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A rainfall- and evaporation recorder with high accuracy

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Contents

Abstract

To match the accurate weighing data of modern weighable lysimeters a recording rainfall- and evaporation meter has been designed. The excess of open water evaporation over rainfall or the reverse is recorded with a responsibility of 0.03 millimeter. This makes it a suitable device for short-period measurements.

Construction and recording charts are discussed. It is indicated how further improvement on details is possible.

1. Introduction

A development in research on evapotranspiration is in progress which already resulted in the construction of very accurate weighing machinery for short-period measurements of evapotranspiration from a lysimeter. The checking or further evaluating of formulae in which the evaporating capacity of the atmosphere is one of the parameters for the calculation of evapotranspiration (RIJTEMA, 1965; VISSER, 1964) might be helped with very accurate and discriminating short-period measurements of evaporation from a pan. It would be possible than to introduce a far wider range of evaporative capacity of the atmosphere into the investigations than when using 24-hour totals.

Which demands should be made on short-period measurements of open water evaporation follows from literature on the subject of the weighable lysimeter. According to some authors (VISSER, 1965, PRUITT and ANGUS, 1960) weighing intervals should not exceed one hour, others (f.i. VAN BAVEL and MYERS, 1962) think in terms of 5 or 10 minutes. Demands on sensitivity of the lysimeter installation range from 0.1 up to 0.05 mm of water.

2. Short survey of the development of recording evaporimeters

It is clear that sufficiently accurate short-period measurements of pan-evaporation are far beyond the possibilities of the micrometer gauge.

Weighing the evaporation pan seems to be a logical solution and weighing techniques are adaptable to the problem, though the evaporated quantity of water will be in a very infavourable proportion to the dead weight involved. Weighed pans have been used for meteorological purposes

but in a rather free conception about exposure (BRAAK, 1936). As an evaporation pan should be sunken (RIJTEMA, 1965) the weighing should be entirely subsurface, which makes it too expensive a solution.

Floats which operate a pen are widely used for the recording of open water evaporation on a chart. In most cases the float is on the water in a tank which communicates with the pan. The fall of the water level in the pan is magnified by a lever ratio of the pen holder. Effects of wind or of frictions in the recording system are magnified also and high demands upon accuracy are not met. Other systems to record the fall of the water level in the pan have been reported (MIHARA, a.o. 1952; TAKEDA, a.o. 1955). They do not eliminate the influence of a changing water level on the rate of pan evaporation (BOYNTON, 1950). Equipments have been designed which keep the water in the pan at a constant level by controlled supply out of a reservoir in which the fall of the water level is sensed by a recorder (SUMNER, 1963, VAN 'T WOUDT, 1963). The water supply is regulated by a float-operated valve plug which has the advantage that the consequences of the pan being used in open air can be met by providing for a second valve plug, making the recording of run-off possible (VAN 'T WOUDT, 1963).

3. Adaption of constant water level principle to high accuracy

Though the recording of both the excess of rainfall over evaporation from a pan or the reverse mark an important milestone, it seems that possibilities for short-period measurement with sufficiently good accuracy still did not exist. To get the extreme out of the principle adopted by B.D. VAN 'T WOUDT, two conditions should be answered:

a. When the dimensions of a pan are sufficiently large a low rate of evaporation very soon equals a fairly large quantity of water. When this is supplied out of a reservoir with a much smaller inner diameter than the pan, very small amounts of evaporation from the pan are transposed into a fall of water level in the reservoir which is accurately measurable (UEHARA, 1953).
b. The rate of supply to or drainage from the pan has to keep up with the rate of evaporation losses or precipitation excesses as close as possible.

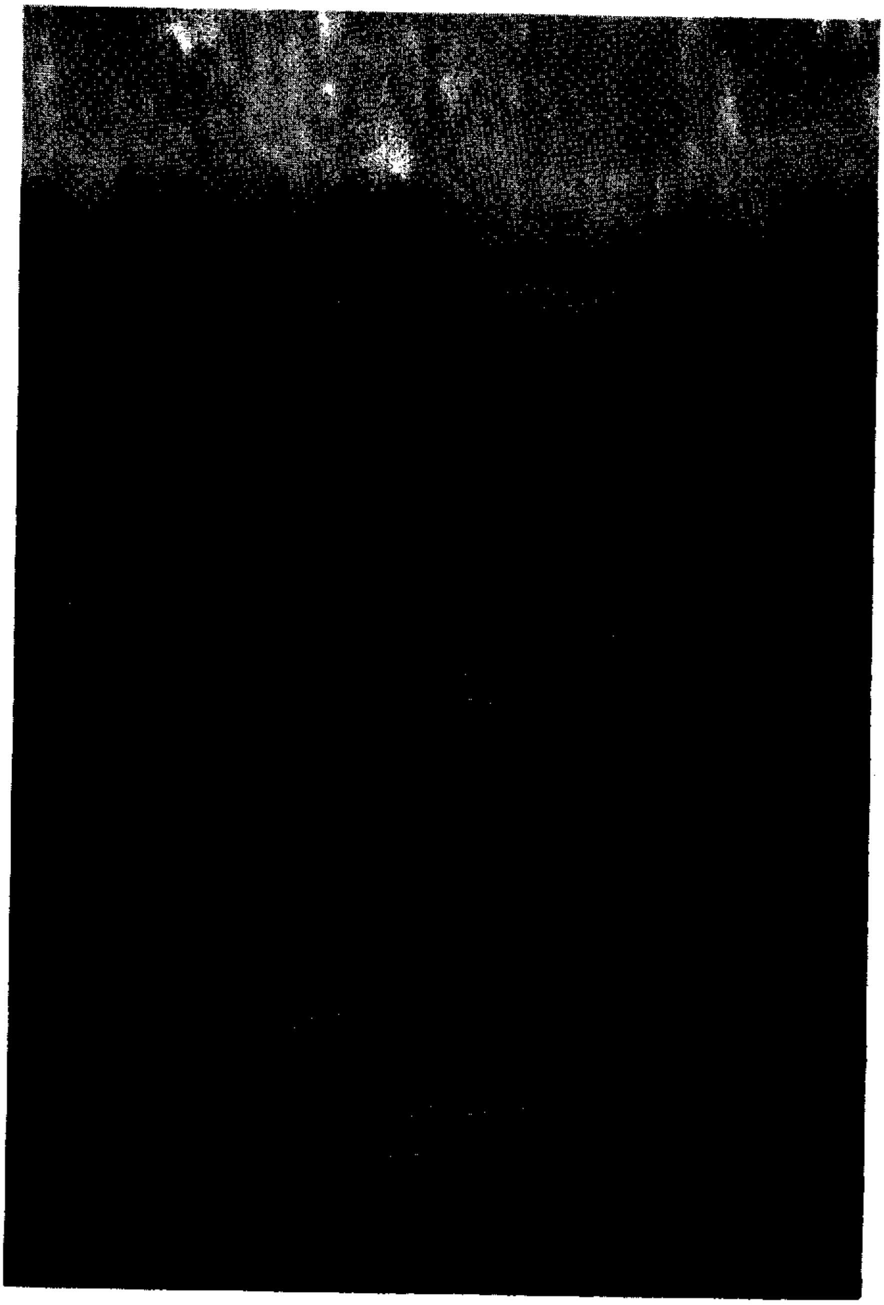
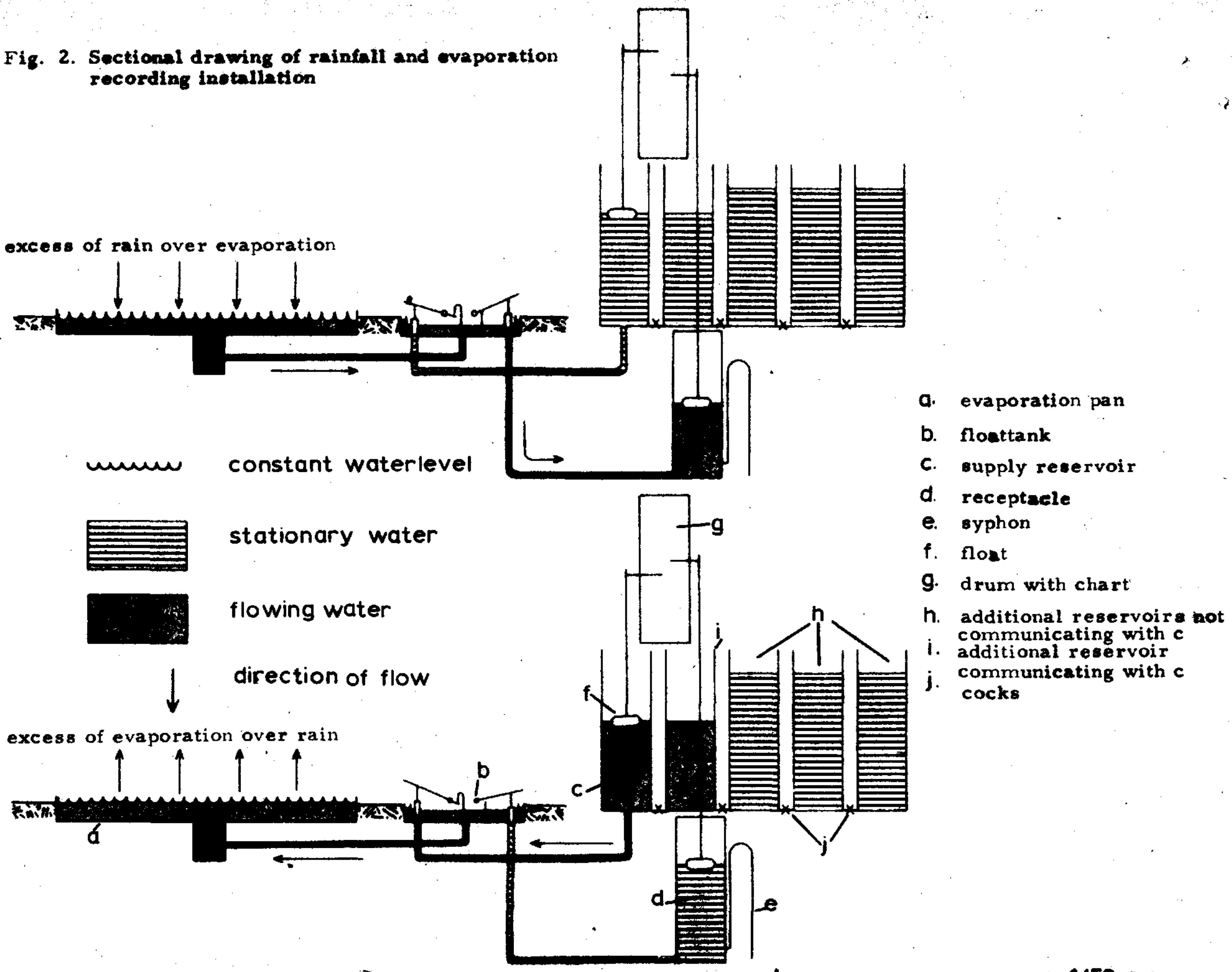


Figure 1. Test site of rainfall and evaporation recorder

Fig. 2. **Sectional drawing of rainfall and evaporation recording installation**



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As to sub a, a ratio of 4 between tank area and pan area, as applied by B.D. VAN 'T WOUDT seems hardly adequate for short-period measurements.

As to sub b, it is clear that when the valve plug is making one part with the float, supply or discharge will lag behind evaporation or precipitation at high rates because the required opening of the valves only occurs after the water level has changed sufficiently by either evaporation or precipitation.

The equipment to be described now, adjusts the realisation of the principle of the constant water level to the demands of short-period accuracy.

4. Description of the equipment

(a) General information

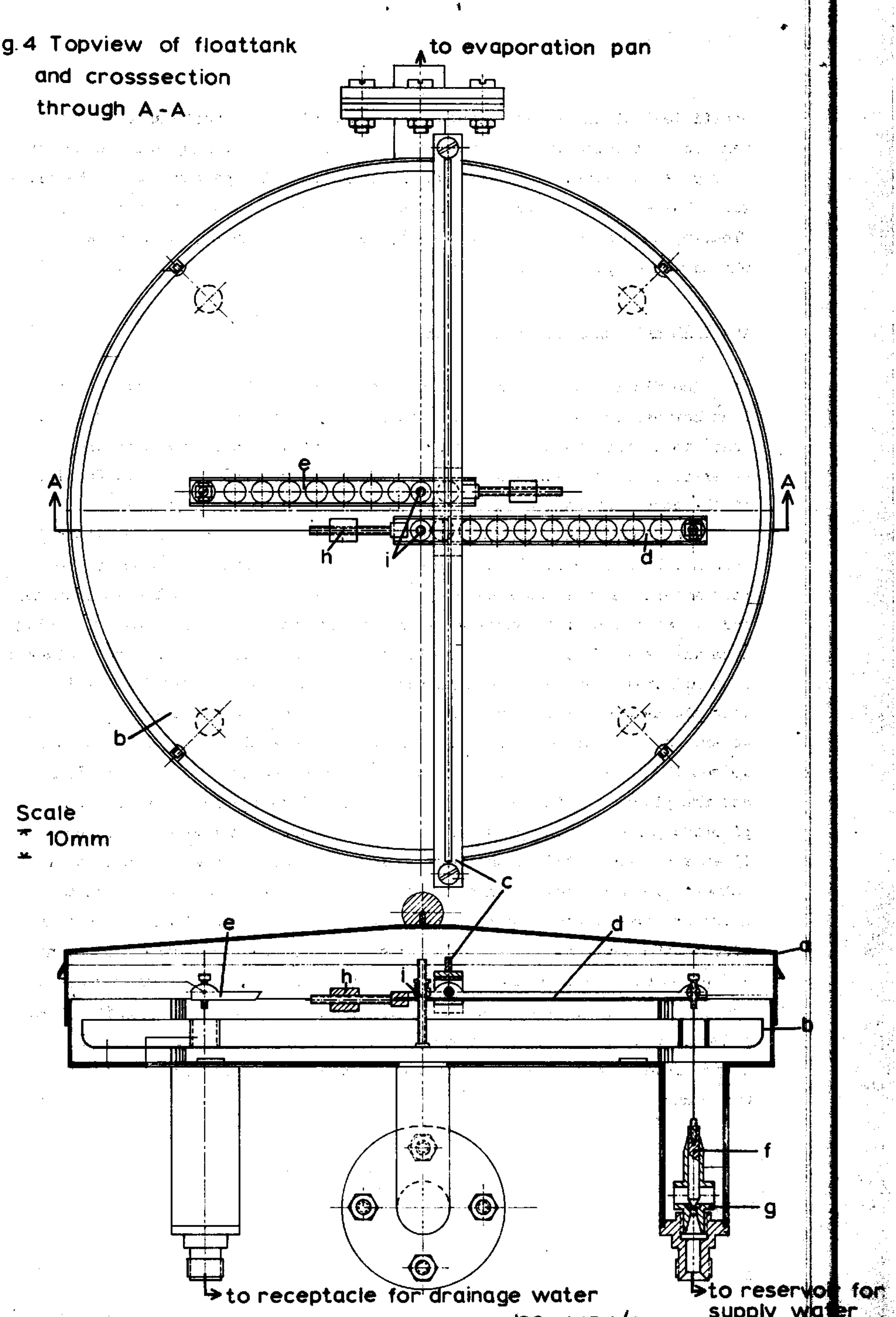
The newly constructed instrument consists of a shallow evaporation pan communicating with a float tank which keeps the water level in the pan at a constant level. It is completed with a recording set which records the water level in a reservoir for supply-water and that in a receptacle for discharged water. In figure 1 a photograph shows the installation in operation in the field. The recording set in the background is at a distance of 20 meters from pan and float tank. In figure 2 a sectional drawing of the instrument shows the principle of operation schematically. Description of evaporation pan, float tank and recording set will give detailed information.

(b) Description of the evaporation-pan

The brass pan has an inner diameter of 60 centimeters which is arbitrarily. Its depth of 5 centimeters is in conformity with the necessity to reduce the effect of temperature fluctuations on the water level to an acceptable limit (VAN 'T WOUDT, 1963). The water level is maintained at 1 centimeter below the rim of the pan. Now for a change in temperature from 10 to 20 degrees C the water level varies o.o58 mm.

The pan is sunken with the rim 1 centimeter above ground surface. The bottom and wall are painted black in order not to influence the reflection

Fig. 4 Topview of floattank and crosssection through A-A



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coefficient of the water surface. The brass piping between pan and float tank is protruding into the pan in the middle of a settling well to prevent as much as possible that dirt, which accumulates in the pan, enters the float tank. The end of the pipe is provided with a copper wire screen to keep floating debris out. This can clearly be seen on figure 3, showing a photograph of pan and float tank.

(c) Description of the float tank

The float tank is the most important part of the device. It is the link between evaporation pan and recording set and controls the supply of water to or the discharge of water from the pan. Connections with the reservoirs in the recording set are made of $\frac{1}{2}$-inch copper tubing. Details of the construction can be seen in the cross-section in figure 4.

The float tank is closed by a lid (a). On the photograph in figure 3 this has been removed. In the tank is a float (b) with a diameter of 24 centimeters. Mounted on a bar (c) over it are two levers (d and e) from the end of which stainless steel valve plugs (f) are suspended by nylon fishing line with a thickness of 12/100 millimeter. These valve plugs have a diameter of 4 millimeter and are 3 centimeters long. One end is tapered and fits into sharp-edged valve seats (g) made of brass with a diameter of $1\frac{1}{2}$ millimeter. The long arm of the levers can be counter-balanced by an adjustable weight (h). The distance between the suspension point of the valve plugs and the pivoting point of the levers is ten times the distance between pivoting point and the point where upward or downward movements of the float are transmitted to the levers. There are adjustable connections (i) between float and levers which are functioning only in one direction and which are free in the other. They are positioned on the float at the same side of the bar, so in the case of one lever (e) between suspension point and pivoting point, in the case of the other one (d) on the other side of the pivoting point. Thus when the float sinks one lever (d) is lifting the valve plug suspended from its end. When the float rises the valve plug is not moved. In the case of the other lever (e) it is just the other way round.

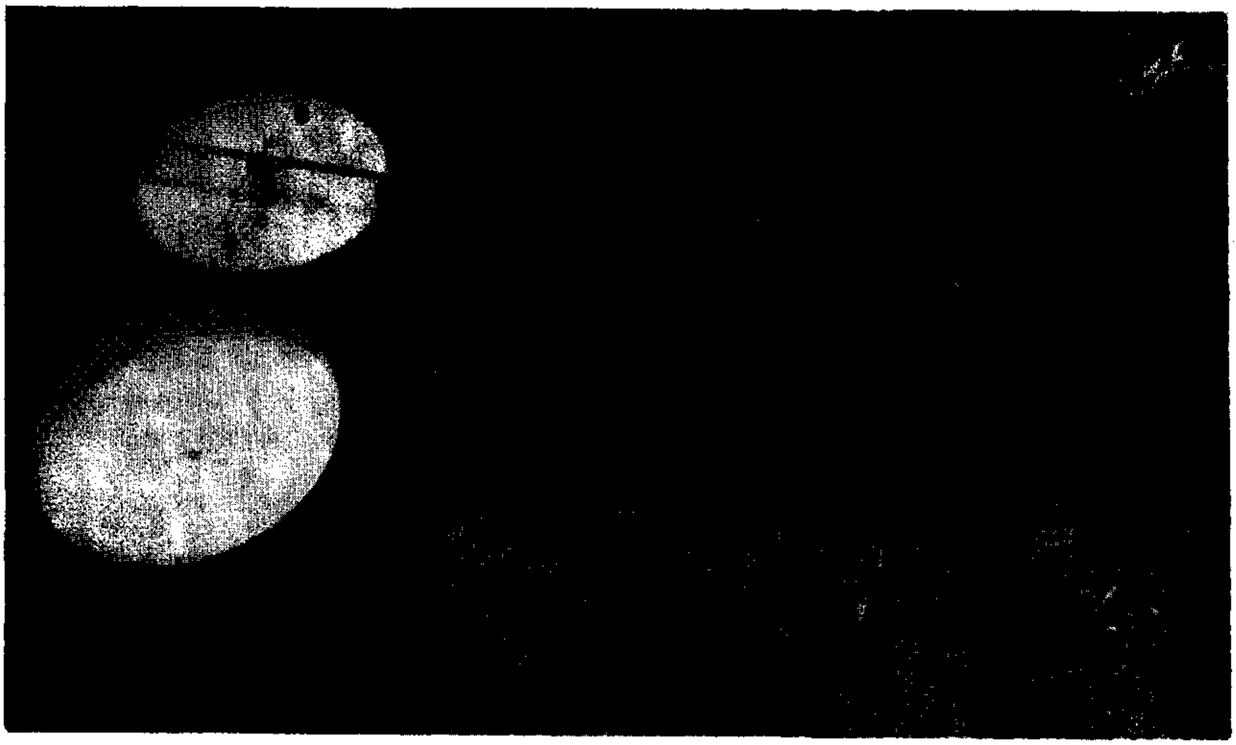


Figure 3. Pan and floattank in the field, seen from above

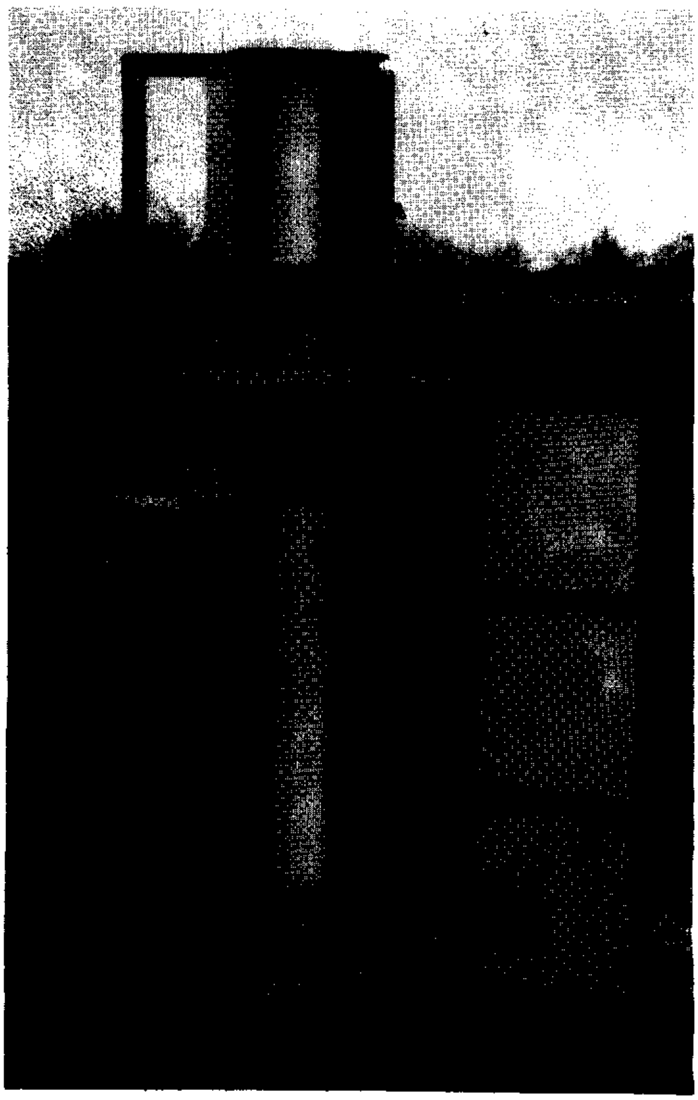


Figure 5. The recording set in the field

(d) Description of the recording set

The recording set is shown on the photograph in figure 5. The reservoir for water supply is above the water level in pan and float tank, the receptacle for discharged water is below it. They have an inner diameter of 12 centimeters, which gives a ratio of 25 to 1 between pan area and reservoir area. As far as the receptacle is concerned, this ratio is 24 : 1, as the drained water is caught in a tube right below the respective valve seat, which has an inner diameter of 25 mm and is communicating with the receptacle.

The water levels in reservoir and receptacle are float-recorded on one 25-centimeter scale chart. The floats have a diameter of 11 centimeters. As the water level in the receptacle for drained water is recorded in a 2 : 1 ratio, one millimeter of rain equals 12 millimeters on the chart. The receptacle is provided with a syphon which keeps the water level in it between a highest and a lowest level which are 50 centimeters apart, so 20,8 millimeters of rain can be held before the receptacle empties.

The water level in the reservoir for water supply is recorded in a 1 : 1 ratio. The supply of one millimeter water-loss by evaporation from the pan equals 25 millimeters on the chart. After 10 millimeters of evaporation the reservoir has to be replenished. As this is rather often in summer, there are four additional reservoirs, which are communicating with the one with the float in it.

As the connections between this reservoir and the additional ones can be closed off separately with cocks, the recording ratio can be reduced from 25 : 1 with 4 intervals to 5 : 1. Now 50 millimeters of evaporation can be recorded without intervention. In The Netherlands this is more than generally may be expected as a very extreme total in 8 days, which is the time of rotation of one of the clocks which may be used in the recorder.

Accurate measurement of the rate of evaporation during short periods is advanced by the use of clocks with daily rotation.

The recorder is a P-10B, manufactured by Alpina - Werke in Kaufbeuren, Western-Germany. It is initially designed for the simultanous recording of a water level on the spot - with reduction 5 : 1, 10 : 1 or 20 : 1 - and of the difference between two water levels, some distance apart, with reduction 1 : 1, 2 : 1, or 4 : 1. It is adapted to the purpose of the

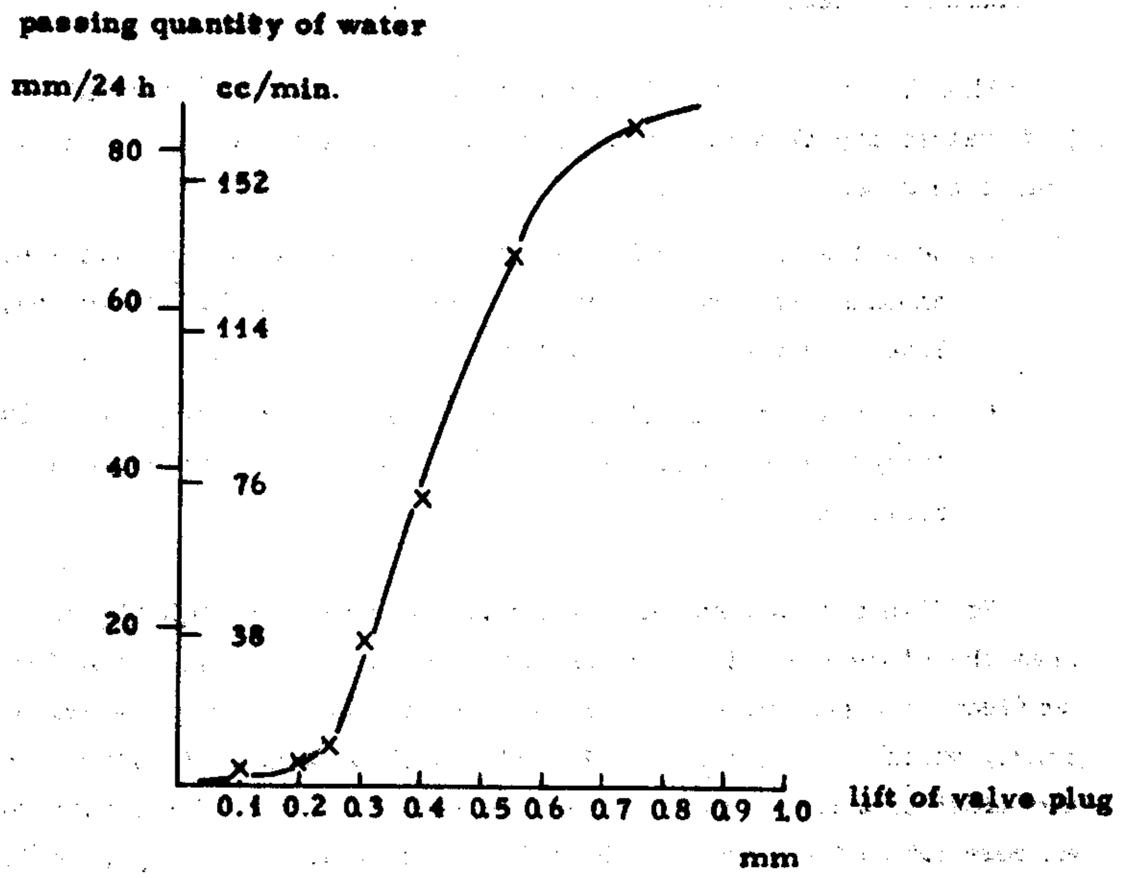


Fig. 6. Calibration of valve plug and seat

recording of the water level on the spot - used for the reservoir with supply-water - in a 1 : 1 ratio with high accuracy. Rainfall is recorded from top to bottom on the chart, evaporation from bottom to top.

5. Details on operation

When the water level in pan and float tank is at the required level both valves are closed. The adjustable connections between float and levers are to be adjusted so that:

a. when the water level makes the slightest fall, the valve plug closing off supply from the reservoir is lifted by the relative lever and the required water level is restored.

b. when the water level rises the valve plug closing off discharge is lifted by the relative lever and the required water level is restored.

In figure 6 is shown how much water can pass through the valve seats when the plugs are lifted to the indicated extent. A lift of 0.3 millimeter suffices to supply water in a rate equal to about 20 millimeters per 24 hours, which is a good estimation of the highest rate of evaporation in the midst of a hot summer day. As the lever ratio is 10 : 1 with this extreme rate of evaporation the fall of the float need only be 3/100 of a millimeter to let supply keep up with evaporation. So there is hardly a chance that replenishment lags behind on evaporation on account of the small dimensions of the valve seats. The same holds of course for the discharge of rain.

If the weight under water of the valve plug of 2.65 grammes would not be reduced by counter balancing, the float would have to put a force of 10 x 2.65 grammes on the short arm of the lever to lift a valve plug. This would require a change of the water level of 0.59 millimeter because the area on the water of the float is 452 cm^2. It is clear that the weight of the valve plugs should be reduced by counter balancing as much as possible to be sure that supply or drainage of water will keep up with evaporation or precipitation as close as possible. Of course some lag is inevitable because the plugs are only lifted as a consequence of a change in the

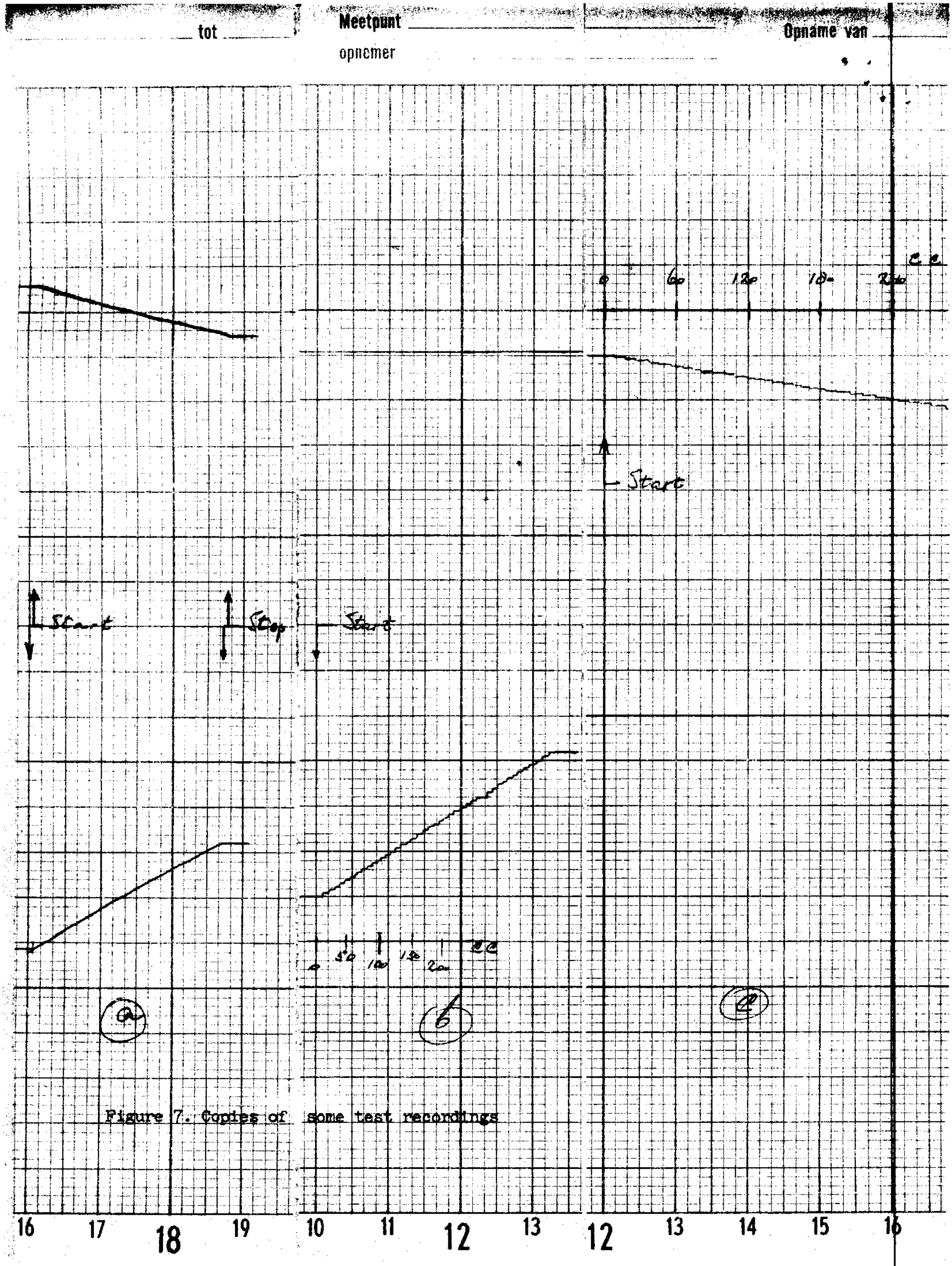


Figure 7. Copies of some test recordings

water level. Besides they have to keep enough weight to be able to stop supply or drainage. In the latter case conditions are more favourable because the direction of water flow is the same as that of the closing movement of the plug. In case of supply the plug has to overcome the pressure of a column of water with a height of about 5 to 30 centimeters.

Laboratory tests have shown that it is possible to have changes of water level of 0.02 to 0.04 millimeters lift the valve plugs. This means that 0.5 grammes of overweight of the plugs suffices to stop drainage or supply of water from the pan. Much depends on the extent to which the valve plugs can be counter balanced. With respect to this it is very important that plugs and seats are carefully machined.

In the discussion of some recording charts it will be shown that the results of the laboratory tests can be matched in the field.

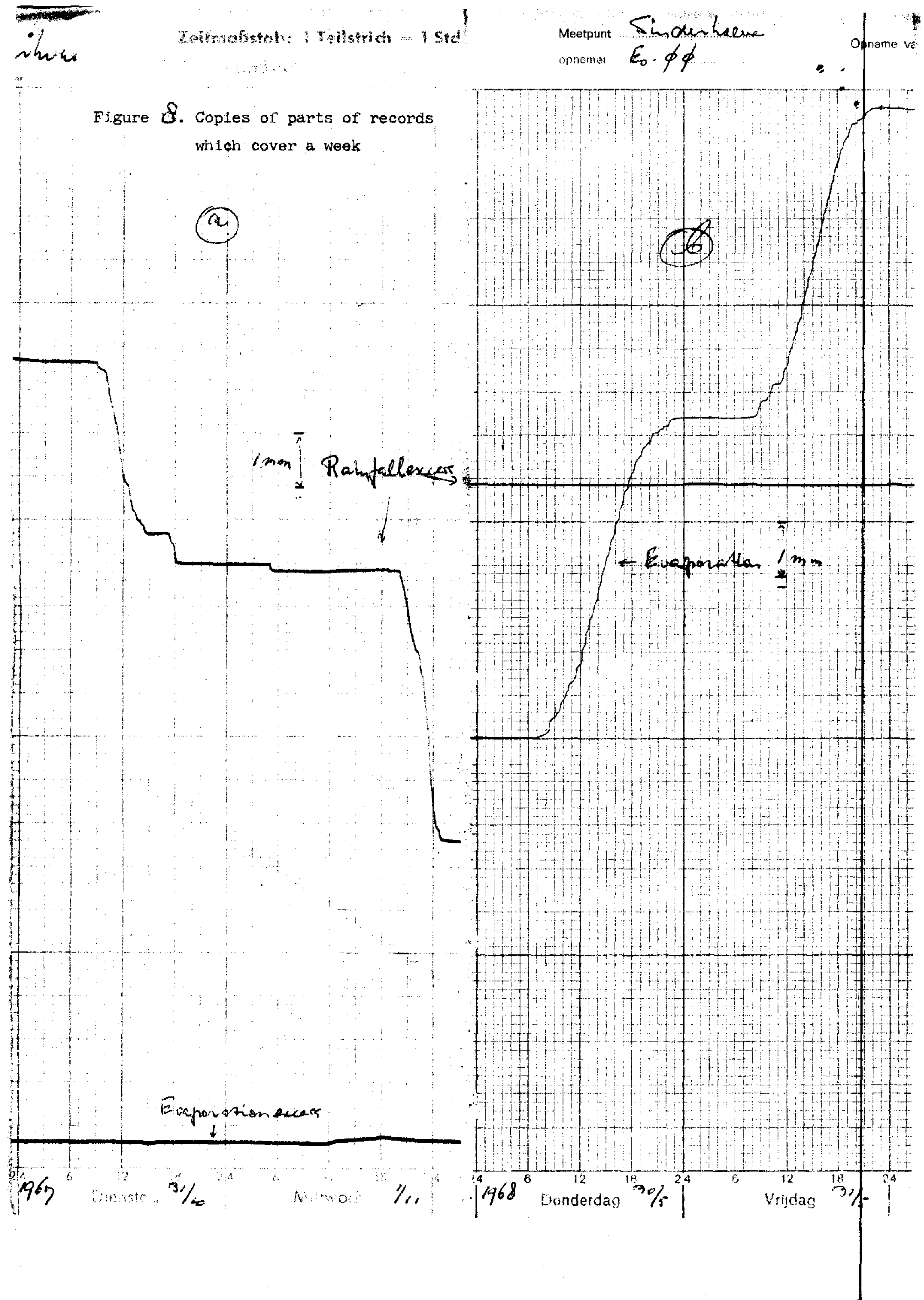
6. <u>Discussion of results</u>

(a) Analysis of some test recordings

a. Figure 7a shows the recording of a slow but steady draining from the supply tank directly into the receptacle for drainage water. This gives fairly straight and smooth lines which is the merit of the recorder. The same holds for the correct reproduction on the chart of the ratio of 25 : 12 between equal amounts of water in reservoir and receptacle. There is a small lag between the start of the test and the effectuation of the pens by the floats, due to frictions in the recorder. Repeated tests proved that the average lag is $3\frac{1}{2}$ cc of drained or supplied water or 0.3 mm water height in reservoir or receptacle. This is equal to an apparent change of water level in the pan of 0.0012 mm. With regard to the discussion of other recording charts these tests are very important.

b. In figure 7b is shown how an artificial draining from the evaporation pan at a steady rate of 113 cc/hour is recorded on a day chart. The line is not smooth but shows alternating vertical and horizontal pieces. This is caused by the alternating opening and closing of the valve plug. The vertical lines have an average

Figure 8. Copies of parts of records which cover a week



length of 0.75 mm. As the scale is 25 : 1 this means that the loss of water from the pan is replenished with intervals corresponding with a fall of the water level of 0.03 millimeters.

On the time scale the loss of water from the pan has been marked. It appears that replenishment starts after 10 cc has been drained, which is a lag of 0.035 millimeters fall of the water level.

c. Figure 7c shows the result of one of the tests with artificial supply of water into the pan at a steady rate. Drainage starts after 8 cc has been supplied. The lag between supply and start of drainage is equivalent to a rise of the water level of 0,028 millimeters.

The results of the tests have a good reproducibility. The average lag between start of water loss from the pan and start of replenishment, or between start of supply and start of drainage, is equivalent to a fall of the water level of 0.03 mm. The average discrepancy was 0.01 mm. These data hold for a succession of identical tests. When tests with artificial supply or drainage are alternated, lags and discrepancies are rather more than twice as large. The cause of this is the impossibility to adjust the connections between float and levers without play. This involves a small change in water level in the pan which is not recorded when rainfall excess changes in evaporation excess, or the reverse.

(b) Discussion of some recording charts

a. Figure 8 shows copies of records obtained under field conditions. The pan is exposed in grassland. For technical reasons the copies show only two days out of records which cover a week. Figure 8a is the record of rainy days in the beginning of November. Separate showers are showing very well. Evaporation is not of any importance. Some fluctuations of the line may be due to temperature influences. In 8 this is further discussed.

Figure 8b is the record of rainless days with high evaporation to Dutch standards. One additional supply reservoir is in use during this recording and in the last two days evaporation amounts to about 6 mm/24 hours. According to chance observations small irregularities in the curve may be due to fluctuations in radiation energy, caused by passing clouds for instance.

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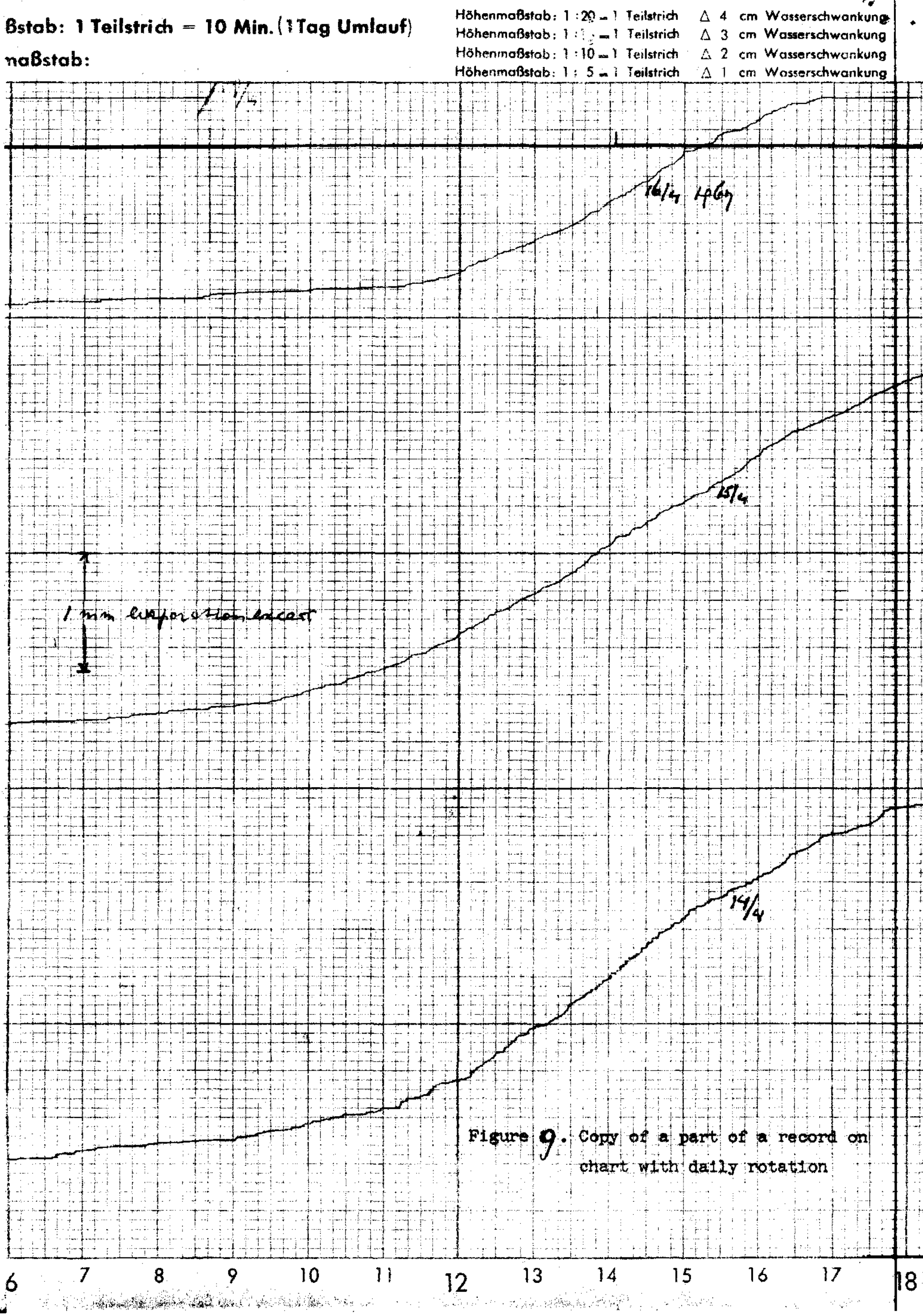

Figure 9. Copy of a part of a record on chart with daily rotation

b. In figure 9 a copy is shown of a part of another record obtained under field conditions. This time a clock with daily rotation was used, so successive days are recorded above each other as far as evaporation is concerned. There has been no rain during these three days. The figure affirms the statement in 6 (a) sub b that replenishment of water loss by evaporation from the pan occurs with intervals corresponding with fluctuations of the water level in the pan of 0.03 mm.

7. Agreement with conventional measurements

In figure 10 daily excesses of rainfall over evaporation or the reverse are compared with those calculated with data from a sunken pan with a diameter of 50 centimeters, which is read once a day with a micro gauge and from a recording rain gauge with an area of 400 cm^2 and with the rim 40 centimeters above the ground surface. The three instruments were a few meters apart. There were two test sites, 80 kilometers apart.

In both cases there is a good general agreement. In the case of figure 10a however there seems to be a tendency of the newly constructed instrument towards smaller rainfall excesses and larger evaporation excesses. As the days without rain have been marked in figure 10, it becomes evident that the pan concerned not only intercepts less rain, but evaporates more than conventional apparatus. Because the other pan does not show these divergences it is considered likely that a difference in exposure of the two sites is involved. As a matter of fact the site of figure 10b is completely open to all sides, while the ground surface is very level. The site of figure 10a is shielded to the east and has uneven immediate surroundings. However there has been no investigation into the cause of the differences between figures 10a and 10b.

It is well known that ground level rain gauges intercept more rain than elevated gauges. Therefore the conclusion of figure 10 must be that the newly constructed instrument possibly suffers from a loss of water because more is splashing out of the pan than into it.

Assuming that figure 10b is representative for correct exposure of the instrument, there is an average discrepancy of 1.34 millimeters per day. How much of this is caused by accidental error is not known. It is considered likely that the newly constructed instrument has a greater [illegible] are [illegible] py [illegible] sh [illegible] obtained [illegible]

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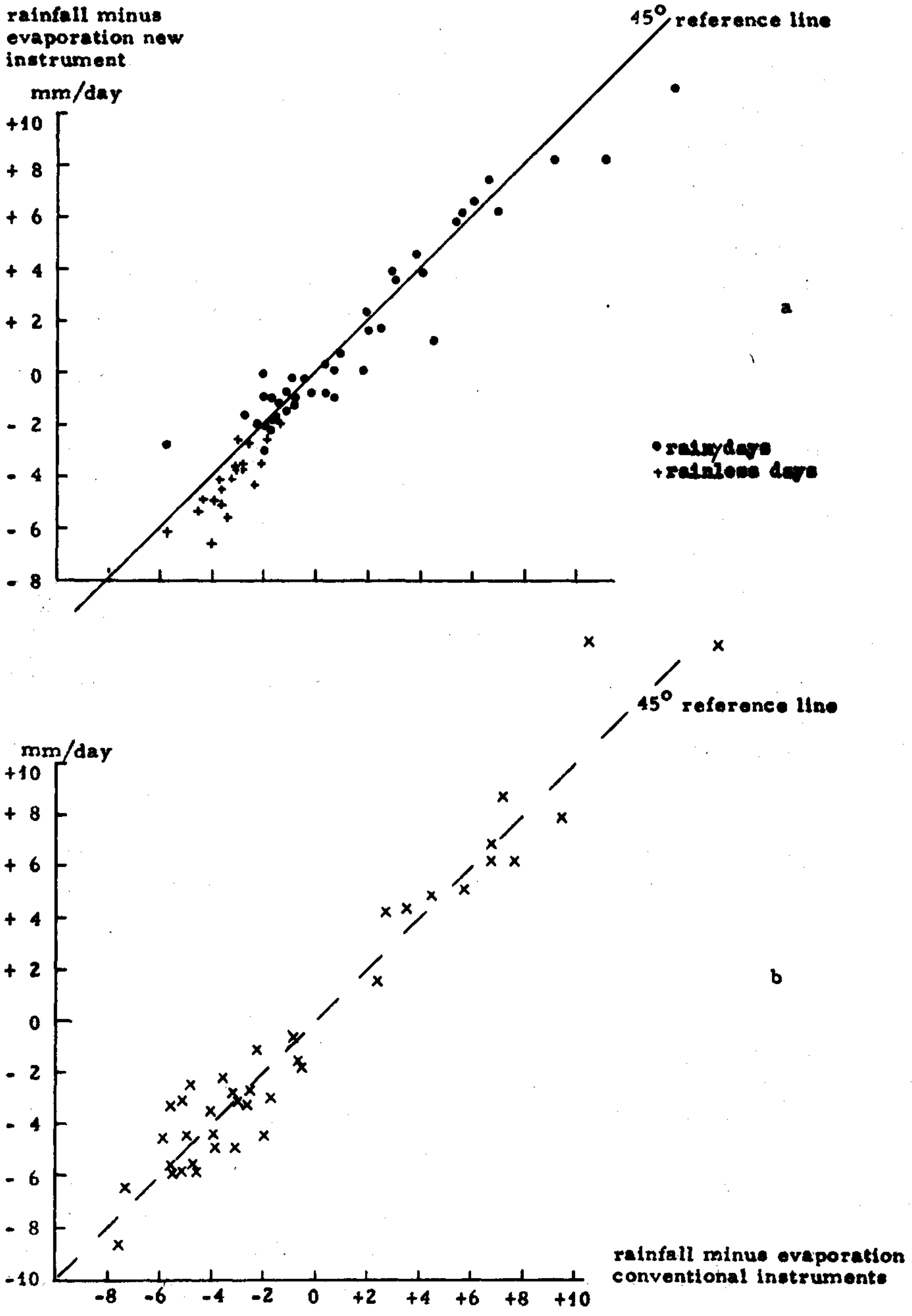
Fig. 10. Measurements of newly constructed instrument compared with those of conventional apparatus



precision because its measurements are taken from the evaporation pan which is rain gauge as well. No errors can come from differences between area, exposition etc. of separate evaporation pan and rain gauge.

8. Some possible improvements

Though after the experimental phase the instrument is functioning satisfactory there are still some minor defects to look after.

a. The instrument is very susceptible to dirt lodging between valve plugs and seats in the float tank, eliminating one of its functions. When the discharge valve is concerned the whole system is consequently emptied. When the supply valve is concerned only the reservoir for water supply is emptied but as long as this is going on the water is passing through the float tank and is discharged into the receptacle. The record breaks down in both cases.

   It should be determined to what extent filtering material in the connections between pan and float tank and float tank and reservoir can be used without unfavourable effects, for instance on the hydraulic head required for the flow of water from pan to float tank. Such effects may be very small but also the instrument is one of small quantities.

   With respect to this point it is obvious that the use of ferruginous water is to be avoided.

b. It attracts attention that when no rainfall excess or evaporation excess occurs, the curves which consequently should be straight may be slightly undulating. This is probably due to considerable temperature fluctuations which affect the water level in the reservoir and receptacle and probably also the length of the thin steel wire between pen holders and floats. The effects are small, as is proved in figure 8a by the line for evaporation excess, and equal apparent amounts of water up to 0.1 millimeter. Nevertheless it fits into the attempts to gain the highest possible accuracy to try to eliminate them. Insulating the recording set may help.

c. Temperature effects in pan and float tank have also been observed. Night frosts may show up in a small supply of water in the night when temperature is lowest, followed by a proportional loss of

water in the morning when the temperature is rising again. This might perhaps be prevented by insulating the float tank and its connection with the pan. In that case the best effect will be secured when the float tank is farther removed from the pan than can be seen on the photograph in figure 3.

When it is really winter the instrument should of course be stopped operating to prevent damage and because at least the evaporation pan can not be prevented from freezing. This would give records of evaporation without any climatological meaning.

d. A systematic error due to splash might be prevented by surrounding the pan with open water of the same depth. Fluctuations of the level of this water should be limited as much as possible with some simple device without recording.

Acknowledgements

Thanks are due to the staff of Van Doorne's Apparaten fabriek at De Bilt, for working out drafts and constructing the mechanism, and to Messrs. BOEKHOUT and VAN BERENSCHOT, engineers with the Winterswijkse Waterleiding Mij., for taking a large part in operating one of the test instruments in the experimental phase.

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