The Dead Sea: mass and energy balances

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Suggested solutions:
1. Leave as is
2. Release freshwater
3. Introduce seawater

The consequences (environmental etc.) of these alternatives are not clear
Expected results of mixing seawater with the Dead Sea brine:

- Change of the Dead Sea composition with time
  - Gypsum precipitation
  - Dilute upper water layer
  - Microbial blooming in the upper layer
  - Reduction conditions in the lower layer
Examination of the consequences of the different alternatives using computer simulations

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Mass and Energy Balances

**Measured data:**
- $(T, P, RH)$ - air, SW radiation
- $(T, P, \text{salinity})$ - water, water level

- **Salt mass balance**
- **Energy balance**
  - **Heat of evaporation**
  - **Evaporation**

- **Total mass balance**

- **Water inflows**
Dead Sea Level (1990-2001)

Level drop ~ 1 m/yr
Area ~ 650 km²
Deficit ~ 650 mcm/yr

Hydrological service
Hydro-meteorological buoy in the Dead Sea
(Gertman I. from IOLR)

(T, P & RH) - air
(T, P) - water
SW radiation
Water temperature at different depths

- Winter cooling
- Warm upper water layer
- Overturn

J Day (after 1/1/1998)
Hydrographical profiles ($T$, salinity, $\rho$)

Every 2 months
Hydrographical profiles (T, salinity, ρ)
Every 2 months

Bottom at ~300m
Measured annual changes:

- Surface level drop ~ 1 m / yr
- Temperature increase ~ 0.2-0.3 °C / yr
- Salinity increase ~ 0.3 g/kg / yr
Measured data:

(T, P & RH) - air, SW radiation
(T, P & salinity) - water, water level

Salt mass balance
Energy balance
Heat of evaporation
Evaporation

Total mass balance
Water inflows
Total mass balance

DS works

End brines

pumped

evaporation

Salt precipitation

Surface inflows

Subsurface inflows
Total mass balance

At a given time:
Mass of water + mass of salts = total mass of brine

\[ m_s + m_w = \rho V_t \]

After some time \( \Delta t \)...
Total mass balance

\[
m_s + m_w + \Delta m_i - \Delta m_e - \Delta m_s - \Delta m_p + \Delta m_r = (\rho + \Delta \rho)(V_t - \Delta V_l - \Delta V_s)
\]
Total mass balance

\[ m_s + m_w + \Delta m_i - \Delta m_e - \Delta m_s - \Delta m_p + \Delta m_r = \]

\[ = (\rho + \Delta \rho)(V_t - \Delta V_l - \Delta V_s) \]
Salt mass balance

After $\Delta t$ - a year

$$\Delta V_s = \frac{(S + \Delta S)(\rho \Delta V_l - \Delta \rho V_t) - \Delta SV_i \rho + S_r \rho_r \Delta V_r - S \rho \Delta V_p}{\rho_s - S_n \rho}$$

2 unknowns remain:

- Freshwater inflows $\Delta V_i$
- Evaporation $\Delta V_e$
Mass and Energy Balances

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Water inflows
Energy balance

\[ Q_n = Q_{SN} - Q_{LW} - Q_e - Q_C \]
Heat of evaporation (Bowen 1926)

\[ Q_e = \frac{Q_{SN} - Q_{LW} - Q_n}{1 + c_b \left( T_s - T_a \right) / \left( e_s - e_a \right)} \]

From heat to rate of evaporation

\[ \Delta h_e = \Delta t \frac{Q_e}{\rho L_e} \]

\[ \Delta h_e = \frac{\Delta V_e}{A} \]

Le - latent heat
Evaporation rate vs. $Q_{\text{LW}}$

\[
\Delta h_e = \frac{\Delta t}{\rho L_e \left(1 + c_b \frac{(T_s - T_a)}{(e_s - e_a)}\right)} \left( Q_{SN} - Q_{LW} - Q_n \right)
\]

Stanhill (1994): 1.05 m/yr
Salameh & El-Naser (2000): 2 m/yr
Mass and Energy Balances

Measured data:

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Salt mass balance

Energy balance

Heat of evaporation

Evaporation

Total mass balance

Water inflows
Energy and mass balances

\[ \Delta V_i = \frac{A}{\rho L_e} \left( \frac{Q_{SN} - Q_{LW} - \rho C_p h_t \Delta T/\Delta t}{1 + c_b (T_s - T_a)/(e_s - e_a)} \right) + X \]

\[ X = \frac{\rho_s - \rho}{\rho_w} \Delta V_s - \frac{\rho}{\rho_w} (\Delta V_t - \Delta V_p) + \frac{\Delta \rho}{\rho_w} V_t - \frac{\rho_r}{\rho_w} \Delta V_r \]

Min. observed
Rate of evaporation and inflows vs. $Q_{LW}$
**Summary**

**Measured data:**
- Salt mass balance
- Energy balance
- Heat of evaporation

**Salt precipitation:**
- 0.1 m/yr

**Evaporation:**
- 1.15 m/yr

**Total mass balance:**
- Total: 265-330 mcm/yr

**Water inflows:**
- Total observed inflows: >265 mcm/yr

**Unobserved:**
- 0-60 mcm/yr
Thank you...