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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Civil Engineering

Semi-Annual Status of Progress Report

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"Inference of Effective Soil Properties from Observed Vegetal Canopy Density"

A. Objectives

The objective of this research is twofold:

1. Testing of an equilibrium hypothesis for the density of natural vegetal systems. This is being accomplished by comparing data from a wide range of climate and soil conditions to a hypothesized physical relationship between the vegetal canopy density, and the ratio of actual to potential evapotranspiration.

2. Use of this hypothesis in an existing mean annual water balance equation to determine the spatial average effective soil properties for a given catchment. For verification, these soil properties will be used in the water balance equation to derive the statistics of annual watershed yield which will be compared with the observed statistics.

B. Technical Progress

1. Testing of Hypothesis

Based upon survival-of-the-fittest arguments, Eagleson [1978] has developed a theoretical relationship between the ratio, J, of actual to potential evapotranspiration (i.e., the evaporation efficiency) and the vegetation canopy density, M_o, under natural equilibrium conditions. This relationship is presented in Fig. 1 for various values of the parameter $\beta h_o/\bar{e}_p$. Here

β^{-1} = expected value of the time between rainstorms, days
h_o = depth of water retained on the surface, cm
$\bar{e}_p$ = average potential rate of evapotranspiration from a bare soil surface

Also shown on this figure are points representing a preliminary analysis of observations from catchments in various climatic regimes throughout the U.S.

The two points labeled Santa Paula and Clinton are the two most thoroughly studied watersheds. Their equilibrium vegetal densities have been estimated at .3 and .8, respectively. Because of the in-depth analysis of the climate and watershed conditions of these two catchments, all the values of necessary parameters and variables were established with little uncertainty, and it can be seen that they afford the best fit to the derived relationship.

All points labeled "W - ***", are catchments whose precipitation and runoff data and general watershed conditions were studied and published by the U.S.D.A. [1963, 1967]. Difficulties arose with the sets of data in that many of the catchments were not in their natural state thus resulting in vegetation densities that may not be the natural equilibrium density. Also, estimates of the albedo and cloud cover, which are important in the calculation of potential evaporation, are not exact. The two points labeled W-3 and W-2 are catchments in Florida where groundwater infiltration from neighboring watersheds is highly possible due to the flat nature of the topography. This infiltration could increase the actual yield of the basin, thus decreasing the observed evapotranspiration, resulting in the point being located below the derived curve. Efforts are being made to obtain more exact data on these watersheds.

The points marked Boco Mtn. and Palo Alto were obtained from a paper by F. A. Branson and J. B. Owen [1978]. In this report, the authors plotted a relationship between runoff and percent bare soil in a watershed. Also given in the paper was the mean annual precipitation for these two catchments. Potential evaporation was calculated for these catchments, for those studied by U.S.D.A., and for Clinton and Santa Paula, from mean annual values for temperature, cloud cover and relative humidity obtained from U.S. Weather Service publications for the nearest weather station.

The evapotranspiration efficiency, J, was estimated by subtracting annual streamflow from annual precipitation, and dividing by the potential evaporation, calculated as explained above.

2. Estimation of Effective Soil Parameters

To estimate the spatial average effective soil parameters, $K(1)$, the saturated intrinsic permeability; c, pore disconnectedness index; and s_o, average soil moisture concentration, the following algorithm is being used:

a. For a given catchment, the vegetation parameters, M_o and K_v, are known from observations

b. A value for n, effective soil porosity, is assumed

c. From the relationship between M_o, J and E, and using the

the hypothesis that $\frac{\partial J}{\partial M} = 0$ at equilibrium, the value of E can be calculated from $M = M_o$. This gives Equation (1)

$$s_o = s_o(K(1), c) \qquad (1)$$

d. Extrapolating the curve of J vs. E from the known value of E at the given M_o to the point J = 1, by some sort of 3rd order approximation, the value of E(1) which corresponds to $s_o = 1$ can be determined from the function [see Figure 2] derived by Eagleson [1978]. This gives Equation (2)

$$s_o = 1 = s_o(K(1), c) \qquad (2)$$

e. The equation for E is

$$E = \left[\frac{2\beta\ n\ K(1)\ \phi(1)}{\pi\ m\ e_p^{-2}}\right] \phi_e\ s_o^{d+2} \qquad (3)$$

where K(1), $\phi(1)$, ϕ_e, d, are functions of K(1) and c, and the other variables are known, for $s_o = 1$, E = E(1), and the above equation can be solved directly for K(1) with c as the only independent variable.

f. It can also be seen from Equation (3) that the only difference between E(1), and E is the last term. With E(1) and E known, and for n given, c and s_o can be directly calculated from

$$s_o = \left[\frac{E}{E(1)}\right]^{1/d+2} \qquad (4)$$

g. Picking a value for c, K(1) and s_o can be calculated. The last equation needed is the water balance equation,

$$s_o = s_o(K(1),\ c) \qquad (5)$$

A trial can then be performed on c until the water balance equation is satisfied.

Presently, difficulties are being experienced in the approximation for E(1). Initially, a simple tangent approximation to the point J = 1 from the known value of E was used to find E(1). However, due to the asymptotic behavior of the function in the area around J = 1, this approach resulted in values of E(1) which are smaller than the actual values. These actual values were calculated from data obtained at Clinton and Santa Paula, and were found to be two orders of magnitude greater than those obtained from the tangent approximation. Use is now being made of a Taylor series expansion of higher orders to simulate the asymptotic behavior of the function.

3. Personnel

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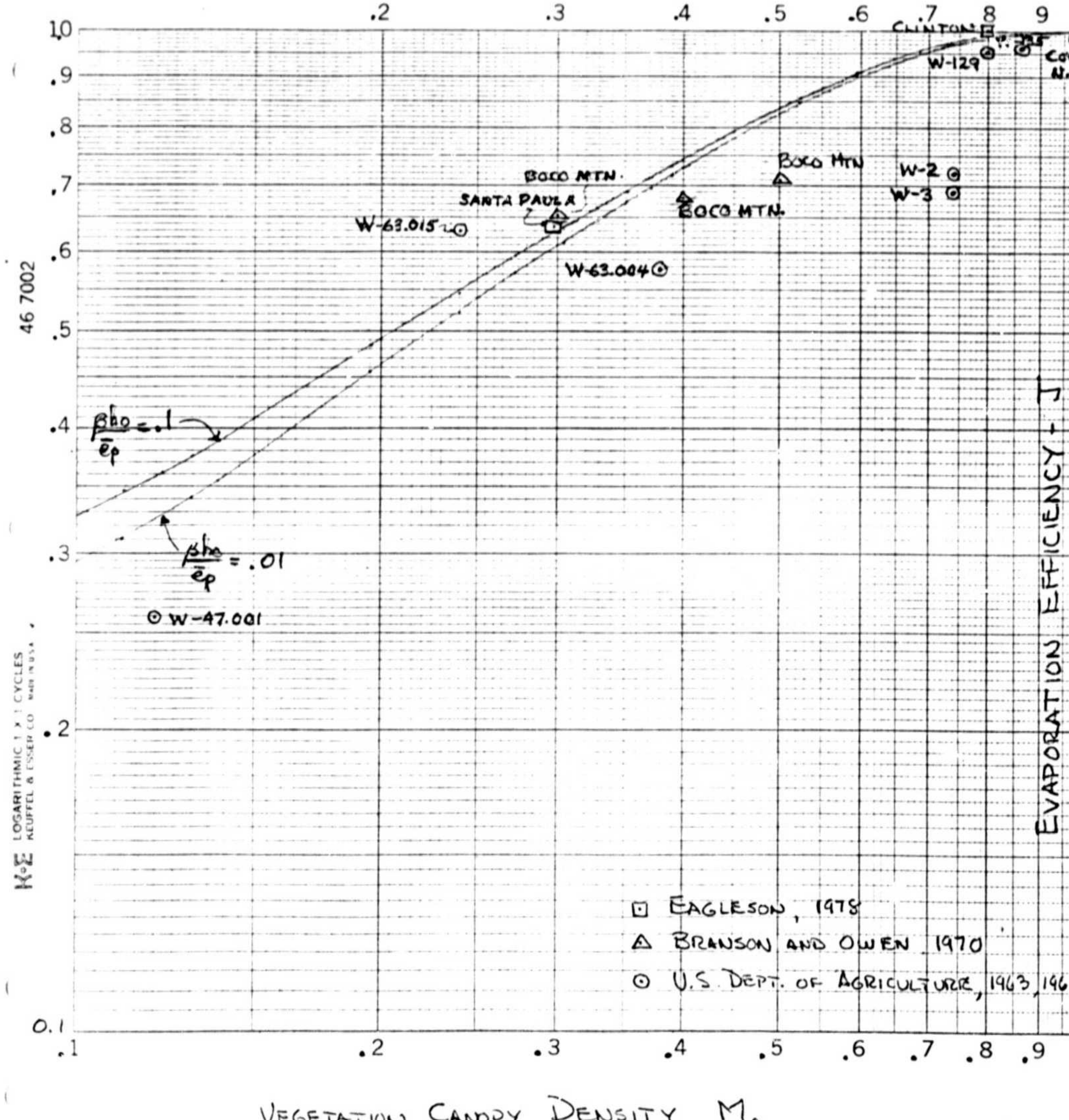

FIG. 1 VEGETATION DENSITY HYPOTHESIS

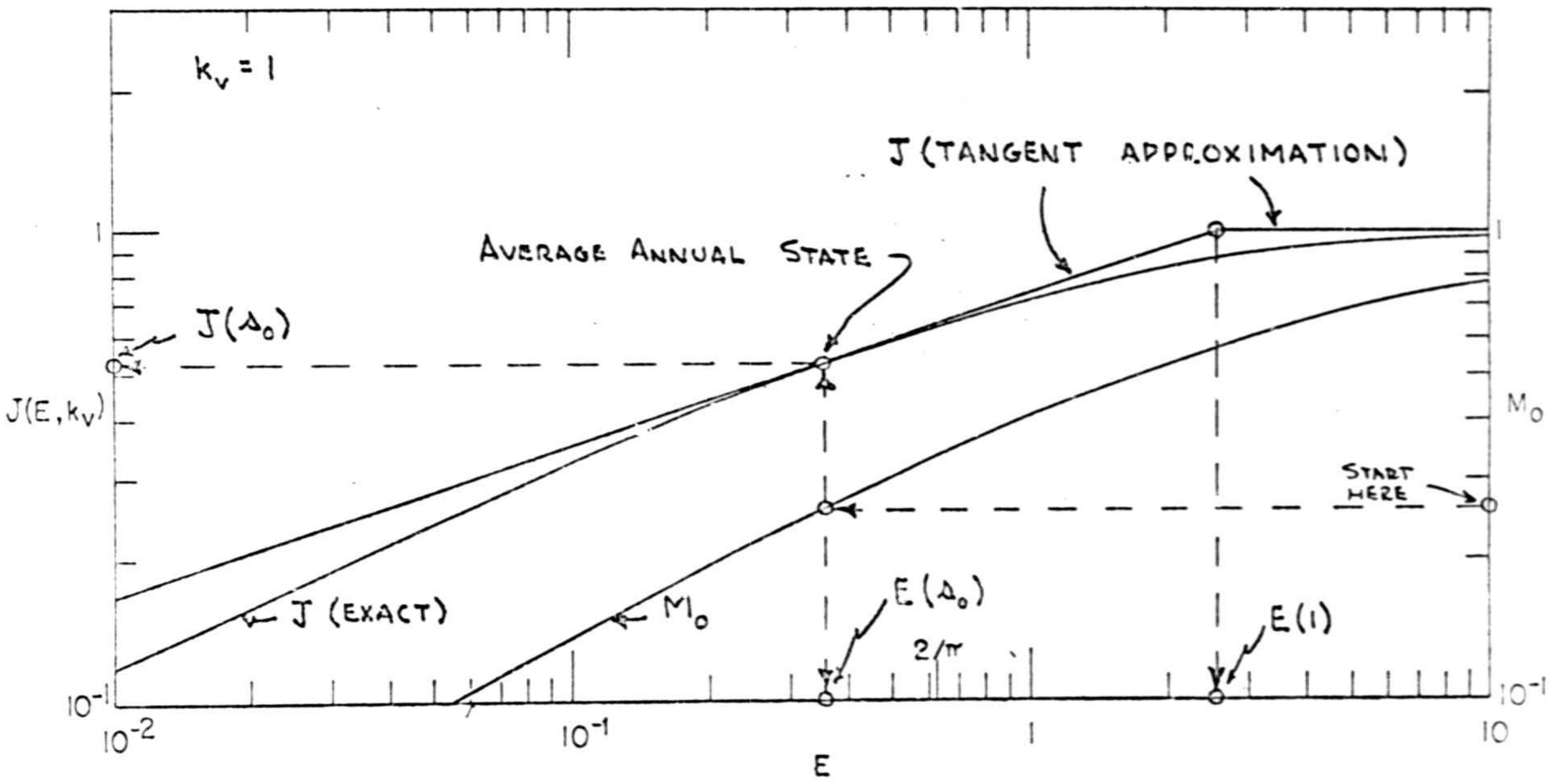

Figure 2

PROPOSED FIRST ORDER APPROXIMATION OF EVAPOTRANSPIRATION FUNCTION