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THE CONCEPT OF THE PERILIMNION

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Seasonal variations in surface and ground water supply and increasing attention to ionic and mass balances in aquatic eco-systems require more specific definitions of hydrologic parameters to recognize sources and sinks for biologically significant geochemistry. The term "Perilimnion" is proposed to define that zone of the catchment in which groundwater developed by surface runoff and percolation may enter (or leave) the limnic environment. The perilimnion, therefore, is an aquifer, whose geochemistry may affect, or be affected by, the waters of a lake. The term "Tardelimnion" is proposed to define that portion of the limnic environment in which deposition of limnogenic sediments (autochthonous or allochthonous) contribute to an aquitard, whose low coefficient of hydraulic permeability ($<10^{-6}$ cm s^{-1}) virtually precludes significant hydrologic or geochemical interaction between lake and ground waters.

Les variations saisonnières dans la disponibilité des eaux de surface et des eaux souterraines et l'attention accrue maintenant accordée aux balances de masse et d'ions dans les écosystèmes aquatiques nécessitent les définitions plus precises des paramètres hydrologiques pour mieux identifier les sources et les sources negatives de la géochimie d'intérêt biologique. Le terme "perilimnion" est proposé pour le zone de captage d'eau dans lequel les eaux developpé par l'écoulement des eaux de surface et les eaux de filtration peuvent entrer ou sortir de l'environnement limnique. Le perilimnion est donc un aquifère qui peut influencer ou etre influencé par les eaux d'un lac. Le terme "tardélimnion" est proposé pour définir la portion de l'environnement limnique dans lequel le dépôt de sédiment limnogénique (autochthone ou allochthone) contribue à un aquitard dont le coéfficient de perméabilité hydraulique bas (10^{-6} cm s^{-1}) empêche des interactions significatives hydrologiques ou géochimique entre les eaux de lac et les eaux souterraines.

Introduction

The responsibility for introducing additional terminology to an already linquistically rich limnological vocabulary is indeed formidable. Increasing recognition that a lake is not a "microcosm" (sensu Forbes, 1887), however, justifies attempts to improve precision.

Although van Helmont's (1748) experiments on a potted willow tree may possibly qualify him as the father of quantitative biogeochemistry, it was the Canadian limnologist D.S. Rawson (1939) who initially emphasized the role of basin morphology, hydrology, and geology on the biological development of lakes. The seminal trophic level studies of Lindeman (1942), and elaboration by Odum (1957) and others focussed increasing attention on the watershed as the biogeochemical 'forcing function' of fresh water ecosystems. Vollenweider (1968), and Deevey, (1970) distinguish between lithologic, hydrologic, and atmospheric sources and sinks for lake nutrients. Detailed and painstaking studies in the Hubbard Brook system (Likens, *et al*, 1977) have demonstrated that interrelations with the terrestrial part of the watershed have important downstream geochemical consequences. Case (1978), using conductivity and geochemical profiles, showed that up to 100% of flow in the Gay's River, Nova Scotia, system was derived from ground water during seasonal periods of low flow.

Ground water hydrologists have long maintained an interest in lake/ground water interactions. Winter (1976) summarizes four schools of thought common among hydrologists and lake water managers:

a) All lakes are discharge points of the ground water system and therefore do not lose water through their beds;

b) All lakes are points of recharge to the ground water system;

c) Ground water discharge occurs on one side of a lake and recharge occurs from the other side; or,

d) All of the above (see Born, *et al*, 1974, for review).

While it is not the purpose of this paper to venture into a hydrological debate, it is obvious from a limnological perspective that lake water/ground water interactions vary greatly between glaciated and unglaciated regions; the humid east and the arid west; the seasonal temperate region, and the thermally stable but hydrologically variable sub-tropic and tropic regions. Opinion (d) seems safest, if unsatisfactorily vague.

It is proposed here, however, that there are two related, but independent regions of lake water/ground water interaction, which are physically recognizable, and spatially definable.

The Perilimnion and the Tardelimnion

Numerical simulation models of the interaction of lakes and ground water (Winter, 1976), and ground water flow models over resistive and "leaky" beds (e.g., Vandenberg, 1982) demonstrate that, depending upon vertical and horizontal coefficients of permeability, some of the ground water originating within the watershed boundary may pass beneath the bed of lacustrine systems, therefore having no effect on the geochemistry of the overlying lake. Similarly, there is a zone at some distance upslope (and up-gradient) from the shoreline and surrounding a lake where percolating ground water, (including some fraction of surficial runoff and interstitial water from the watershed perimeter), may enter or leave the littoral zone, and is therefore an aquifer. I propose that this active zone should be formalized as the *Perilimnion* (Fig. 1), i.e., that portion of the catchment in which groundwater may enter or leave the limnic environment.

During periods of recharge and high runoff, it is probable that the perilimnion is a temporary source of ground water as a result of hydraulic head developed by more rapid rise of the lake surface level relative to the belated response of percolating ground water.

In most natural lakes fine-grained sediments of the central basin extend shoreward to the lower limit of the wave zone, and constitute an aquitard, with horizontal and vertical permeability coefficients $<10^{-6}$ cm s^{-1}. This zone, which consists of both allochthonous and autochthonous organic and inorganic particles, is underlain by even more impermeable silts and clays throughout glaciated regions. Frequently, glacier meltwater lakes are in clay-rich till, and moving ground water is restricted to the upper leached soil horizons. I propose that this zone of confined, or restricted ground water movement through lake sediments be formalized as the *Tardelimnion.*

In Sallie Lake, Minnesota, seepage accounted for 14% of annual inflow. McBride and Pfannkuch (1975) reported that 99% of ground water seepage into the lake occurred within 120 m of shore (<1/10 the distance to the center of the lake), in <2.0 m of water. They noted that fine-grained sediments (viz., the tardelimnion) in the central basin began about 300m from the shoreline.

Observations in Nova Scotian lakes indicate that gyttja underlain by silty clay occurs below about 3 m water depth (Yuill and Ogden, 1982). Shallow ground water wells, extending into bedrock beneath lake sediment (gyttja, silty clay, till) shows the presence of an hydraulic head against the lake bottom compared with shoreline piezometers in Second Chain Lake. Close interval thermal profiling with an armored Whitney thermal probe failed to indicate any ground water intrusion despite a steep thermal gradient between lake water (22.0 ± 0.2°C) and ground water (8.0 ± 0.5°C).

Similarly, at Kilkenny Lake, Nova Scotia, Ogden and Gillis, (1982) found that only ground water within *ca* 100 m of the lake shore entered the lake intermittently, and was quantitatively insignificant. Using ground water flow models developed by Van-

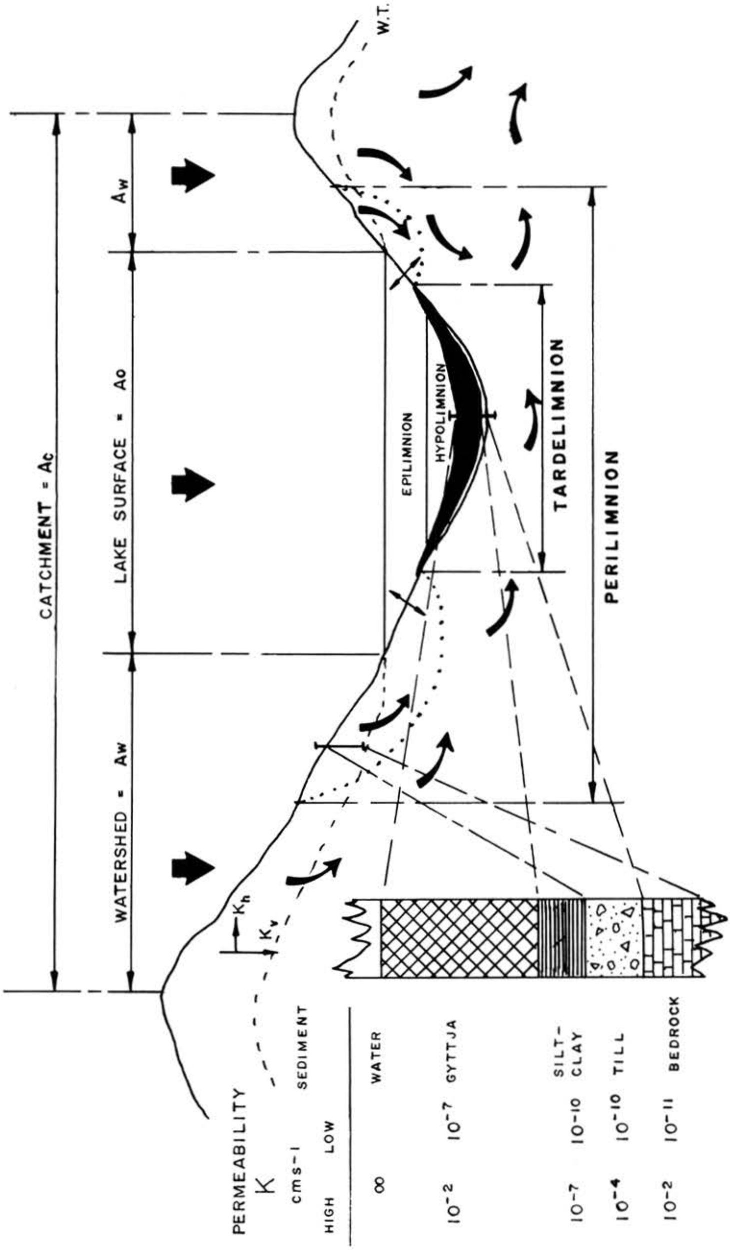

Fig. 1 Diagrammatic section through a catchment. Ground Water Table (W.T.) shown by dashes (————), perilimnion by dots (.....). K_h = horizontal groundwater permeability coefficient; K_v = vertical groundwater permeability coefficient. Precipitation input and implied groundwater movement shown by solid arrows.

denberg (1982), and modified to represent permeabilities determined from geophysical studies by Geocon (1975), it is apparent that <20% of the Kilkenny Lake watershed is a potential ground water source to the lake.

As quantification of geochemical mass balances improves, more detailed studies are required to further refine and model the dimensions of perilimnion and tardelimnion. Seepage flux in the perilimnion may be monitored using simple and inexpensive instrumentation as described by Lee (1977). One hopes that simulation studies, as detailed in Winter (1976) will provide guidelines to determine boundaries of the perilimnion upslope from the waters edge. The tardelimnion is readily definable by physical limnological methods, using sediment probes to determine the boundary of the fine-grained gyttja and clay/silt/till aquitards.

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References

Born, S.M., Smith, S.H. and **Stephenson, D.A.** 1974. The hydrogeologic regions of glacial-terrain lakes, with management and planning applications. Univ. Wisconsin, Inland lake renewal and management demonstration project. 73 p.

Case, M.L. 1978. The relationship of heavy metals to stream ecology in the prospective lead-zinc mining area at Gay's River, N.S. Unpubl. Ph.D. thesis, Dalhousie University, Halifax, N.S.

Deevey, E.S. 1970. Mineral Cycles. *Sc. Amer.* 223: 147-158.

Forbes, S.A. 1877. The lake as a microcosm. *Bull. Peoria Sci. Assoc.* 1887: 77-87.

Geoçon (1975), 1979. Report V8392. Cape Breton Development Corp. 120 p.

Lee, D.R. 1977. A device for measuring seepage flux in lakes and estuaries. *Limnol. and Oceanog.* 22:140-147.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S. and **Johnson, N.M.** 1977. *Biochemistry of a forested ecosystem.* Springer-Verlag, N.Y. 135 p.

Lindeman, R.L. 1942. The trophic-dynamic aspect of ecology. *Ecol.* 23: 399-418.

McBride, M.S. and **Pfannkuch, H.O.** 1975. The distribution of seepage in lake beds. *Jour. Res. U.S. Geol. Survey* 3(5):505-512.

Odum, J.T. 1957. Trophic structure and productivity of Silver Springs, Florida. *Ecol. Monog.* 27: 55-112.

Ogden, J.G. and **Gillis, E.M.** 1982. *A limnological survey of Kilkenny Lake,* Cape Breton, N.S. Report, Cape Breton Development Corp., Sydney, N.S. 120 p.

Rawson, D.S. 1939. *Some physical and chemical factors in the metabolism of lakes. in:* E.R. Moulton, ed., Problems of Lake Biology. Publ. 10, AAAS, Washington, D.C. pp. 9-26.

Vanderberg, A. 1982. A one-dimensional model of unconfined ground water flow over a sloping impermeable base. *Natl. Hydrol. Inst. (Can) Res. Paper* 17, 30 p.

van Helmont, J.B. (1748). Quoted in Gabriel, M.L. & Fogel, S. "Great Experiments in Biology" 1955, Prentice Hall Inc., Englewood Cliffs, N.J.

Vollenweider, R.A. 1968. *Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to Nitrogen and Phosphorus as factors in eutrophication.* OECD, Paris: DAS/CSI/68.27. 192 p.

Winter, T.C. 1976. Numeric simulation analysis of the interaction of lakes and groundwater. *U.S. Geol. Survey Prof. Paper* 1001, 45 p.

Yuill, S.A. and **Ogden, J.G.** 1982. *Bayer's Lake watershed hydrology and hydrogeology.* Publ. Service Comm. Halifax, N.S. 33 p.