests a maximum moisture variation depth (Hs) of 4 metre at TMI values –25 to –40. This depth increases in drier climates. Walsh *et a2* (1998) and Fox in the Australia Geomechanicsjournal (2000) suggest a Climate Zone 6 and (Hs) >4 metre (and possibly 6-8 metre) for an Arid climate with a TMI <-40. In these conditions they say that a soil drying and wetting zone may be required in calculating the y_s value. The Instability Index (Ipt) is calculated for each layer. The surface seasonal suction variation and depth of this variation has been postulated from anecdotal evidence and a formula devised by Aitchson *et al* (1960) and reorganized by Mitchell *et al* (1984) as follows :

$$y_s = \Sigma \Delta u . Ipt . dh \qquad (1)$$

Where: ***Ipt*** = Soil Instability Index *Au* = Change in suction *(for each layer)* h = Depth of the layer y_s = CSM

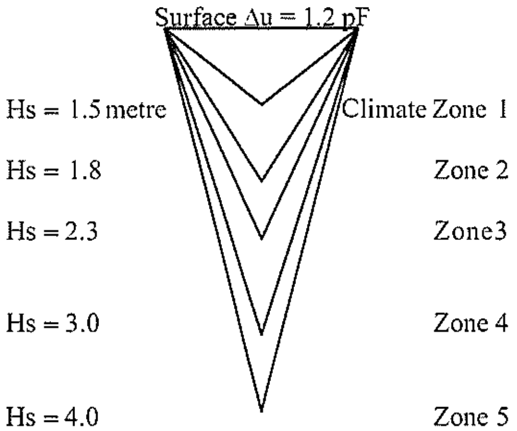

Figure 1: AS 2870-Suction Variation Model

Climate	Zone	Suction Range	(Δu)	(Hs)
Alpine/Wet Coastal	1	2.5-3.5 pF	1.0 pF	1.5 m
Wet Temperate	2	2.8-4.0 pF	1.2 pF	1.8 m
Temperate	3	3.0-4.2 pF	1.2 pF	2.3 m
Dry Temperate	4	3.5-4.7 pF	1.2 pF	3.0 m
Semi Arid	5	4.0-5.0 pF	1.0 pF	4.0 m
*Semi Arid Flood Prone	5	3.5-5.0 pF	1.5pF	4.0 m
*Arid	6	4.0-5.0 pF	1.0 pF	6.0 m
*Arid Flood Prone	6	3.5-5.0 pF	1.5 pF	6.0 m

* New climate condition suggested by the writers.

Table 1 : Newly Proposed surface suction variation (Au) and moisture variation depth (Hs)

These suction triangles can only be considered an idealized approximation of the suction and depth of moisture variations and are useful for calculation purposes, but not necessarily representative of the actual field conditions. Sheet flooding is common in low-lying *dry* land in Australia, thus exposing the soil profile to quickly alternating wet and *dry* conditions. The Δu in this condition will depend greatly on the topography and soil types. Where the topography is flat the water will pond for long periods and has the opportunity to wet the soil profile to a greater depth. The writers therefore suggest that in flat, poorly drained, *dry* climate sites, the surface soil suction variation (Au) is greater, (possibly 1.5 pF – refer Table 1); hence the surface movement could be greater than that shown in AS 2870-1996.

SITE CLASSIFICATION METHOD (AS 2870)

Ipt is calculated from test methods outlined in AS2870. They, (CSM) is calculated for the full depth of suction change using the suction models for various climate zones shown in Figure 1 and Equation (1). Once the CSM is calculated, the building site can be "Classified" with respect to shrinking and swelling of the foundation clay as follows (Table 2):

Table 2: Classification by Characteristic Surface Movement (AS 2870)

Primary Classification of Site	Surface Movement
S (slight shrink/swell)	0mm < y_s ≤20 mm
M (moderate shrink/swell)	20mm < y_s 140 mm
H (high shrink/swell)	40mm < y_s ≤70 mm
E (extremely high shrink/swell)	y_s >70 mm

The engineer then may choose a standard footing design from the Standard. The slab and other footing designs are based on a soil mound model developed by Walsh (1975) and anecdotal experience. This method has been used since 1986 with reasonable success, however in recent years, anecdotal evidence, suggests that the climate in Australia has become drier. Droughts have been more severe and longer lasting; winters are milder and summers longer. Considering the effect of climate in this classification method the writers undertook to re-calculate the location of the Climate Zones in Australia, using the climatic data taken from 1960-1991.

THORNTHWAITE MOISTURE INDEX (TMI) CALCULATIONS AND *MAPS*

The Thornthwaite formula used by Stephens (1964) and by the writers is: --

$$TMI = (100D - 60d)/Ep \qquad (2)$$

where : D = P-Ep (Surplus) d=Ep-AE (Deficit) P = Precipitation.
Ep = Potential Evapotranspiration AE=Actual Evapotranspiration

The new TMI's were calculated from records of 791 Australian stations using the average rainfall and evapotranspiration readings taken from 1961-1990. (Data supplied by the Australian Climate Centre).

Appendices 1-4 show the climate zones according to Stephens and the new zones. It is intended to continue these calculations for 1991-2003 period, which includes the most severe drought on record. For clarity not all the TMI's have been drawn in the attached maps (Appendices 1-4)

CONCLUSIONS

The new TMI calculations from data read between 1961-1990 have confirmed the belief that the Australian climate has generally become drier since the last period (1940-1960) calculated by Stephens (1964). Where the TMI's are negative for long periods, the soil is in desiccation mode. This may represent a drying cycle in a long-term climatic oscillation. This change in climate may also affect the performance of standard footing and slab designs in the Australian "Residential Slabs and Footing" Standard. Where the climate zones have become drier (most of the populated areas of Australia), they, (CSM) will increase. A change in the climate zone from zone 2 to zone 3 increases the Hs from 1.8m to 2.3m. Thus, increase in they, by 28%. Where there has been a change from zone 2 to zone 4, the Hs increases from 1.8m to 3m increasing they, to 67%. If these new Zones were to be accepted, many building sites would require more costly footings

South East Queensland

The coastal area, which carries 90% of the local population, has dried from Climate Zone 1 to 2. Zone 1 only remains in the hinterland West of the Gold Coast. The whole of Brisbane is now Zone 2 while Toowoomba and the Darling Downs are now Zone 4. Zone 4 has expanded both East to take up some of the previous Zone 3 and to the West where it has taken up some of the previous Zone 5. (Refer Appendix 1)

New South Wales

The –25 isopleth has moved away from the coast (similar to South East Queensland) and Zone 1 has mostly retreated to the Great Divide. Zone 2 has expanded (mostly taking-up the previous Zone 1) while Zone 4 has expanded, taking up portion of 3 and 5. The Southern coast has also dried to eliminate zone 1. The North and Central coast has dried from Zone I to 2. (Refer Appendix 3)

Victoria

The –25 isopleth (which approximately coincides with the southern boundary of the Mallee area) has remained very close to its original position while Zone 4 has extended to the South and East by >60% covering the Wimmera and the Western suburbs of Melbourne. In Eastern Victoria (Gippsland) Zones 3 and 4 have replaced most of the previous Zone 2. In East Gippsland the previous Zone 1 is now Zone 2. In Central Victoria, Zone 3 has extended to the South East and has largely replaced the previous Zone 2, while in coastal South Western Victoria, Zones 1 and 2 have shrunk considerably, being replaced by Zones 3 and 2. In the Eastern suburbs of Melbourne Zone 2 has contracted to a narrow band parallel the Dandenong Ranges. (Refer Appendix 4)

South Australia

As for Victoria there has been little change in the –25 TMI isopleth, except in the Eyre Peninsula where it has dropped south to Port Lincoln. South of Adelaide and in the McLaren Vale Wine district, Zone 1 has severely dried and is now classified as Zone 3 and 4. The Adelaide C.B.D. and near suburbs were previously covered by 3 Zones (2, 3 & 4) but are now only in Zones 2 and 3. North of Adelaide the climate has become more benign changing from Zone 5 to 4 while the Clare Valley remains in Zone 4. (Refer Appendix 4)

South West, Western Australia

Generally speaking, the +40 isopleth has been replaced by the –5 isopleth thus Zone 5 has moved hundreds of kilometers closer to the coast. The Margaret River and Southern Vales wine districts have also dried significantly as has the Perth district. The former has changed from Zone 1 to 2 and the latter from 2 to 3. The isopleths for the remainder of Western Australia are still being calculated. (Refer Appendix 2)

Tasmania

Early calculations indicate severe drying in most of the state except for the West Coast. The major cities of Launcenston and Hobart have also dried considerably.

Summary

The re-calculation of the TMI isopleths for the more densely populated regions of Australia has shown an apparent trend of drying since the 1960's. This may be part of a long-term climatic cycle, which could have an effect on the long-term performance of the standard foundation designs in As 2870. Structures built to this Standard may be subjected to larger soil movement than anticipated at the time of construction thus possibly requiring footings with a higher Classification.

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APPENDIX 1

THORNTHWAITE MOISTURE INDEX -- SOUTH EAST QUEENSLAND
C.S.R.I.O. (1940-1960) & (NEW) (1960-1991)

Maps Sent previously

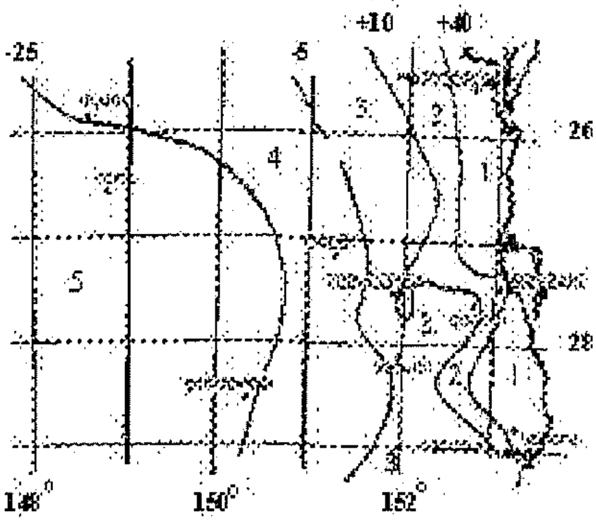
APPENDIX 2

THORNTHWAITE MOISTURE INDEX – SOUTH WEST, WESTERN AUSTRALIA
C.S.R.I.O. (1940-1960) & (NEW) (1960-1991)

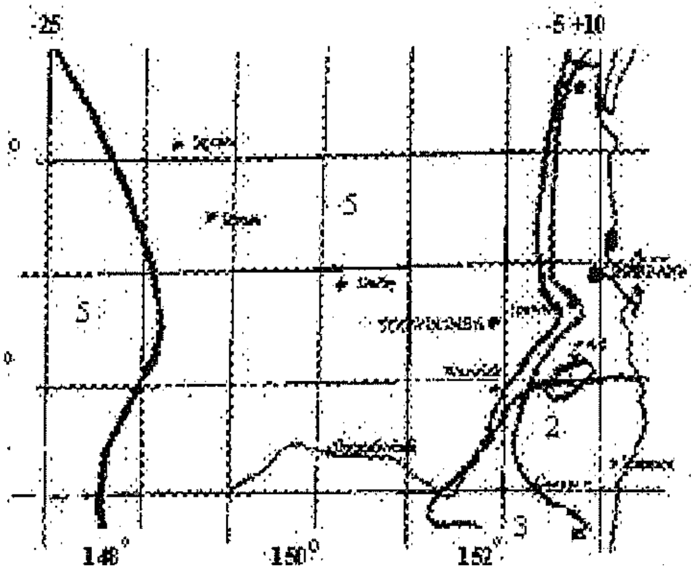
Maps Sent Previously

APPENDIX I

THORNTHWAITE MOISTURE INDEX -- SOUTH EAST QUEENSLAND
C.S.R.I.O. (1940-1960) & (PROPOSED) (1960-1991)



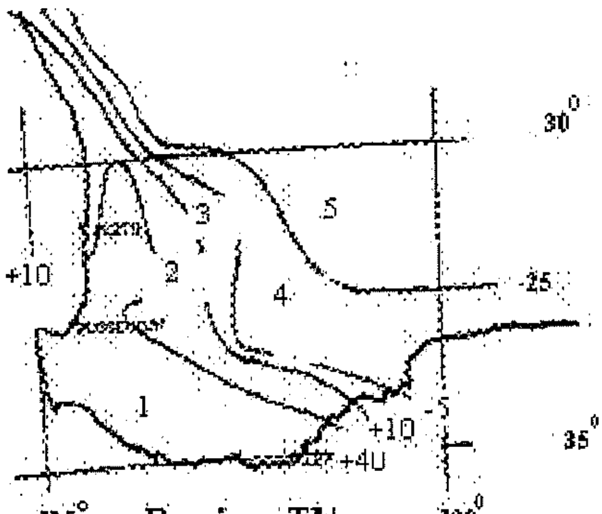
Previous TMI



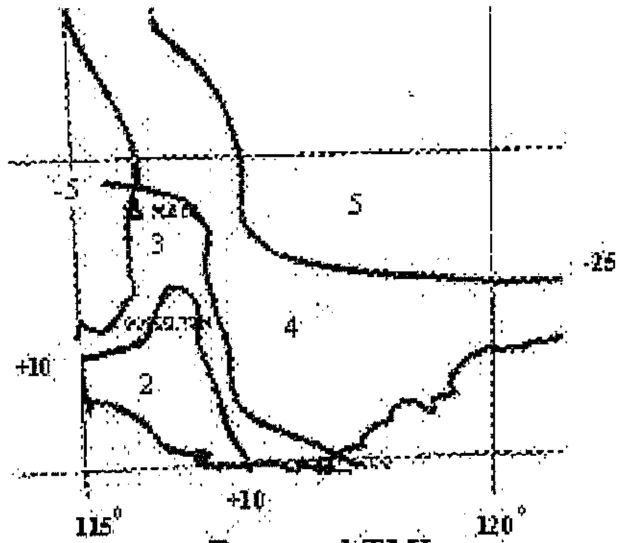
Proposed TMI

APPENDIX 2

THORNTHWAITE MOISTURE INDEX – SOUTH WEST, WESTERN AUSTRALIA
C.S.R.I.O. (1940-1960) & (PROPOSED) (1960-1991)



Previous TMI



Proposed TMI

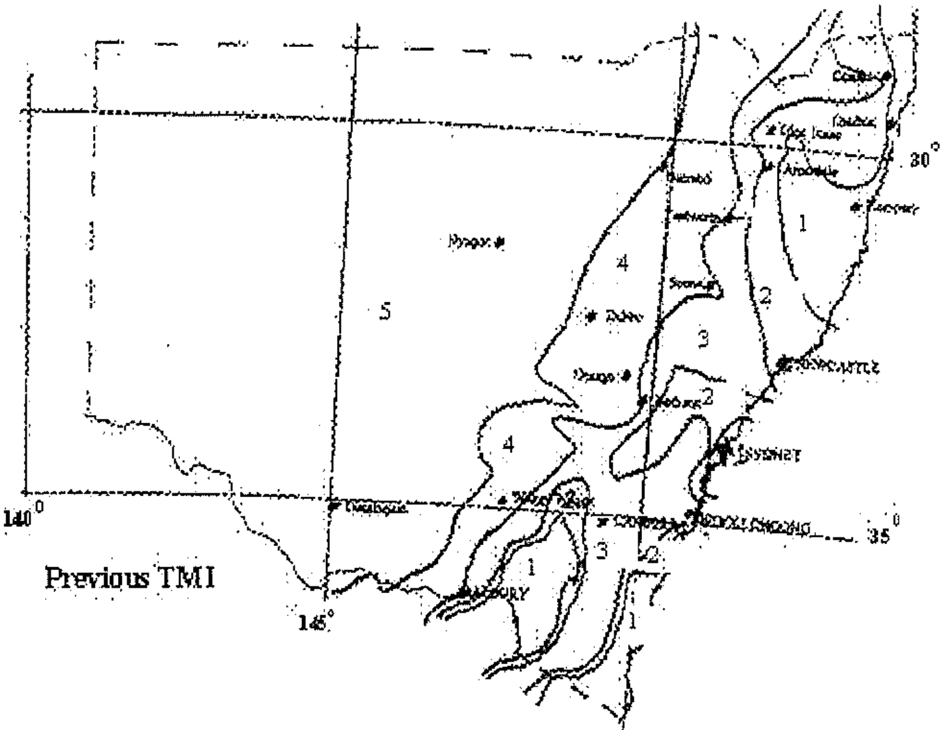
APPENDIX 3

THORNTHWAITE MOISTURE INDEX – NEW SOUTH WALES
C.S.R.I.O. (1940-1960) & (NEW) (1960-1991)

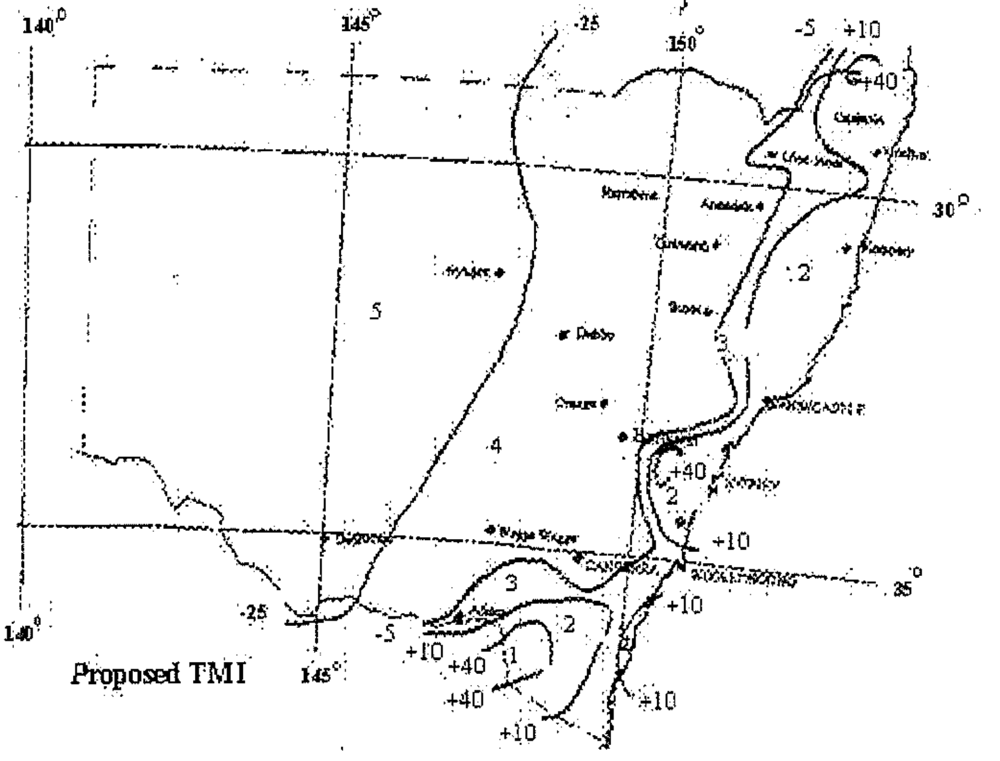
Maps Sent Previously

APPENDIX 3

THORNTHWAITE MOISTURE INDEX – NEW SOUTH WALES
C.S.R.I.O. (1940-1960) & (PROPOSED) (1960-1991)



Previous TMI



Proposed TMI

APPENDIX 4

THORNTHWAITE MOISTURE INDEX – VICTORIA AND SOUTHERN SOUTH AUSTRALIA
C.S.R.I.O. (1940-1960) & (NEW) (1960-1991)

Maps Sent Previously

APPENDIX 4

CLIMATE ZONES (AS2870) – VICTORIA & SOUTHERN SOUTH AUSTRALIA
As per T.M.I.'s C.S.I.R.O (1940-1960) & (1960 – 1991)