Handshake across the Jordan:
Water and Understanding

in Pella, Jordan

# Mixing Time for the Dead Sea Based on Water and Salt Mass Balances

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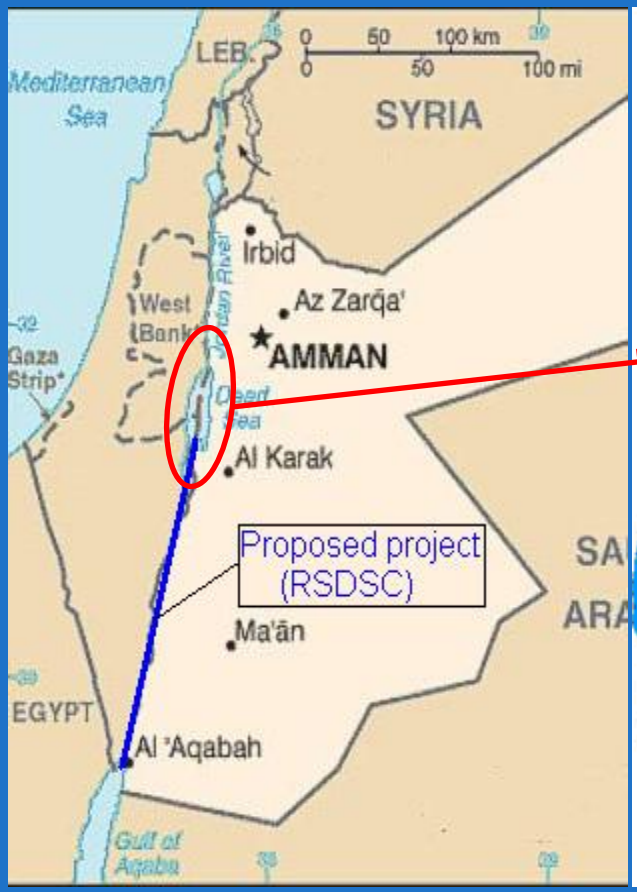
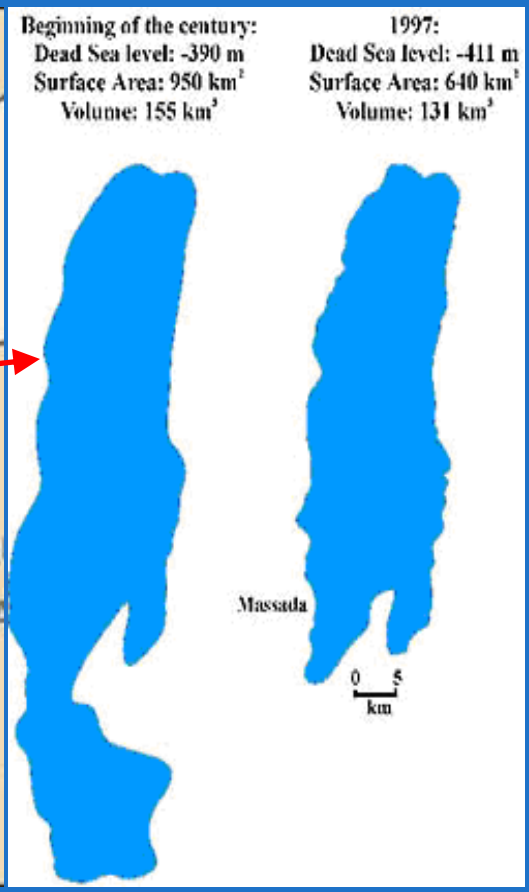
# Introduction

- Lowest Place on Earth
- Saltiest Body of Water
- Geological Complexity
- Drop in Sea Level
- Land Deterioration
- Water Pollution
- Technical and Political
- Medicinal Treatments

Proposed Red Sea-Dead Sea Canal Project (RSDSC) yearly water (≈):

- Total water = 2000 MCM
- Fresh water = 850 MCM
- Brine water = 1100 MCM





# Introduction

Dead Sea modeled by water and salt balances considering differences in salinity and including and excluding the proposed (RSDSC) in:

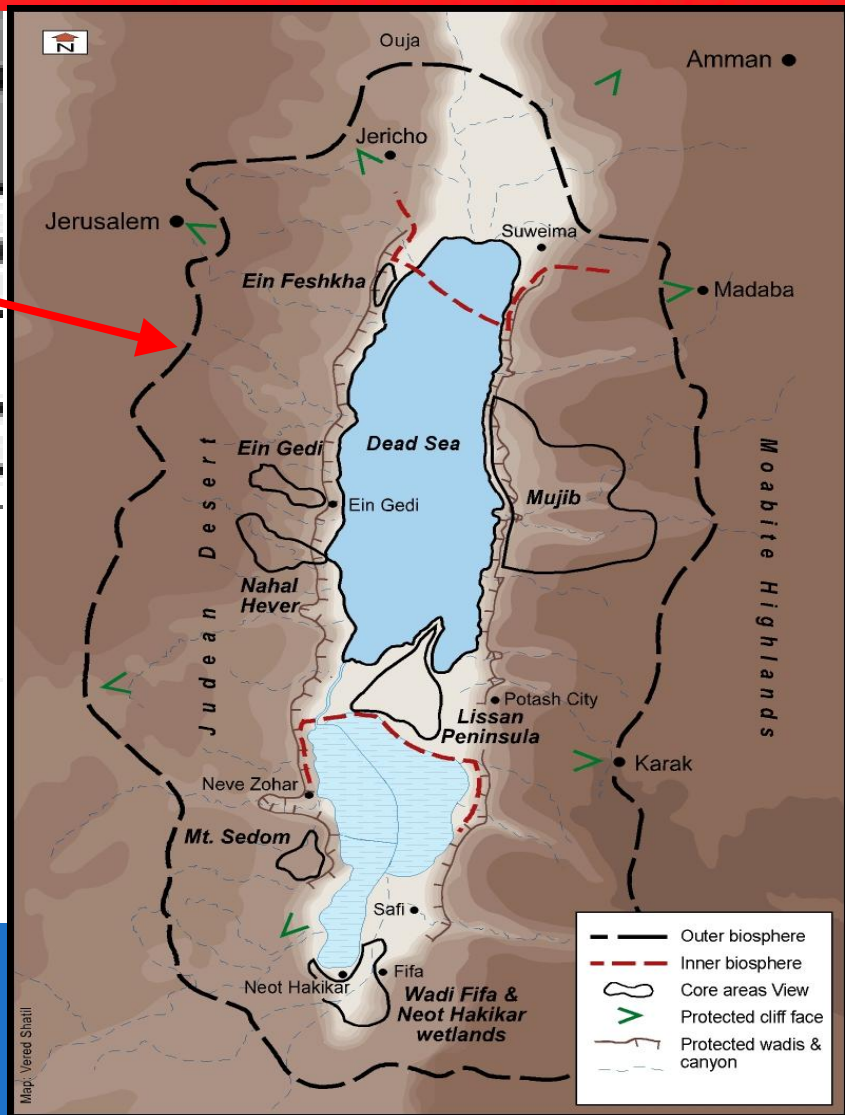
- Single Simple Box (well-mixed system) and
- Two- Layer Box (stratified system)

- Evolution and predicted over 100-years
  - Volume, Elevation, Surface area, cumulative height and
  - Exchange time (mixing time)
- Historical evolution over 30-years compared regarding
  - Water mass balance and Salt mass balance
- The whole study have been implemented and developed using the LOICZ Biogeochemical Modeling Guidelines

# Overview of the Study Area

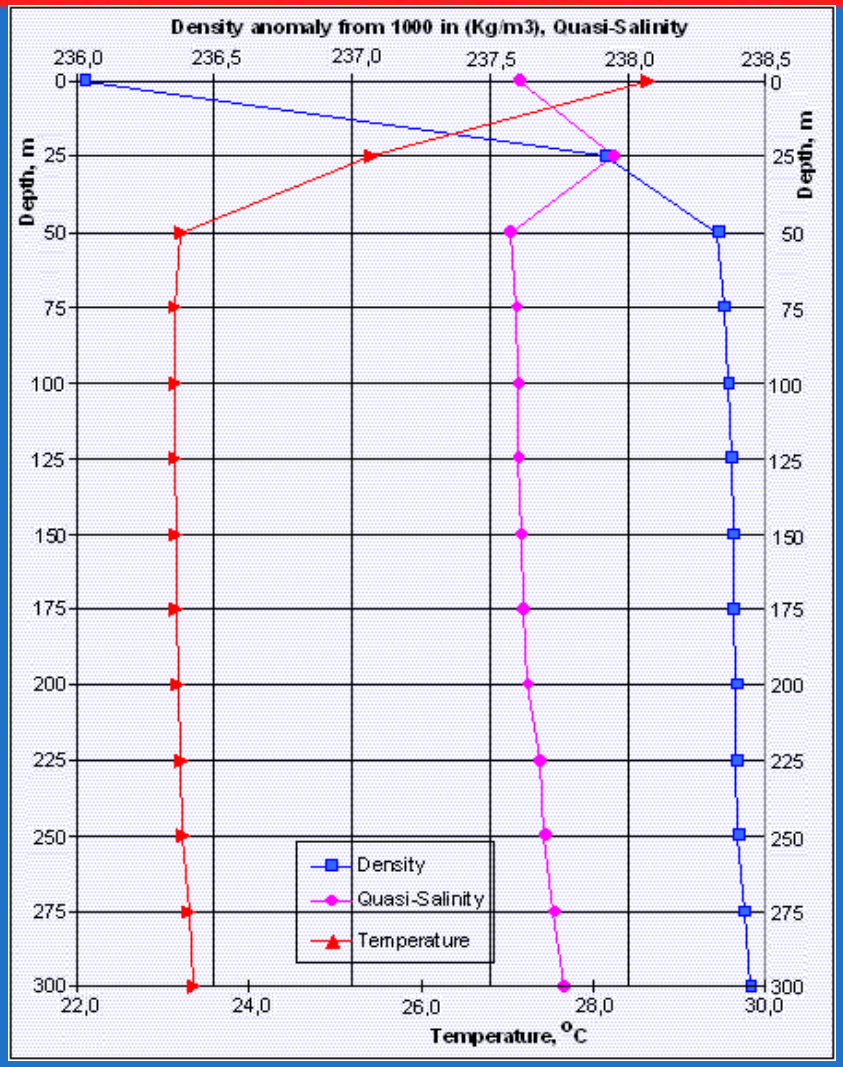
| Volume ($km^3$) | | Area ($km^2$) | | Elevation (m) | | Rainfall (mm) | | Evaporation (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| 1983 | 1997 | 1983 | 1997 | 1983 | 1997 | min | max | min | max |
| 155 | 131 | 950 | 640 | -390 | -411 | 70 | 90 | 1300 | 1600 |

| Output/Input | Annually, MCM | | Density, $kg/m^3$ | | Salinity, ppt | |
|---|---|---|---|---|---|---|
| | min | max | min | max | min | max |
| Industrial intake (outflow) | 450 | 550 | 1250 | 1350 | 300 | 400 |
| Industrial Brine (inflow) | 200 | 250 | 1300 | 1400 | 400 | 500 |
| Brine disposal (inflow) RO | 1000 | 1200 | 1025 | 1060 | 60 | 75 |
| Evaporation | 832 | 1024 | 1000 | 1000 | --- | --- |
| Rainfall | 44.8 | 57.6 | 1000 | 1000 | --- | --- |
| River inflow | 350 | 400 | 1000 | 1050 | 20 | 30 |


RSDSC project location map
(Perry-Castaneda Library)

Data from June 1998 to December 2007 at the Ein-Gedi 320 station shows that the DS is stratified of the first 10% of the maximum depth



# Chemistry of the Dead Sea

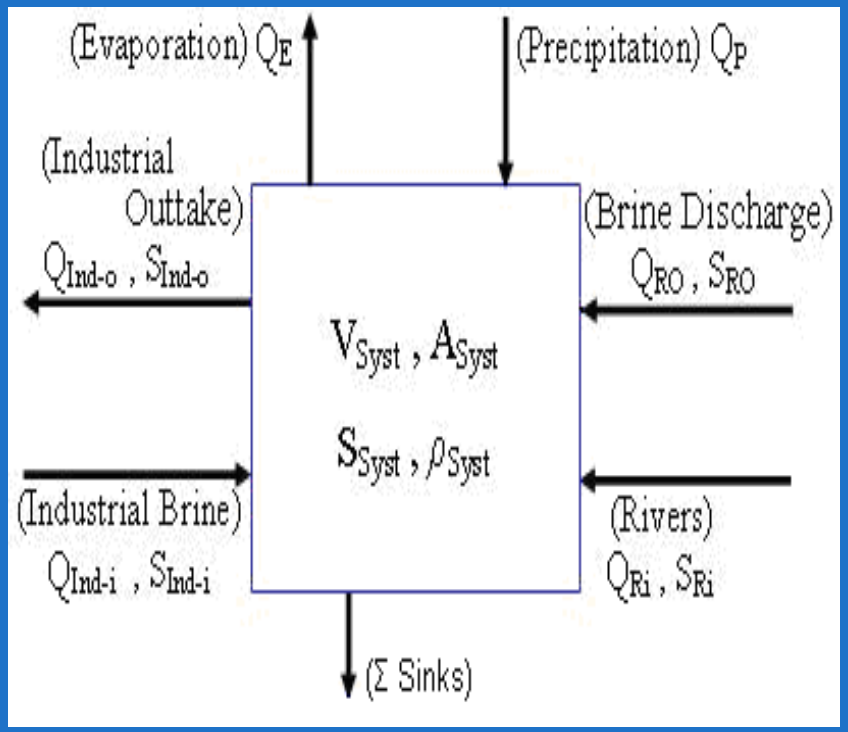
## Dead Sea chemical composition from 1961 to 2006

| Element | Dead Sea Concentration, (g/l) | | | | | | JR Conc. (g/l) | RS Conc. (g/l) | MS Conc. (g/l) |
|---|---|---|---|---|---|---|---|---|---|
| | 1961 | 1969 | 1981 | 1994 | 2006 | 2005 | | | |
| Cl | 180.8 | 208.0 | 216.0 | 219.25 | 224.0 | 228.6 | 0.474 | 23.46 | 22.90 |
| Mg | 34.50 | 41.96 | 42.5 | 42.43 | 44.0 | 47.1 | 0.071 | 1.558 | 1.490 |
| Na | 33.50 | 34.94 | 34.3 | 39.70 | 40.1 | 34.3 | 0.253 | 13.34 | 12.70 |
| Ca | 13.00 | 15.80 | 17.1 | 17.18 | 17.65 | 18.3 | 0.080 | 0.685 | 0.470 |
| K | 6.30 | 7.56 | 6.65 | 7.59 | 7.65 | 8.0 | 0.015 | 0.466 | 0.470 |
| Br | 4.10 | 5.92 | ---- | 5.27 | 5.30 | 5.4 | 0.004 | 0.086 | 0.076 |

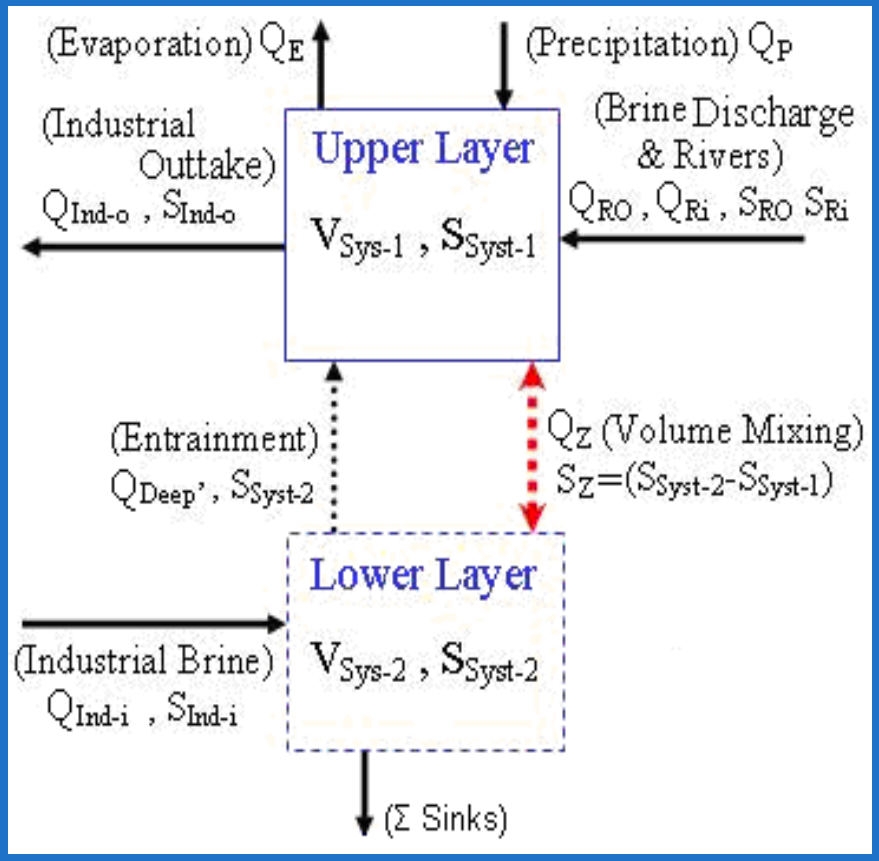
# Results from Previous Studies

- Gavrieli and Bein (2006) studied a period of 40 years
  - RSDSC diversion capacity of 60$m^3/s$
  - Two scenarios were studied $\pm$(RSDSC)
  - Reaches to 400.5 and 444.4m bmsl respectively
- Asmar & Ergenzinger (2002) studied 50 years period for two-layer
  - Two scenarios were studied (water & salt balance)
  - Reaches to 389 and 396m bmsl respectively
- Al-Weshah (2000) studied two scenarios 50-years for water balance
  - First assumed a diversion of 70 $m^3/s$ gives a level of 395m bmsl
  - Second assumed a diversion of 60 $m^3/s$ gives a level of 400.5

# Methodology




Simple-single-box (well-mixed system)




Two-layer systems (stratified system)

# Result and Discussion

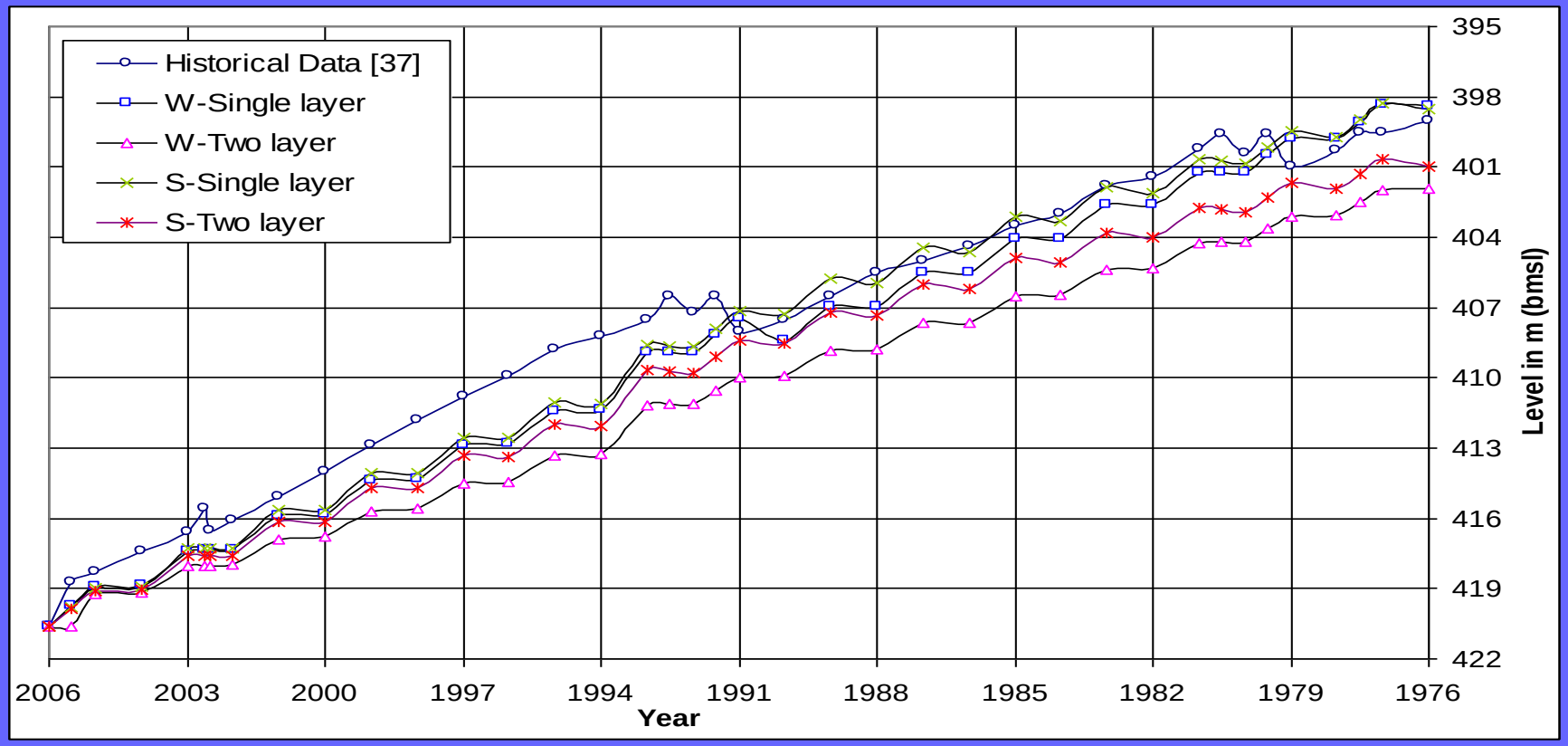
## Single-layer versus two-layer system

- A mathematical model was developed for 100-yrs period
- The model has been implemented using the idea of LOICZ Biogeochemical Modeling
- Including and excluding the proposed RSDSC
- Calculation by eliminating the terms that are equal to or close to zero
- Simple single box assumed as well-mixed system
- Two-layer box assumed as stratified system as the Dead Sea
- Assumption is due to vertical variations between upper and lower layers

# Historical Data Comparison

Historical comparison in 30-years for the two models showed that:

- Significant variations during some years e.g. 1991 and 1992 rainfall
- Differences also may be caused by uncertainties in the potash company production and salts extracted from the Dead Sea
- The amount of salt production was found to be approximately 0.1m/yr as stated in previous studies



# Result and Discussion

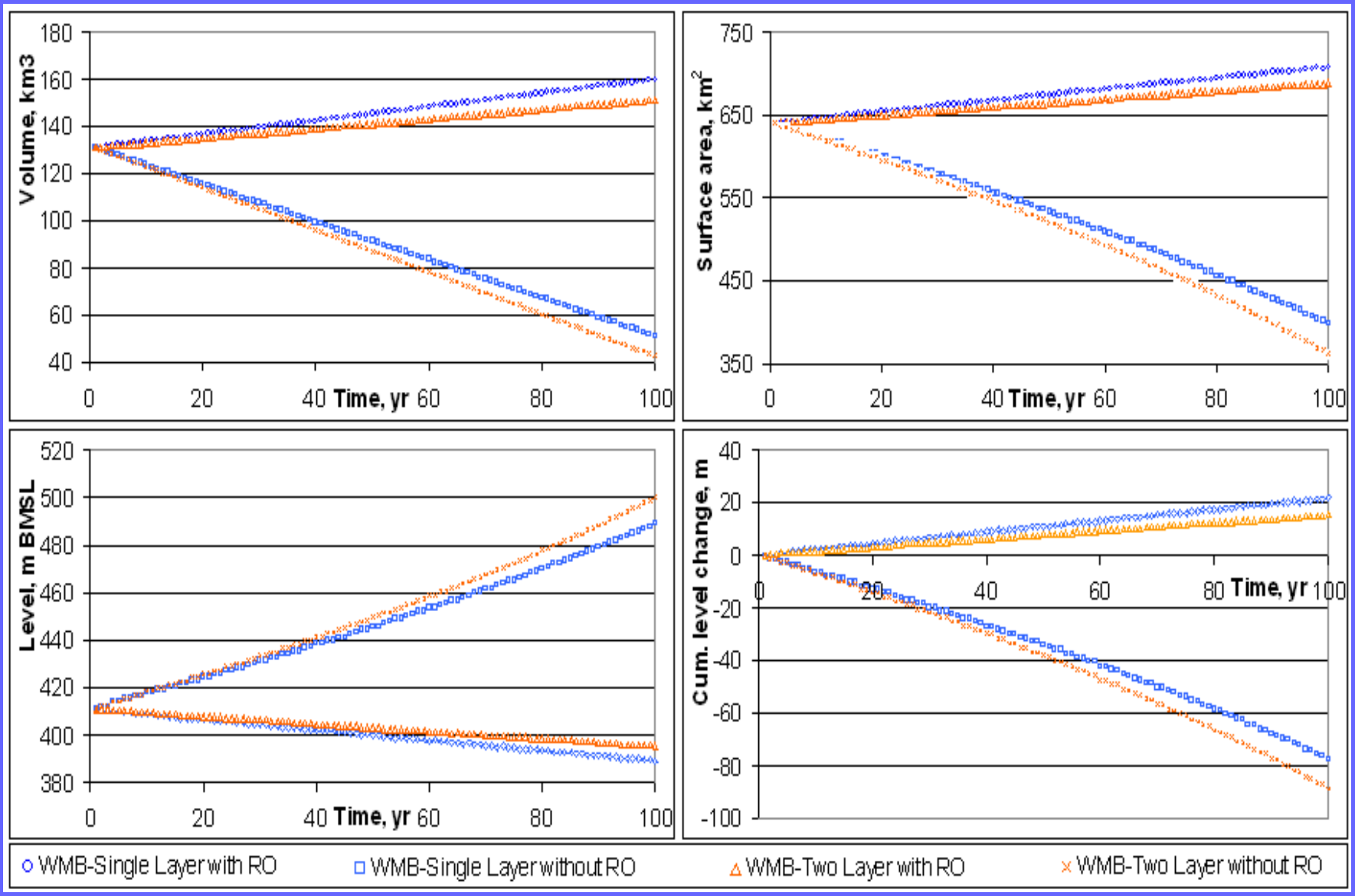
| Results of single-layer and two-layer in the first year including salinity variations | | | RO discharge | | (%) |
|---|---|---|---|---|---|
| | | | Included | Excluded | |
| **Simple Single Box** | **Water mass balance:** | | | | |
| | Residual Volume, $Q_N$ (MCM/yr) | | 292.2 | 807.8 | 63.8 |
| | Residence Time, τ (year) | | 57 | 110 | 48.2 |
| | **Salt mass balance:** | | | | |
| | Residual Volume, $Q_N$ (MCM/yr) | | 132 | 427 | 69.1 |
| | Residence Time, τ (year) | | 58 | 116 | 50.0 |
| **Two Layers Box** | Entrainment Volume, $Q_{Deep}$, (MCM/yr) | | 138.3 | 426 | 62.8 |
| | Vertical Exchange Volume, $Q_Z$ (MCM/yr) | | 10561 | 7281 | 31.1 |
| | **Exchange Time, τ (year)** | $T_1$ | 1.2 | 1.7 | 29.8 |
| | | $T_2$ | 11 | 15.3 | 28 |



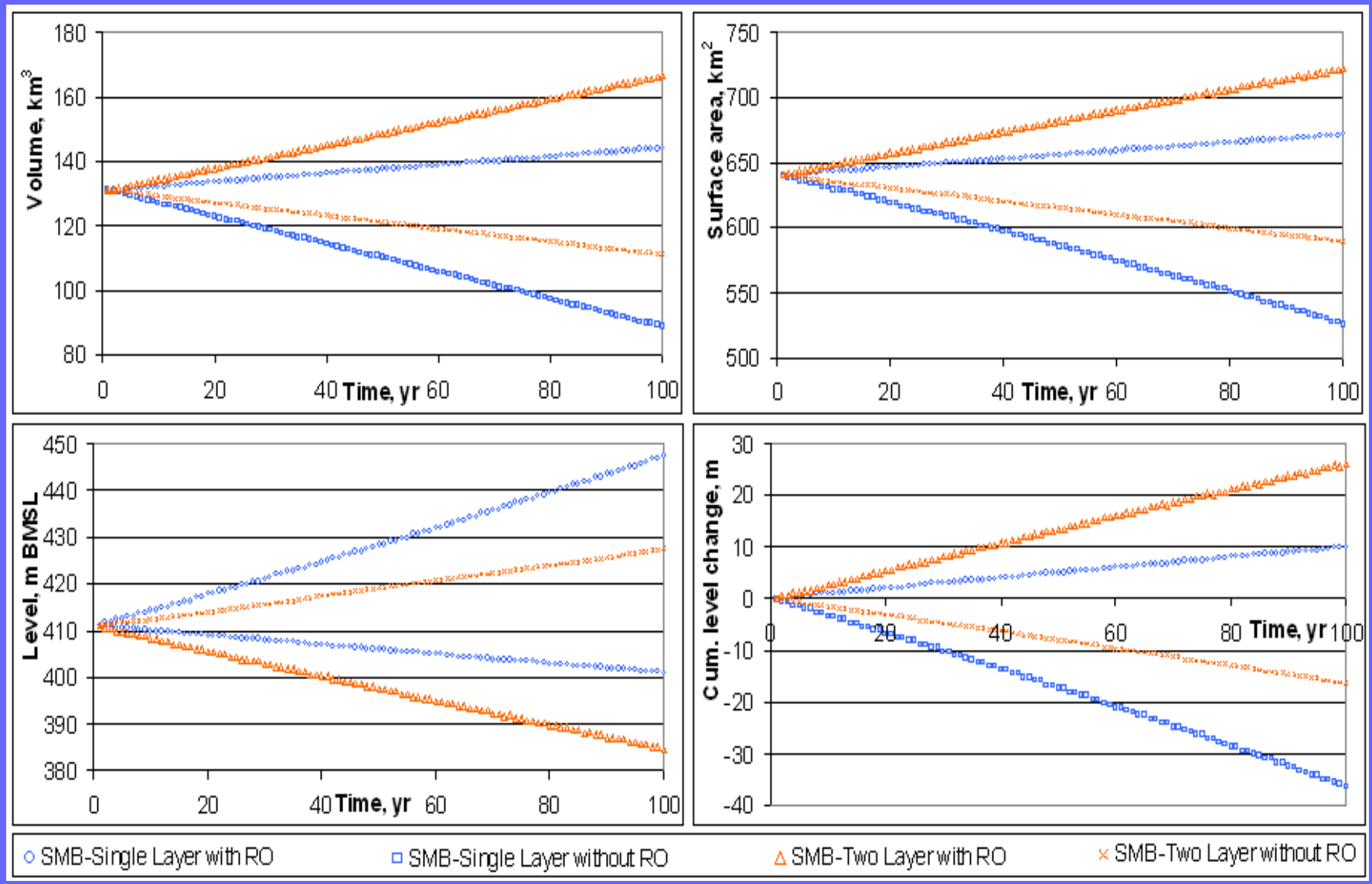
# Result and Discussion

Dead Sea simulations for different scenarios including salinity variations

| | | Water Mass Balance | | | | Salt Mass Balance | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | RO included | | RO excluded | | RO included | | RO excluded | |
| **Year** | | Single -layer | Two-layer | Single -layer | Two-layer | Single -layer | Two-layer | Single -layer | Two-layer |
| **1** | **Vol. km³** | 131 | 131 | 131 | 131 | 131 | 131 | 131 | 131 |
| | **Area km²** | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| | **H (m) (±)** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **El. m bmsl** | 411 | 411 | 411 | 411 | 411 | 411 | 411 | 411 |
| **90** | **Vol. km³** | 157.0 | 149.3 | 59.1 | 51.39 | 142.7 | 162.9 | 93.0 | 113.0 |
| | **Area km²** | 701.4 | 683.7 | 427.8 | 398.4 | 668.4 | 714.6 | 538.1 | 594 |
| | **H (m) (±)** | 19.63 | 13.98 | -67.88 | -77.26 | 9.1 | 23.85 | -32.6 | -14.73 |
| | **El. m bmsl** | 391.4 | 397.0 | 479.0 | 488.6 | 401.9 | 387.15 | 443.6 | 425.7 |




Predicted DS volume, surface area, elevation, and cumulative height for a 100-years in a single-layer and two-layer model for the water mass balance




Predicted DS volume, surface area, elevation, and cumulative height for 100-years in a single-layer and two-layer model for the salt mass balance

# Conclusions

After 100-yrs with the current condition and additive of brine water:

- The prediction of the DS for shorter and longer periods were satisfied
- Results strongly depend on differences in salinity and brine discharge
- Exchange time or mixing time was significantly different; Two-layer model displayed much lower values than the single-layer model
- It is important to have a mixing time less than one year
- Less dense fluid in the upper layer implies a higher evaporation rate
- A single-layer model predicts a 1.4% and 2% better level than the two-layer model in the water mass balance with and without brine water
- A two-layer model yields a 3.7% and 4% better level than the single-layer model in the salt mass balance with and without brine water
- Compared to previous studies, DS is a very complex dynamic system


اوطأ نقطة في العالم
٣٩٤ متر (١٢٩١ قدم)
تحت سطح البحر
WORLD'S LOWEST
POINT
394 Mtrs(1291Ft.)
BELOW SEA LEVEL