AquaSPICE

Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations

Water Integration

Design of a Maximum Water Reuse System

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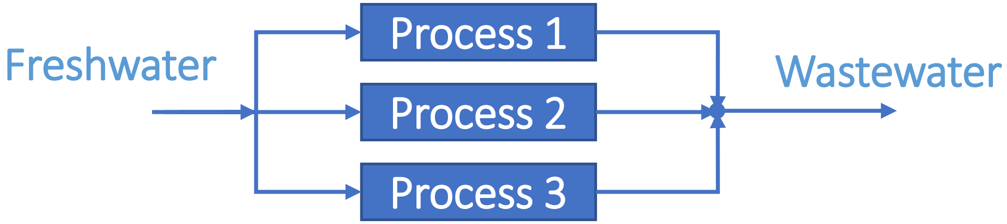
Learning Objectives

- Understand the different options for water reuse and regeneration in an industrial plant with multiple processes
- Size and design a maximum water reuse system

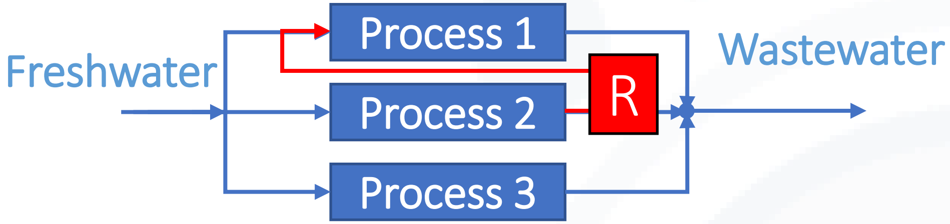
Motivation for Water Integration

- Water was assumed to be an infinite low-cost resource
- Nowadays, there is an increasing pressure on water resources
- Water scarcity is increasing as demand for water intensifies with population and economic growth
  - Restrictions in water use
  - Stricter discharge regulations
  - Recycle, Reuse & Regenerate

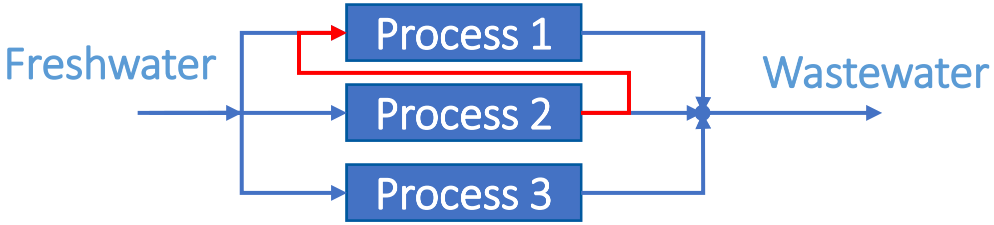
Alternative Water Reuse Schemes



(a) Freshwater Use

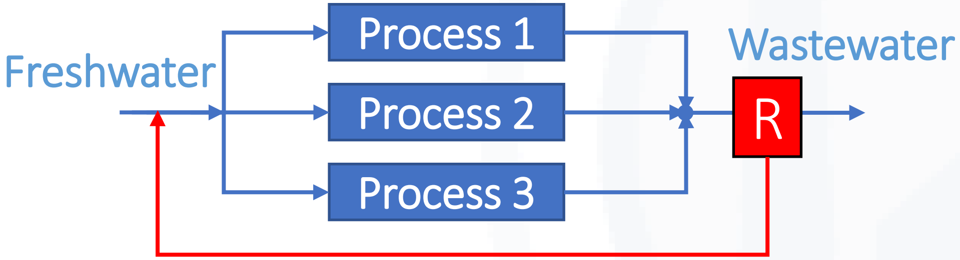


(c) Regeneration Reuse



(b) Water Reuse

Contamination level at the outlet of (2) should be acceptable at the inlet of (1)



(d) Regeneration Recycle

Contrary to regeneration reuse, water can go through any given process more than once

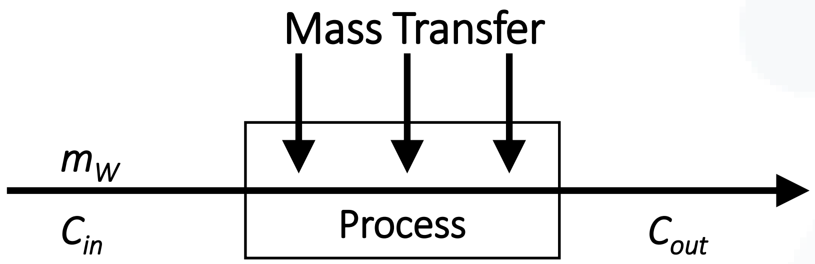
Analysis for a Single Contaminant

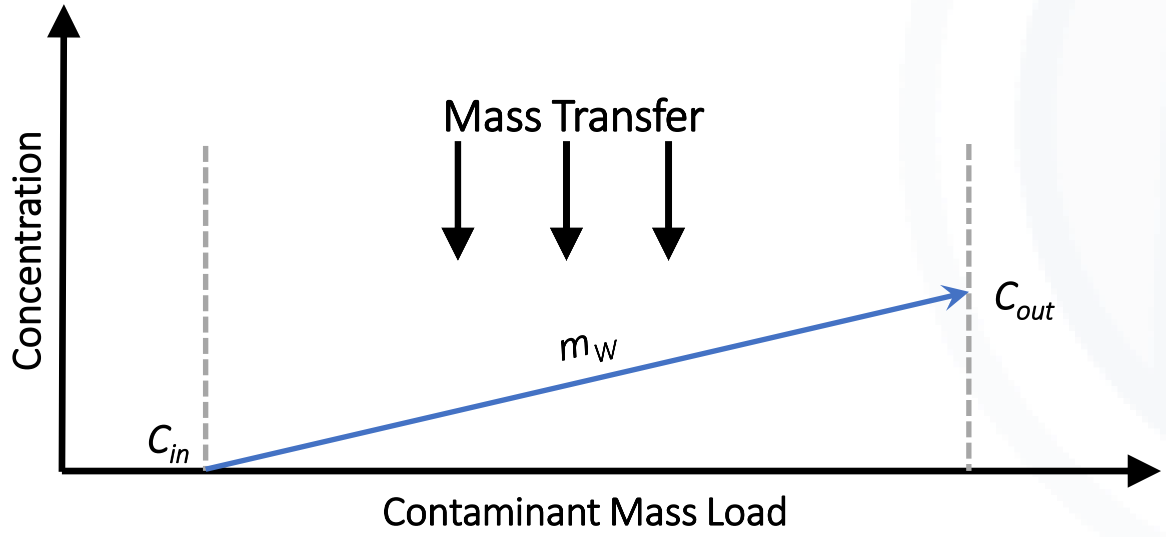
- All water use processes have one thing in common.
- Water comes into contact with process materials and becomes contaminated
- For a given process, with a specific contaminant load (ΔmC), then:

$$\Delta m_C = m_W \times \Delta C$$

- where m_W is the water flowrate and ΔC = $C_{out} - C_{in}$ the concentration change of the water
- **Note**: Concentration is defined on the basis of the mass flowrate of the water and not of the mixture, since the difference between the two quantities is very small

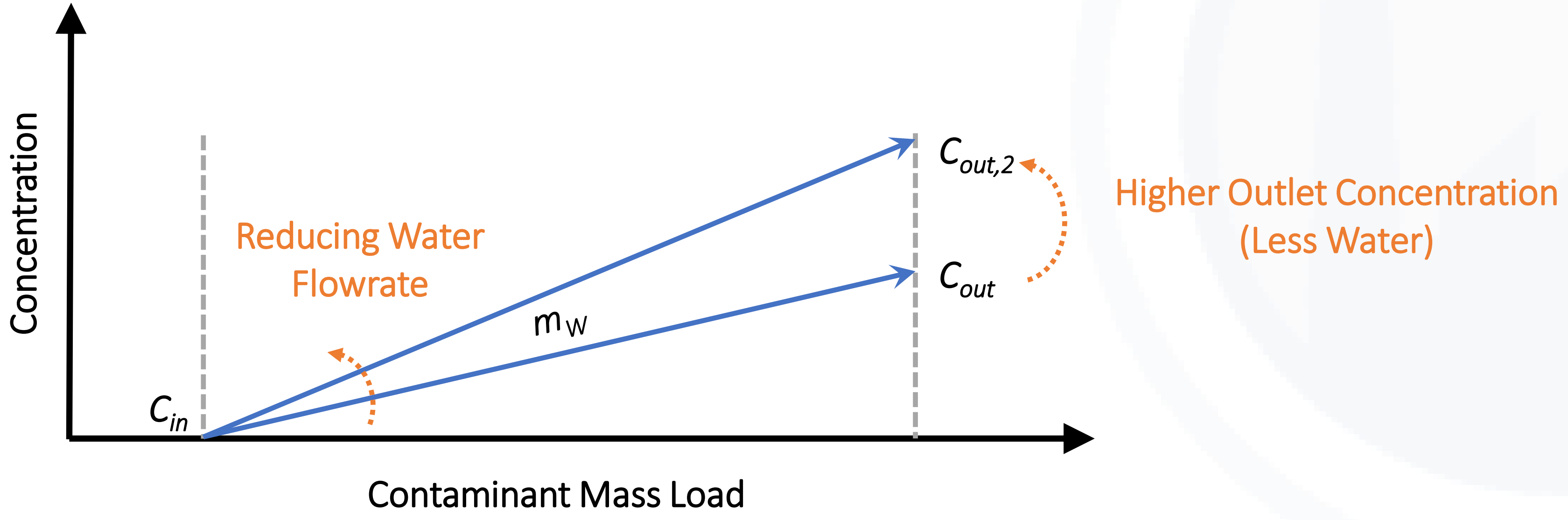
Representing Water Use





Representing Changes in Flowrate

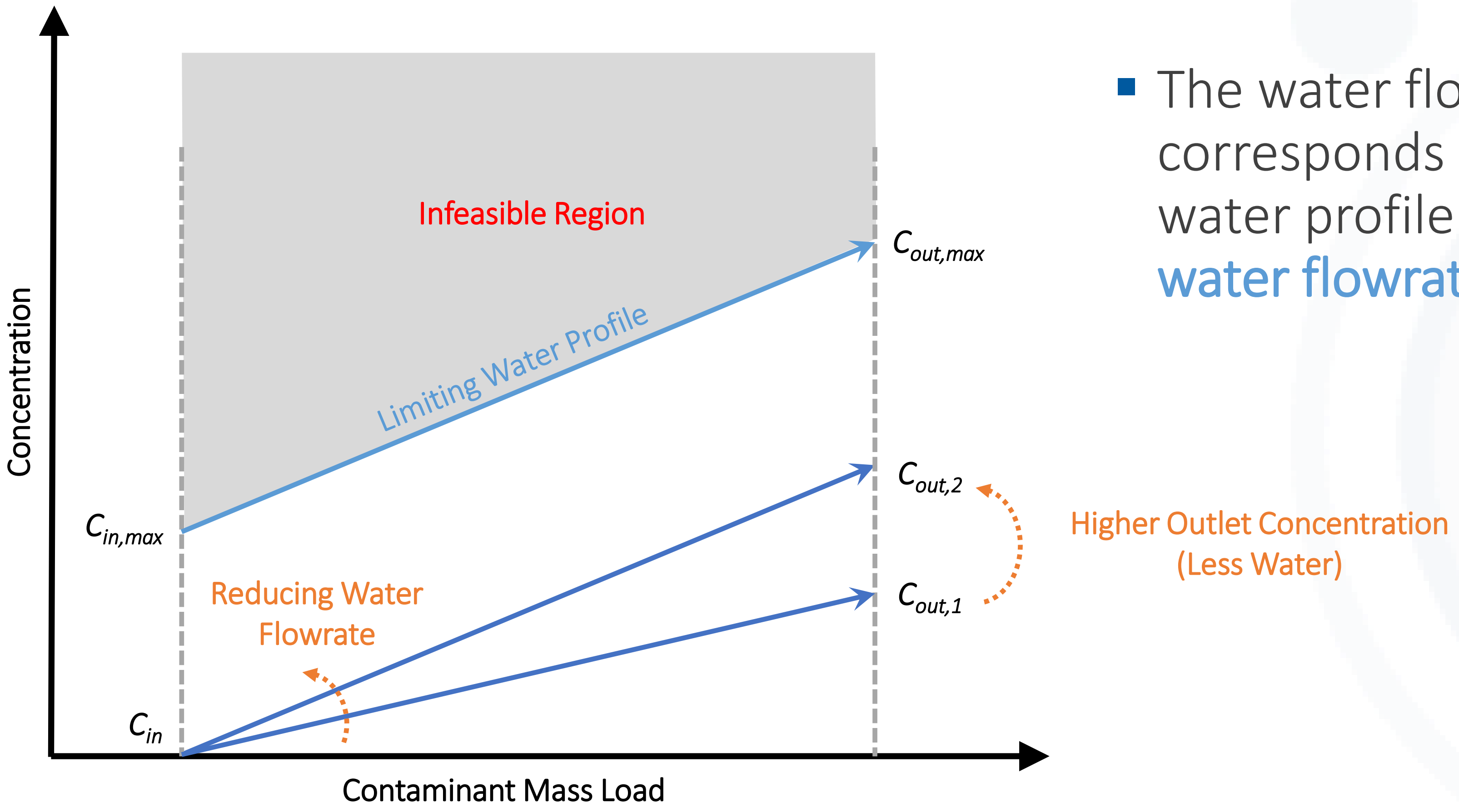
- If **water flowrate is reduced** for the same mass load of contaminant the result will be:
  - Higher outlet concentration
  - Steeper line



Achieving minimum water use

- The objective is to reduce water use as much as possible
- Limitations:
  - Minimum flowrate required by the operation
  - Maximum value for outlet concentration (discharge limitations)
- Moreover, in order to allow for reuse, some level of inlet contamination should be allowed

Limiting Water Profile



- The water flowrate that corresponds to the limiting water profile is called limiting water flowrate

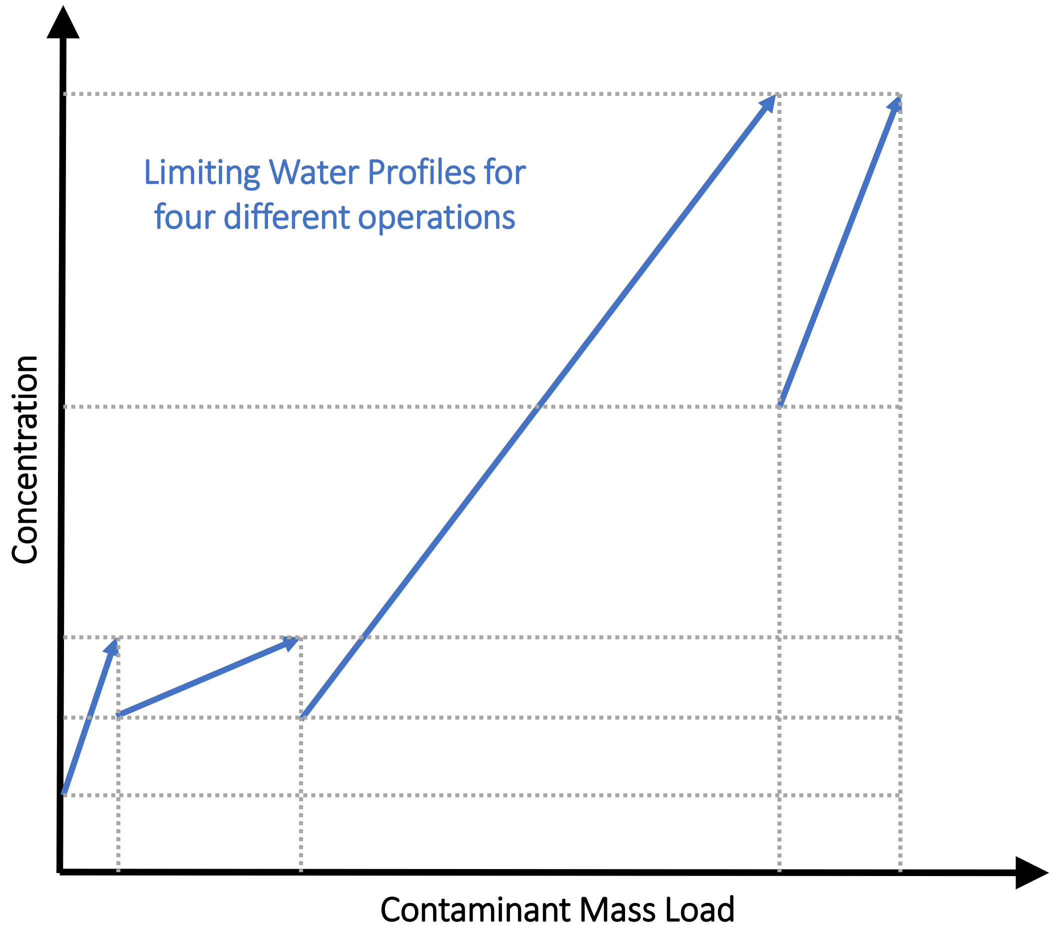
Limiting Water Profile

Advantages of its usage

- Operations with different characteristics can be compared
- Mass transfer does not need to be modeled in detail
- The flow pattern does not affect the results
- Can be applied in all different types of water use operations (co-current, countercurrent)

Limiting Composite Curve

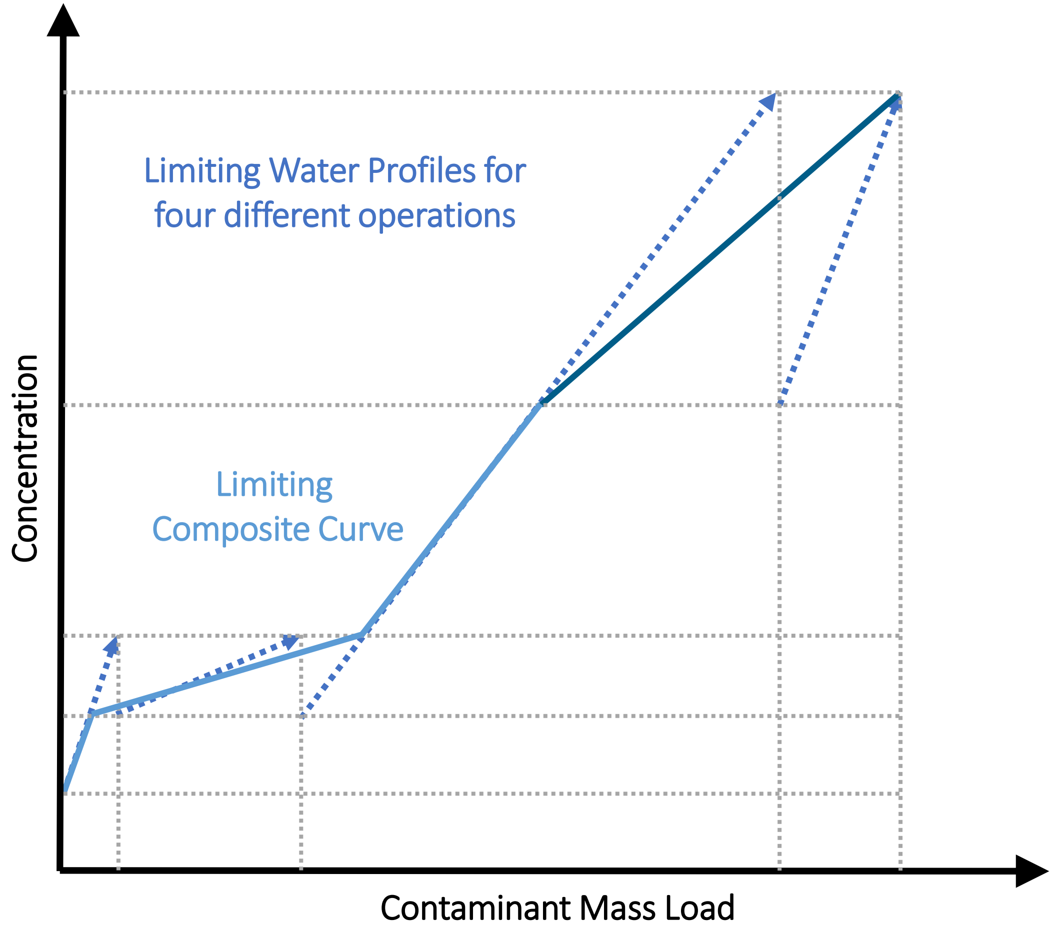
The case of one contaminant



- When combining limiting water profiles for various operations in the same chart, the output will be the limiting composite curve of the water streams

Limiting Composite Curve

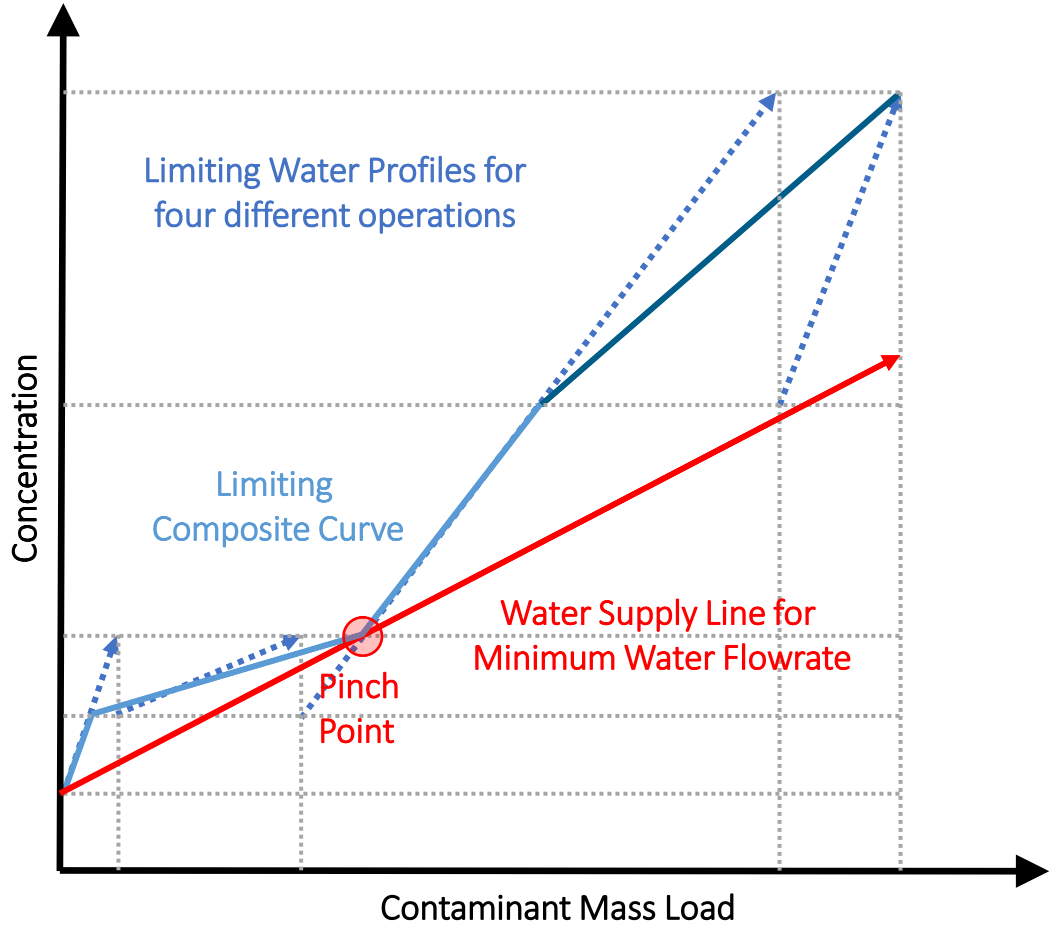
The case of one contaminant



- The drawing of the limiting composite curve is analogous to the composite curve for heat integration.
- The y-axis is divided into the corresponding concentration intervals and the contaminant loads in each interval are combined to create the composite curve.

Limiting Composite Curve

The case of one contaminant



- The minimum water flowrate for a given process can be specified by drawing the water profile curve which **begins from the minimum acceptable inlet concentration and passes from the pinch point**

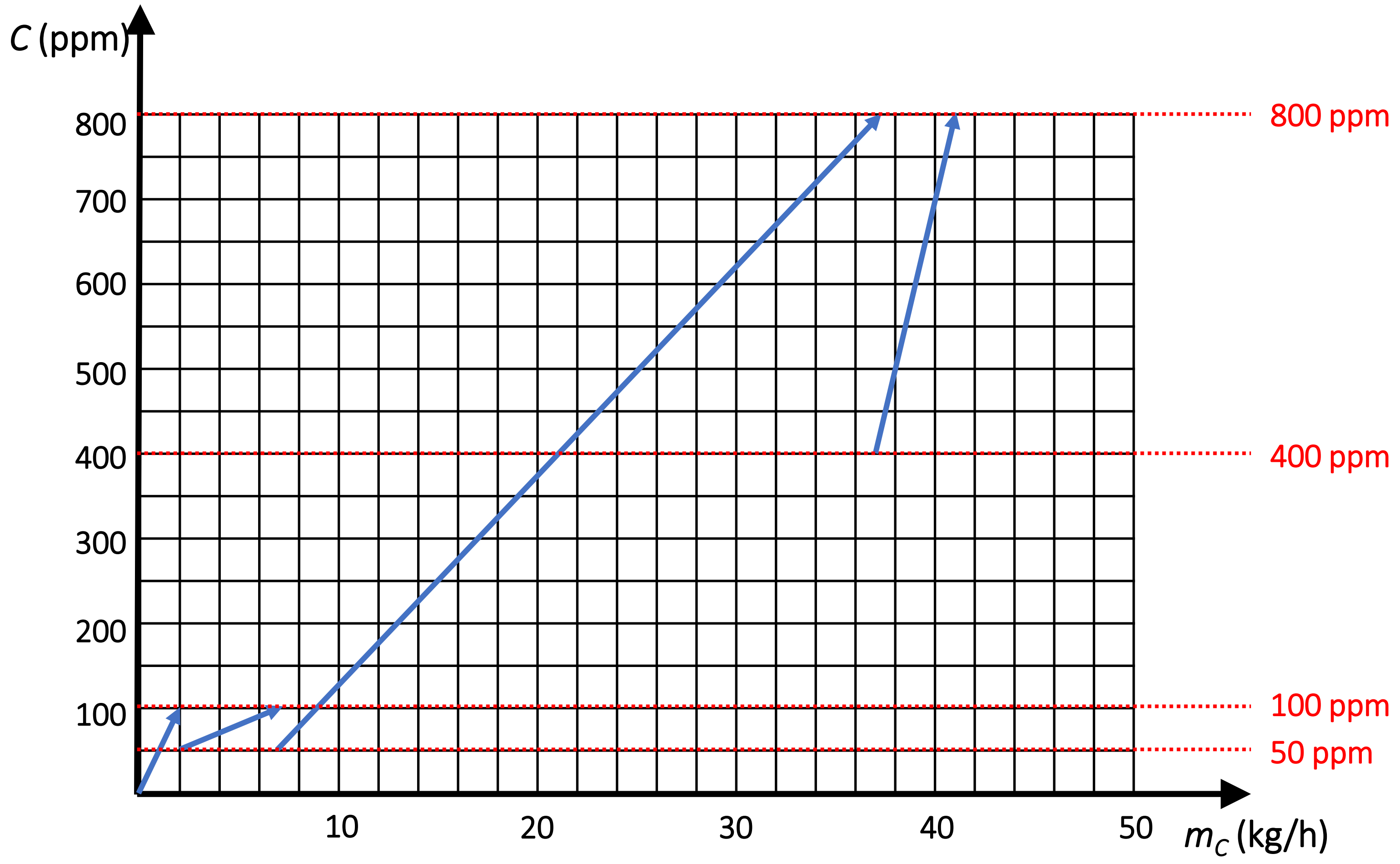
Let's try an example

- An industrial unit has 4 operations which use water, and their specifications are presented in the following table. If the maximum inlet and outlet concentrations refer to a single contaminant:
  - Calculate the limiting water flowrate, which would maximize the water reuse in the system and draw the corresponding water supply line
  - Estimate the water savings compared to the case where all processes use freshwater

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	20
2	5000	50	100	100
3	30000	50	800	40
4	4000	400	800	10

Step 1. Limiting Water Profiles

Draw the Limiting Water Profiles for the four different operations



Step 2. Concentration Intervals

Calculate the concentration intervals and the corresponding contaminant loads in each interval

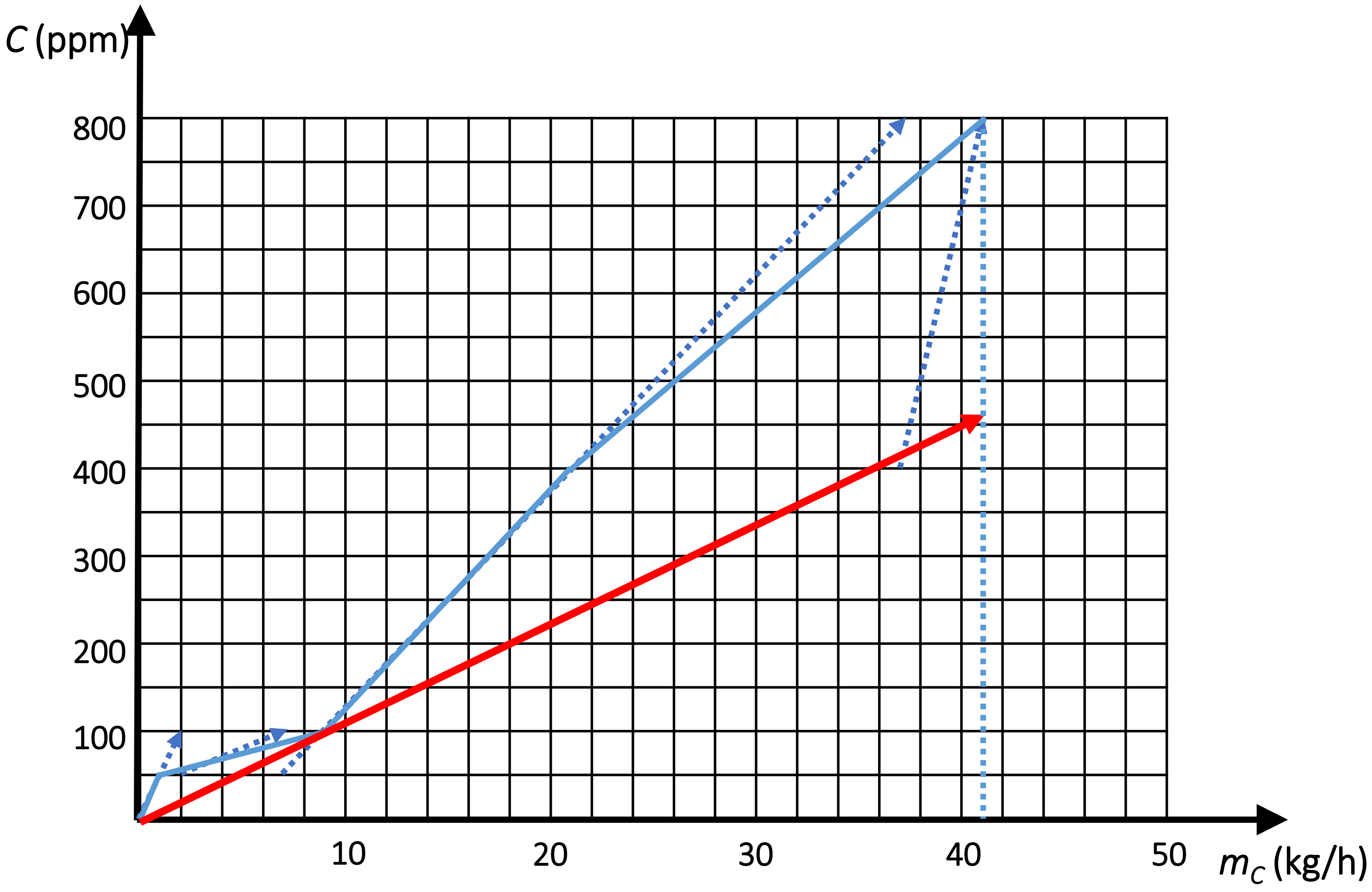
No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load
C1	0	50	20	1000
C2	50	100	100 + 40 + 20	8000
C3	100	400	40	12000
C4	400	800	40 + 10	20000

$$\Delta m_{C1} = m_{W1} \times \Delta C_1 = 20 \times (50 - 0) = 1000$$

$$\Delta m_{C2} = m_{W2} \times \Delta C_2 = 160 \times (100 - 50) = 8000$$

Step 3. Composite Curve

Draw the composite curve and the minimum flowrate water supply line



Step 4. Minimum Flowrate

Calculate the minimum flowrate and water savings

- From the pinch point

$$m_{w,min} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{9000}{100} = 90 \text{ t/h}$$

- If all processes used freshwater:

No	Contaminant Mass (g/h)	Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	2000/100 = 20
2	5000	0	100	5000/100 = 50
3	30000	0	800	30000/800 = 37.5
4	4000	0	800	4000/800 = 5

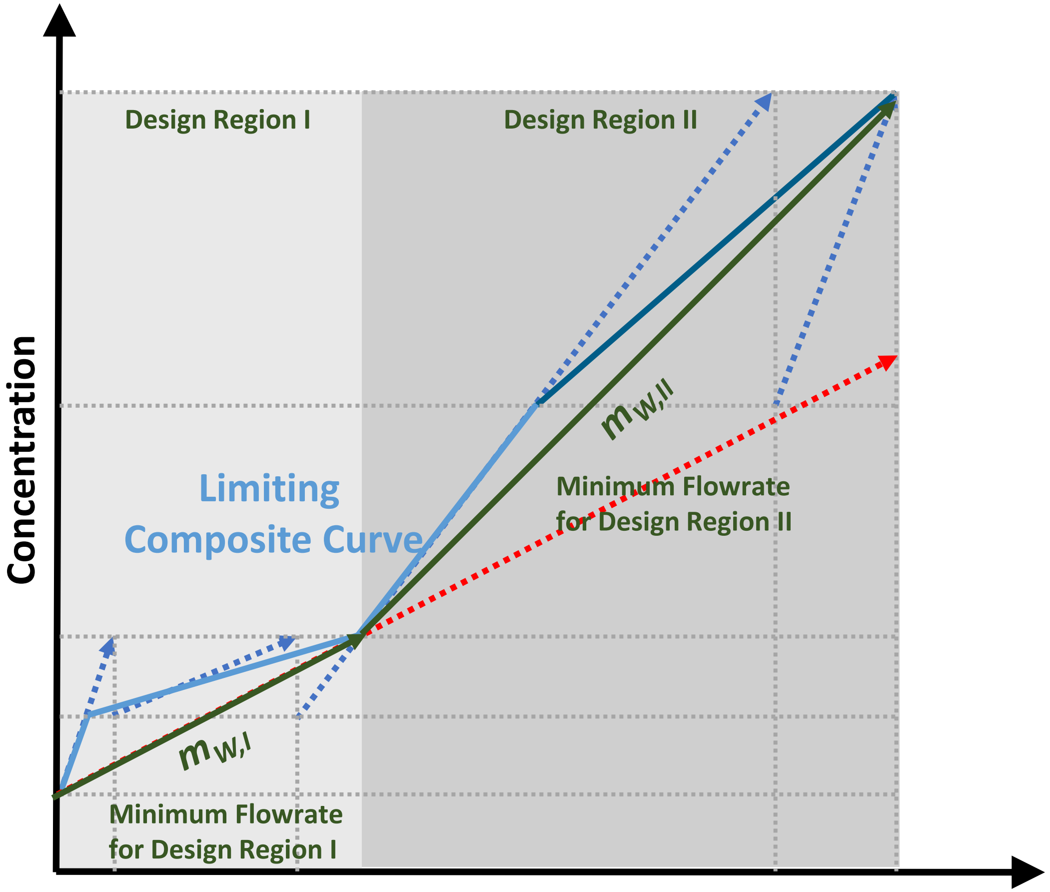
Savings = 112.5 – 90 = 22.5 t/h

Designing a maximum reuse system

In the case of a single contaminant

- After having calculated the minimum water flowrate required for the system, the next step is to actually design the system
  - Specify how exactly the water will flow among the different processes.
- Two (or more) different design regions can be identified in any scheme
  - Below the pinch, with limiting flowrate equal to the target minimum water flowrate of the system
  - Above the pinch, where the flowrate can be lower than the target minimum water flowrate

Separate Design Regions

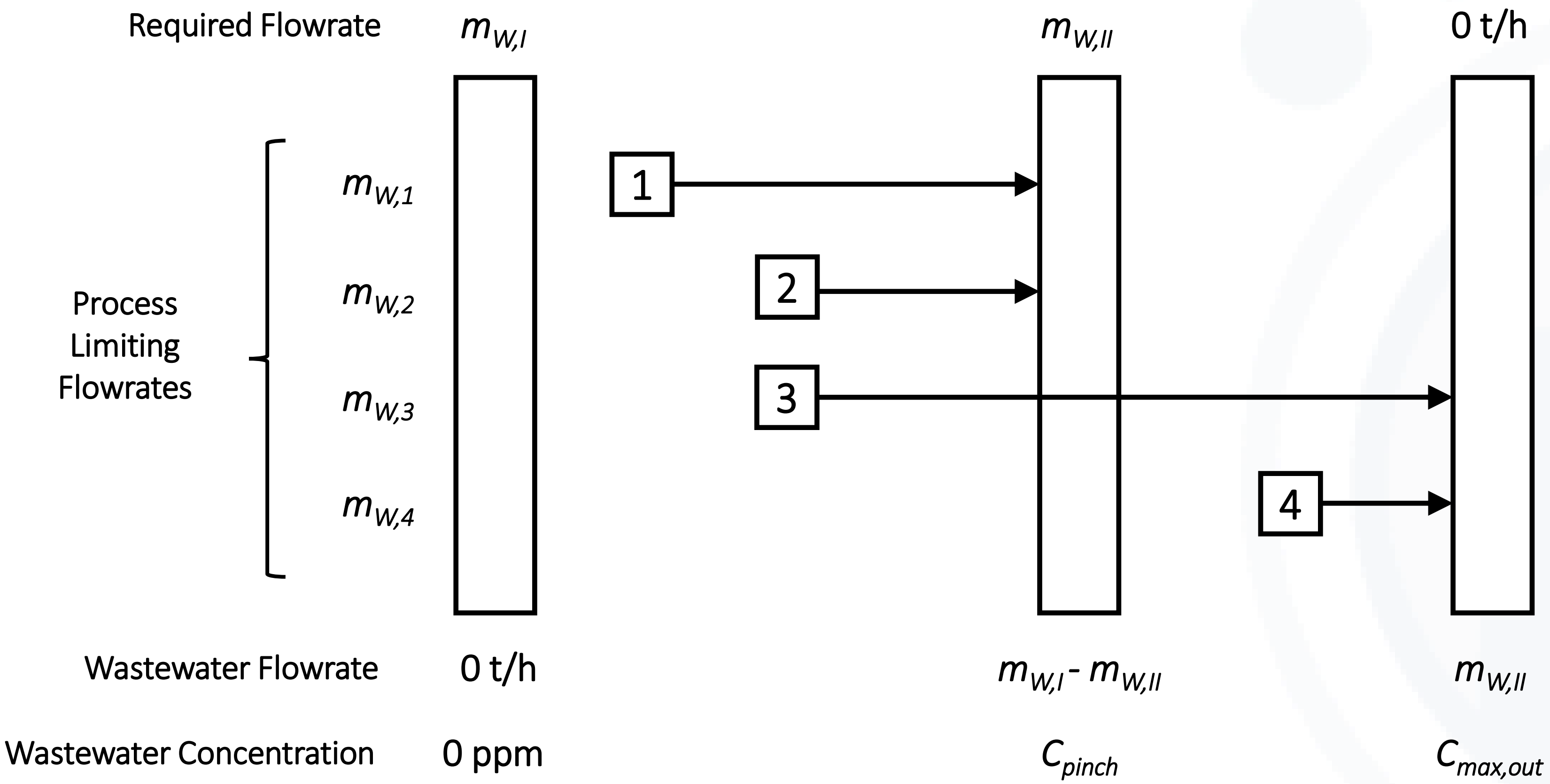


Designing a maximum water reuse system

In the case of a single contaminant

- Objective of the design
  - Use the target flowrate below the pinch and only the required flowrate in the other regions
- Four step procedure
  - Set up the design grid and include all the necessary water mains
    - Freshwater stream
    - Stream(s) with pinch concentration
    - Stream with maximum acceptable concentration;
  - Connect all the processes with water mains;
  - Amend the individual processes where the flowrate changes among water mains; and
  - Remove all the unnecessary water mains and connect all the processes directly, where possible.

A typical design grid



Let's carry on with that example

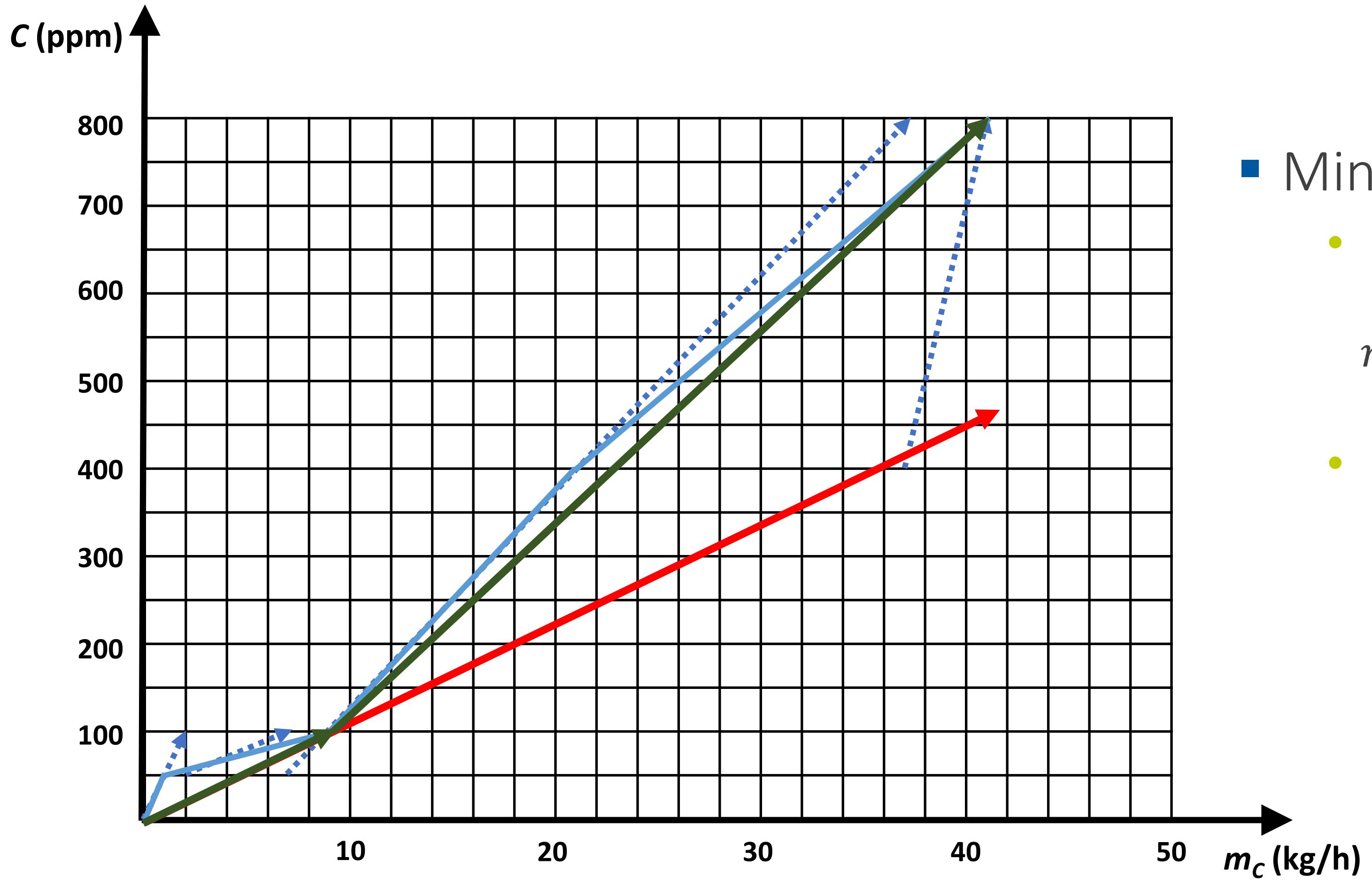
- Designing a network for the target water consumption, as calculated earlier.

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	2000	0	100	20
2	5000	50	100	100
3	30000	50	800	40
4	4000	400	800	10

- Two processes operating below pinch (1 & 2), one process operating above pinch (4) and one process operating in both regions.

Step 5. Minimum water use per region

Calculate minimum flow rate for each design region



- Minimum flow rate
  - Flow Rate in Design Region I

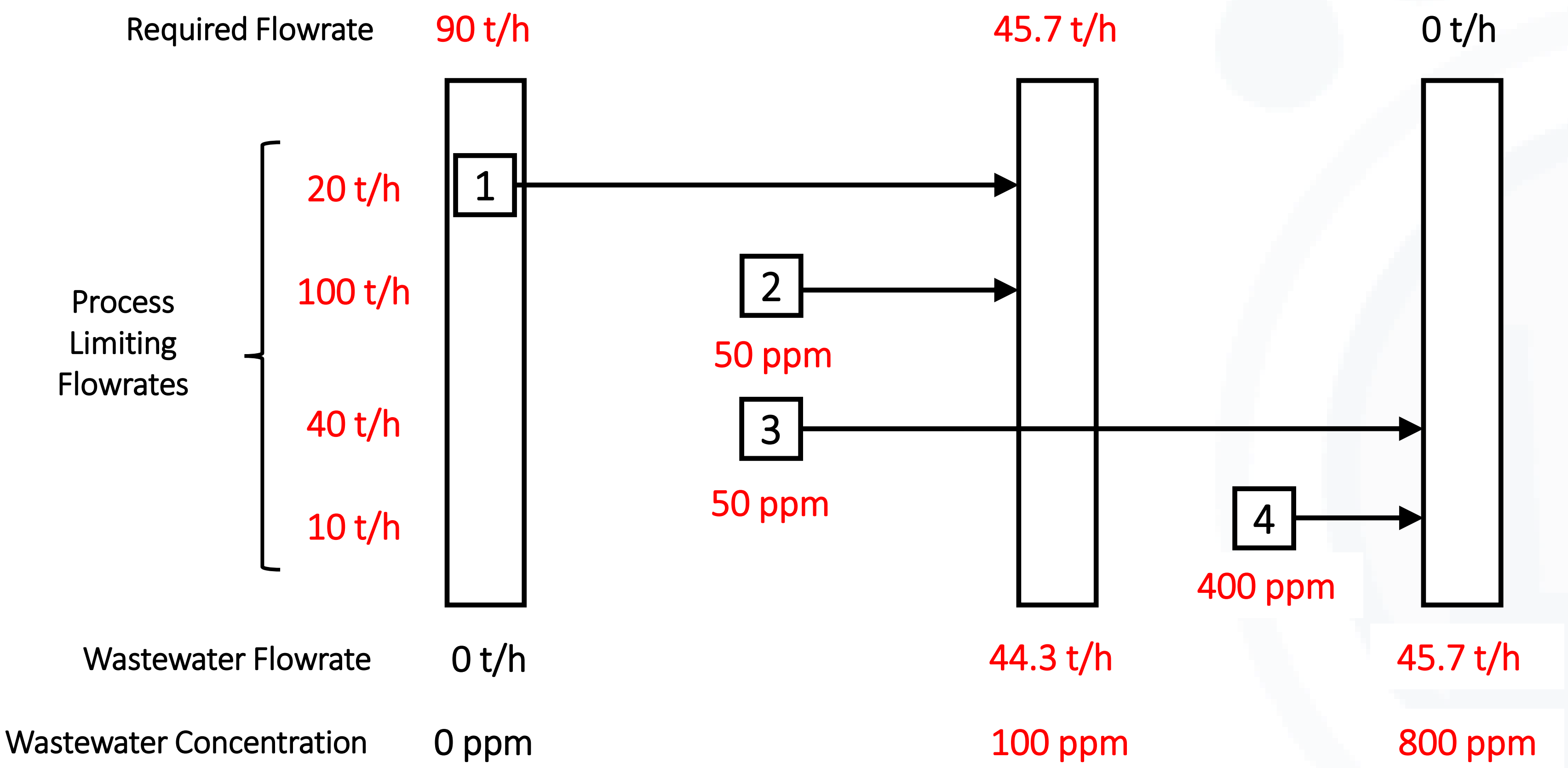
$$m_{w,I} = \frac{\Delta m_{C,pinch}}{\Delta C_{pinch}} = \frac{9000}{100} = 90\ \text{t/h}$$

  - Flow Rate in Design Region II

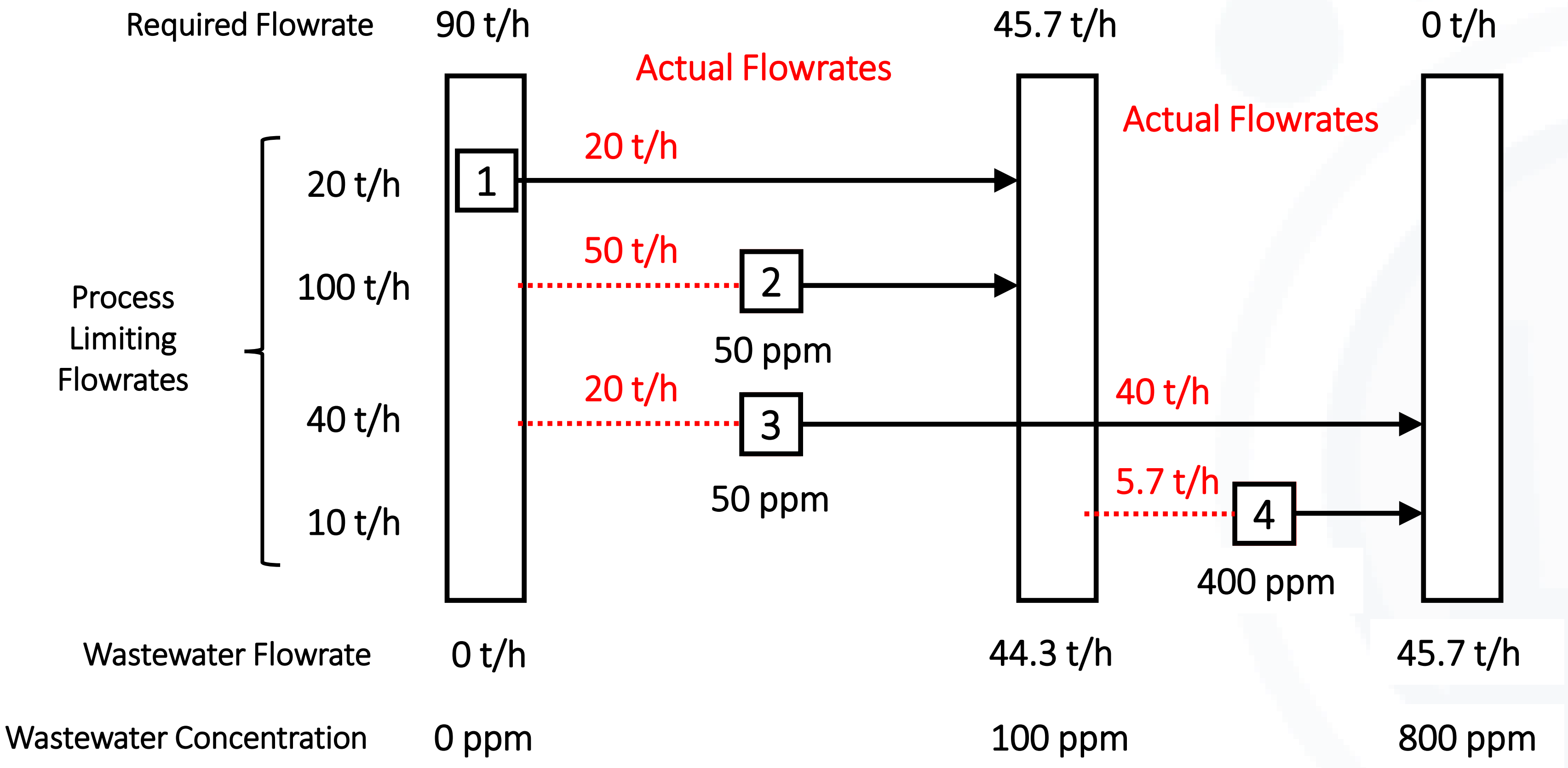
$$m_{w,II} = \frac{\Delta m_{C,II}}{\Delta C_{II}} = \frac{32000}{700} = 45.7\ \text{t/h}$$

Step 6. Design Grip Setup

Set up the design grid and include all the necessary water mains

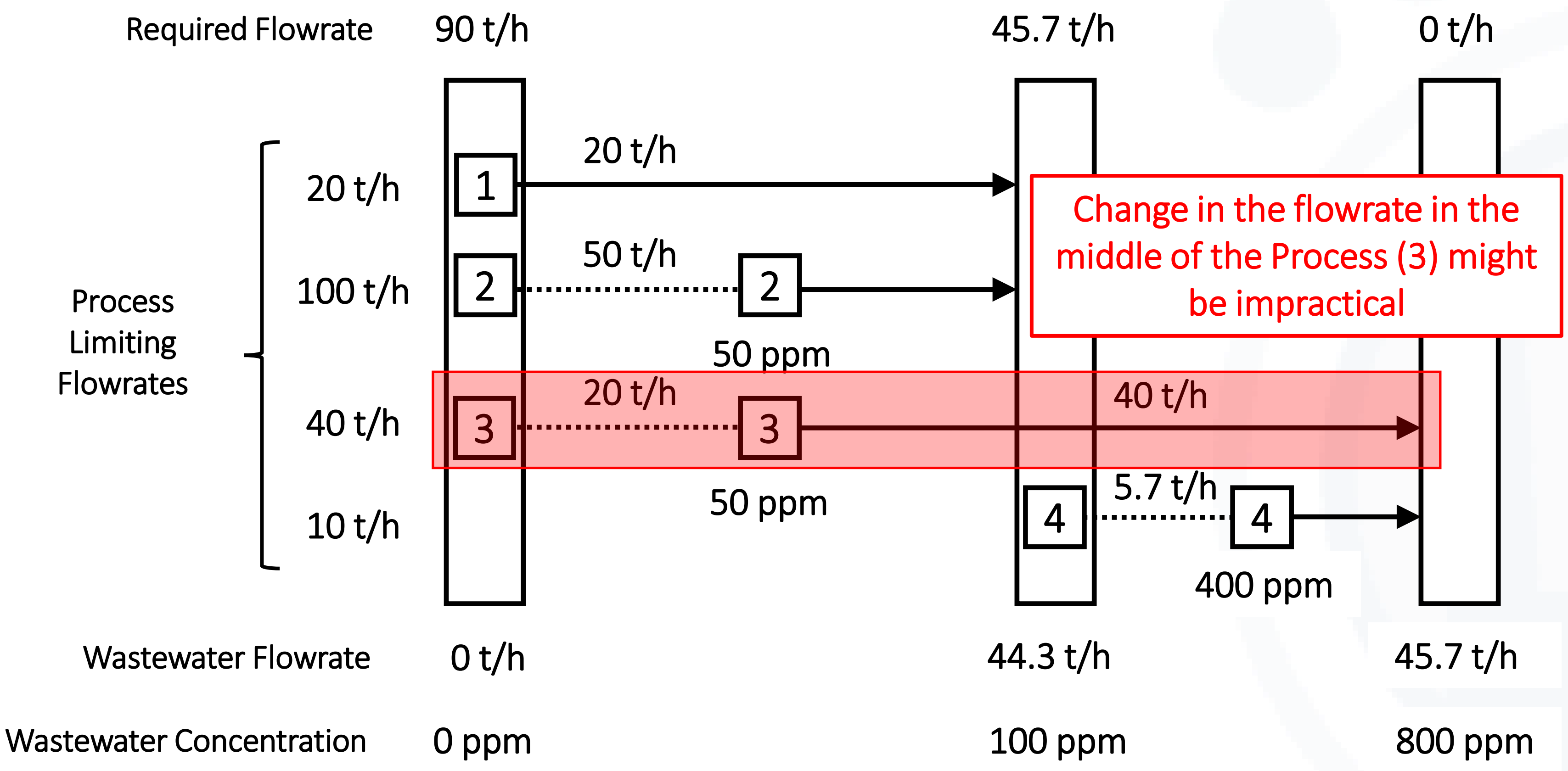


Step 7. Connect all the processes with water mains



Step 8. Amend flowrate where necessary

Amend the processes where the flowrate changes among water mains



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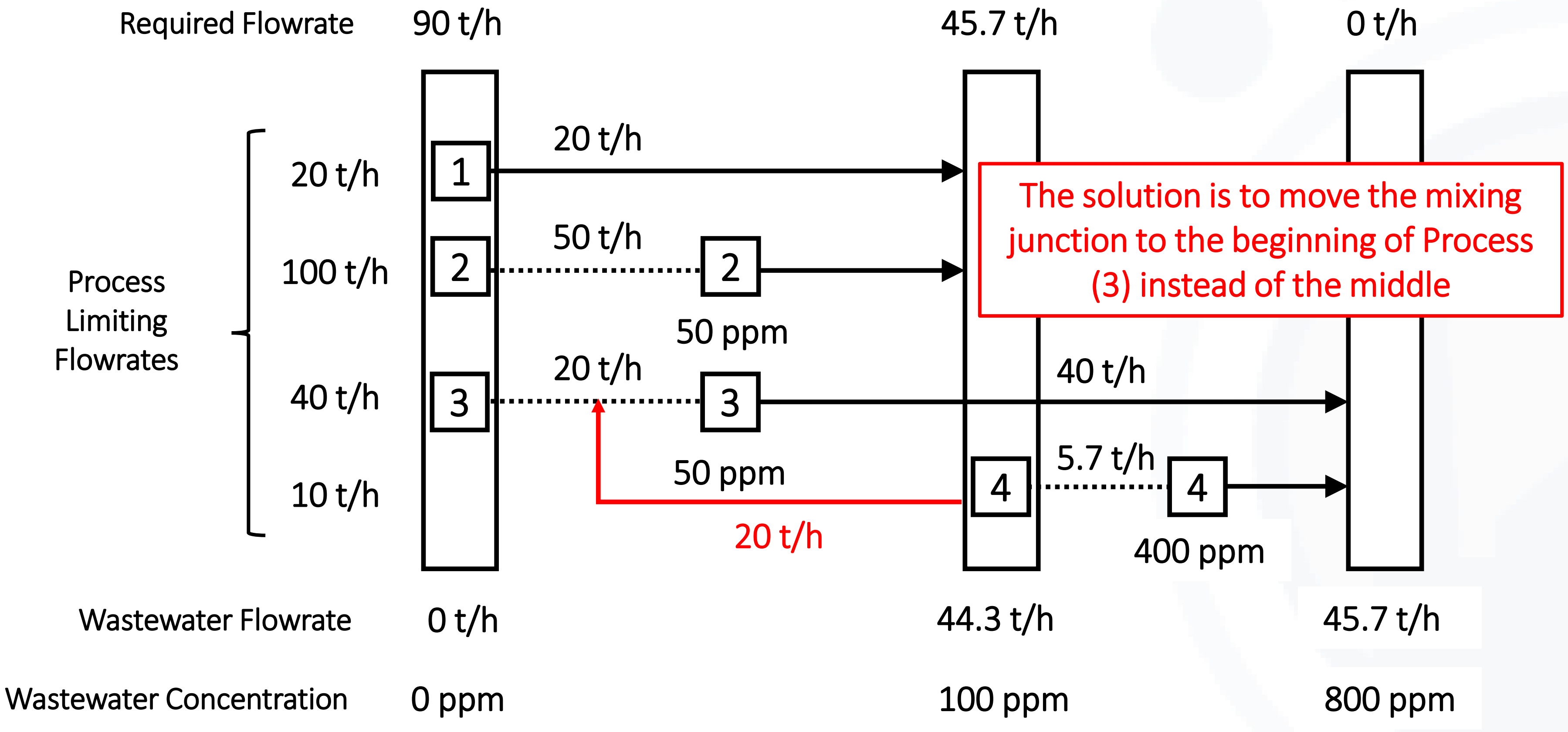
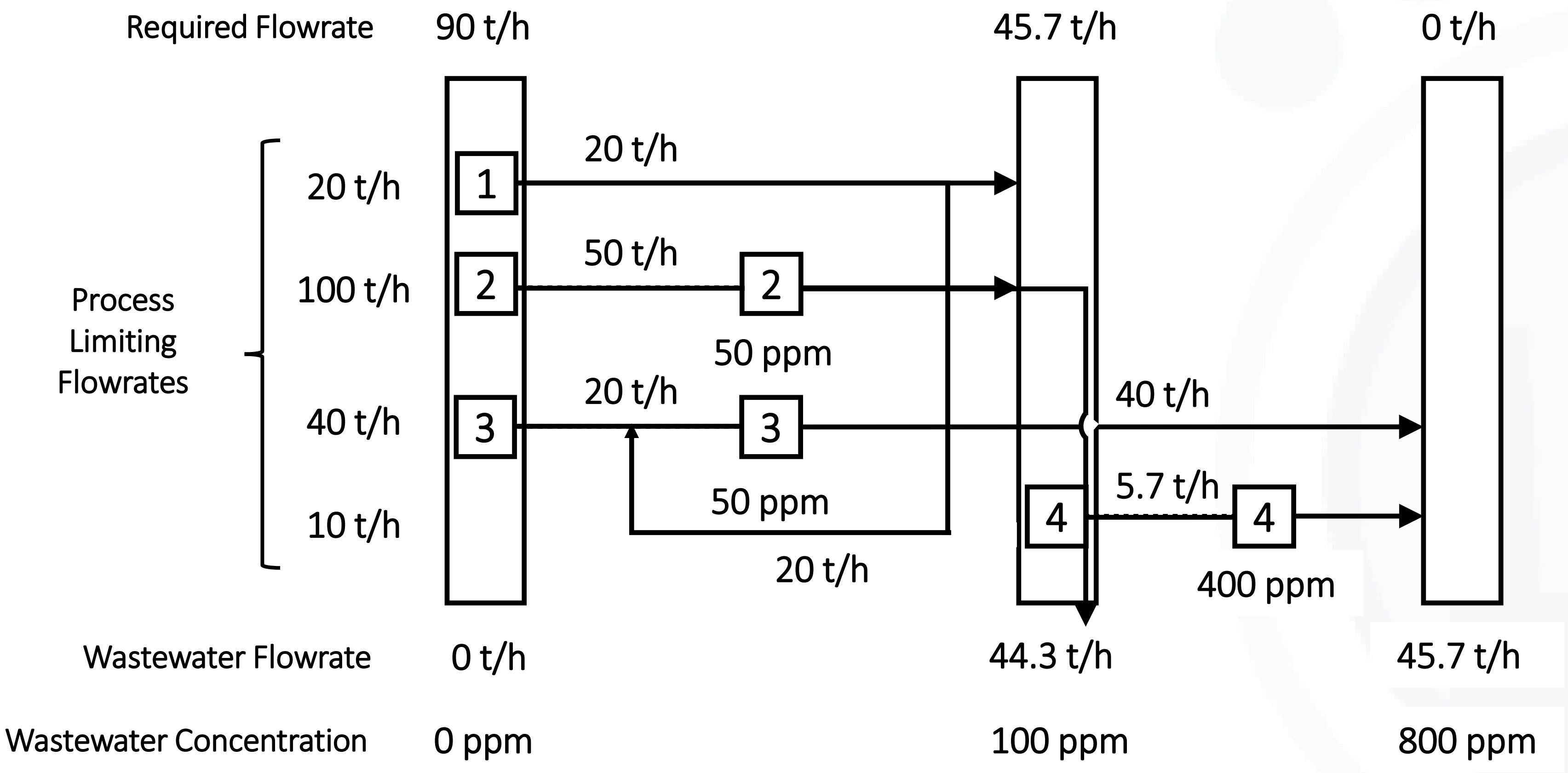
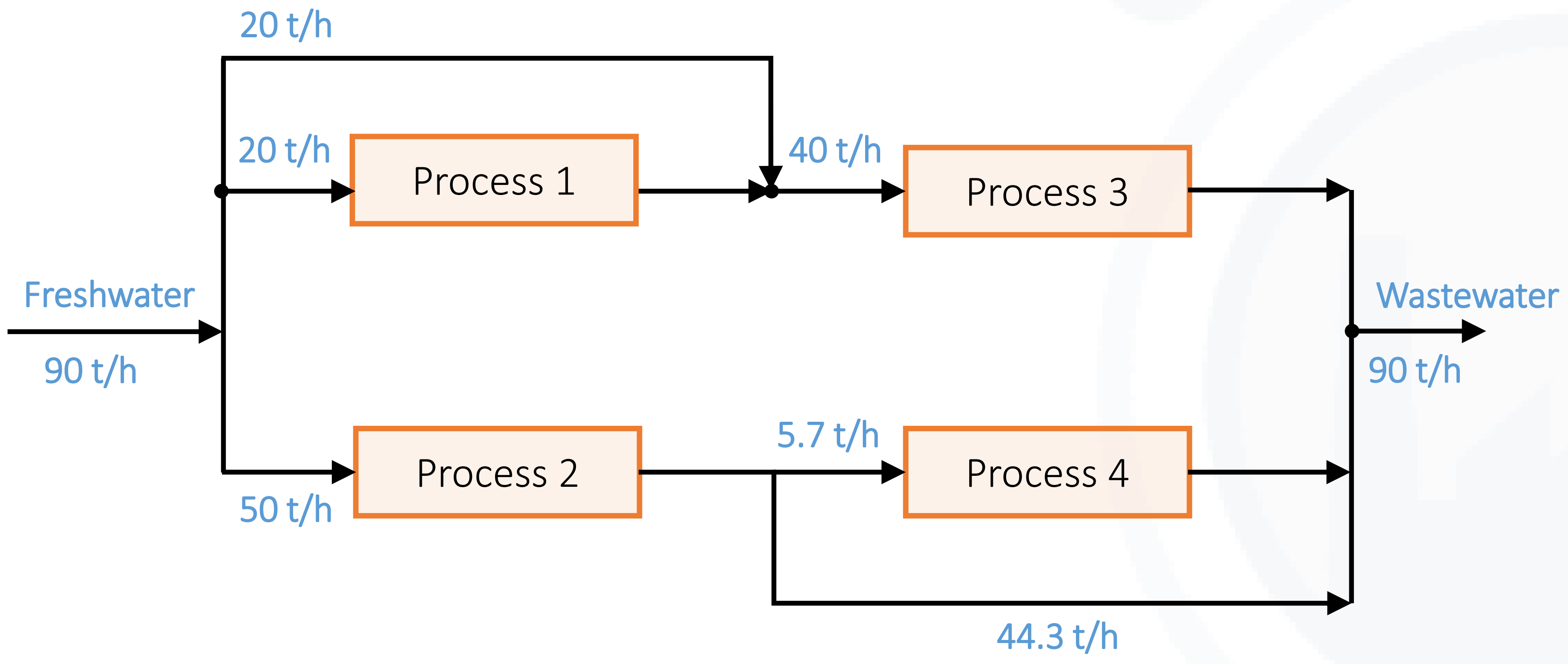


Step 9. Finalise the network

Remove the unnecessary water mains and connect all processes directly



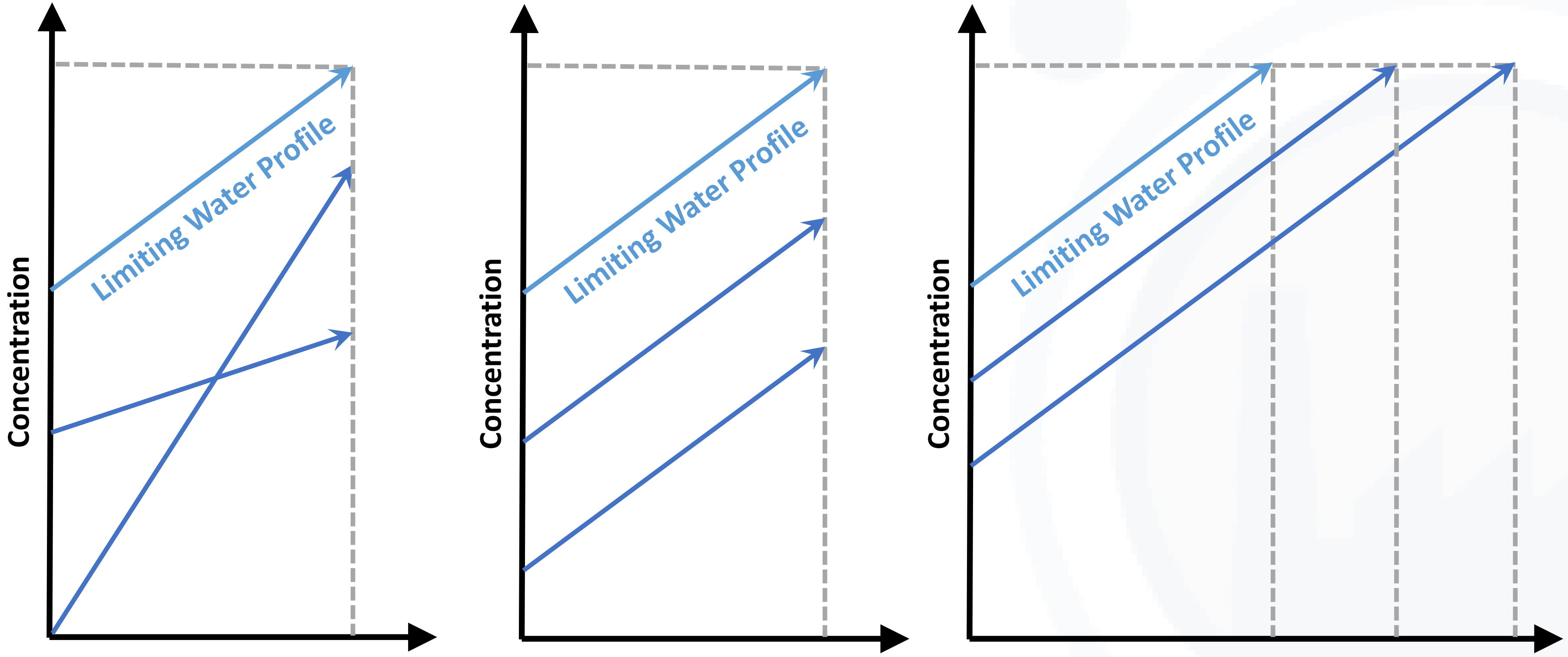
Step 10. Draw the flow diagram



Real Life Limitations

- Water losses in the systems
- More than one sources in the system (e.g. river, lake, potable, demineralized)
- More than one contaminants
- Different mass transfer models

Different Mass Transfer Models



Fixed Contaminant Mass Load and Variable Flowrate

Fixed Contaminant Mass Load and Fixed Flowrate

Fixed Outlet Concentration and Fixed Flowrate

References & Useful Resources

- Alwi, S, Varbanov, P.S., Manan, Z.A. & Klemes, J.J. (2014). *Process integration and intensification: saving energy and resources*, De Gruyter.
- Smith, R. (2016), *Chemical process design and integration,* 2nd Ed. Wiley Blackwell, Chichester, West Sussex.