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The Implications of Using Estimated Solar Radiation on the Derivation of Potential Evapotranspiration and Soil Moisture Deficit within an Embankment

Peter Helm[1], Ross Stirling[1] and Stephanie Glendinning[1]
[1]Newcastle University,Newcastle-upon-Tyne, U.K.
peter.helm@newcastle.ac.uk, ross.stirling@newcastle.ac.uk

Abstract
In the absence of measured data, evapotranspiration is commonly estimated at a given site according to the methods outlined by Allen et al. (1998). Their work provides a system of calculation to derive the solar radiation values required to predict the available energy for water vaporisation. As such estimations of evapotranspiration are very dependent on the available data.In this work, meteorological parameters including air temperature, relative humidity, wind speed, near-surface soil temperature, shortwave and net solar radiation were measured for a complete year at the BIONICS trial embankment, Newcastle, UK.
Estimates were made of the net radiation for a number of cases (1. no radiation data and 2. measured incident short wave radiation) and compared to the field monitored values. These data were in turn used to estimate the potential evapotranspiration (ET_p) from the embankment. The results indicate that the net radiation and hence ET_p derived entirely from estimated data are significantly higher than those derived with measured shortwave or net radiation. Results for estimates of ET_p derived from monitored shortwave and net radiation data are a close match to each other.
In order to investigate the potential effects on slope stability, an assessment of soil moisture deficit was undertaken. The results indicate that numerical models using the varying estimates of ET_p would likely produce different results in terms of generated suctions and suction dissipation and so undergo different magnitudes of shrink-swell cycling, in turn leading to varying rates of strain softening behaviour, differing calculated factors of safety and differing modelled time to failure.

*Keywords:*Evapotranspiration, Net radiation, Soil moisture deficit, Slope stability

1 Introduction

A significant factor influencing infrastructure slope stability is the fluctuation of pore water pressures due to changing weather patterns. Researchers have investigated the influence of changing

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weather on infrastructure slope pore water pressures (Smethurst et al., 2006; 2012; Glendinning et al., 2014 amongst others) as well as the resultant effect of fluctuating pore pressures on stability via laboratory and numerical modelling studies (Potts et al., 1997; Nyambayo et al., 2004; O'Brien et al, 2004; Ellis and O'Brien, 2007; Rouainia et al, 2009; Nyambayo and Potts, 2010; Take and Bolton, 2011; Davies et al., 2014).

Dijkstra and Dixon (2010) highlighted the extremely wet winter conditions in 2000-2001 which led to widespread slope failures in south east England, Wales and Scotland which is further evidence of the influence of rainfall on stability. However along with the influence of antecedent rainfall in triggering instability, progressive failure and strength reduction is also a significant mechanism in the behavior of infrastructure slopes, particularly in high plasticity over consolidated clays (see for example Potts et al., 1997; Leroueil, 2001: Take and Bolton, 2011). This mechanism typically requires shrink-swell behavior to occur over time and in turn requires moisture content (and pore water pressure) changes in the soil which at the near surface are generated by rainfall (as previously mentioned) and evapotranspiration (ET).

The process of evapotranspiration will act to remove water from the near surface and in the zone of influence of vegetation roots, leading to the generation of suctions, elevated effective stress and hence volume change. As such to model shrink-swell behavior and its influence on progressive failure in high plasticity clays it is in turn necessary to derive the near surface water balance. The rainfall reaching the soil surface can be measured directly, however the evapotranspiration is most commonly estimated from meteorological parameters recorded at or near the site of interest.

Potential evapotranspiration (ET_p) is commonly estimated using the Penman-Monteith equation (Montieth, 1965) which requires a number of meteorological parameters. The majority of these are measured directly, however the net radiation flux (R_n) is commonly estimated from monitored incident shortwave radiation (R_s) using the methods outlined by Allen et al. (1998). In the absence of measured shortwave radiation it may in turn be estimated based on a calculation of the extraterrestrial radiation (R_a).

In this work the potential evapotranspiration (ET_p) occurring from the surface of a trial infrastructure embankment is estimated using the procedures outlined above. In turn the influence of the resultant ET_p on soil moisture deficit (used as a proxy for slope stability) is investigated in order to attempt to provide guidance on the requirements for the monitoring of meteorological parameters as inputs for numerical modelling.

The site used for this work was the BIONICS embankment which was constructed in 2005 and is located at Nafferton Farm near Stocksfield, Northumberland, UK (OS Grid Reference: NZ 064657). The construction and extensive research activity at this site is described in more detail by Hughes et al. (2009) and Glendinning et al. (2014).

2 Potential Evapotranspiration

The two processes of evaporation and transpiration are together commonly referred to as evapotranspiration (ET). A detailed discussion of these processes is given in Allen et al. (1998). A very brief summary of the most significant details is given here.