

An aerial photograph showing a series of interconnected lakes and wetlands. The landscape is a mix of brown, green, and blue, with a prominent blue text box in the lower-left quadrant. The text box contains the title and author information. The background shows a vast expanse of water and land, with a city skyline visible in the distance under a clear blue sky.

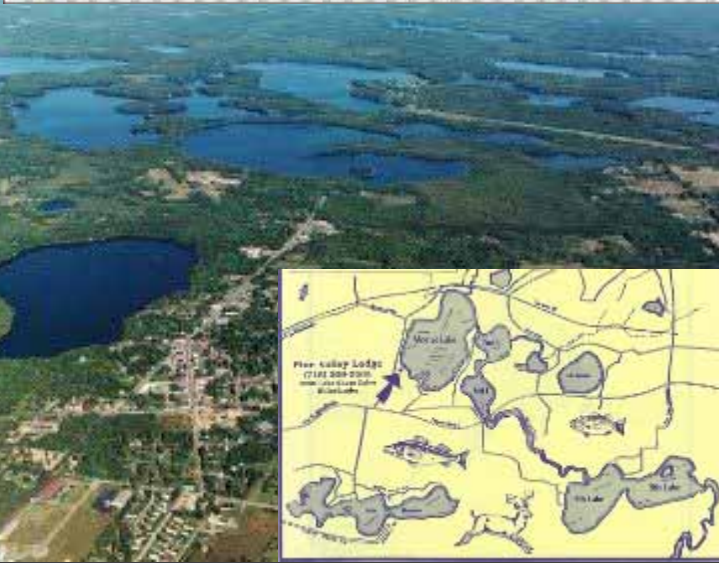
# Water Quality Management of Lakes in Series (Lake Chains)

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Photo: C. DeWitt

# Lake Chains

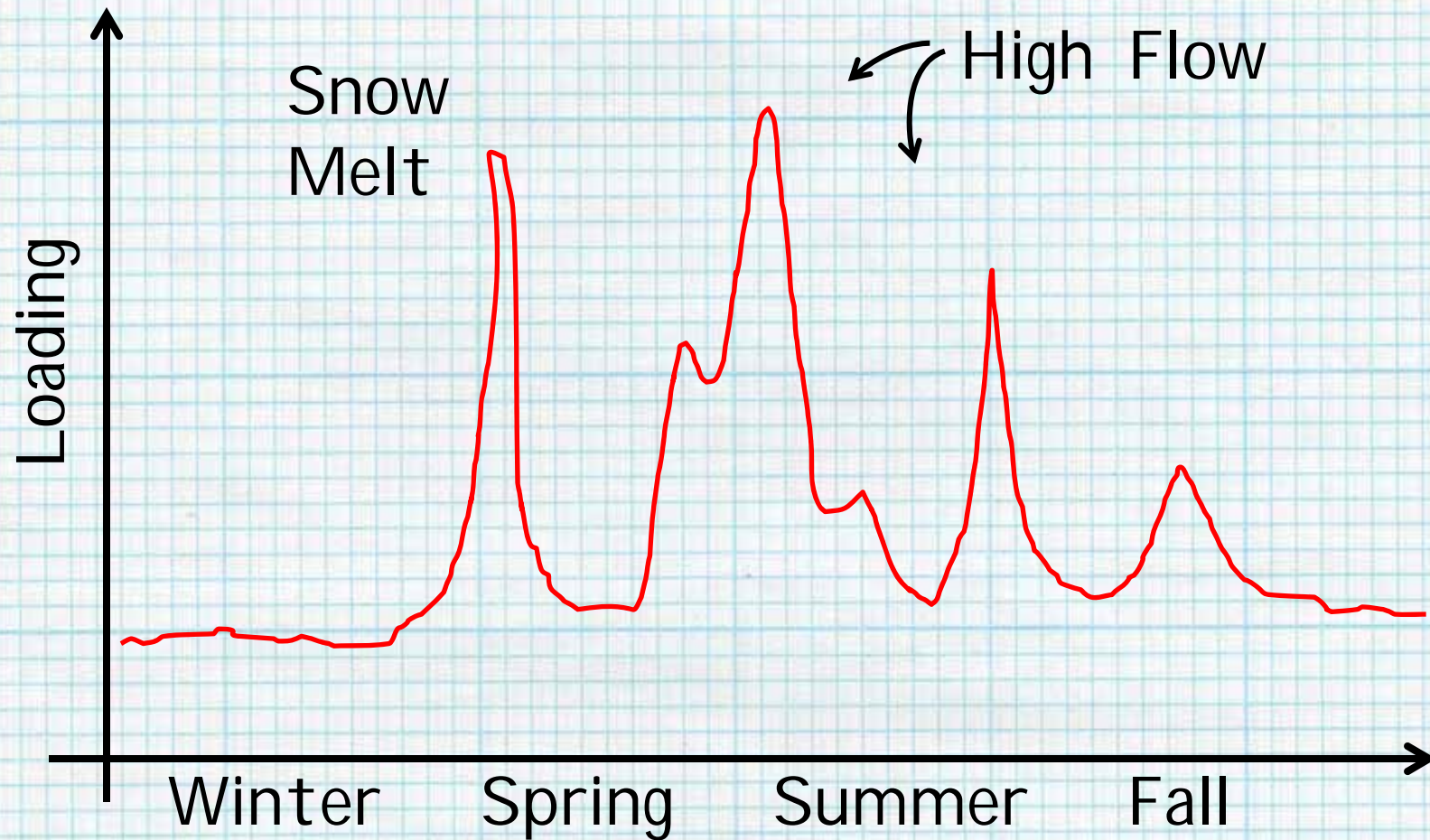


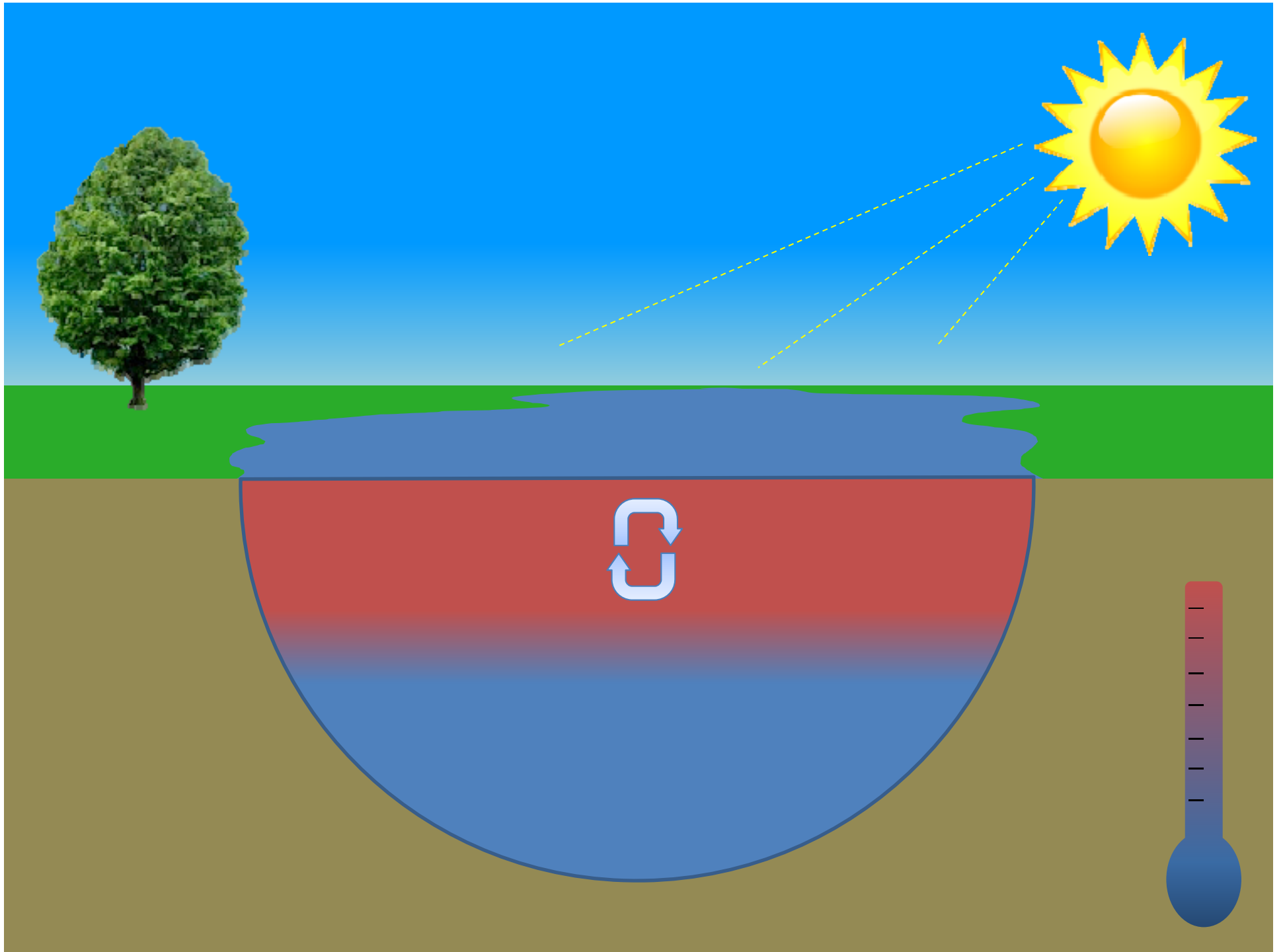
# Overview

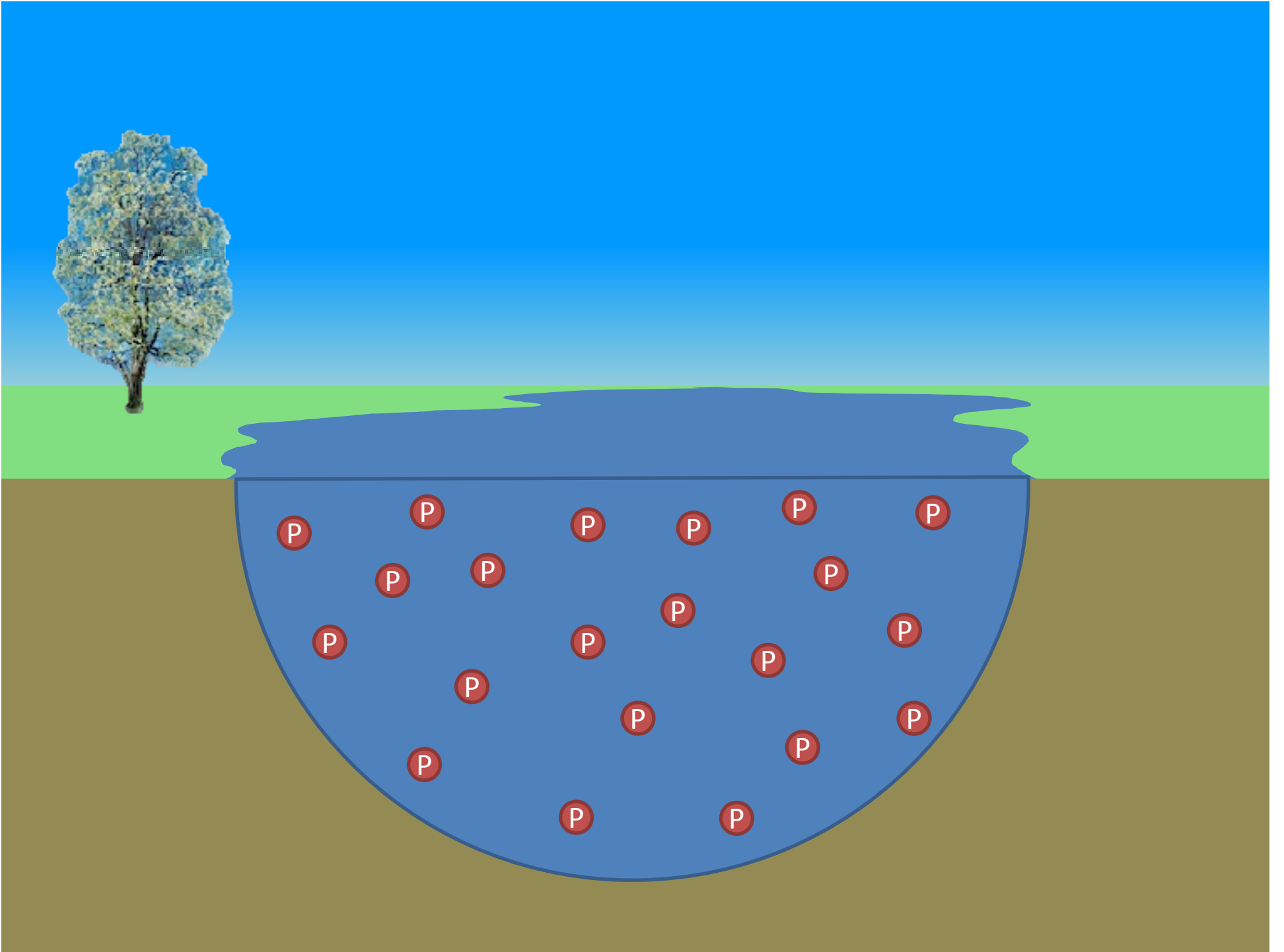
- Concepts
  - Watershed P export through the seasons
  - In-lake seasonal nutrient cycling and export
  - Lake flushing rates
- Combining these concepts and applying to lake chains
  - Example: Yahara Lakes Phosphorus

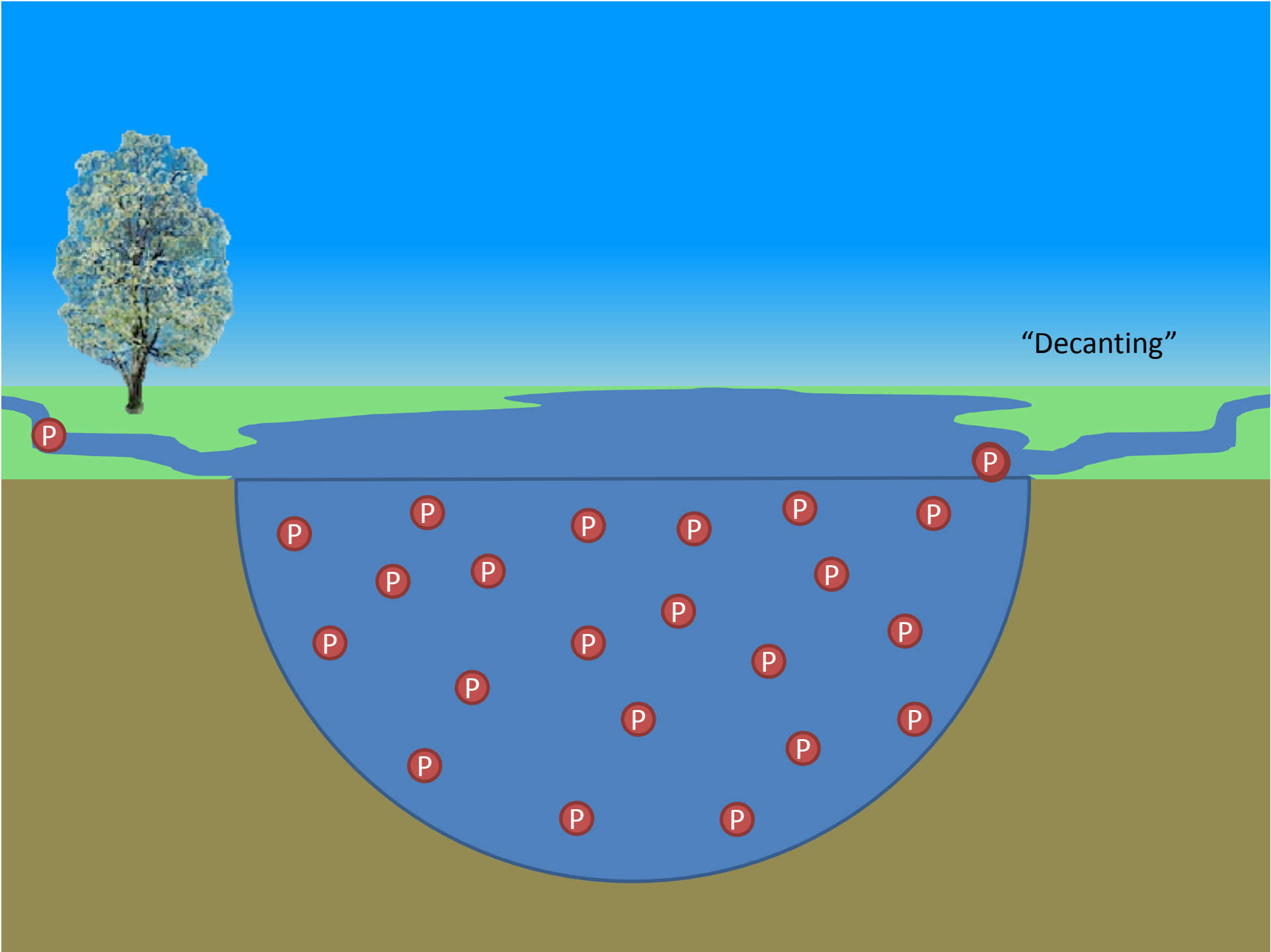


# Seasonal Phosphorus Loading (from watershed)









"Decanting"

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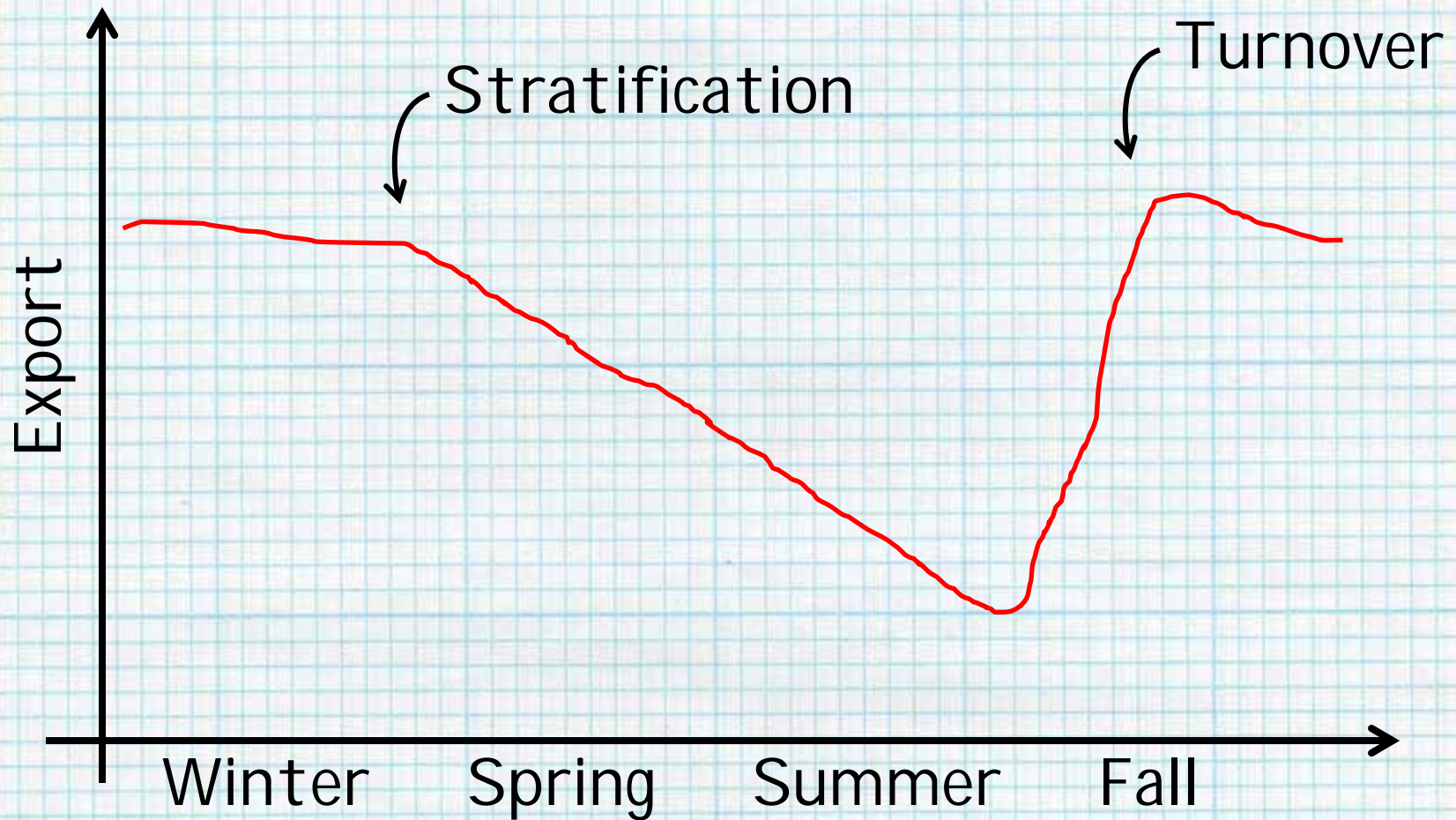
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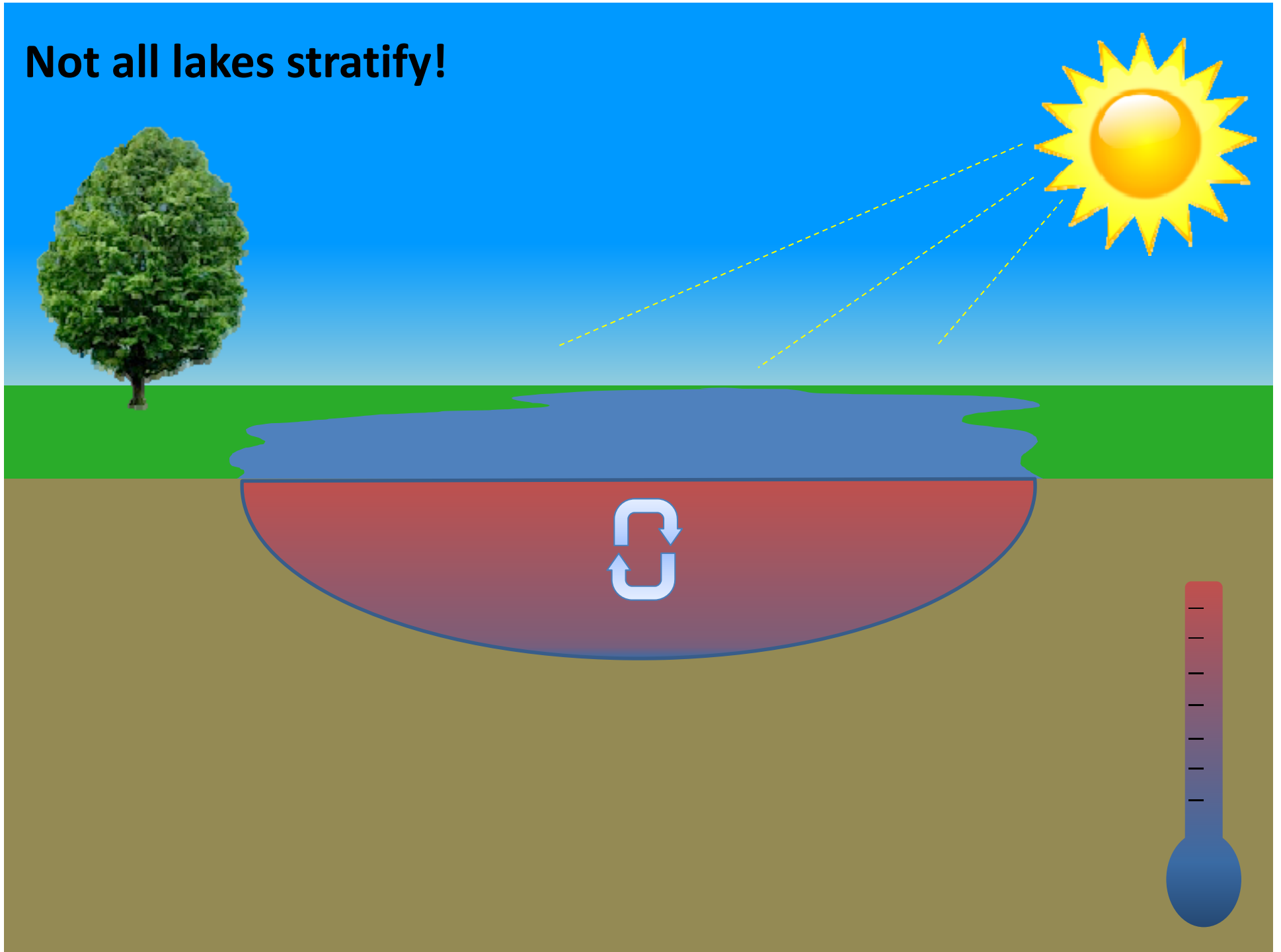


# Seasonal Phosphorus Export

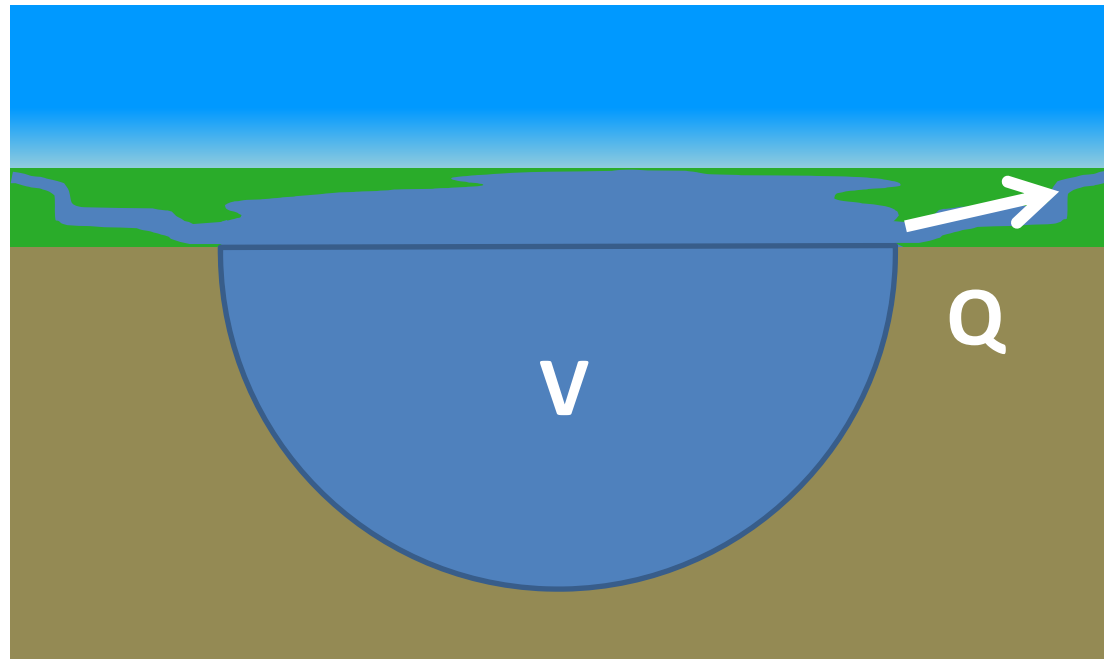
(from stratified lake)



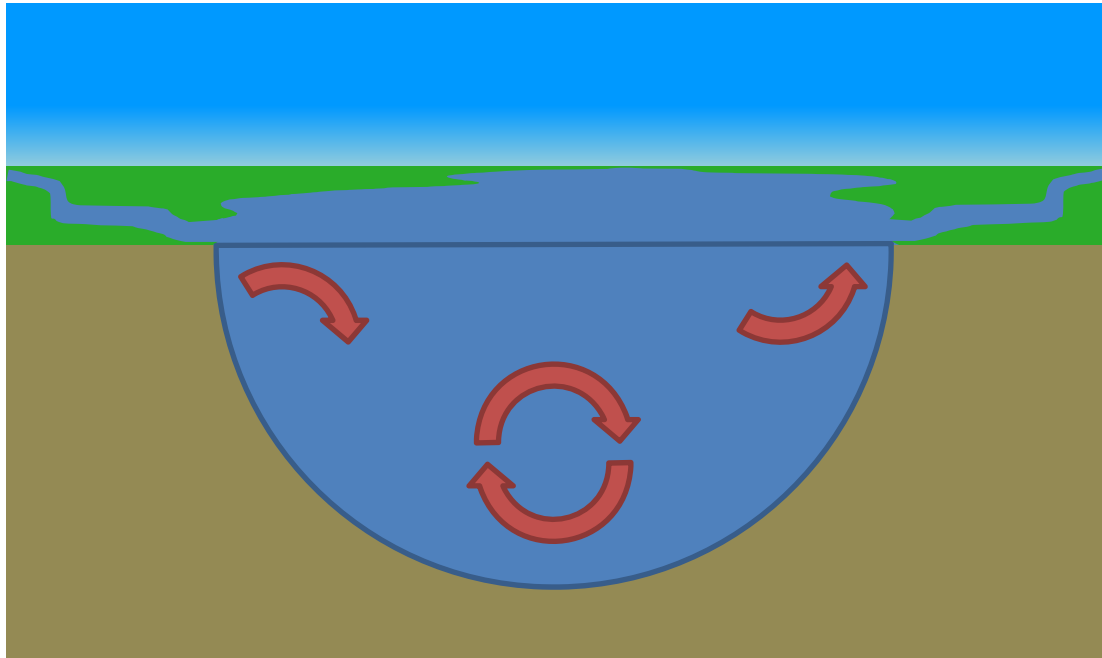
**Not all lakes stratify!**



# Water (hydraulic) retention time

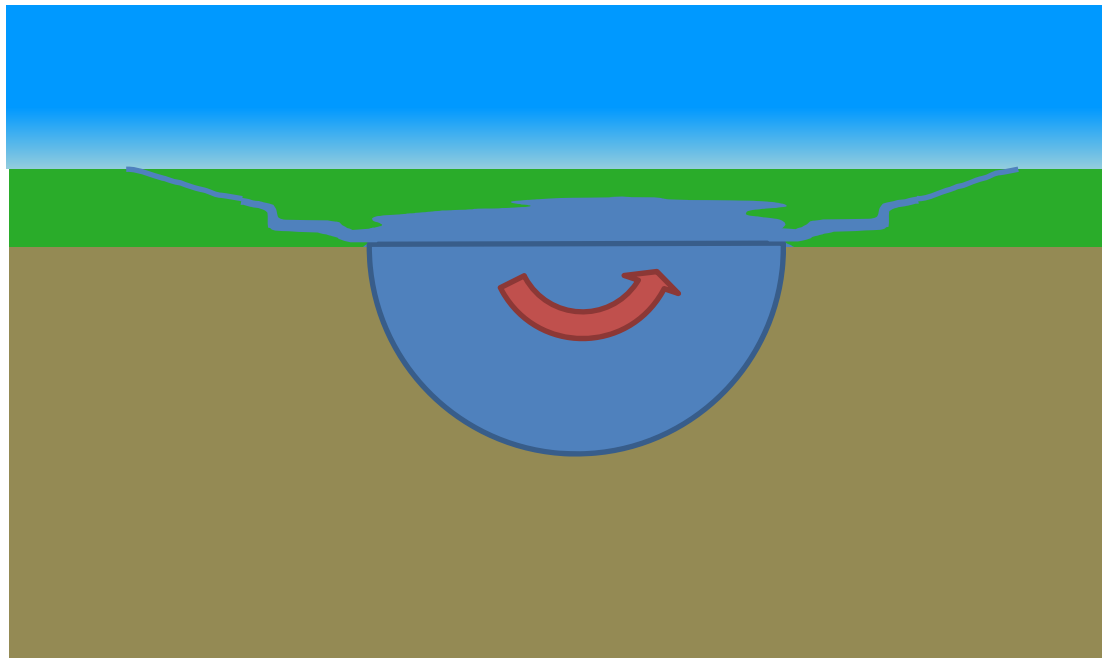


$$\tau = \frac{\text{Volume}}{\text{Outflow}} = \frac{V}{Q}$$



### Slow-flushing Lakes

- Longer Phosphorus Residence
- Longer “Memory” of Loading



### Fast-flushing Lakes

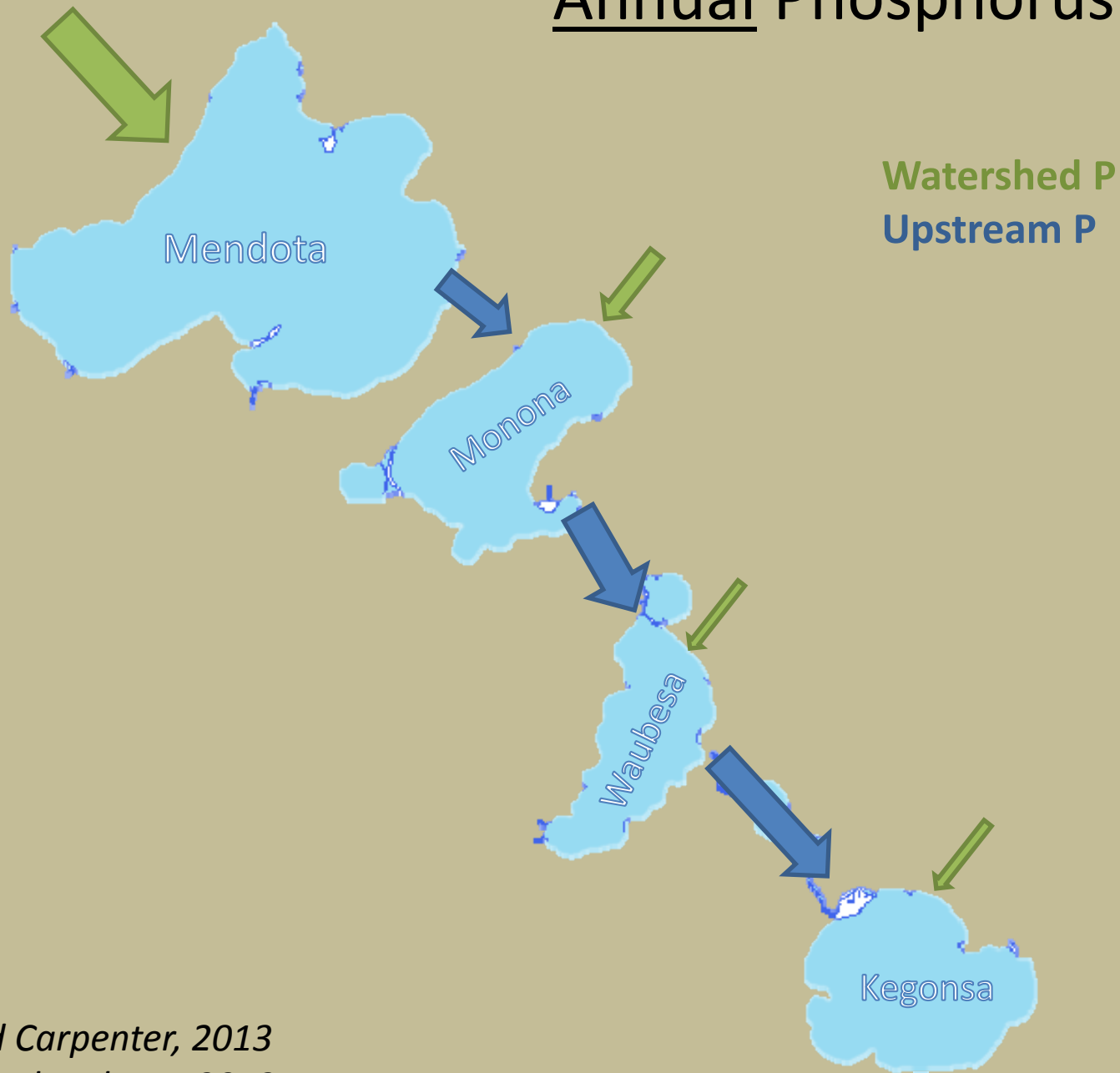
- Shorter Phosphorus Residence
- Shorter “Memory” of Loading

# Yahara Lakes, Dane County

- Chain of 4 main lakes along Yahara River: Mendota, Monona, Waubesa, Kegonsa
- Based on annual nutrient budgets, the uppermost watershed (Mendota) has been identified as critical source of phosphorus to chain

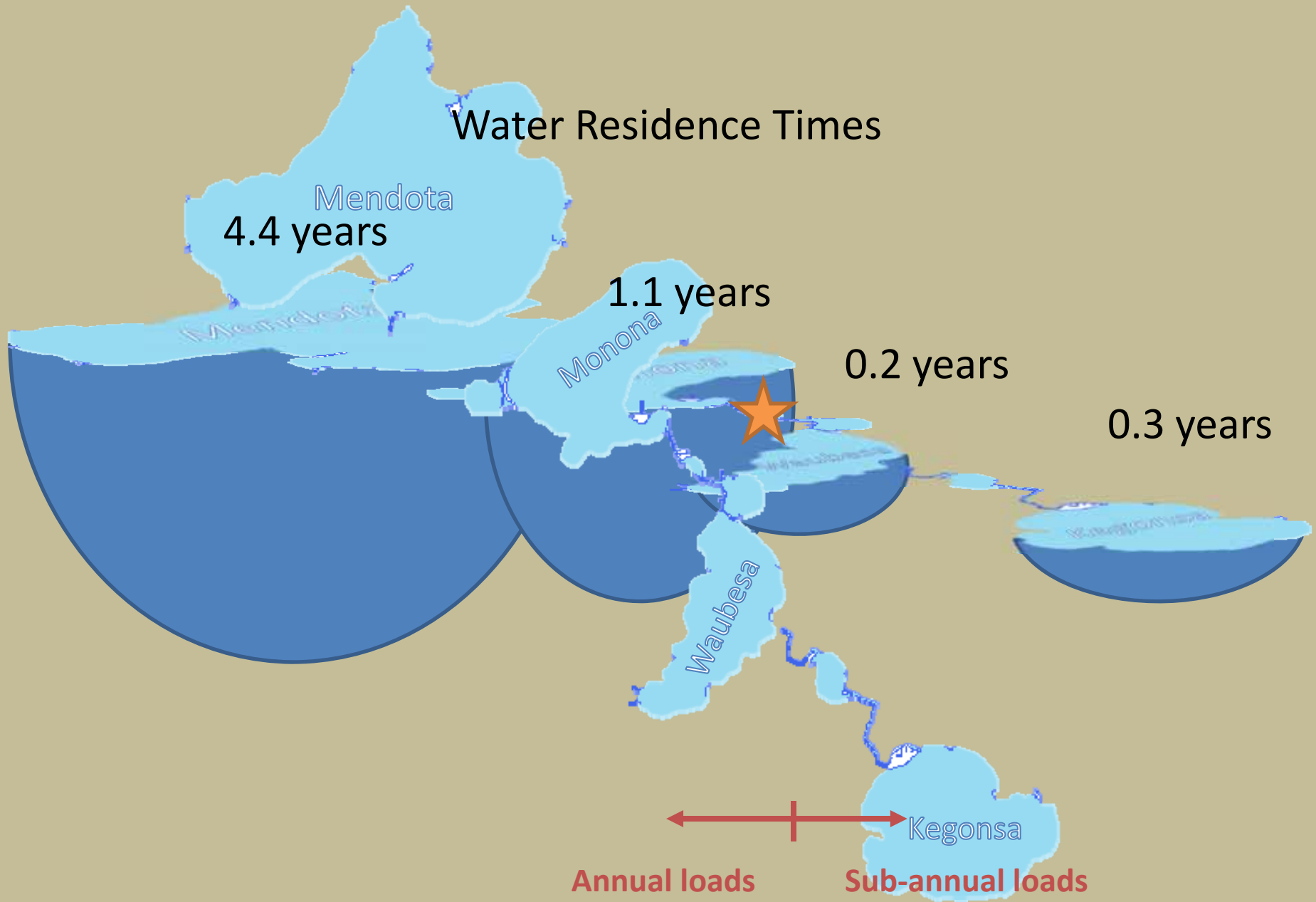


# Annual Phosphorus Budget



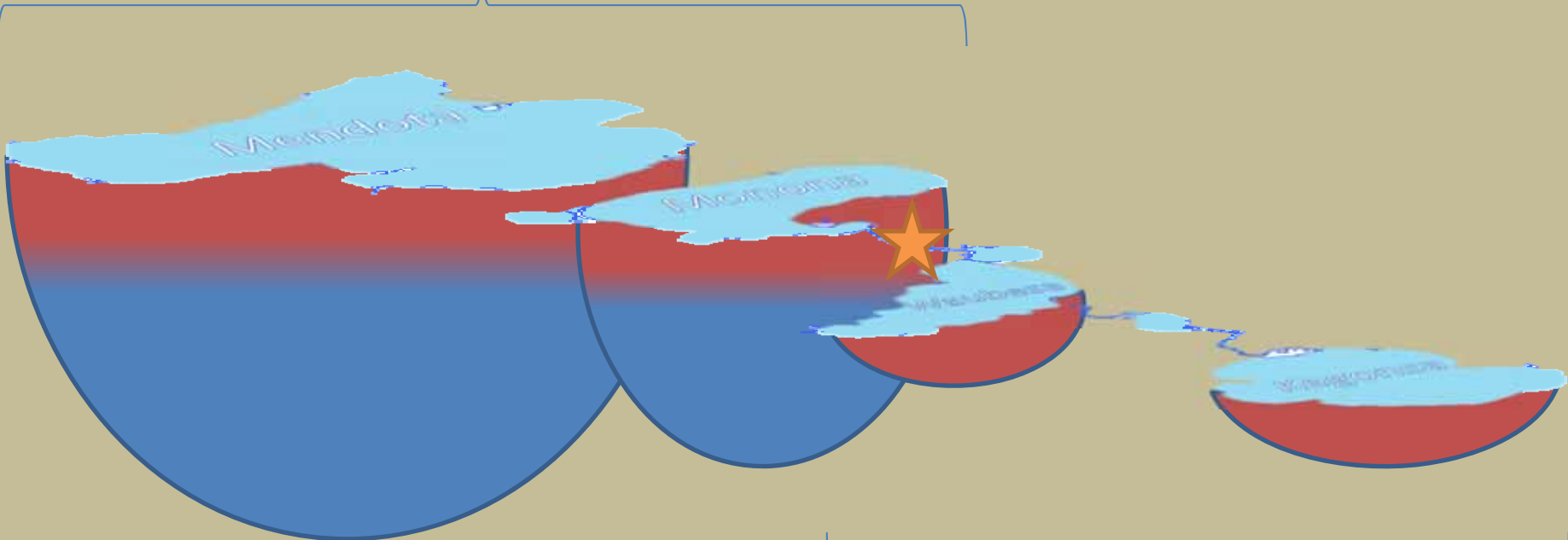
*Lathrop and Carpenter, 2013*  
*Carpenter and Lathrop, 2013*

# Water Residence Times



Summer:

Stratified



Unstratified

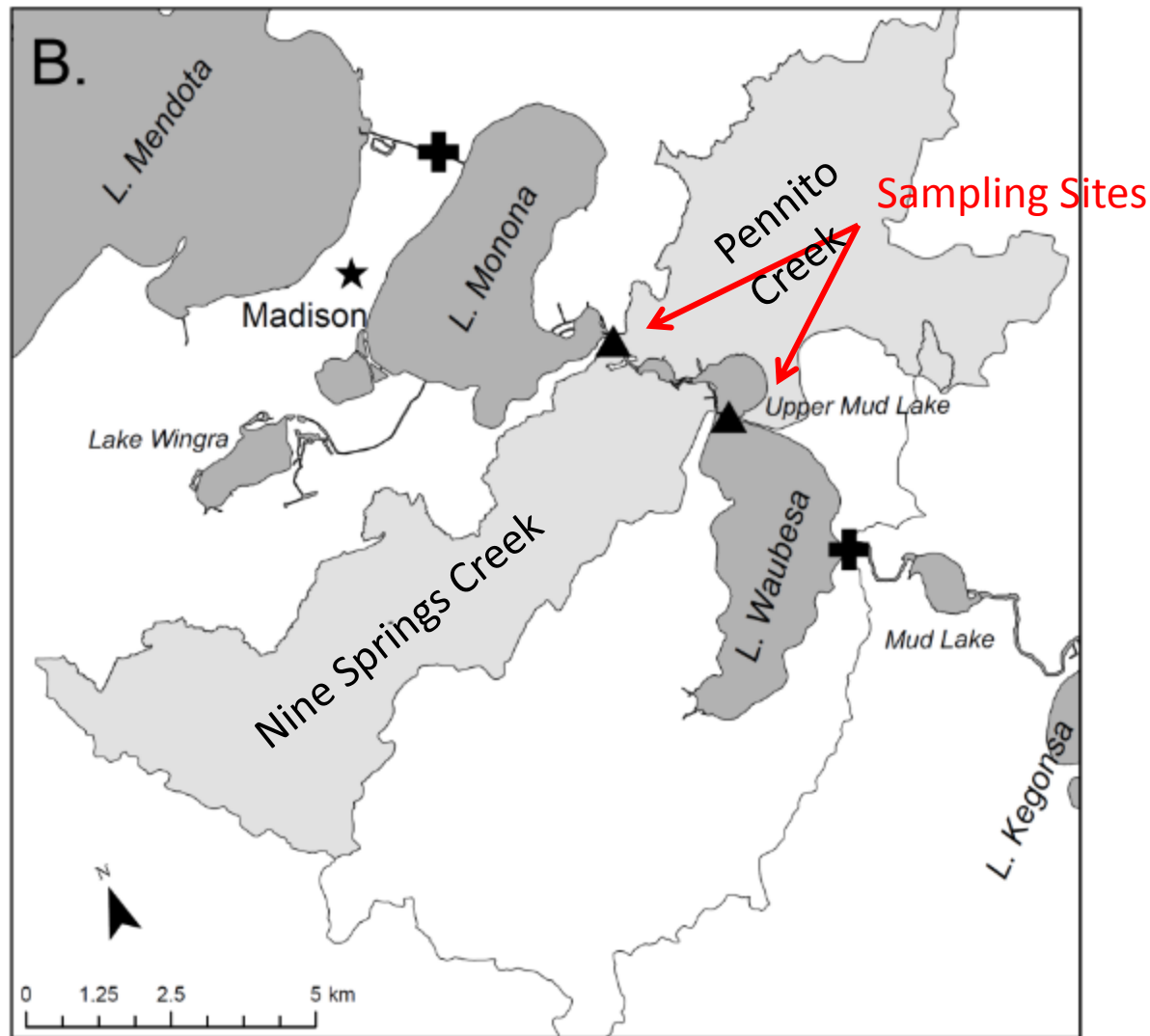


Decanting

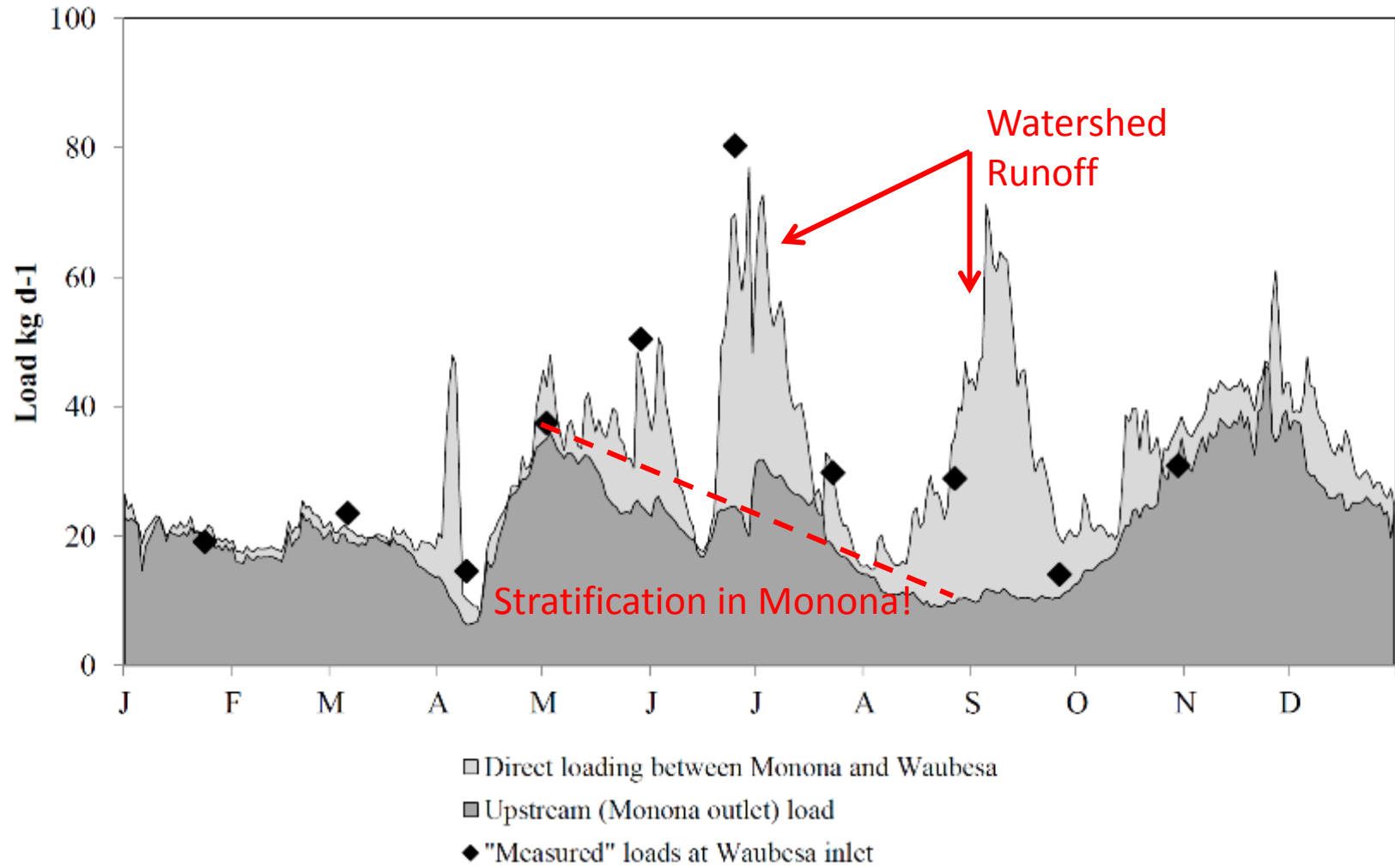
No decanting



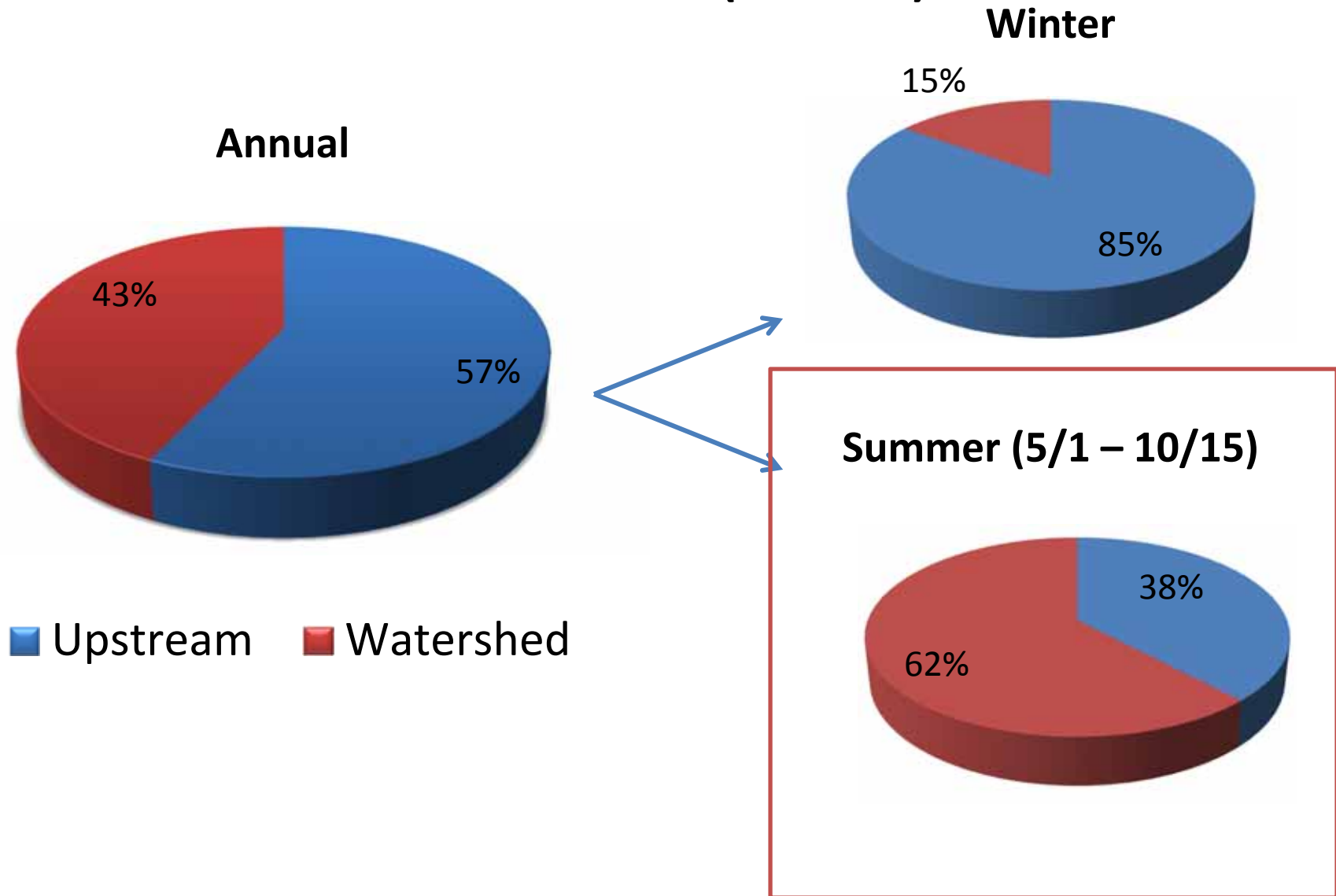
# Monona-Waubesa TP Study (2014)



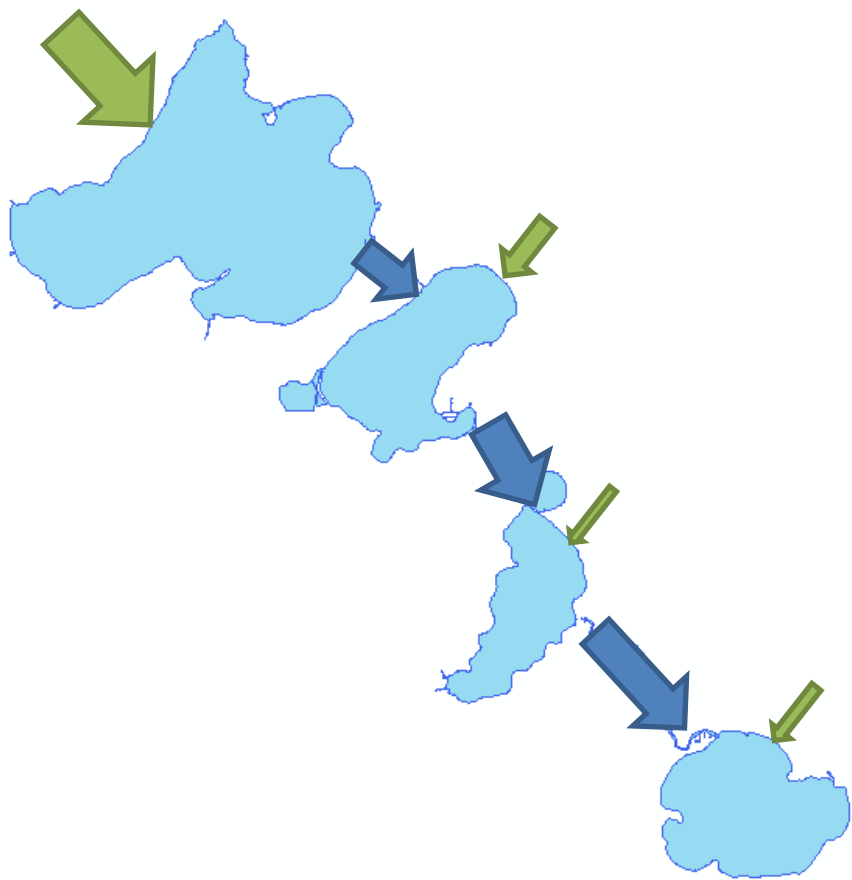
# Phosphorus Loading to L. Waubesa



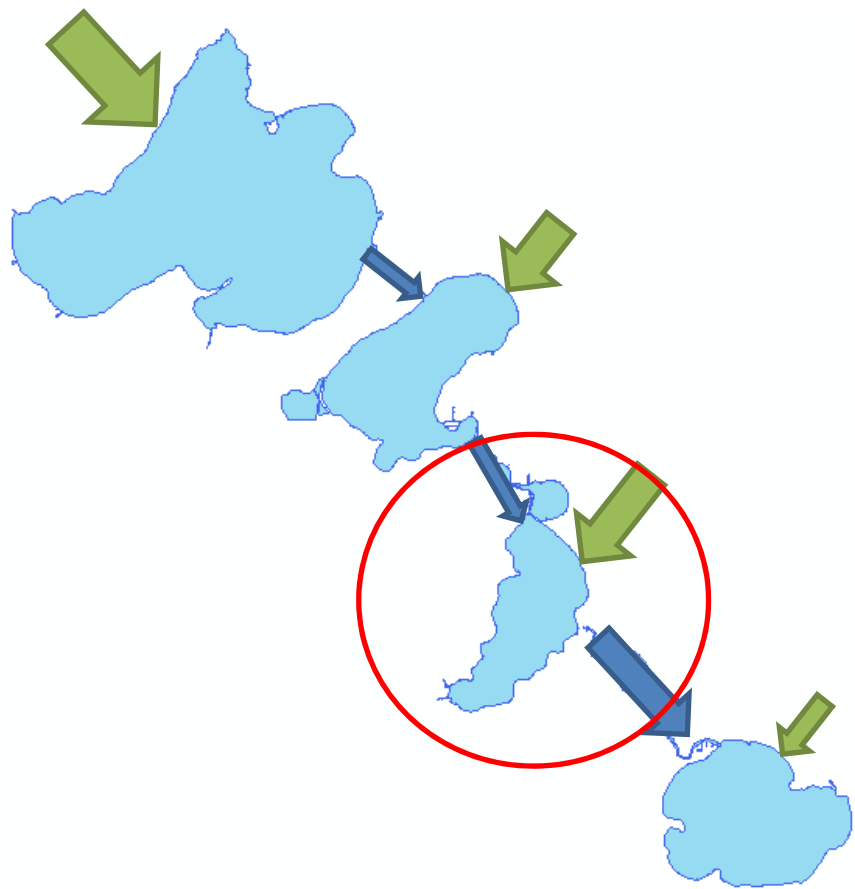
# Estimated Phosphorus Loads to Lake Waubesa (2014)



# Annual Phosphorus Budget



# Summer Phosphorus Budget



Watershed P  
Upstream P

# Summary

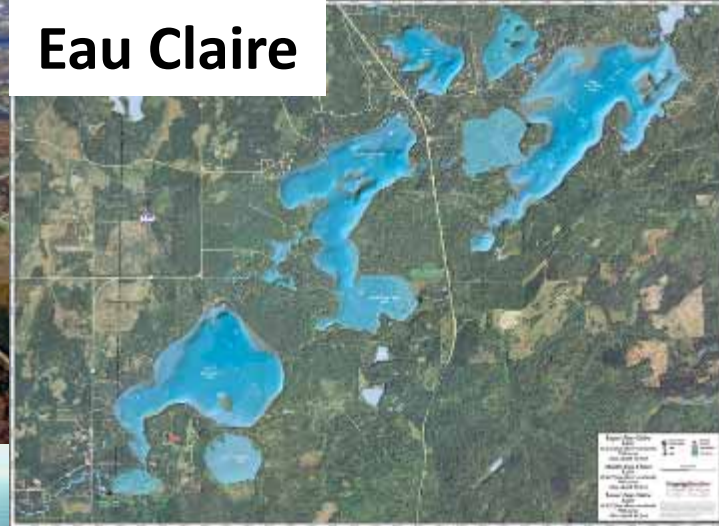
- Summer nutrient loads from local watersheds a major driver of WQ in lower Yahara Lakes
  - Despite being small part of annual load
  - Good news for WQ outlook in Waubesa/Kegonsa
- When lakes in series vary in terms of physical characteristics, watershed management approaches should consider each lake individually, as well as the whole system
  - When are the *critical* nutrient loads delivered and where are they coming from?

# Questions?

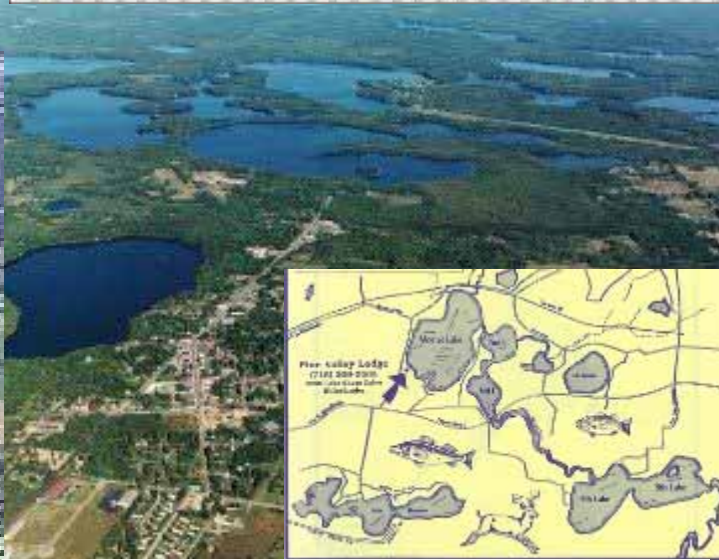
**Waupaca**



**Eau Claire**



**Chetek**



**Eagle River – Three Lakes**

**Moen**