The Water Level Fall of Lake Megali Prespa (N Greece): an Indicator of Regional Water Stress Driven by Climate Change and Amplified by Water Extraction?

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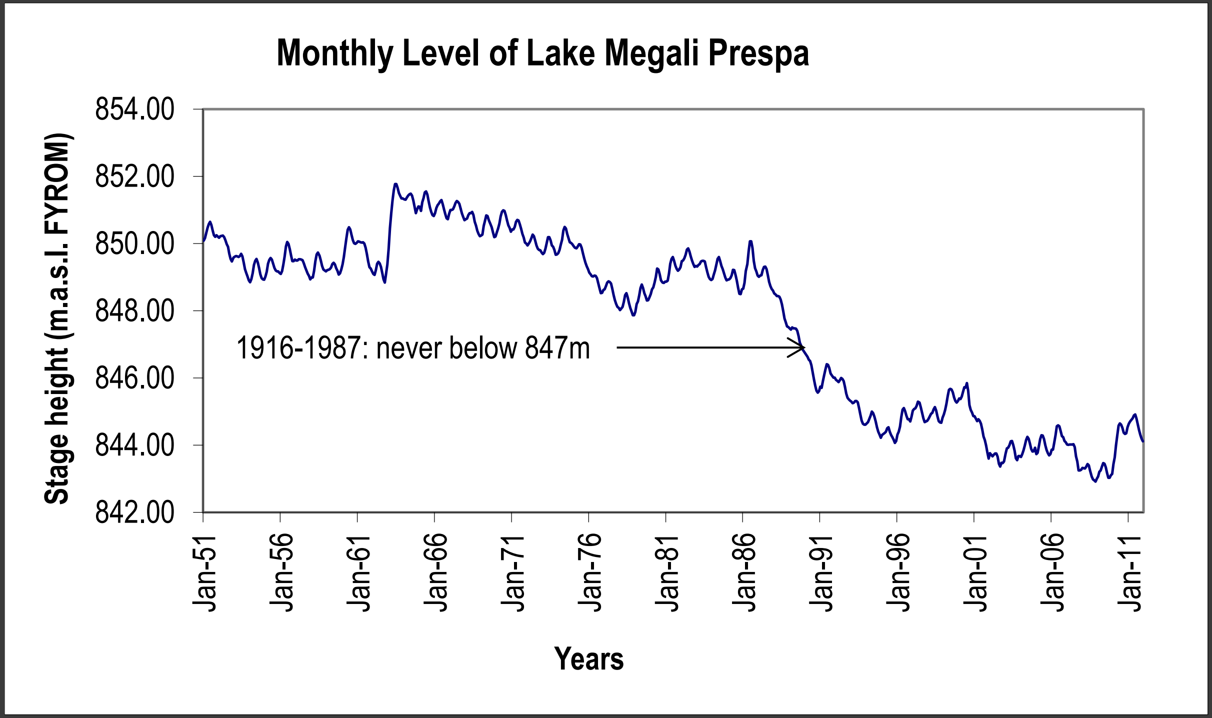
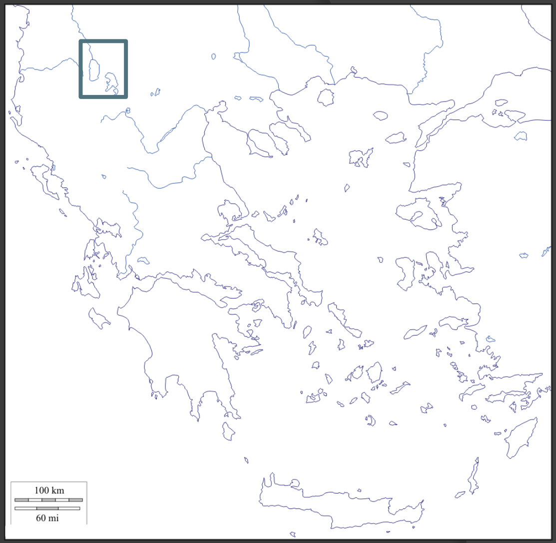
SOCIETY FOR THE PROTECTION OF PRESPA

SEVENTH FRAMEWORK PROGRAMME

The presented work is part of the project **CLIM-HYDROLAKE** (*Improving future projections of **clim**ate change induced **hydro**logical responses by looking into the past: the **Lake** Prespa / Aliakmonas River case study in Greece*). This project is supported by the European Community under a Marie Curie Career Integration Grant (*Framework Program 7, Grant 321979*)

Why is the water level of Lake Prespa falling?





Biodiversity hotspot of global significance: the interconnected Prespa-Ohrid Lakes and the Drim R.

Lake level fall and associated decrease in lake volume affect the water quantity and quality (pollution & eutrophication), as well as freshwater habitats. Thus it threatens global biodiversity & regional water resources (Greece, Albania, FYROM).

Aim: to explain lake level fall with available data

Lake level fall has been linked to either water **abstraction**, tectonically-induced changes in the **groundwater outflow** rate or **climate** change.

However, there are no conclusive answers to date, due to problems with data access (records are divided amongst 3 countries and various institutes).

Research had fortunately access to all major hydro-meteorological records in the Prespa catchment (1951-2004: SPP database) – *thus able to provide the answer*?

Main records:

- Rainfall (average from 7 stations; at lake level)
- Water abstraction data (compilation based on multiple records from all countries)
- Evaporation (open-pan measurements covering 2 decades; extended by “Penman” formula)
- Lake level data of Megali Prespa (monthly averages; internally cross-checked FYROM data)
- Fluvial Discharge (Brajcinska River only)

Additional records:

- Estimates for groundwater flow
- Earthquake records
- Snowfall records (short temporal / limited spatial coverage)

Geology

The catchment geology and topography strongly influence the hydrology of the lake.

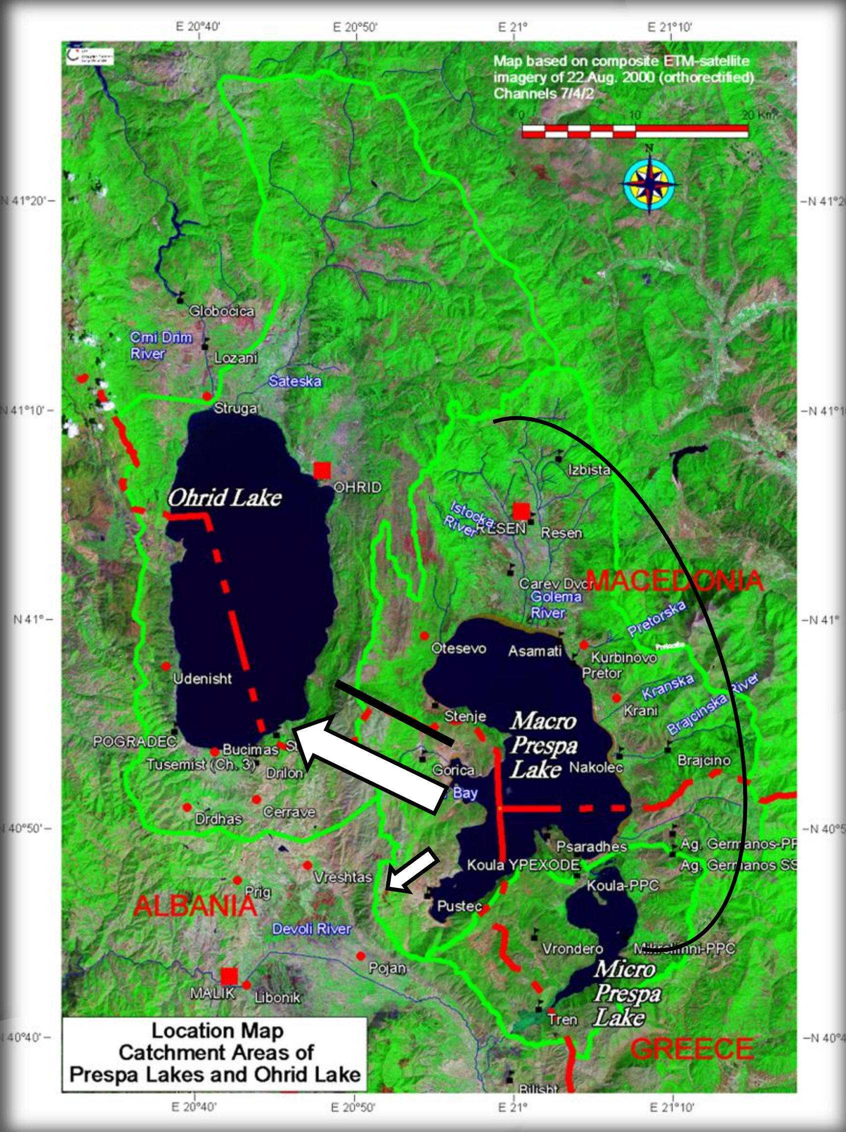
Internally draining basin, surrounded by high mountains (2400m). Adjacent catchments have lower topographic elevations.

Intrusive rocks to the N, E and at the basement forming **aquicludes** (*therefore*: no input of distant groundwater). Alluvium fringing the lake to the N,E with small (open) **aquifers** feeding into the lake.

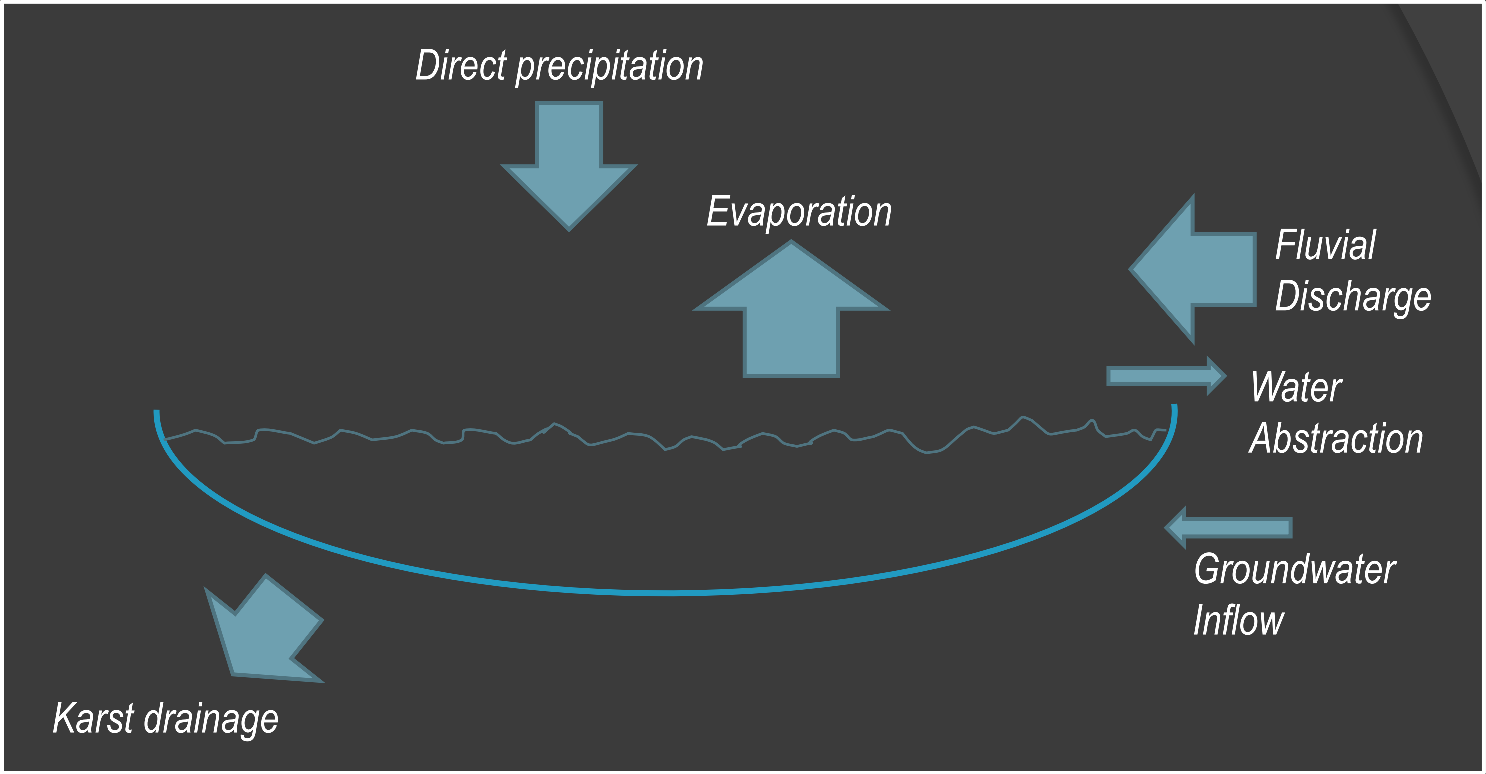
Limestone (aquifer) overlying basement rocks in W, downfaulted in SW (below lake level): here underground **karst outflow** (mainly to 160m lower Lake Ohrid).

Streams are short (15-20km) and steep, and originate within the steep-rimmed catchment.

All groundwater / fluvial discharge is locally generated (in balance with current/local climate)!



Lake Water Balance: Lake Megali Prespa



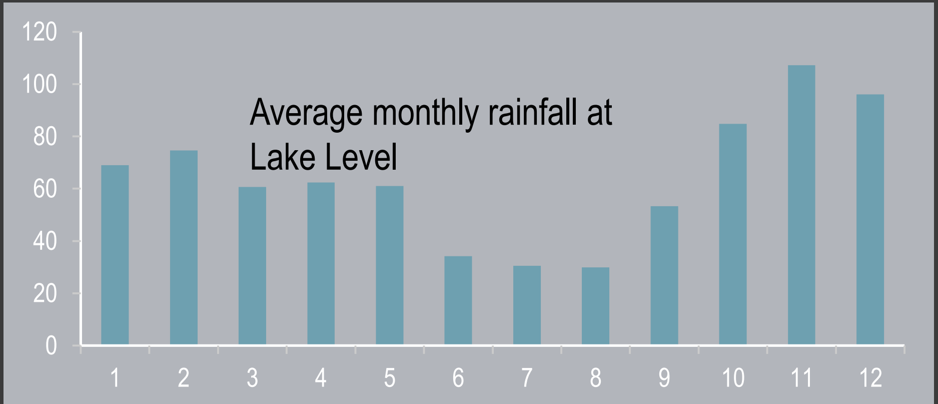
It is helpful to look at the LWB to understand the main parameters influencing lake level; however, the LWB cannot be accurately calculated (too many parameters unknown). *Outcomes of various studies yielded very different results.*

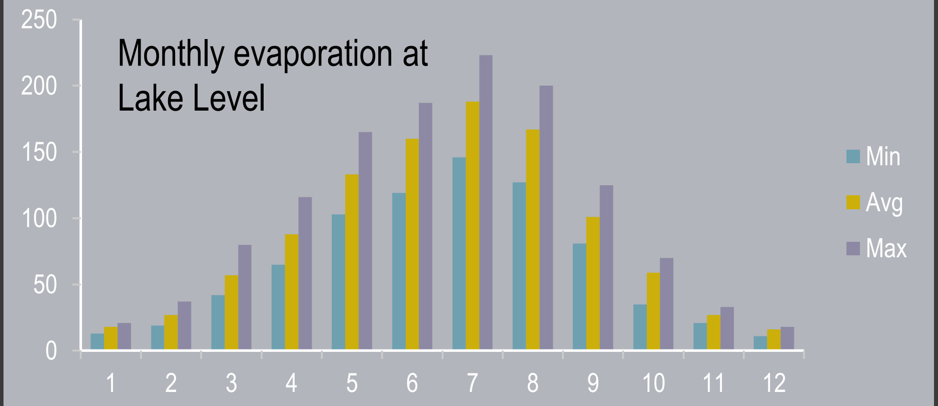
Main elements of the Lake Water Balance

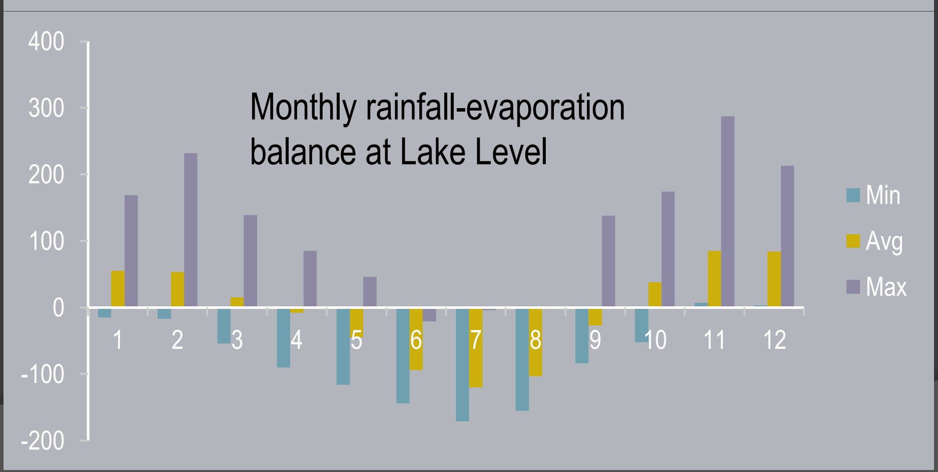
In: Direct Precipitation, Fluvial Discharge, Groundwater

Out: Evaporation, Water Abstraction and Karst Drainage

Catchment rainfall, snowfall and evaporation





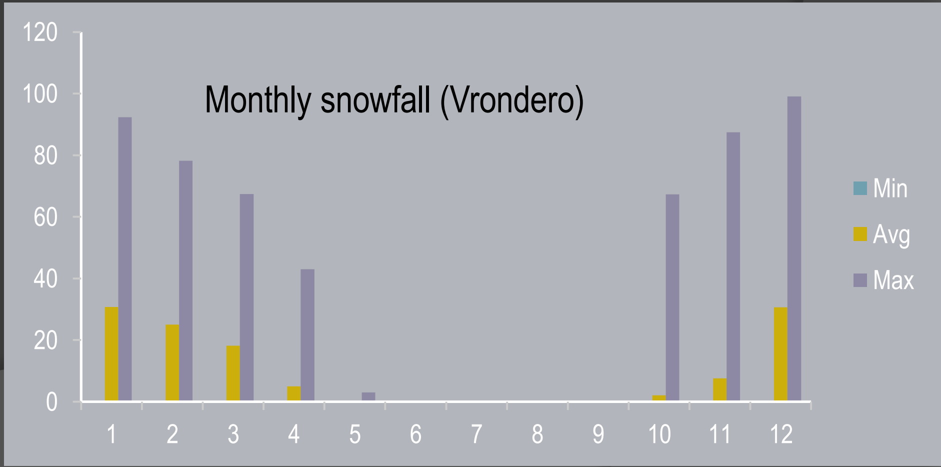


Mediterranean climate with continental influences.

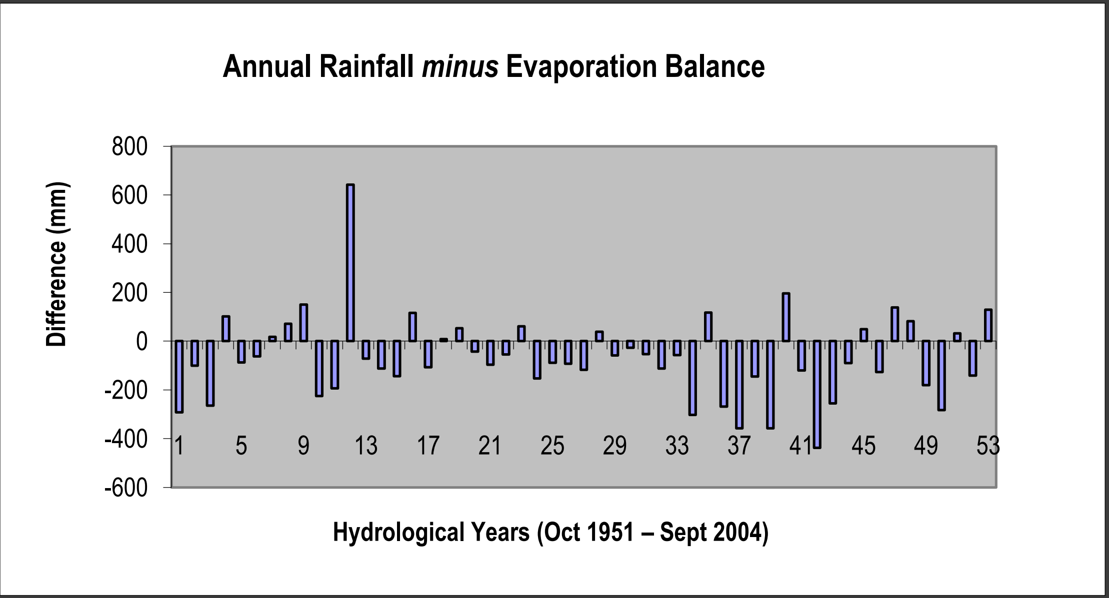
There is a positive rainfall *minus* evaporation balance from Oct-Apr (c. 860m - near Lake Level) – "wet season"

These months also receive significant snowfall (e.g. at Vrondero, Greece; 1000m)

Rainfall / snowfall must be much higher in the surrounding mountains (up to 2400m)



Hydrological characteristics

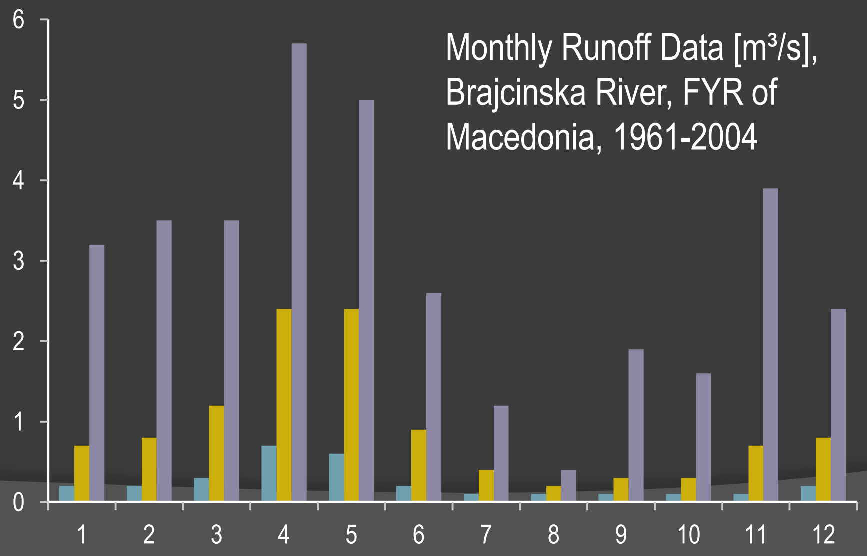


1951-2004: annual rainfall-evaporation balance at lake level is mostly negative.

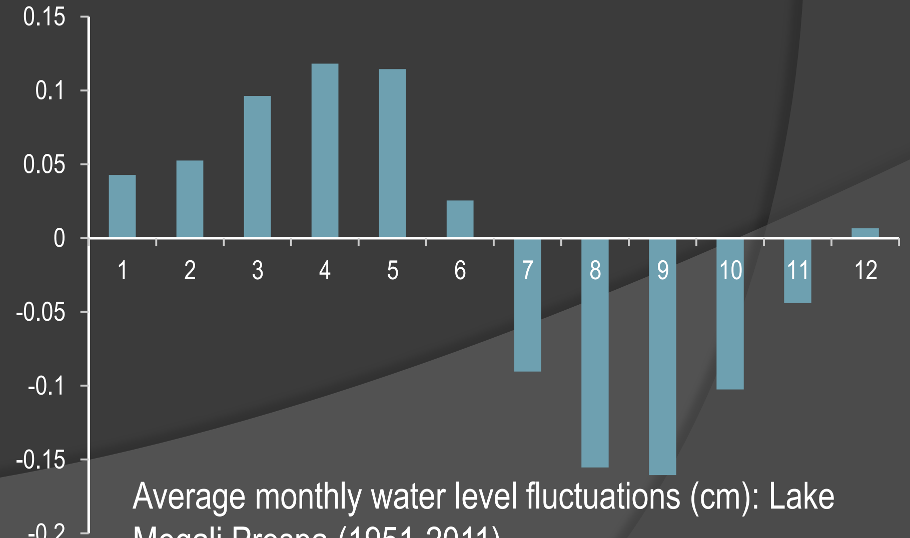
Suggests significant fluvial input (and minor input from direct snow fall?)…

Confirmed: Apr-May are the months of max. snow-melt fed discharge (4-5 month lag).

Max. monthly rainfall: Nov-Dec
Max. monthly snowfall: Dec-Jan
Max lake level: May-June

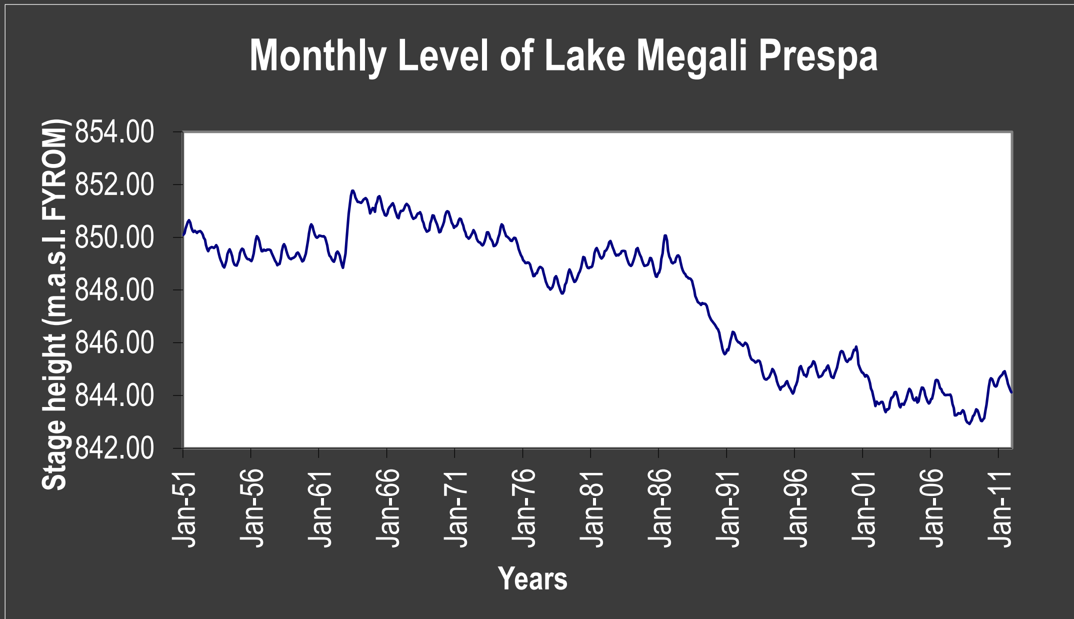


Monthly Runoff Data [m³/s], Brajcinska River, FYR of Macedonia, 1961-2004



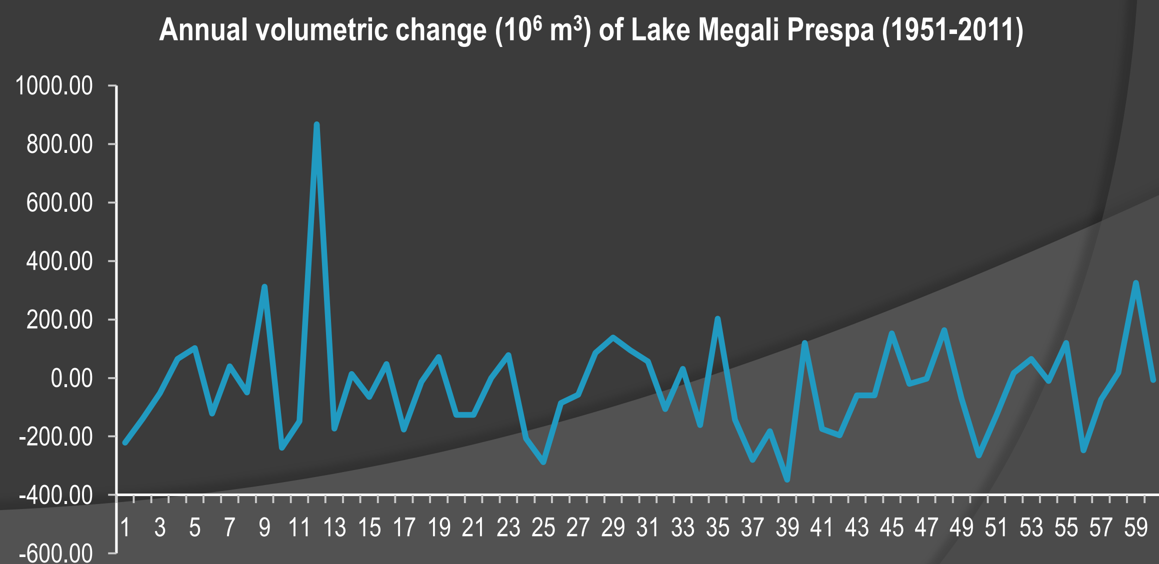
Average monthly water level fluctuations (cm): Lake Megali Prespa (1951-2011)

Volumetric conversion: to compare lake level with in-/outflow



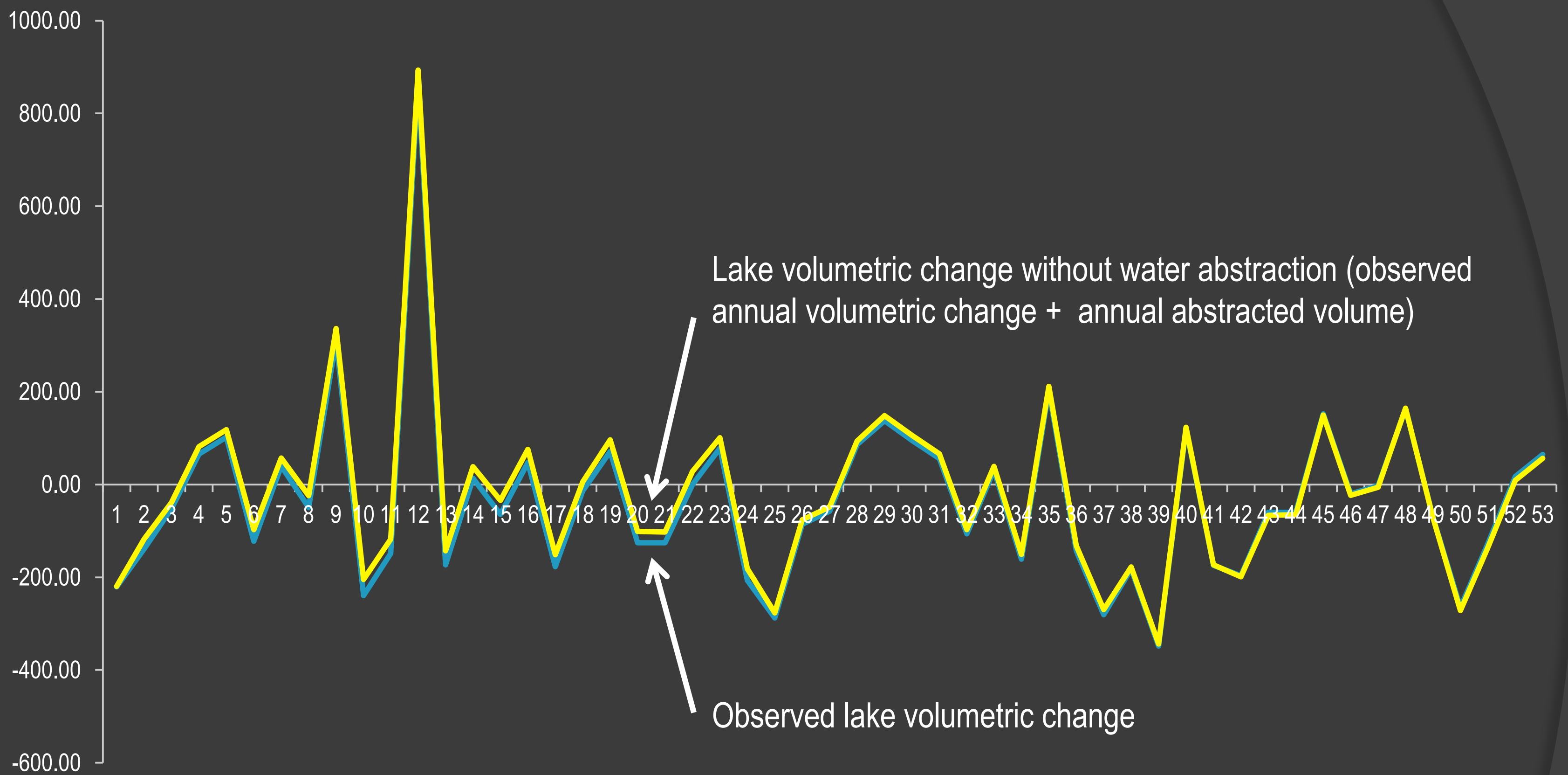
Water level fluctuations are a function of **in-/ outflow parameters** AND **bathymetry**.

Lake level changes (m) must be converted to volumetric changes (m^3): annual volumetric changes are ONLY related to in-/outflow parameters



This conversion is based on the DEM of the basin; the DEM for the upper part of the lake is most reliable

Abstraction & Lake Volumetric Change ($10^6 m^3/yr$): 1951-2004

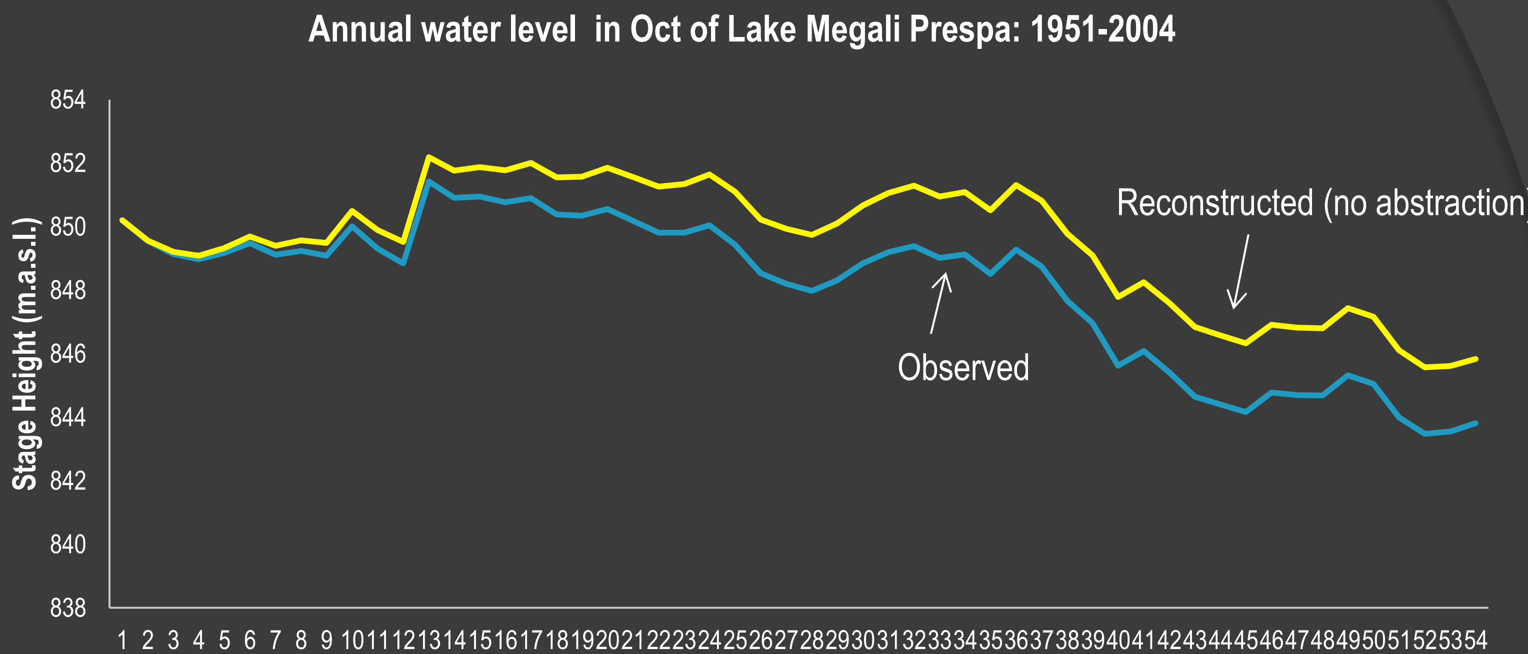


Water abstraction data (incl. groundwater abstraction) have been collected from various sources. A time-series of abstraction was reconstructed for 1951-2004 (best estimate).

Abstraction prior to 1979: 20-30 $10^3 m^3$, after 1979: 10-14 $10^3 m^3$ (max: ~0.005% of total lake volume).

Water abstraction has very limited impact on an ANNUAL basis, due to small volumes involved!

Water Abstraction: Long-term Impact on Lake Level

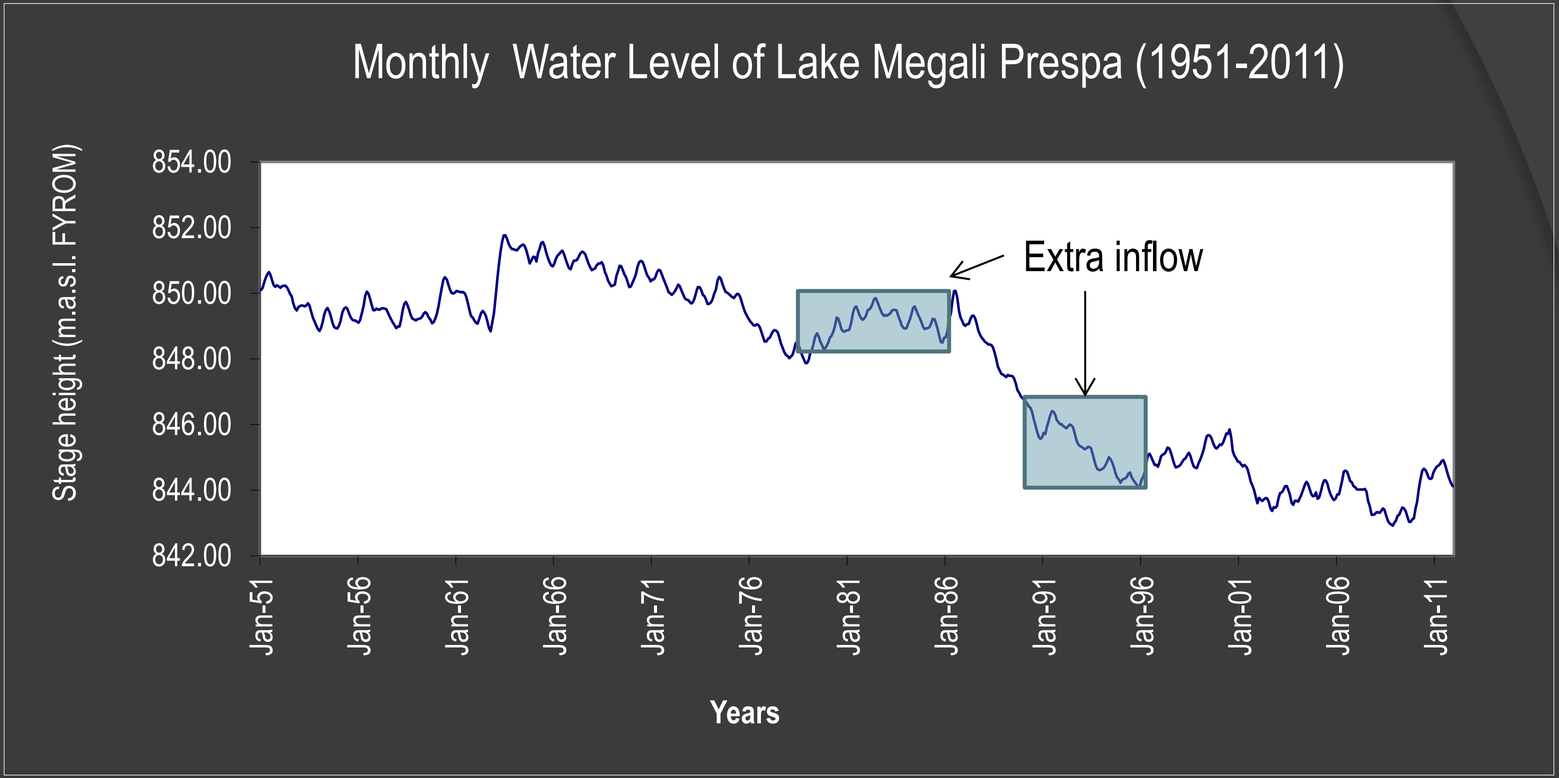


Reconstructed lake level change (no abstraction scenario). Annual abstraction was ***added*** to annual lake volumetric change (both in m^3); the resulting value was converted to Lake level stage height (m). Subsequently the lake surface area difference was calculated between actual/computed lake level; annual evaporation over the extra surface area was calculated and subtracted from the computed lake level.

Water abstraction has a significant **cumulative** impact on lake level (not visible in annual volumetric change curve!).

Balance is reached after multiple decades: lake level falls, lake surface area shrinks and the eventual lake surface evaporation decrease is equivalent to the abstracted volume. NOTE: lake level falls are dependent on the bathymetry! <u>However, explains only part of the falling trend</u>….

Tectonic impact on groundwater flows & Lake level?



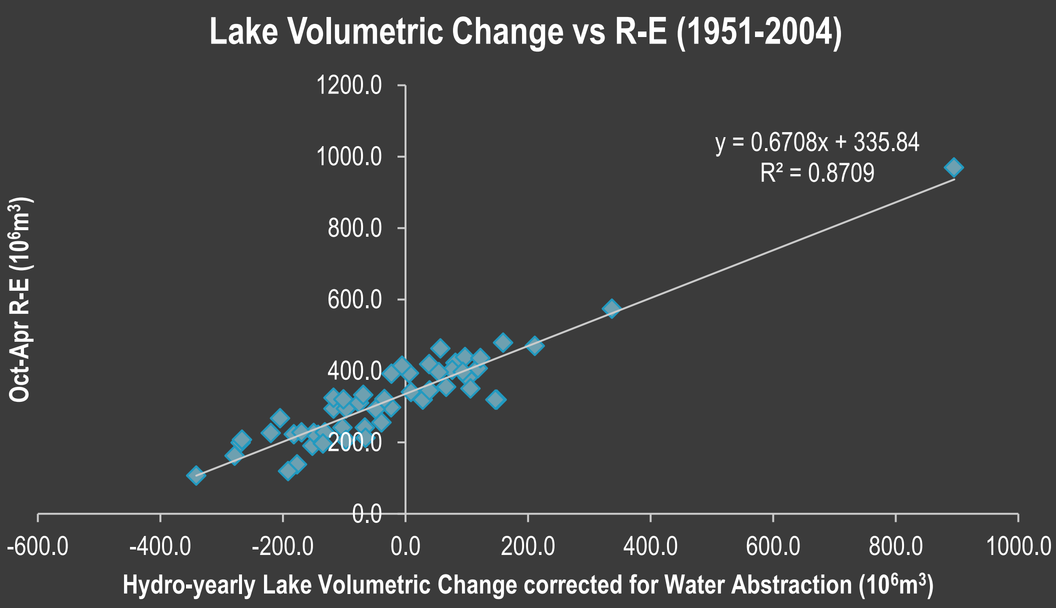
Lake Water Balance models suggests *steady* groundwater in-/outflow rates. **Inflow** (alluvium) is estimated at 10-60 $10^6 m^3$ per year; **outflow** (karst channels) is estimated at 335-385 $10^6 m^3$ per year.

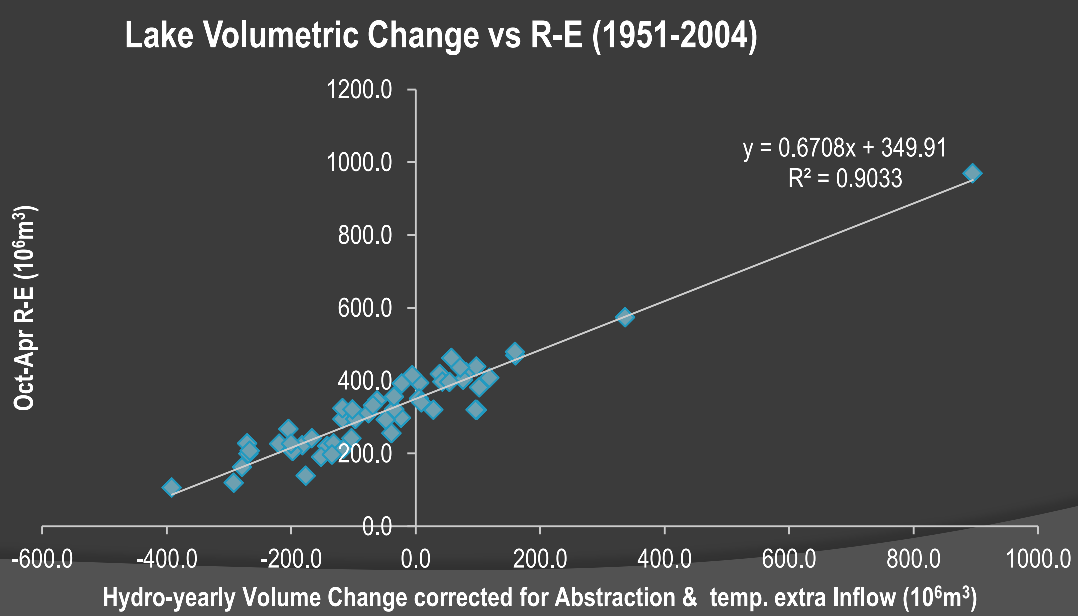
Extra groundwater inflow may have followed major lake level falls – through adjustment of alluvial aquifers (Oct 1978 – Sep 1986: 606 $10^6 m^3$ extra inflow, and Oct 1989 – Sep 1996: 505 $10^6 m^3$ extra inflow).

The timing of significant lake level changes does not coincide with recorded earthquakes. The 1962-1963 extreme lake level rise matches a wet event that is recognised throughout Greece; significant falls (1974-1978 & 1987-1995) correspond with major Mediterranean-wide droughts, when regional Lakes Skardar, Ohrid & Dorjan also fall.

This regional synchronisation suggests that local tectonics do not control major Prespa lake level changes.

Rainfall & discharge: influence on Lake Level?





Annual lake volumetric change (Oct-Oct) is strongly related to the cumulative Oct-Apr "rainfall *minus* evaporation" balance

Correlations improve when corrections for water abstraction and temporary extra groundwater inflow are incorporated.

If more months (>7) are included correlations become poorer.

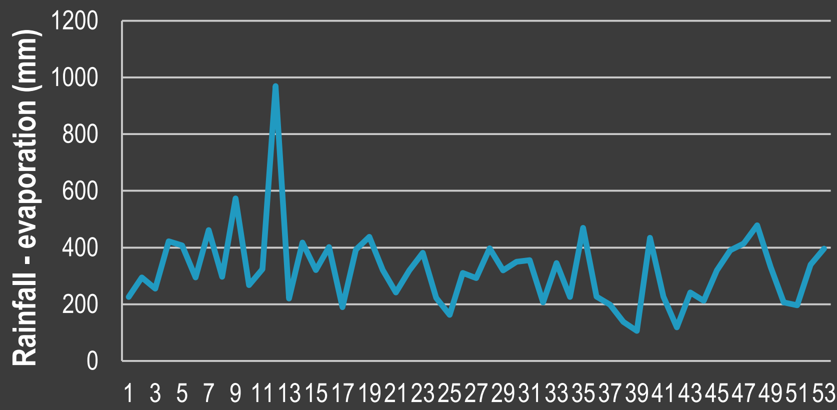
Points representing lake level falls are close to the regression line (thus not supporting a tectonic cause)!

Regression analysis between annual lake volumetric change and **Brajcinska River Discharge** gives an R^2 of 0.74 (catchment: 10% of Prespa), suggesting that total fluvial inflow exerts a strong control on lake level.

Lake Level fall: climate variability or -change?

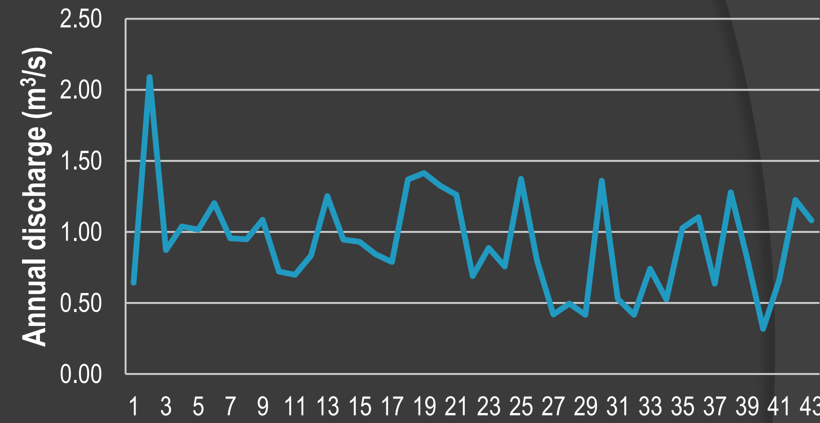
Non-parametric bootstrap testing (i.e. not assuming normal distribution) of equally split data-sets (rainfall & evaporation; local snowfall & discharge)

Oct-Apr rainfall *minus* evaporation 1951-2004



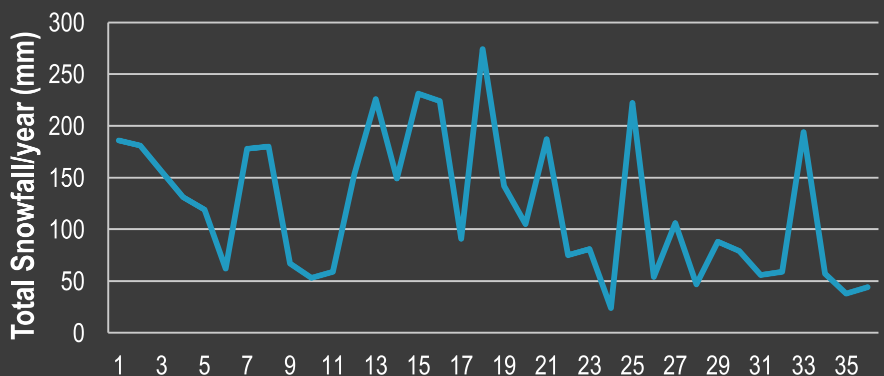
25^{th} percentile: 267 vs 207 (robust), mean: 354 vs 294 (non-robust) – 26/26yr split

Oct-Sept Discharge Brajcinska R. 1962-2004



25^{th} percentile: 0.84 vs 0.53, and mean: 1.1 vs 0.8 (robust), median: 0.96 vs 0.76 (non-robust) - 21/21yr split

Snowfall Vrondero: Oct 1966-Sept 2002



25^{th} percentile: 91 vs 54, median: 155 vs 77, and mean: 151 vs 92 (robust) - 18/18yr split

Wet season rainfall decreasing, snowfall decreasing, runoff decreasing, droughts increasing

Conclusions

- **Annual lake level is strongly related to wet season (Oct-Apr) rainfall (and snowfall), as well as snow-melt fed discharge.** Winter precipitation and snow cover are allied to the North Atlantic Oscillation winter index (negative – more precipitation);
- **The significant fall in lake level since 1987 is likely driven by climate changes.** Wet season rainfall and snowfall are decreasing, while droughts are increasing;
- **Minor water abstraction amplifies the long-term falling lake level trend** (not visible in regression analyses of annual data). Abstraction has a progressive impact on lake level with a lag-time of multiple decades (bathymetry-dependent): it explains ~30% of the observed fall since 1987;
- **Abrupt, large falls in lake level may induce one-off emptying of groundwater stores** (through the adjustment of the groundwater table in the adjacent alluvial aquifers);
- **There is no link between earthquake-occurrence over the observation period (1951-2004) and major lake level fluctuations**;
- The S Balkans experience decreasing snowfall / winter precipitation and increasing droughts; future climate change scenarios suggest this trend to continue, while increasing lake water abstraction is likely.
- Lake levels are thus likely to fall further and stabilise at an even lower level. Urgent issues: (i) lake volume reduction: increasing pollutant concentrations and accelerating the current eutrophication, and (ii) reduced underground outflow to lake Ohrid. Significant impacts on water resources and biodiversity of the entire Prespa-Ohrid-Drim catchment are likely.