 EVAPORATION MEMO. NO. 21A

CALCULATION OF ESTIMATES OF POTENTIAL AND ACTUAL EVAPORATION, SOIL MOISTURE DEFICIT AND EFFECTIVE RAINFALL FOR POINTS AND AREAS. - OPERATIONAL SYSTEM FOR COMPUTER APPLICATION.

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1. Introduction.

These calculations depend, firstly, upon a means of estimating or measuring the rate of potential evaporation (including transpiration). The method here considered will be the well-known Penman formula.
Secondly, a method of modelling the varying difference between the rates of potential and actual evaporation is required. The model will be based on Penman's concept of root constant, as introduced (into the Meteorological Office) and developed by J. Grindley.
Thirdly, the model requires adequate, daily rainfall data.

2. Definitions and notes.

Soil Moisture Deficit. When rainfall is not sufficient to make good the loss of water from the soil by transpiration and evaporation, some water is extracted from storage (in the soil) and a soil moisture deficit is said to exist. Clearly, it is possible to maintain a running balance sheet which will, at times, show SMD = 0, the state defined as Field Capacity. In the Model used in the Meteorological Office (July 1972) for operational bulletins issued by Met.O.8c, the soil is reckoned not to become moistened beyond field capacity, the surplus being carried away as run-off and by percolation downwards.

Transpiration is considered to take place at the potential rate (defined as the maximum rate at which the available solar energy and the evaporative power of the air-mass, at a given time and place, can evaporate water and remove it as vapour) whilst the layer of soil from which the roots can draw water is at field capacity (i.e. water freely available) and for a short while thereafter.
Evaporation from water and wet surfaces also takes place at the potential rate. Soon after the soil water supply to root systems begins to be restricted, transpiration falls below the potential rate and decreases as the soil moisture supply diminishes. The model caters for reduction and subsequent cessation of evaporation from soils, etc., as the top layer dries out.

Effective Rainfall. When the SMD of a given block of soil is zero (field capacity condition) the rainfall which percolates to deep storage, assuming no run-off, is

Effective Rainfall = Total Rainfall - Potential Evaporation

Land-use modelling. To estimate Actual Evaporation, Soil Moisture Deficit and Effective Rainfall we estimate Potential Evaporation and measure Rainfall. These values of PE and R are used as input data for a computer model which has already been supplied with details of land-use. A model for some part of England might consist of percentages devoted to vegetation having various root depths, grazing, fallow, forest, open water and urban areas.

Root Constant. Vegetation root type is specified in terms of Root Constant, a concept introduced by H.L.Penman. Root constant defines a specified amount of soil moisture (expressed as equivalent depth of water) which can be extracted from the soil, without difficulty, by the vegetation. A further inch of moisture is considered to be extractable, but with increasing difficulty because of the increase in soil moisture tension as the deficit of soil moisture develops. After this further inch of moisture has been extracted from the soil, extraction is considered to become minimal.
(References: Hydrological Memorandum No.38 "The calculation of actual evaporation and soil moisture deficit over specified catchment areas" and Introductory Notes to "Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain" both by J.Grindley.)

General areas and special sites. Calculations can be made for special sites or for general areas. The basic method is the same in both cases but although site data of good quality are applicable and appropriate to the site they are not applicable to the general area in which the site lies unless the site is typical of the area in its effect on the various meteorological variables.

3 Potential Evaporation (PE)

For a point estimate, the data listed on page 6 are required. If wind speed is not measured at 2 m above the ground (but at some other height) a method of reduction from anemometer height to 10 metres (due to N.C.Helliwell and others) may be applied, followed by a power-law reduction from 10 metres to 2 metres; (see Evaporation Memo. No.20a.)

For areal estimates we require all the data at each of a regular network of points. The method proposed in this memorandum allows for the use of all available data by dealing with each element and each grid-square separately. Fields of each meteorological variable are obtained and values interpolated to grid-points. The site (or grid-square) variables are latitude, albedo and Angstrom regression constants. Flow-diagrams showing the computerized processing of synoptic and specially reported climatological station data are shown. The Penman formula is set out, with notes, on page 5.

4. Actual Evaporation, Soil Moisture Deficit and Effective Rainfall.

The distribution of land-usage is assessed for site or grid-square and input, in percentage form, into a model which keeps a running balance of SMD, AE and ER, using PE and R (rainfall) as input. Land-usage is subject to seasonal change (crop cycles, etc.)

To maintain the existing series of monthly estimates of PE and month-end estimates of SMD, calculations will be made using monthly, average meteorological data to produce PE estimates which, together with daily rainfall data, will be processed using the idealised, standard land-usage model (50% 3" root constant, 30% 8" root constant and 20% riparian land) and also the model in which a universal 3" root constant is used, to simulate grassed surfaces beneath which, due to the limited water extraction capacity of the shallow roots, large soil moisture deficits do not occur.

For grid-square estimates of AE, SMD and ER, the PE estimates and rainfall data will be used as input for the real land-usage model and for a model which assumes the whole country to be covered by short-rooted (3" constant) vegetation.

5. Special reports from climatological stations.

These will contain some or all of the following:

7 daily averages of mean air temperature.
7 daily averages of saturation vapour pressures (from mean temperatures)
7 daily 09 GMT vapour pressures
7 daily totals of duration of bright sunshine

7 daily values of rainfall

6. Computer Output.

Input data scrutiny. Grid-point presentation of meteorological variables

A. Rainfall and derived variables

7-day and monthly totals	7th day and month-end estimates
(i) rainfall	(vii) soil moisture deficit (real land use)

7-day and monthly totals (continued)

(ii) potential evaporation

(iii) actual evaporation (real land use)

(iv) actual evaporation (grass)

(v) effective rainfall (real land use)

(vi) effective rainfall (grass).

7th day and month-end estimates

(viii) Soil moisture deficit (grass)

B. Meteorological variables

7-day and monthly averages

(i) (screen) air temperature

(ii) (screen) saturation vapour pressure

(iii) (screen) vapour pressure

(iv) daily duration of bright sunshine

(v) wind speed at 2 metres (or total run-of-wind)

Computer-drawn (isopleth) analyses

All variables listed in (A).

Estimates for stations on selected list (print-out)

A. Potential evaporation and soil moisture deficit

(i) 7-day P.E. using sunshine/radiation and local wind data.

(ii) 7-day P.E. using sunshine/radiation and system wind estimate

(iii) Monthly PE using sunshine/radiation and local wind data

(iv) Monthly PE using sunshine/radiation and system wind estimate

(v) Monthly PE (short form).

(vi) Month-end SMD using (v) and 50/30/20 land use.

(vii) Month-end SMD using (iv) and real land use.

B. Meteorological variables

(i) Monthly average temperature

(ii) " " saturation vapour pressure

(iii) " " vapour pressure

(iv) " " $\overline{V_2}$ (estimated wind speed at 2 metres)

(v) 7-day " $\overline{V_2}$ (" " " ")

(vi) Monthly " daily duration of bright sunshine.

Estimates for major hydrological areas (print-out)

(i) 7th day SMD for river authority areas (real land use)

- Calcomp output for grid of 40 x 40 km squares

Penman's formula for estimating the rate of Potential Evapo(transpi)ration.

$$E = \frac{\Delta}{\Delta+\gamma} R_A(a_1+a_2 n/N)(1 - r)$$
$$- \frac{\Delta}{\Delta+\gamma} 0.95\sigma T_a^4(a_3 - a_4\sqrt{e_d})(a_5 + a_6 n/N)$$
$$+ \frac{\gamma}{\Delta+\gamma} a_7(a_8 + a_9 u)(e_a - e_d)$$

Where E = the rate of PE in mm/day

r = albedo

Δ = slope of saturation vapour pressure curve at air temperature T_a

γ = constant of the aspirated wet and dry bulb hygrometer equation (0.66 mb/°C)

R_A = the Angot value of short wave radiation, from sun and sky, with a completely clear atmosphere. (Values expressed in mWh/cm^2/day are multiplied by 1/68.5 to convert to equivalent depth of water evaporated in mm/day.)

n = measured duration of bright sunshine (hrs.)

N = possible maximum duration of bright sunshine (hrs.)

σT_a^4 = theoretical black body radiation at mean air temperature T_a (expressed as equivalent depth of water evaporated in mm/day).*

e_d = vapour pressure (in the screen) in mb.

e_a = saturation vapour pressure at air temperature T_a (in the screen) in mb.

T_a = mean air temperature in °C absolute (°K)

a_1 = first Angstrom regression constant "a"

a_2 = second Angstrom regression constant "b" } $R_I/R_A = a + b\,n/N$

a_3 = 0.56

a_4 = 0.08 (for vapour pressure in mb.)

a_5 = 0.10

a_6 = 0.90

a_7 = 0.26 (for vapour pressure in mb.)

a_8 = 1.0

a_9 = 0.01 (for wind run in miles/day)

0.006 (for wind run in km/day)

u = run of wind at 2 metres above ground (miles/day)/(km/day)

(To convert mean speed in knots to miles/day : v(24)76/66 = 27.64v where v is wind speed in knots.)

* The factor 0.95 allows for vegetation not radiating as a perfect black body.

Data input for Penman PE computer programmes.

Astronomical data: Date or period for which PE required

Latitude of point or station

Radiation data: Albedo

Angstrom constants "a" and "b"

Meteorological data:

Air temperature

Vapour pressure

Saturation vapour pressure

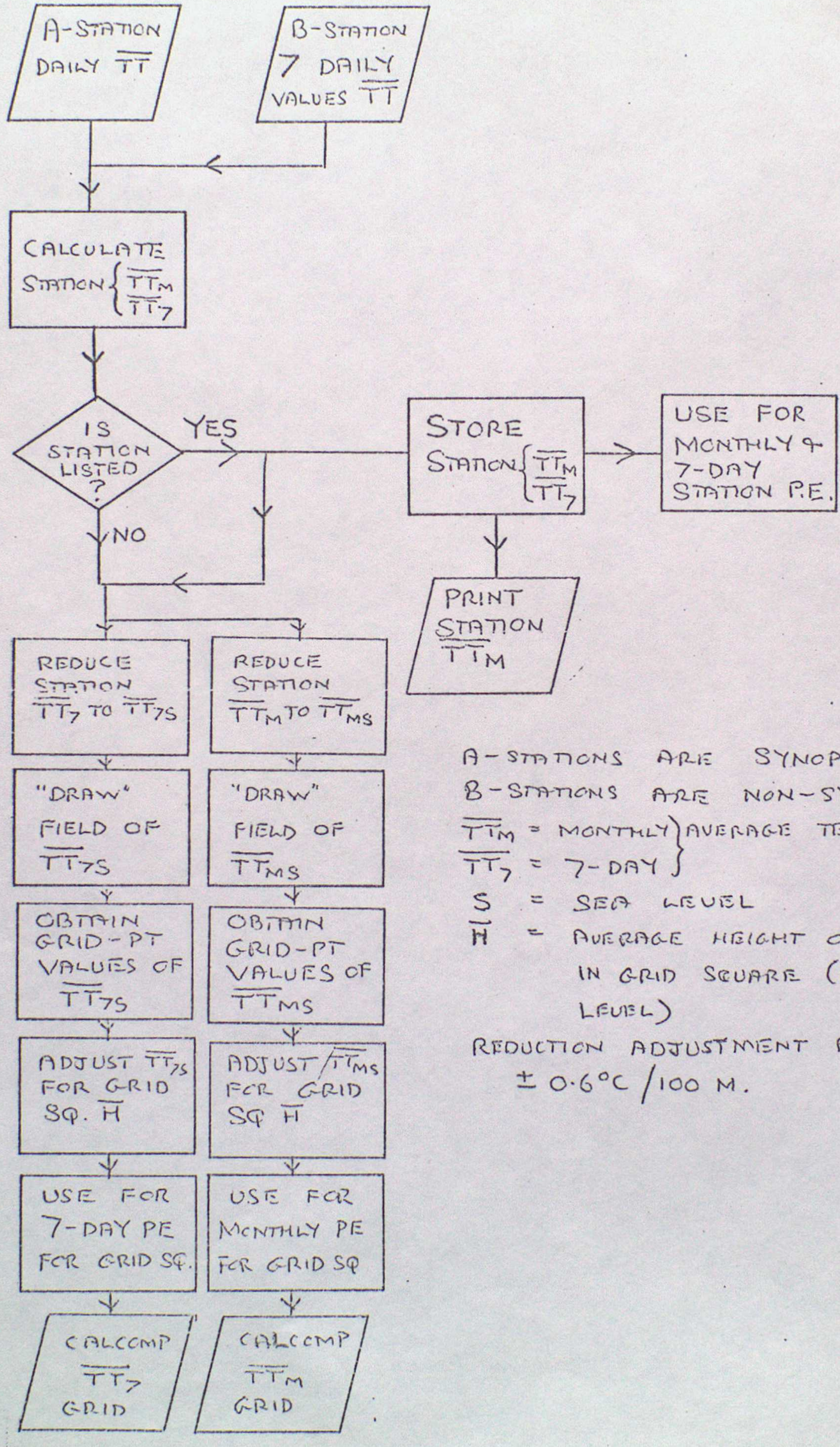
Daily duration of bright sunshine

Run of wind at 2 m.

The constants a_3 to a_9 are not normally varied but it should be possible to vary them if required.

June 1973

FLOW DIAGRAM 1 TEMPERATURE (°C)



A-STATIONS ARE SYNOPTIC

B-STATIONS ARE NON-SYNOPTIC

$\overline{TT}_M$ = MONTHLY } AVERAGE TEMPERATURE

$\overline{TT}_7$ = 7-DAY }

S = SEA LEVEL

$\overline{H}$ = AVERAGE HEIGHT OF GROUND IN GRID SQUARE (ABOVE SEA LEVEL)

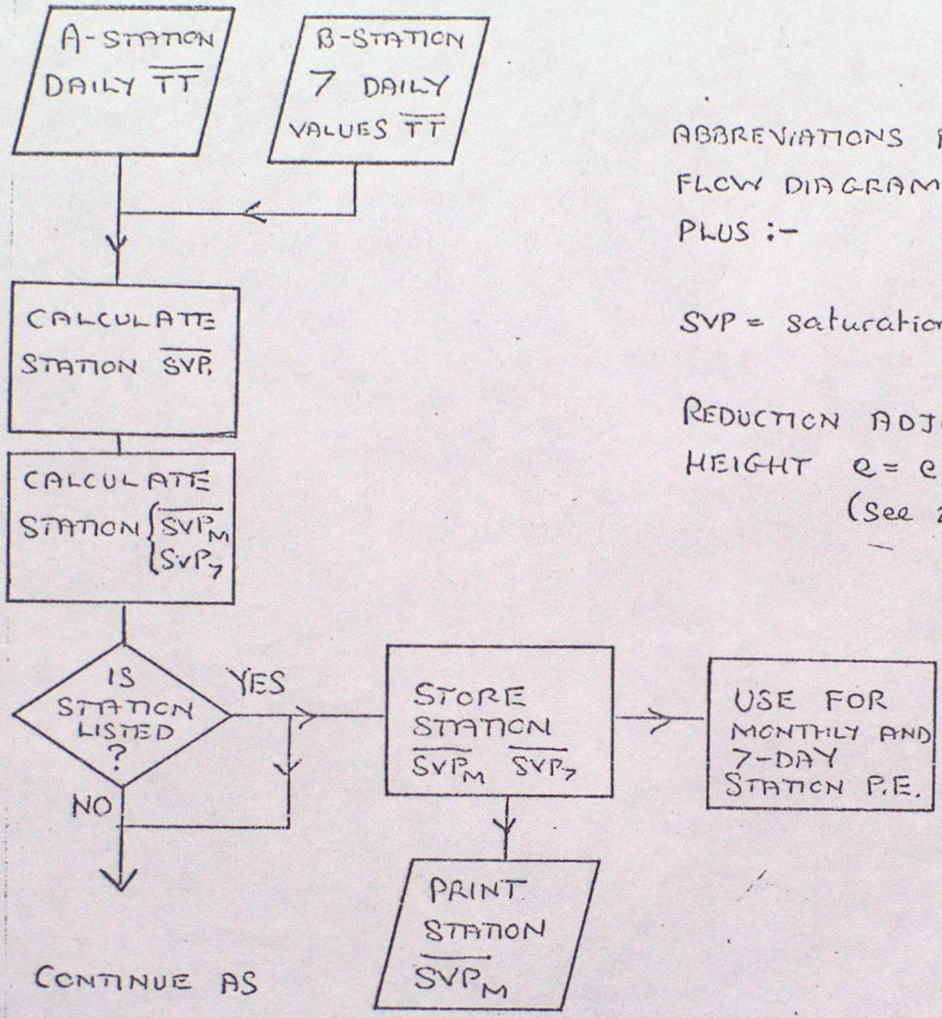
REDUCTION ADJUSTMENT FOR HEIGHT ± 0·6°C / 100 M.

FLOW DIAGRAM 2 SATURATION VAPOUR PRESSURE (mb)

ABBREVIATIONS AS IN FLOW DIAGRAM 1 PLUS :-

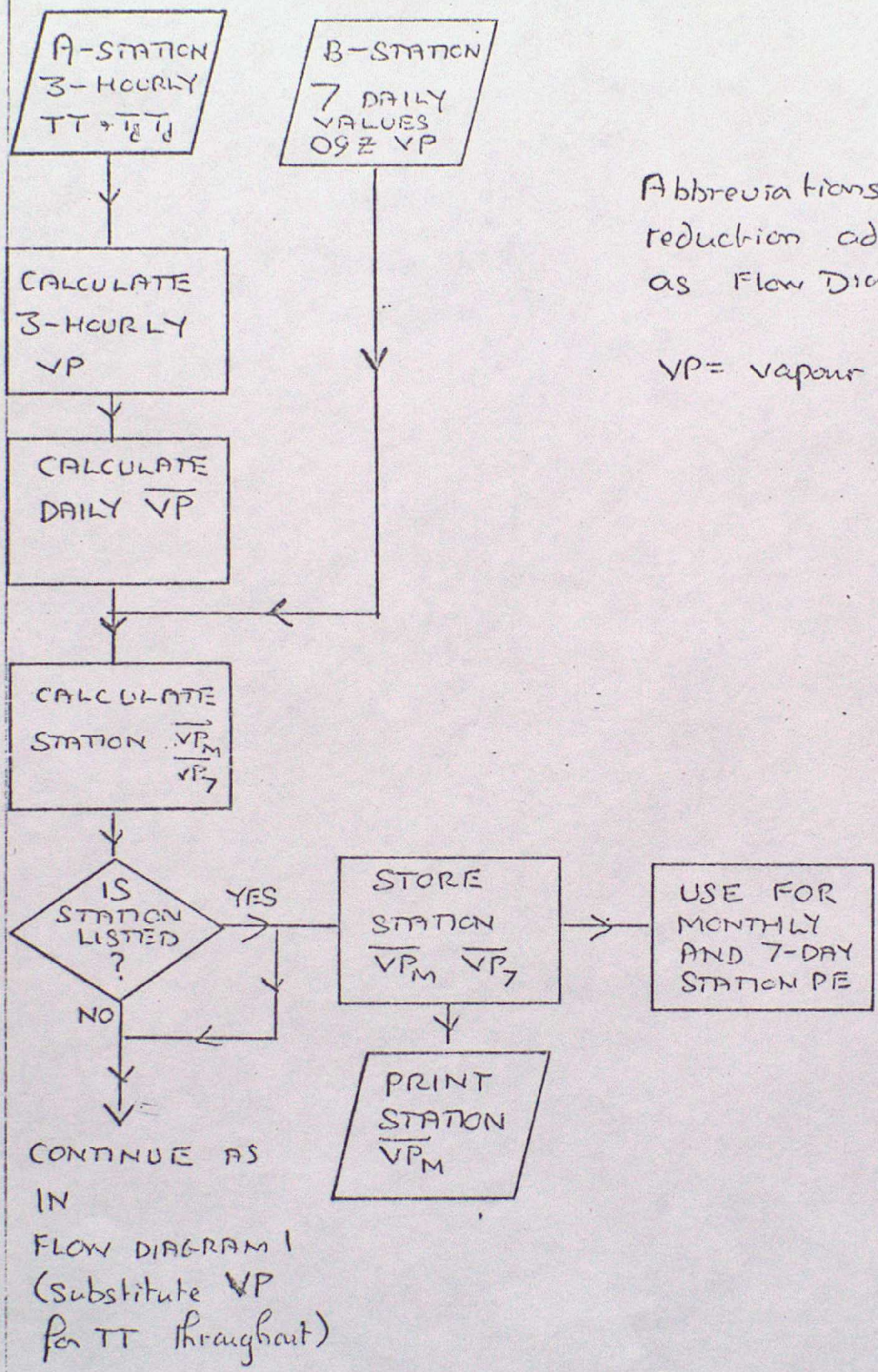
SVP = saturation vapour pressure

REDUCTION ADJUSTMENT FOR HEIGHT $e = e_0 (1 - 0.00025 h)$
(See 2.6.2. (ii))



CONTINUE AS IN FLOW DIAGRAM 1.
(substitute SVP for TT throughout)

FLOW DIAGRAM 3 VAPOUR PRESSURE. (mb.)

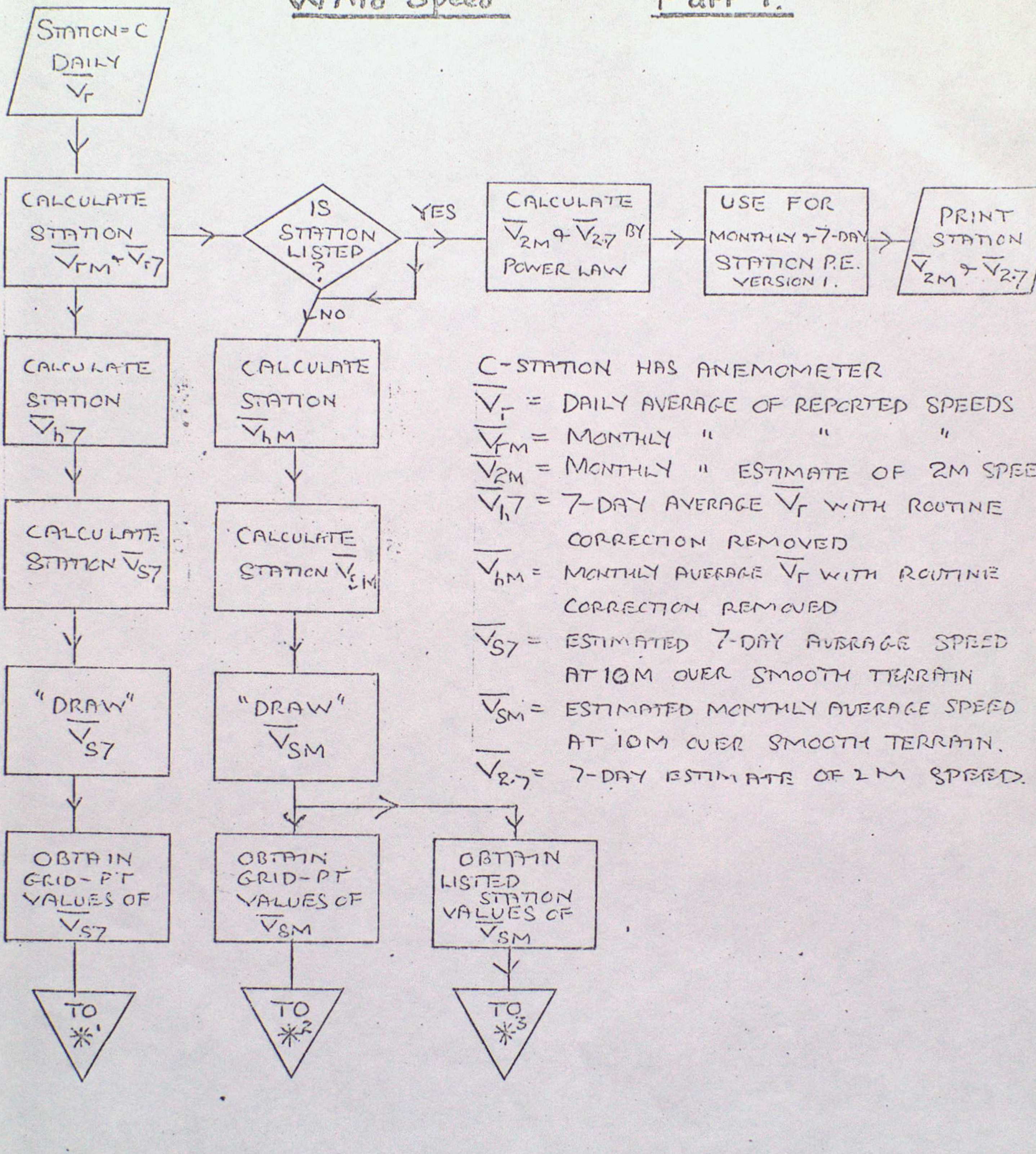


Abbreviations and reduction adjustment as Flow Diagrams 1 and 2

VP= vapour pressure.

FLOW DIAGRAM 4

Wind Speed Part 1.



C-STATION HAS ANEMOMETER

$\overline{V}_r$ = DAILY AVERAGE OF REPORTED SPEEDS

$\overline{V}_{rM}$ = MONTHLY " " "

$\overline{V}_{2M}$ = MONTHLY " ESTIMATE OF 2M SPEED

$\overline{V}_{h7}$ = 7-DAY AVERAGE $\overline{V}_r$ WITH ROUTINE CORRECTION REMOVED

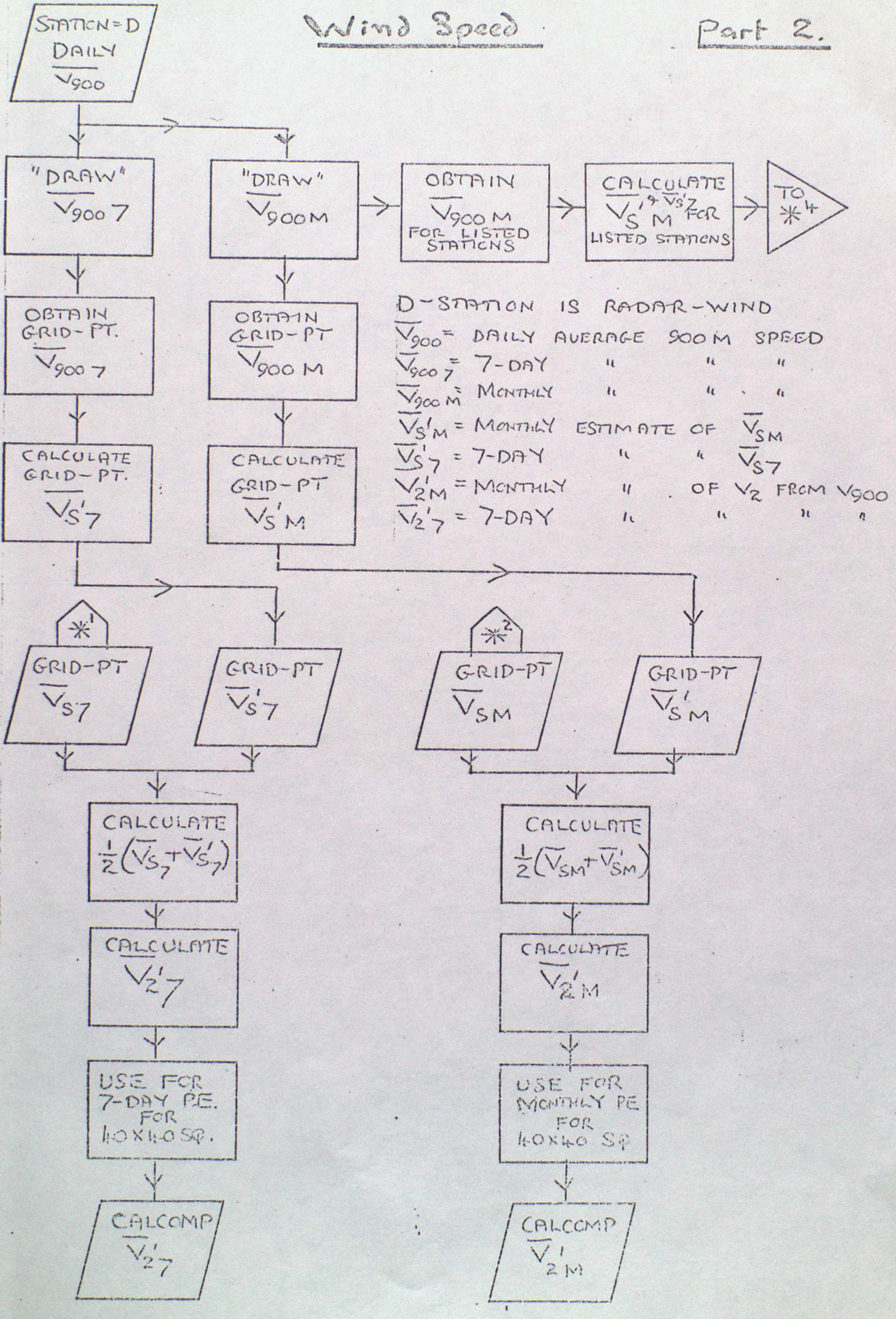
$\overline{V}_{hM}$ = MONTHLY AVERAGE $\overline{V}_r$ WITH ROUTINE CORRECTION REMOVED

$\overline{V}_{S7}$ = ESTIMATED 7-DAY AVERAGE SPEED AT 10M OVER SMOOTH TERRAIN

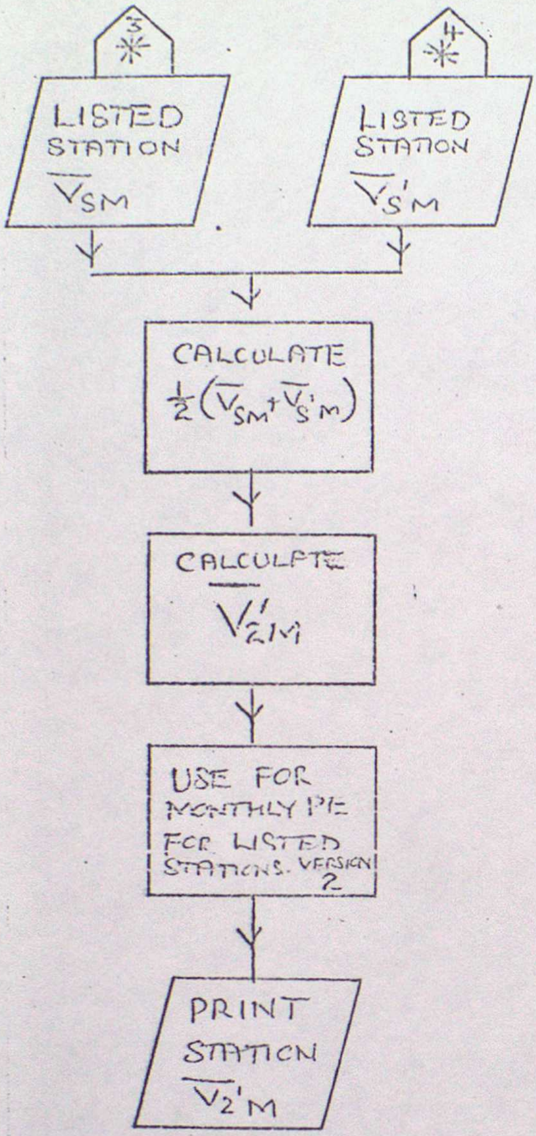
$\overline{V}_{SM}$ = ESTIMATED MONTHLY AVERAGE SPEED AT 10M OVER SMOOTH TERRAIN.

$\overline{V}_{2\cdot7}$ = 7-DAY ESTIMATE OF 2M SPEED.

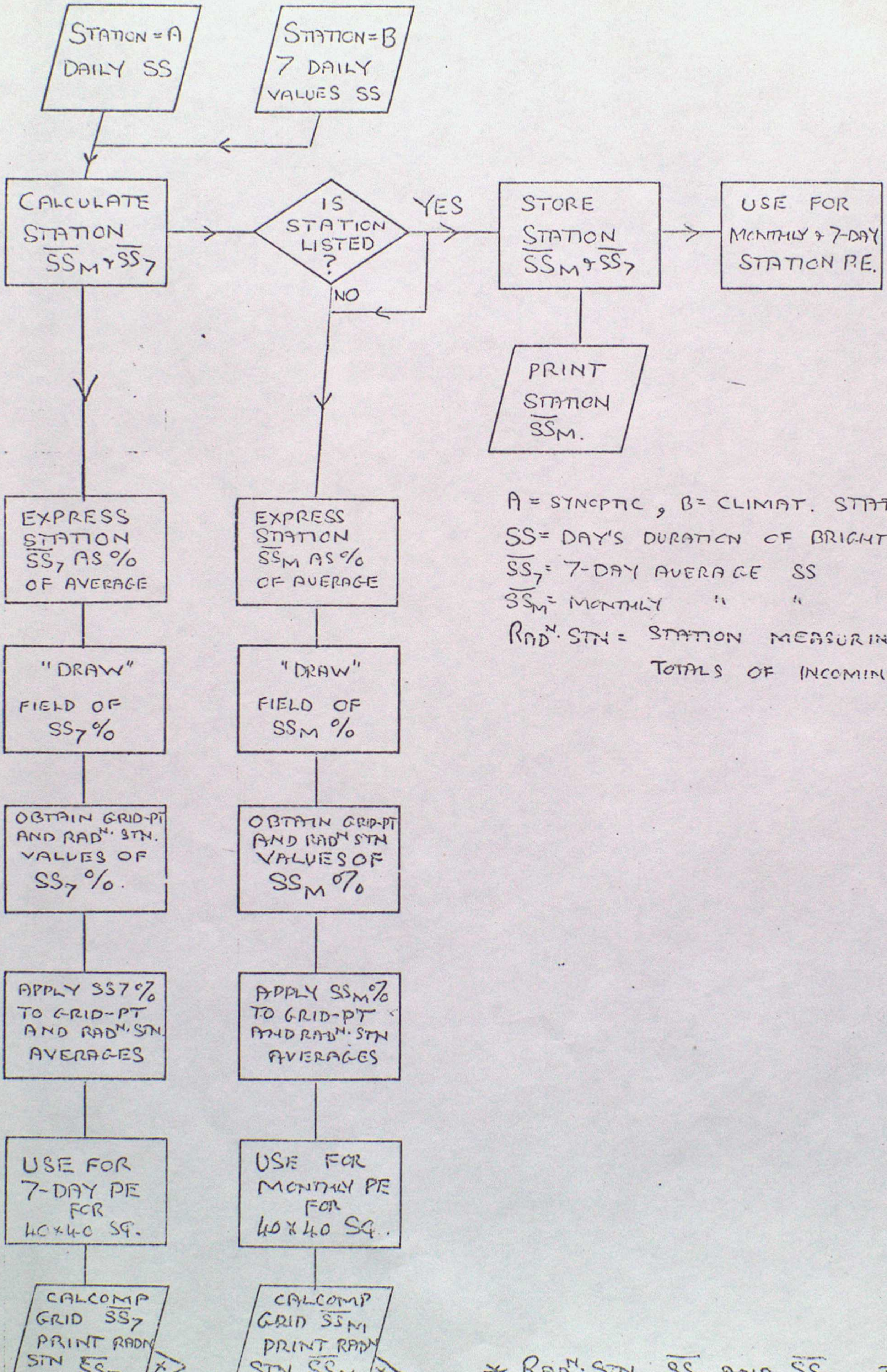
Wind Speed Part 2.



Wind Speed. Part 3.



Flow Diagram 5 — Daily Duration of Bright Sunshine.



A = SYNOPTIC, B = CLIMAT. STATION

SS = DAY'S DURATION OF BRIGHT SUNSHINE

$\overline{SS}_7$ = 7-DAY AVERAGE SS

$\overline{SS}_M$ = MONTHLY " "

RAD^N. STN = STATION MEASURING DAILY TOTALS OF INCOMING RADIATION

* RAD^N. STN. $\overline{SS}_7$ AND $\overline{SS}_M$ TO ANGSTROM CONSTANT PROGRAMME.

FLOW DIAGRAM 6 - RAINFALL.