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Night-Time Cooling of Surface Water: Laboratory experiment and numerical simulation

Nick van de Giesen[1], John Selker[2], Koen Hilgersom[1], and Anna Solcerova[3]
[1]Delft University of Technology, Water Management, Water Resources, Delft, Netherlands (n.c.vandegiesen@tudelft.nl)
[2]Oregon State University, Biological & Ecological Engineering, Corvallis, USA
[3]Amsterdam University of Applied Sciences, Urban Technology, Amsterdam, Netherlands

In the framework of the Small Reservoirs Project (www.smallreservoirs.org), evaporation in semi-arid areas from open water has been measured through water balances, floating evaporation pans, and eddy covariance measurements. Each method showed that the actual evaporation was 30%-50% less than the evaporation from open water as predicted by Penman. During daytime, this reduced evaporation may be due to the formation of a stable internal boundary layer over the reservoirs. One would expect that this evaporation reducing effect would at least partially be offset during the night when the warm water would induce strong turbulent transport through an unstable local boundary layer. Through detailed Distributed Temperature Sensing observation in ponds, lakes, and reservoirs in different parts of the world, it was observed that during cloudless nights with low wind speeds or no wind, the top layer (1cm-2cm) of the water was one to two degrees colder than the air immediately above it. Such a temperature difference would again set up a stable layer, hindering turbulent transport of heat and water vapor into the atmosphere.

It was hypothesized that outward longwave radiation, which during cloudless nights can quickly reach 200 W/m2, would cause a thin layer of cold water on top of the warmer water body. Through conduction, this cold layer would grow until it would become unstable, at which point the surface would be (partially) refreshed through downward finger flow. Detailed numerical simulations of the heat transport in the water body were undertaken to test this hypothesis. The numerical results indeed showed the cooling of the top layer and formation of instabilities with characteristic length and time scales. To test these results and the general concept, a MacGyver-worthy laboratory set-up was built consisting of an insulated 20 liter bucket, covered by a double hemispheric dome of perspex. On the inside of the dome, a thermal camera was attached at the apex. The space between the inner and outer dome was filled with dry ice to create an inside surface temperature of about 230K. After the dry ice was added, surface cooling was observed, followed by the formation of zones with upwelling warm water and downwelling cold water. These circulation cells were comparable in size to the simulated ones. A detailed analysis of spatial and temporal scales of the laboratory and simulation results will be presented.