Gabriola Streamkeepers—Water levels and quality

Observations at Coats Marsh, Gabriola Island

—with notes on Coats Marsh Creek, East Path Creek, and Stump Farm Streams.

Notes on evaporation and evapotranspiration

The master file is:
Observations at Coats Marsh RP , File 673 .

Observation files containing field notes are:

2015: Supplementary file "Field Observations 2015", File 673d.

2016 (Jan. - Mar.): Supplementary file "Field Observations 2016-1", File 673e.

2016 (Apr. - June): Supplementary file "Field Observations 2016-2", File 673f.

2016 (July - September): Supplementary file "Field Observations 2016-3", File 673g.

2016 (October - December): Supplementary file "Field Observations 2016-4", File 673h.

2017 (Jan. - Mar.): Supplementary file "Field Observations 2017-1", File 673j.

Evapotranspiration

Evapotranspiration (ET), the combined effect of evaporation and transpiration from plants, is a major source of water loss during the summer when there is little rain. The other sources, leakage through the baffle when the level is below the sill, and infiltration into the lake bed, appear to be much smaller.

Of interest then are answers to the questions: is the observed rate the level drops in the range 2–5 mm/day commensurate with the theoretical evaporation rate? and does the growth of watershield (*Brasenia schreberi*) over much of the surface in late-summer affect this in any way?

In thinking about this, I'll ignore the effect of the few patches of water lilies and of the reeds around the margins of the lake.

Evaporation (ET with no plants)

The rate of evaporation from open water depends on the surface and air temperatures, the relative humidity, and the movement of the air due to convection and wind. Estimating the rate is best done using empirical data because the theory is complicated. The interest in calculating the loss of water from aquariums and swimming pools gives many formulas for calculating evaporation losses. The one I'll use is an empirical formula from the online engineering toolbox.[1]

The formula they give is: $g = \Theta A (x_s - x)$ kg/hour, where:

$\Theta = (25 + 19 v)$ = evaporation coefficient (kg/m^2h)
v = velocity of air above the water surface (m/s)
A = water surface area (m^2)
x_s = humidity ratio in saturated air at the temperature T_s of the water surface (kg/kg) (kg of H_2O in kg of dry air)
x_a = humidity ratio of the air at the temperature T_a of the air (kg/kg) (kg of H_2O in kg of dry air).

[the units don't match because this is an empirical formula].[2]

Introducing the relative humidity φ, defined here as the ratio x/x_s, and dividing by A gives:
$g/A = \Theta x_s (1 - \varphi)$ kg/hour/m^2

Take the density of water at the temperature T_s to be σ_s kg/m^3
then $g/A = \Theta x_s (1 - \varphi) / \sigma_s$ m/hour, which is:
$E = 24000 \Theta x_s (1 - \varphi) / \sigma_s \approx 24 \Theta x_s (1 - \varphi)$ mm/day.

Values of x_s for various temperatures T_s (ºC) are readily available in tables which we can summarize in the spreadsheet formula:[3]
$x_s = 10^{-6} \times (0.416 T_s^3 + 2.788 T_s^2 + 319.9 T_s + 3733)$ for example, $T_s = 16$ºC, $x_s = 0.0113$.

We're not going to know precise values of φ as defined, so it will be sufficient to take it as being the relative humidity RH as conventionally defined expressed as a fraction.

[1] *Evaporation from water surfaces*, http://www.engineeringtoolbox.com.

[2] Nanaimo weather averages for Apr.-Sept. are T_a = 16.5ºC, v = 2.3 m/s (4.4 knots), RH = 65%.

[3] x_s is also a function of atmospheric pressure, but the dependency is slight so 100 kPa has been assumed.

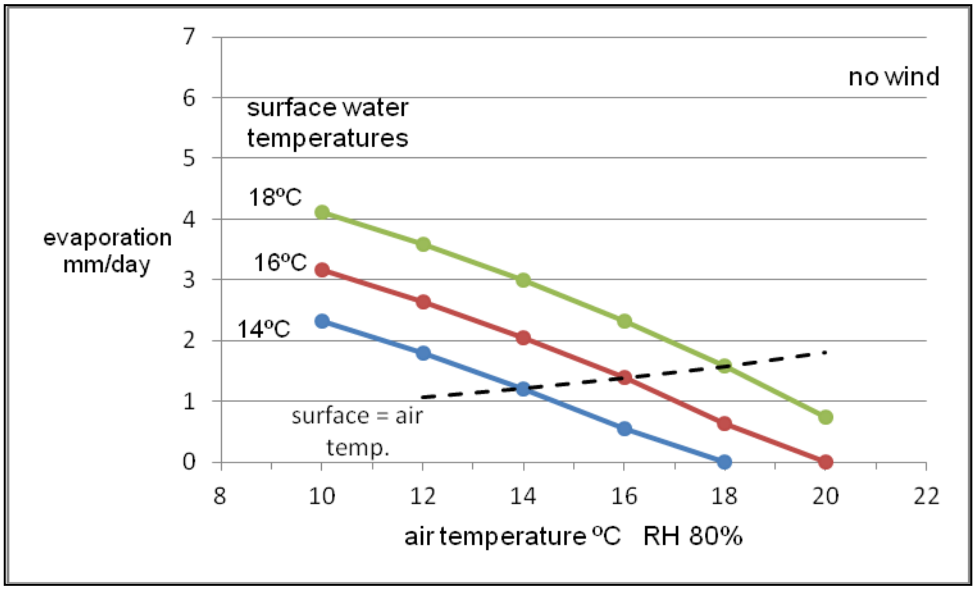


Figure 1: evaporation rates E (mm/day) as a function of air temperature (ºC), with no wind, and relative humidity 80%, for three values of surface water temperature (ºC) .

The higher rates occur when the air is cooler than the surface of the water. If the daily average temperatures of the surface water and the air are about the same, E is around 1–2 mm/day.

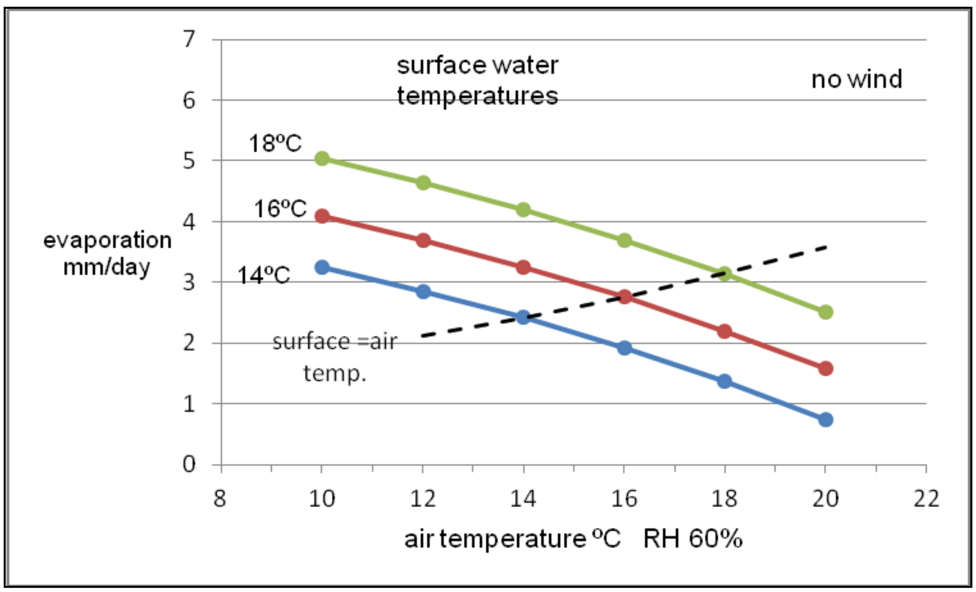


Figure 2: evaporation rates E (mm/day) under the same conditions as for Figure 1 except for a reduced relative humidity of 60%.

If the daily average temperatures of the surface water and the air are about the same, E is around 2–3.5 mm/day.

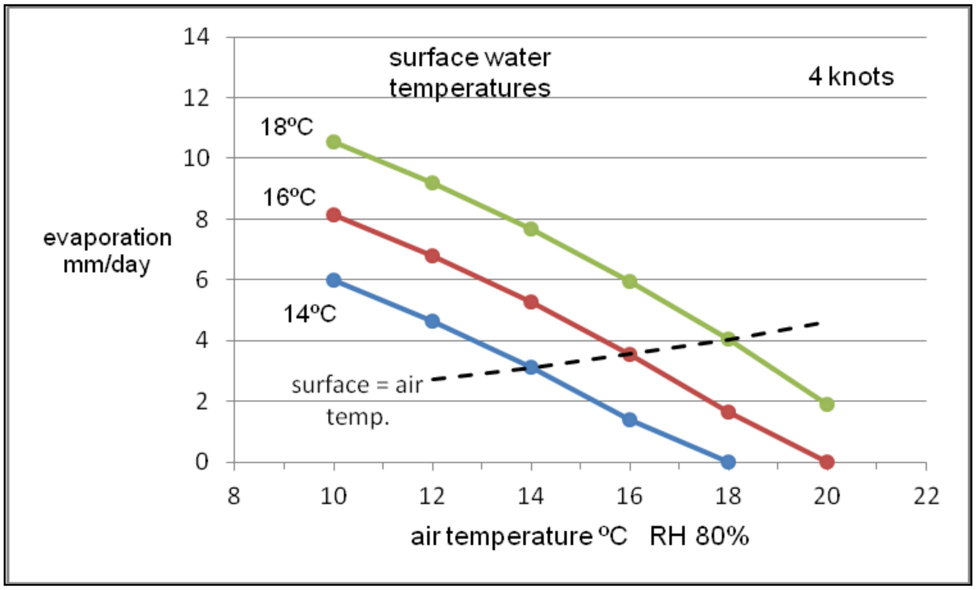


Figure 3: evaporation rates E (mm/day) under the same conditions as for Figure 1 except for a wind speed of 4 knots.

If the daily average temperatures of the surface water and the air are about the same, E is around 3–5 mm/day.

Four knots (2.1 m/s, 7.4 km/h, Bft.2) is the annual average wind speed here with relatively little monthly variation throughout the year. This is a *light breeze*; leaves rustling with small branches moving only in gusts (Bft.3); wind direction apparent with a wetted finger; light flags not fully extended except in gusts; ripples and small wavelets; no white-caps except very occasionally in gusts.

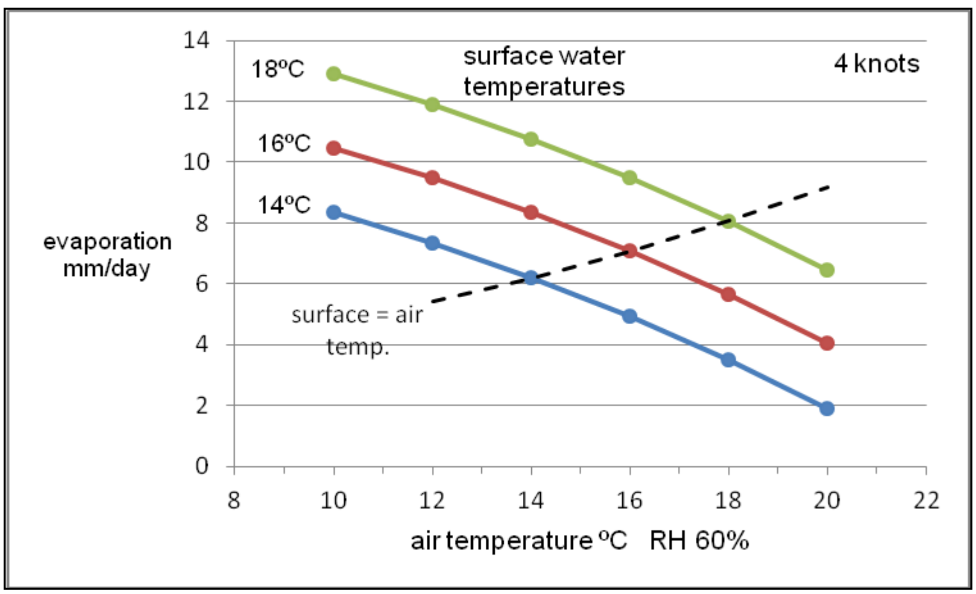


Figure 4: evaporation rates E (mm/day) under the same conditions as for Figure 2 except for a wind speed of 4 knots.

If the daily average temperatures of the surface water and the air are about the same, E is around 5–9 mm/day.

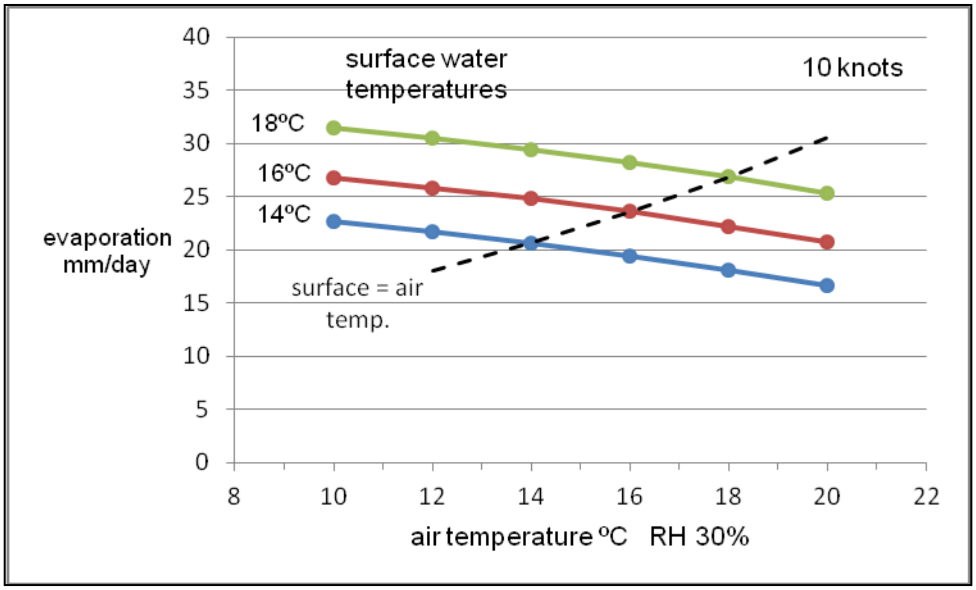


Figure 5: evaporation rates E (mm/day) as a function of air temperature (ºC), with a wind of 10 knots, and relative humidity of only 30%. These are the most extreme conditions.

If the daily average temperatures of the surface water and the air are about the same, E is around 20–30 mm/day.

Because of the shelter afforded by the forest, "storm" winds do not reach a lot more than 20 knots at ground level in the marsh (Bft.5). The highest winds are associated with SE rain storms in winter when ET is of little interest, but summer anticyclonic winds from the NW can blow steadily for days at around 10 knots (Bft.3–4), are mild, and can be very dry (RH≈30%). There is however, weak evidence that the watershield cover in summer may reduce the effect of the wind (see comments on Figure 7 below).

Transpiration (ET with plants)

The rate of transpiration from aquatic plants depends on the same parameters as for evaporation with the added variable, species.

At first glance, it's easy to image that ET is reduced by plants like watershield because they provide shade and so lower the surface temperature. Data that is applicable to the situation under consideration is lacking, but the general impression left by literature on the topic is that this simple assessment is wrong.

Plants sometimes do reduce ET, but they also sometimes increase it, which they do primarily by increasing the area of the evaporation surface on their leaves on a micro-scale. The evaporation surface area is greater than what it would be if the area covered by the leaf were open water.

The following graphs are for duckweed (*Lemna* L.).[4]

In these graphs, data extracted from the reference has been plotted as monthly average values on a clockface running clockwise with December at the top, March on the right, June at the bottom, and September on the left. All monthly average values of the variables have been normalized to the annual mean monthly average for that variable, so that, for example, a variable showing no variation from month-to-month appears as a circle with radius 1, shown in the graphs with a black-dashed line.

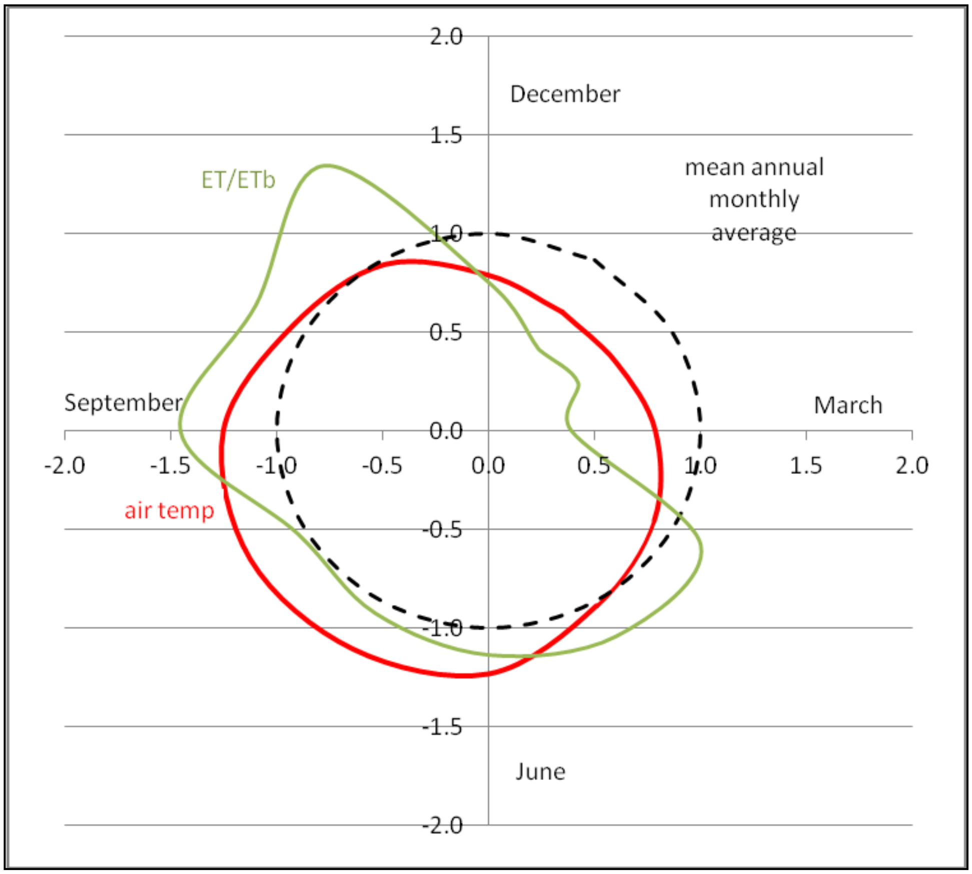


Figure 6. Green line: the normalized ratio of ET in a tank containing duckweed to the ET of a blank tank, ET_b. The annual average ratio used for normalization is 1.19. On average, the duckweed increases ET.

Red line: the average monthly air temperature. The annual average monthly temperature used for normalization is 21.5ºC.

The plot for solar radiation (SR, annual average 249 W/m^2) is not shown because it is strongly correlated with air temperature which is shown. The plot for relative humidity (RH%, annual average 69%) is also not shown because the month-to-month variation is so relatively small.

When the monthly average air temperature is lower (in the spring, red line within the black-dashed circle), the ET/ET_b ratio is also lower. When the monthly average air temperature is average or higher (red line on or outside the black-dashed circle), the ET/ET_b ratio is also higher except that at the height of summer (July-August) when the ET/ET_b ratio drops back down to the annual average.

[4] Ahmed Ali Rashed, *Assessment of aquatic plants evapotranspiration for secondary agriculture drains (case study: Edfina drain, Egypt)*, Egyptian Journal of Aquatic Research, 40, pp.117–124, 2014.

The suggestion is that the transpiration ratio of the duckweed increases with increasing temperature possibly because of growth, but that there is a limiting temperature. When the temperature reaches and exceeds this limit, the increase in transpiration ratio is curtailed and reversed, possibly because growth stops at the highest temperatures.

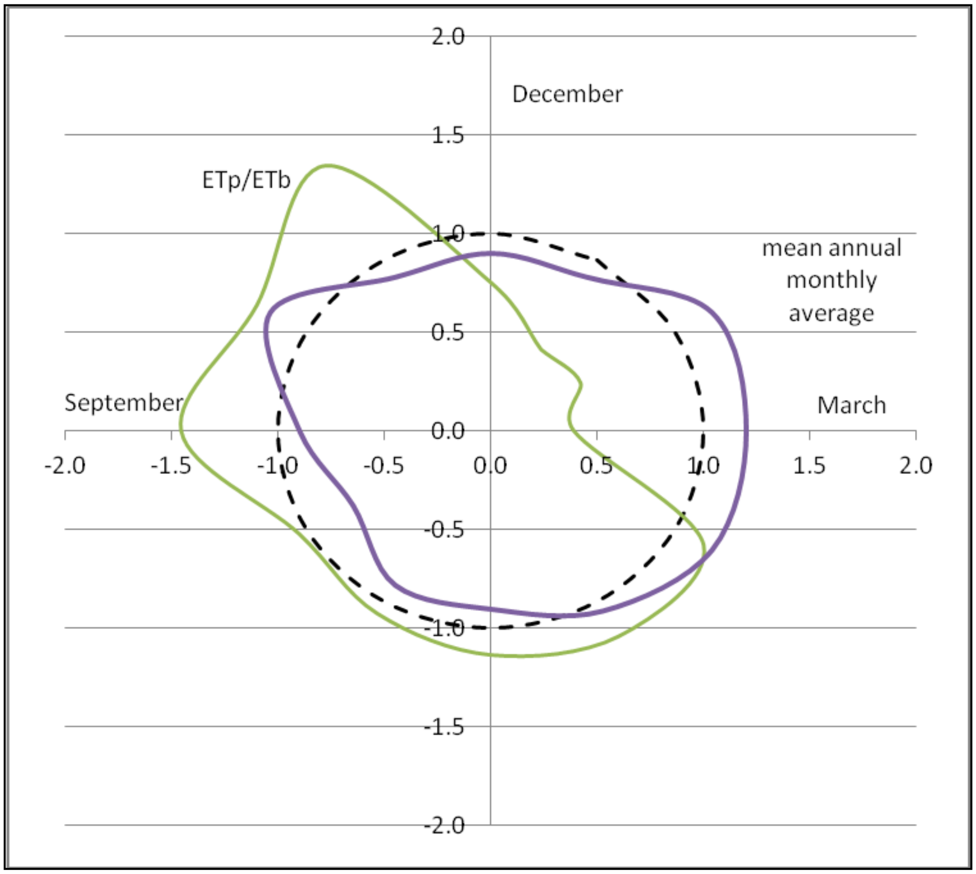


Figure 7. Green line: as in Figure 6.

Purple line: the average monthly wind velocity. The annual average monthly velocity used for normalization is 3.3 m/s = 6.5 knots.

Interpretation is not easy, because of the possibly anomalous reading for October. If this is ignored, it appears that when wind speeds are higher (purple line outside the black-dashed circle), the plants reduce ET below what it would be if it were open water. They "shade" the water from the wind. Conversely, when wind speeds are lower (purple line inside the black-dashed circle), the transpiration ratio is higher (the ET is higher with plants than it would be if it were open water). This is likely because of factors unrelated to the wind.

Conclusion

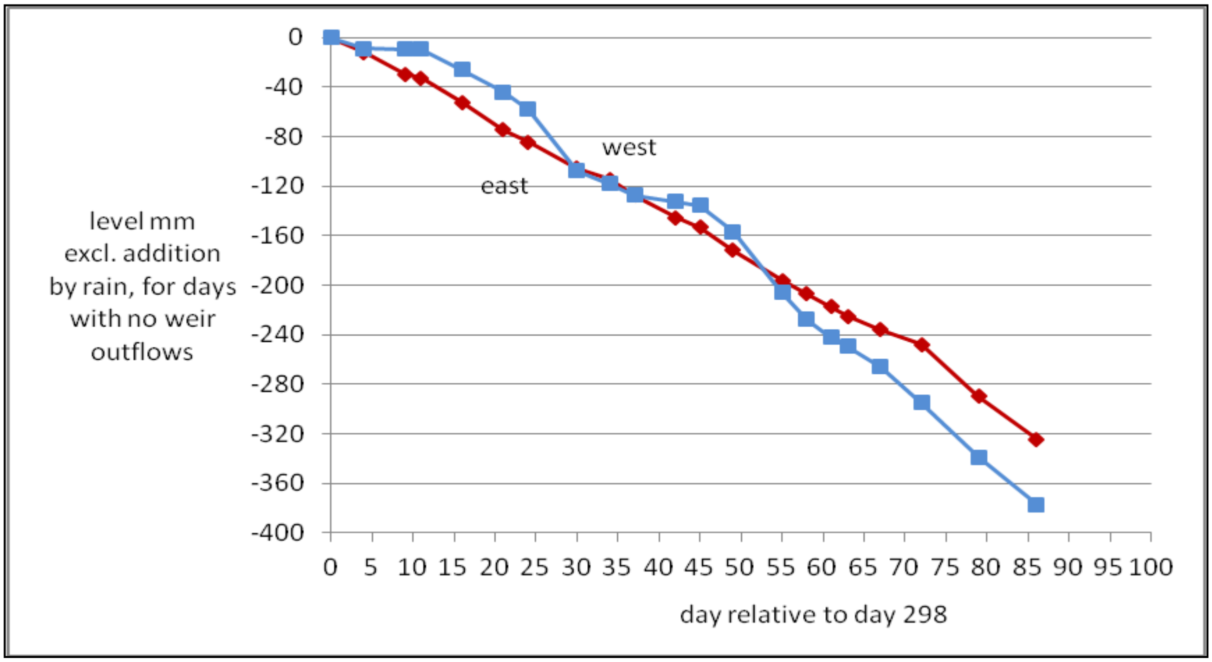
My conclusion is that it does seem that aqueous plants can either increase or decrease ET depending on the weather and the season; however, being more definite for a particular location and for a particular species of plant would need more observational data than we have.

What is interesting though is that the increase and decrease in ET caused by the plants is only within the range 50–150%. For particular cases, this may seem large, but within the context of varying surface and air temperatures, varying relative humidities, and varying wind speeds, this degree of variation is actually fairly, and perhaps surprisingly, small.

The observed range of ET of 2–5 mm/day is very comfortably within the range of possibilities suggested by far-more detailed observations of evaporation and transpiration made elsewhere. This is particularly so if we accept the weak evidence that the watershield cover in summer reduces the ET when the wind is blowing below what it would be if the water were open.

Observations

Shown are results of measurements of water levels on both sides of the beaver dam (east & west) with rainfall subtracted, and for days with no flow over the baffle or from the leveller. Levels are relative to those on day 298 (May 11–Aug. 19).



While the rate of fall in level on the east side is fairly steady at around 3.5 mm/day, the rate of fall on the west side (in the weir bay) is more variable.

The most important factors engendering the difference are:

<u>factors sporadically reducing rate of fall of the west end compared to the east end</u>:
higher rainfall (presumably small but there is no rain-gauge at the weir);
ratio of the catchment area to the open-water area greater than in the main marsh.

<u>factors continually reducing rate of fall of the west end compared to the east end</u>:
ET conditions (wind and plant species) less severe than in the main marsh;
lower lake-bed infiltration rate;
leakage through the beaver dam.

<u>factors sporadically increasing rate of fall of the west end compared to the east end</u>:
less rainfall (presumably small but there is no rain-gauge at the weir);
ratio of the catchment area to the open-water area less than in the main marsh;
sporadic leakage through the debris holding back the water from the baffle, but only up to relative day 55 when the level falls below the top of the baffle.

factors continually increasing rate of fall of the west end compared to the east end:
ET conditions (wind and plant species) more severe than in the main marsh;
steady leakage through the debris holding back the water from the baffle, but only up to relative day 55 when the level falls below the top of the baffle;
higher lake-bed infiltration rate;
leakage through the baffle into the creek (but the observed leakage is small and not enough to get the creek flowing).

Overall, results are consistent with there being no unknown sinks or sources on the east side.

A method of estimating evaporation on a day-to-day basis based on mean values for temperature, relative humidity, and wind speed

Since no daily measurements were made of temperature, relative humidity, or wind speed, I have develped a method of estimating evaporation for the lake and a rougher estimate for evapotranspiration in the forest of the catchment area based on monthly mean averages for Nanaimo Airport as measured by Environment Canada.

Parameters

Day

The input parameter required is the day number OD in the observation files.

OD = 0 is July 18, 2015, which is Julian Day 2457222 at 4 a.m. PST.
OD is incremented by 1 each day regardless of the calendar date.

OD is used to calculate the day of the year D starting with 0 on Jan. 1 and ending with 364 on Dec. 31 where:
D = mod(198+OD, 365) and
the function mod(a,b) = a - b*int(a/b) where int(a/b) = a/b rounded down to the nearest integer. Leap-year complications are ignored.

To calculate D, the day number starting on January 1 of any year, again ignoring leap year complications, put
D = mod(OD – 167, 365)
0= Jan 1; 31= Feb 1; 59= Mar. 1; 90= Apr 1; 120= May 1; 151= Jun.1;
181= Jul. 1; 212= Aug. 1; 243= Sep. 1; 273= Oct. 1; 304= Nov.1; 334= Dec.1.

Temperature

The mean daily temperature ºC is calculated from the empirical formula:

$T = 2.86 + (16.73 – 2.86)/2) * [1–\cos(2*\pi * \{d+o\})]$
$d = D/365.25$
$o = 0.0286 – 0.113*\sin(\pi * d)$

Relative humidity

The mean daily relative humidity % is calculated from the empirical formula:

$RH = –635.4*R^4+1387.4*R^3–870.05*R^2+133.64*R+78.23$

$R =$ if $d \geq 0.123$, $R=d$; else if $d < 0.123$, $R=(1+d)$

Wind speed

The mean daily wind speed m/s is calculated from the empirical formula:

$V = 1.773 + (2.341 – 1.773)/2) * [1–\cos(2*\pi * \{d+m\})]$

$m = –0.12 + 0.213*\sin(\pi * d)$

EV

The mean daily evaporation mm/day is calculated from the empirical formula:

EV = s * 24 * (25 + 19 V) * x * [1 – RH/100]

s = 0.476 for the lake, a scaling factor chosen so that the maximum EV corresponds to the measured maximum EV of 3.5 mm/day

s = 0.405 for the catchment area forest, a scaling factor chosen so that the total mean EV for the year corresponds to an estimated 500 mm

$x = 10^{-6} * [0.416*T^3 + 2.788*T^2 + 319.9*T + 3733]$

Example

OD = 285 (April 28, 2016)
D = 118
d = 0.323
o = –0.0677
T = 10.03 ºC

R = 0.323
RH = 70.5 %

m = 0.0614
V = 2.27 m/s

s = 0.405 (forest)
x = 0.00764
ET = 1.8 mm/day

Evapotranspiration

Using this method to estimate evapotranspiration may only be a rough estimate. A UBC forestry department study found that for a stand of mature Douglas-fir, the evapotranspiration was 49% of annual precipitation with a significant portion of that occurring in winter.[5]

However, another study of a mixed Douglas-fir and red alder stands,[6] close to what we have in Coats Marsh RP, measured winter (October to March) evapotranspiration to be 20% of the annual loss. This is almost exactly the same as the percentage predicted by the above analysis. ◊

[5] Groundwater budgets (for Gabriola), *SHALE* 14, pp.18–32, September 2006.

[6] Moore, G.W., Bond, B.J., & Jones, J.A., A comparison of annual transpiration and productivity in monoculture and mixed-species Douglas-fir and red alder stands, Forest Ecology and Management, 262(2011), pp.2263–2270.