**Evaporation**

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1. **Introduction**

A watershed is the area that contributes all the water that passes through a given cross section of a stream on the basis of topography. A watershed is also called drainage basin, river basin, or catchment. The boundary line that delimits a watershed is called a divide. A watershed is treated as a unit for hydrologic investigations as its topographic divide defines hydrologic boundaries that enable water budgets to be computed. The water balance for a given watershed is calculated using the water balance equation for any time period of length t:



Where P is precipitation (liquid and solid), is ground-water inflow (liquid), Q is stream outflow (liquid), ET is evapotranspiration (vapor), is ground-water outflow (liquid), and is the change in all forms of storage (liquid and solid) over the time period.



*Fig. 1 Schematic diagram of a watershed.*

Evaporation is a type of vaporization of a liquid that occurs only on the surface of a liquid. It is an essential part of the water cycle driven by solar energy, which can evaporate water from oceans, lakes, moisture in the soil, and so on. Evaporation of water occurs when the surface of the liquid is exposed, allowing molecules to escape and form water vapor, and then the water vapor can rise up and form clouds.

Related literature:

*Dingman, S.L., 2008. Evapotranspiration: Infiltration and Redistribution in Physical Hydrology, pp273~251.*

**Practice:**

Question for Students 1

Evaporation is a common phenomenon in our daily environment. Which factors do influence evaporation, and what is the mechanism? (Hint: keep in mind that the essence of evaporation process is the diffusion of water molecules from high concentration to low concentration).

*Answer for Instructors 1: As the evaporation process is essentially the diffusion of water molecules, we just need to think about which factors will influence diffusion processes. First, the concentration difference plays an important role; with regard to evaporation differences between the vapor pressures of the evaporating surface and the overlying air are most important, and temperature controls these pressures. Secondly, the flow of air affects evaporation—i.e. wind can help bringing the high water concentration air away from the evaporation surface, and thus increase the concentration difference, and speed up the evaporation process. Besides, the air pressure, and density will also influence diffusion, which in turn will influence the evaporation process. The influence of eddies, and air properties are all demonstrated through the parameter KE, the efficiency of vertical transport of water vapor.*

*Lastly, the condition of underlying surface is another important factor that determines evaporation, for instance, the evaporation rate will be quite different between a lake surface and bare soil, or a vegetated surface.*

Question for Students 2

Evaporation can be calculated with Fick’s first law, which is shown in the excel file ‘Evaporation’ sheet ‘Fick’s first law. Compare the parameters of the equation with your answers for question 1, are the relationships proportional or inversely proportional?

*Answer for Instructors 2: answers for discussion are shown in table 1:*

|  |  |  |
| --- | --- | --- |
| *Factors* | *Parameters in the equation* | *Relationship* |
| *Air pressure, density, Turbulent eddies* | *KE* | *Proportional to air density, Inversely related to air pressure and vapor density* |
| *Wind* | *va* | *Proportional* |
| *Vapor pressure difference* | *es, ea* | *Proportional* |
| *Temperature* | *es, ea* | *Proportional* |

There are several practices in the excel sheet, you can fill in values and answer the following questions:

*2A*  In sheet ‘Fick’s equation’, we present an equation to calculate KE at a lake surface, which shows that KE is inverse to lake area; why would this be the case?

*Answer for Instructors 2A:*

*There are two reasons that lake area affects evaporation:*

1. *Since water surfaces are smoother than land surfaces, the efficiency of turbulent eddies in the vertical transport of water vapor decreases as the wind travels over a longer distance over a lake.*
2. *The value of ea will increase with downwind distance as evaporation occurs, decreasing the effective vapor-pressure difference over the lake compared with the value measured anywhere except on the downwind shore.*

*2B*  Practice 1 uses a relationship between evaporation and KE. Please calculate E, and plot a graph of E as a function of KE. Make notes on the plot that you made, what is the relationship based on the plot trendline? Will KE greatly influence E? (Hint: check the slope of the trendline)

*Answer for Instructors 2B: The calculations and graph are shown for instructors in the excel worksheet ‘Fick’s equation’. The graph shows that E increases with KE, if we draw a trend line, the slope shows to be 457920, which means small changes in KE will lead to large changes in E. Discuss with the students that the relative change is small, evaporation is only 7% less for a lake >4 times as large (comparing Lake Ontario and Superior).*

*2C*  Practice 2 illustrates the relationship between E and wind speed vs, calculate E, and plot a graph of E as a function of vs, what did you get? What is the slope of the trendline?

*Answer for Instructors 2C: The calculation and graph are shown for instructors in the excel worksheet ‘Fick’s equation’, the graph shows that E is proportional to vs. If we draw a trend line, the slope shows to be 0.94, close to 1, which means evaporation will change linearly and at the same order with wind speed.*

*2D*  Practice 3 is used to show the relationship between evaporation and vapor pressure. Please calculate E, and plot a graph of E as a function of (es – ea), what did you get? Is pressure difference more important for evaporation than wind speed?

*Answer for Instructors 2D: The calculation and graphare shown for instructors in excel sheet ‘Fick’s equation’. The graph shows that E is proportional with (es – ea). If we draw a trend line, the slope shows to be 4.45, much larger than 1, which means vapor pressure difference is a more critical factor in determining evaporation.*

Question for Students 3

Evaporation varies for different underlying surfaces. For free water surfaces (for instance, lakes and wetland) evaporation is simplest, we can directly use the equations used in the excel sheet ‘Fick’s first law. Look at the practice in the excel sheet ‘evaporation at water surface’; calculate the value of E with the provided parameters.

*Answer for Instructors 3: Both the steps for calculation and the result are in the sheet ‘evaporation at water surface’.*

Question for Students 4

Evaporation for bare soil is quite different than evaporation over a free water surface. Evaporation from a soil surface includes two stages:

1) the atmosphere-controlled stage, in which the evaporation rate is largely determined by the surface condition, which can be determined using the same method as for a free water surface.

2) the soil-controlled stage, in which the evaporation rate is determined by the rate at which water can be conducted to the soil surface in response to potential gradients induced by upward-decreasing soil-water conditions. Generally, the evaporation at this stage is less than the free-water stage. In excel sheet ‘evaporation for bare soil’, we list the equation for bare soil evaporation, please use the equations to answer the questions asked in the worksheet.

*Answer for Instructors 4:*

*Both the calculation steps and the result are shown in the sheet ‘evaporation for bare soil’.*