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1.020 Ecology II: Engineering for Sustainability  
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## 1.020 Ecology II: Engineering for Sustainability

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### Lectures 08\_11 Outline: Open System Thermodynamics, Heat Discharge

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#### Motivation/Objective

Develop a model to determine how heat discharges from a power plant affect temperature in a stream.

#### Approach

1. Define open system (stream reach with mass inflows and outflows). Specify steady-state inflow and outflow rates, time-dependent inflow and outflow temperatures. Identify unknown (stream temperature).
2. Write open system mass (steady-state) and energy balance (rate form) equations.
3. Relate terms in energy balance equation to unknown stream temperature and other inputs
4. Specify inputs, stream properties, etc. solve energy balance eq. for unknown stream temperature (MATLAB)
5. Examine impact of discharge rate, discharge temperature, and upstream flow rate.

#### Concepts and Definitions Needed:

Extend energy balance eq. to account for energy transport due to mass moving across boundaries in each reach.

First Law of Thermodynamics for an open system:

$$\text{Rate form: } \frac{dU_{cv}}{dt} = \dot{Q}_{other} - \dot{W}_{other} + \dot{m}_{in} h_{in} - \dot{m}_{out} h_{out}$$

Internal energy term:  $\frac{dU_{cv}}{dt} = c_p \rho V \frac{dT}{dt}$ ,  $h$  = specific enthalpy (tabulated)

Bulk heat transfer term: Accounts for net conduction, convection, radiation across stream-atmosphere boundary and power plant discharge into stream:

$$\dot{Q}_{other} = -\lambda_a A_a (T - T_a), \lambda_a = \text{air-water heat transfer coefficient (w m}^{-2} \text{ C}^{-1}\text{)}$$

Work term: Assume  $\dot{W}_{other} = 0$

Mass rate terms: Use  $\dot{m} = \rho q$  and steady-state mass balance, approximate specific enthalpy by  $h = c_p T$  ( $T$  in °C)

#### Complete Balance Eqs:

$$\frac{dM}{dt} = 0 = \rho q_{up} + \rho q_d - \rho q_{down} \quad \text{Mass (steady-state)}$$

$$c_p \rho V \frac{dT}{dt} = -\lambda_a A_a (T - T_a) + c_p \rho q_d T_d + c_p \rho q_{up} T_{up} - c_p \rho q_{down} T \quad \text{Energy}$$

#### Modeling Example -- Heat discharge

Plot stream temperature vs time. Note sensitivity of stream temperature to inputs.