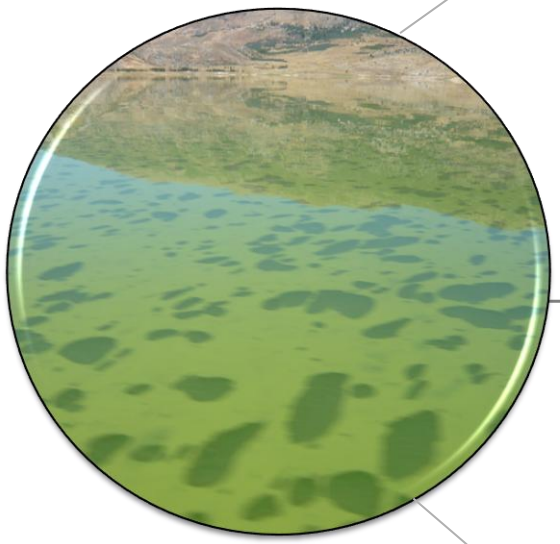
Qaraoun Reservoir Eutrophication Dynamics: Assessing the Role of Climate and Excessive Nutrient Loading

Jan 7 2020

Ibrahim Alameddine

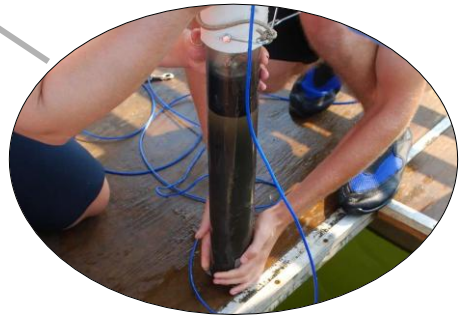
Drivers of Eutrophication



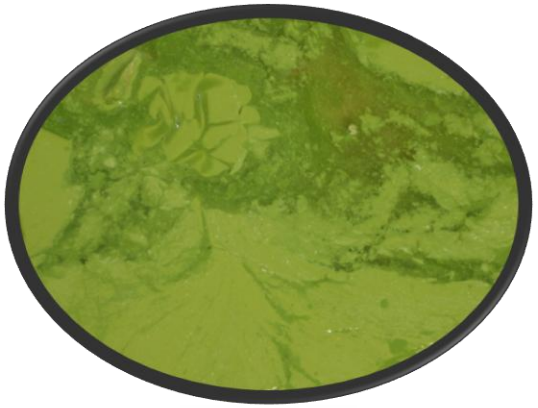
Light

Nutrient Inputs (Nitrogen and Phosphorus)

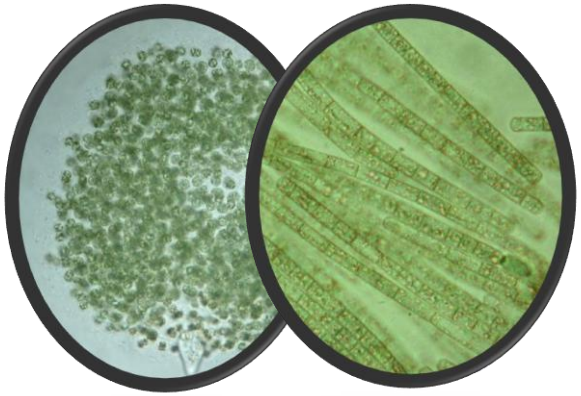
Temperature



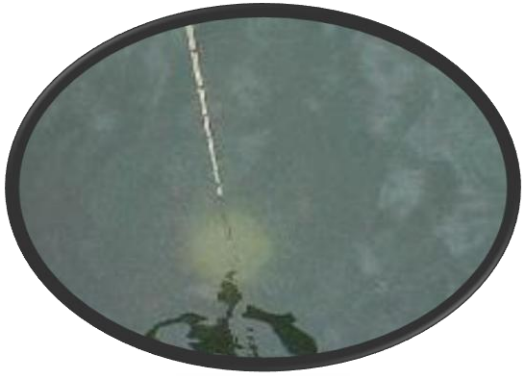
Eutrophication Effects



Increased Phytoplankton/ Cyanobacterial Biomass

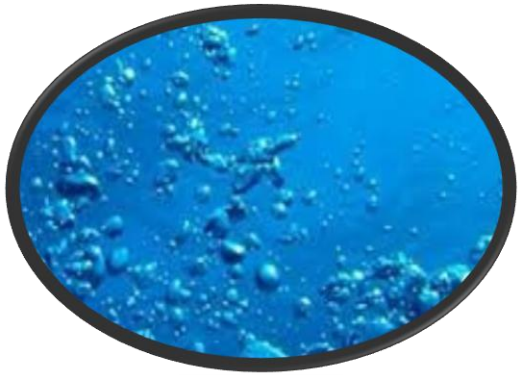


Toxic Phytoplankton Species



Decreased Water Transparency

Changes in Macrophyte Biomass



Dissolved Oxygen Depletion

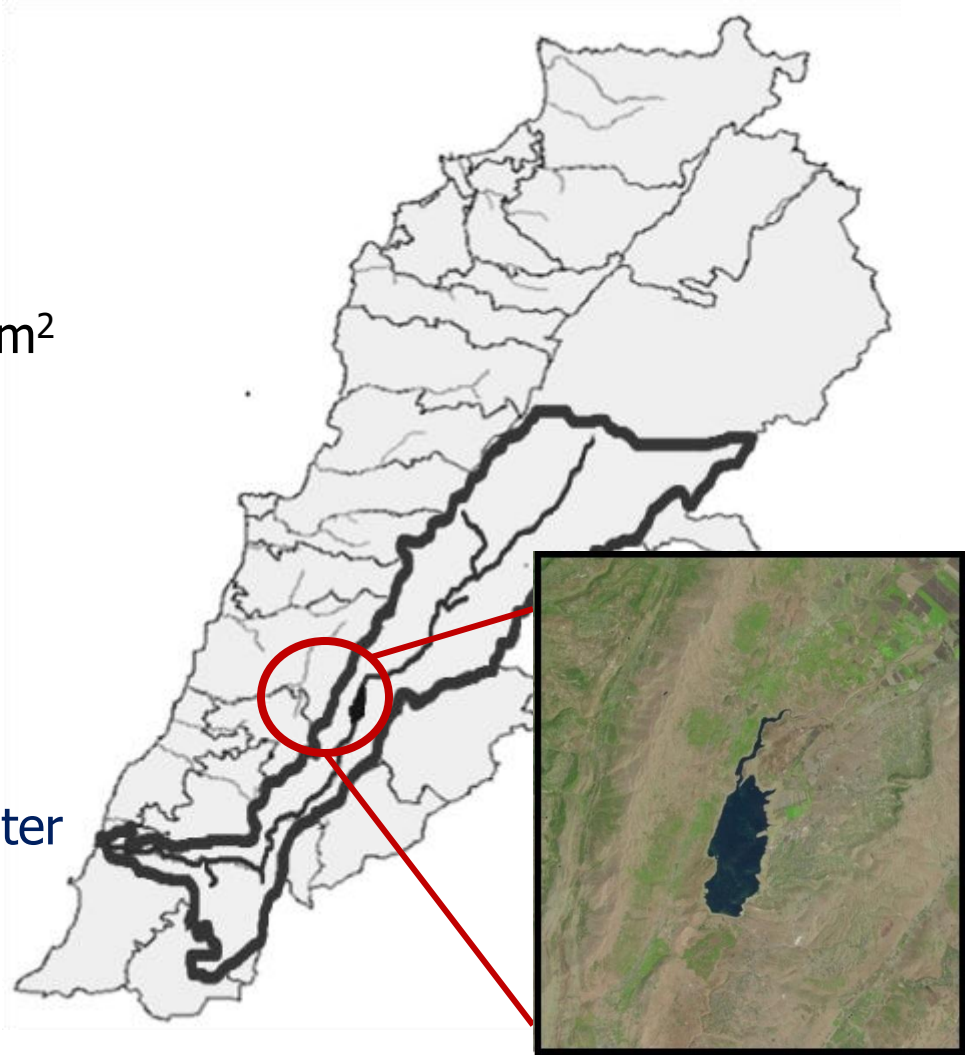
Increased Fish Kills

Eutrophication: a Global Problem

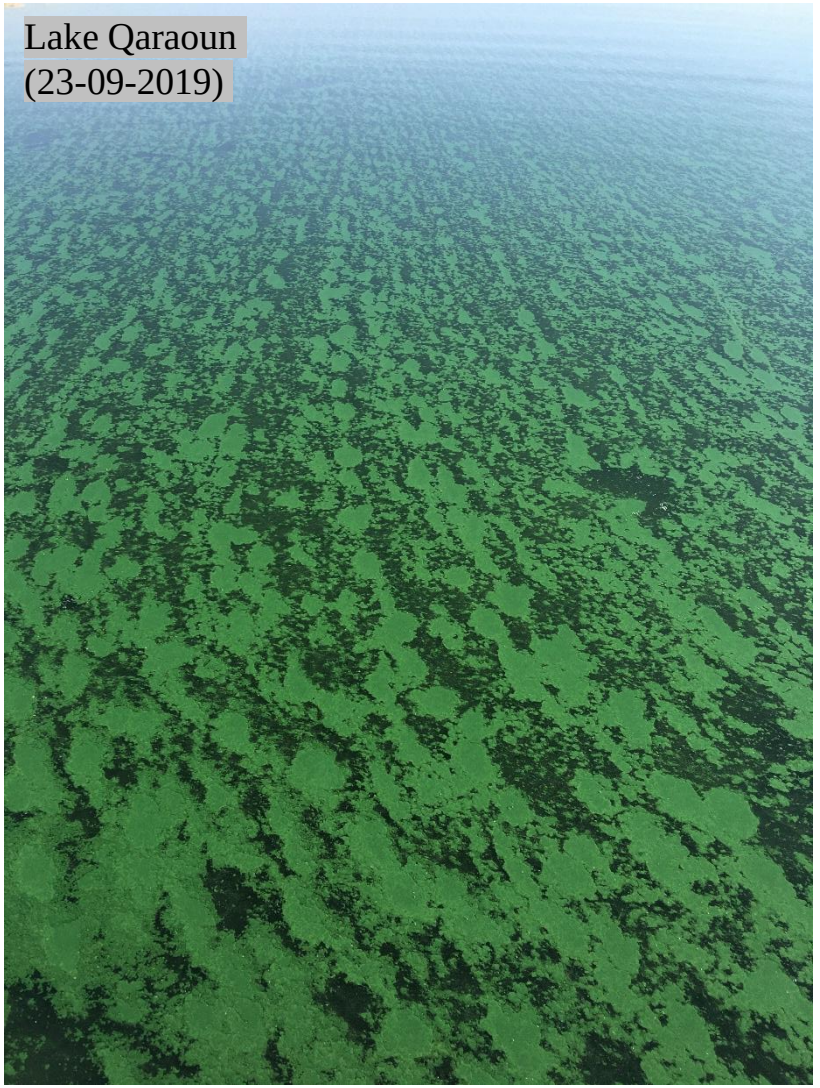
Qaraoun Reservoir

- Constructed on Litani River
- Dam completed in 1959
- Surface area: 4-11 km^2
- Depth near dam: >45 m
- Useful volume: 220 MCM
- Upstream catchment 1600 km^2

- **Uses:**
  - Hydropower generation
  - Irrigation of 68,000 acres
  - Some tourism
  - Small fishing industry
  - Potential for domestic water supply



Qaraoun Reservoir



Qaraoun Reservoir in the News

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Fish die en masse after Qaraoun Lake poisoned

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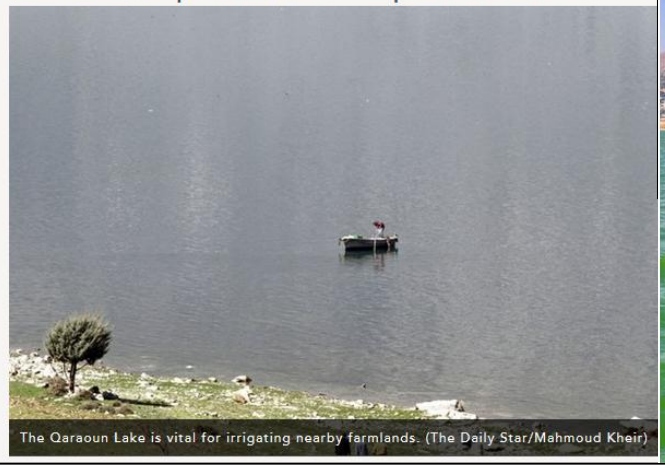
Qaraoun residents cut off irrigation canals to protest lake pollution



The Qaraoun Lake is vital for irrigating nearby farmlands. (The Daily Star/Mahmoud Kheir)

Authorities stop pumping from Qaraoun Dam

The Daily Star (Lebanon) 19 Sep 2016

QARAOUN: The Litani Authority

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Sarah Abdallah August 21, 2019

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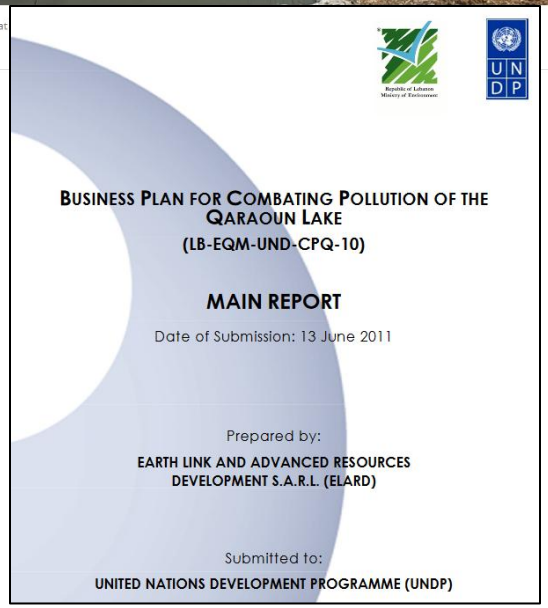


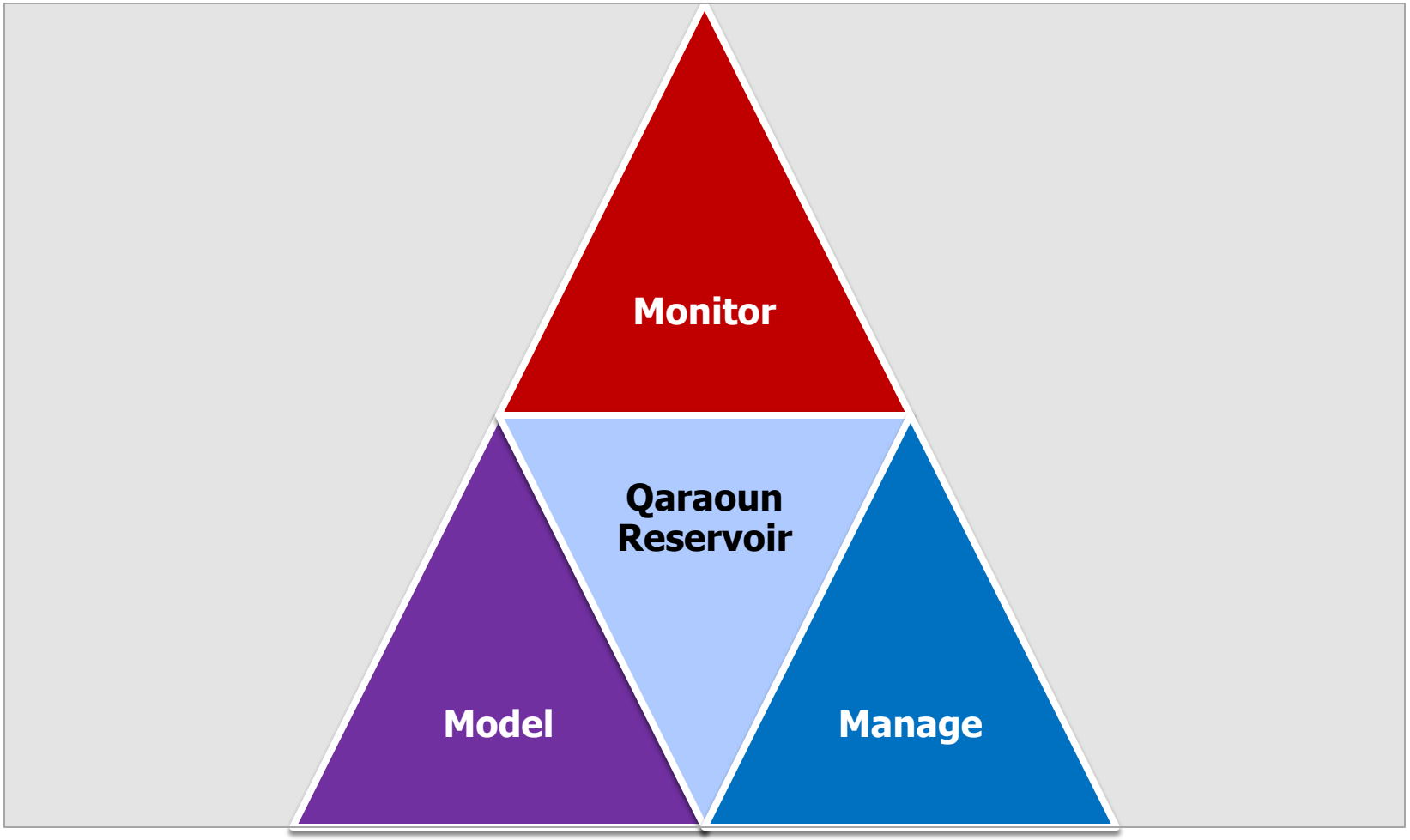
Official launch of the Ultra-sonic algae control devices and algae monitoring stations in Lake Qaraoun, Lebanon

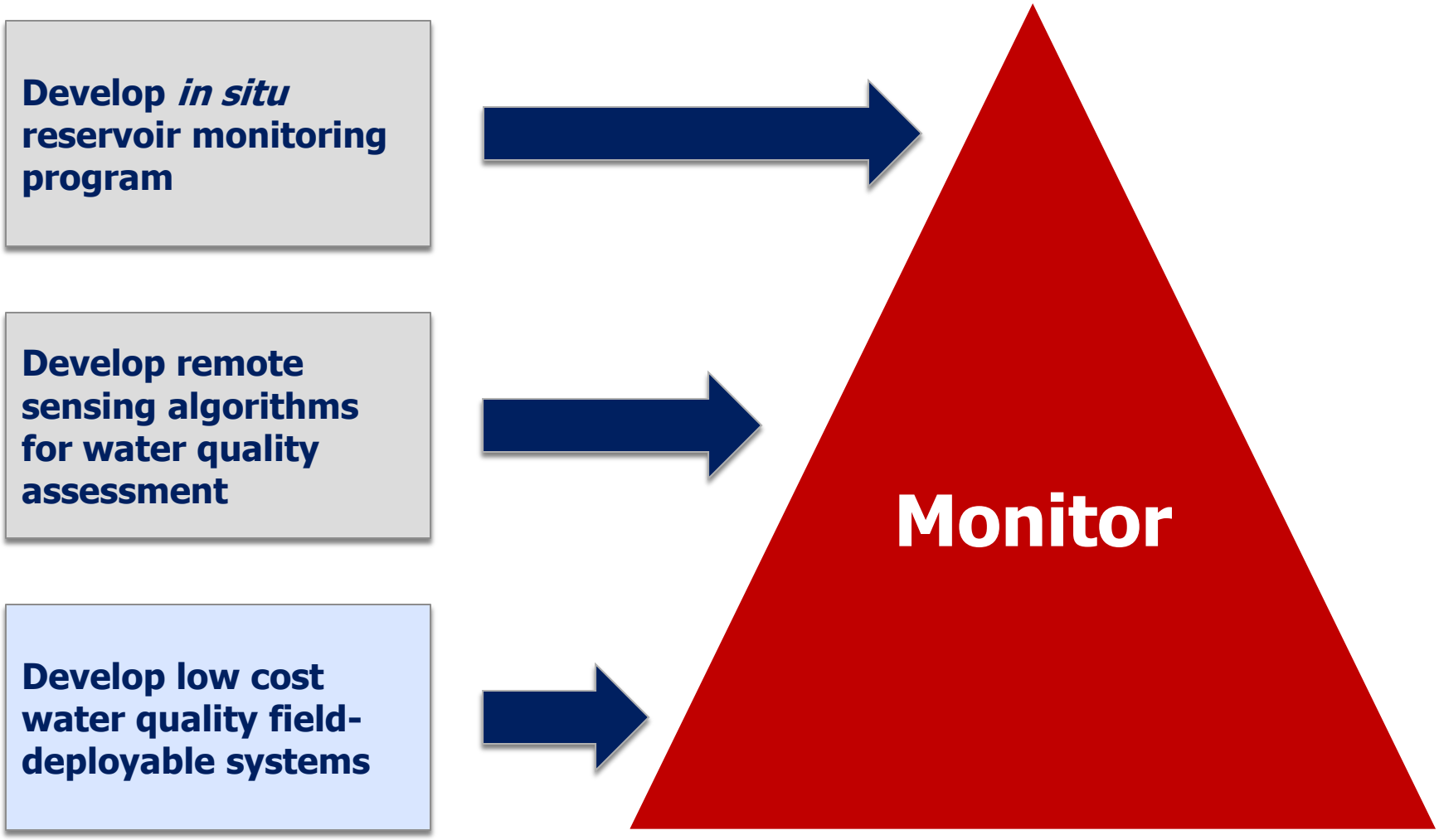
Wed. 19 September 2018 - by Lidi Remmelzwaal

On 19 September 2018, the official inauguration of the 11 buoys took place on location at Lake Qaraoun. In the capacity as President of the Supervisory Board, I represented World Waternet at that occasion.

The ultrasound algae monitoring and control stations (buoys) in Lake Qaraoun have been functioning since early August already demonstrated good results. This activity has been realised in close cooperation between World Waternet (WWn) and Litani River Authority (LRA) under the programme Strengthening Lebanese Water and Agriculture Sector (SLWAS) funded by the Netherlands' Government. Litani River and Lake Qaraoun are very important sources for irrigation water in Lebanon, but the water is highly polluted, including by harmful toxins from blue algae.

You can't manage what you don't measure

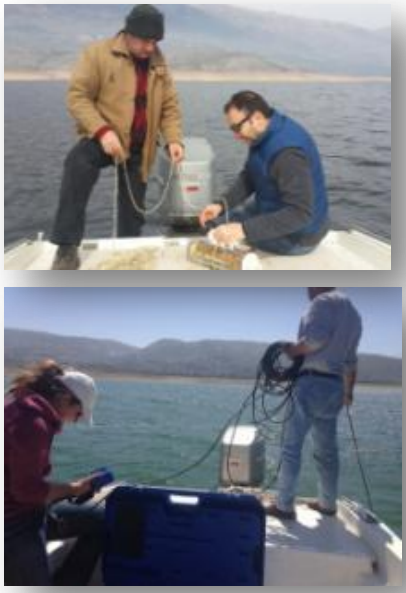



Develop *in situ* reservoir monitoring program
Develop remote sensing algorithms for water quality assessment
Develop low cost water quality field-deployable systems
Monitor

In Situ Monitoring Program

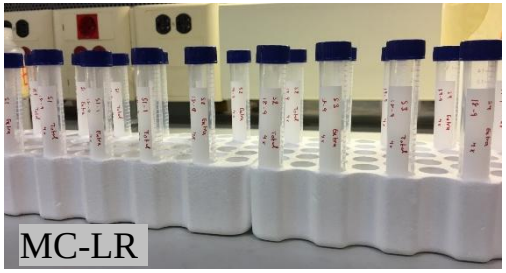
- Monitoring from **2012-present**

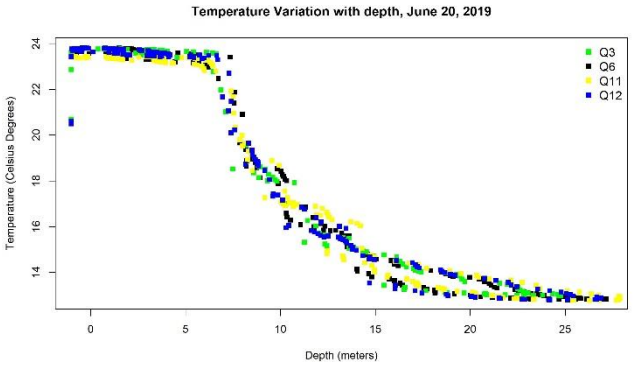
- Sampling include:
  - **Chlorophyll-a**
  - **Toxins (MC-LR)**
  - **Temperature profiles**
  - **Algae composition**
  - **TSS**
  - **SDD**
  - **Dissolved Oxygen**
  - **NH_3, NO_3, NO_2**
  - **TP, PO_4**
  - **pH, Cond, TDS**



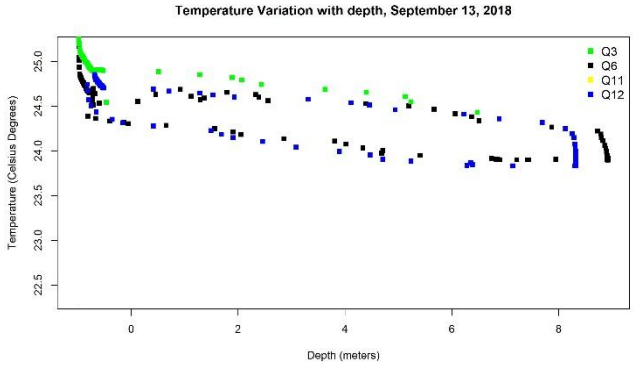
In Situ Monitoring Program

- Grab samples taken from the surface and bottom using a Van Dorn water sampler
- Vertical profiles of the lake taken using the YSI sonde EXO 2 multi-parameter sonde

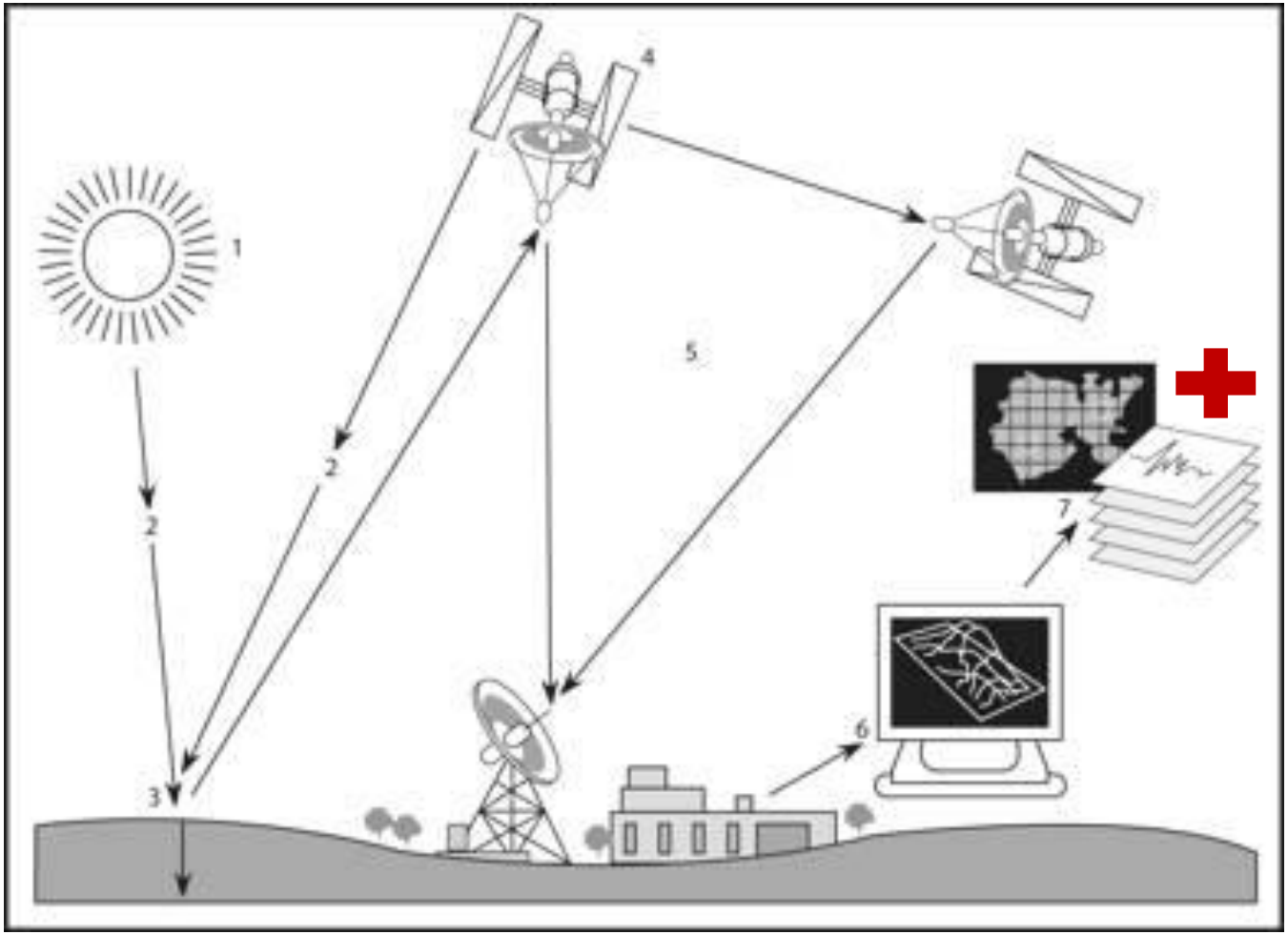

MC-LR




Chl-a



Remote Monitoring of WQ



Field sampling is costly and provides low spatio-temporal resolution

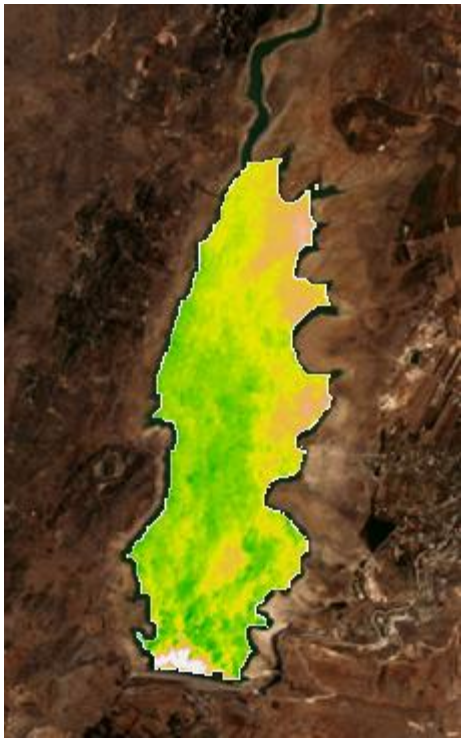
Remote Sensing Monitoring Program

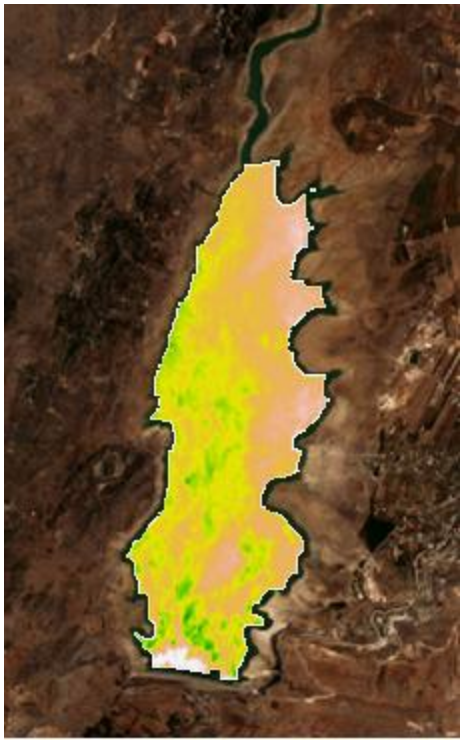
- **Landsat 7 ETM+/ Landsat 4 & 5 TM**
  - **1982 - present**
- **Landsat 8 OLI**
  - **2013 - present**
- **Sentinel 2**
  - **2015 - present**

Chlorophyll-a, TSS, SDD

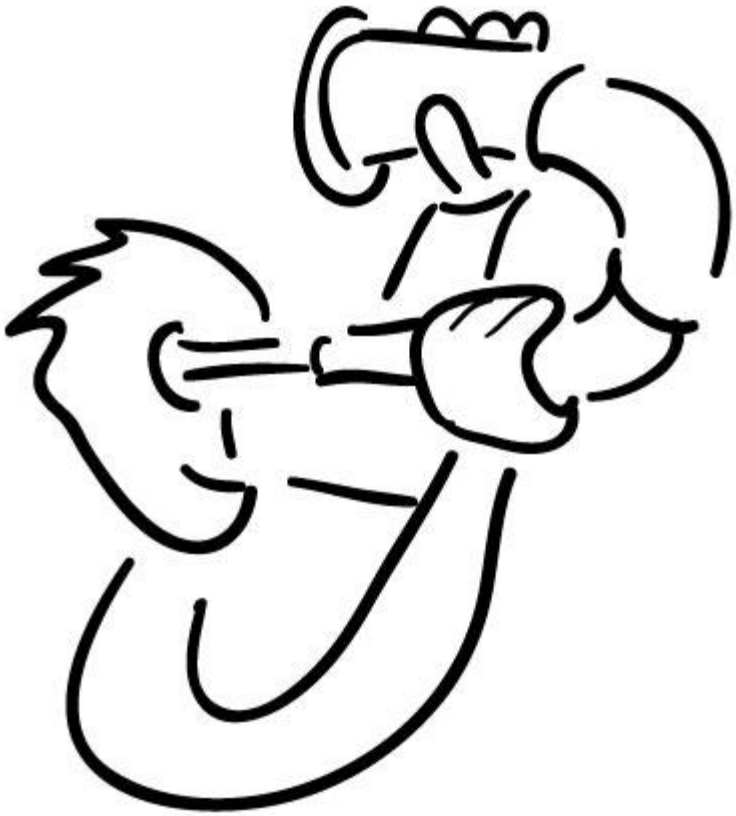
Remote Sensing Monitoring

- Calibrated, validated, and verified reservoir specific water quality models
- Models can be used to:
  - Assess surface water quality changes on a regular basis
  - Provide an early warning system of toxic algal blooms



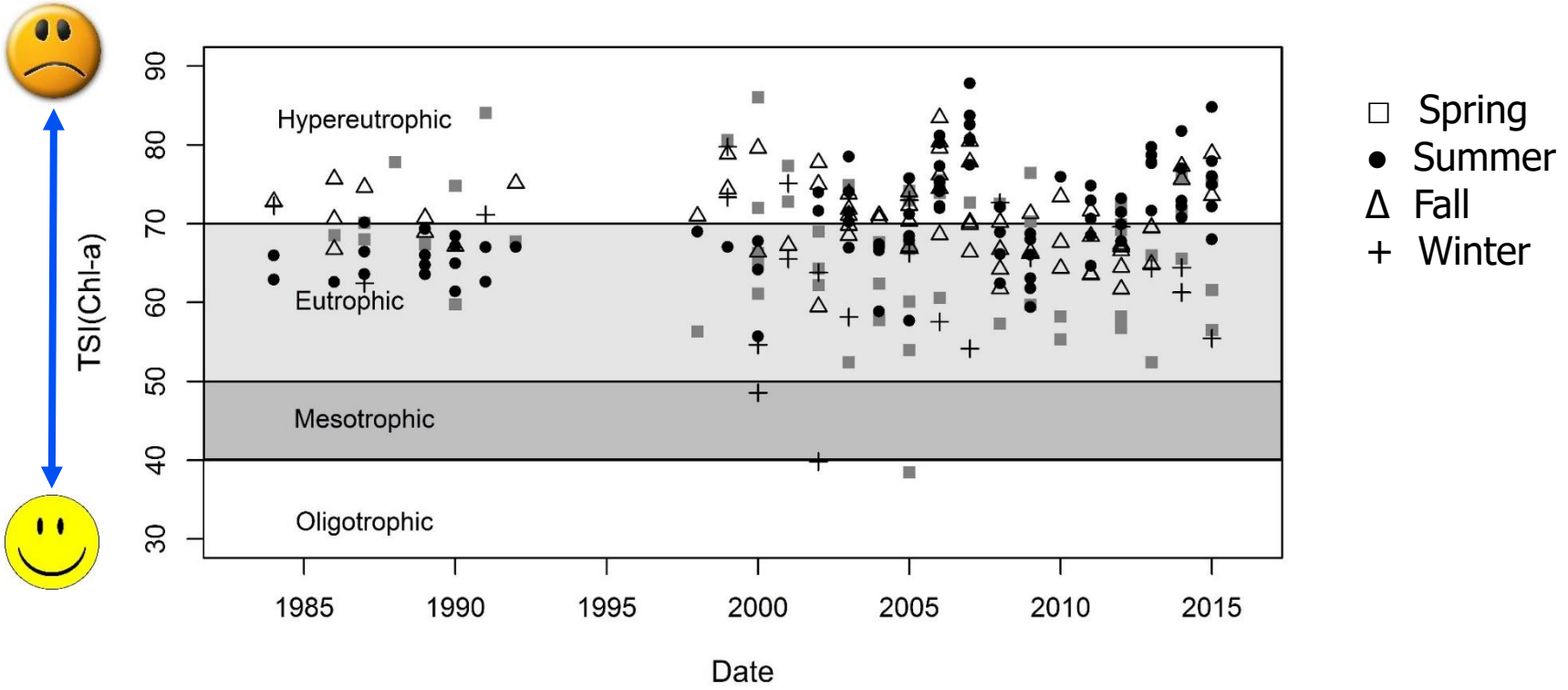


Hindcasting



Hindcasting Results

- **Eutrophication** has been a problem for 3 decades in Qaraoun, and has significantly increased in severity in the last decade
  - Increased pollution in basin post civil war
  - Increased occurrence of cyanobacterial blooms



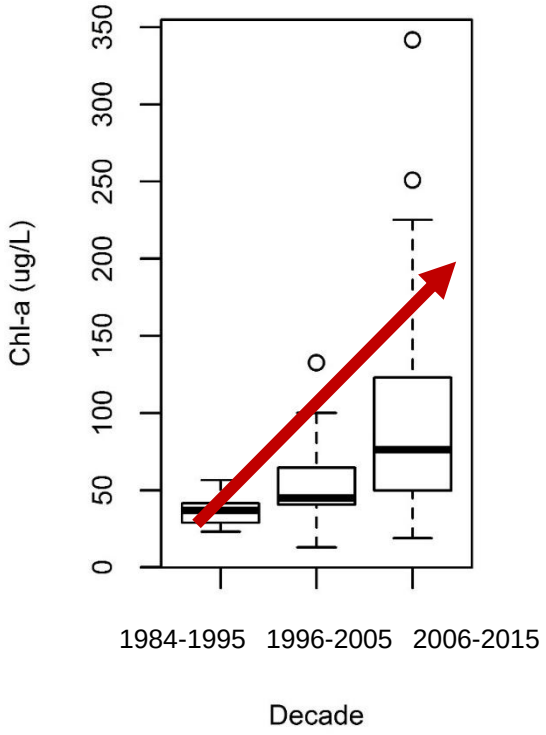
Summers becoming more hypereutrophic

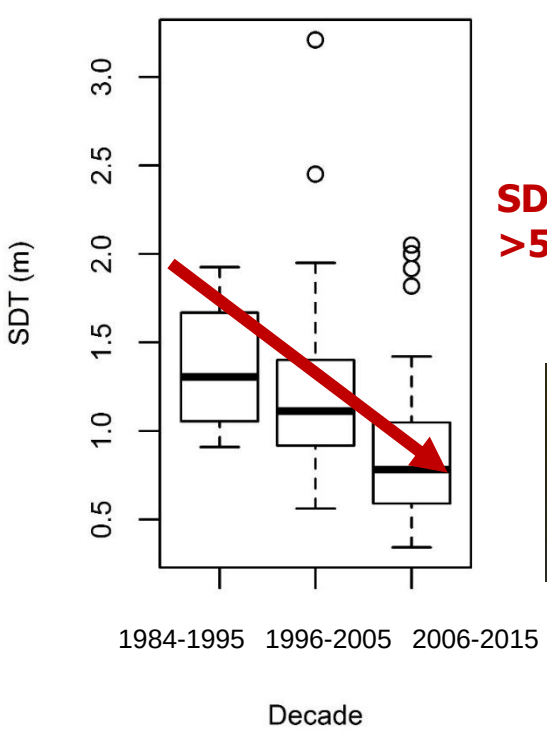
$$\mathbf{TSI(Chl-a)} = 10 * \left[6 - \left(\frac{2.04 - 0.68 * ln(Chl-a_{pred})}{ln(2)}\right)\right]$$

Hindcasting Results

- **Eutrophication** has been a problem for 3 decades in Qaraoun, and has significantly increased in severity in the last decade
  - Increased pollution in basin post civil war
  - Increased occurrence of cyanobacterial blooms

Chl-a (µg/L) increased > 163%



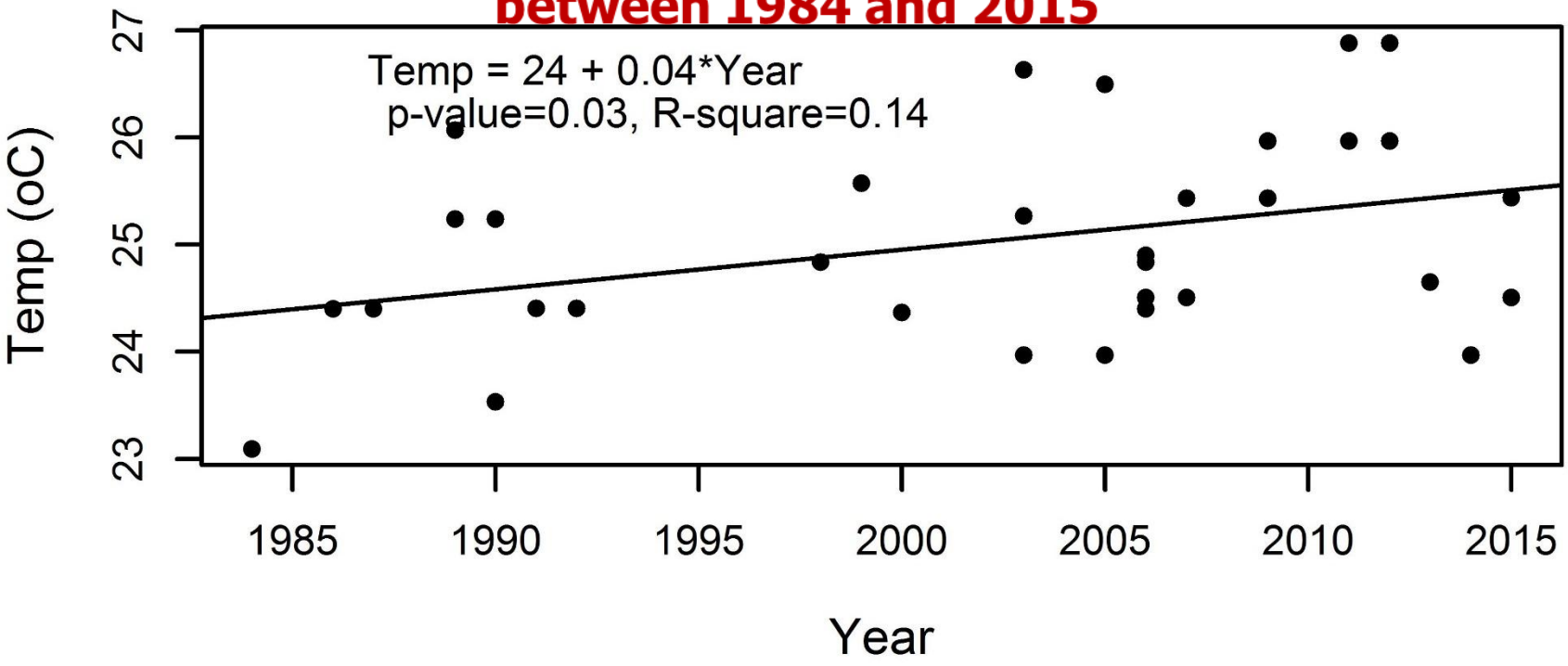


SDD (m) decreased >58%

Hindcasting Results

- Summer **temperatures** are increasing, with ecological consequences for the reservoir
  - Algae growth dynamics
  - Internal nutrient release

August temperature increased 1.24°C between 1984 and 2015



Environ Monit Assess (2018) 190: 141
https://doi.org/10.1007/s10661-018-6506-9

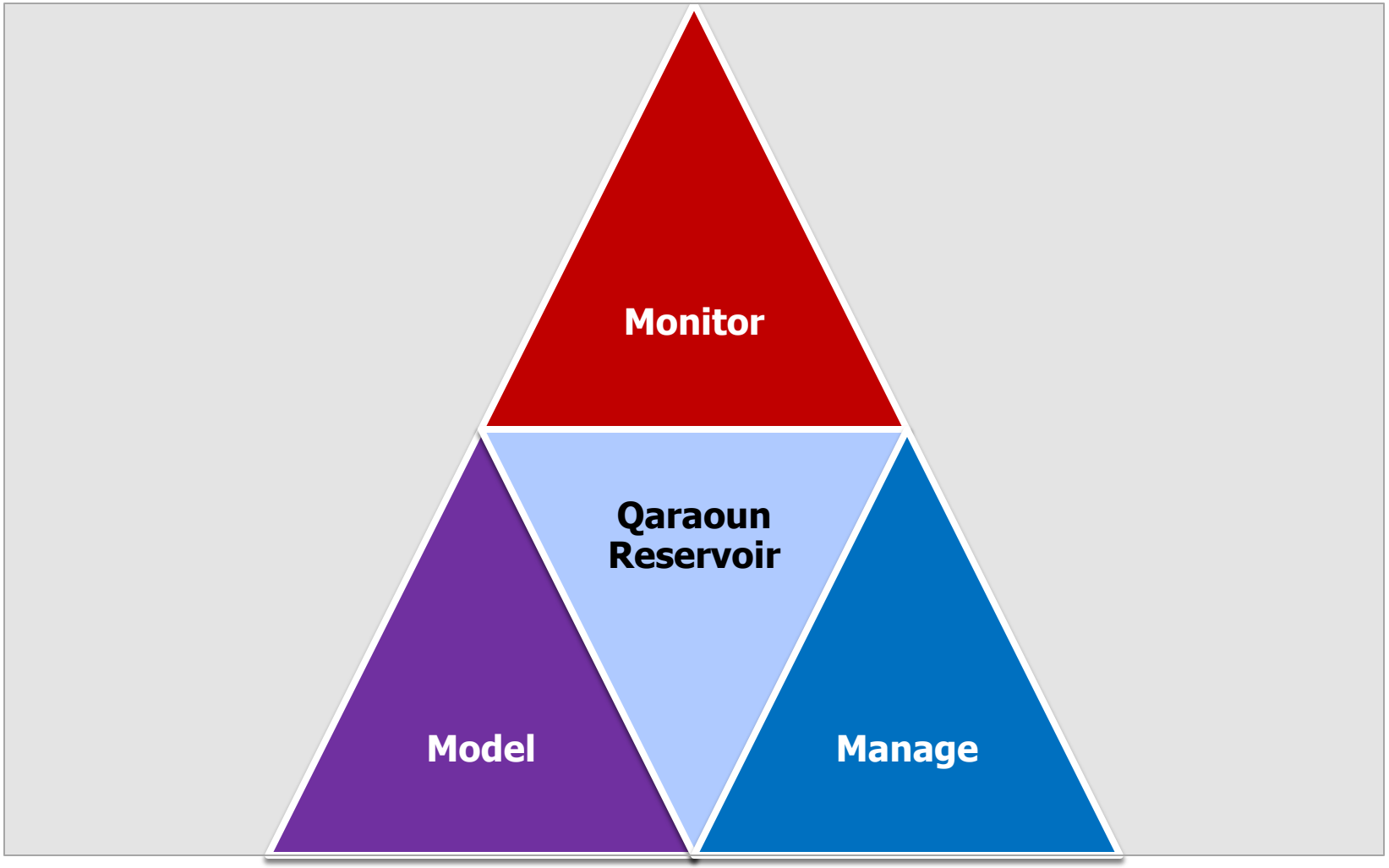
Monitoring water quality in a hypereutrophic reservoir using Landsat ETM+ and OLI sensors: how transferable are the water quality algorithms?

Eliza S. Deutsch · Ibrahim Alameddine · Mutasem El-Fadel

Hindcasting eutrophication and changes in temperature and storage volume in a semi-arid reservoir: a multi-decadal Landsat-based assessment

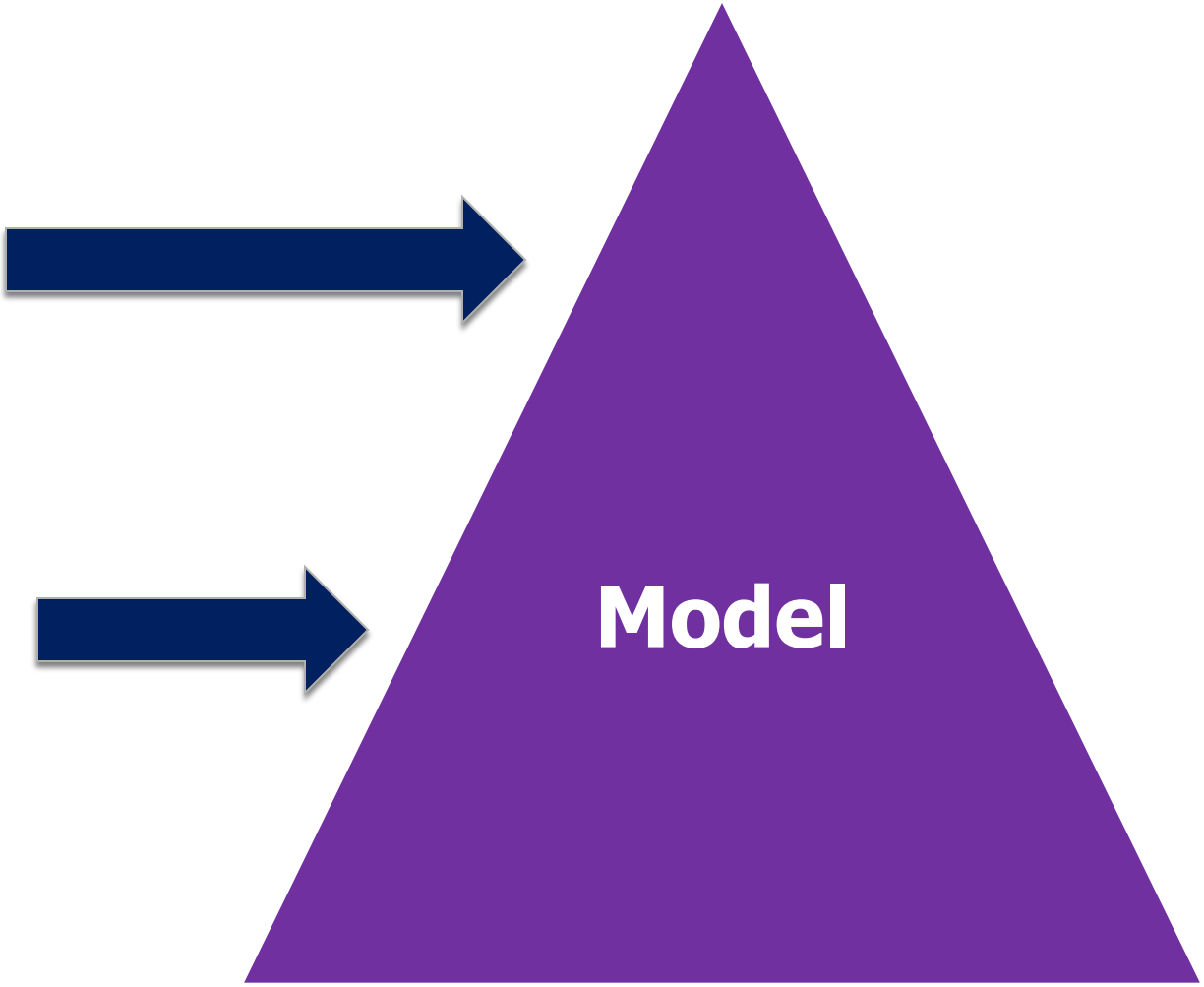
Eliza S. Deutsch · Ibrahim Alameddine

All models are wrong but some are useful



Assess relationship between algae community and reservoir environment

Model drivers of high algae biovolume (temperature vs nutrient effects)

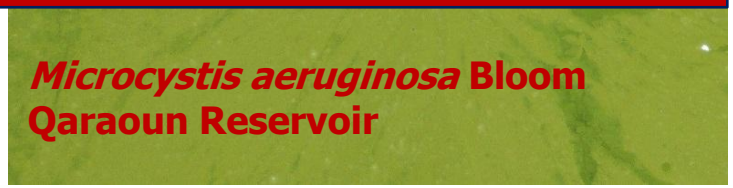


Microcystis

Major player in Qaraoun Reservoir algae community/ eutrophication outcome
Main source of MC-LR toxin in the lake

What drives *Microcystis* blooms?

Microcystis aeruginosa



***Microcystis aeruginosa* Bloom Qaraoun Reservoir**

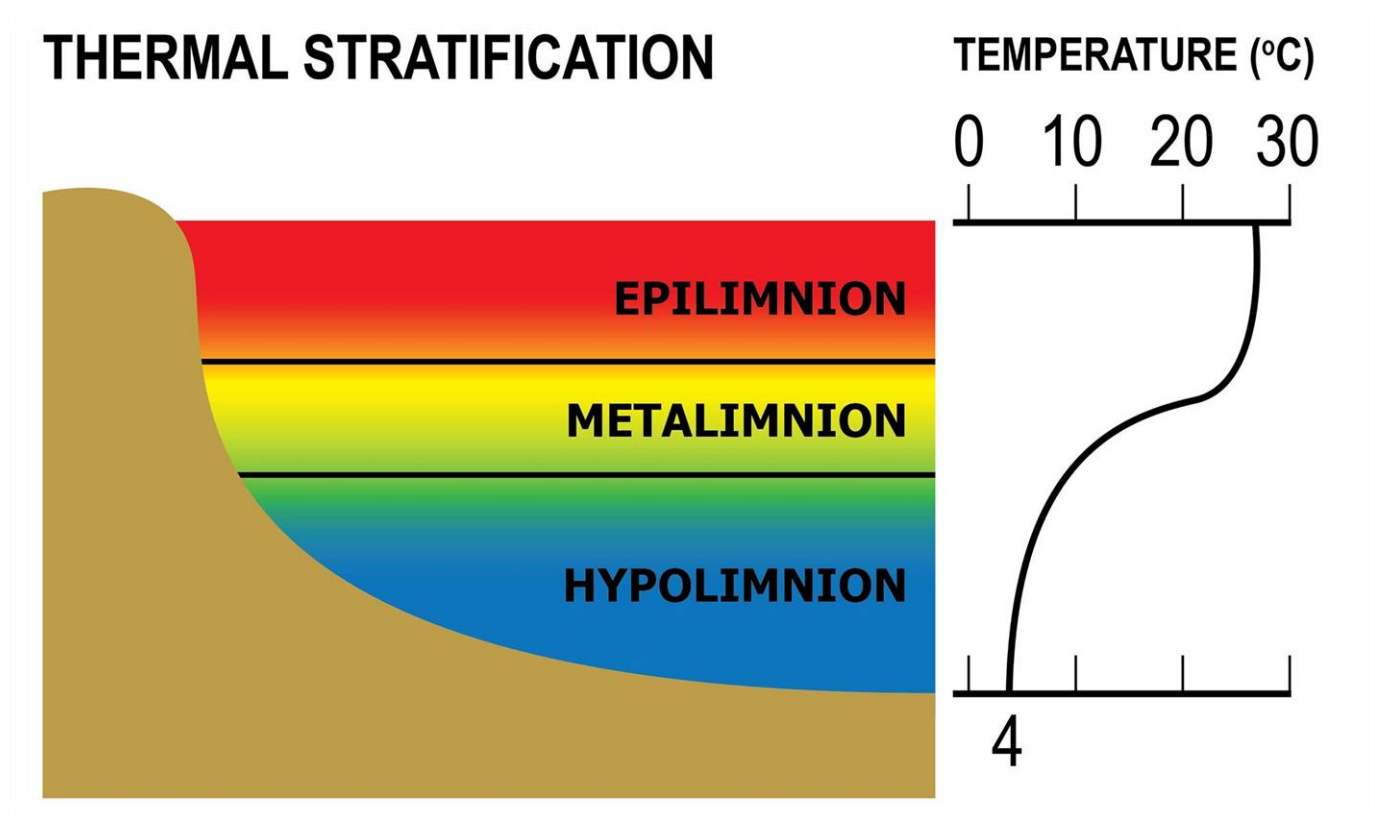
Modeling Approach

- Developed a **Structural Equation Model (SEM)** of the lake:
  - Tests theoretical/ hypothesized relationships between variables
  - Accounts for direct and indirect pathways between variables
  - Very effective in defining causal relationships in complex systems
  - Able to generate predictions

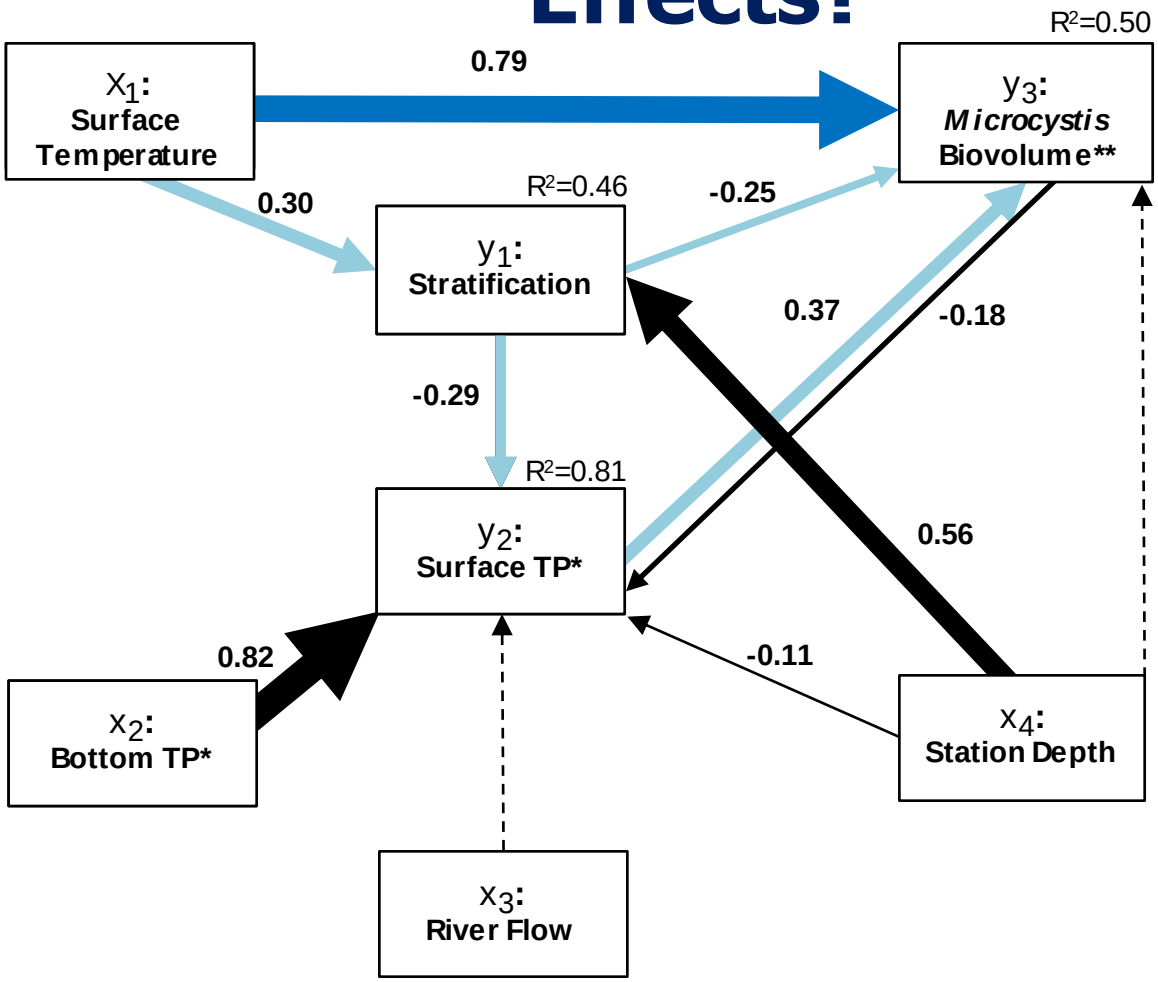
- ***A priori* method**: Develop conceptual model and test it against covariance structure in the data
  - Model fit by minimizing difference between model-predicted covariances and data implied covariances (Maximum Likelihood Estimator)

Wanted a model to address 3 fundamental questions about eutrophication dynamics

Question 1:
Direct vs Indirect Temperature Effects?



Question 1: Direct vs Indirect Temperature Effects?



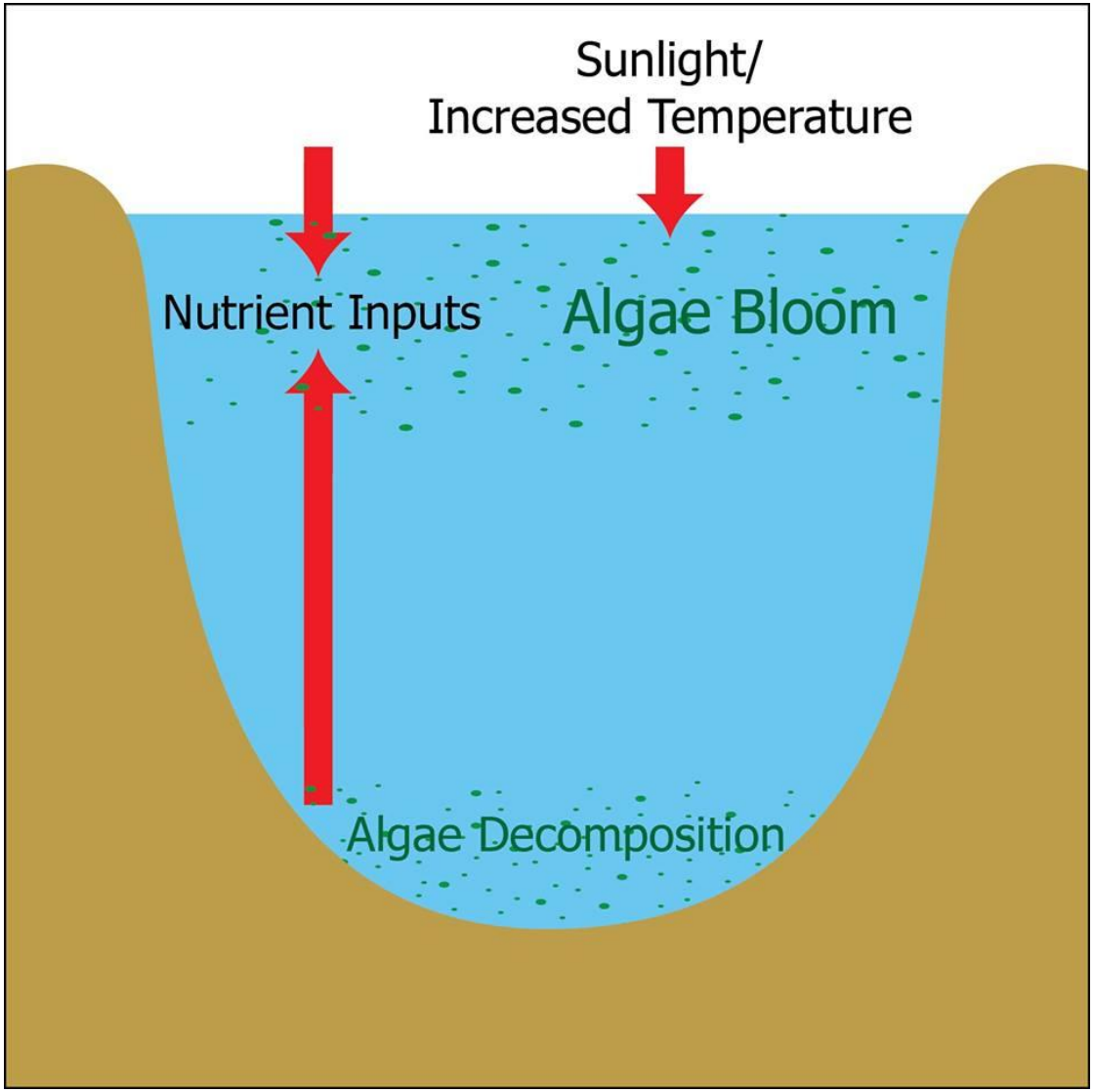
x8

Direct:
= **0.79**

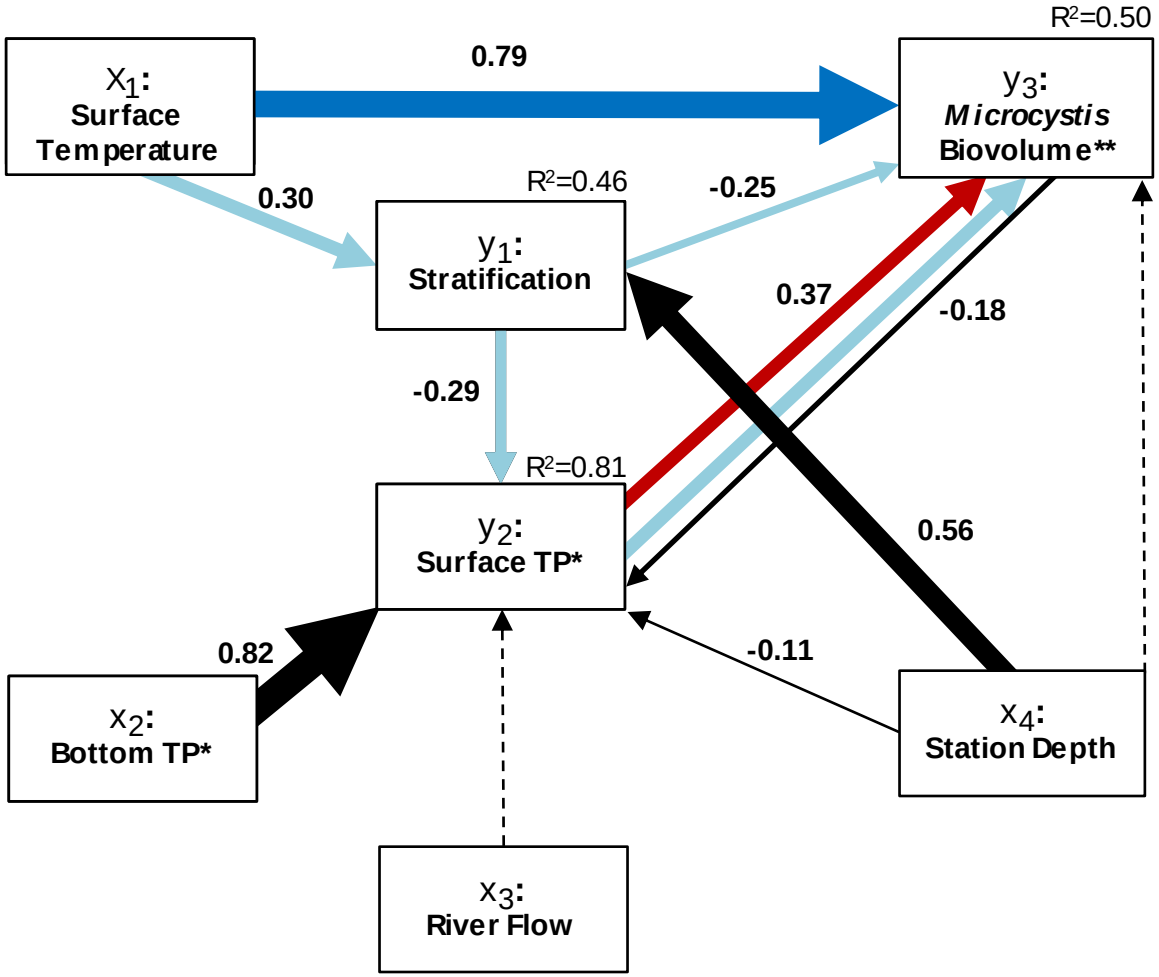
Indirect:
(0.30*-0.25) +
(0.30*-0.29*0.37)
= **-0.11**

Direct temperature effects major promoter of *Microcystis* biovolume in Qaraoun
Indirect temperature effects (stratification) hinder *Microcystis* growth by limiting **nutrient** access and inducing **light** limitation

Question 2:
Temperature vs. Nutrients?



Question 2: Temperature vs. Nutrients?



x2

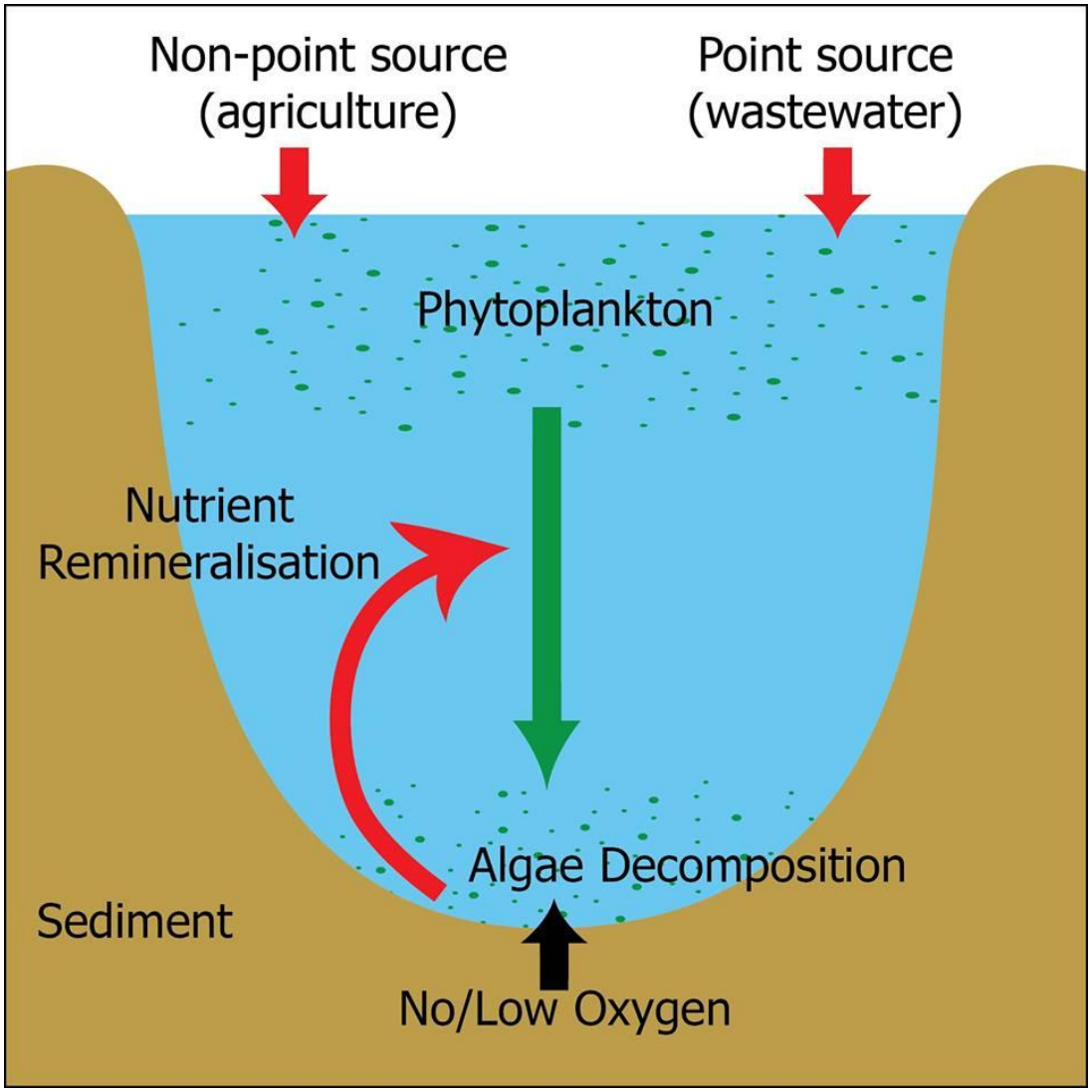
Temperature:
(0.79 -0.11)
= **0.68**

Nutrients:
= **0.37**

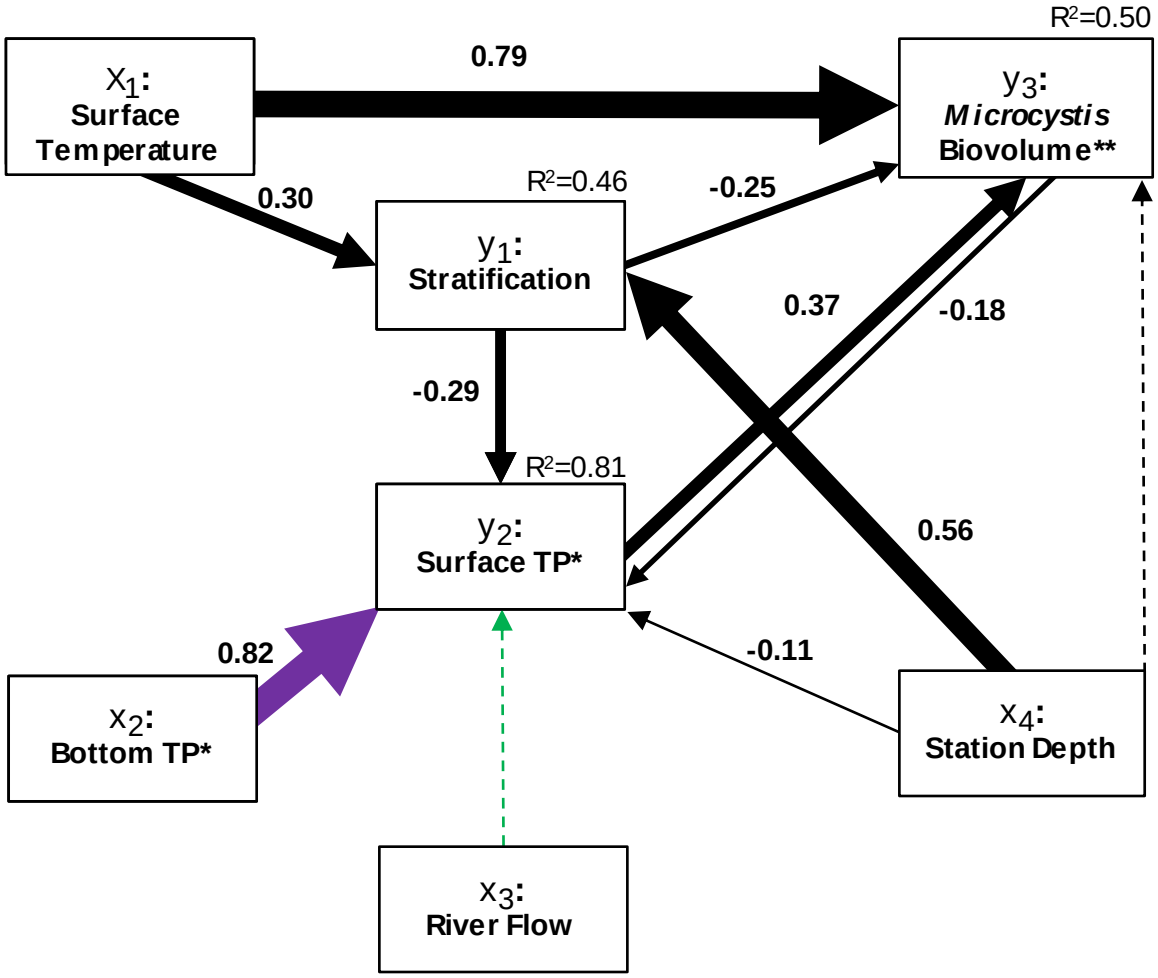
Nutrient to *Microcystis* pathway weaker than expected

- Reservoir hypereutrophic
- *Microcystis* strong competitors for nutrients

Question 3:
Internal vs. External Loads?



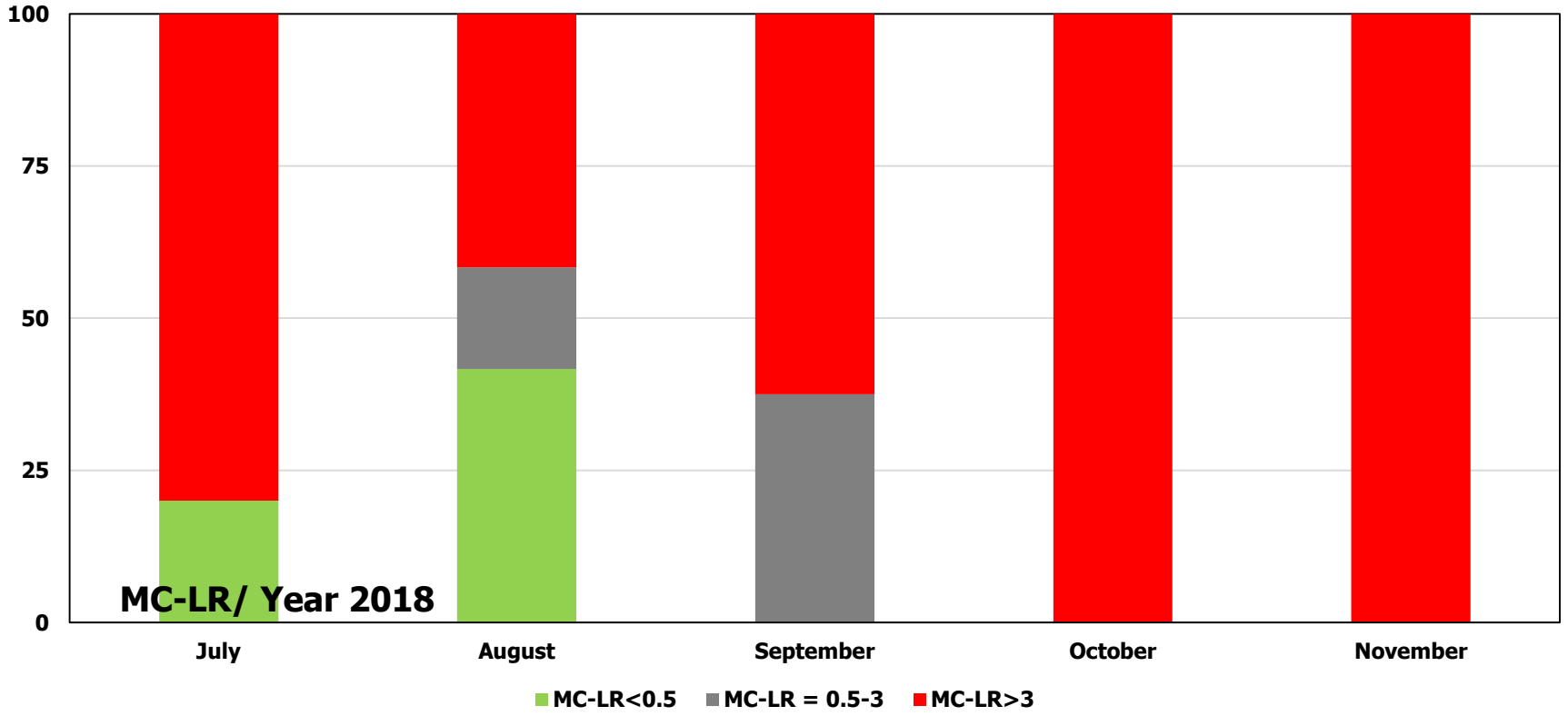
Question 3:
Internal vs. External Loads?



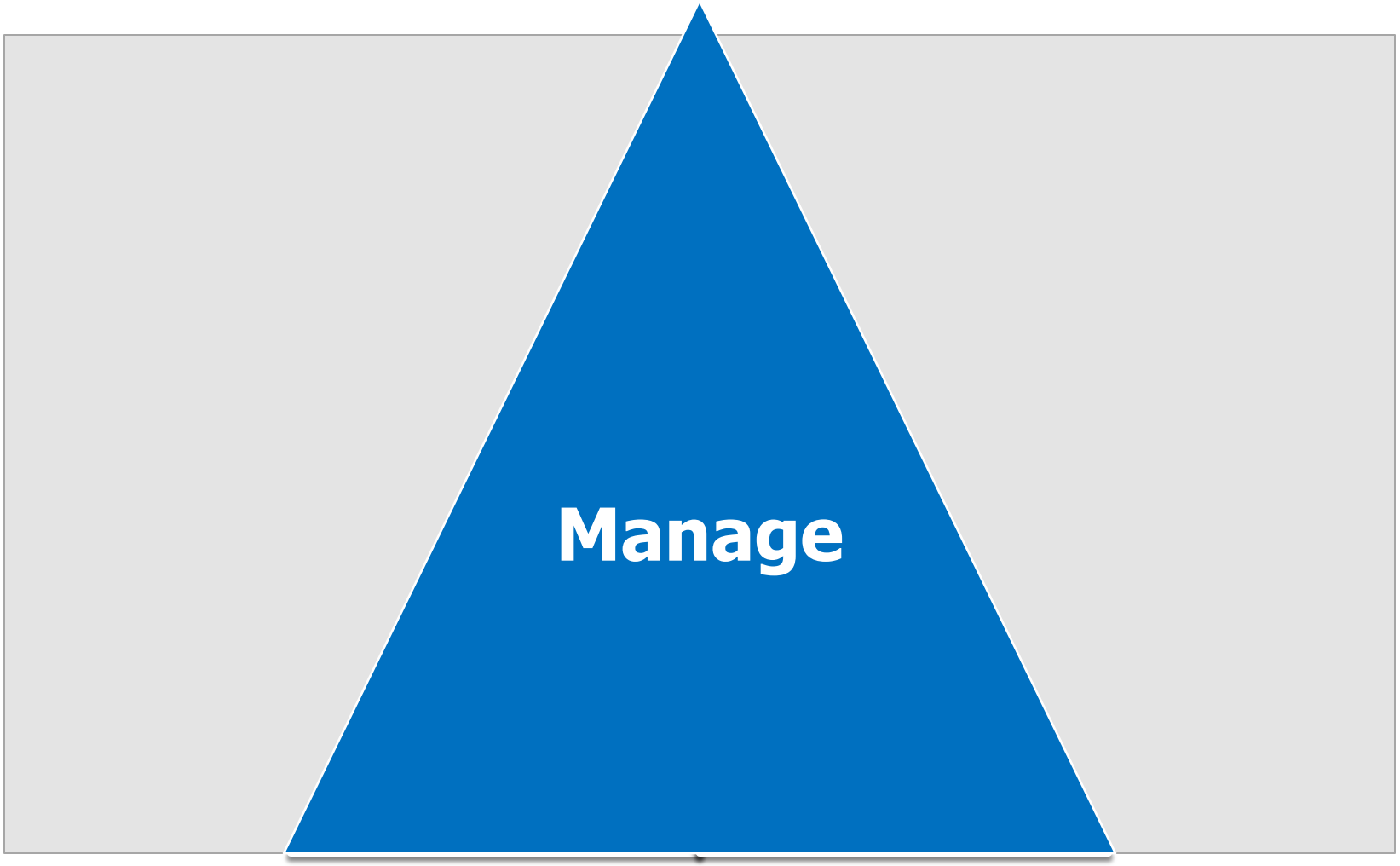
Internal loads more important than external loads for promoting summer *Microcystis* blooms

External loads during winter months significantly contributes to nutrient status & high summer internal loads

Next Question: What about toxin dynamics?

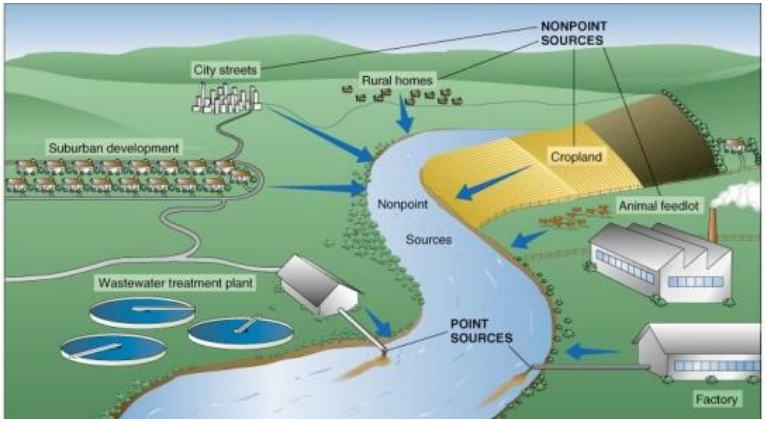


Research Framework



Load Management

- **Point source management**
  - Effective construction and operation of **wastewater treatment facilities**
  - Stronger **regulation** and **enforcement** of wastewater treatment
- **Non-point source management**
  - Assessment of **land-uses** and **soil types** in watershed
  - **Farmer education** programs
  - Enforced regulation of **fertilizer** and **pesticide** applications
  - Treatment programs for **domestic animal wastes**
- **Dredging**
  - Mechanical removal of sediment from lake bottom
- **Chemical precipitation of nutrients**
  - Using alums or clays
  - Locks phosphorus in sediment by forming sealed crust



Temporary Management Measures

- **Artificial mixing**
  - Air injectors
  - Centrifugal pumps
  - Propellers (mechanical de-stratification)

- **Algaecide application**
  - Copper Sulfate
  - Diquat
  - Potassium Permanganate
  - Hydrogen Peroxide

- **Ultrasonic treatment**
  - Emit ultrasonic waves in the 40 to 110 kHz range
  - Rupture cyanobacterial gas vacuoles ➔ sink

Acknowledgements

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Dania Hamzeh
Ayda Nawam

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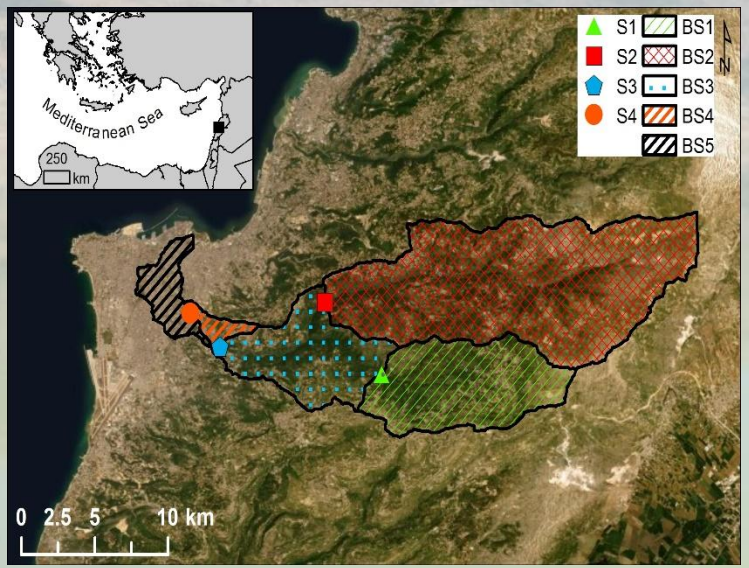

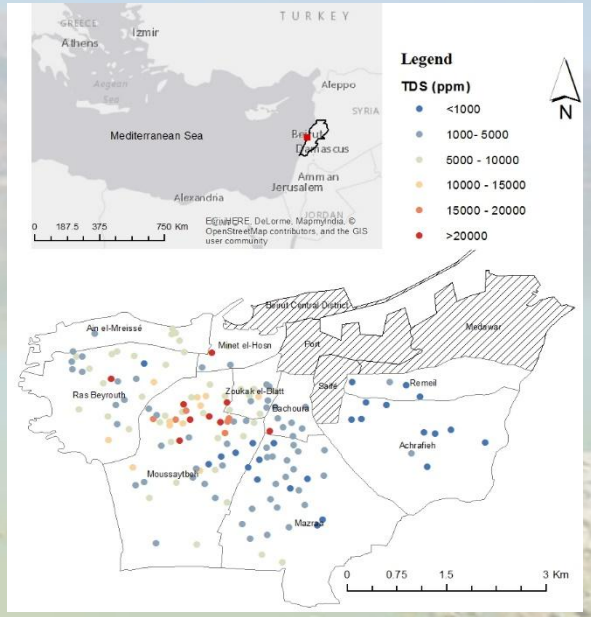

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