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A PRACTICAL INTRODUCTION TO WATER QUALITY MODELLING

Adding some relevance to what we do first…

- Citarum River, Indonesia
- Unreported World: "The World's Most Polluted River"
- Pollution due to domestic waste and textile factories
- https://www.youtube.com/watch?v=AkSXB-IRAp0

Citarum River

- "Tragedy of the Commons"
  - 1 small textile plant is not a problem, dozens are
  - 10 villages of 6,000 inhabitants are not a problem, hundreds of them are
- Multifaceted problem
  - Textile factories → jobs → population growth → more domestic waste
  - Jobs → economy
  - No waste-collection system
  - No enforcement of legislation
- Who is responsible for the problem?
- Who is responsible to solve it?

So what is the role of water quality models?

- Models are not a solution, but..
- Water quality models can assess impacts of individual developments
  - Typically what is done in EIA and EMMP studies
- Water quality models can aid planning purposes
  - Given certain effluent standards, how many factories can discharge to this water course before surface water quality standards are exceeded?
  - Is measure X effective to counteract the expected increase in pollution due to population growth of Y%

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Purpose of today's course

- To be equipped to review modelling works done as part of environmental impact assessments
- To understand the use of models in assessing and quantifying environmental impacts of project generated pollution

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Contents

Item No	Topic	Duration [min.]
1	WQ modelling basics	45
2	Application of basics in review of ADB funded projects	45
3	Data and data collection	45
4	Interpretation of model results	45
5	Challenges and opportunities in water quality	30
6	ToR for water quality modelling consultant	20

Water quality modelling basics

What is a model and how can we use models?

- https://www.youtube.com/watch?v=uWuNfhDvZz8

What is a model?

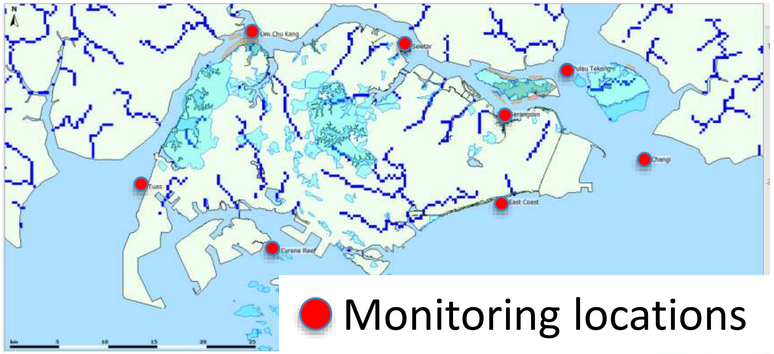
- "A **simplified representation** of reality that tells you **how something works or will work**."
- Used for known things, **unknowns** and **predictions**
- **Not** (and nor ever will be) **perfect**

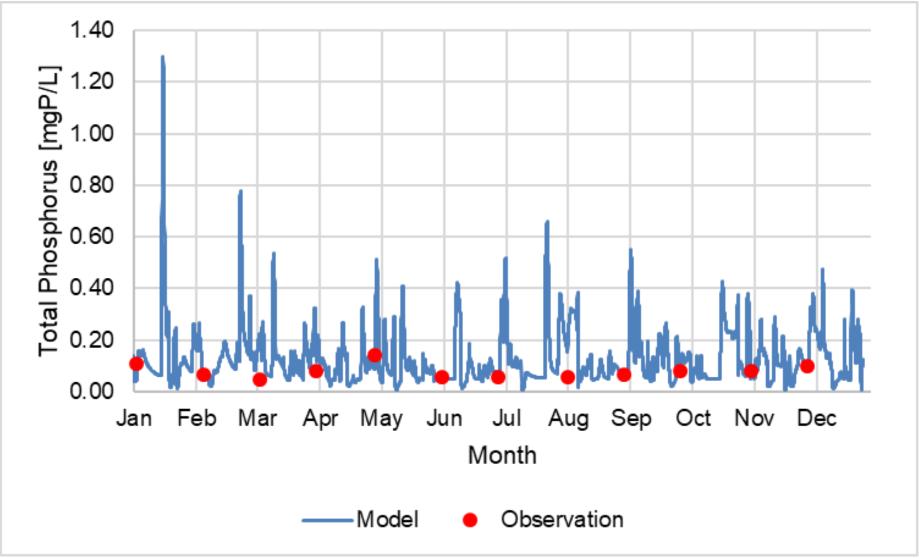
Use of **water quality** models

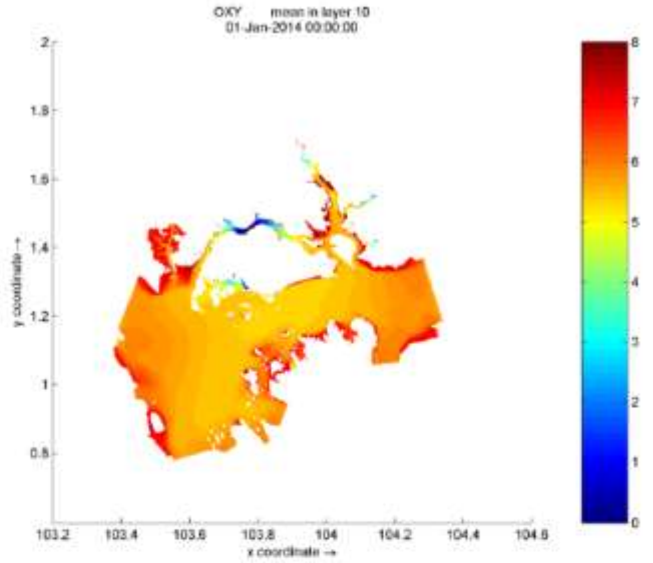
- Representation of known things
  - Model verification: calibration and validation

Use of **water quality** models

- Understand unknowns
  - Interpolate in time
  - Interpolate in space
  - Unobserved parameters







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Use of **water quality** models

- Predict what could happen
  - Environmental Impact Assessment (EIA)
  - Planning purposes
    - Create pollutant risk maps for the intake of a new plant
    - Master planning
  - Climate impacts
  - Environmental Monitoring and Management Programme (EMMP)
  - Real-time advisory
    - Oil and chemical spills
    - Beach water quality
    - Aquaculture operations
  - …

Not perfect. Models…

- Need to be fine-tuned
  - We deal with the environment → continuous changes require regular models updates and recalibration
- Used properly and carefully
  - Modelling: everyone can use a GUI or edit text files; not everyone understands what goes on behind the GUI
- Are only as good as the information you put in
  - More assumptions → more uncertainty
- Are a simplified representation of reality
  - Purpose of modelling determines level of complexity

Model useful if

- Clear defined purpose
- Understand the limitations of the model
- Confident that the outcome is a good representation of reality

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Purpose

1. Location of countries on earth
2. Location of countries on earth AND distance between places
3. All the above and I want to be able to determine the shortest route from place to place…

From purpose to model choice

- Purpose → Simplifications → Level of Complexity → Model choice

Model	Complexity	Simplifications	Purpose
Map of earth	Simple	Flat	Location of places
Globe	Medium	No roads	Location of places; Distance between places
Computer	Complex	Only major roads included	Location of places; Distance between places; Route finding

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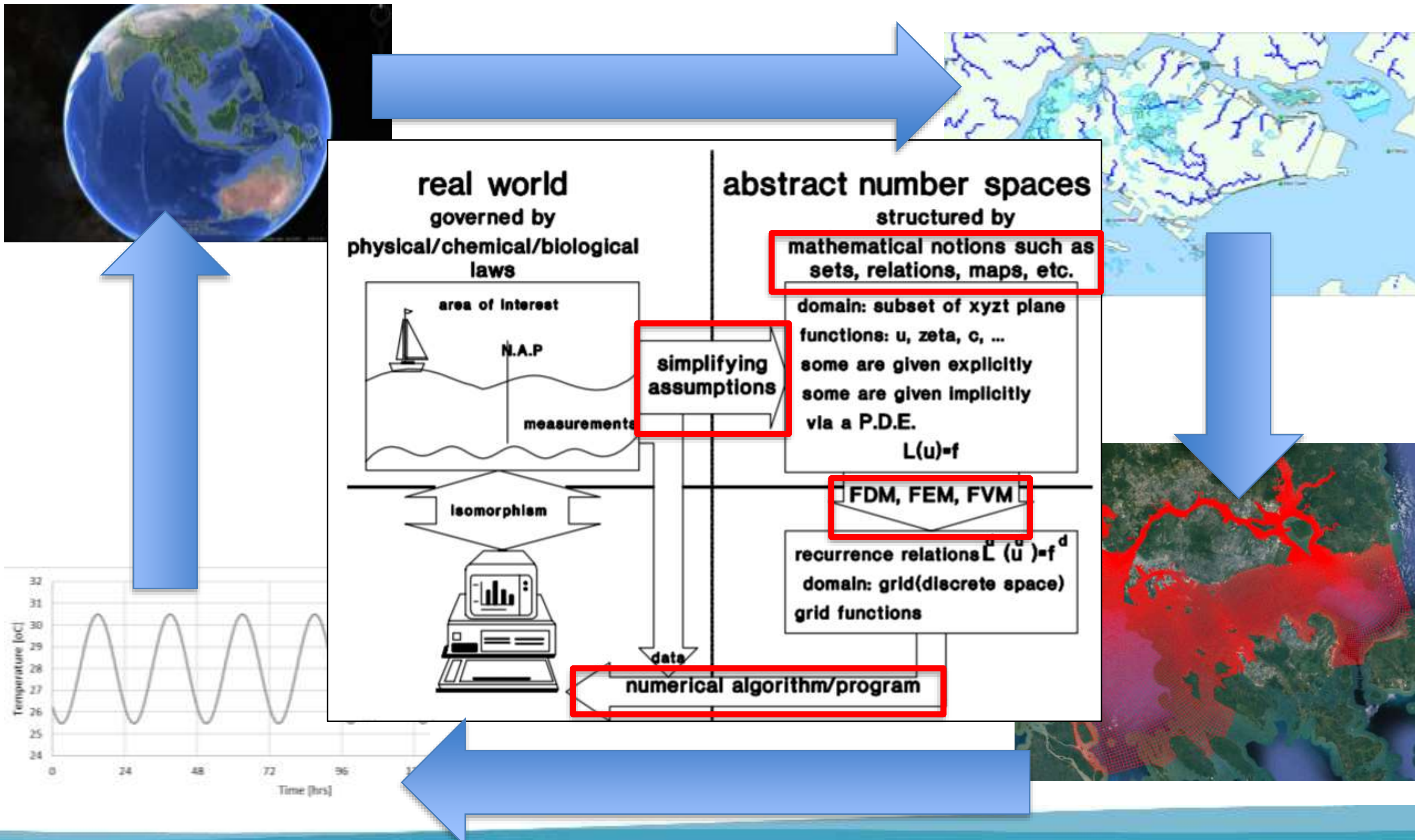
Understand model limitations

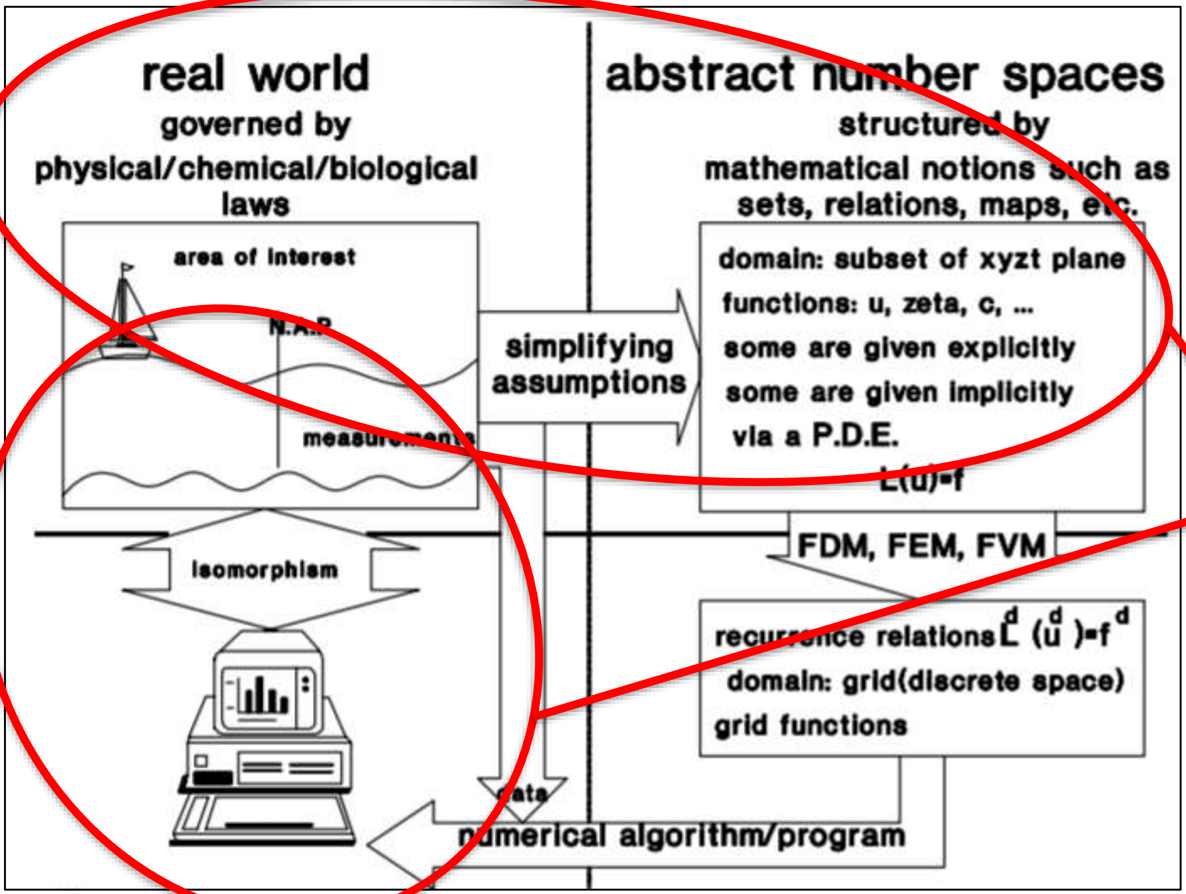
- From modelling purpose and associated simplifications, you can derive what a model can and cannot be used for

Model	Complexity	Simplifications	Purpose
Map of earth	Simple	Flat	Location of places
Globe	Medium	No roads	Location of places; Distance between places
Computer	Complex	Only major roads included	Location of places; Distance between places; Route finding

Computer models



Our focus



Main focus of today

Mass balance equation

$$M_i^{t+\Delta t} = M_i^t + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{Tr} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_P + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_S$$

- The mass of a pollutant in my **model segment** in the next time step is a function of:
  - Current mass (Mi)
  - Transport (Tr)
  - Processes (P) (i.e. physical, chemical, biological for WQ)
  - Adding/subtraction by sources/sinks (S)

Transport

$$M_i^{t+\Delta t} = M_i^t + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{Tr} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_P + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_S$$

- Transport from segment to segment

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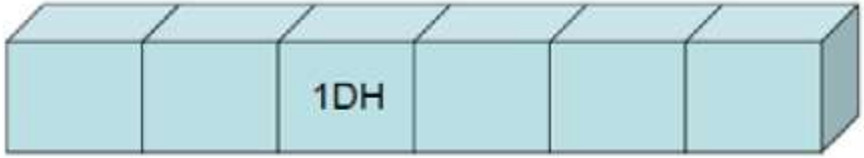
Processes

$$M_i^{t+\Delta t} = M_i^t + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{Tr} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{P} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{S}$$

- Physical: reaeration, settling, light reflection
- Chemical: mineralisation of organic matter, phosphate adsorption
- Biological: primary production by algae, mortality of bacteria



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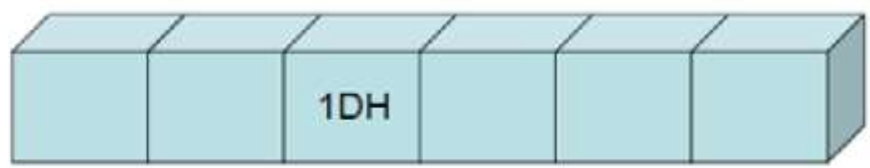
Sources / discharges

$$M_i^{t+\Delta t} = M_i^t + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{Tr} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_P + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_S$$

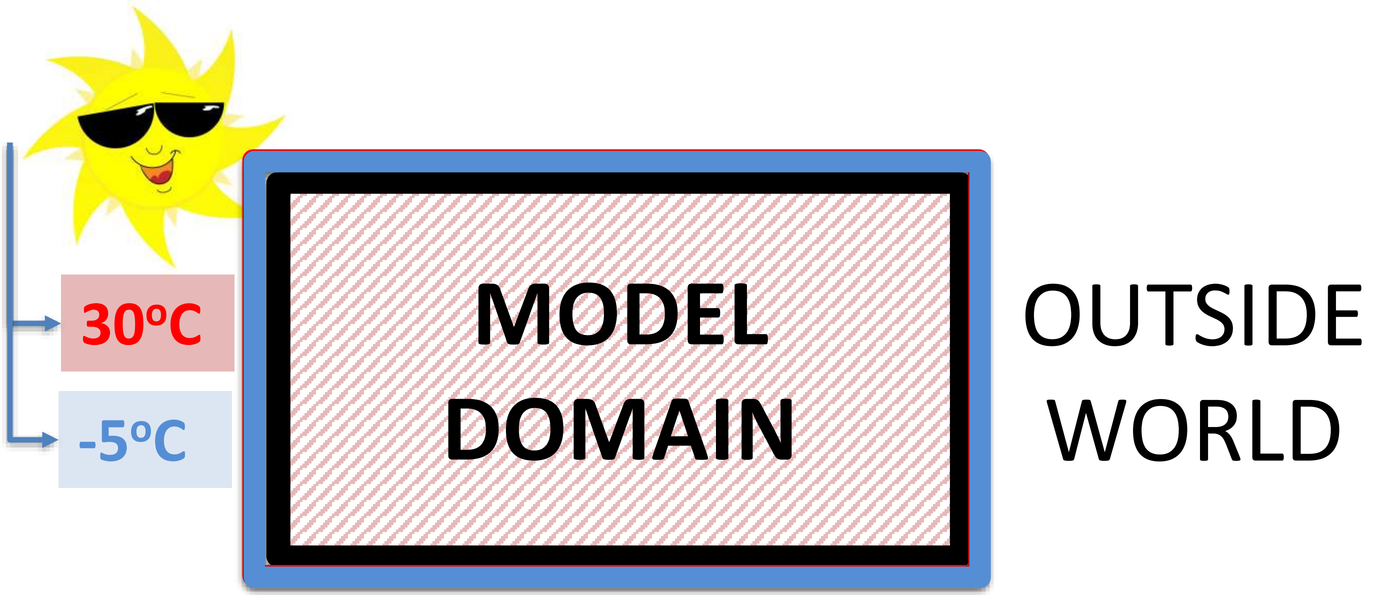
- River discharges
- Incidental spills
- Atmospheric deposition
- Boundary flows



Cooling of a classroom

Boundary conditions

- What is a boundary condition?



BC = representation of the outside world (i.e. a representation of everything we don’t model)

Boundary conditions

- How does a boundary condition impact a model?
- Let’s consider the following situation…

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Would you swim here?

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And how about here?

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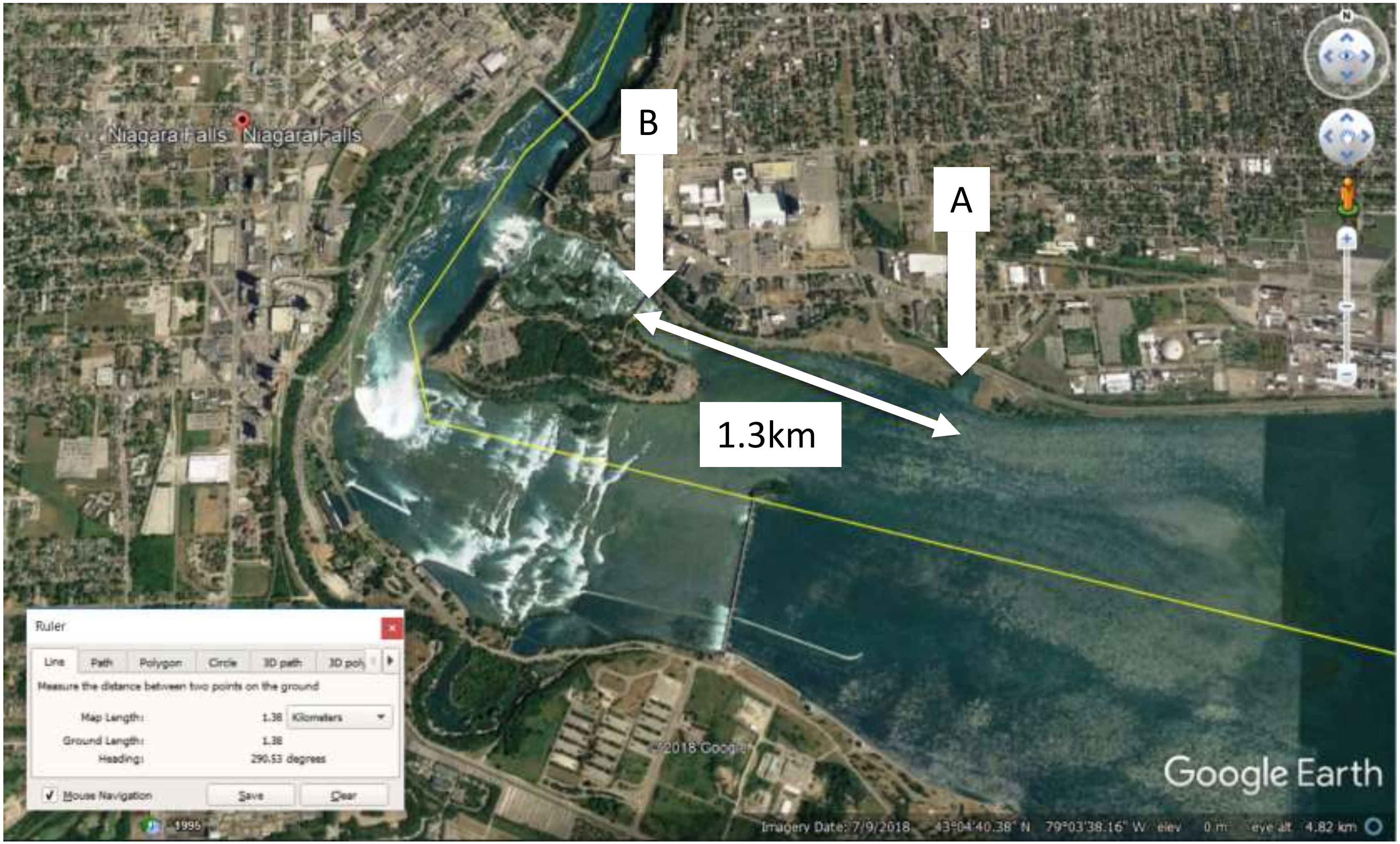


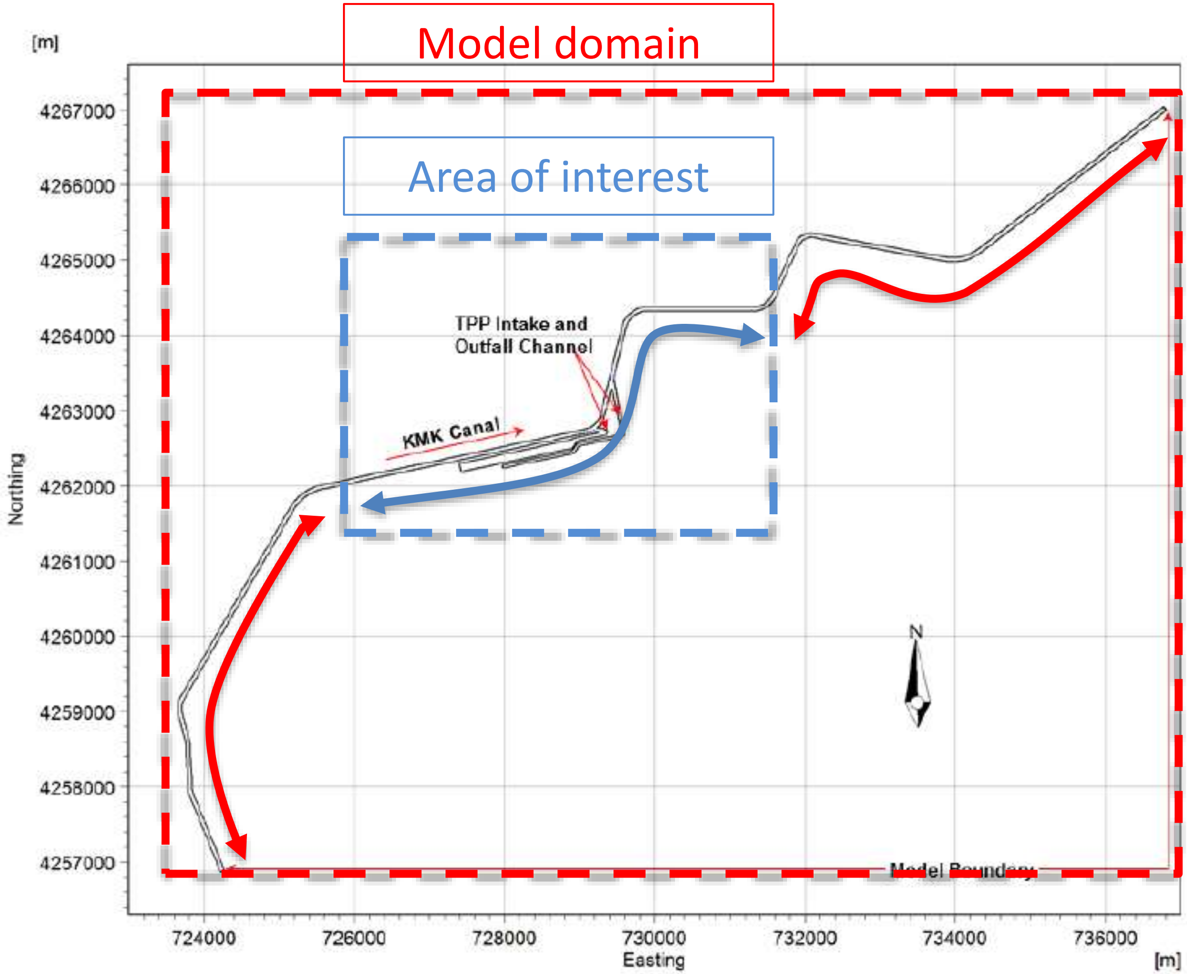
Boundary conditions

- How does a boundary condition impact a model?
  - Boundary conditions “compete” with internal processes

Boundary conditions

- How does a boundary condition impact a model?
  - Boundary conditions “compete” with internal processes
  - Boundary conditions win this “competition” at the edge of a model
  - A relatively small model may be impacted much by the boundary condition
    - Extending the model domain may help to avoid impact of boundary conditions
    - Else, you need to know the boundary condition very well to reduce its impact

Example 1



Source: Mott MacDonald, 2018.

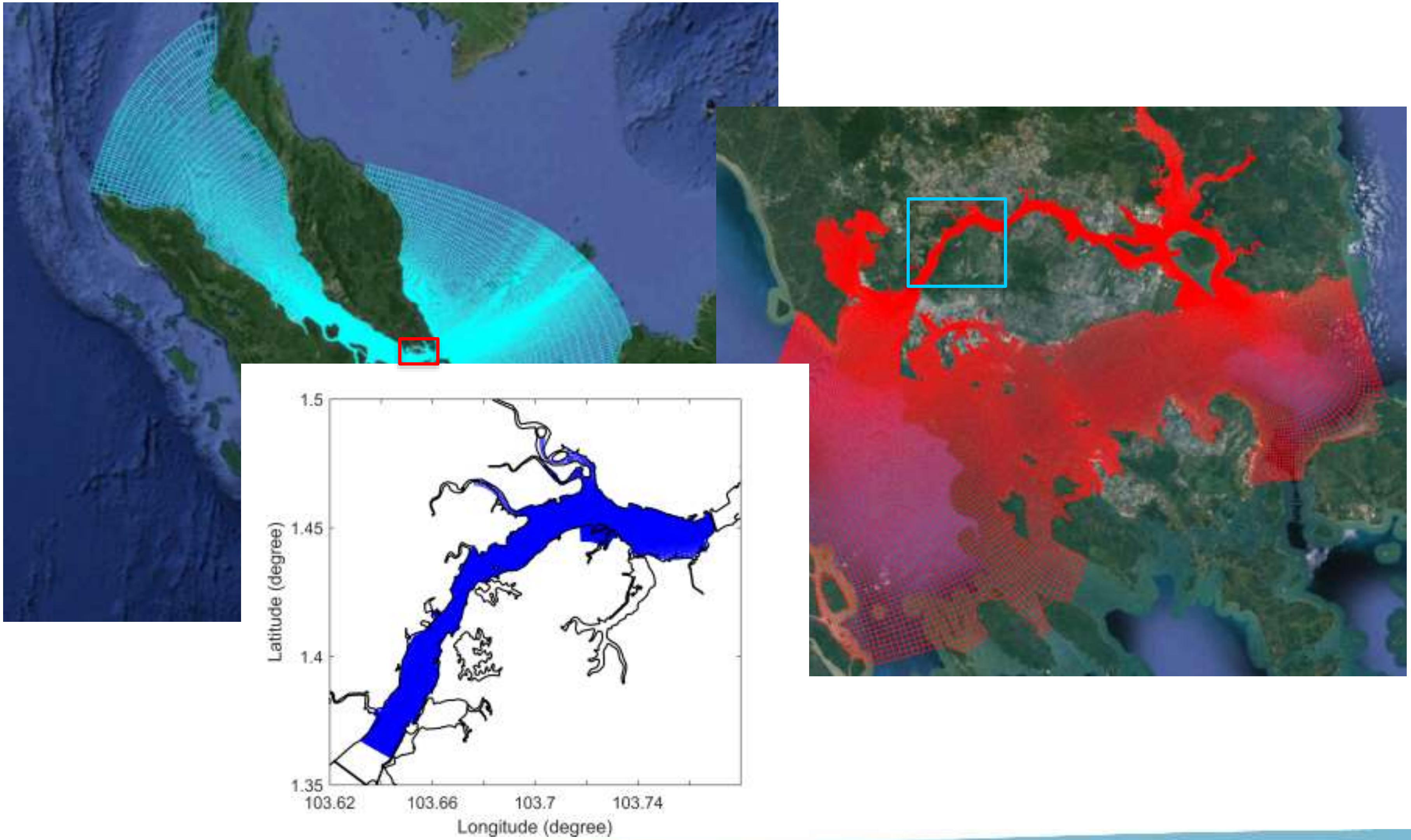
T dominated by:

- Boundary condition
- Processes (heat exchange between water and air)

T dominated by:

- Processes (heat exchange between water and air)
- Thermal discharge

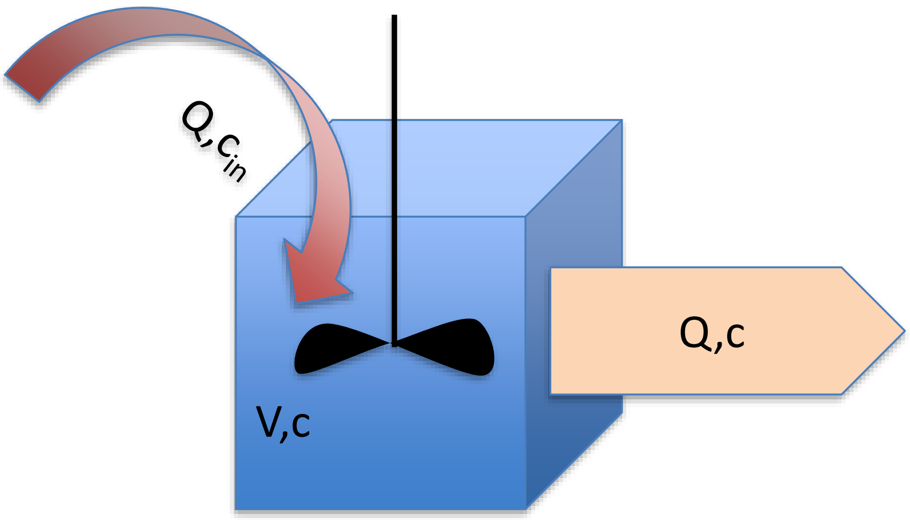
Example 2


1.5
1.45
1.4
1.35
Latitude (degree)
103.62
103.66
103.7
103.74
Longitude (degree)

Initial conditions

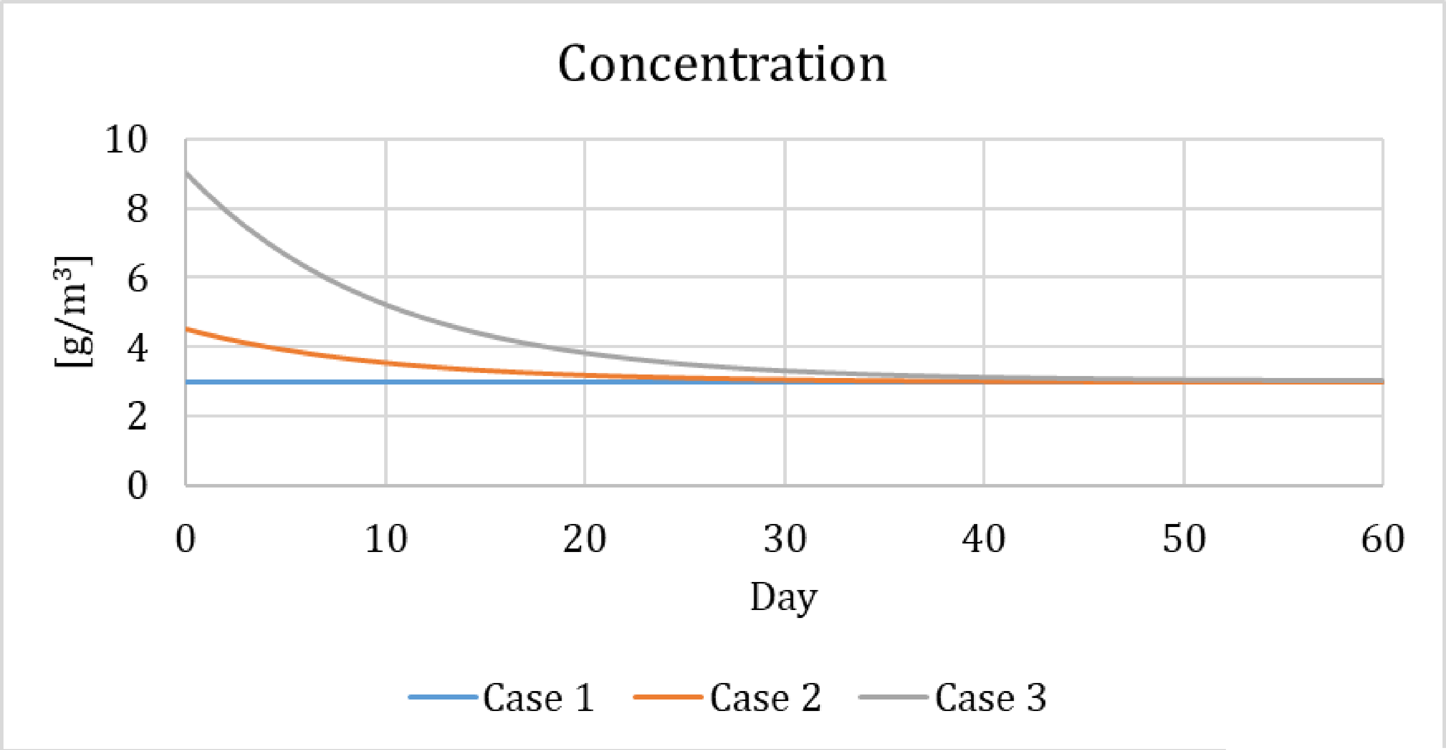
- At t_0, is the temperature $0^{o}C$, $20^{o}C$, $35^{o}C$?
- Ultimately, the model reaches an equilibrium condition between BC, internal processes and internal sources → Steady-state
- Like BC, the IC should not impact our area of interest

Initial conditions

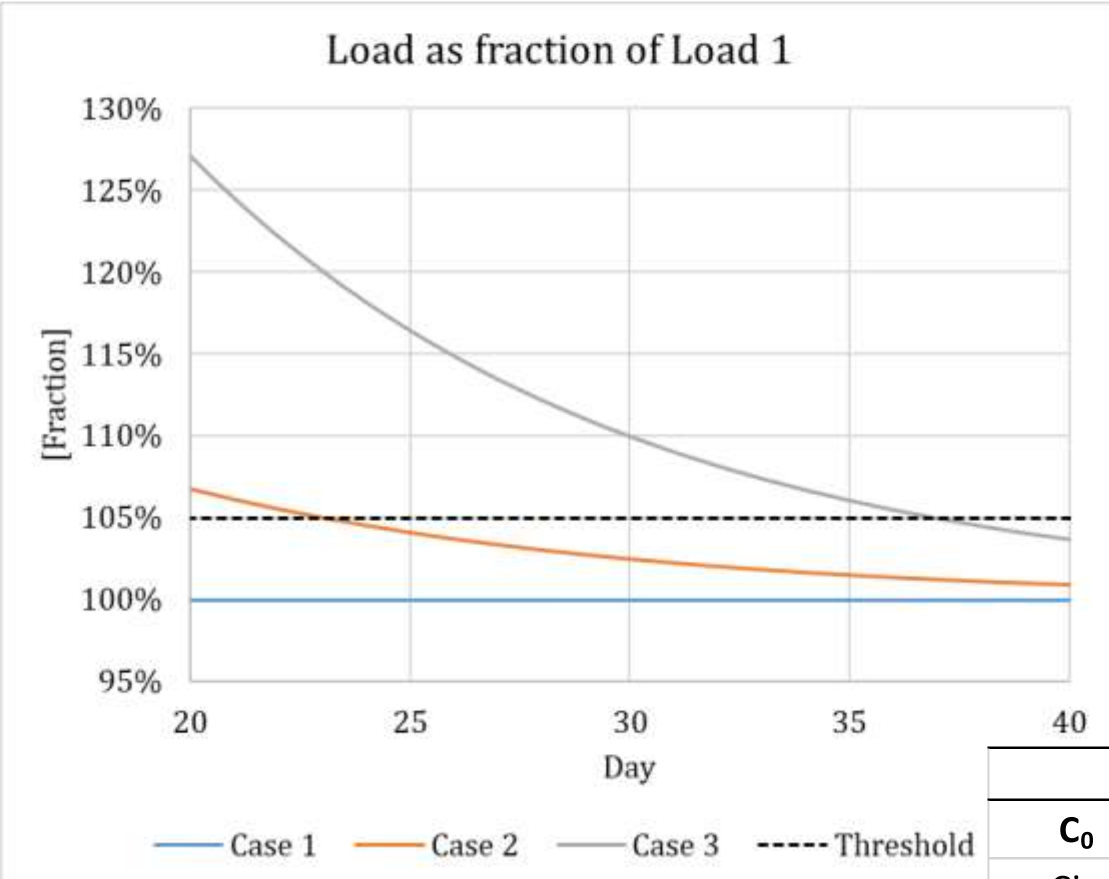


- How do you expect the concentration to change over time for each of the cases?

		Case 1	Case 2	Case 3
C_0	**[g/m^3]**	**3**	**4.5**	**9**
Cin	[g/m^3]	3	3	3
Q	[m^3/d]	0.1	0.1	0.1
L	[g/d]	0.3	0.3	0.3



		Case 1	Case 2	Case 3
C_0	**[g/m^3]**	**3**	**4.5**	**9**
Cin	[g/m^3]	3	3	3
Q	[m^3/d]	0.1	0.1	0.1
L	**[g/d]**	**0.3**	**0.3**	**0.3**



- Threshold → acceptable error margin (5%)
- Load 2 → stable after ~24 days
- Load 3 → stable after ~37 days

		Case 1	Case 2	Case 3
C_0	**[g/m^3]**	**3**	**4.5**	**9**
Cin	[g/m^3]	3	3	3
Q	[m^3/d]	0.1	0.1	0.1
L	**[g/d]**	**0.3**	**0.3**	**0.3**

Key messages

- Water quality models consist of:
  - Transport
  - Processes
  - Source terms
- Aside, two main features are present in models:
  - Boundary conditions: impact model results spatially → choose extent such that area of interest is minimally impacted by BC
  - Initial conditions: impact model results temporally → run model till a steady-state is reached and only then use it for assessments

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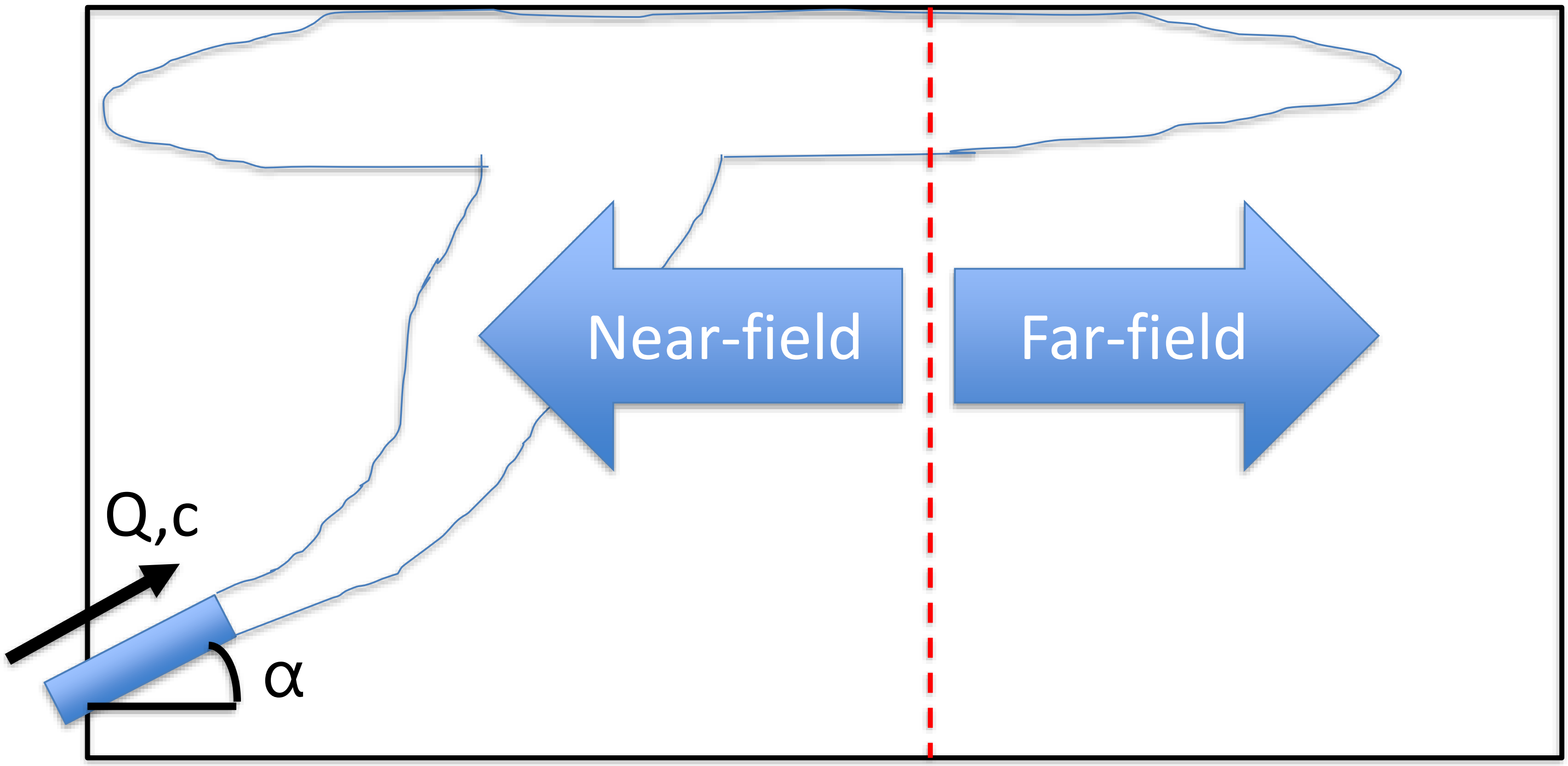
Before we break..
Mixing zones

- Definition… (from: IFC EHS Guidelines 2017)

41. In general, thermal discharge should be designed to ensure that discharge water temperature does not result in exceeding relevant ambient water temperature standards outside a scientifically established mixing zone.[40] The mixing zone is typically defined as the zone where initial dilution of a discharge takes place within which relevant water quality temperature standards are allowed to exceed and takes into account cumulative impact of seasonal variations, ambient water quality, receiving water use, potential receptors and assimilative capacity among other considerations. Establishment of such a mixing zone is project specific and may be established by local regulatory agencies and confirmed or updated through the project's EA process. Thermal discharges should be designed to prevent negative impacts to the receiving water taking into account the following criteria:

[40] A mixing zone is an established area where water quality standards can be exceeded as long as acutely toxic conditions are prevented and all beneficial uses, such as drinking water, fish habitat, recreation and other uses are protected. The mixing zone concept is widely used in the US, the EU and other parts of the world. Mixing zone boundaries are usually determined through a mass-balance or mathematical modelling approach. Mass-balance calculations essentially involve defining the effective volume of the receiving water and calculating the amount of a substance that can be discharged into that volume to achieve a desired concentration. Mixing zones may be spherical or elongated, turbulent or calm, stratified or diffuse depending on the specific characteristics of the effluent and the receiving water bodies. For confined waters (e.g., water bodies with narrow channels or low flow), in some countries a limit is placed upon the proportion of the channel width occupied by the mixing zone. For example, in the UK, it is recommended that the mixing zone should not occupy more than 25% of the cross-sectional area of the estuarine channel for the annual 98th percentile (i.e., it may be exceeded for no more than 2% of the time).

Before we break..
Mixing zones



Mixing zones

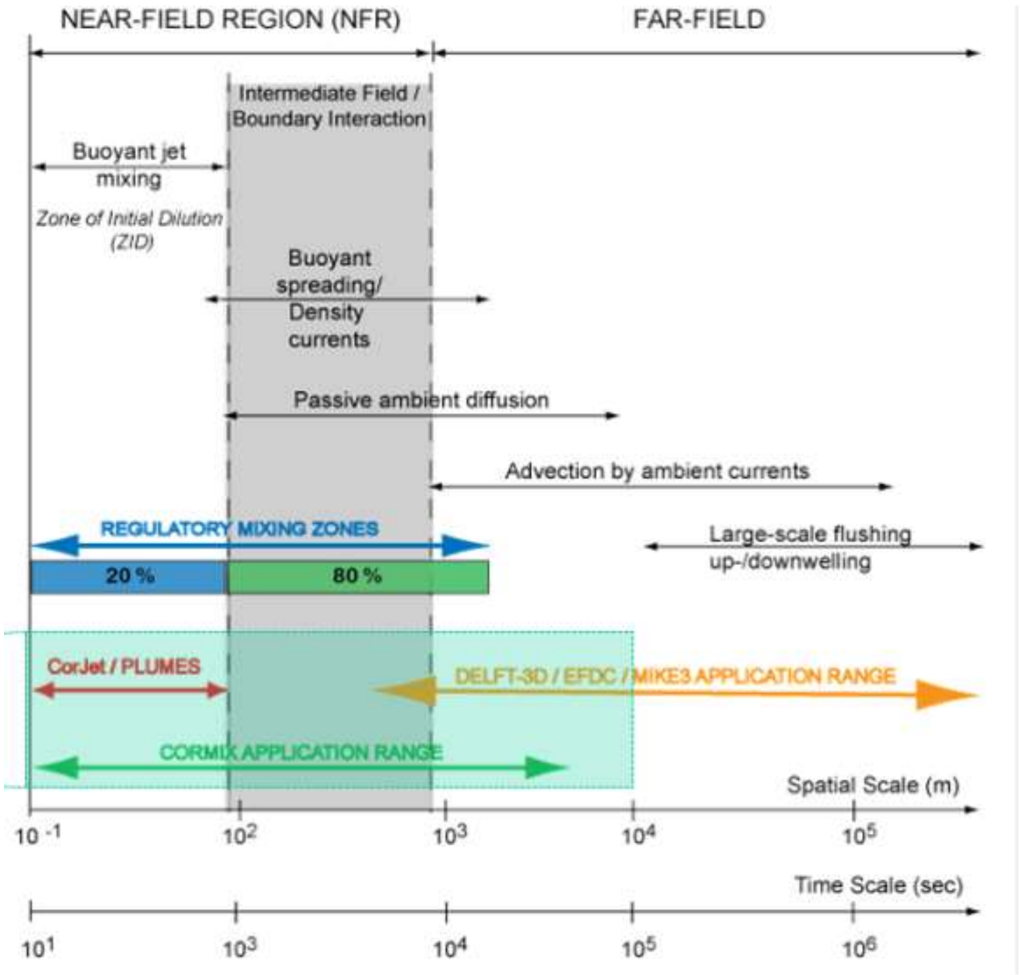


Figure from: http://www.cormix.info/cormix-delft3d.php

When to use what?

- Non jet-like phenomena → use far-field model
- Jet-like phenomena → can opt for combination of near-field and far-field model

Application of Basics in Review of ADB Funded Projects

Case introduction

- Project location: Jaffna, Sri Lanka
- Facility: Seawater reverse osmosis desalination plant
- Effluent: concentrated brine
- Environmental Category: A

Evaluate the report

- Is the purpose of the modelling clearly stated?
  - If yes, describe the purpose.
  - If no, what do you think the purpose is? From which information do you derive this?
- Are the limitations/assumptions of the model described and understood?
  - If yes, describe the limitations.
  - If no, what do you think makes the model most uncertain?
- Can you trace back basic information about the model setup (e.g. boundary conditions, outfall characteristics, baseline)
  - If yes, please describe.
  - If no, what information is missing?
- Is the model a good representation of reality?
  - If yes, how do you know it is?
  - If no, what is needed to show the model is?
- Based on your answers to the foregoing questions, do you find the modelling done useful?

Case introduction

- Project location: Talimarjan, Uzbekistan
- Facility: Thermal power plant
- Effluent: thermal discharge
- Environmental Category: A

Evaluate the report

- Is the purpose of the modelling clearly stated?
  - If yes, describe the purpose.
  - If no, what do you think the purpose is? From which information do you derive this?
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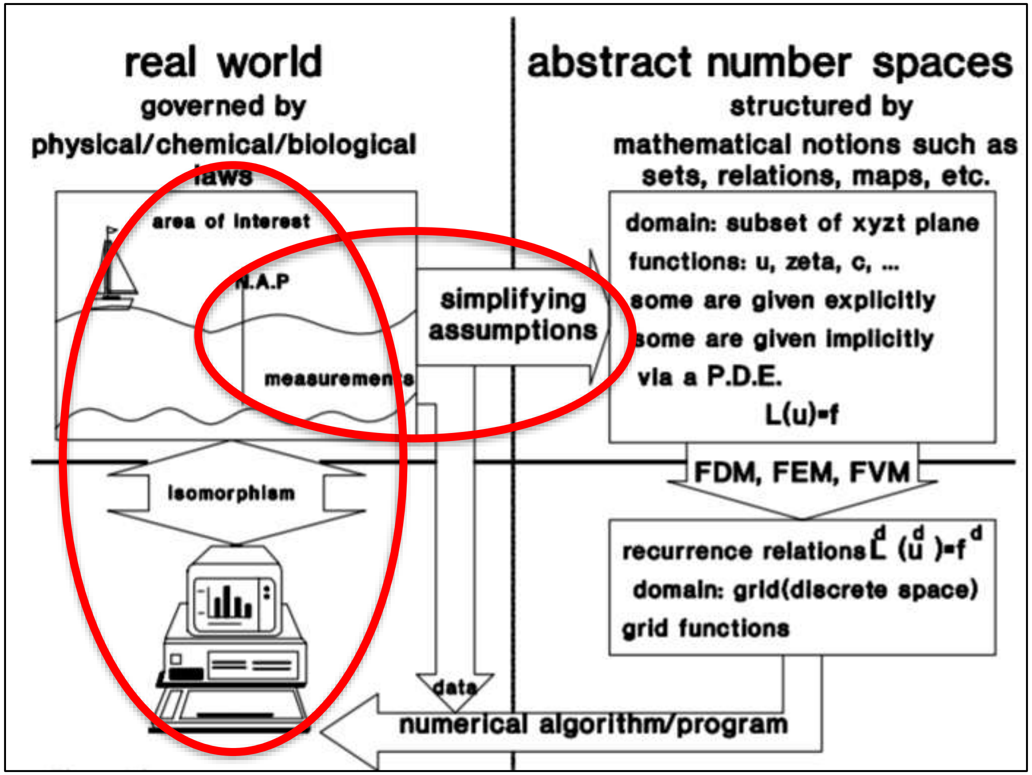
Data and Data Collection

Overview

- Baseline data
- Data requirements for operational models
- Data for model calibration and validation → will be discussed in next block (Interpretation of Model Results)

- But first..
  - Why talk about data in a modelling course?
  - Some basic principles about water quality data and water quality data collection

Why talk about data?

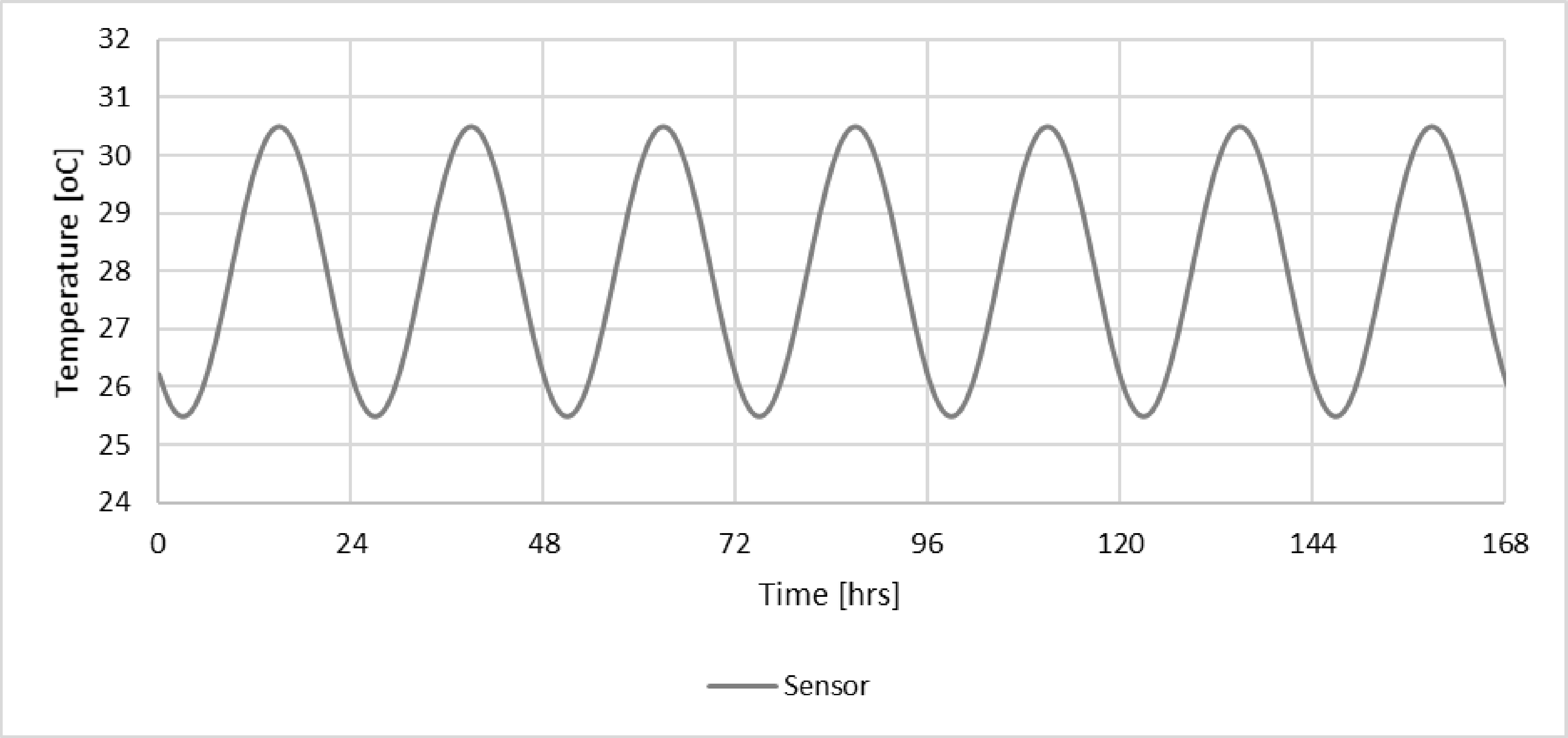


$$M_i^{t+\Delta t} = M_i^t + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_{Tr} + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_P + \Delta t\left(\frac{\Delta M}{\Delta t}\right)_S$$

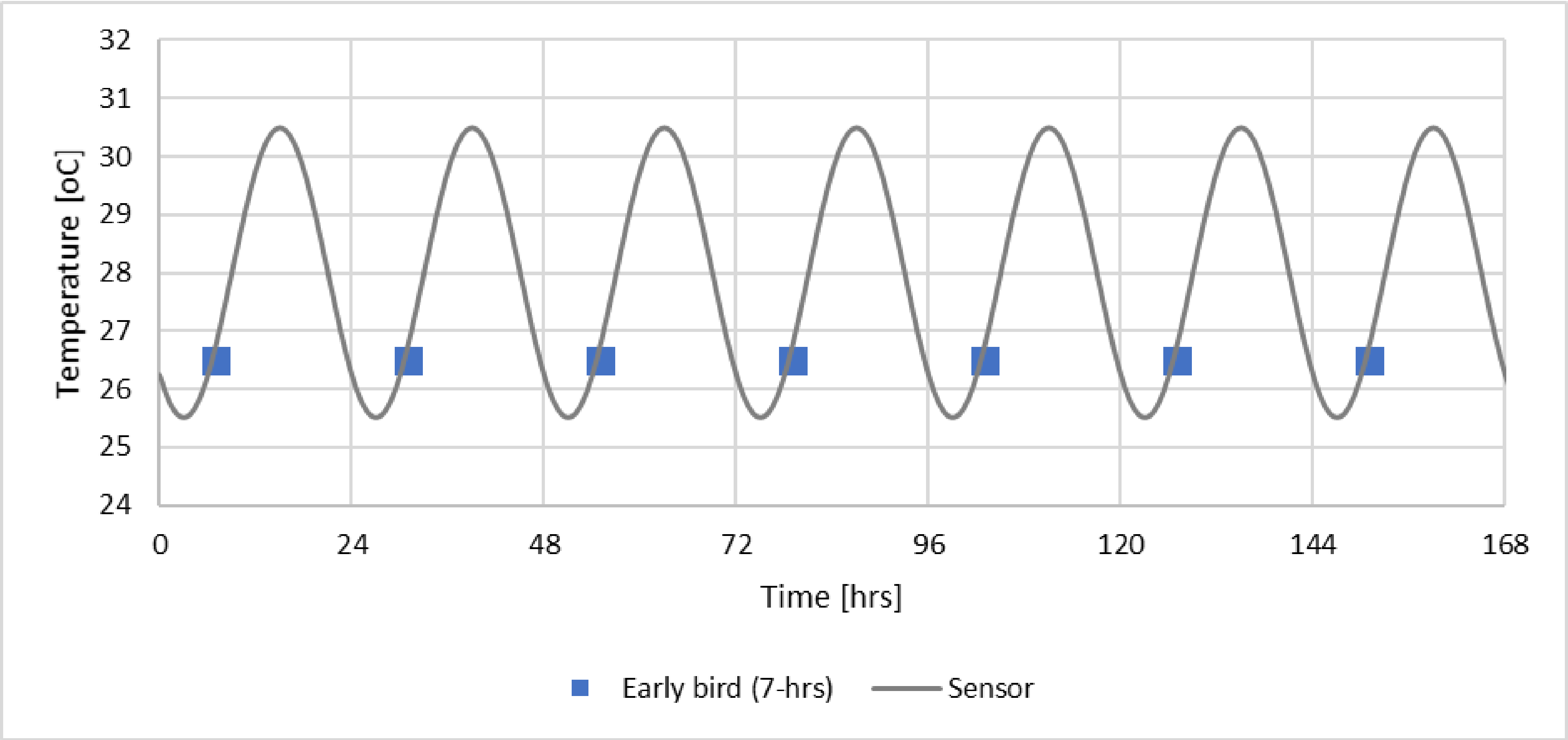
Some specific concerns with water quality data

- Data, often, are still sparse (in time and space)
  - Temperature, conductivity, dissolved oxygen, chlorophyll-a, turbidity can be measured with high temporal frequency.
  - Others need sample collection and lab analysis
    - Temporal frequency tends to be low (cost)
    - Results tend to be available with a delay
- Data quality is a concern, especially with sensors deployed in natural environments

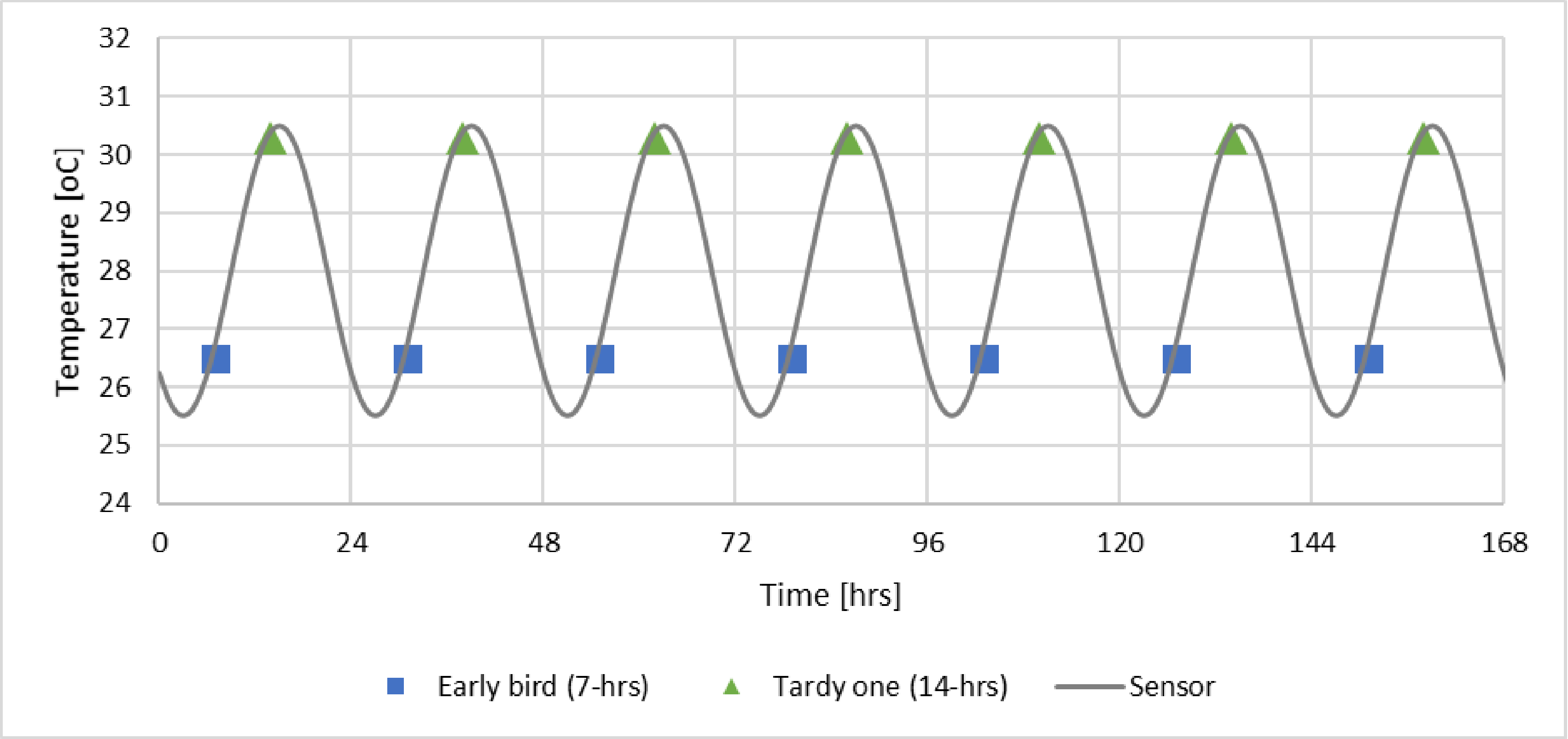
Undersampling



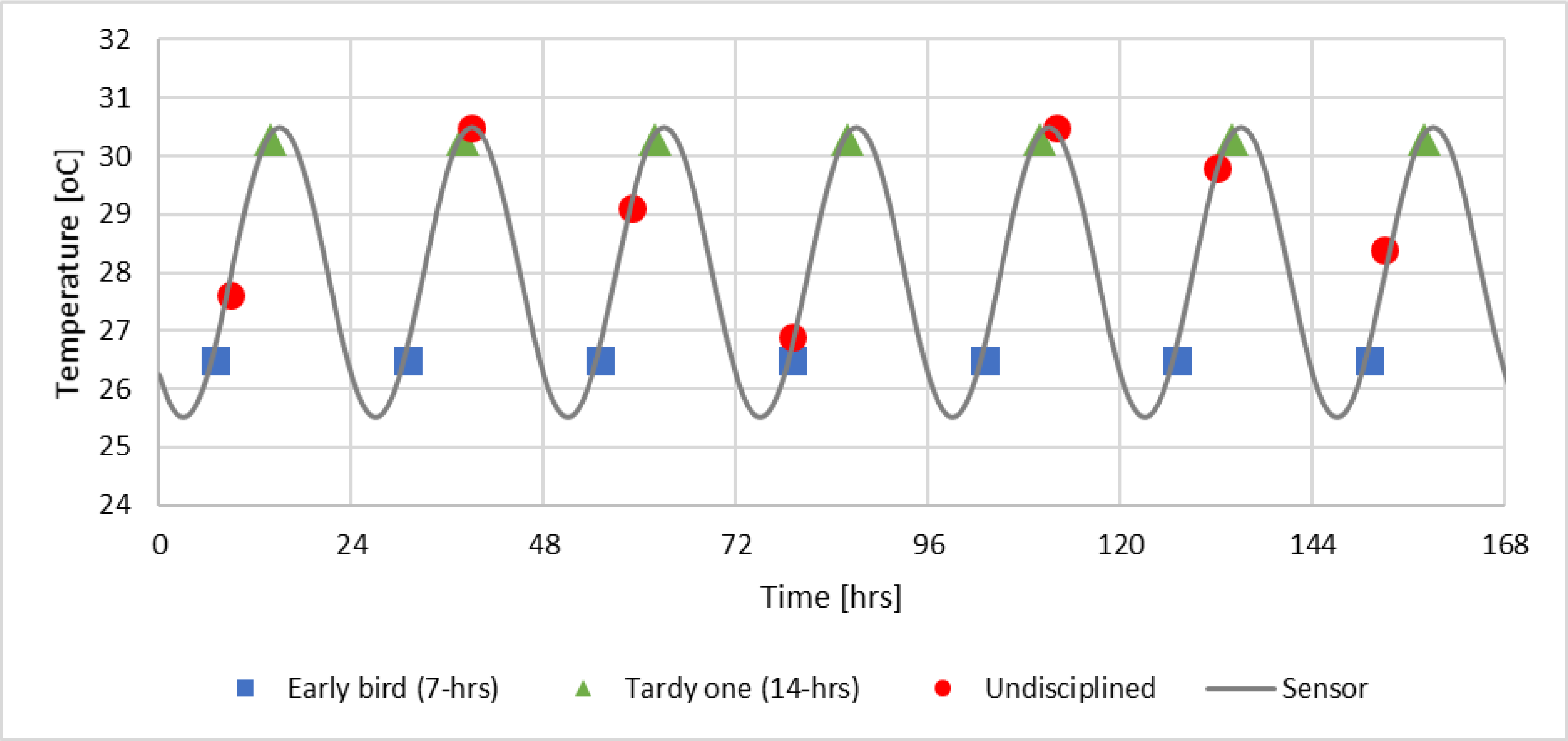
The early bird..



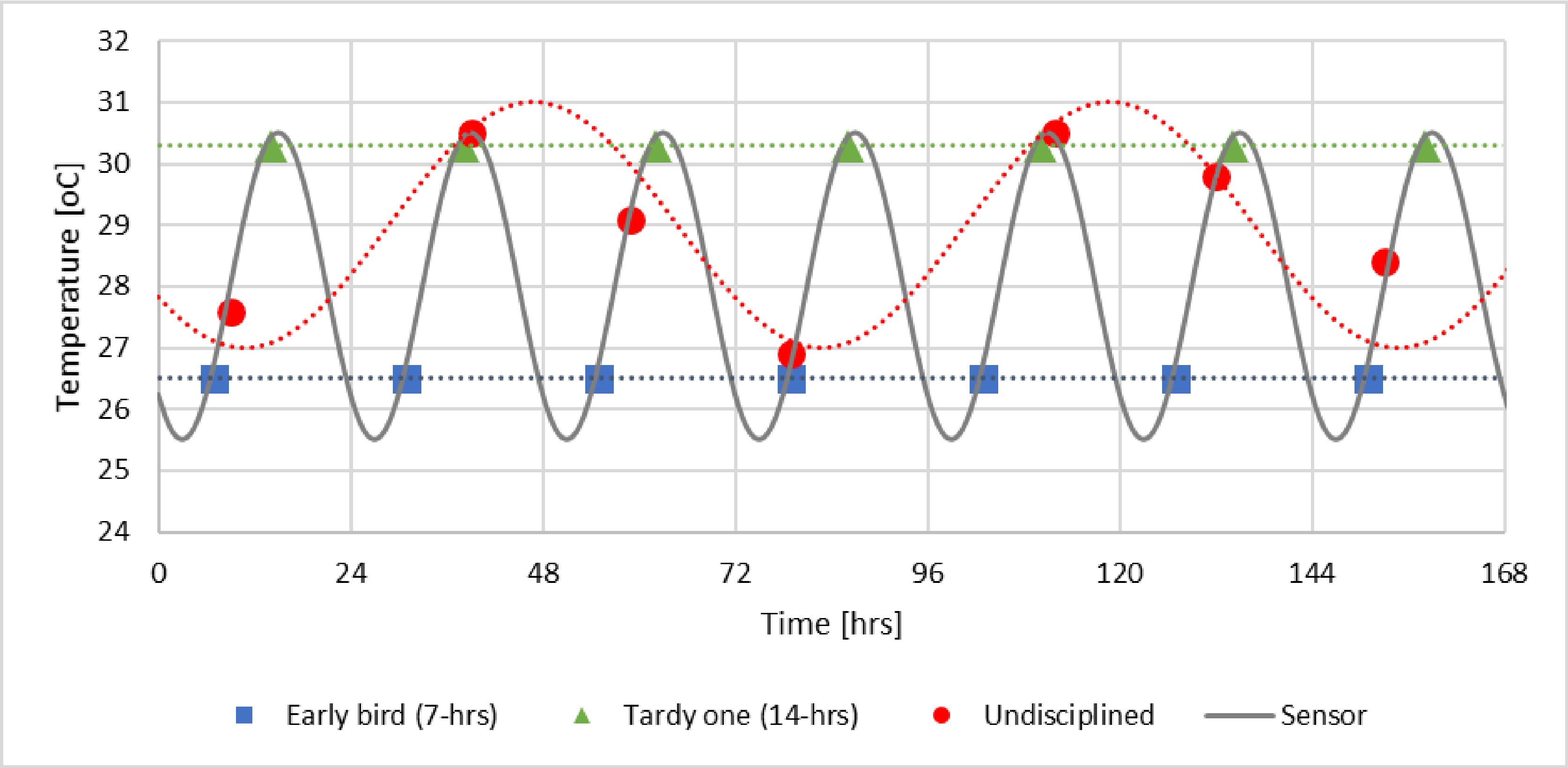
The tardy one..



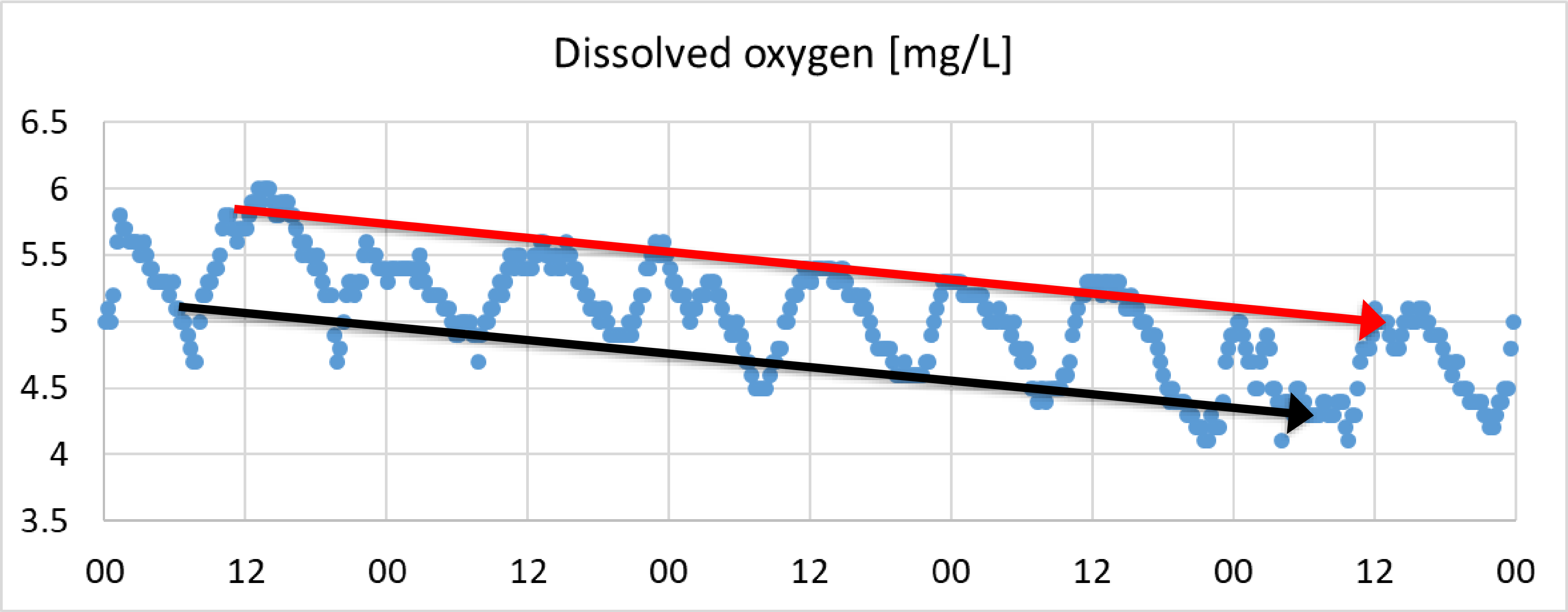
And the undisciplined.



Curve fitting



Example of real data set

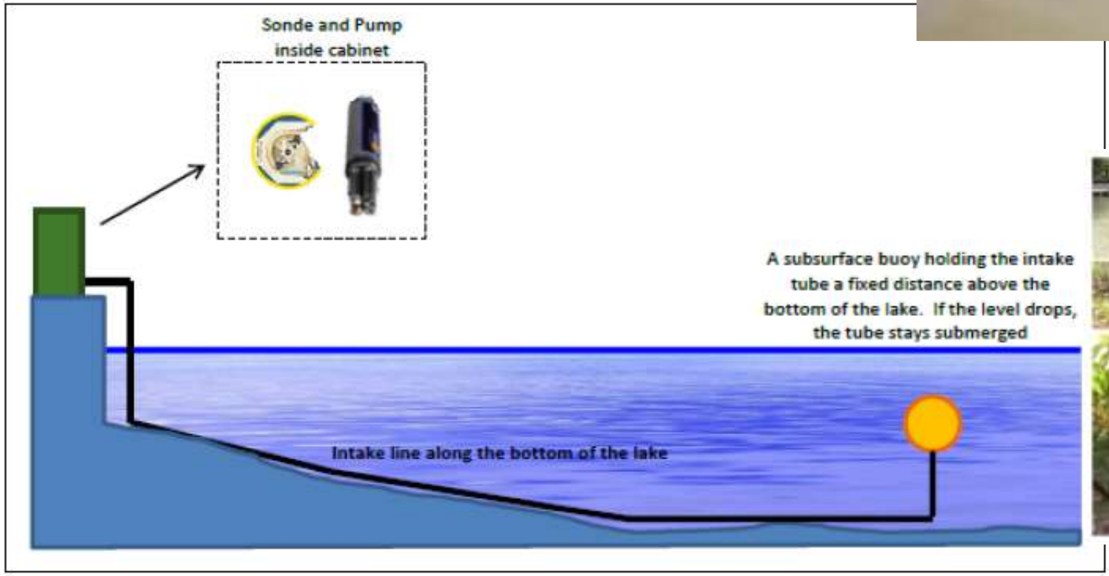


Key messages

- **Not** that we always need to measure so often
- But how we measure matters and needs to be documented
- We can introduce biases in models if our measurements are biased

Data quality

- Sensors
  - Deployed in water
  - Site-mounted



Data quality

- Sensors
  - If permanently deployed in water → Cleaning
    - Sedimentation
    - Bio-fouling
  - If site-mounted → Design
    - Tube clogging
    - Artificial heating of water samples
  - In both instances → Calibration and other preventive maintenance required
- Samples
  - Sample collection and storage practices
  - Sample analysis practices

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Probe cleaning






Probe calibration

Key messages

- Data quality assurance is absolutely necessary
  - Strict maintenance schedules and procedures are needed to ensure quality of collected data
  - Before using data (in models), data cleaning is a necessity!
    - Outlier removal
    - Identification (and correction) of sensor offset
    - Identification (and correction) of sensor drift

Overview

- Baseline data
- Data requirements for operational models
- Data for model calibration and validation → will be discussed in next block (Interpretation of Model Results)

- But first.. some basic principles about water quality data and water quality data collection

Baseline

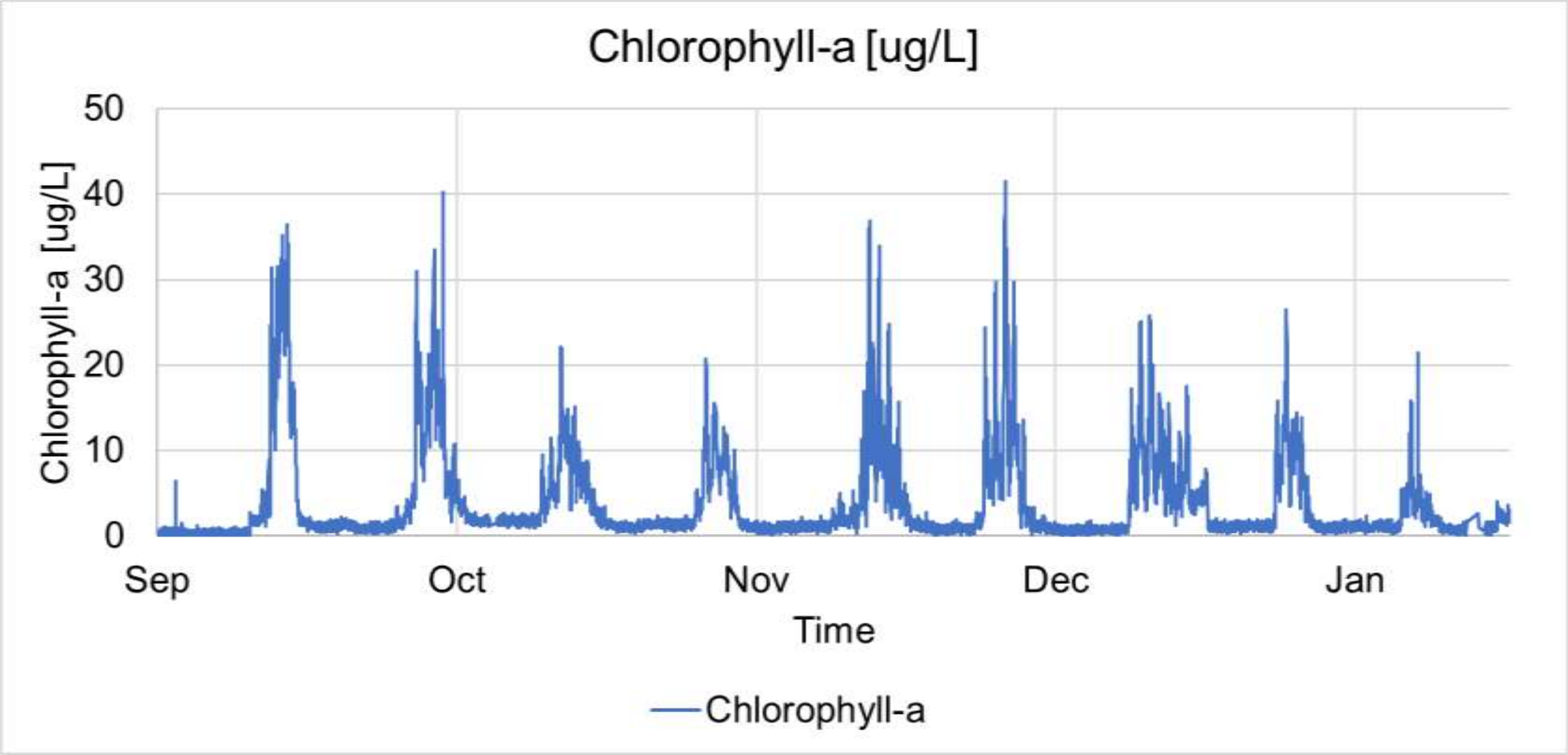
- Four options:
    1.) Long term data
    2.) Calibrated model
    3.) Compare with standards
    4.) Requirements of specific receptors

Long term data (Option 1)

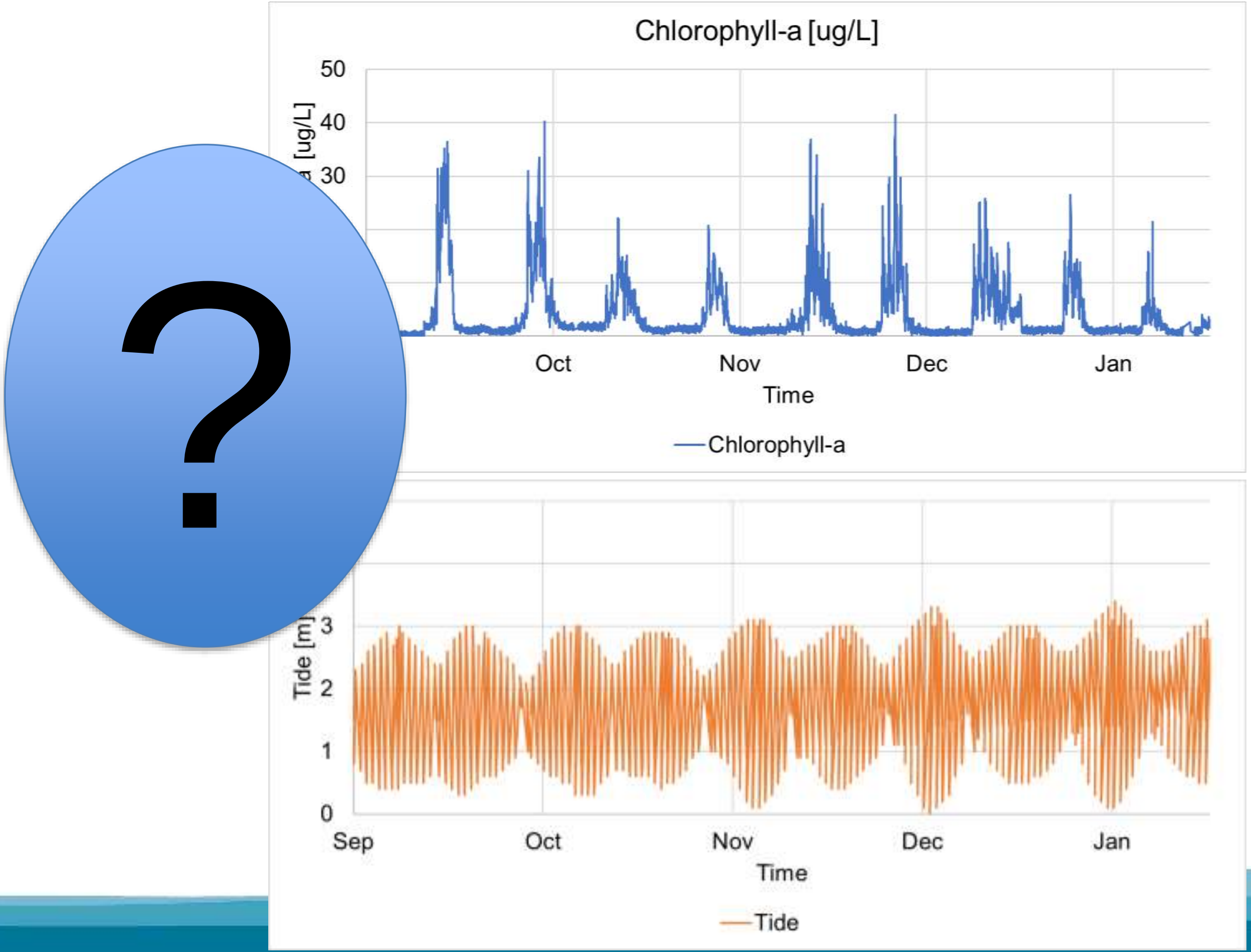
- Is today's situation representative?

Long term data (Option 1)

- What is long? It depends…

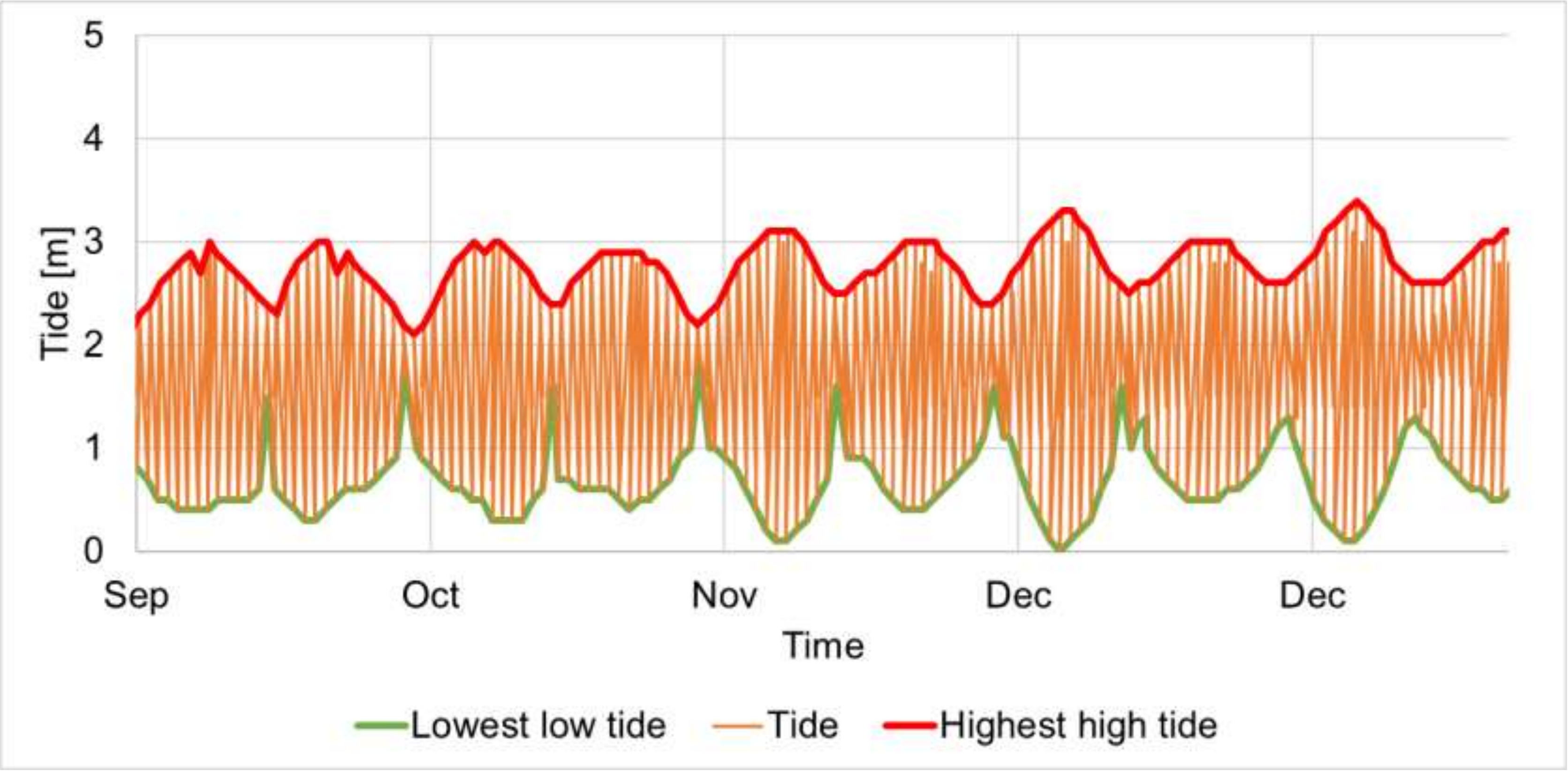


Chl-a vs. Tide

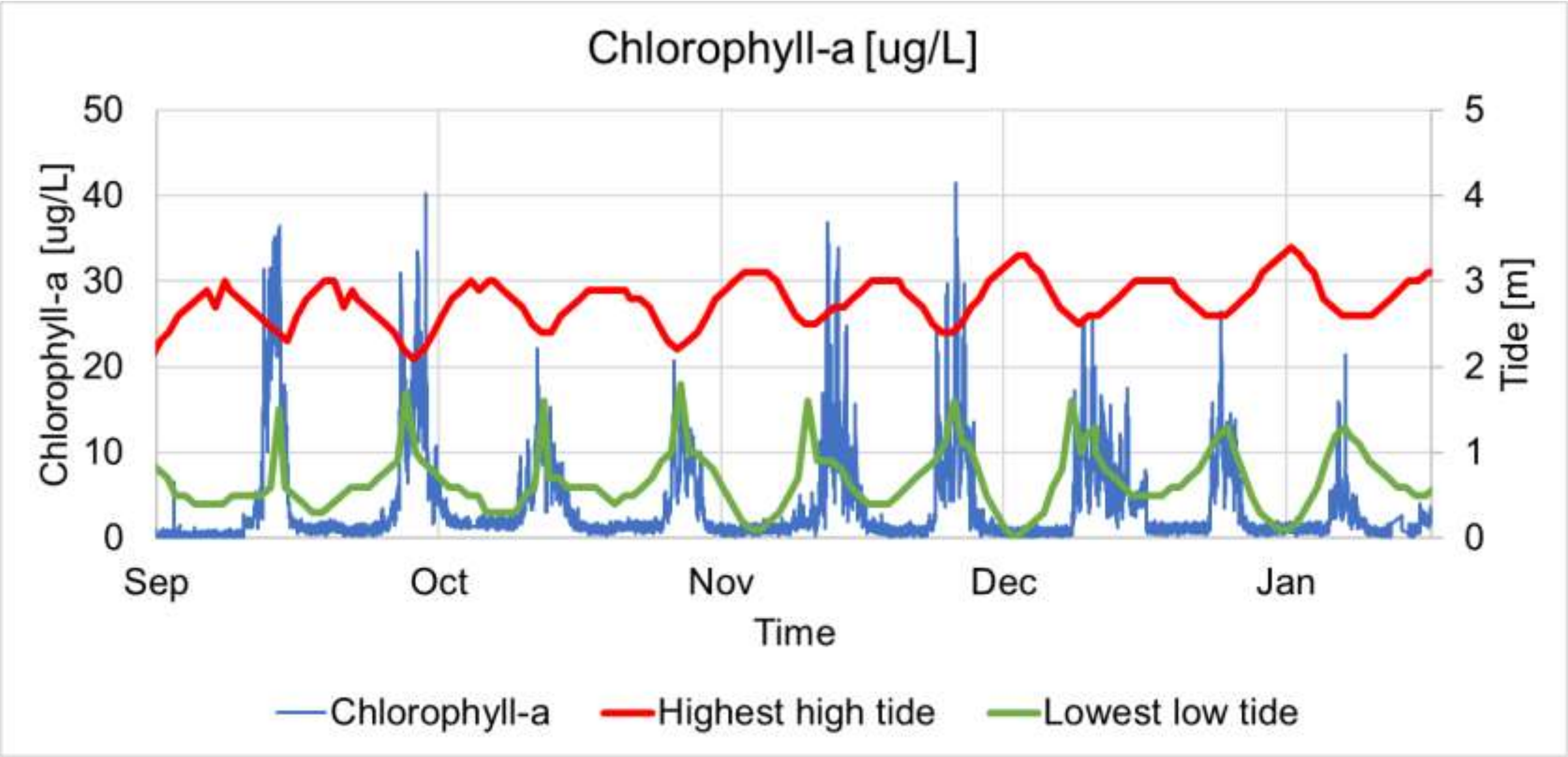


Chlorophyll-a [ug/L]
50
40
30
Oct
Nov
Dec
Jan
Time
Chlorophyll-a
Tide [m]
3
2
1
0
Sep
Oct
Nov
Dec
Jan
Time
Tide

Extracting LLT and HHT



Chl-a vs. LLT & HHT



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So, what's long term?

- A representative baseline should at least cover the time scale of the phenomena (natural or anthropogenic) that drive the system's behaviour.
- Hence, what is long term depends on the time scales of the driving phenomena.

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Natural phenomena

- Which natural phenomena can you think off and what is their time scale?

Calibrated model (Option 2)

- Calibrated model is supposed to represent observation data well
- Suitable for locations where no observations are available (remember, observation → 1/several point(s); model → spatial information)

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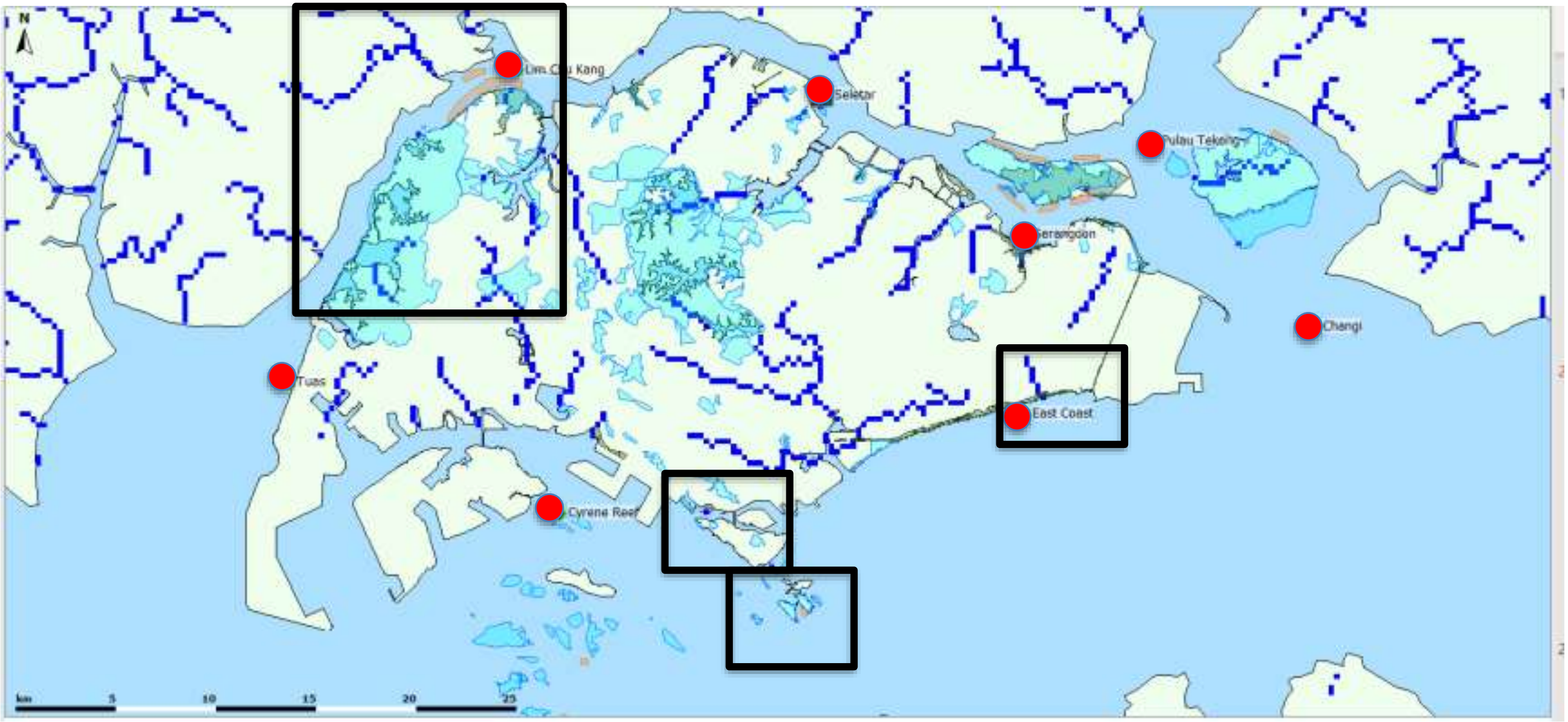
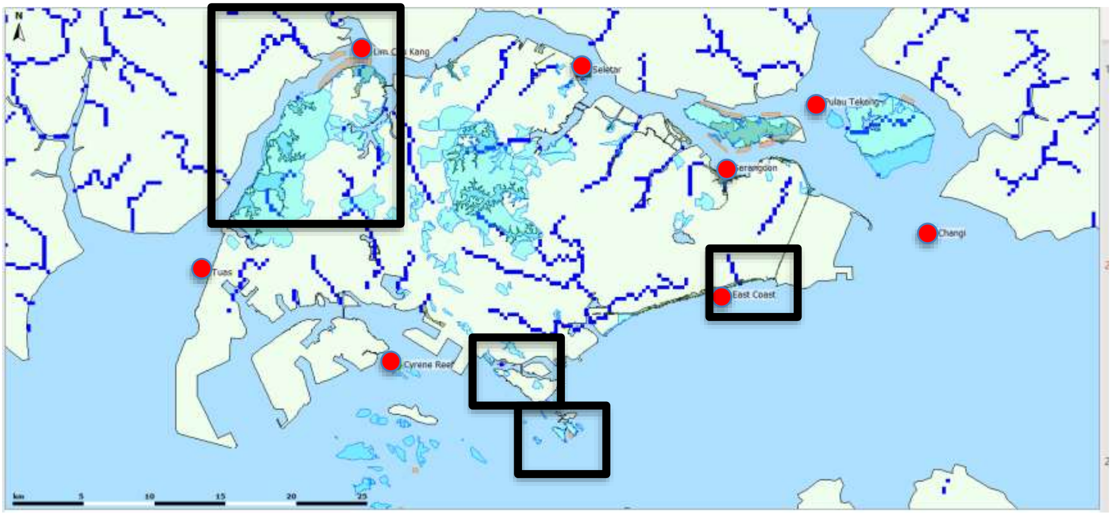
Example

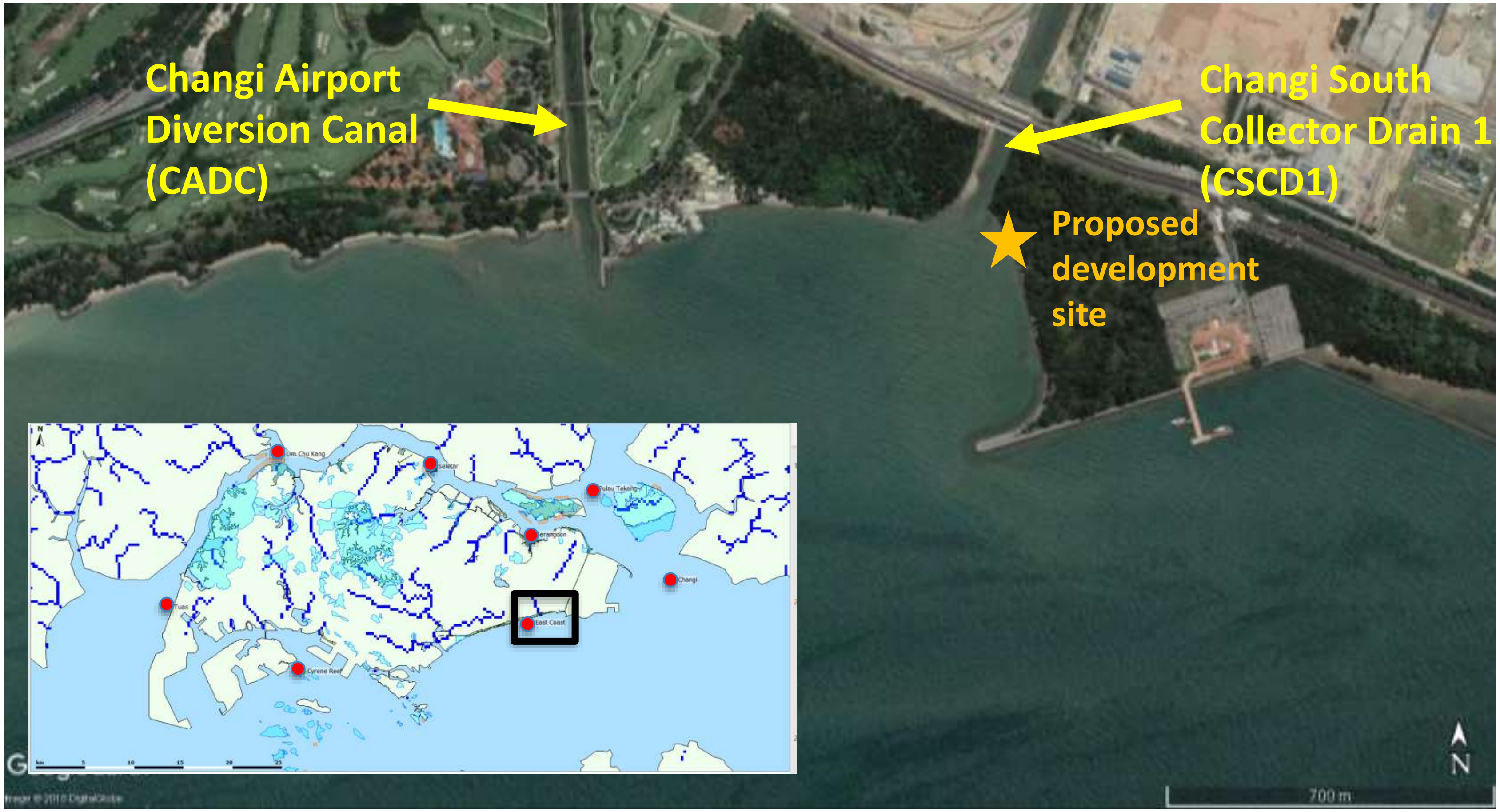


Disadvantages

- Model calibrated for regional scale, not local scale
- Local impacts (rivers/canals, industries, …) not taken into account (in detail)
  - Important to assess additional impacts of new developments



Local impact



Local impact

- Suppose I have relevant local monitoring data, do I still need to model the discharges from the drains?

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Local impact

- It depends…

- First: what is the purpose of our model?
- To identify the impact of the development

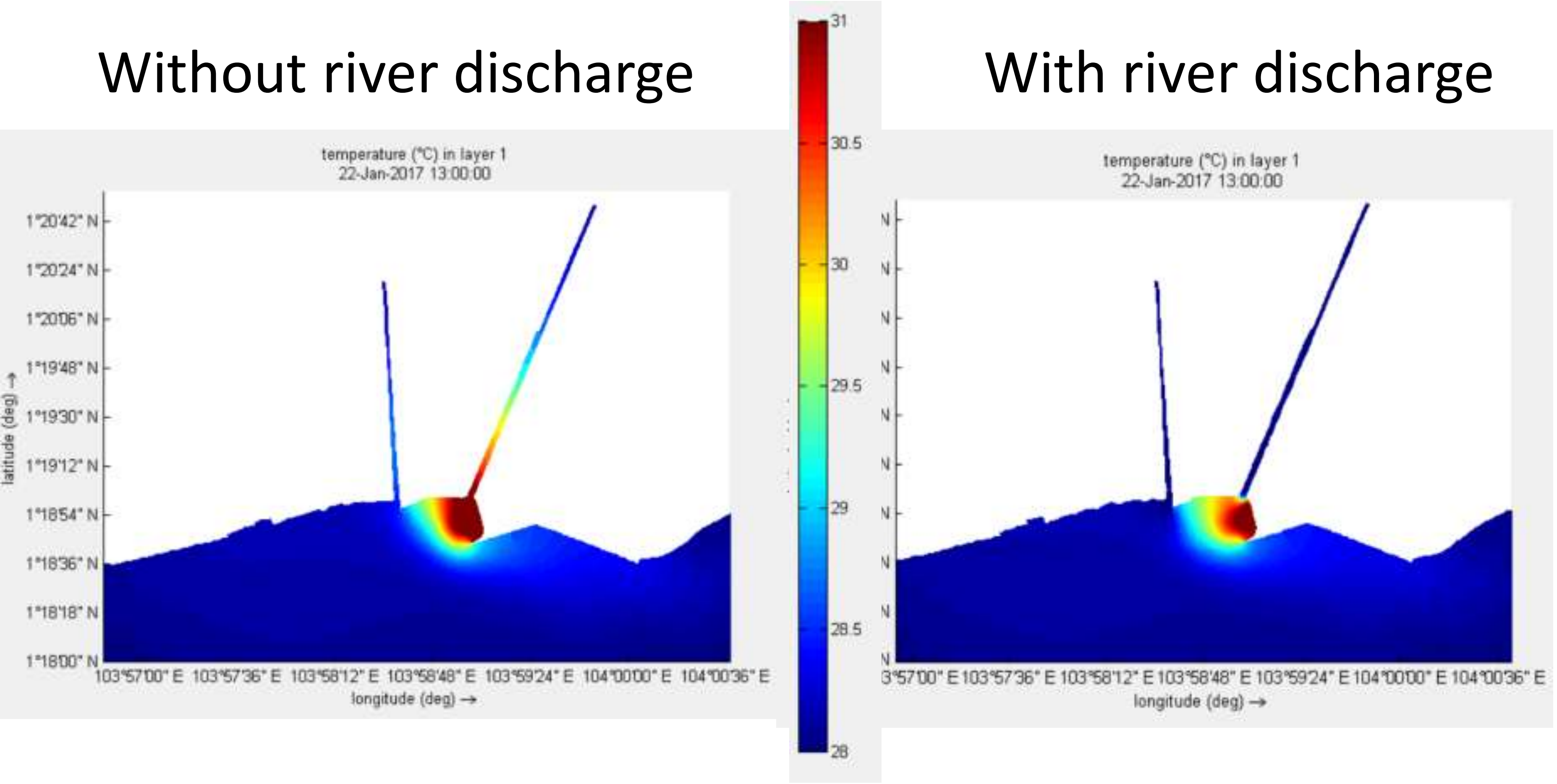
- The water quality of the discharge does not necessarily need to be included
  - assuming baseline data reflects the impacts of the discharges already

- The hydrodynamics probably need to be included
  - if the impact of it affects local flow conditions

Local impact

Without river discharge

With river discharge



Compare with standards (option 3)

- Two standards:
  - Surface water quality standards (marine or fresh water)
  - Effluent discharge standards

- Example of the first
  - ASEAN Marina Water Quality Criteria (AMWQC)

- Examples of the latter
  - EHS Guidelines (WBG)
  - Trade Effluent Discharge Singapore (NEA)

For Aquatic Life Protection		
Parameter	**Criteria Values**	**Note**
Ammonia (NH_3-N)	70 µg L^{-1}	
Cadmium	10 ug L^{-1}	
Chromium (VI)	50 µg L^{-1}	Criteria value proposed by CPMS-II is 48 µg L^{-1}. The meeting recommended adoption of 50 µg L^{-1}, following the existing national standards of member states.
Copper	8 µg L^{-1}	As the proposed value 2.9 µg L^{-1} is too stringent, the Meeting agreed to use rounded-up value of 7.7 µg L^{-1}, the product of the lowest LOEC from a chronic study 77 µg L^{-1} for reproduction for *Mysidopsis bahia* and a safety factor of 0.1.
Temperature	Increase not more than 2C° above the maximum ambient temperature.	
Cyanide	7 µg L^{-1}	
Dissolved oxygen	4 mg L^{-1}	
Lead	8.5 µg L^{-1}	
Mercury	0.16 ug L^{-1}	
Nitrate (NO_3-N)	60 µg L^{-1}	A single criteria value should be derived for nitrate and nitrite combined in future.
Nitrite (NO_2-N)	55 µg L^{-1}	
Oil and grease	0.14 mg/L	Other related parameters, e.g., PAH, should be included in future monitoring.
Total phenol	0.12 mg L^{-1}	
Phosphate (PO_4^{3-}-P)	15 µg L^{-1} (coastal) 45 µg L^{-1} (estuarine)	
Tributyltin	10 ng L^{-1}	
Total suspended solids	Permissible 10% maximum increase over seasonal average concentration.	

For Human Health Protection		
Parameter	**Criteria Values**	**Note**
Bacteria	100 faecal coliform 100 mL^{-1} 35 enterococci 100 mL^{-1}	Coastal water quality for recreational activities.

Left: AMWQC
Below: EHS Guidelines

Table 1.3.1 Indicative Values for Treated Sanitary Sewage Discharges[a]		
Pollutants	**Units**	**Guideline Value**
pH	pH	6 – 9
BOD	mg/l	30
COD	mg/l	125
Total nitrogen	mg/l	10
Total phosphorus	mg/l	2
Oil and grease	mg/l	10
Total suspended solids	mg/l	50
Total coliform bacteria	MPN[b] / 100 ml	400[a]

Notes:
[a] Not applicable to centralized, municipal, wastewater treatment systems which are included in EHS Guidelines for Water and Sanitation.
[b] MPN = Most Probable Number

AMWQC vs. EHS Guidelines

Parameter	Units	AMWQC	Sanitary sewage discharge (EHS Guidelines)
Nitrite (NO2-N)	mg/L	0.055	-
Nitrate (NO3-N)	mg/L	0.060	-
Total Nitrogen	mg/L	-	10
Ortho-phosphate (PO4-P)	mg/L	0.015 (coastal) 0.045 (estuarine)	-
Total Phosphorus	mg/L	-	2
Faecal coliform bacteria	MPN/100mL	100	-
Enterococcus	MPN/100mL	35	-
Total coliform bacteria	MPN/100mL	-	400

Requirements of specific receptors (option 4)

- Sensitive (natural) habitats:
  - Coral reefs
  - Mangroves
- Sites with certain other values:
  - Communal usage: domestic use (drinking water, bathing), fishing (think of the surface to groundwater seepage in Indonesia)
  - Economic, as well as food security: Fishery grounds
  - Recreational: Safety (algae blooms, bacterial concentrations) and Aesthetic value (murky water, algae blooms)

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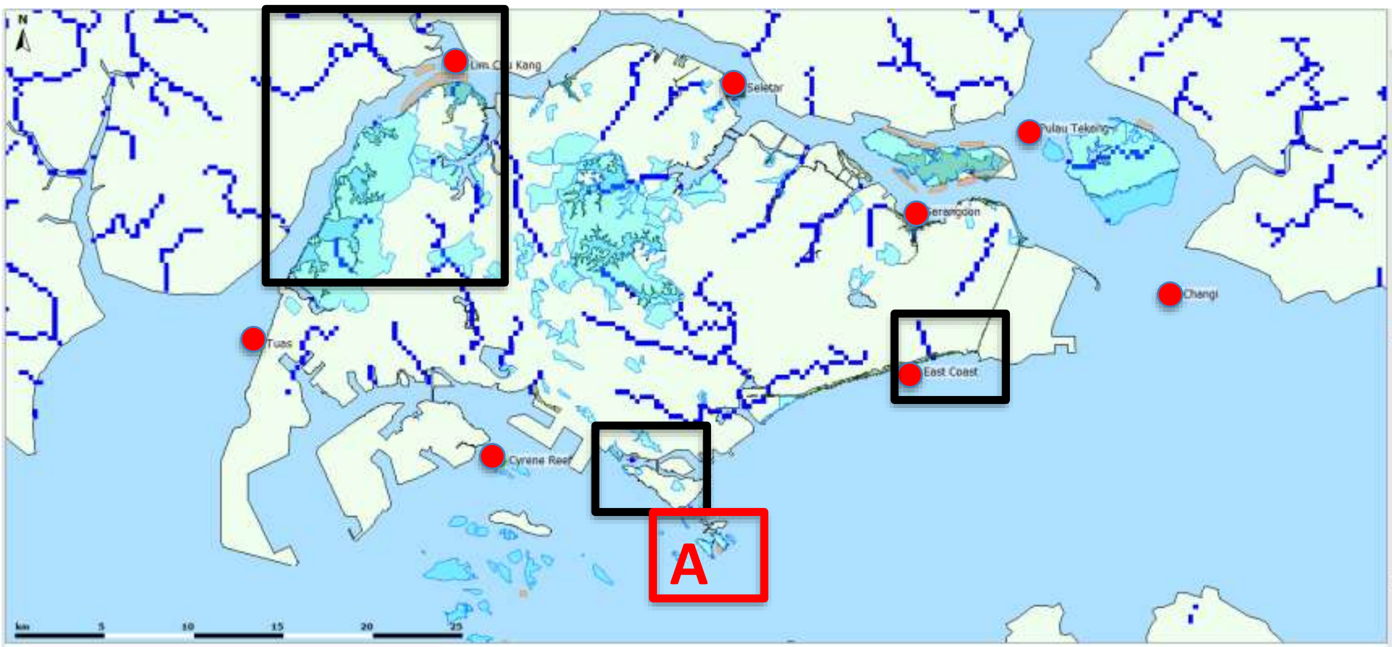
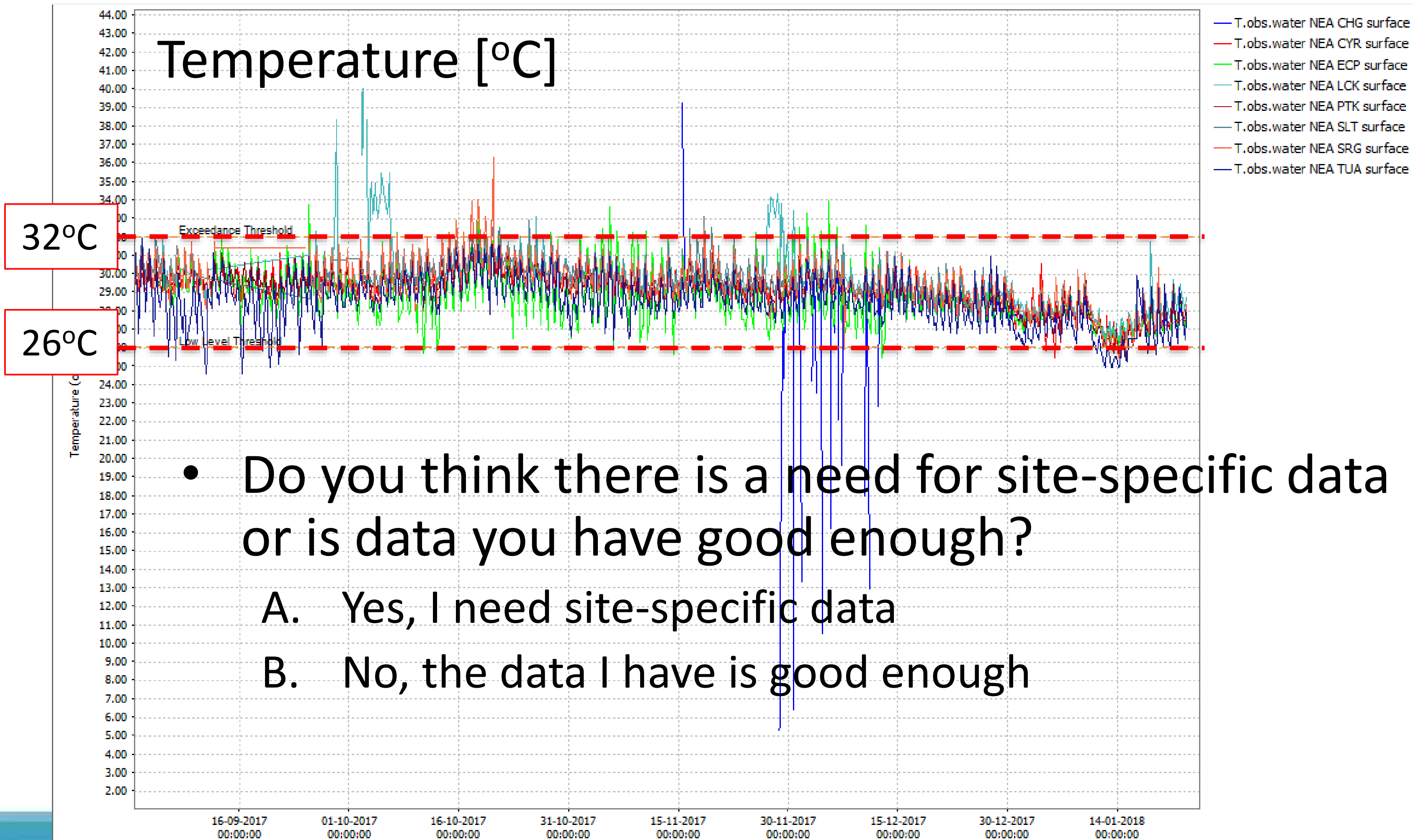
Choosing baseline data

- Case: you perform an EIA study for a thermal outfall at site A. You are interested in the impacts of the outfall on ambient water temperature.



Choosing baseline data

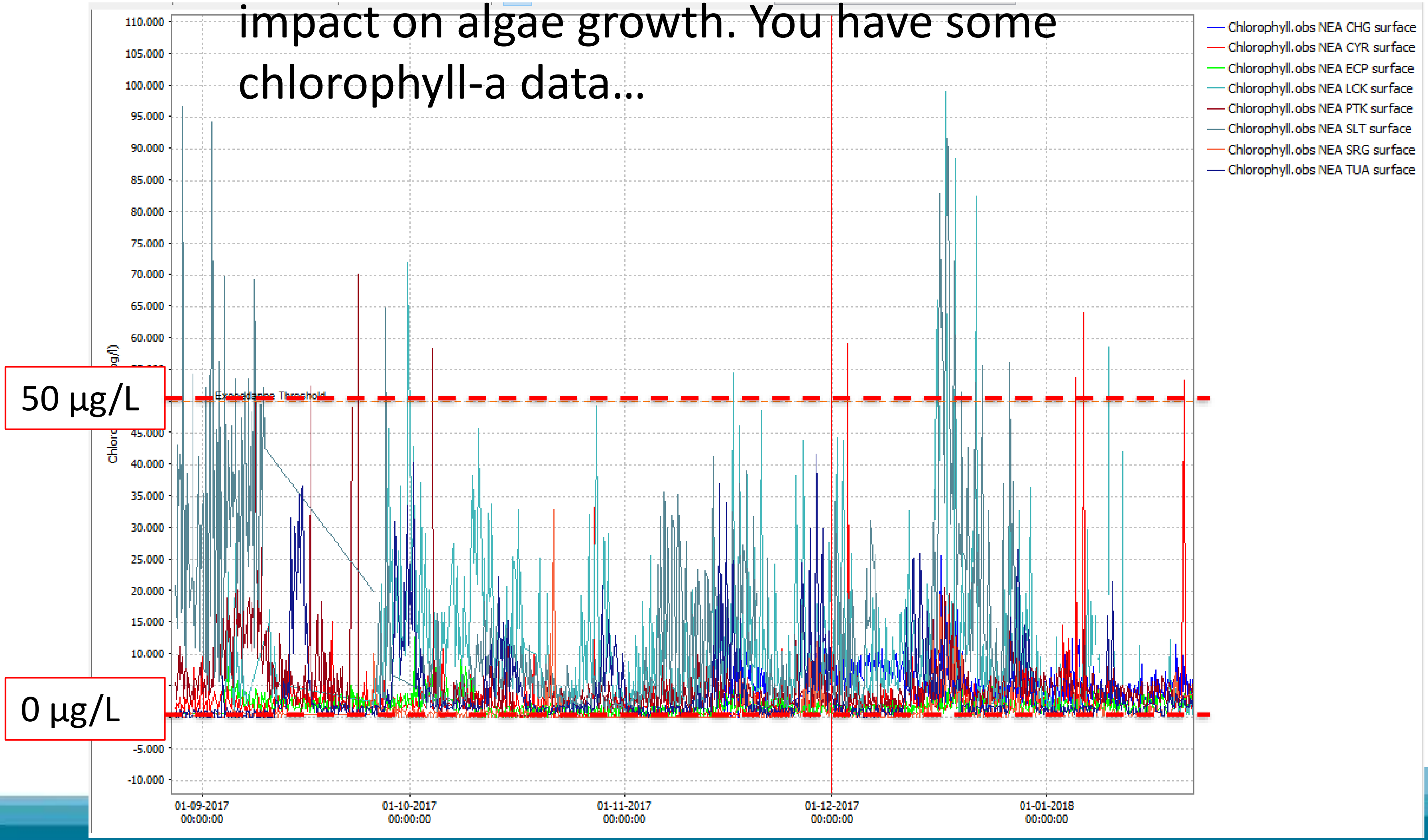
- You have the following data



- Do you think there is a need for site-specific data or is data you have good enough?
  A. Yes, I need site-specific data
  B. No, the data I have is good enough

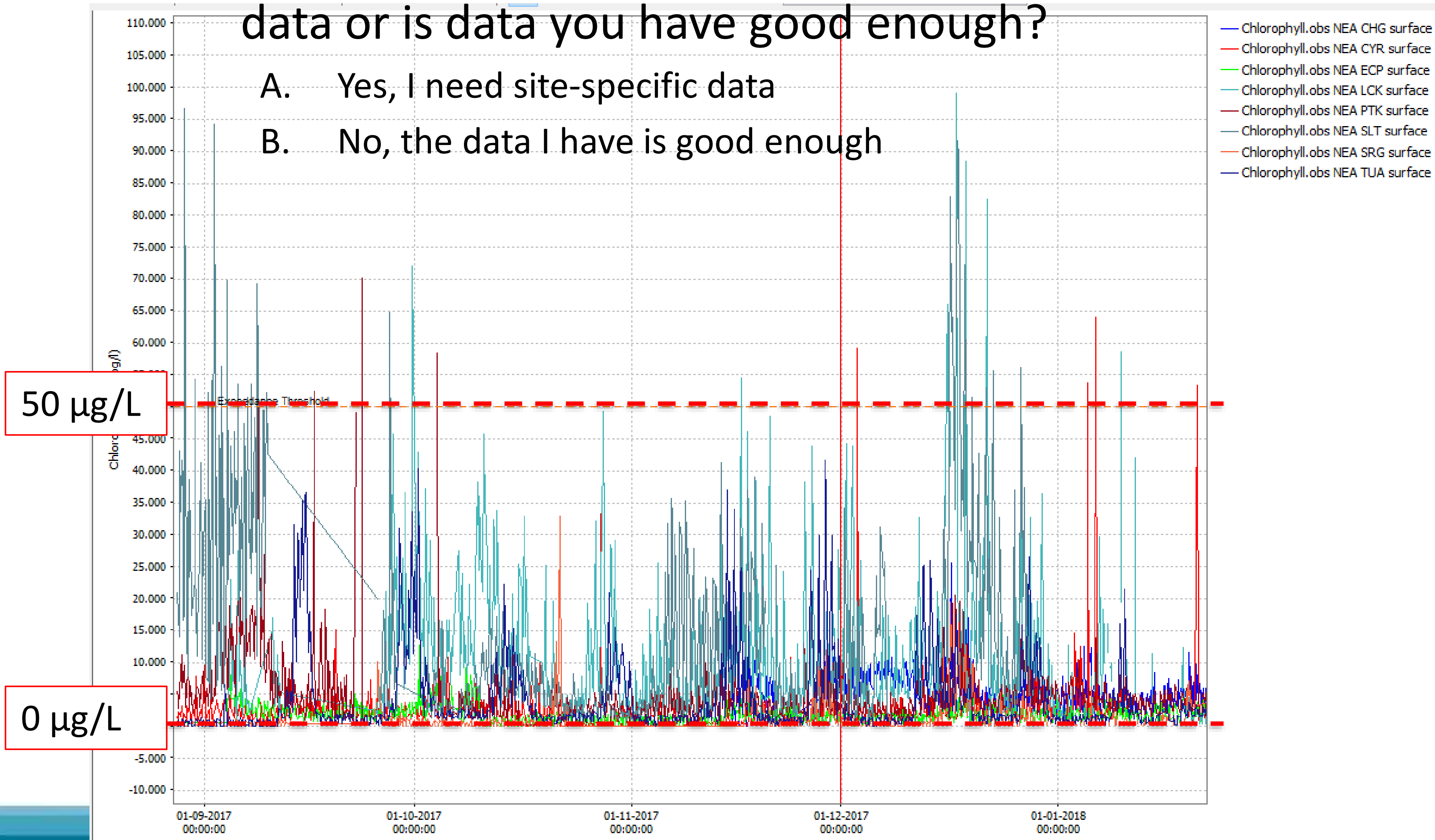
Choosing baseline data

- Now you also want to know if there will be an impact on algae growth. You have some chlorophyll-a data…



Choosing baseline data

- Do you think there is a need for site-specific data or is data you have good enough?
  A. Yes, I need site-specific data
  B. No, the data I have is good enough



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Overview

- Baseline data
- Data requirements for operational models
- Data for model calibration and validation → will be discussed in next block (Interpretation of Model Results)

- But first.. some basic principles about water quality data and water quality data collection

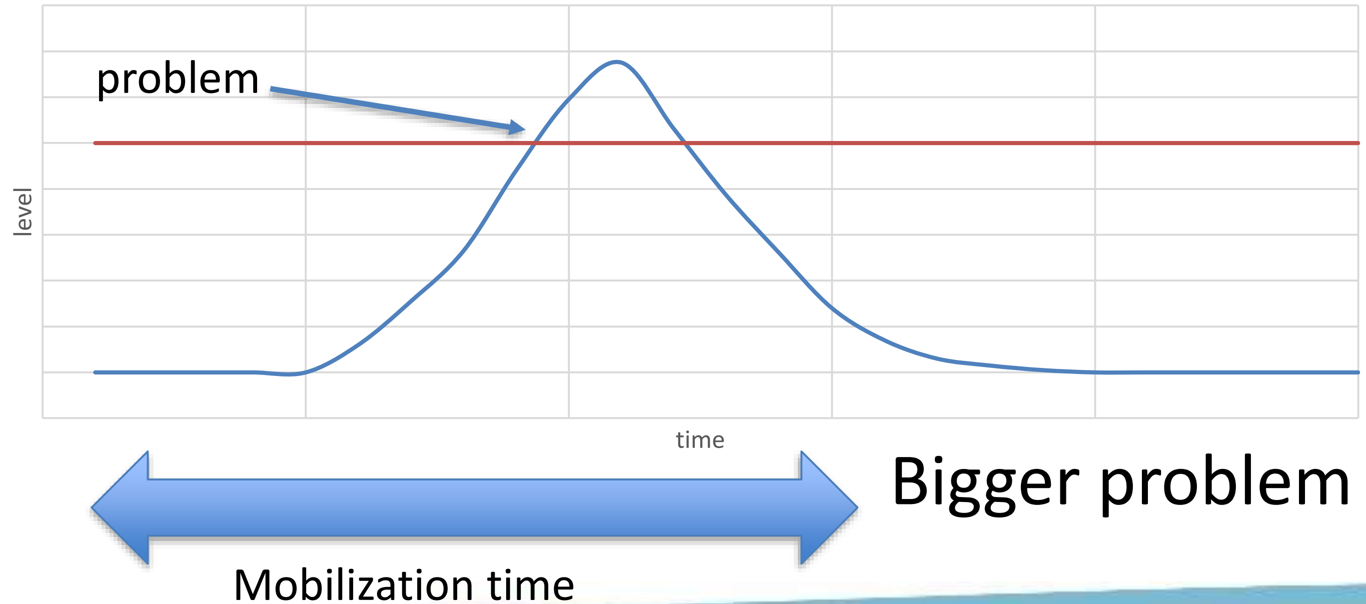
Operational models

- Characteristics of operational models
  - Aimed to support decision-making
  - Work in real-time

- Real-time modelling
  - Environmental Monitoring and Management Program (EMMP)
  - Spill response (oil, chemicals)
  - Flood forecasting systems
  - Operational water quality forecasts (fishfarms, beach water quality, etc.)

Lead time

- Time you have to prepare
  - How long in advance are you aware there is going to be a problem?
  - What is the duration of a disturbance?
  - How long does it take before a control action has effect?



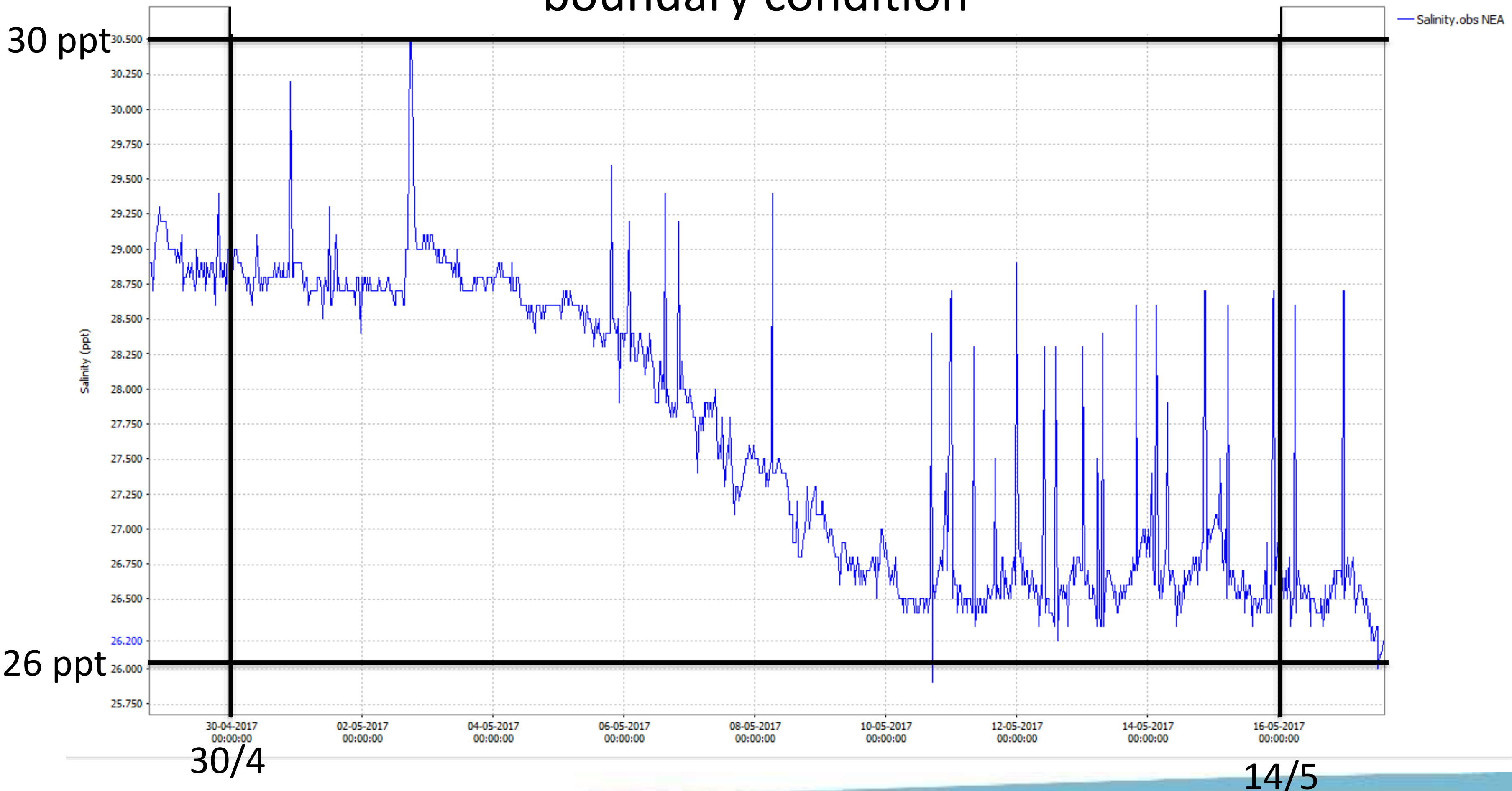
Bigger problem

Real-time data

- Limitations to what you know:
  - No time to wait for water samples analysis in laboratories
- Limitations to the data quality/accuracy:
  - No time for extensive evaluation of data

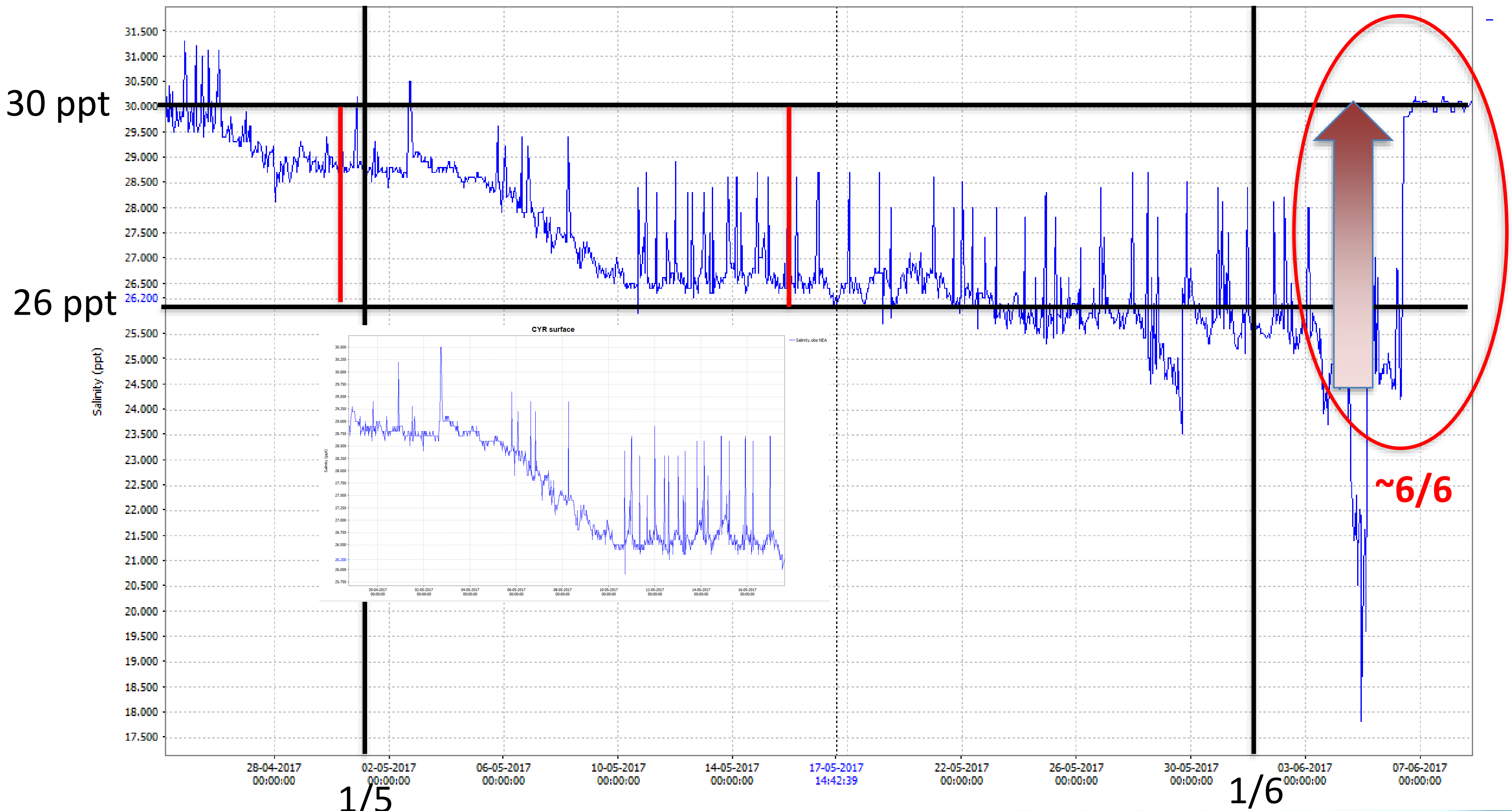
Data and data collection

Observed salinity (real-time) used as model boundary condition

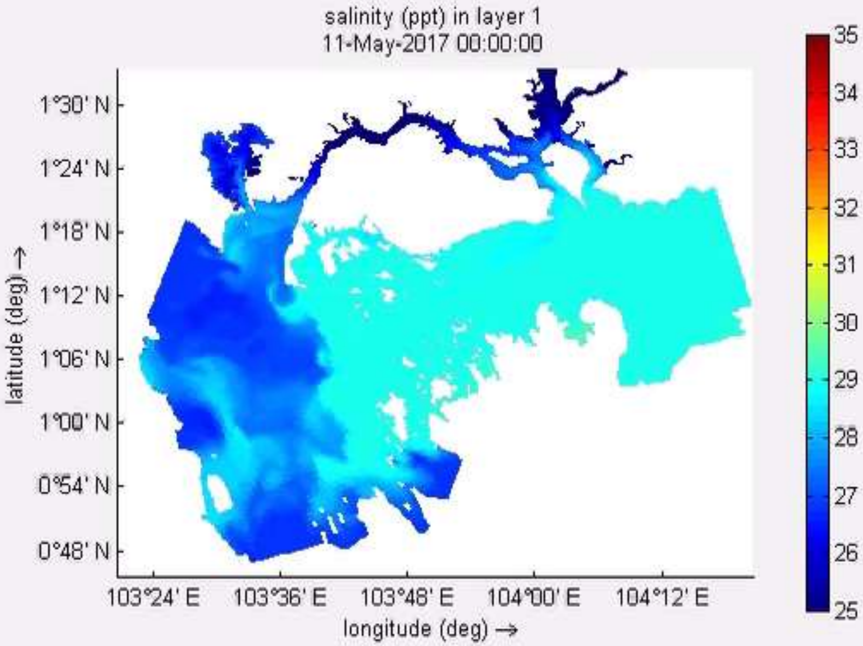


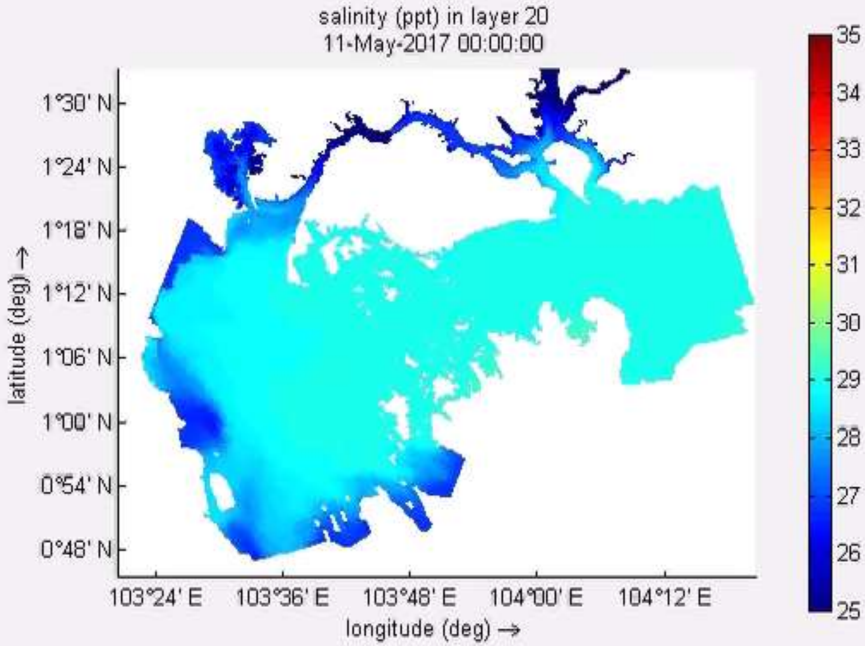
Data and data collection

Is data reliable?



The consequences…





Key messages

- (Operational) models…
  … are only as good as the information you put in
- Data evaluation to be done on a regular basis to ensure operational models continue to receive correct feeds
  - Automated scripts
  - Manual
- Model results cannot be taken for granted if one has not reviewed the data that has gone into it

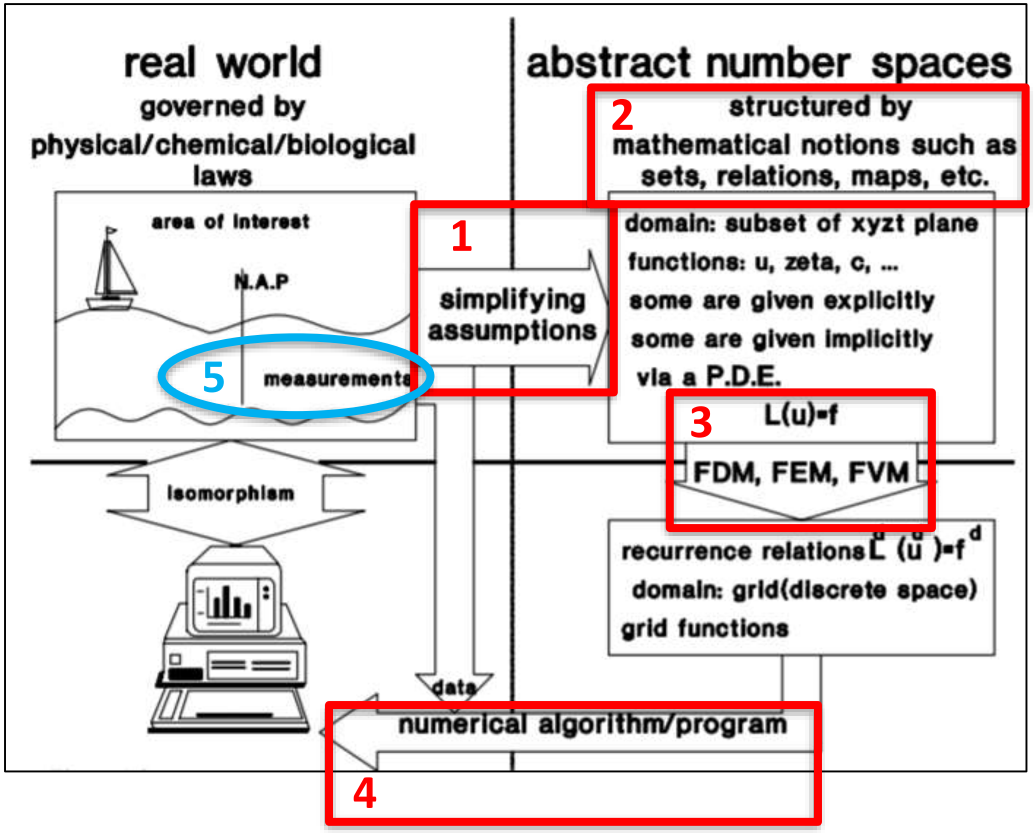
Interpretation of Model Results

Overview

- Dealing with uncertainty
- Model verification: calibration & validation
- Defining scenarios

Uncertainties/Errors

1. In translating the real world to a workable model (simplifications)
2. In model structure
3. Discretisation
4. Solvers (numerical methods)
5. Measurements



Simplifying assumptions

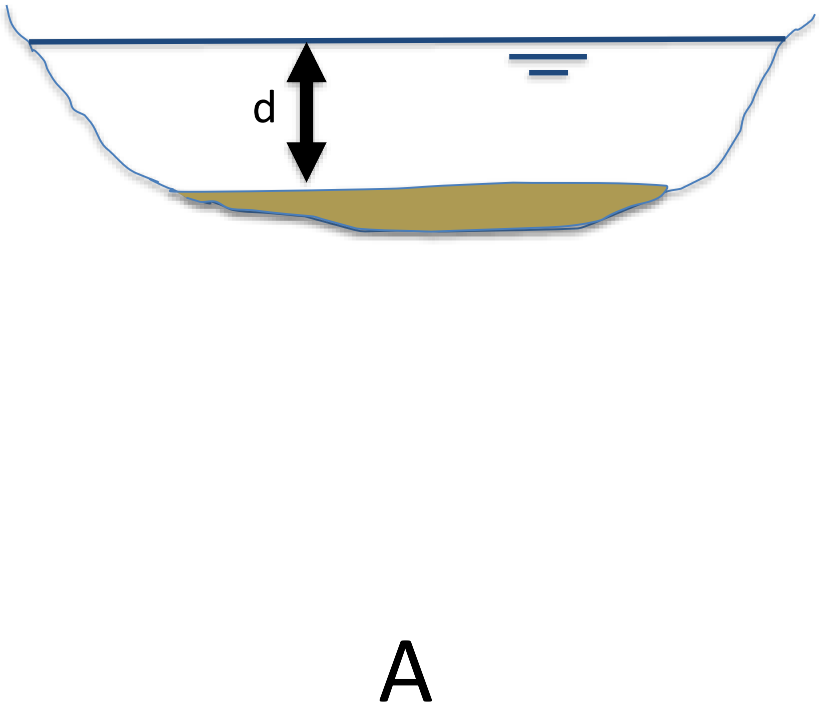
- Data sparsity in space and time → some form of interpolation required
- We decide to include and exclude certain elements in our models
  - A matter of our modelling purposes
  - Area of interest

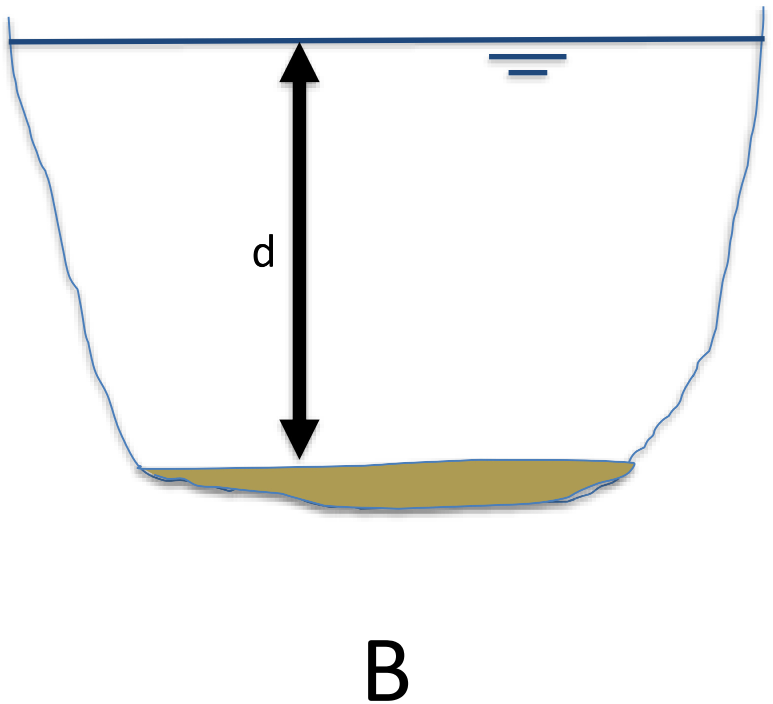
Model structure

- Modelling purposes
  - Simplifications → Model structure with certain degree of complexity
- What processes do we need to take into account when modelling dissolved oxygen?
  - Reaeration (natural and artificial)
  - Mineralisation (CBOD)
  - Nitrification (NBOD)
  - Photosynthesis and respiration
  - Sediment oxygen demand

Model structure

- Everything else being the same, for which lake is sediment oxygen demand a more relevant process?





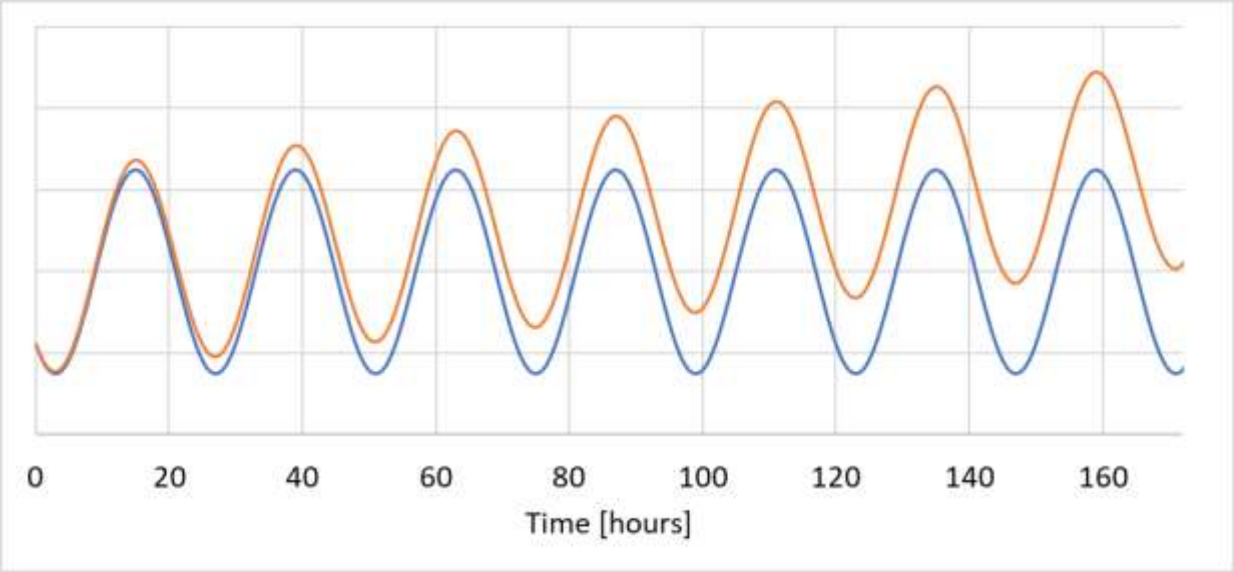
In general

- Practical considerations:
  - Computation time → More processes yields longer computations
  - Preparation time → More substances/processes/sources yields more model elements that need to be defined

- Scientific considerations:
  - More processes → more parameters → more degrees of freedom to calibrate model
  - Supporting data to justify additional complexity

Sensitivity test

- How much is the model result impacted by a change of X % in one/multiple loads?
- How much is the model result impacted by a change of X % in the parameter value?



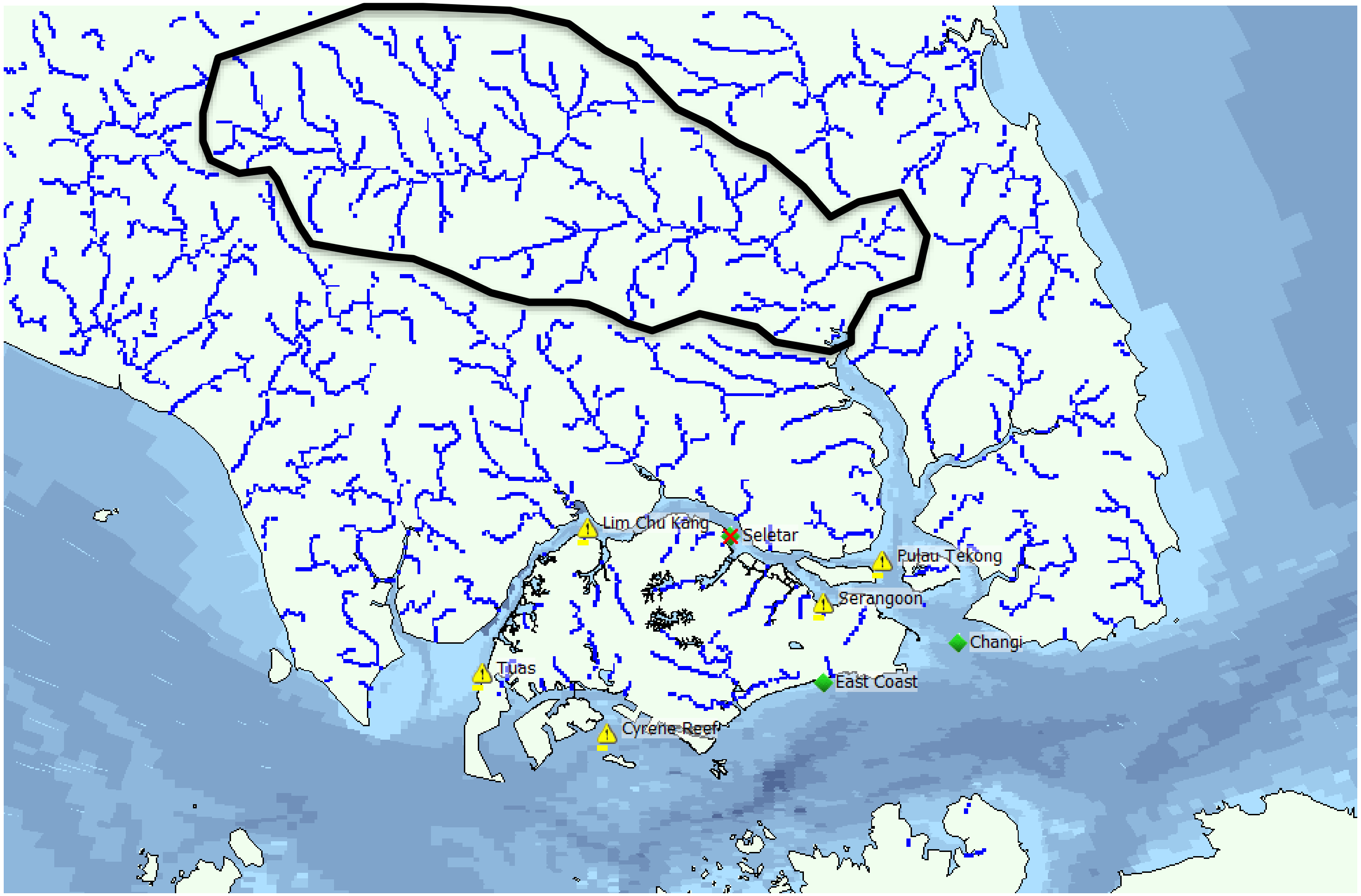
Sensitivity test

- Sensitive loads/parameters, with high uncertainty: troublesome
- Multiple sensitive loads/parameters, with high uncertainty: equifinality issues

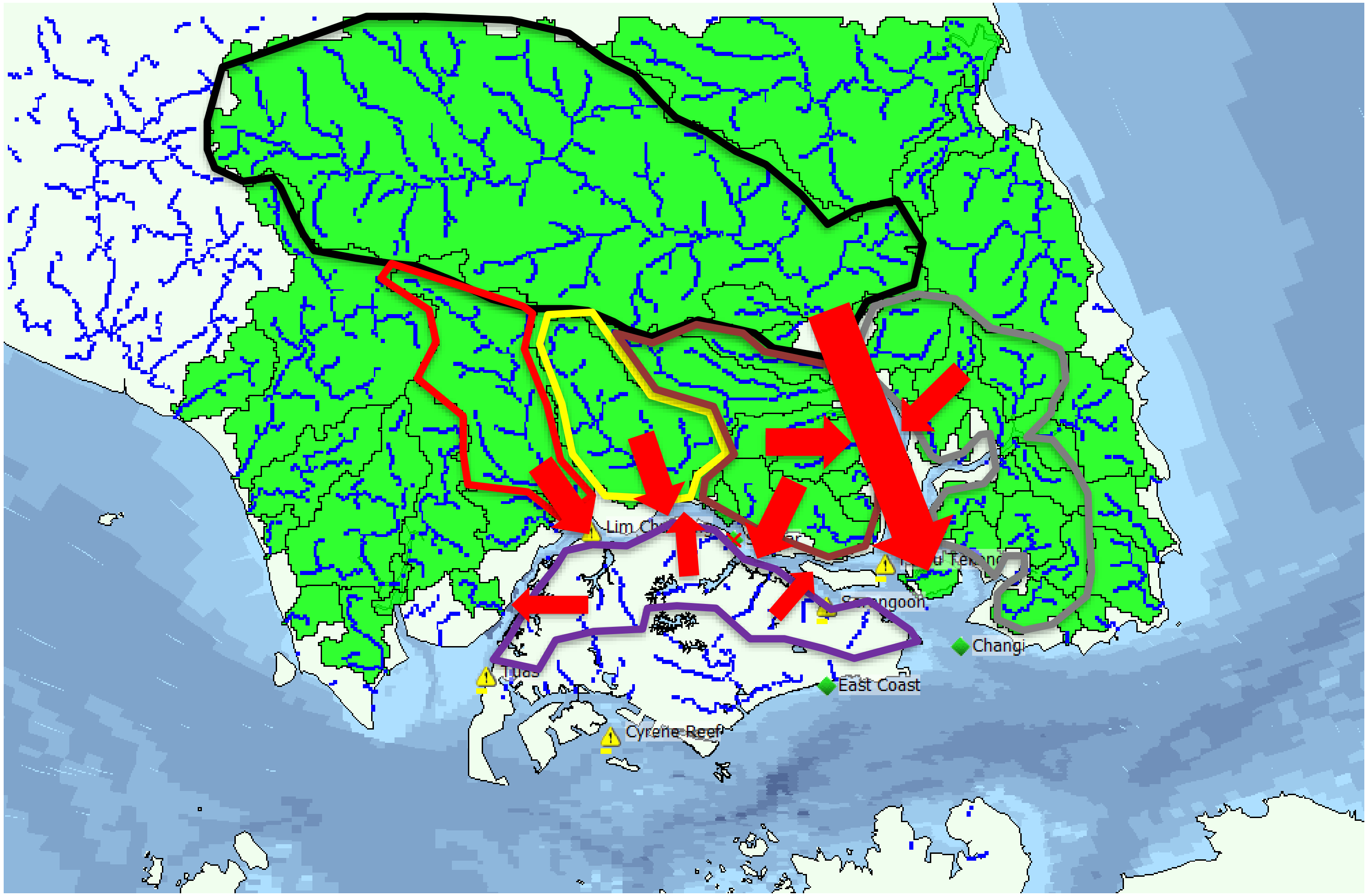
A practical example: Uncertainty in loads

- Uncertainty in loads
  - Not measured at all
  - Not frequently measured
  - No data access (e.g. transboundary pollution)

Uncertainty in loads



Uncertainty in loads



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Overview

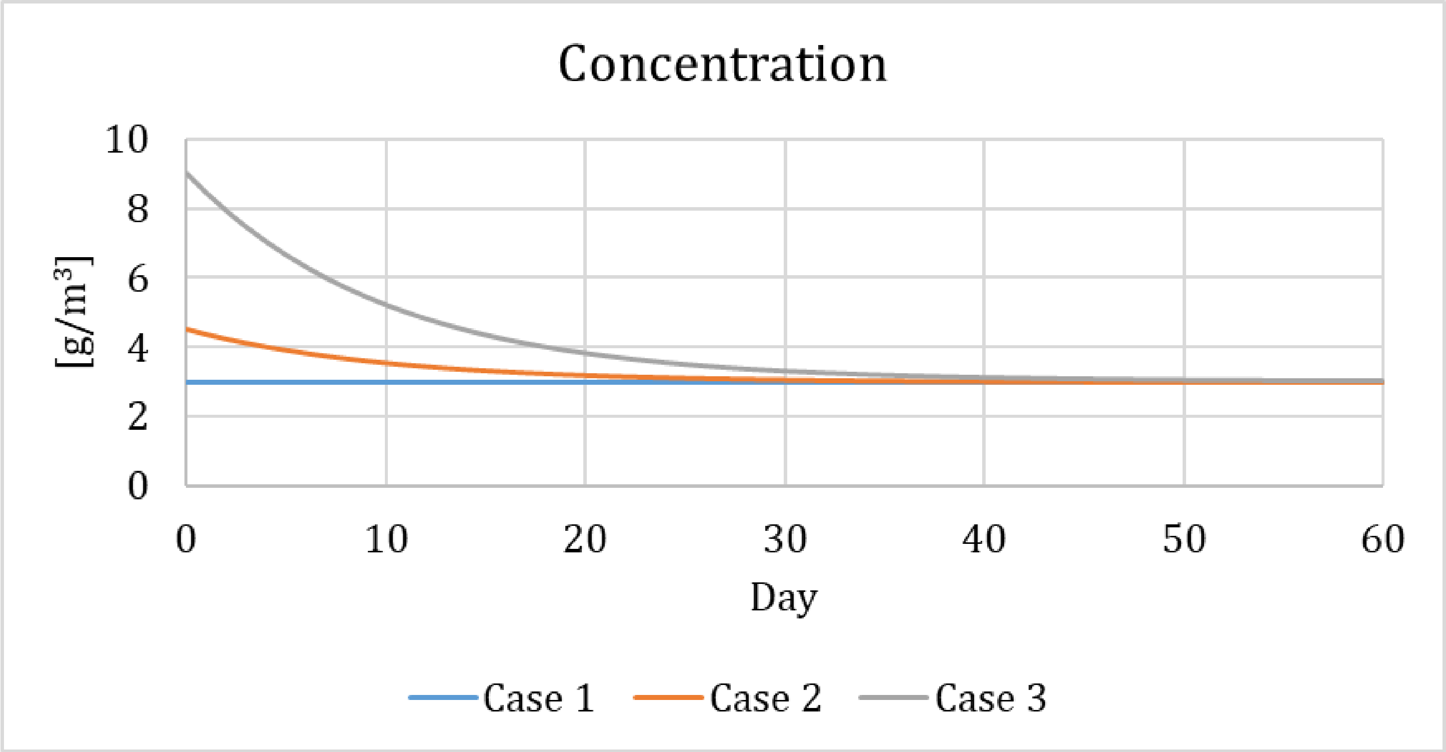
- Dealing with uncertainty
- Model verification: calibration & validation
- Defining scenarios

The role of model calibration and validation

- Is my model a reasonable representation of reality?

Model calibration

- Ensure model is not impacted by initial conditions anymore (model is spun-up or in steady-state)



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Model calibration

- Identify components with the largest uncertainty
  - Data
  - Simplifying assumptions
  - Model structure and parameterisation
- Identify how sensitive the model results are to these uncertain components
- Change their values such that a good match is obtained between the model and observations

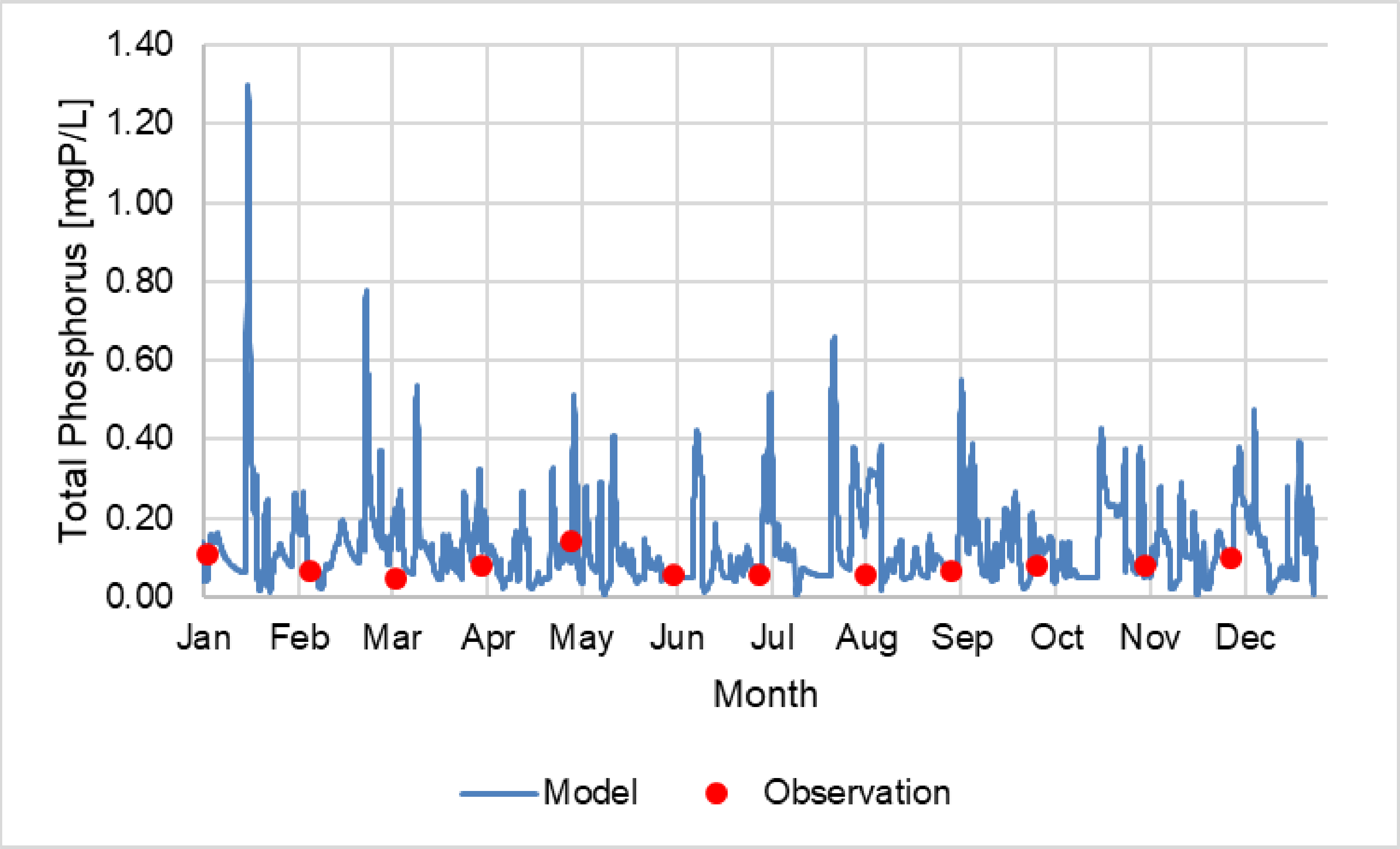
Model validation

- Verify calibration using a different data set.
- What type of different data sets can you think of?
  - Different time period
  - Different geographical location/entity
  - Different stresses/circumstances

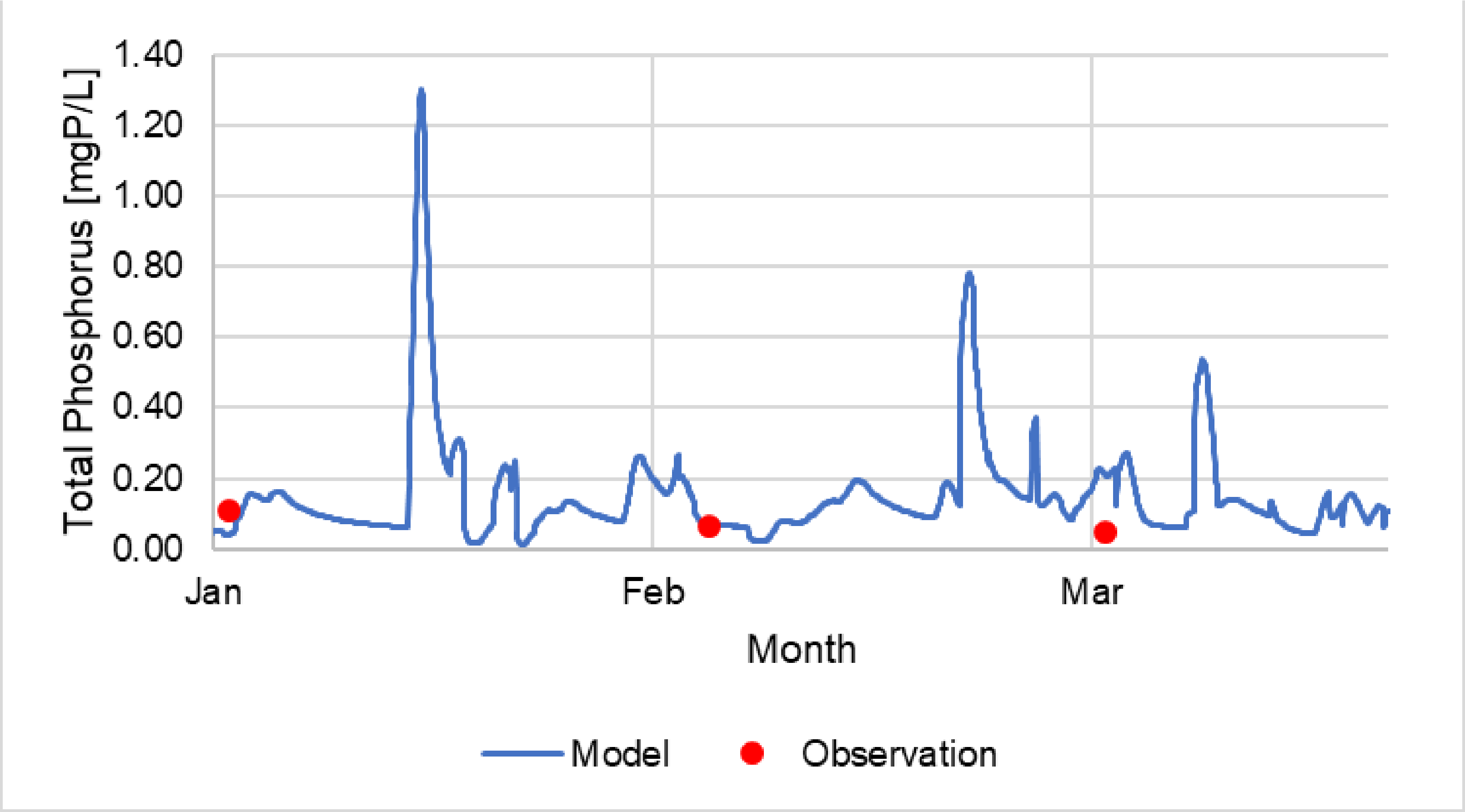
Data for model verification

- Central questions:
  - If you are yet to collect the data
    - What do you need the model for?
    - What sort of data is required to verify such model?
  - If data had been collected
    - What are the characteristics of the data?
      - Temporal frequency
      - Spatial frequency
    - How can the data help me verify my model?

Good or not good?



Let's zoom in



1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Total Phosphorus [mgP/L]
Jan
Feb
Mar
Month
Model
Observation

So, what to look out for if data is sparse?

- Temperature and salinity
  - Conservative substances
  - Transport processes well represented
  - Remaining uncertainty in loads, chemical and biological processes and parameterisation
- Systematic bias (over-/underestimation)
- Are long term trends in water quality replicated by the model?
  - Seasonal patterns (winter/summer, monsoon/inter-monsoon)

Overview

- Dealing with uncertainty
- Model verification: calibration & validation
- Defining scenarios

Scenarios

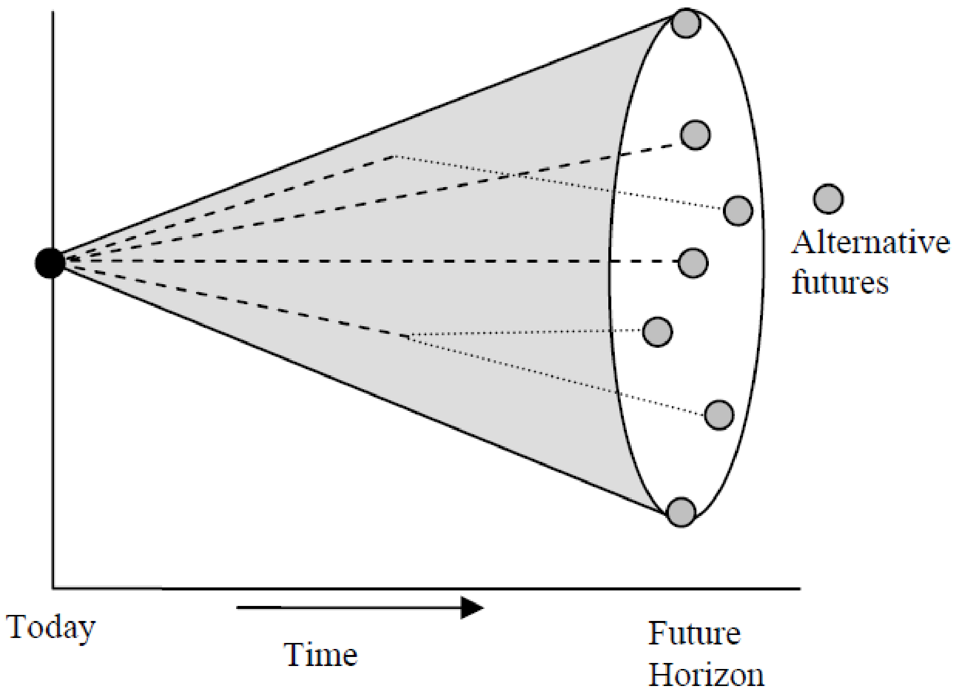


Fig.1. Conceptual diagram of a scenario funnel. Aadapted from Timpe & Scheepers (2003)

Figure from: Liu et al (2008). Formal Scenario Development For Environmental Impact Assessment Studies

"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold."

(IPCC, http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=125)

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Defining scenarios

- Risks: combination of probability and consequences (cost, environment, public health, etc.)
- Normal natural and operational conditions
  - High probability
  - Probably small consequences
- Extreme conditions
  - Low probability
  - Probably large consequences
- “Wild card” scenarios: extreme situations with high impacts
  - Extreme meteorological conditions (e.g. prolonged droughts)
  - Extreme demand from plant (e.g. prolonged increase in demand)

Scenario definition

- Should consider:
  - Time horizon and intervals
  - Regional extent
  - System components to be considered (e.g. climate variability, water resources regulations and policies, socioeconomic development patters)

From: Liu et al (2008). Formal Scenario Development For Environmental Impact Assessment Studies

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Several aspects to consider

Table 5: Modelling Scenarios for Thermal Dispersion modelling

Scenario	TPP demand m^3/s	KMK Flow m^3/s	Ambient water temperature (deg. Celsius)	Air temperature (deg. Celsius)	Excess temperature over ambient (deg. Celsius)	Wind speed (m/s)	Relative humidity (%)	Season
A1	54	54	16	26	10	4	73	Summer
B1	54	81	12	22	10	4	87	Winter
B2	54	81	16	26	10	4	73	Summer
B3	54	81	20	30	10	4	60	Summer
C1	54	108	20	30	10	4	60	Summer
C2	54	108	28	38	10	4	33	Summer
D1	40	10	10	20	10	4	100	Winter
D2	54	10	10	20	10	4	100	Winter

Source: Mott MacDonald, 2018.

Modelling reservoir water quality under the effects of climate change

Looking at reservoir water quality under different climatological and socio-economic projections

The study concludes that climate change alone yields no significant impact on the change of water quality and showed that the greatest effects upon water quality parameters could be attributed to future socio-economic activities and associated pollution emission scenarios.

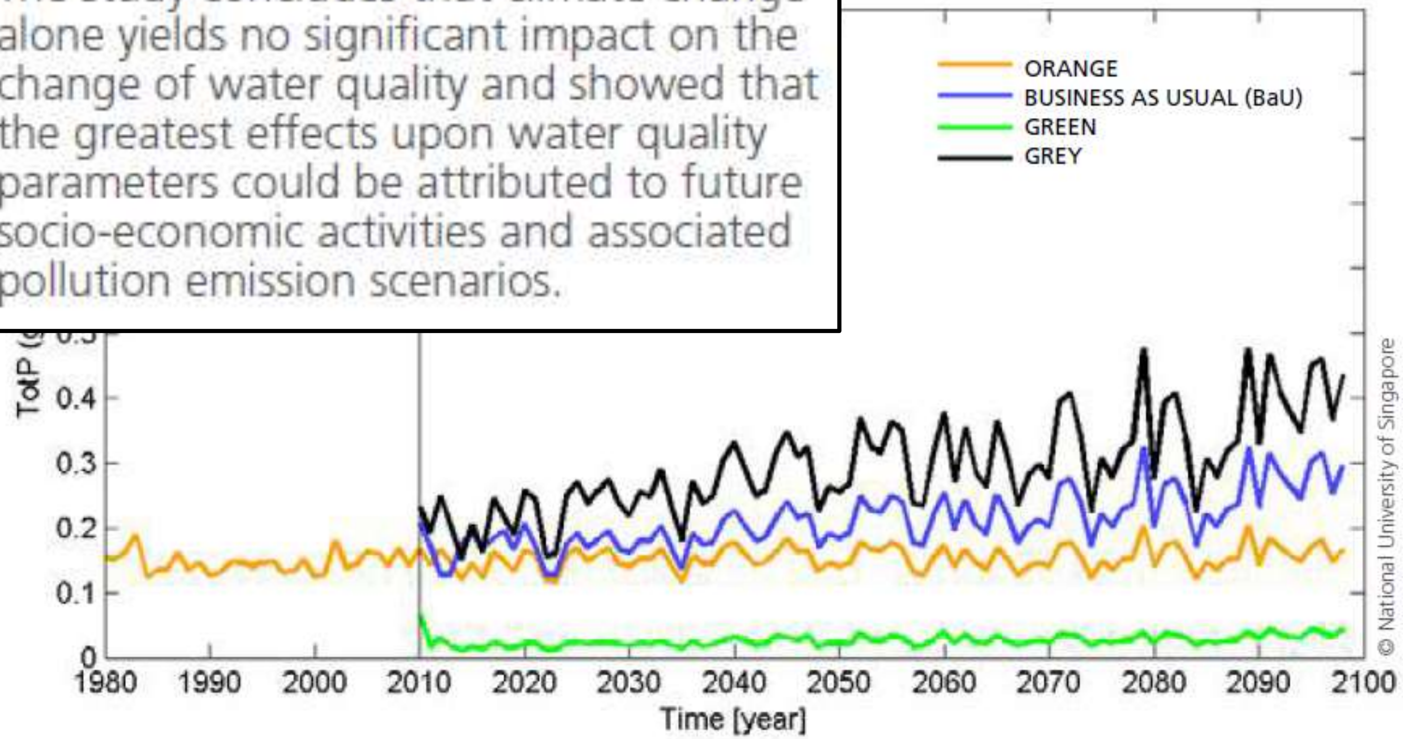

Fig. 1: Projected changes in total phosphorus concentration at a station in Punggol Reservoir. The chart shows the impact of climate change alone (Orange), compared to that of climate change and socio-economic developments under three scenarios: Business as Usual (BaU), limited sustainable development measures (Grey) and full-scale measures (Green)

Researchers and affiliations
V. Babovic, J. Zhang, S.H.X. Tay, X. Wang, G. Pijcke, N. Manocha, X. Li, A. Meshgi | *National University of Singapore*
J. van Gils, T. Minns | *Deltares*
M. Ong | *PUB Singapore*

Key messages

- Uncertainty/errors in every component of the modelling cycle
- Data uncertainty is very present in water quality studies
- Sensitivity analysis can help to identify impact of uncertainty on model outcome
- Model calibration and validation is critical to have confidence in model output
- Water quality model verification may be complicated by lack of data as well

Challenges & opportunities in water quality

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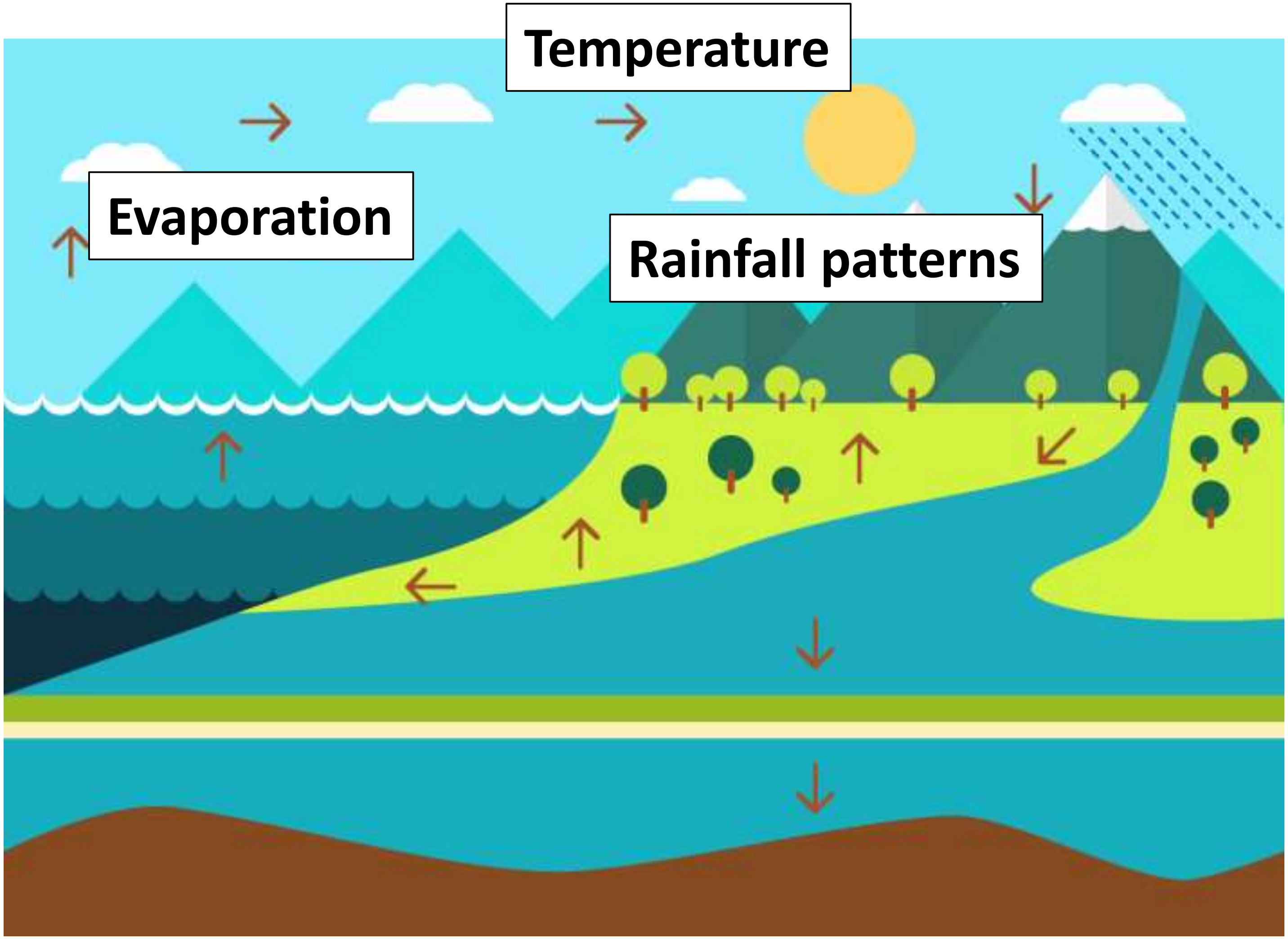
What we shall consider..

- Climate change
- Emerging Contaminants
- Sensing techniques (big data)

Climate change



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Climate change

- In relation to EIA:
  - Meteorological impacts: different background conditions (e.g. air temperature)
  - Hydrological impacts: water availability for cooling (e.g. thermal powerplant along a river)

- Sustainability of a plant's operations
  - What if my water intake falls? For how long? How often?

Emerging contaminants, what are they?

- Chemicals
  - Which are not commonly monitored
  - Whose fate, behaviour and ecotoxicological effects are not well understood
- They are not necessarily new chemicals
- Examples
  - Pesticides
  - Pharmaceuticals
  - Personal care products
  - Hormones
  - Microplastics
  - …
- They are many!

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Emerging contaminants, bioaccumulation

- Some may breakdown very slow (e.g. plastics)
- Bioaccumulation

Oldest message in a bottle found on Western Australia beach

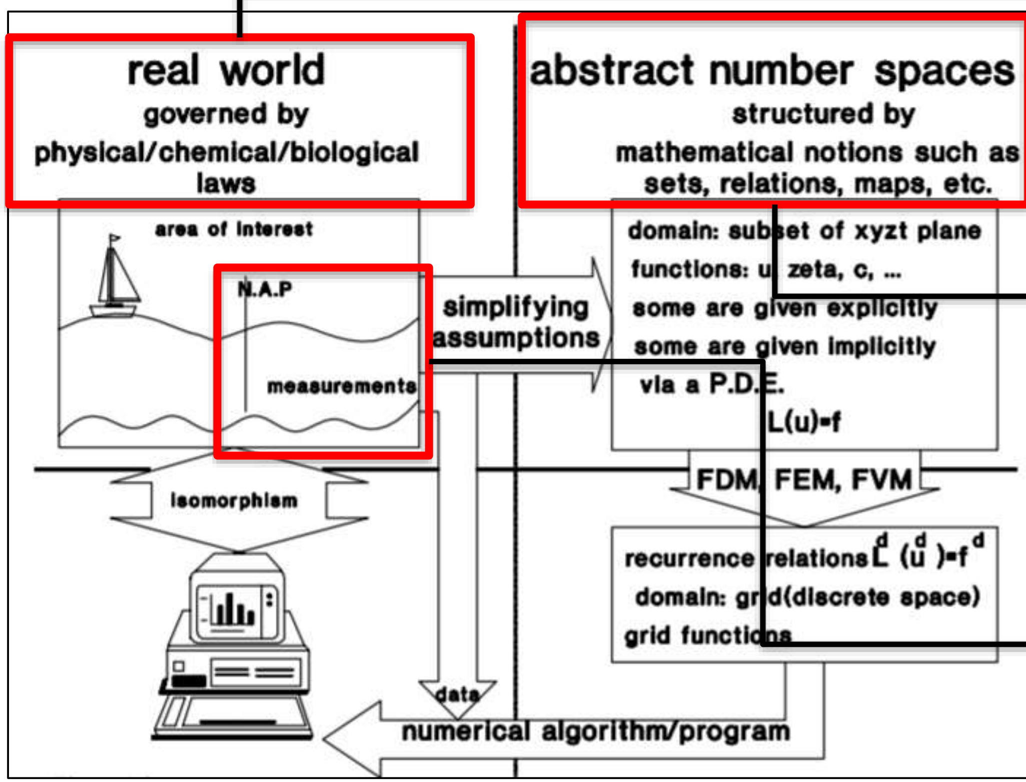
6 March 2018

Share

From: https://www.bbc.com/news/world-australia-43299283

Emerging contaminants

- Relatively little is known about emerging contaminants



Processes are not yet understood well

Mathematical formulations for models in development

Measurement techniques: detection limits, in development

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Sensing techniques

- Nutrient analyser
- Cameras detecting and analysing algae species
- Remote sensing data

Terms of Reference

Model useful if

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What do you need the model for?

An example..

2. Objective

2.1 The objective of this Contract is to improve the performance of the current Marina Reservoir Modelling System in terms of accuracy and operational efficiency by reducing the computing time required.

2.2 In addition, the objective of this Contract is to provide user-friendly modelling tools, including but not limited to, a new emission model to differentiate pollutant loads and identify major pollutant sources into Marina Reservoir.

Sure…

… but this lacks context and specifications

An example…

2. **Objective**

2.1 The objective of this Contract is to improve the performance of the current Marina Reservoir Modelling System in terms of accuracy and operational efficiency by reducing the computing time required.

2.2 In addition, the objective of this Contract is to provide user-friendly modelling tools, including but not limited to, a new emission model to differentiate pollutant loads and identify major pollutant sources into Marina Reservoir.

- Accuracy – Required accuracy was specified for each model in more detailed specifications. However, current performance was not.
- Reduce computing time – By how much? And within what boundaries (can I cut out any irrelevant processes)?

An example...

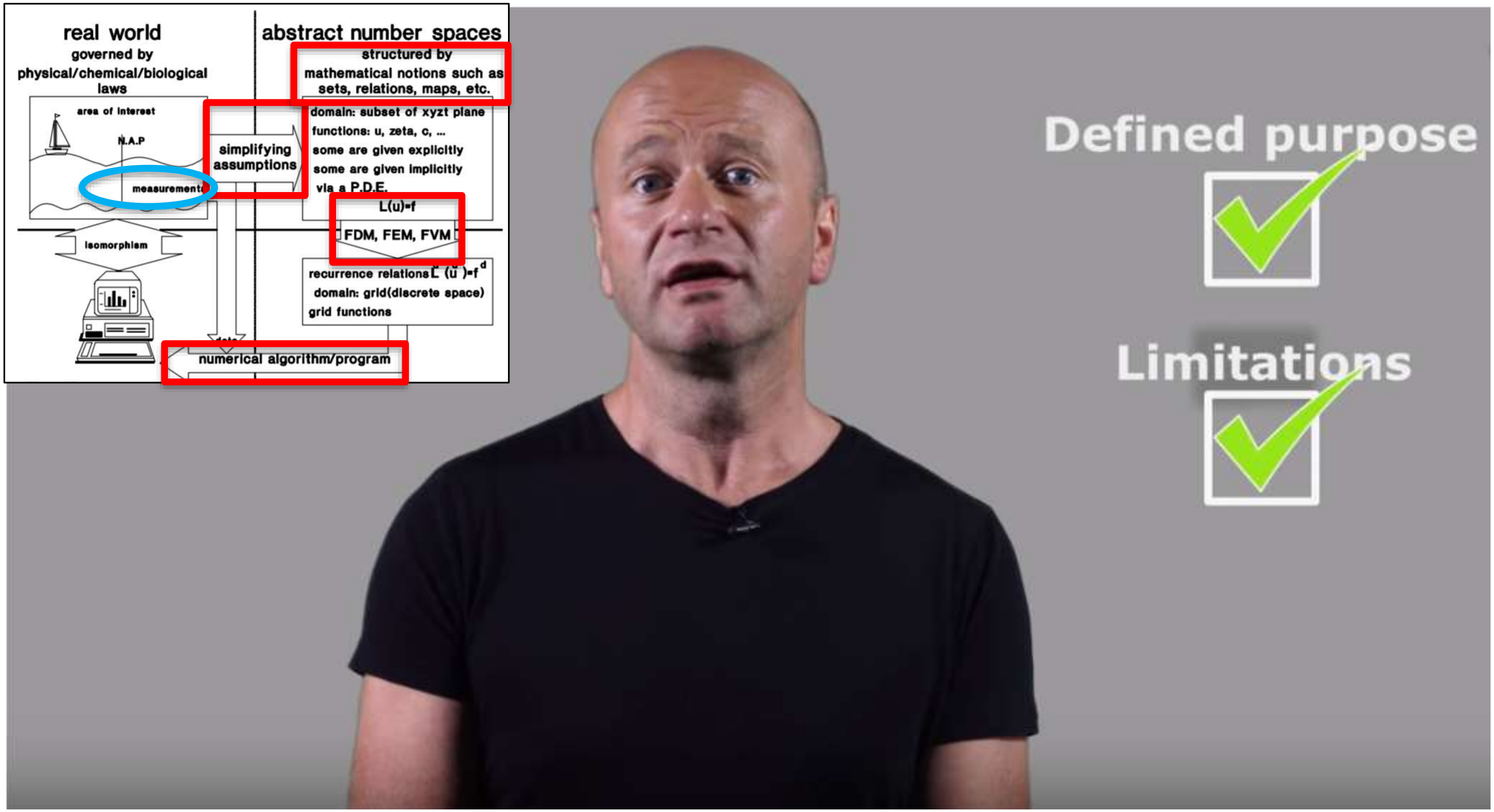
2. Objective

2.1 The objective of this Contract is to improve the performance of the current Marina Reservoir Modelling System in terms of accuracy and operational efficiency by reducing the computing time required.

2.2 In addition, the objective of this Contract is to provide user-friendly modelling tools, including but not limited to, a new emission model to differentiate pollutant loads and identify major pollutant sources into Marina Reservoir.

- User-friendly - For a modeller a model in a text editor is considered user-friendly, or a Matlab/Python/R script… For policy makers typically not

Is what you need/expect realistic?



Personnel requirements

- Is modelling of temperature and salinity work for a water quality modeller?
  - No, this is considered hydrodynamic modelling (because temperature and salinity have an impact on transport processes)
- You may need someone who can assess the impacts of temperature/salinity increase to the relevant receptors, but that does not need to be a modeller

Writing a ToR

- Project A: EIA for a sediment plume in the coastal environment, resulting from rainfall-runoff from a construction-site on land
  - Purpose of model: **One-off assessment** of the extent and magnitude of sediment plume from the construction site

- Project B: EMMP for dredging works.
  - Purpose of the model: To have a **real-time operational forecast** of the sediment plume motion for construction activities planned within the next 72 hours.

- What are the requirements of the models developed for project A and B in terms of:
  - Computation time of a single model simulation?
  - Data?
  - Evaluation of model performance?

At the end of the day…

Tender submissions for a consultant are much like this…

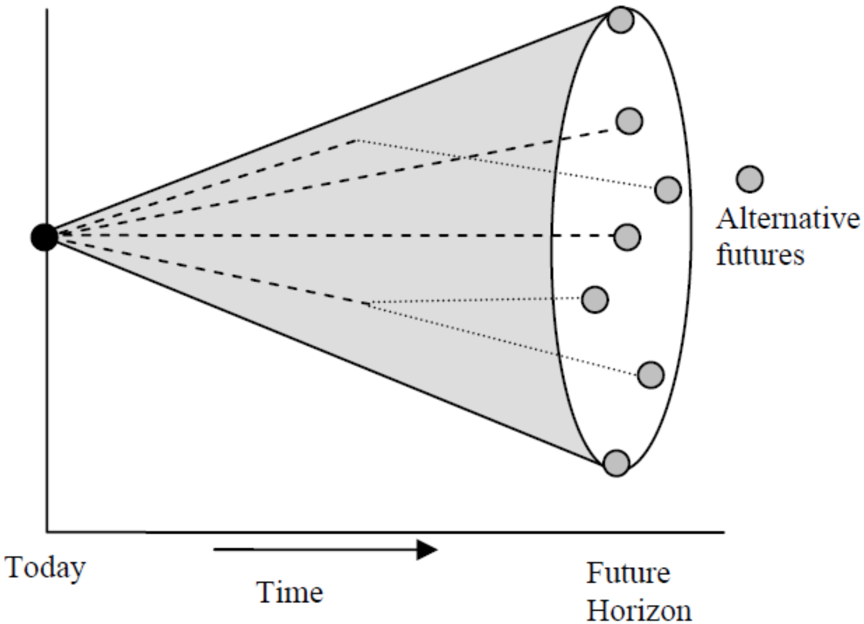


Fig.1. Conceptual diagram of a scenario funnel.
Aadapted from Timpe & Scheepers (2003)

…and, he got to deal with that.

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THANK YOU!