

RESEARCH NOTES



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A WATER BALANCE APPROACH TO
MOISTURE STORAGE ESTIMATION IN FOREST SOILS

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ABSTRACT

A water balance is presented which reveals soil moisture behavior at the Ford Forestry Center, located at Alberta in Baraga County in Michigan's Upper Peninsula, for both normal and drought conditions. The utility of the method is briefly discussed. The results presented are being used as the basis for the design of investigations into water behavior in forested soils.

SYMBOLS

P	= Precipitation	mm
T _p	= Transpiration	mm
I	= Interception	mm
E	= Evaporation	mm
Q	= Streamflow	mm
L	= Leakages	mm
S	= Storage	mm
E _t	= Evapotranspiration (includes interception)	mm
S _s	= Snow Storage	mm
S _g	= Soil Storage	mm
T	= Daily mean air temperature in excess of 10°C	°C
L _v	= Latent heat of vaporization (20°C)	g/cal.
ly	= langley	gcal/cm ²

INTRODUCTION

It is the purpose of this research note to examine the average monthly behavior of soil moisture storage in the forested area around the Ford Forestry Center at Alberta, located in Baraga County in Michigan's Upper Peninsula. Since no direct measurements of this quantity were available, a water balance was constructed for the area, and solved for the soil moisture storage term. This term, as reported here, is expressed as a monthly average for the area within a five mile radius of Alberta. The area possesses a variety of soils with different hydrologic characteristics. The interpretation of the areally averaged results will differ for each soil.

The water balance approach to hydrological problems applies the law of mass conservation for the estimation of some critical aspect of water behavior within a particular region. The problem is formulated as:

$$\text{Water in} - \text{Water out} = \text{Water Stored in System} \quad (1)$$

When individual flows and storages replace these more general ideas, we have the terms of the water balance equation which may be generally written as:

$$(P) - (T_p + I + E) - Q \pm L = \Delta S \quad (2)$$

For Alberta, transpiration, interception and evaporation cannot be usefully separated and must be combined as evapotranspiration, leakages are assumed to be very small in comparison to average values of the other terms, and the storage term must be expanded to include both snow and soil moisture storages. This equation may then be simplified to:

$$P = E_t - Q = \Delta S_s + \Delta S_g \quad (3)$$

If four of the terms in this equation are known, it is very easy to calculate the fifth, unknown term.

METHODS

Precipitation (P) has been measured at Alberta on a daily basis since 1956 (Appendix I). These records were averaged on a monthly basis for the twenty year period 1957-1976. The values obtained were placed in column one of the water balance table (Table I).

Evapotranspiration (E_t) is the most difficult term to estimate in the water balance equation. Since daily temperature records are available for Alberta for the period 1957-1976, the Budyko (1956) method for calculating average potential evapotranspiration (E_o) was used. The relationship used was:

$$E_o = 0.2 \Sigma T \text{ mm mo}^{-1} \quad (4)$$

where ΣT is the sum of all daily mean temperatures greater than 10°C. This equation gives physical meaning to air temperature as a predictor of potential evapotranspiration by first relating air temperature to

Streamflow values (Q) were calculated on the basis of flow rates reported in the literature for streams in the near vicinity of Alberta (Hendrickson *et al.*, 1973; Knutilla, 1974). The important value to estimate was a minimum monthly flow rate provided by ground water discharge. Flow rates in cubic feet per second per square mile were assumed to be representative of mean monthly minimum flow for a 30-day period, and multiplied by 28.338 to convert these rates to mm mo^{-1} amounts. The values attained are listed in Table II.

TABLE II. *Observed Streamflow near Alberta, Michigan.*

A. Minimum Flows (mm mo^{-1})

	West Branch Sturgeon River	East Branch Ontonagon River	West Branch Otter River
Mean Discharge	29.2	47.0	24.1
Median 7 day Minimum Discharge	7.4	25.5	7.6

B. High Flows and Low Flows (mm mo^{-1})

	Pelkie Creek	Sturgeon River	Plumbago Creek
High (April)	363.0	387.0	416.0
Low (May)	22.9	34.0	44.2

Average low flow of these streams is about 24 mm mo^{-1} , and the value 20 mm mo^{-1} was used to approximate mean minimum monthly streamflow. The estimated value used is lower than the average, since the three low flow values in Table IIB were observed in May, when streamflow is still influenced by the spring snowmelt.

The flow behavior displayed in the water balance shows very limited average variation from June through February. This results from the assumption that all flow stems from groundwater discharge during these months. The assumption reflects observed streamflow behavior in the Upper Peninsula (Hendrickson, *et al.*, 1973).

Starting in May, with a saturated soil, we may then calculate the monthly variation in soil moisture status expressed as the deviation from saturation at the month's end.

DISCUSSION

The water balance indicates that there is an absolute water deficit on the average for the months of July and August, and it predicts a loss of 111 mm by the end of August, which is only slightly improved by the end of September. Under average conditions, trees could undergo moisture stress during these months on soils with low available water storage capacities within the rooting depths.

The accompanying graph (Figure 1) shows the moisture storage capacity of soil as a function of bulk density and the depth of the soil. Under average conditions, trees on a very shallow soil with a high bulk density, experience moisture stress. Initial observations indicate that for the range of bulk densities and soil depths normally encountered around Alberta (Shetron, pers. comm.) trees will not undergo stressful conditions.

The water balance further predicts a slow decrease in soil moisture storage until snow melt brings the soil to a saturated condition in March (Table I).

Using the precipitation records for 1976, the driest year in our 20 years of observations, and making some assumptions concerning evapotranspiration during that year, it was possible to calculate a worst case soil moisture drawdown for the Alberta area using the water balance method (Table III). It can be seen on the graph that all soils to the 75 cm depth will lose all available water, and that there will be a serious loss of water in soils 100 and 125 cm deep. Several of the most important forest soils at Alberta have fragipans or bed rock within 75 cm of the soil surface which impede both water movement and root penetration. Under worst case conditions then, it is evident that trees on these soils would experience severe moisture stress.

TABLE III. *Soil Moisture Storage - Worst Case Conditions (mm)*

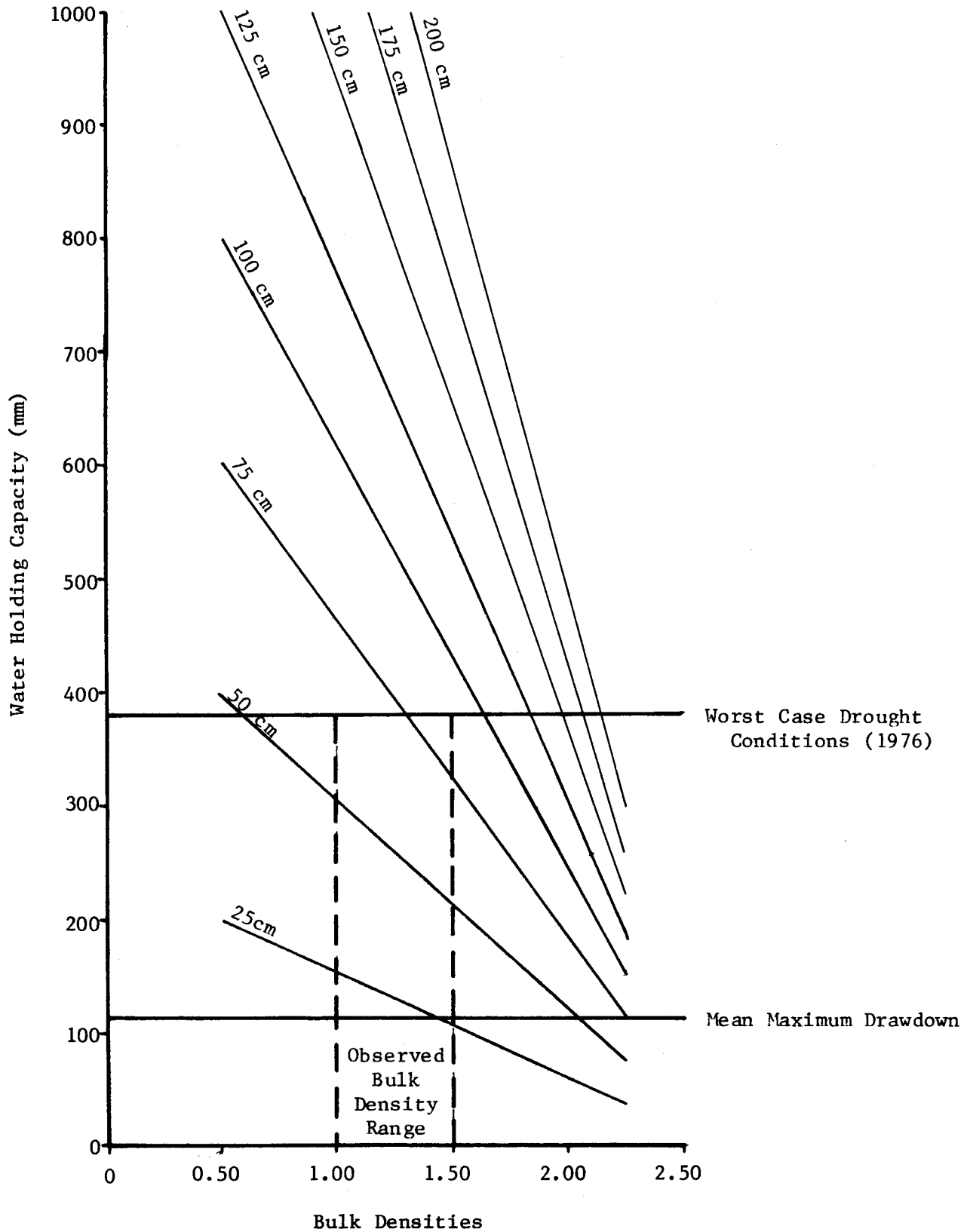
Month	25 Percent Greater PET	10 Percent Greater PET	Normal PET	PET (1976)
April	0	0	0	0
May	-35	-28	-24	-21
June	-177	-96	-83	-98
July	-247	-208	-184	-203
Aug.	-393	-337	-302	-330
Sept.*	-464	-397	-355	-380

* Greatest drawdown

In addition, it may be seen from the water balance (Table I), that a soil moisture deficit of this magnitude would not be made-up during a following normal year. This effect is amplified by resistances to water movement in very dry soils, which, when coupled to the rapidity of snowmelt, would divert a large percentage of spring snowmelt to streamflow.

The deficit could be mitigated somewhat by the decline in streamflow as ever increasing areas lost their ability to contribute water to local brooks and rivers. The worst case condition drawdown, as shown on the graph, is the greatest average drawdown for all soils in the area that could possibly occur under the stated conditions. It is probably somewhat in excess of the soil moisture loss which actually occurred. Nevertheless, we may reasonably conclude that the drought of 1976 exhausted available moisture in several forest soils, placed

Figure 1. Water holding capacity as a function of bulk density and effective soil depth.



a large area of forest under moisture stress, and that the moisture deficit was not made up under the more normal conditions occurring the following year.

CONCLUSIONS

The water balance approach is very useful for the detection of water problems, and for the clarification of the grosser aspects of water behavior for a particular region. It permits the user to detect periods of moisture deficit, outline normal patterns of streamflow, and plan strategies for dealing with problems of growth limitation and streamflow. The approach is limited by the availability of data applicable to the area under study, and particularly by the difficulty of obtaining good estimates of evapotranspiration. Because of its neglect of the details of an area's water behavior, many important aspects of that behavior cannot be examined with a water balance.

Although the approach presents average values for the area and for the period of record, it can be applied to considerations of individual soils under specified conditions of drought or surplus. In this way, the approach can be used to define moisture problems limiting management possibilities for a particular region. The water balance for the Alberta area presented above, is only one example of the use of this approach. Any change in any of the terms due to construction, forest management, changes in weather, soil loss, or mine tailing disposal, will be reflected in other aspects of water behavior for an area. The water balance approach is an extremely useful initial planning tool.

Concerning the water balance constructed for Alberta, it may be concluded that:

- The Budyko approximation gives a useful estimate of evapotranspiration for this region.
- There is a small absolute soil moisture deficit for the months of July and August. It may be tentatively concluded that this deficit will not normally cause serious moisture stress problems in the vegetation.
- A severe drought year will not only cause serious moisture stress during that year, but the soil moisture deficit will not be completely made up the following year with a return to more usual conditions. This means that the forest vegetation may enter the spring growing season under moisture stress.

LITERATURE CITED

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APPENDIX I

Precipitation Statistics for Alberta (mm) - 20 years record (1957-1976)

Month	Mean	Mean Total	Max	Min	Drought Year (1976) amount	Drought Year (1976) total	Recovery Year (1977) amount	Recovery Year (1977) total	Snow Accumulation Mean
Jan	40	40	70	16	46	46	33	33	508
Feb	37	77	81	15	42	88	23	56	584
Mar	52	129	120	16	120	208	80	136	345
Apr	58	187	150	25	32	240	100	236	5
May	95	282	172	25	42	282	62	298	0
Jun	98	380	207	46	55	337	90	388	0
Jul	87	467	256	22	34	371	120	508	0
Aug	83	550	132	12	12	383	103	611	0
Sep	102	652	205	37	37	420	141	752	0
Oct	79	731	180	35	49	469	57	809	0
Nov	78	809	144	38	38	507	55	864	173
Dec	<u>48</u>	857	101	20	<u>27</u>	534	<u>71</u>	935	325
Year	857		1205*	534*	534		935		

*Annual minimum and maximum Totals

APPENDIX II

Pan Evaporation Statistics for Alberta (mm) - 8 years (1961-67, 1969)

Month	Mean	Mean Total	Max	Year	Min	Year
May	102	102	139	1964	97	1963*
Jun	116	218	141	1965	59	1967
Jul	110	328	157	1966	109	1961
Aug	91	419	123	1969	64	1964
Sep	64	483	82	1967	49	1962
Oct	50	533	70	1963	24	1966*
Year	533					

* Record not complete (adjusted)