Monitoring and Modeling Water Quality in a Pristine Northern Michigan Lake

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Outline

Consider some different approaches to managing water quality

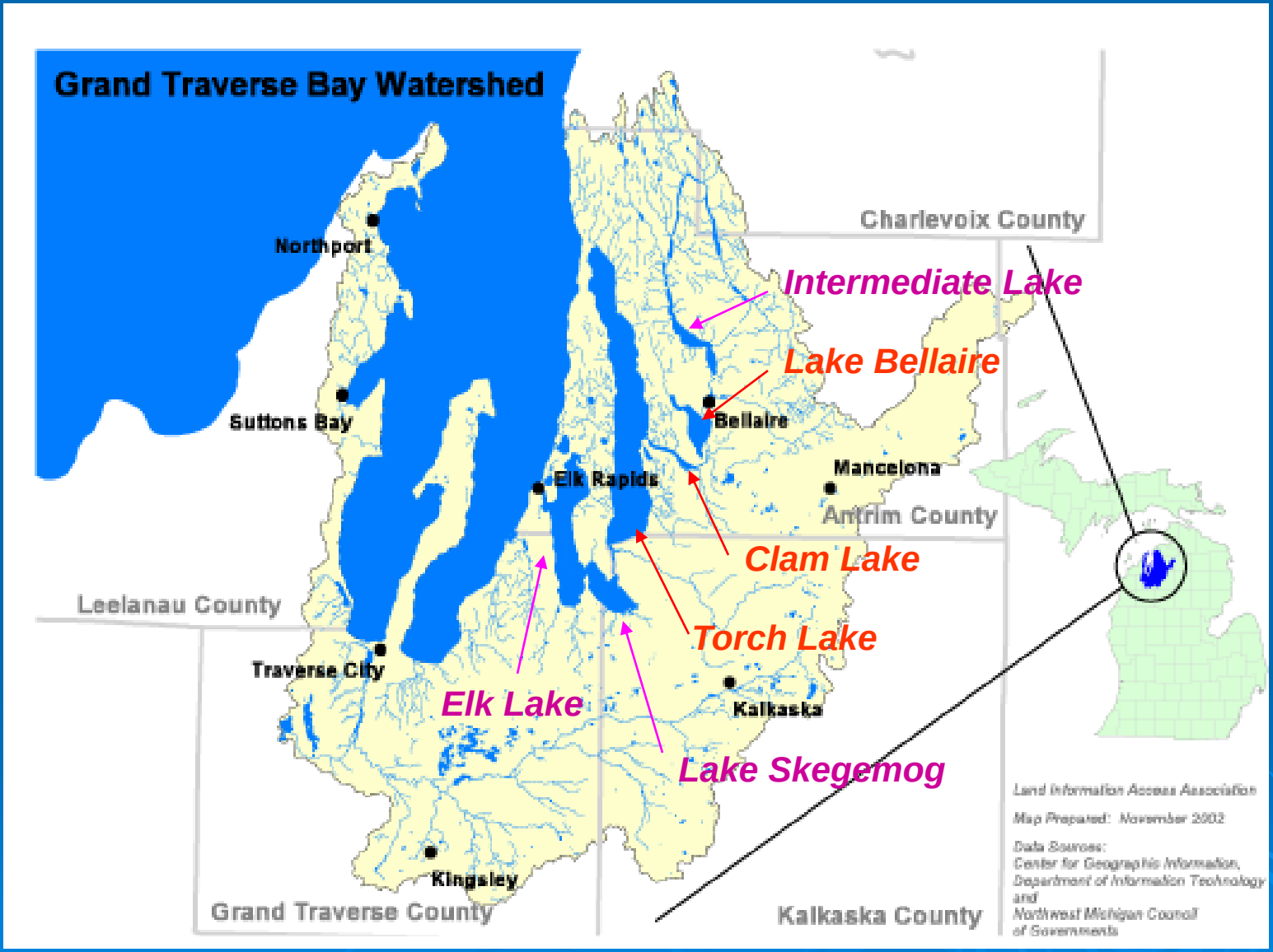
Review monitoring data for several important water quality parameters in Torch Lake

Present modeling and mass balance studies as another tool for studying water quality

Illustrate how a paradigm shift* can challenge the understanding and management of water quality

* a fundamental change in approach or underlying assumptions.

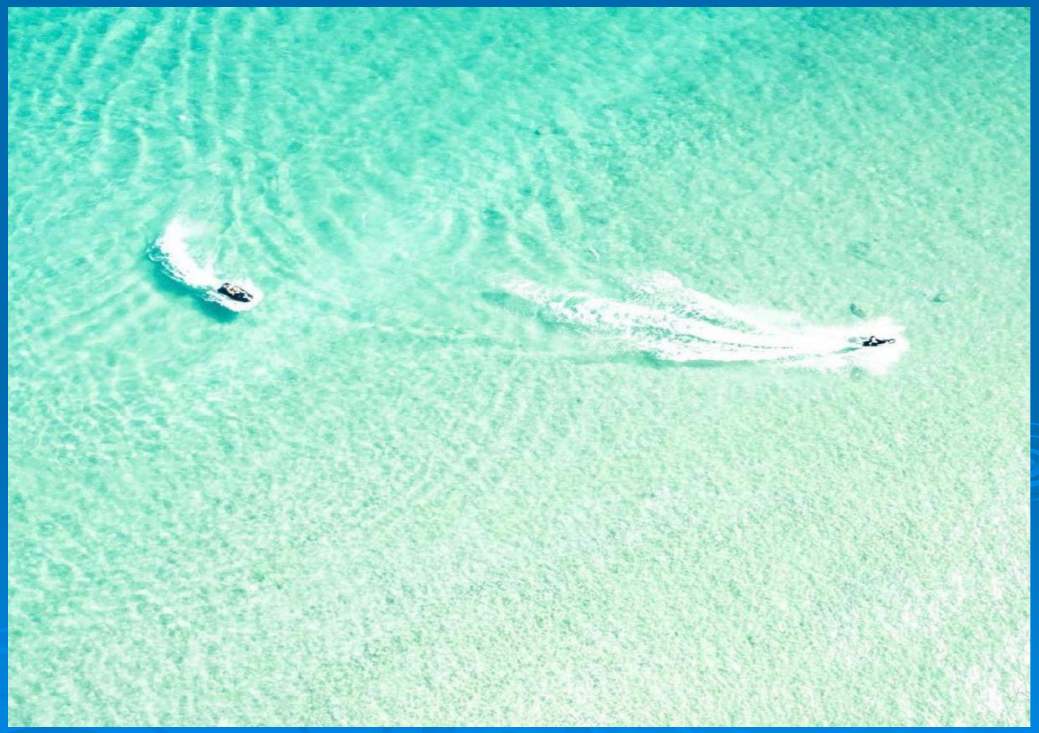
Elk River Chain of Lakes



- Elk River and the Chain of Lakes are a 75-mile long waterway
- This river/lake system drains about half of the Grand Traverse Bay watershed.

In a region blessed with pristine, high-quality waters, what is remarkable about Torch Lake?

- Second largest inland lake in Michigan
- Exceptional water clarity in spring/early summer
- The lake can by visually stunning
- Referred to as the "Caribbean of the North"
- Mythically "The third most beautiful lake in the world".



Citizen groups interested in protecting water quality in Torch Lake have traditionally viewed population growth and development as significant threats.

How can growth and development In Torch Lake be managed in a way that protects water quality?

Alternative approaches to management:

- Don't worry
- Worry…*development, population increase, invasive species, climate change*
- Monitor changes in water quality
- Model water quality using a mass balance approach

Long-term monitoring of water quality in Torch Lake

Focus on 3 parameters:

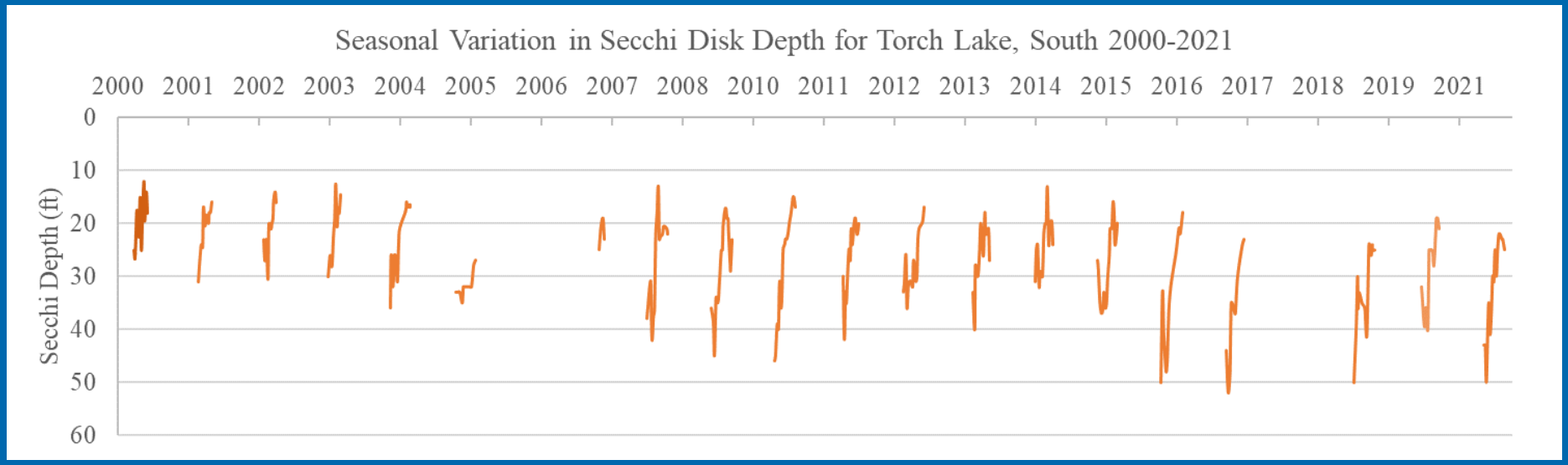
- **Secchi depth** – optical measure of water clarity
- **Total phosphorus (TP)** – concentration of limiting nutrient for phytoplankton growth
- **Chlorophyll a** – pigment used to measure phytoplankton concentration

These 3 water quality parameters are often monitored together in lakes and are typically related to overall water quality

- **Higher Phosphorus Loading -> More phytoplankton growth**
- **Phytoplankton is the base of the aquatic food chain, but excess can lead to various problems: reduced water clarity, low DO, taste & odor problems and toxic algae blooms**

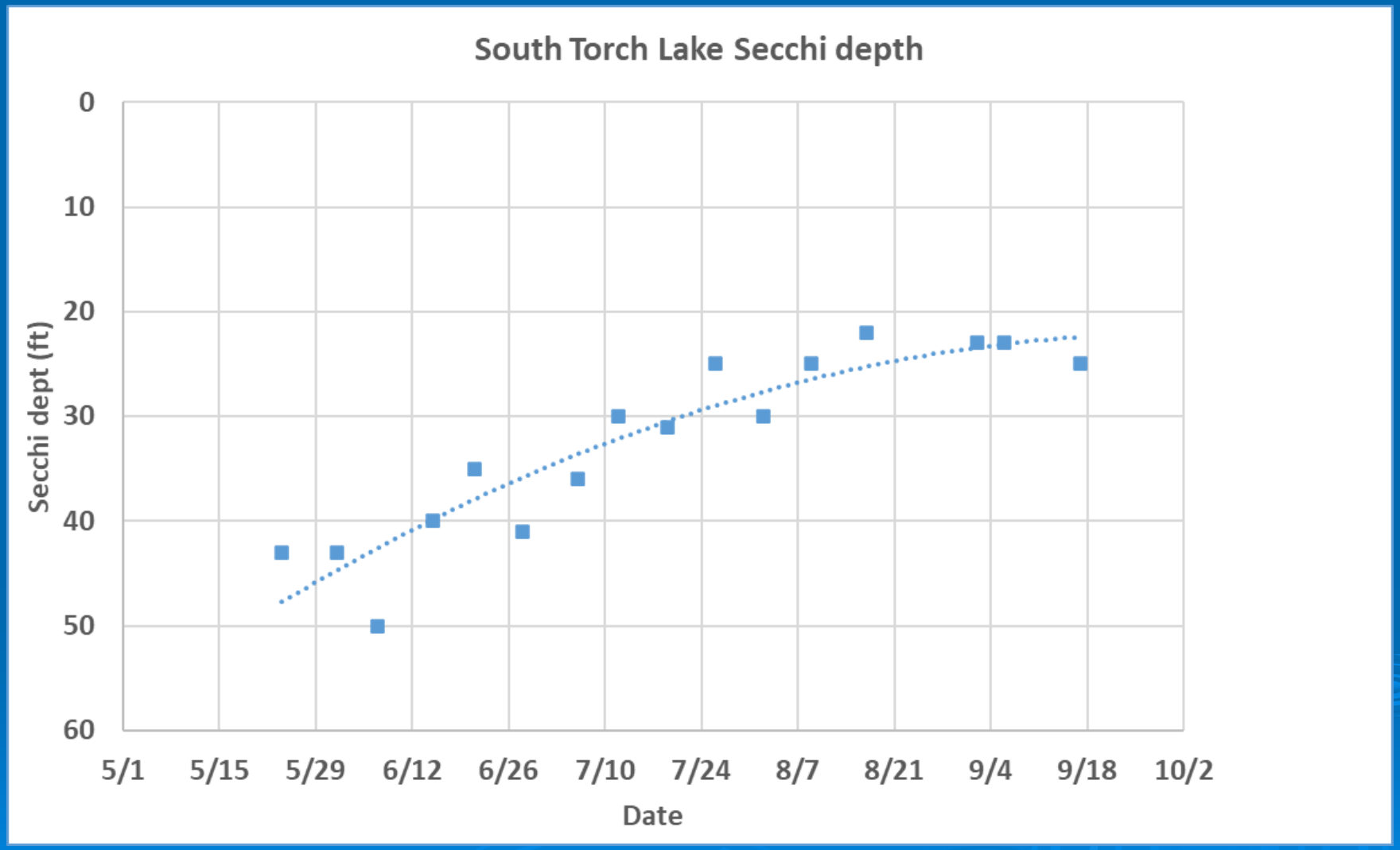
These 3 parameters have been monitored annually in Torch Lake since before 2000; more sporadic sampling as far back as 1960s.

Secchi depths 2000 – 2021 (Volunteer Torch Lake data)



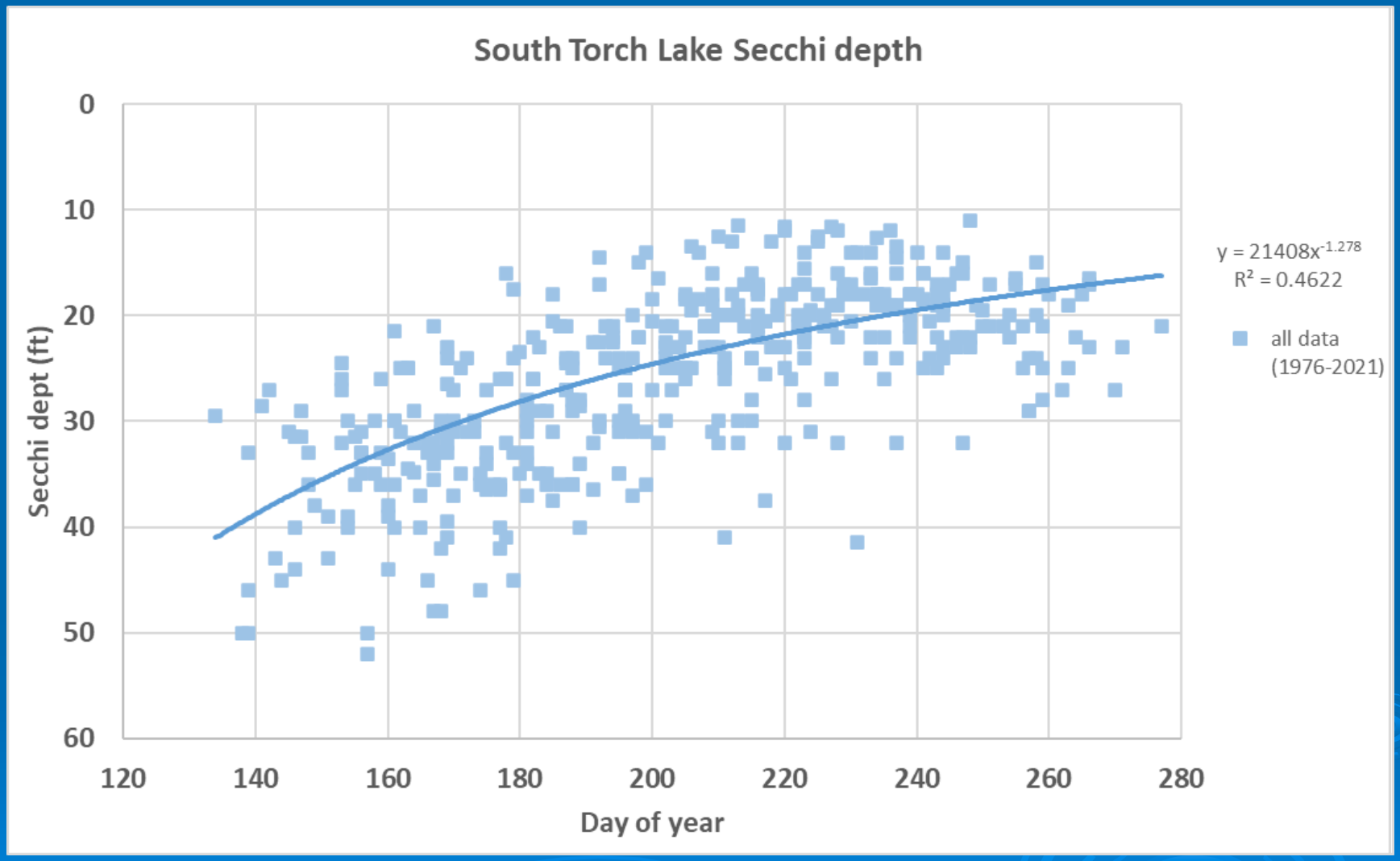
- In most years, Secchi depths are measured 10-20 times over the course of the summer
- Maximum annual Secchi depths range from 27 to 52 ft.
- Minimum depths range from 12 to 27 ft.

Secchi depth seasonal variation (2021)



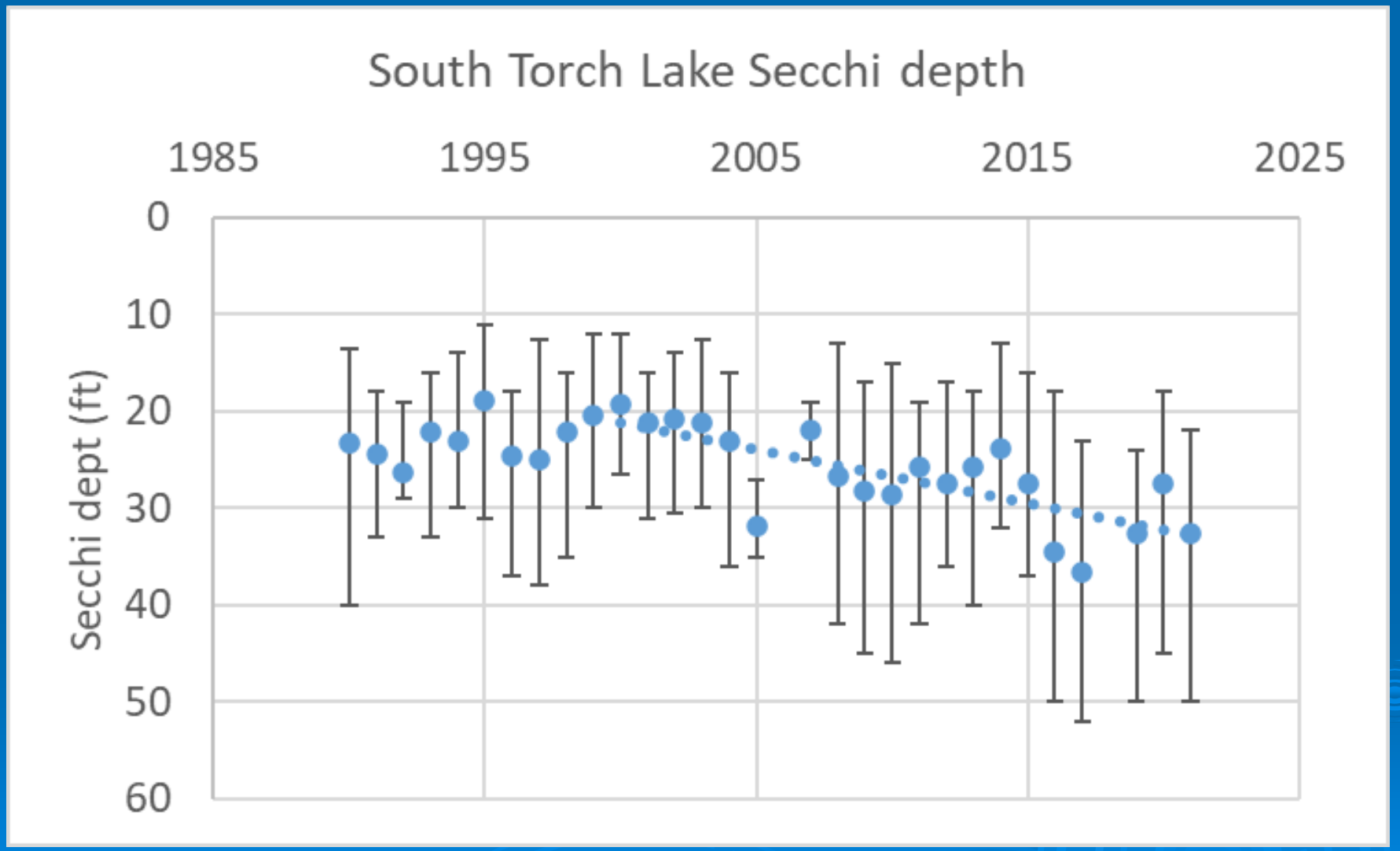
- Secchi depths decline from 50 ft. in early June to 22 ft. in mid-August

Secchi depth seasonal variation (all years: 1990 – 2021)



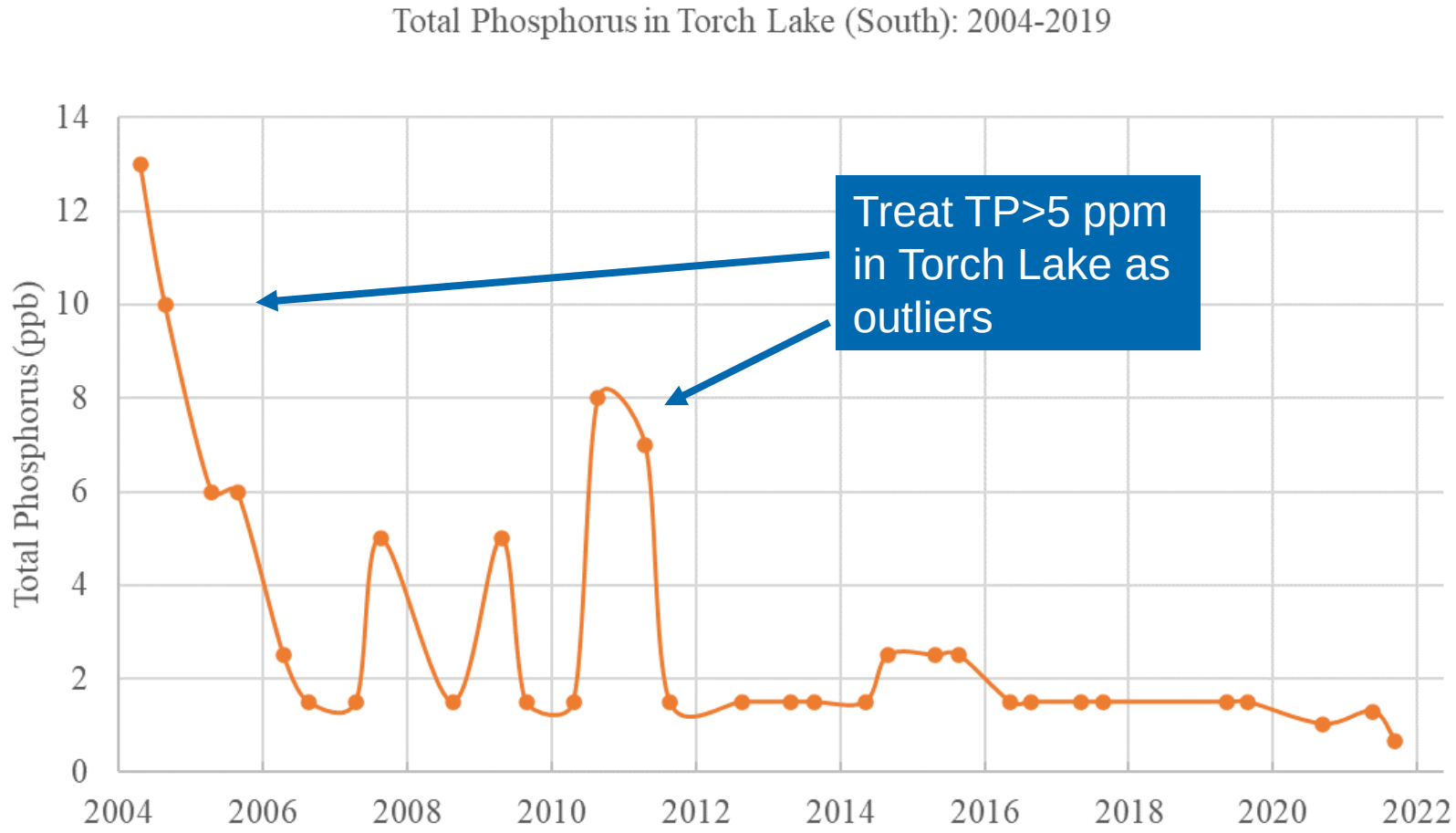
- Considerable scatter due to year-to-year variability
- Definite seasonal trend of declining water clarity: average Secchi depth decreases from ~40 ft. in mid-May to ~20 ft. in September.

Secchi depths: annual average, min and max (1990 – 2021)



- Average water clarity has been improving since early 2000's.

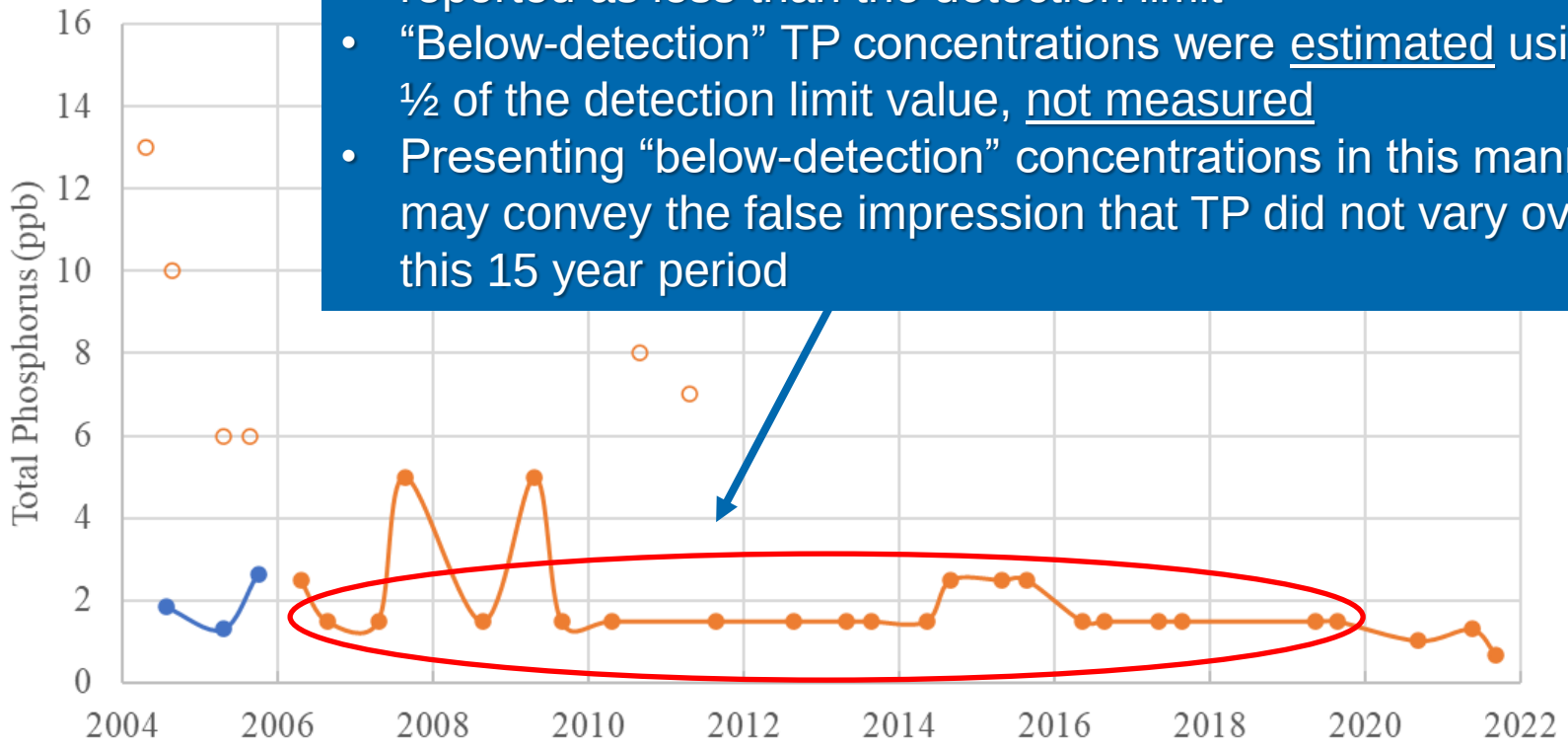
Total phosphorus (Cooperative Lakes Monitoring Program) spring and fall, 2004-2021



- Phosphorus concentrations greater than 5 ppb in Torch Lake are probably outliers
- Why?
  Because water samples are easily contaminated when concentrations are this low.

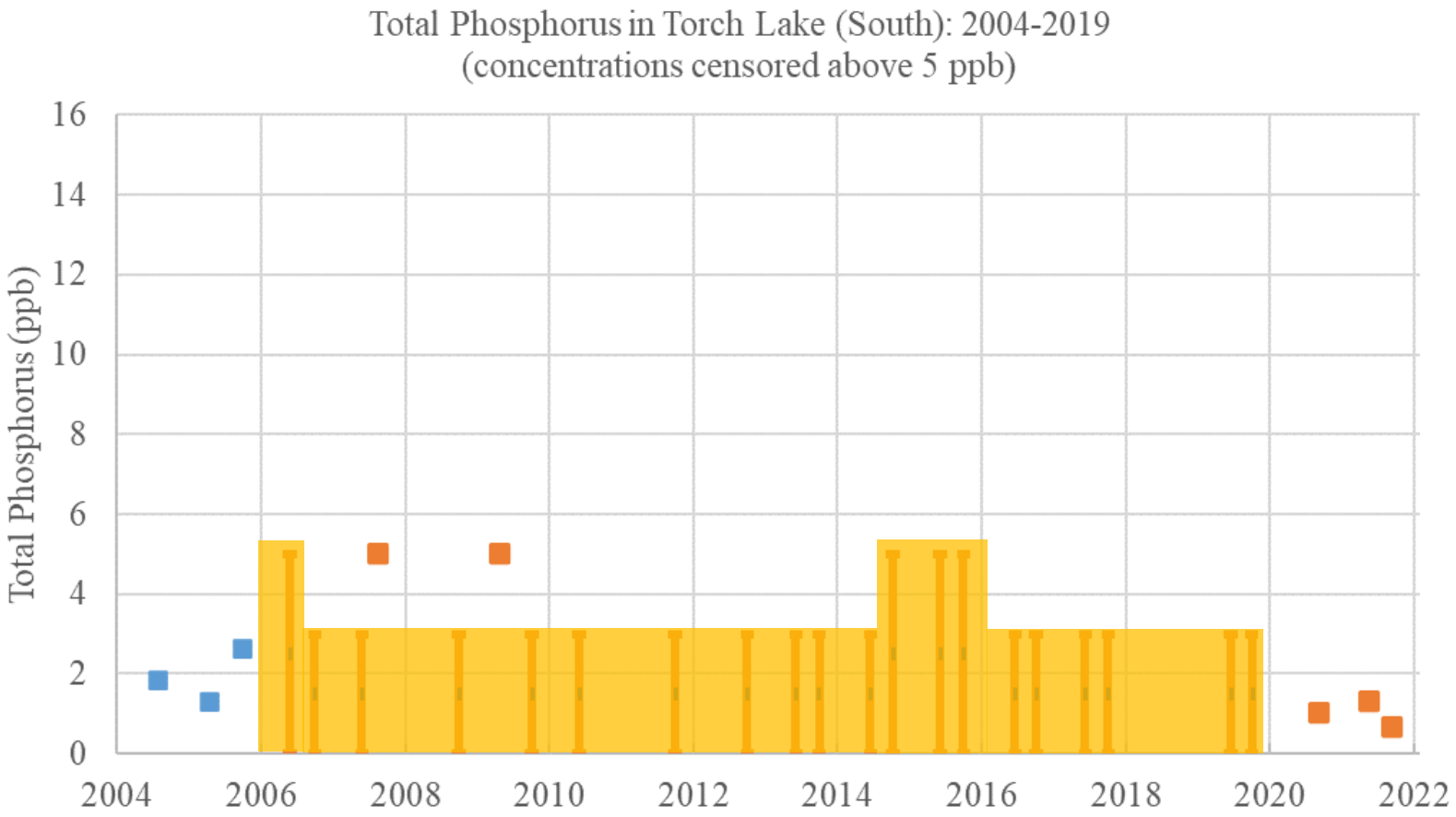
Total phosphorus (Cooperative Lakes Monitoring Program) spring and fall, 2004-2021

- The phosphorus concentrations circled below were reported as less than the detection limit
- "Below-detection" TP concentrations were estimated using ½ of the detection limit value, not measured
- Presenting "below-detection" concentrations in this manner may convey the false impression that TP did not vary over this 15 year period



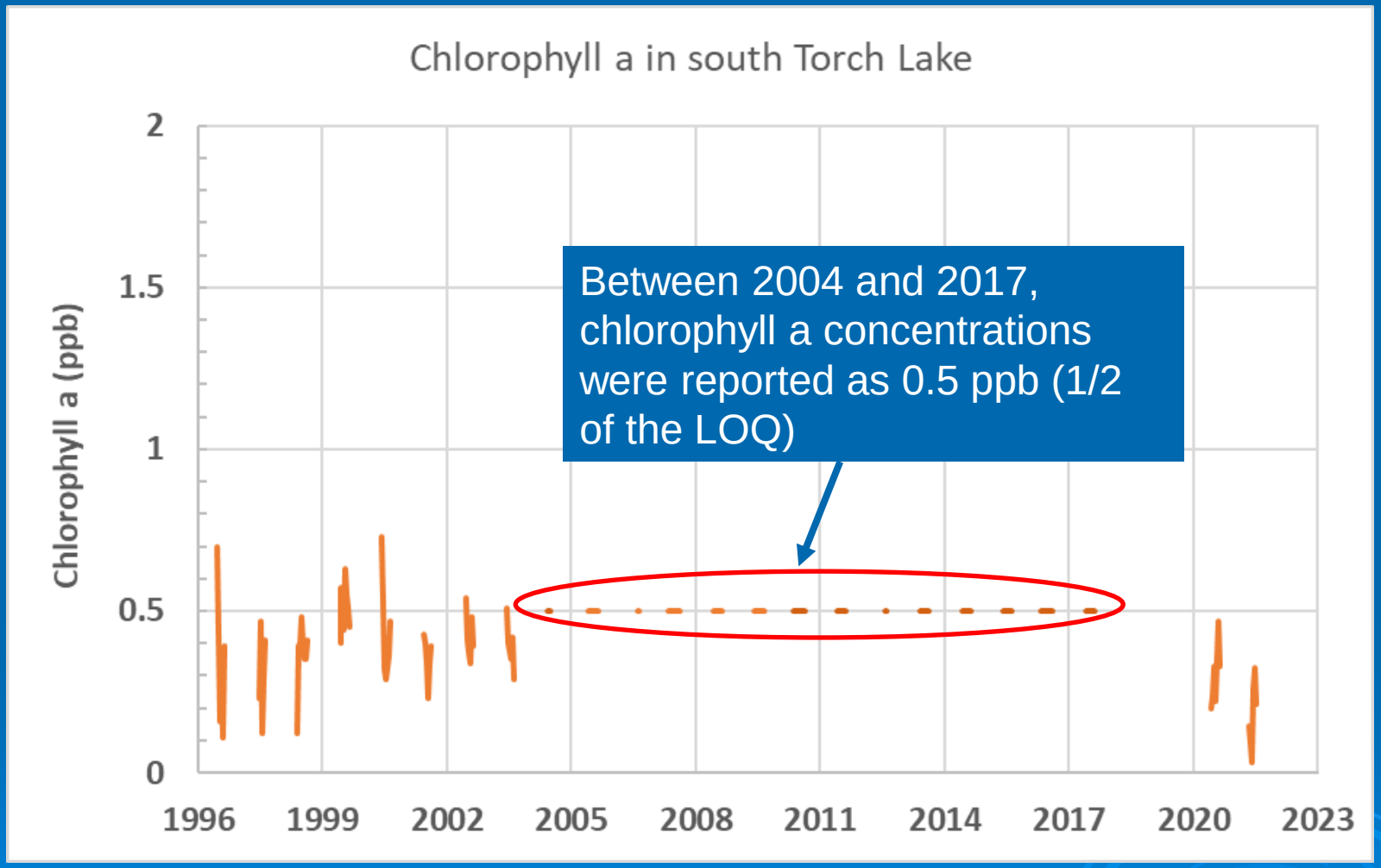
- With outliers removed, we can see that phosphorus concentrations in Torch Lake are ~~extremely~~ remarkably low
- In fact, many of these concentrations were too low for the laboratory to measure!

Total phosphorus (Cooperative Lakes Monitoring Program) spring and fall, 2004-2021



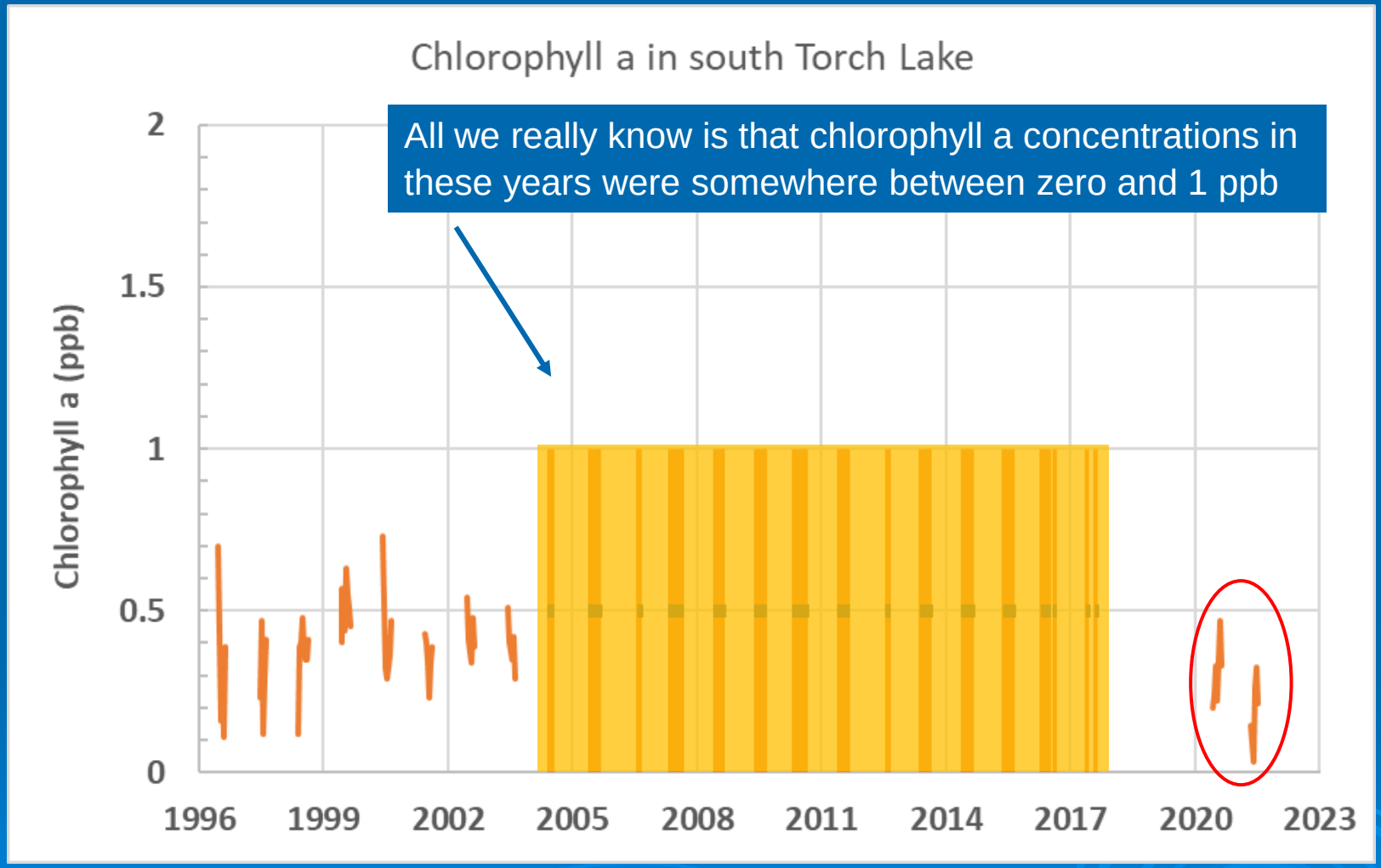
- All we really know: TP concentrations from 2006 thru 2020 were somewhere between zero and the detection limit (3 or 5 ppb)
- The trend in TP concentrations over this decade is uncertain.

Chlorophyll a (Volunteer Torch Lake and CLMP) Summer 1996-2021



- As was the case with phosphorus, chlorophyll a concentrations were extremely low
- And again, many of these concentrations were too low for the laboratory to measure!

Chlorophyll a (Volunteer Torch Lake and CLMP) Summer 1996-2021



- The trend in chlorophyll a between 2004 and 2017 is uncertain
- Extremely low chlorophyll a concentrations in 2020 and especially 2021.

What is a water quality model, and how can it useful?

A water quality model is a mathematical description of a body of water, which shows how water quality responds to factors such as flow rates and mass loadings (pollutant inputs)

Water quality models are useful for:

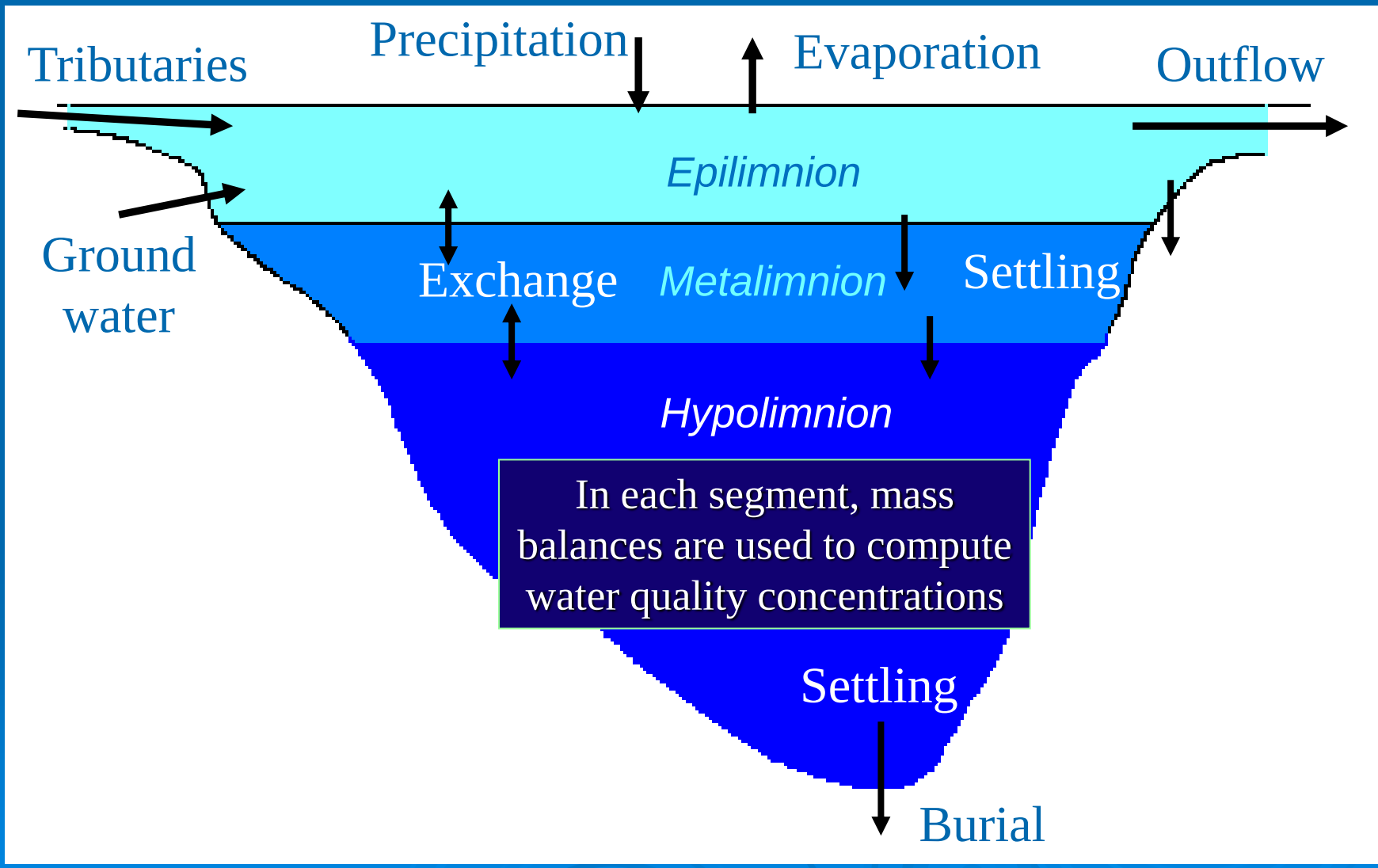
- Assessing the current status of a waterbody
- Understanding how and why water quality responds to external and internal factors
- Forecasting changes in water quality

Water quality models are usually constructed using data from a mass balance study, an intensive monitoring approach to measure all inputs and outputs of pollutants of interest.

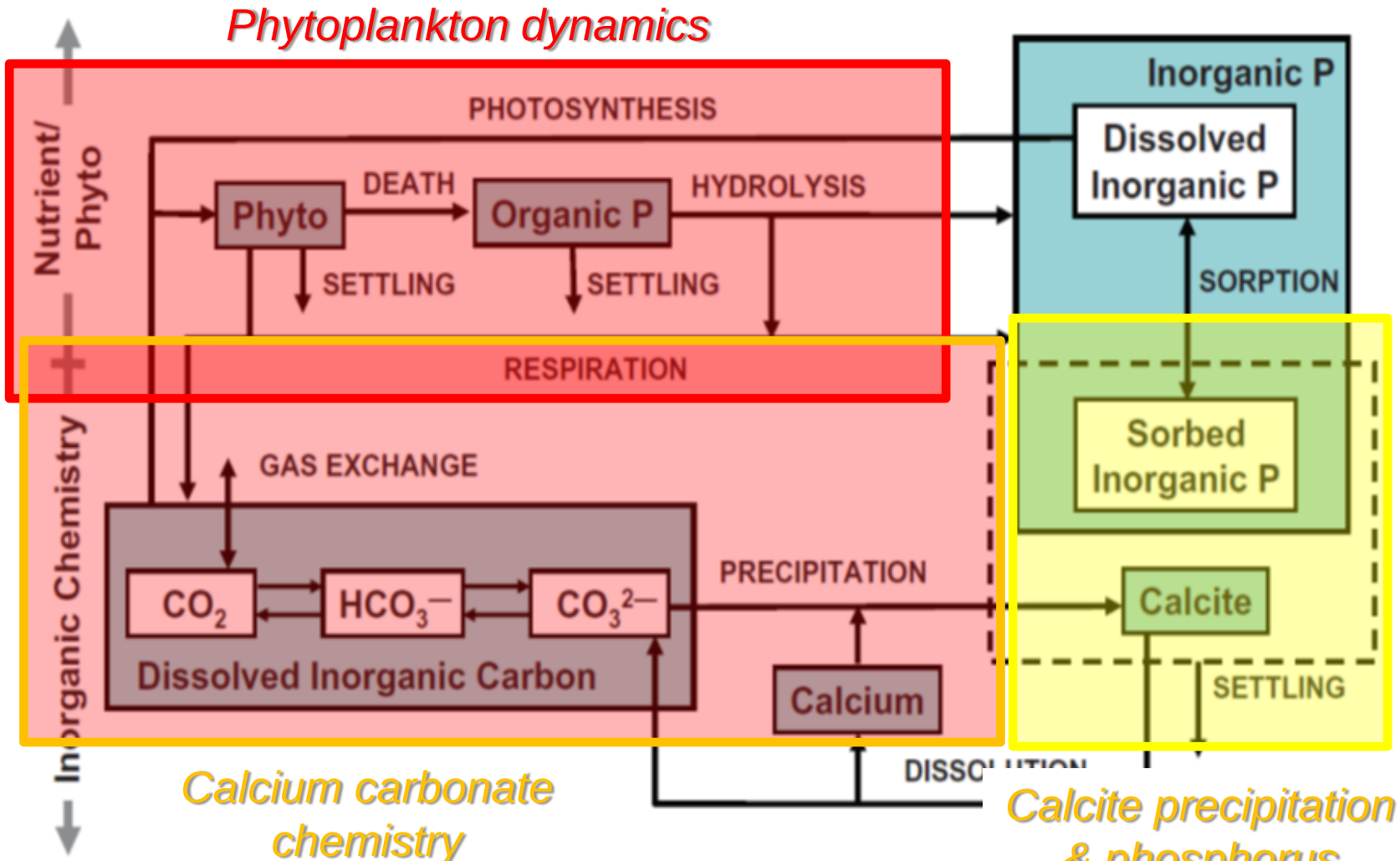
Example: Torch Lake Mass Balance Study and Water Quality Model

- GLEC collaborated with Three Lakes Association (TLA) to conduct a mass balance study of Torch Lake in 2004-05 and use the data that was generated to develop a water quality model
- Funded by Michigan Department of Environmental Quality (now EGLE) *Local Water Quality Monitoring Grant* for $62,000
- We applied LAKE2k, an Excel spreadsheet model developed by Tufts University
- Project report “Development of a Predictive Nutrient-Based Water Quality Model for Torch Lake” (2006) **is** available on TLA website (https://www.3lakes.com/projects/water-quality-model/).

LAKE2k schematic: vertical segmentation, inflow/outflow and transport pathways

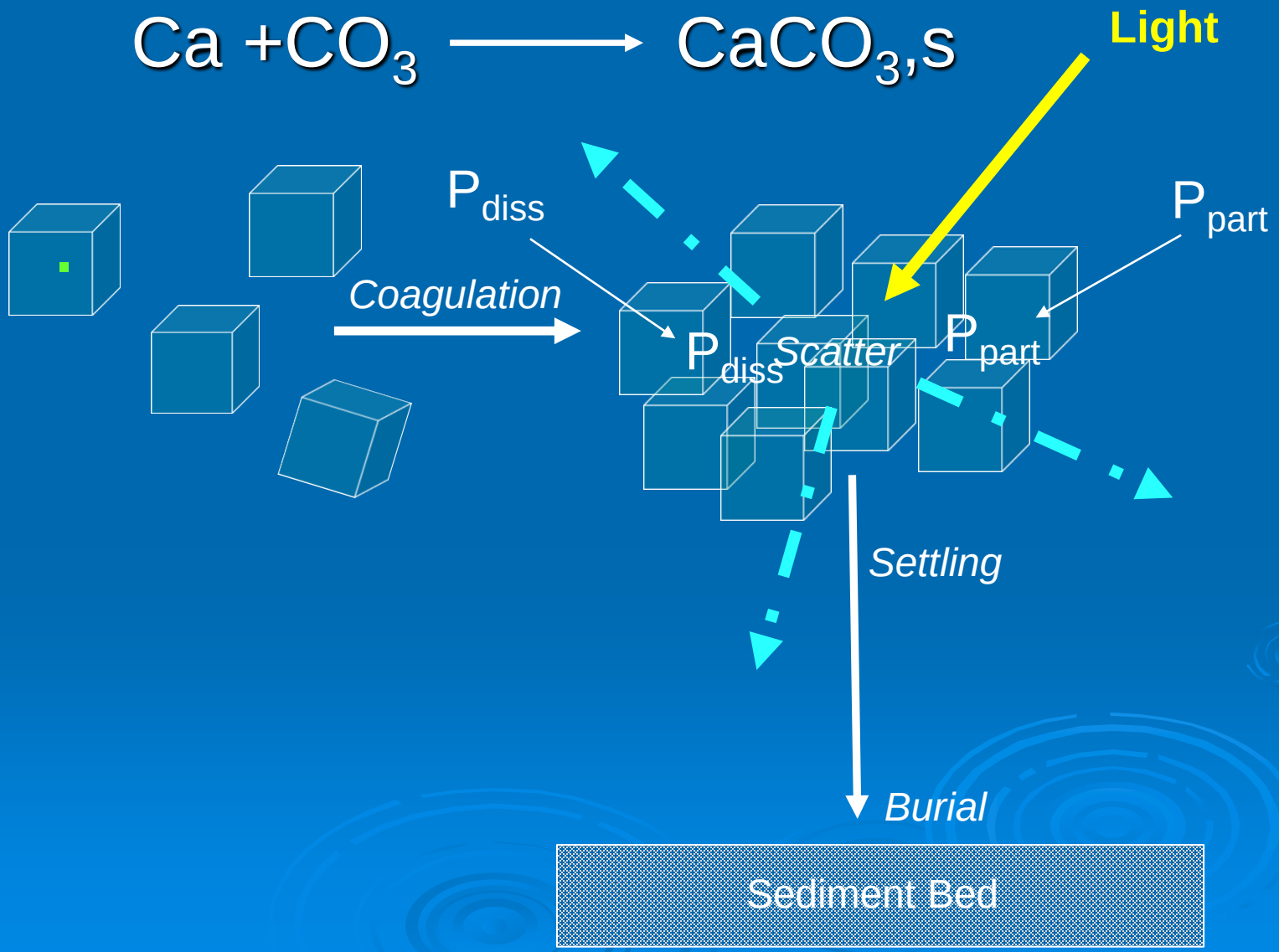


LAKE2K process schematic for inorganic chemistry, phosphorus and phytoplankton



Calcite precipitation: what's that?

$$Ca + CO_3 \longrightarrow CaCO_3,s$$



Sediment Trap Deployment in Torch Lake

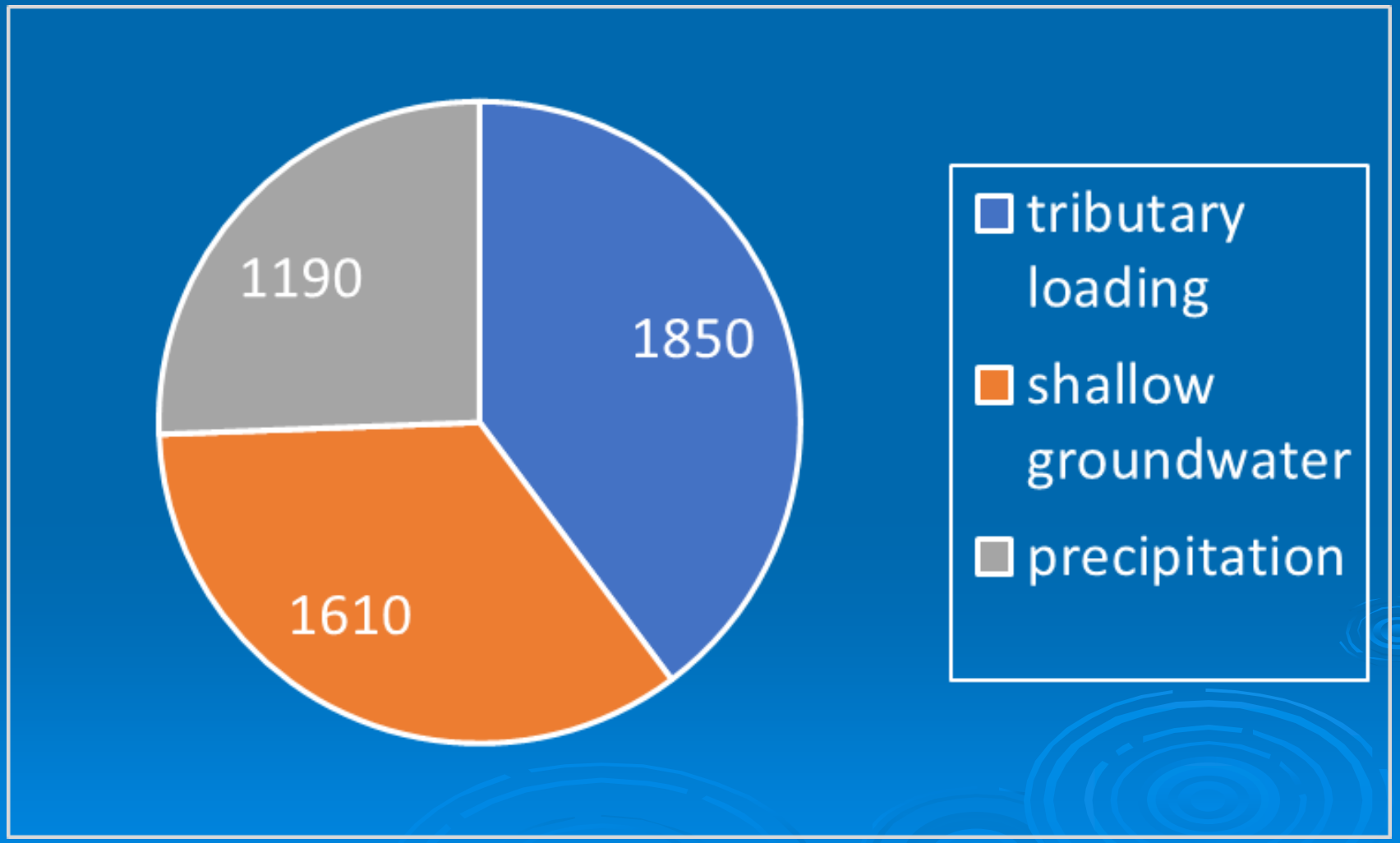
We deployed sediment traps in Torch Lake in 2005 and again in 2020 to measure the loss of phosphorus by calcite settling/burial.

What data was collected in the mass balance study to build a water quality model for Torch Lake?

- Water balance:
  - Tributary inflows and outflow
  - Groundwater seepage
  - Precipitation and evaporation
- Mass loadings of phosphorus:
  - Point sources (none)
  - Nonpoint sources (tributaries, groundwater, precipitation/atmospheric deposition)
- Water quality measurements:
  - HydroLab (Temperature, pH, DO, conductivity)
  - Nutrients (Total and dissolved phosphorus; nitrogen)
  - Other parameters: chlorophyll a, alkalinity, calcium
  - Sediment traps to measure particle settling rates.

Three Lake Association volunteers did most of the field sampling for the mass balance study

2004-05 Mass balance results: phosphorus loading estimates (kilograms of phosphorus)



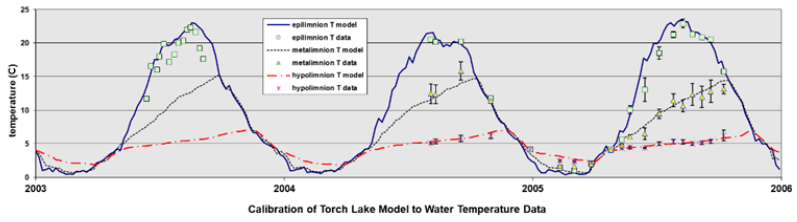
Mass Balance for Total Phosphorus in Torch Lake in 2004-05

- Total Phosphorus Loading: 4,650 kg
- Phosphorus Outflow (Torch River): 904 kg
- Phosphorus Loss by Settling with Calcite: 4,110 kg (90% of loading)
- Mass balance data and calculations demonstrated that phosphorus in Torch Lake was near steady state (inputs ≈ losses).

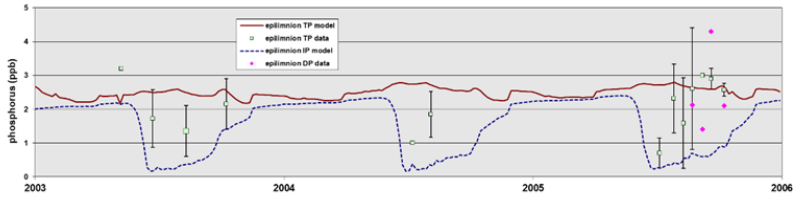
Torch Lake Water Quality Model Calibration

Model was calibrated to data from 2003-2005:

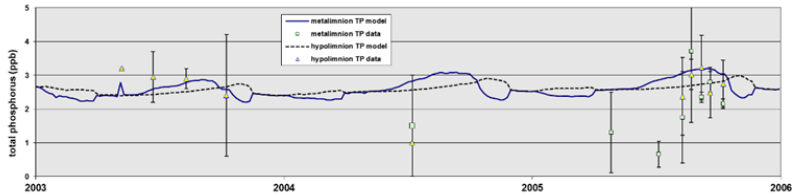
- Temperature
- Total and dissolved phosphorus
- Chlorophyll a
- Dissolved oxygen
- Secchi depth.



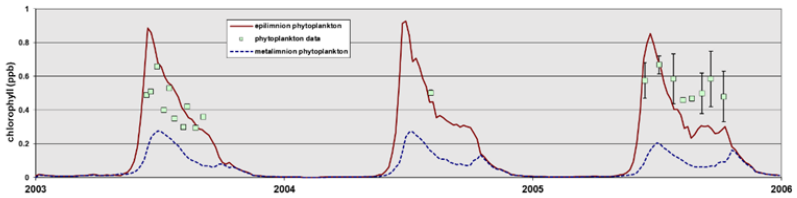
Calibration of Torch Lake Model to Water Temperature Data



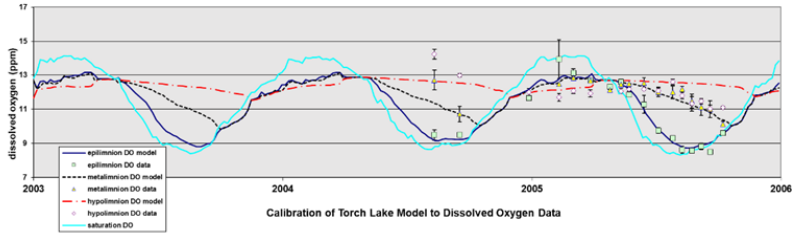
Calibration of Torch Lake Model to Epilimnion Total and Dissolved Phosphorus Data



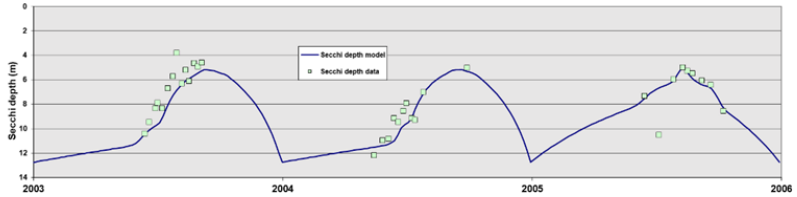
Calibration of Torch Lake Model to Metalimnion and Hypolimnion Total Phosphorus Data



Calibration of Torch Lake Model to Phytoplankton (chlorophyll a) Data



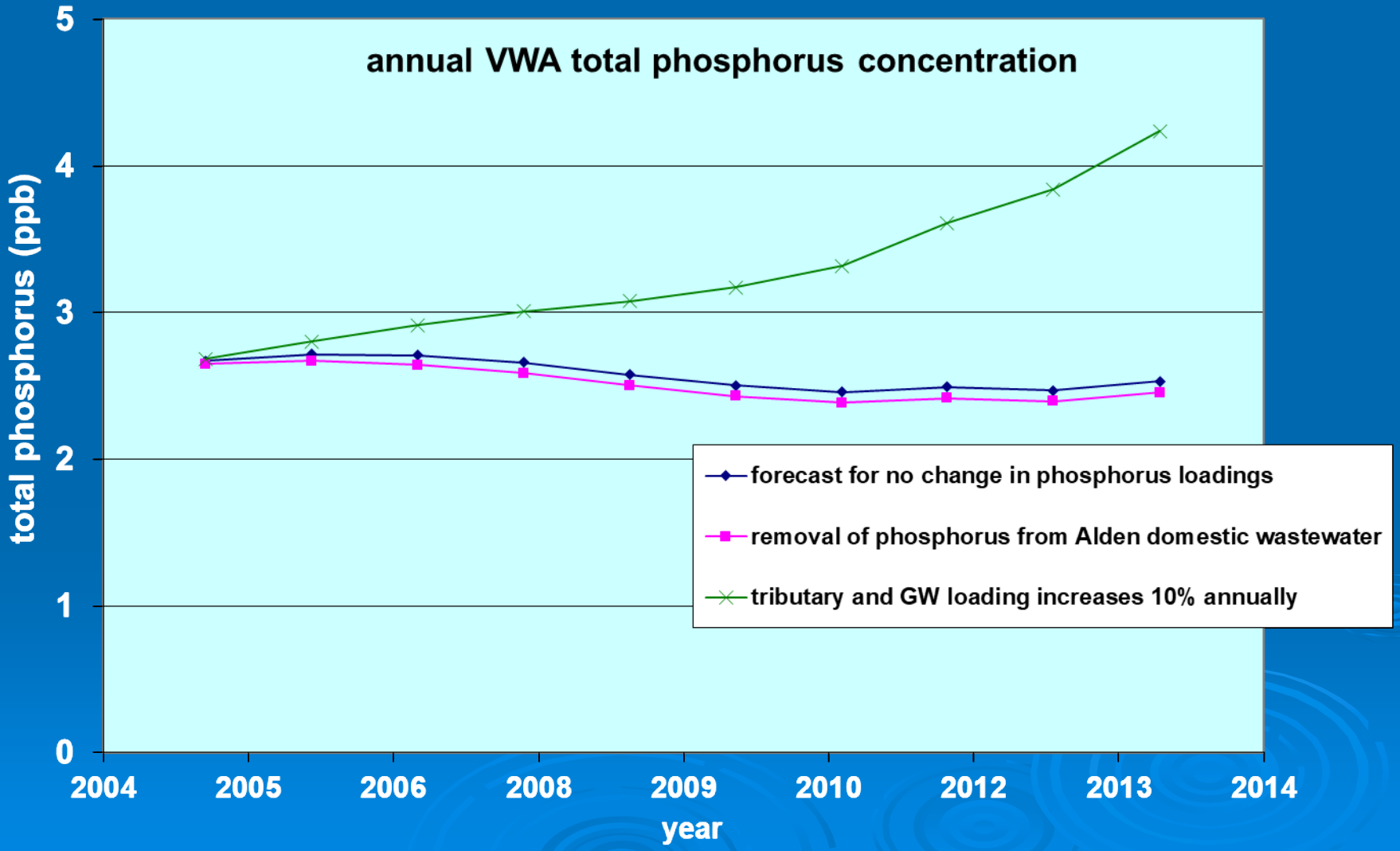
Calibration of Torch Lake Model to Dissolved Oxygen Data



Calibration of Torch Lake Model to Secchi Depth Data

Demonstration of Long-term (10 year) Model Forecasts

- Model has been applied on a number of occasions to forecast future water quality in Torch Lake for different management scenarios



- Uncertainty of model forecasts were not considering here.

Paradigm Shifts – sure to be encountered in science
Torch Lake water quality as an example

- **Conventional phosphorus-control water quality paradigm:**

  Higher Phosphorus Loading -> More phytoplankton growth
  -> Reduced water clarity, low DO, taste & odor and toxic algae blooms
  Review of Torch Lake monitoring data: Phosphorus and Chlorophyll a concentrations are very low, Secchi depth and DO high … all is well!

- **2004-05: Mass balance study investigated the role of calcite precipitation in affecting other water quality parameters in Torch Lake**

  Data showed that calcite precipitation was very effective in removing phosphorus and reducing water clarity

  Calcite precipitation -> Reduces phosphorus concentrations
  -> Reduces water clarity
  - **Phytoplankton abundance has little to do with reducing water clarity**
  - **Water clarity cannot be improve by reducing phosphorus loading!**

- **2010-2020: Appearance and proliferation of golden brown algae (GBA).**

What is Golden Brown Algae?

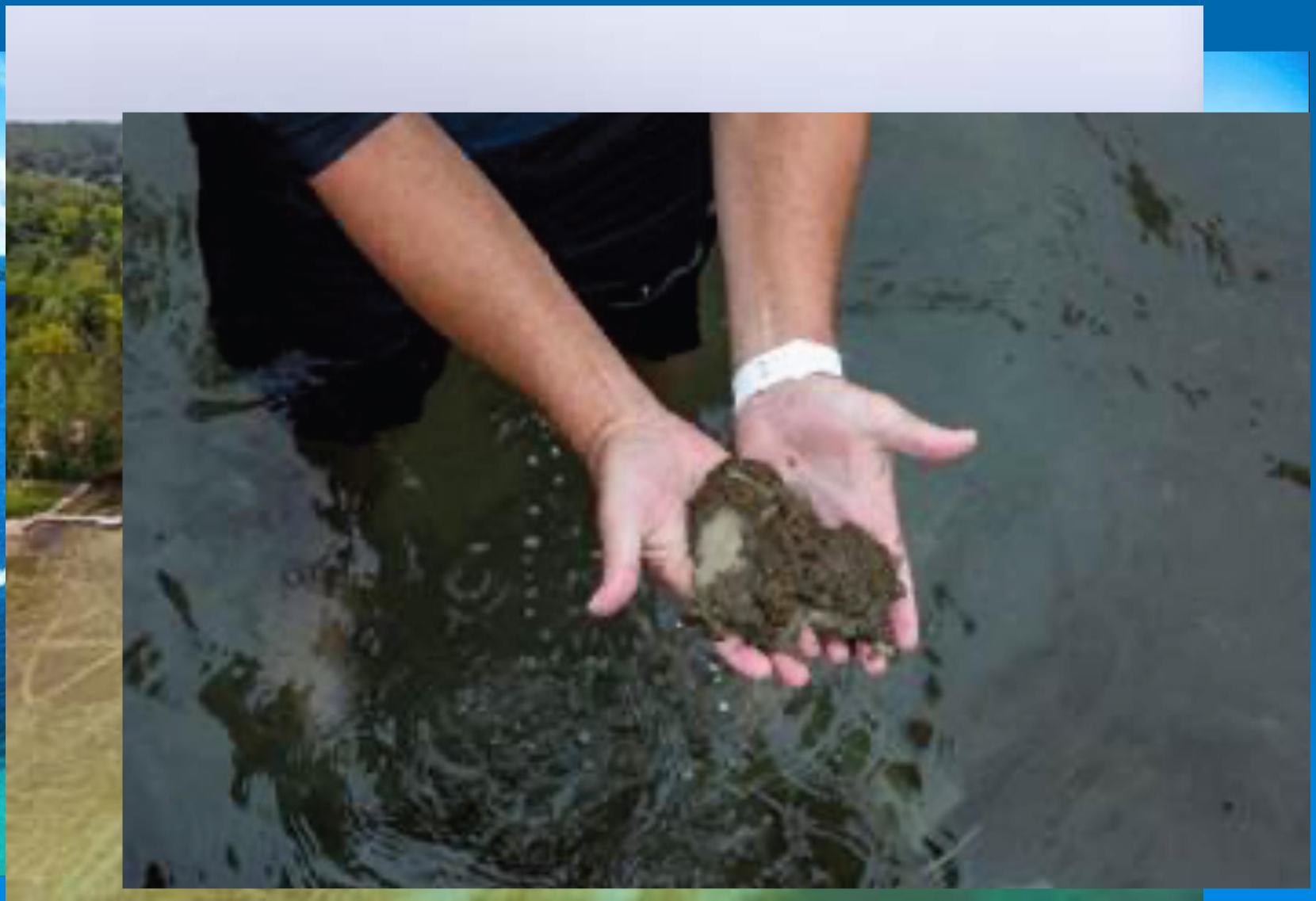
- GBA is a benthic algae that forms a mat covering the sediment surface

2010 ⟶

Aerial Photos taken at same location in Torch Lake north of Sand Point

2020 ⟶

GBA in Torch Lake: Before and After



Appearance and proliferation of GBA in Torch Lake: Why?

Numerous alternative explanations have been proposed and researched* for the past 5 years

- **Zebra Mussels Enrich Sediments**
- **Changing Light Conditions**
- **Runoff from Big Storms Enriches Surface H_20**
- **Disease Killed Grazers Allowing Algae to Grow**
- **Non-native Invasive Algal Species**
- **“Algae in the News and on Your Mind”**
- **Climate change & a warmer lake**
- **Groundwater contamination**
- **Phosphorus decreases in surface waters**
- **Calcium carbonate deposition and burial of benthos.**

** Jan Stevenson, 2017-2021 Studies of Golden Brown Algae on the Bottom of Torch Lake, Lake Bellaire, and Clam Lake*

Focus on one explanation for GBA appearance and proliferation:

Very low phosphorus -> More benthic algae
(GBA has a competitive advantage under low-P conditions)

- **If this explaination is correct, it basically turns the "conventional" phosphorus-control water quality paradigm on its head!**
- Recall: water quality monitoring trends for phosphorus and chlorophyll a in Torch Lake between 2010-2020 were uncertain
- Because of this, monitoring data doesn't help us understand GBA dynamics in Torch Lake over the time period in which it appeared and proliferated.

2022 Torch Lake Collaborative Adaptive Management Meeting

Fifty experts from Michigan, Wisconsin and around the country met on June 10, 2022 to participate in a technical forum to discuss a path forward for understanding and managing GBA in Torch Lake

Two major conclusions emerged from the technical meeting:

1. We simply cannot answer the fundamental question of "what changed" to cause GBA to appear/proliferate in Torch Lake
2. Several hypotheses have been suggested to explain GBA. Although well grounded in science, the scientific data to either confirm or dispute these hypotheses is not available.

To address the scientific and water quality management issues associated with GBA, Torch Lake Protection Alliance (TLPA), Torch Conservation Center (TCC) and Three Lakes Association (TLA) are collaborating to revisit the water quality/mass balance approach 20 years after our first such study in Torch Lake:

- Comprehensive monitoring program for Torch Lake led by Dale Robertson of the US Geological Survey Upper Midwest Water Science Center
- Merged with and developed in conjunction with the continuing field and laboratory research led by Dr. Jan Stevenson of Michigan State University

The new mass balance study will begin in 2023 and is expected to continue though 2025.

Summary

- Water quality is an extremely valuable resource that should be managed and monitored for trends
- “Pristine” northern Michigan waters offer unique challenges to water quality management
- Water samples must be analyzed by labs with sufficiently sensitive chemistry methods to measure low concentrations
- Monitoring data needs interpretation to provide context
- Periodically, additional study (mass balance, water quality modeling, scientific studies) is useful for management and necessary to understand unexpected changes and paradigm shifts
- We need to stay engaged and ask questions: What is changing? Why? Is the change desirable?
  If not, what can be done about it?

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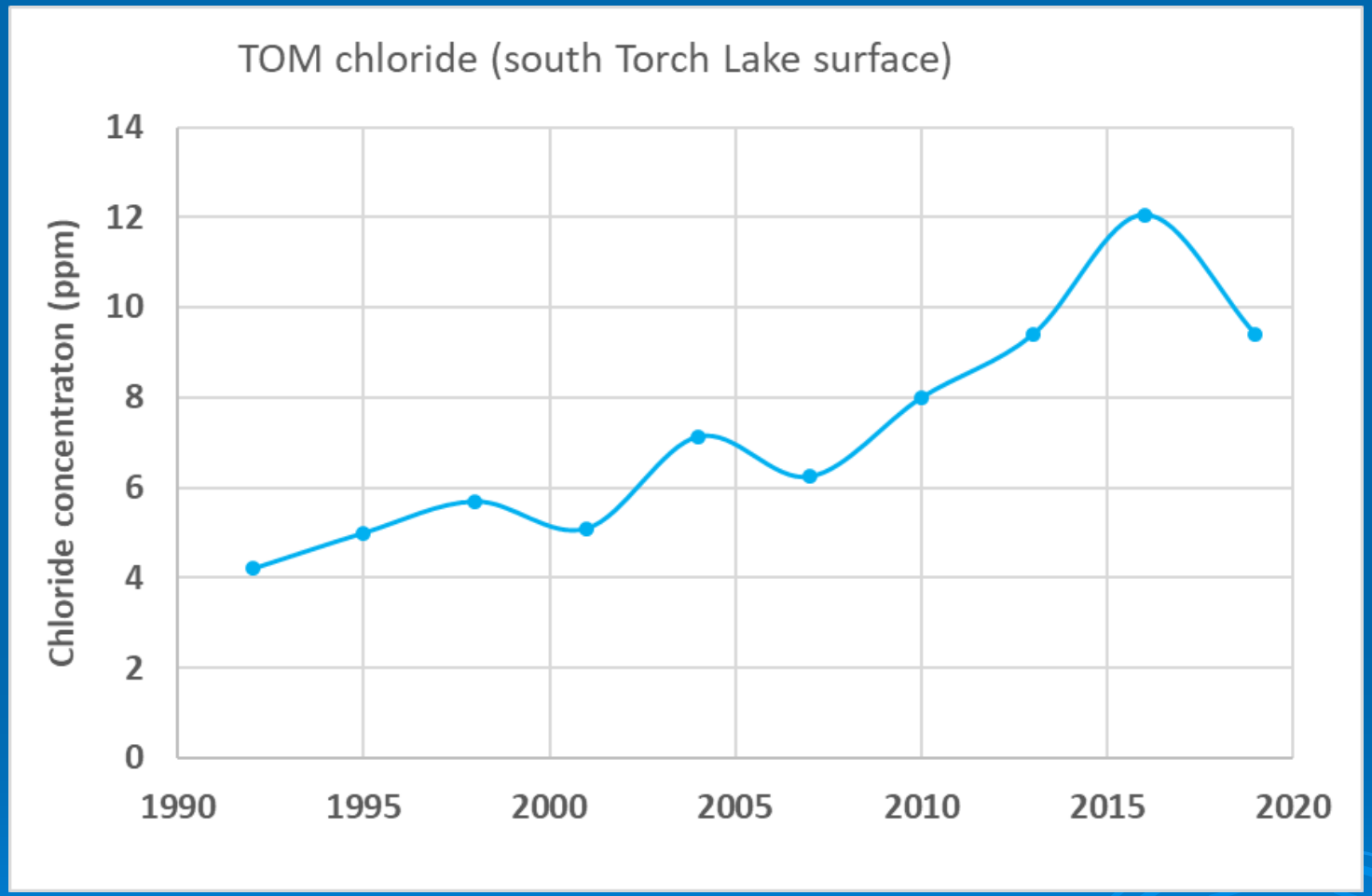
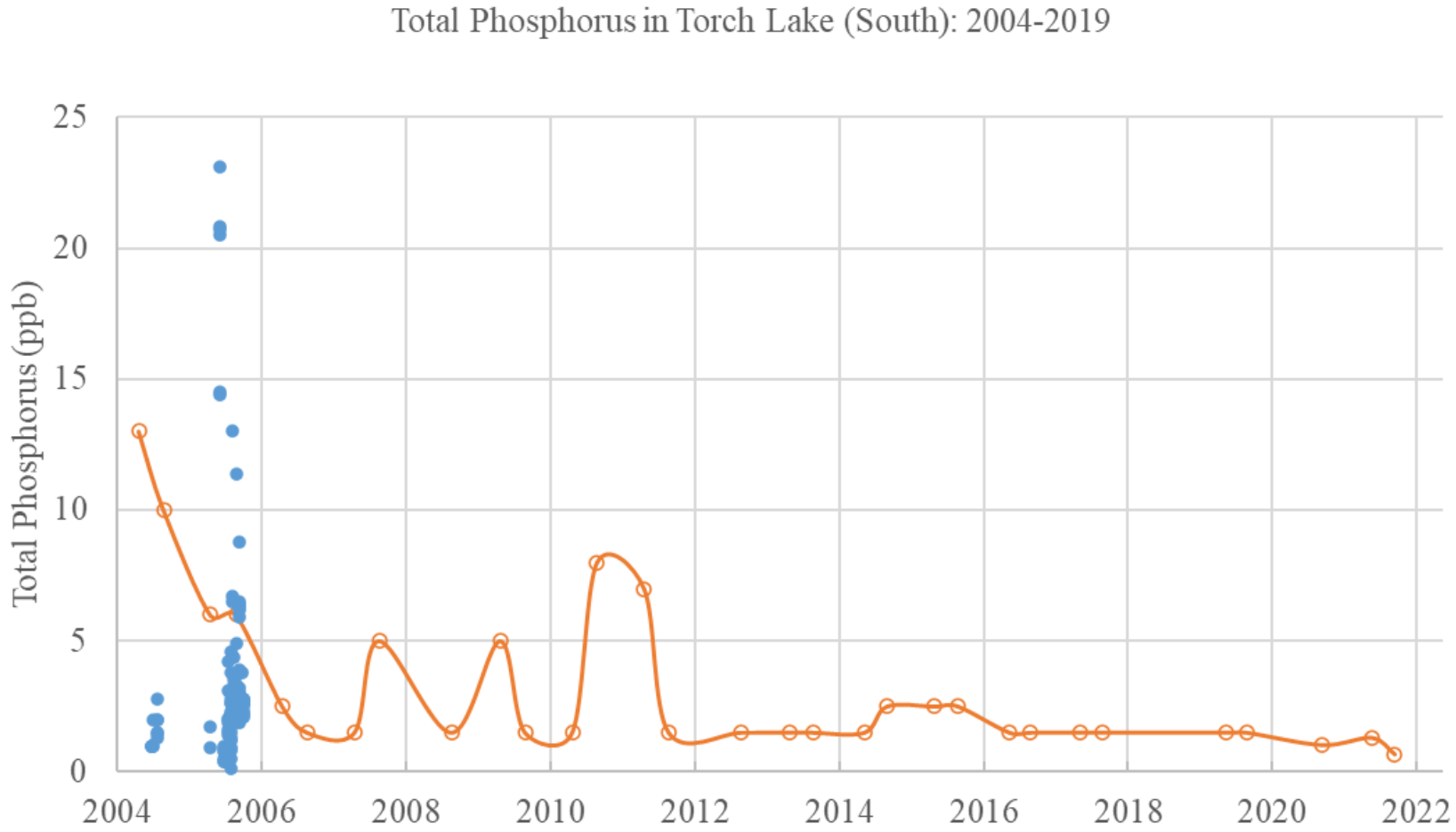
Cutting Room Floor

Chloride (Tip of the Mitt Monitoring Program) spring, 1992-2019



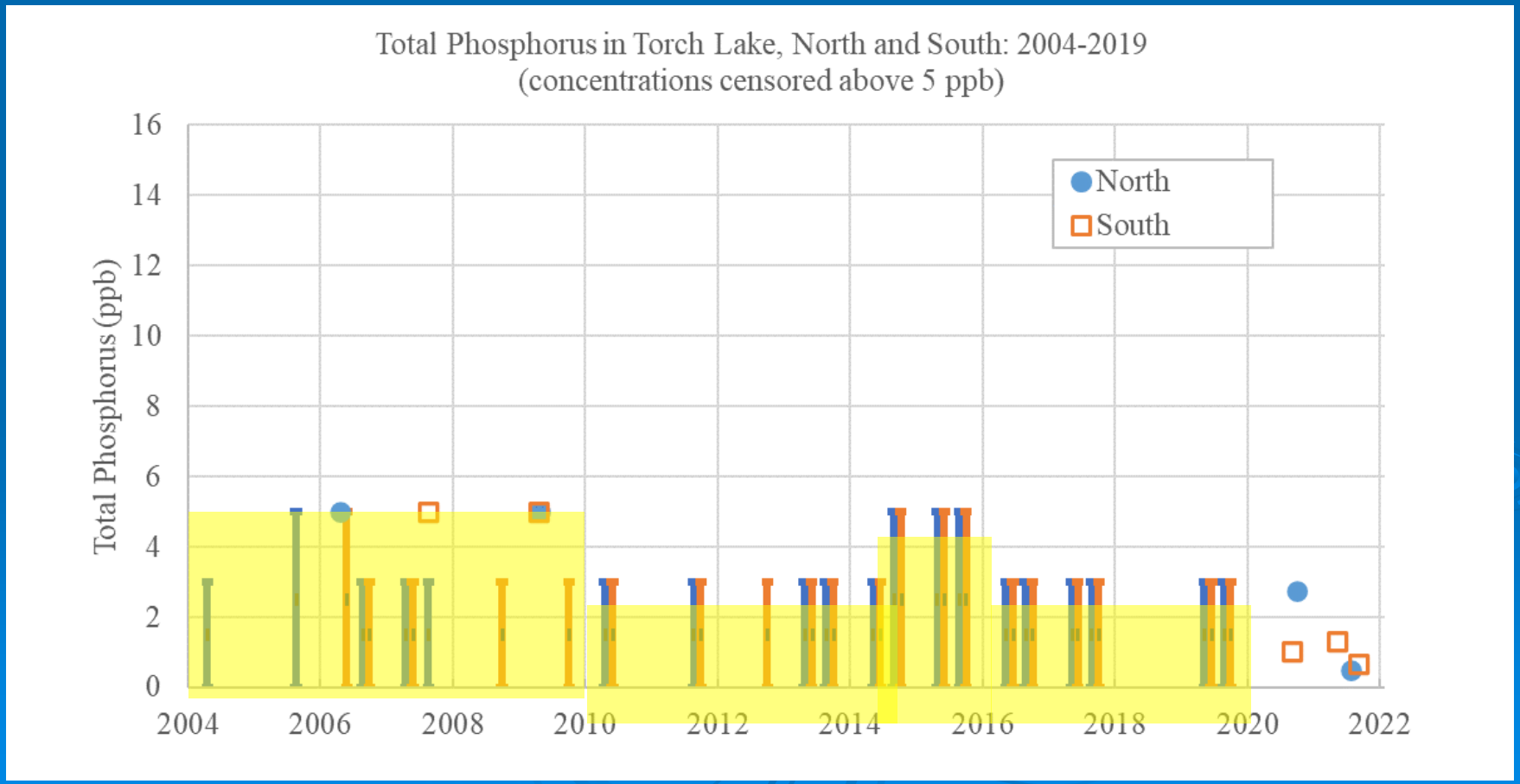
- Chloride ion associated with anthropogenc activity including road deicing
- Chloride concentration in Torch Lake is doubling every 15 years.

Total phosphorus (Cooperative Lakes Monitoring Program) spring and fall, 2004-2021



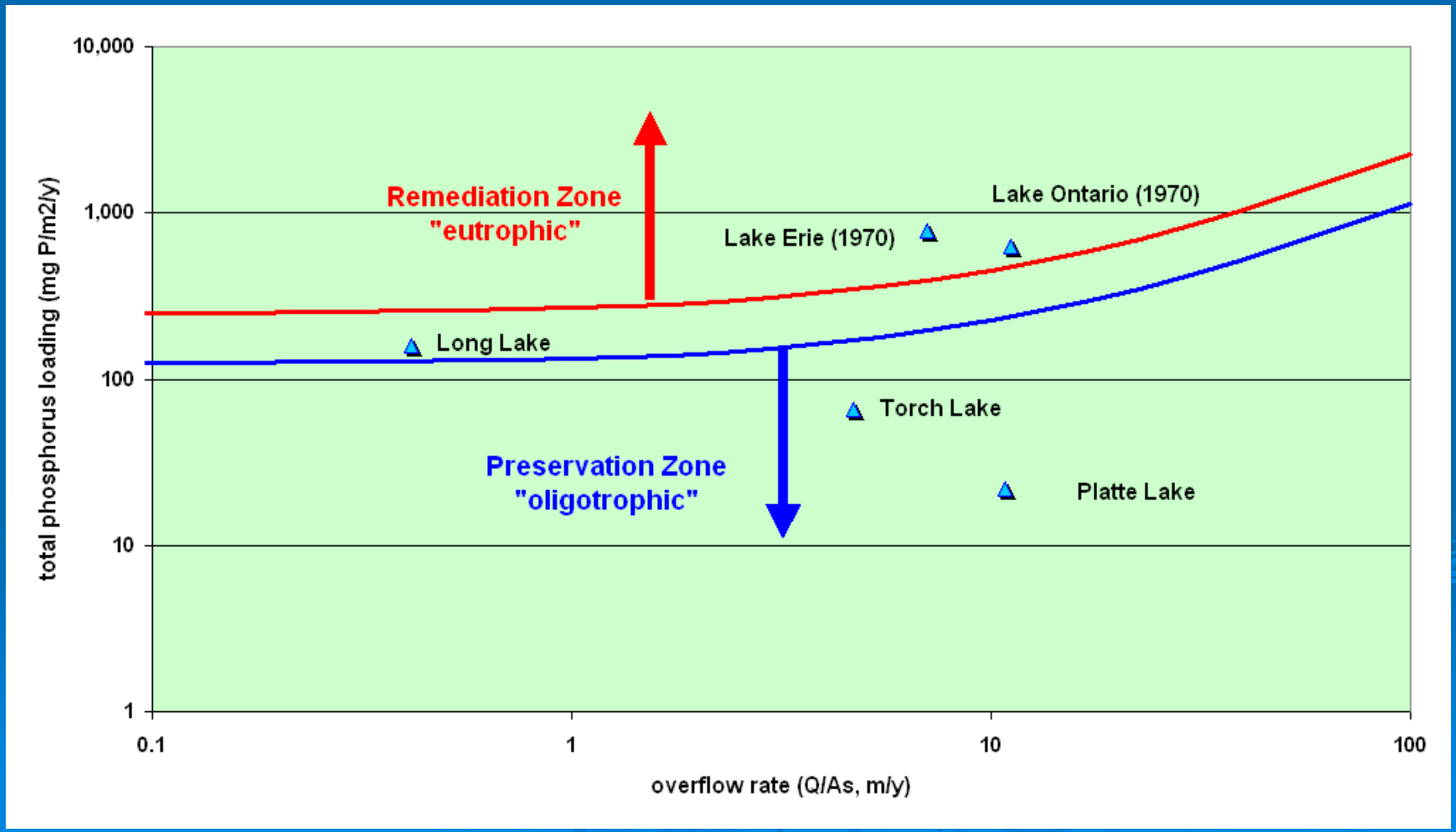
Total phosphorus (CLMP) spring and fall, 2004-2021 (continued)

- Since the early 2000's, most phosphorus (TP) concentrations from spring/fall samples of Torch Lake have been reported as less than the detection limit
- For such "below-detection" data it is common to estimating TP concentrations using ½ of the detection limit
- This may convey the false impression that TP did not vary over that 15 year period.
- All we really know: TP concentrations in those years were somewhere between zero and 3 (or 5) ppb.



Vollenweider Phosphorus Budget Model

- 1975: First model to relate water quality to phosphorus loading
- Represents a simple tool to manage lakes according to whether they require remediation or preservation



Other examples of water quality model application

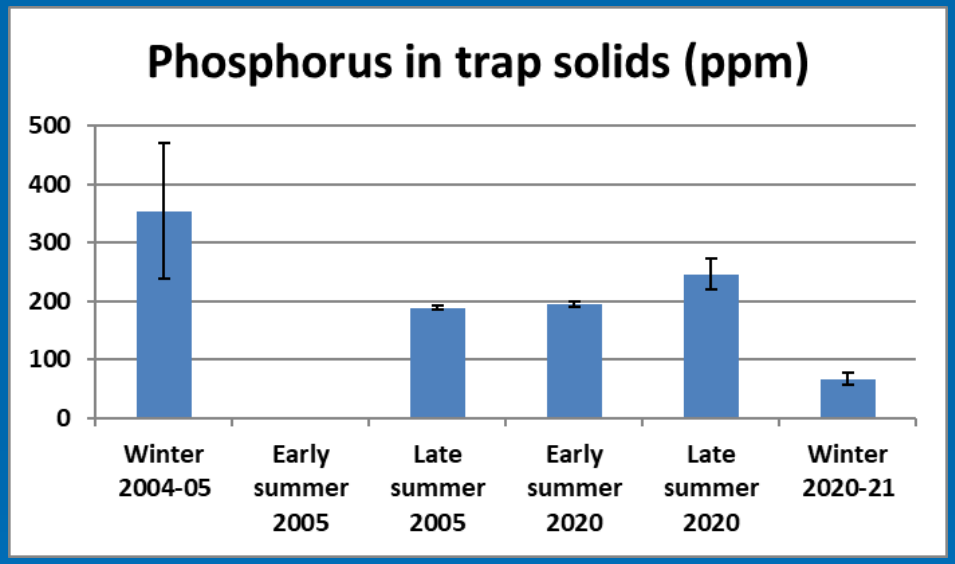
- 1970s: Eutrophication Modeling in Lake Erie and Lake Ontario
- 1980s: Venice Lagoon
- 1990s: Ecosystem Modeling in Chesapeake Bay and its Watershed
- 2000s: Lake Tahoe Clarity Model
- Water Quality Modeling and Mass Balances are now incorporated in the Clean Water Act through the Total Maximum Daily Load (TMDL) process

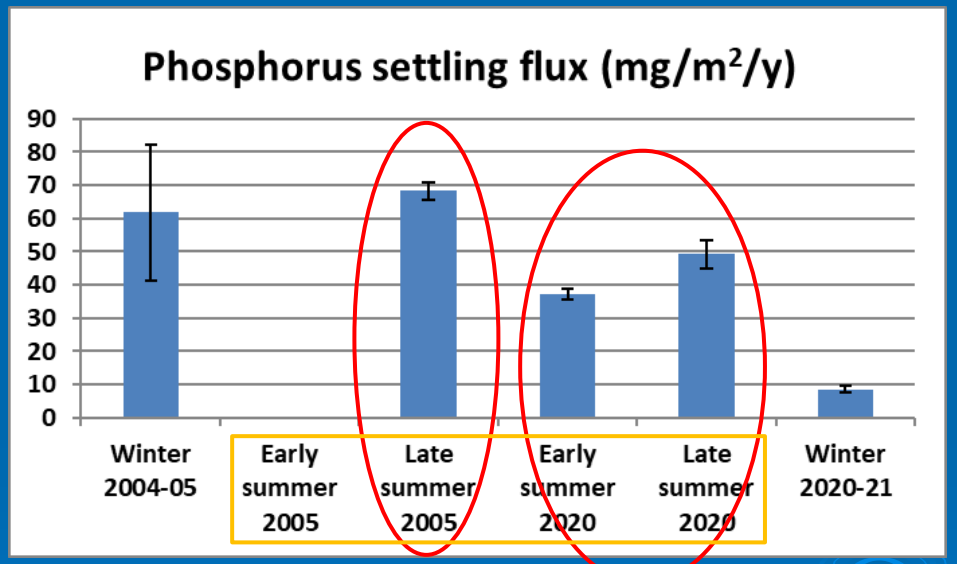
Introduce a « wild card »: paradigm shift

- Water quality management works well when we apply monitoring and science to known problems
- Greatest uncertainties in forecasts are due to unknowns
- Things you don’t know about can bite you in the back side!

Sediment traps were deployed in Torch Lake in 2005 and 2020 to measure the loss of phosphorus by settling

- Calcite adsorbs phosphorus and removes the nutrient from the water column as it settles.
- This process removes most of the phosphorus input to the lake each year (the balance flows out thru Torch River).



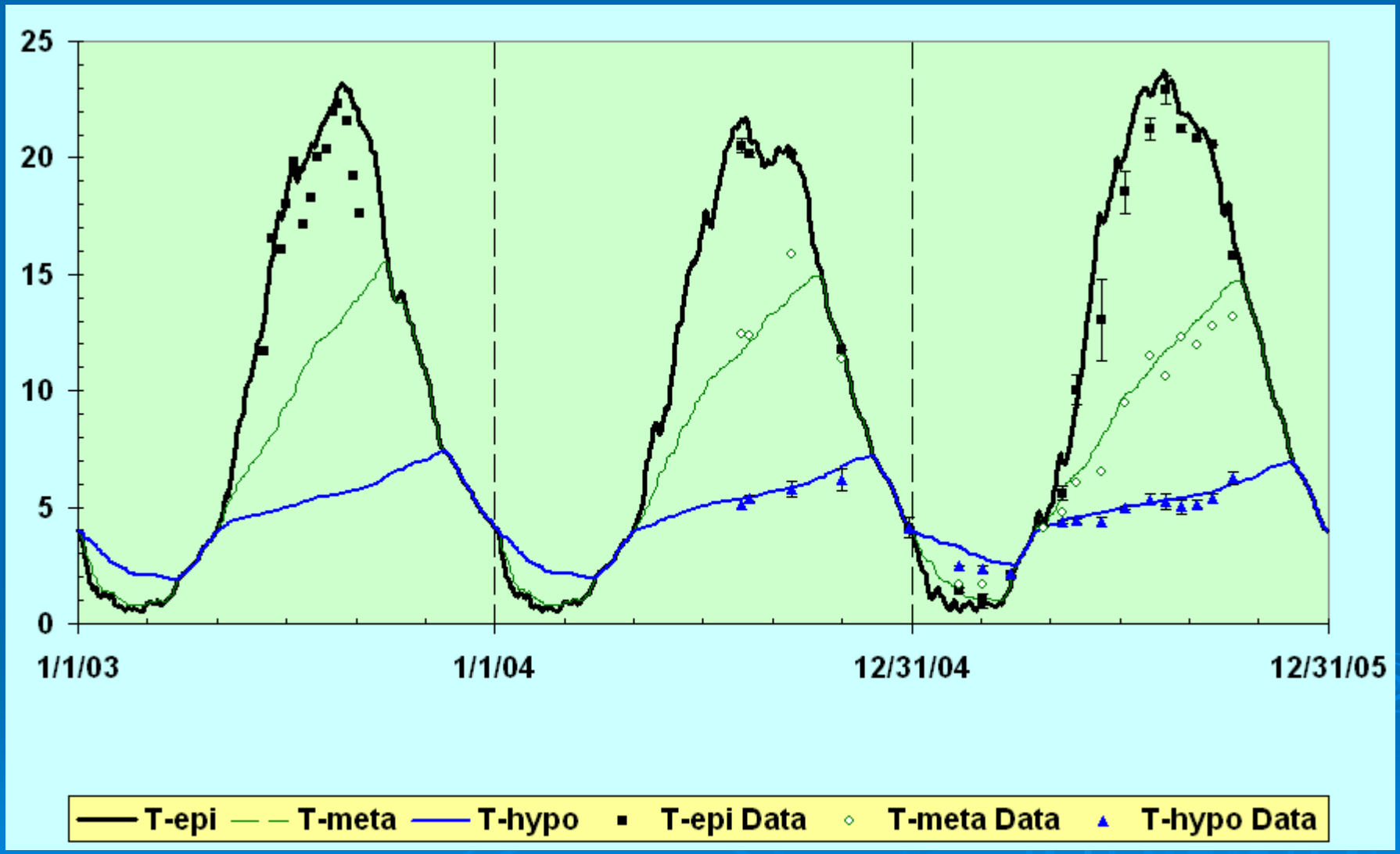


- We focus on the stratified summer period fluxes
- The timing of removal appears to vary from year to year. In 2005, essentially all of the settling took place after July, but in 2021 about half of it occurred earlier in the summer.
- This timing may be related to how early the surface water heats in summer
- Sediment trap data suggests that total phosphorus loadings and concentrations have been fairly consistent between 2005 and 2020

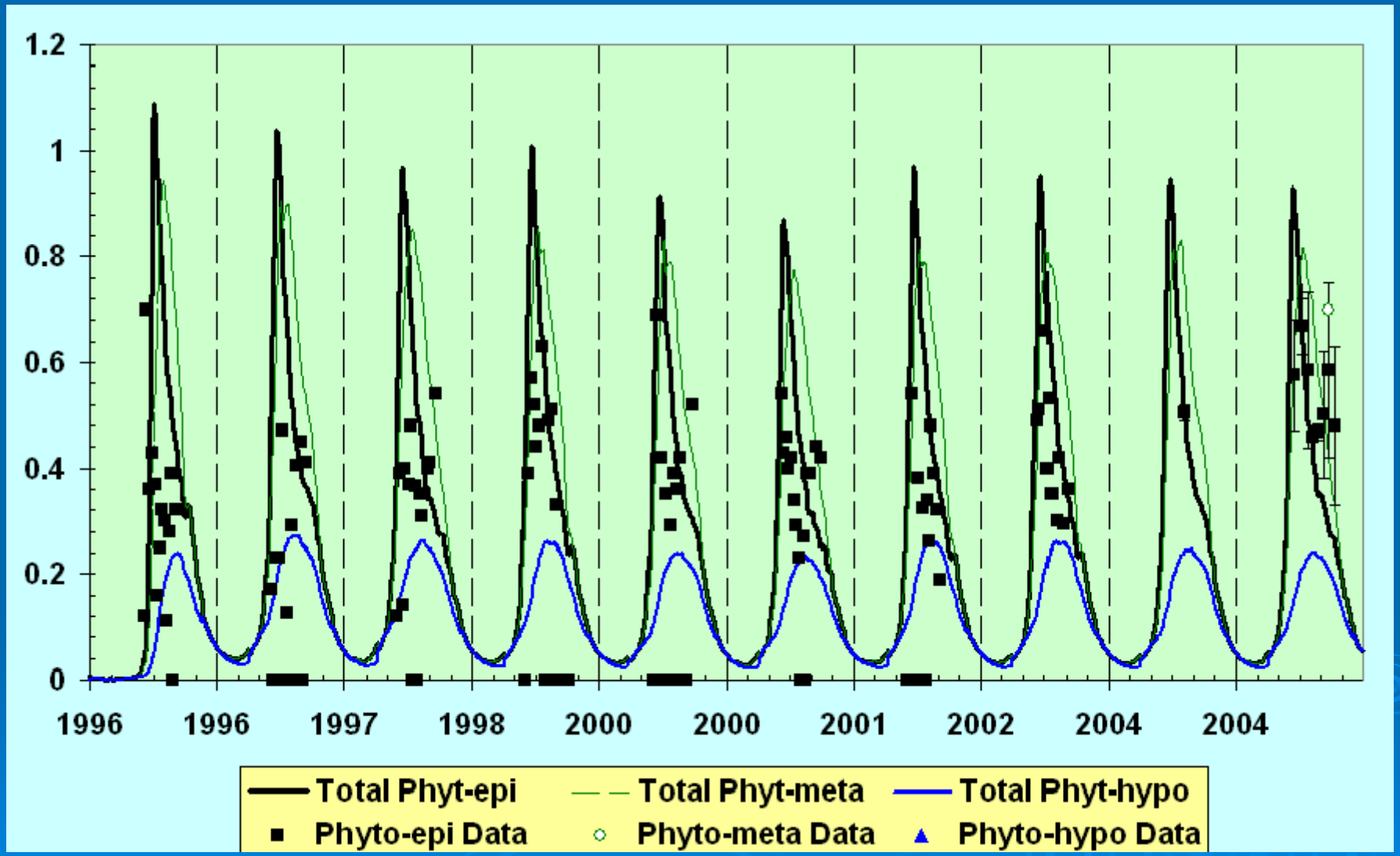
How Was the 2004-2005 Mass Balance Study Funded?

- In 1999, GLEC and Dr. Ray Canale developed a proposal for a water quality study at the request of Torch Lake Protection Alliance. A source of funding could not be found.
- In 2003, Three Lakes Association (TLA) and GLEC worked together to develop a revised proposal for a water quality study and identify funding options.
- In 2004 TLA was awarded a Michigan Department of Environmental Quality *Local Water Quality Monitoring Grant* for $62,000 to conduct a mass balance study for Torch Lake and develop a predictive water quality model.
- In 2005 TLA was awarded a second grant for $80,000 to develop water quality models for Clam Lake and Lake Bellaire, as well as a watershed model for the drainage basin.

Temperature Calibration (2003-05)



Chlorophyll a calibration (1996-2005)



$4 Million Torch Lake Cottage

- Reasonable question: How is the value of real estate on Torch Lake related to outstanding water quality?