PLANT DISTURBANCE ECOLOGY

The Process and the Response

Second Edition

Edited by

EDWARD A. JOHNSON

Professor of Biological Sciences Ecology and Evolutionary Biology, University of Calgary, Calgary, AB, Canada

KIYOKO MIYANISHI

Professor Emeritus, University of Guelph, Guelph, ON, Canada

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CHAPTER NINE

Water level changes in ponds and lakes: The hydrological processes

Masaki Hayashi[a] **and Garth van der Kamp**[b]
[a]Department of Geoscience, University of Calgary, Calgary, AB, Canada
[b]Global Institute for Water Security, University of Saskatchewan, Saskatoon, SK, Canada

List of symbols

A	area of lake or pond $[L^2]$
c	recession rate of pond water level $[L\,T^{-1}]$
d	thickness of saturated sediments [L]
e_a	vapor pressure of air $[M\,L^{-1}\,T^{-2}]$
e_s	vapor pressure at the water surface $[ML^{-1}\,T^{-2}]$
$f(u)$	wind function $[L\,T^{-1}]$
h	lake water level [L]
h_A, h_B	groundwater hydraulic head [L]
H	depth of lake or pond [L]
H_0	reference depth [L]
K	hydraulic conductivity $[L\,T^{-1}]$
p	shape constant in Eq. (9.9)
P/A	ratio of pond (or lake) perimeter to area $[L^{-1}]$
q	groundwater specific discharge $[L\,T^{-1}]$
Q	groundwater flow rate $[L^3\,T^{-1}]$
Q_a	net energy input by stream and groundwater per area $[M\,T^{-3}]$
Q_e	latent heat transfer $[M\,T^{-3}]$
Q_g	energy flux into lake bottom sediment $[M\,T^{-3}]$
Q_h	sensible heat transfer $[M\,T^{-3}]$
Q_{in}	total water input $[L^3\,T^{-1}]$
Q_n	net radiation $[M\,T^{-3}]$
Q_{out}	total water output $[L^3\,T^{-1}]$
Q_w	rate of energy storage change per lake area $[M\,T^{-3}]$
s	scaling constant in Eq. (9.9) $[L^2]$
T_a	air temperature [K]
T_s	temperature of surface [K]
u	wind speed $[L\,T^{-1}]$
V	lake or pond volume $[L^3]$
w	cross sectional width of groundwater flow [L]
β	Bowen ratio
Δl, Δx	distance $[L^{-1}]$
γ	psychrometric constant $[M\,L^{-1}\,T^{-2}\,K^{-1}]$

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Introduction

Lakes and ponds occur in a wide range of depths, sizes, and permanence—from deep lakes having a permanent body of surface water to shallow ponds having water only for a few weeks each year. These factors also vary within each lake or pond, resulting in diverse communities of aquatic plants growing in various patterns. Certain types of plants require relatively high water levels, while others cannot tolerate standing water. Therefore, water-level change is considered a disturbance to many aquatic plants. In addition, soil development in the riparian zone is strongly influenced by the water-level regime of the ponds and lakes, as is the salinity of the water and the soils.

Dynamic changes in water level are controlled by the balance between inputs and outputs of water, which are in turn controlled by the hydrological processes. Many hydrological processes are sensitive to changes in meteorological conditions. For example, during a prolonged drought, precipitation inputs generally decrease and evaporation outputs increase, resulting in a drawdown of lake level or even to a complete drying out. Meteorological conditions also affect the lake water balance by changing the amount of stream flow and groundwater flow into the lake, but the response of the hydrologic processes to meteorological forcing is complicated due to the complex interactions among climate, vegetation, soil, and groundwater. Such interactions are also strongly affected by land-cover change caused by natural (e.g., fire) or anthropogenic (e.g., agriculture) processes.

Presented in this chapter are the hydrological processes that control the water level change of surface water and shallow groundwater. The objective is to present essential hydrological principles and practices so that ecologists and hydrologists can engage in meaningful interdisciplinary research. The concept of the water balance is first presented, followed by a discussion of individual components of the water balance. The effects of meteorological fluctuations and land-use change on the water balance will also be discussed using examples from prairie lakes and wetland ecosystems, with particular emphasis on the eco-hydrological linkage between water and riparian vegetation.

Water balance

Water balance equation

The change of water level in a lake (or pond) over a given period of time is equal to the difference between input and output of water:

$$Q_{in} - Q_{out} = A\frac{\Delta h}{\Delta t} \tag{9.1}$$

where Q_{in} [$L^3\ T^{-1}$] is the sum of all water inputs, Q_{out} [$L^3\ T^{-1}$] is the sum of all outputs, A [L^2] is the surface area of the lake, Δh [L] is the water-level change during a time interval Δt [T]. For example, suppose a closed-basin lake with no inflow and outflow loses 150 mm of water by evaporation during 1 month. If it receives 50 mm of rainfall during the month the water level will decline by 100 mm. Note that A represents the water-covered area, which increases with h in most natural lakes.

The water-level regime of a lake (i.e., how A and h change over time) is determined by the seasonal, inter-annual, and inter-decadal variability of $Q_{in} - Q_{out}$. Therefore, understanding the water regime requires some knowledge of the hydrological processes controlling Q_{in} and Q_{out}. The inputs include perennial and intermittent streams, groundwater inflow, direct precipitation onto the lake, diffuse runoff from the shoreline, and snowdrift. The outputs include streams, groundwater outflow, and evaporation and transpiration, which are commonly referred to as evapotranspiration (Fig. 9.1). In addition to these natural processes, Q_{in} and Q_{out} may include artificial terms such as water intake for irrigation or wastewater discharge. Important processes affecting each component of Q_{in} and Q_{out} are discussed below, while more detailed information on measurement and estimation techniques can be found in hydrological textbooks such as Rosenberry and Hayashi (2013).

Precipitation

Direct precipitation is an important component of the lake water balance. Depending on the atmospheric conditions, precipitation occurs as rain, snow, hail, and various other forms. Rainfall is relatively easily measured in principle and, hence, is usually the most accurately measured term in the water balance equation. However, precipitation may have substantial

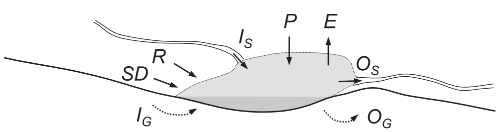

Fig. 9.1 Schematic diagram showing water-balance components: precipitation (*P*), evapotranspiration (*E*), stream inflow (I_S), stream outflow (O_S), diffuse runoff (*R*), snow drift (*SD*), groundwater inflow (I_G), and groundwater outflow (O_G).

spatial variability even over a relatively small area, especially for individual precipitation events. Winter precipitation in cold regions mostly occurs as snow. Snowflakes are easily influenced by the turbulence caused by wind, and deflected from the intake of a precipitation gauge, resulting in under-measurement of snowfall, called wind-induced undercatch (e.g., Kochendorfer, 2017). This makes it difficult to measure snowfall accurately even with gauges equipped with windshields. A number of empirical equations have been proposed to correct for undercatch, but they all have uncertainties (Kochendorfer, 2017). Therefore, one should be aware of the uncertainty associated with winter precipitation measurements. Publicly available precipitation data from meteorological agencies are usually not corrected for undercatch and other issues, and may be affected by substantial errors (e.g., Mekis and Vincent, 2011; Milewska et al., 2019).

Once deposited on the ground or frozen lake surface, the snowpack typically remains frozen for several days to months, allowing wind-driven snowdrifts to redistribute snow across the landscape (Pomeroy et al., 1998). Emergent vegetation in ponds and lake margins and tall grasses or brush on the land effectively trap drifting snow and serve as a snow 'sink'. Where vegetation is nearly absent, such as on cultivated fields, snow tends to accumulate in topographic depressions and, upon melting, releases a major water input to upland ponds and wetlands that form in these depressions (van der Kamp et al., 2003). The weight of snow accumulated on the frozen surfaces of large lakes produces an equivalent increase of the water level (or water pressure) of the lake.

Evapotranspiration

Water is transferred from ponds and lakes to the atmosphere by direct evaporation from the water surface and transpiration by emergent plants. Part of precipitation is intercepted by leaves and stems of emergent plants and returned to the atmosphere by evaporation. This process can be important for the water balance of shallow marshes having a sizable area covered by plants. These processes are driven by the same meteorological factors and are commonly lumped together as evapotranspiration (ET). The phase change of water from liquid to vapor is an essential part of ET. Therefore, ET can be understood in context of the energy exchange at the lake surface. However, the phase change needs to be accompanied by removal of vapor from the lake or leaf surface by the turbulent mixing of air. Therefore, ET can also be regarded as an aerodynamic mass-transfer process.