AquaSPICE

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

Water Integration

Design of a Wastewater Regeneration System

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Wastewater Regeneration

- Process similar to the design of water reuse networks
  - Regeneration Reuse
  - Regeneration Recycle
- Divide the processes into two categories:
  - Those that must definitely use freshwater
  - Those that can accept a concentration greater than what regeneration can achieve
- Design is performed in two individual regions; one using freshwater and one using regenerated water

Let's try an example…

- An industrial unit has 3 water consuming operations. The management is considering installing a regeneration process which can achieve an outlet concentration of 5 ppm.
- Design four different water use schemes and find which one consumers the lowest amount of freshwater:
  - Freshwater only
  - Water reuse only scheme, without any regeneration
  - Regeneration reuse scheme
  - Regeneration recycling scheme

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	4000	0	200	20
2	5000	100	200	50
3	9000	100	400	30

Freshwater Use Only

Calculation of freshwater used

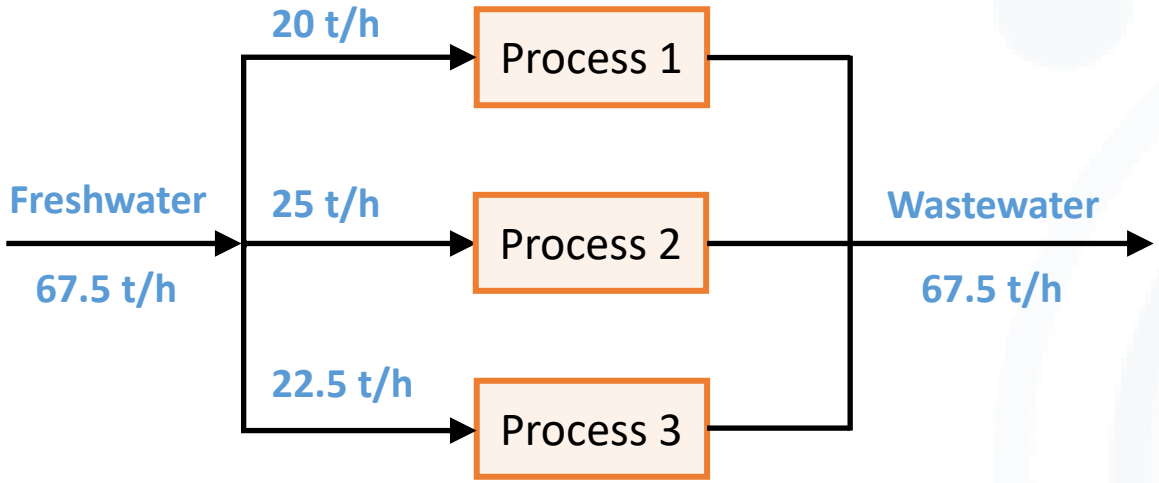
- Freshwater Use Only
  - Calculate the amount of freshwater used in each process by setting the inlet concentration equal to 0.

No	Contaminant Mass (g/h)	Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Freshwater Flowrate (t/h)
C1	4000	0	200	20
C2	5000	0	200	25
C3	9000	0	400	22.5

Total Freshwater Use: 67.5 t/h

Freshwater Use Only

Process Flow Diagram

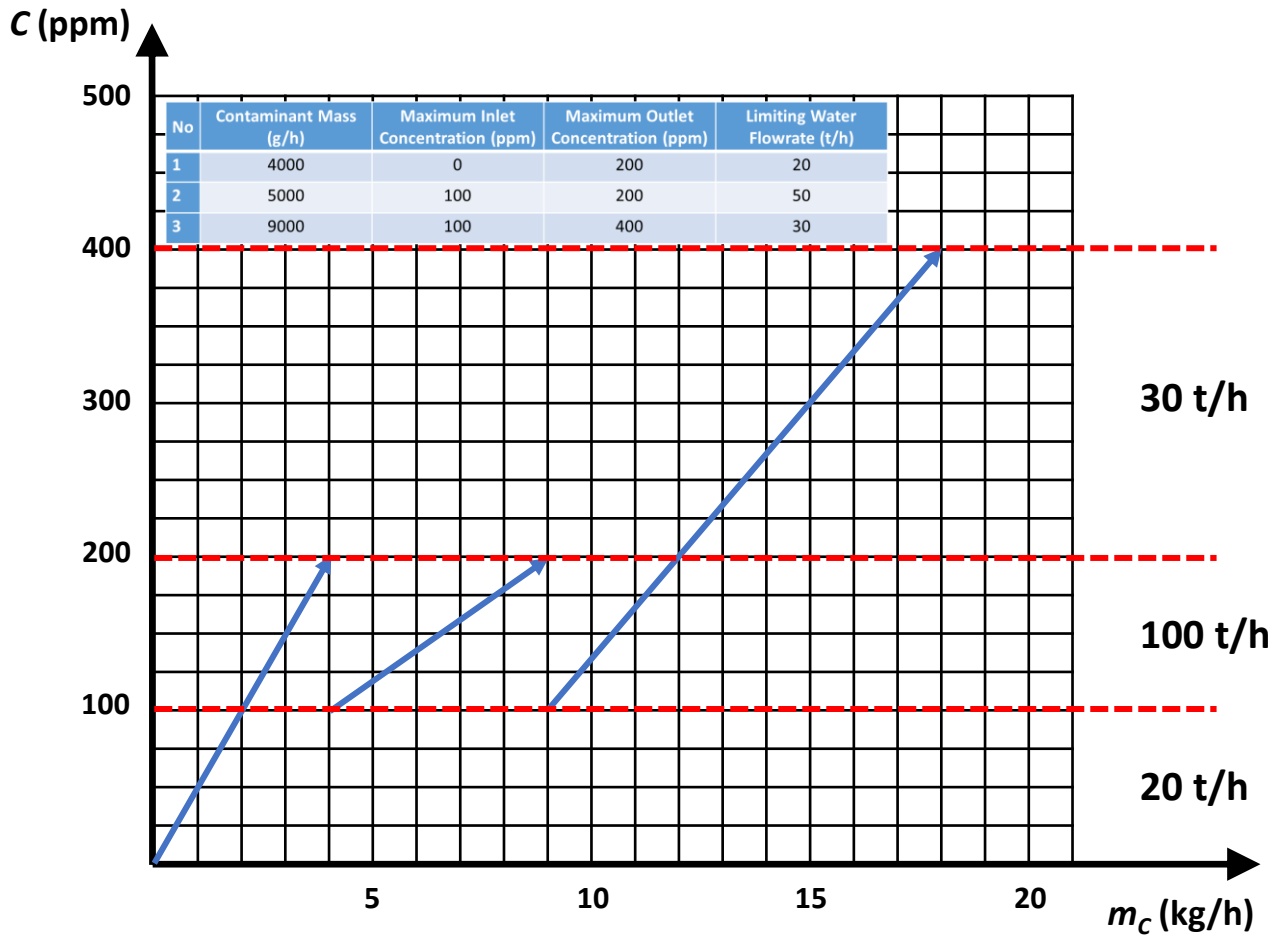


Total Freshwater Use: 67.5 t/h

Water Reuse Only

Draw the Limiting Water Profiles for the three different operations

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
1	4000	0	200	20
2	5000	100	200	50
3	9000	100	400	30



Water Reuse Only

Calculate the concentration intervals

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	100	20	2000
C2	100	200	100	10000
C3	200	400	30	6000

$$\Delta m_{C1} = m_{W1} \times \Delta C_1 = 20 \times (100 - 0) = 2000\ g/h$$

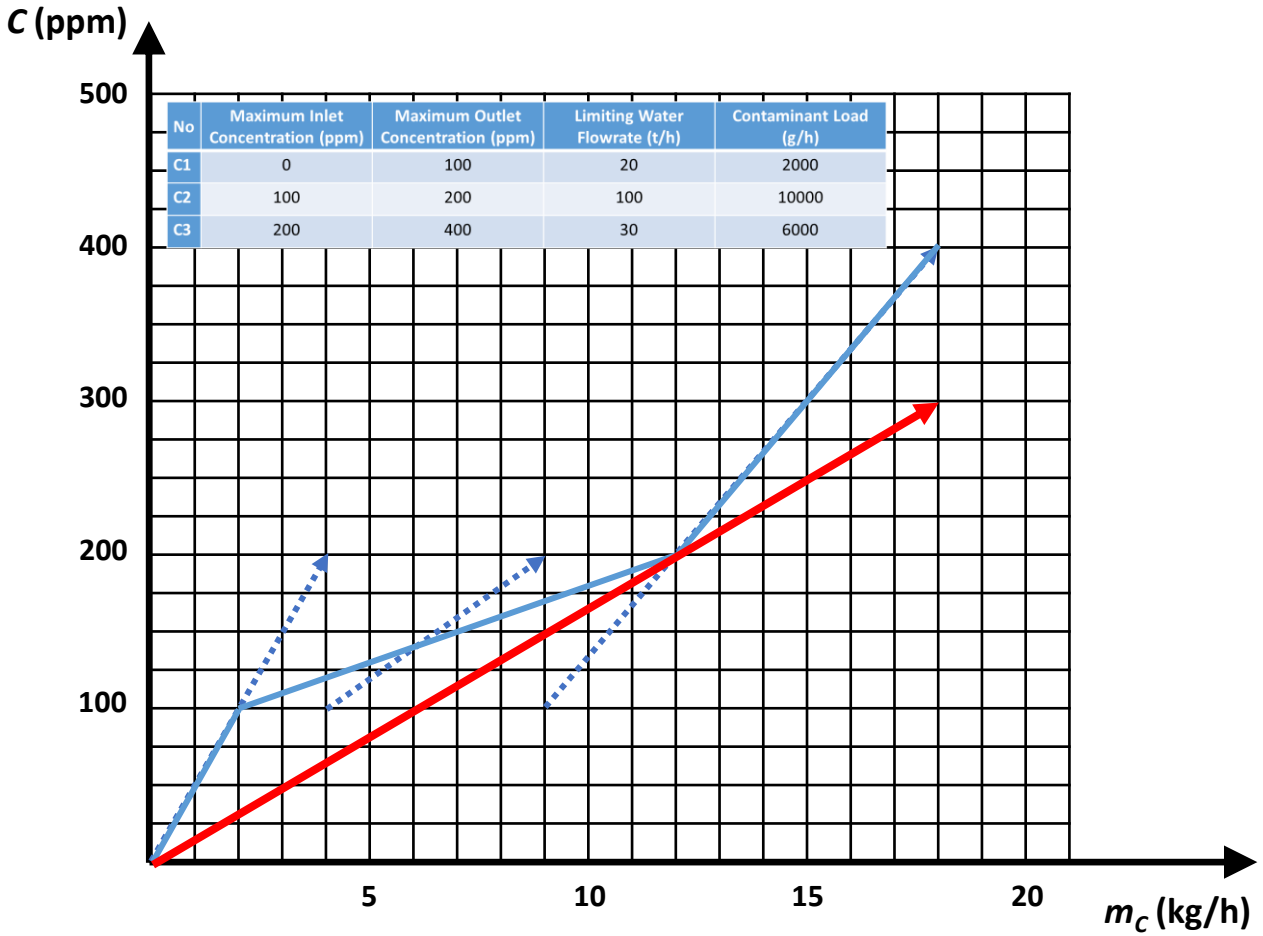
$$\Delta m_{C2} = m_{W1} \times \Delta C_2 = 100 \times (200 - 100) = 10000\ g/h$$

$$\Delta m_{C3} = m_{W1} \times \Delta C_3 = 30 \times (400 - 200) = 6000\ g/h$$

Water Reuse Only

Draw the composite curve and the minimum flowrate water supply line

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	100	20	2000
C2	100	200	100	10000
C3	200	400	30	6000



Minimum Flowrate for Reuse Only

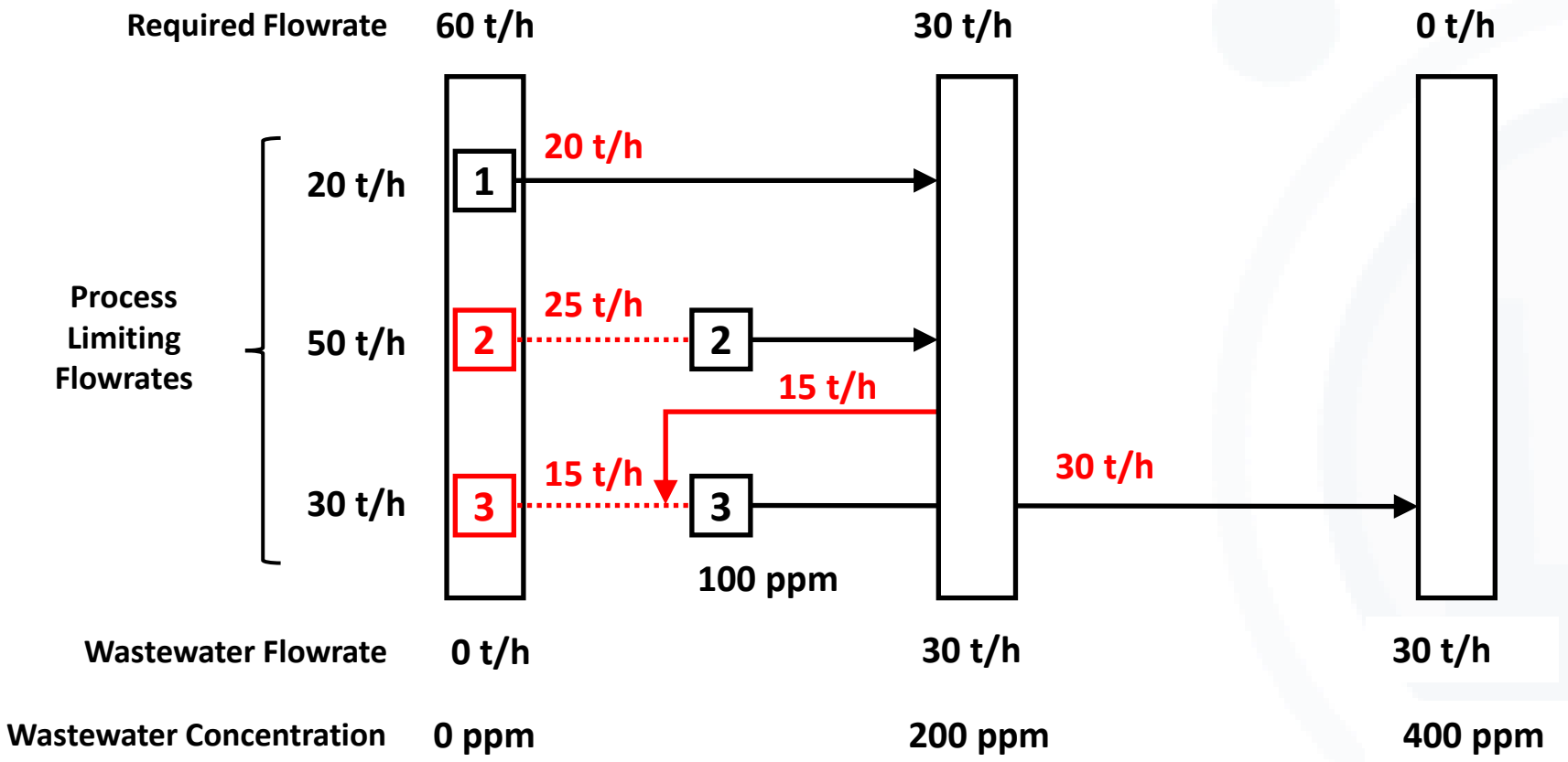
$$m_{w,min} = \frac{12000}{200} = 60 \text{ t/h}$$

Flowrate Above the Pinch

$$m_{w,II} = \frac{6000}{200} = 30 \text{ t/h}$$

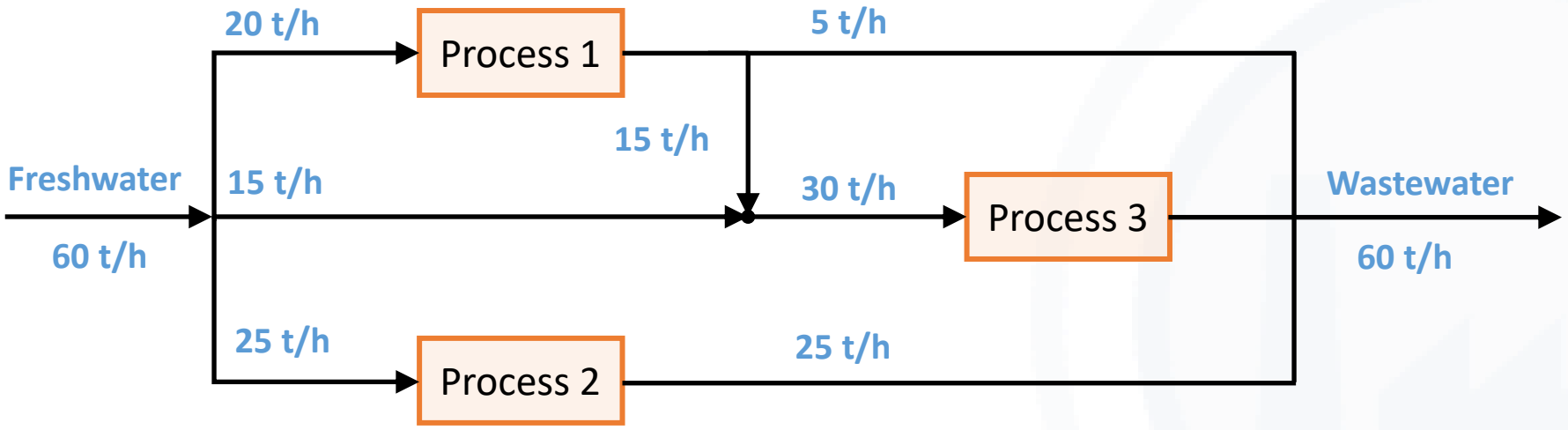
Water Reuse Only

Set up the design grid



Water Reuse Only

Process Flow Diagram



Total Freshwater Use: 60 t/h

Wastewater Regeneration Reuse

Steps to Design a Regeneration Reuse System

- Find the pinch point
- Divide the processes in “freshwater only” and “regenerated water”
- Split processes to evenly distribute mass load below the “reuse only” pinch point
- Draw the composite curve and calculate the minimum flowrate for the two design regions
- Design the wastewater regeneration reuse system

Wastewater Regeneration Reuse

Divide the processes into “freshwater” and “regenerated water”

- Two processes can accept regenerated water (2 and 3) and one process must use freshwater (1)
- Contaminant mass loads for each process below pinch
  - Process 1: $\Delta m_{C1BP} = mW_1 \times \Delta C_1 = 20 \times (200 - 0) = 4000\ \mathrm{g/h}$
  - Process 2: $\Delta m_{C2BP} = mW_2 \times \Delta C_2 = 50 \times (200 - 100) = 5000\ \mathrm{g/h}$
  - Process 3: $\Delta m_{C3BP} = mW_3 \times \Delta C_3 = 30 \times (200 - 100) = 3000\ \mathrm{g/h}$

Wastewater Regeneration Reuse

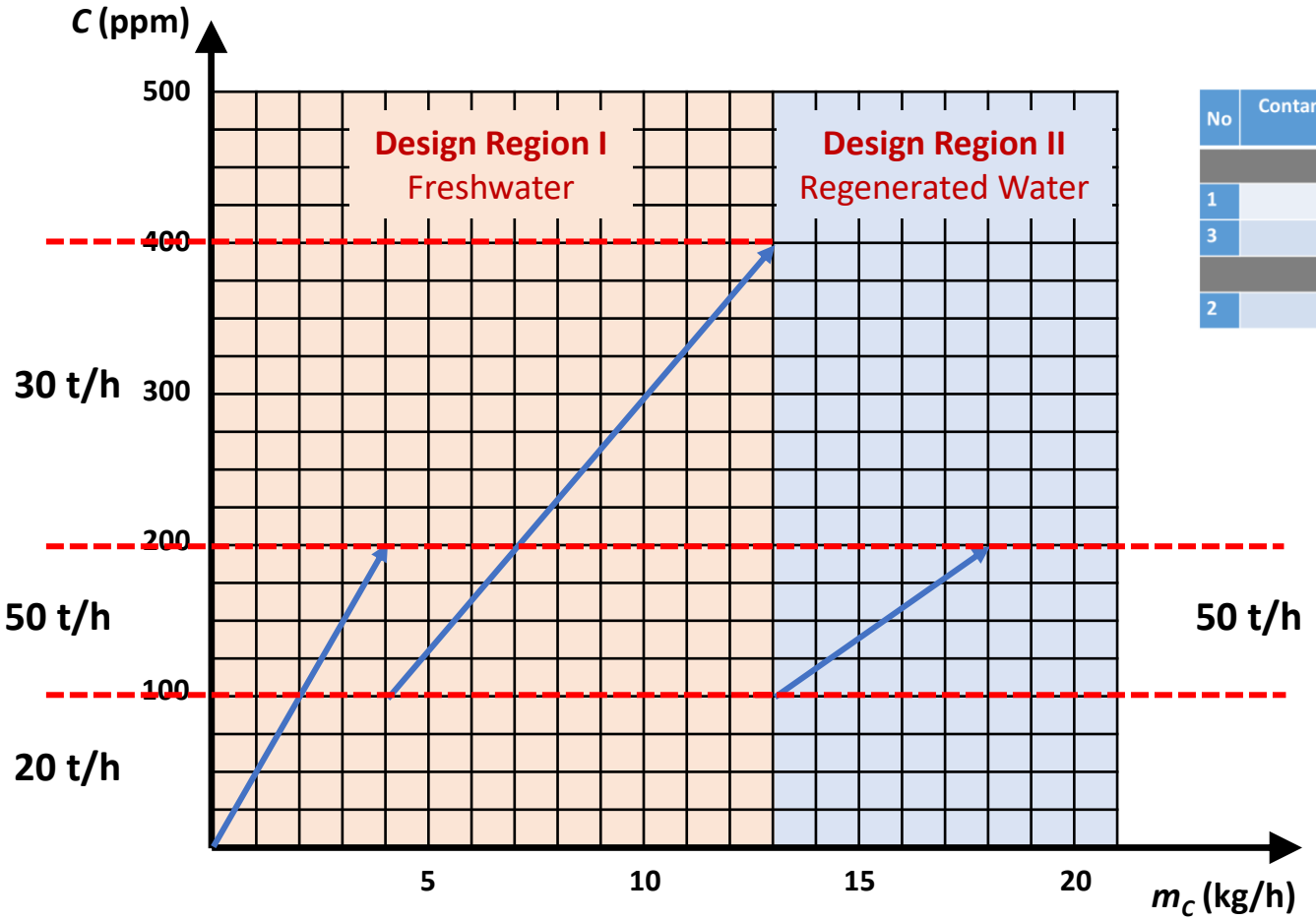
Evenly distribute mass load

- To evenly distribute mass loads processes 1 and 3 will get freshwater whereas process 2 will receive regenerated water

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
Freshwater				
1	4000	0	200	20
3	9000	100	400	30
Regenerated Water				
2	5000	100	200	50

Wastewater Regeneration Reuse

Draw the Limiting Water Profiles for the two design regions



No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
Freshwater				
1	4000	0	200	20
3	9000	100	400	30
Regenerated Water				
2	5000	100	200	50

Wastewater Regeneration Reuse

Calculate the concentration intervals for both design regions

Design Region I - Freshwater

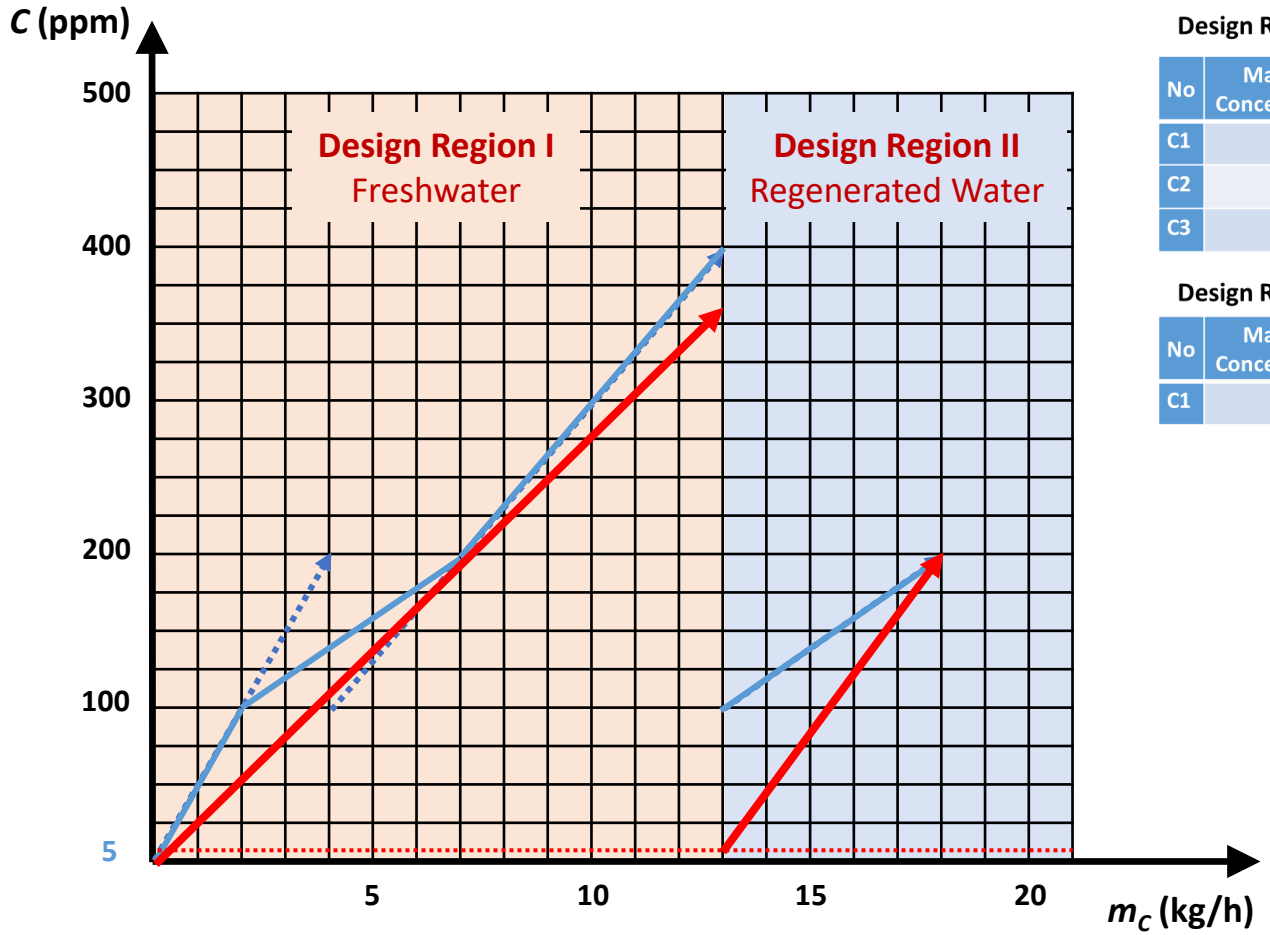
No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	100	20	2000
C2	100	200	50	5000
C3	200	400	30	6000

Design Region II – Regenerated Water

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	100	200	50	5000

Wastewater Regeneration Reuse

Draw the composite curve and the minimum flowrate water supply line



Design Region I - Freshwater

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	100	20	2000
C2	100	200	50	5000
C3	200	400	30	6000

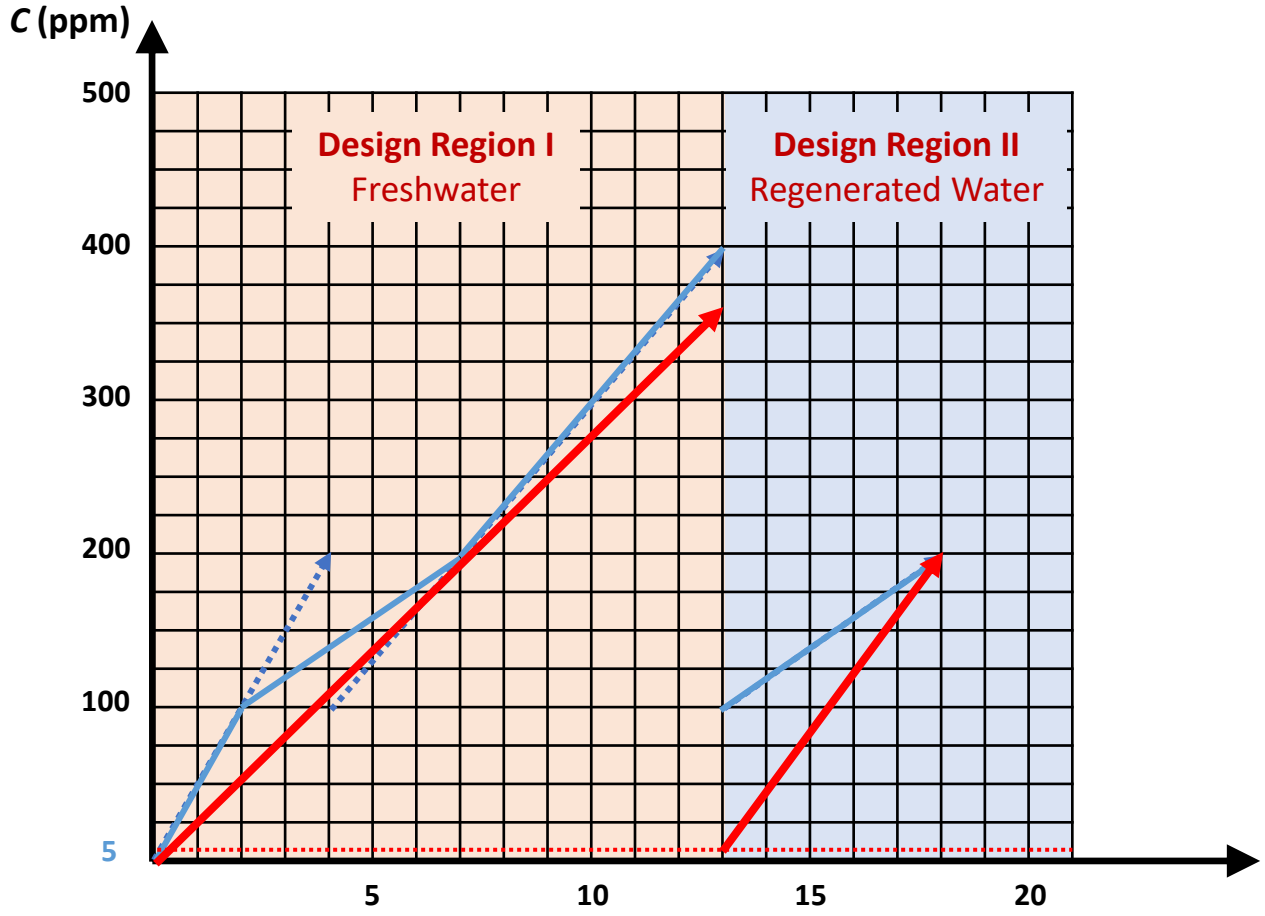
Design Region II – Regenerated Water

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	100	200	50	5000

Remember: The management is considering installing a regeneration process which can achieve an **outlet concentration of 5 ppm.**

Wastewater Regeneration Reuse

Draw the composite curve and the minimum flowrate water supply line



Minimum Flowrate for Freshwater

$$m_{FW,I} = \frac{7000}{200 - 0} = 35 \text{ t/h}$$

Flowrate for Freshwater above the Pinch

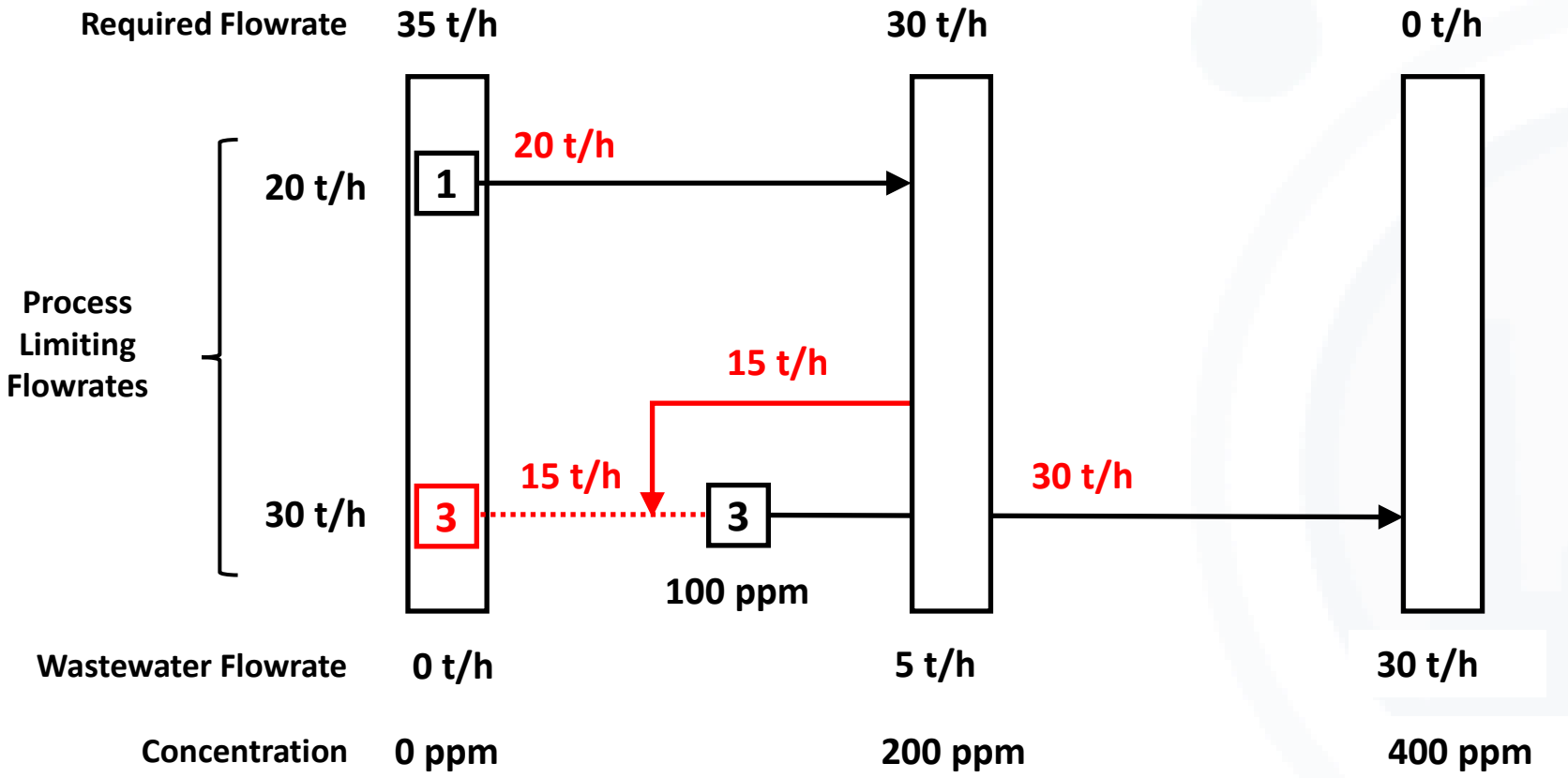
$$m_{FW,II} = \frac{13000 - 7000}{400 - 200} = 30 \text{ t/h}$$

Minimum Flowrate for Regenerated Water

$$m_{RW} = \frac{18000 - 13000}{200 - 5} = 25.6 \text{ t/h}$$

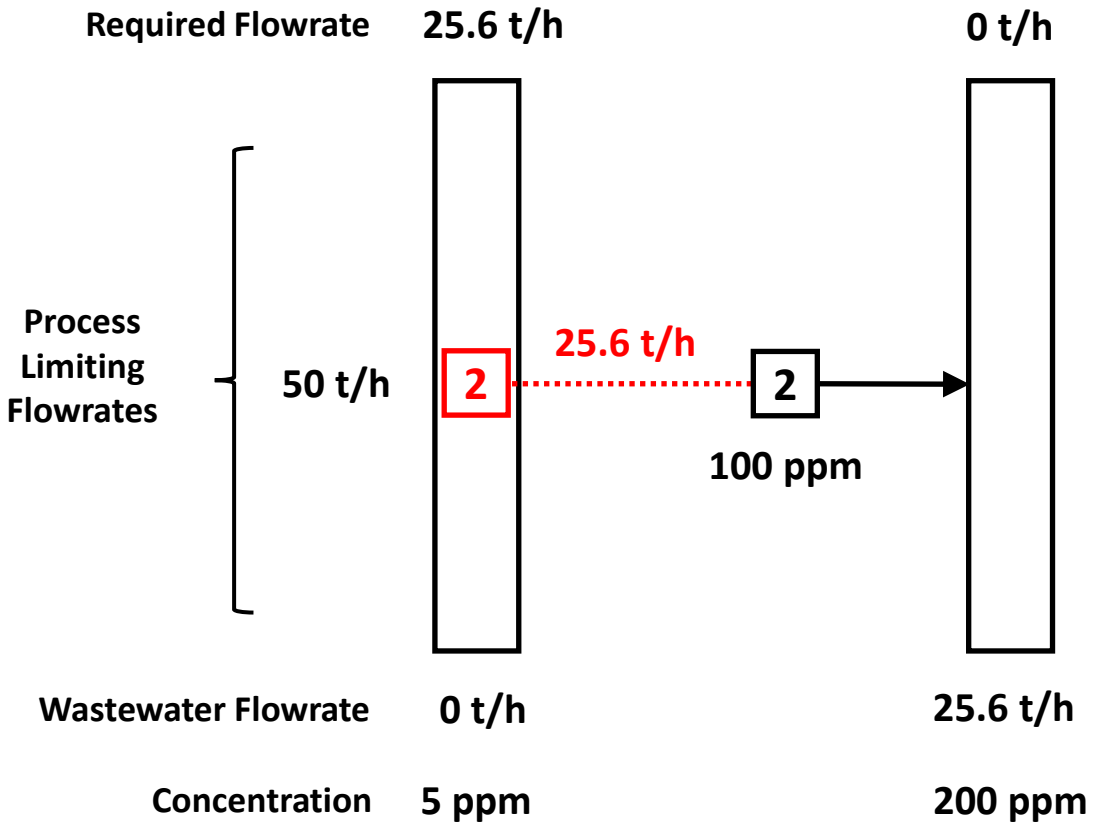
Wastewater Regeneration Reuse

Set up the design grid for Design Region I – Freshwater Use



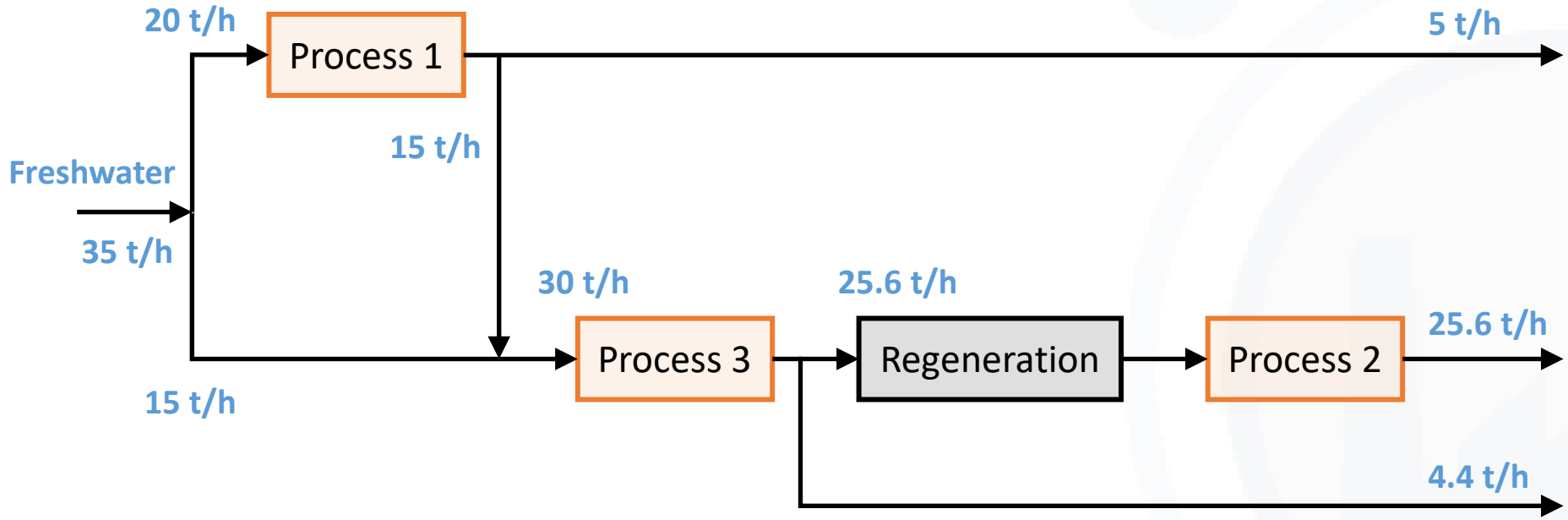
Wastewater Regeneration Reuse

Set up the design grid for Design Region II – Regenerated Water Use



Wastewater Regeneration Reuse

Process Flow Diagram



Total Freshwater Use: 35 t/h

Wastewater Regeneration Recycling

Steps to Design a Regeneration Recycling System

- Divide the processes in “freshwater only” and “regenerated water”
- Draw the composite curve and calculate the minimum flowrate for the two design regions
- Design the wastewater regeneration recycling system

Wastewater Regeneration Recycling

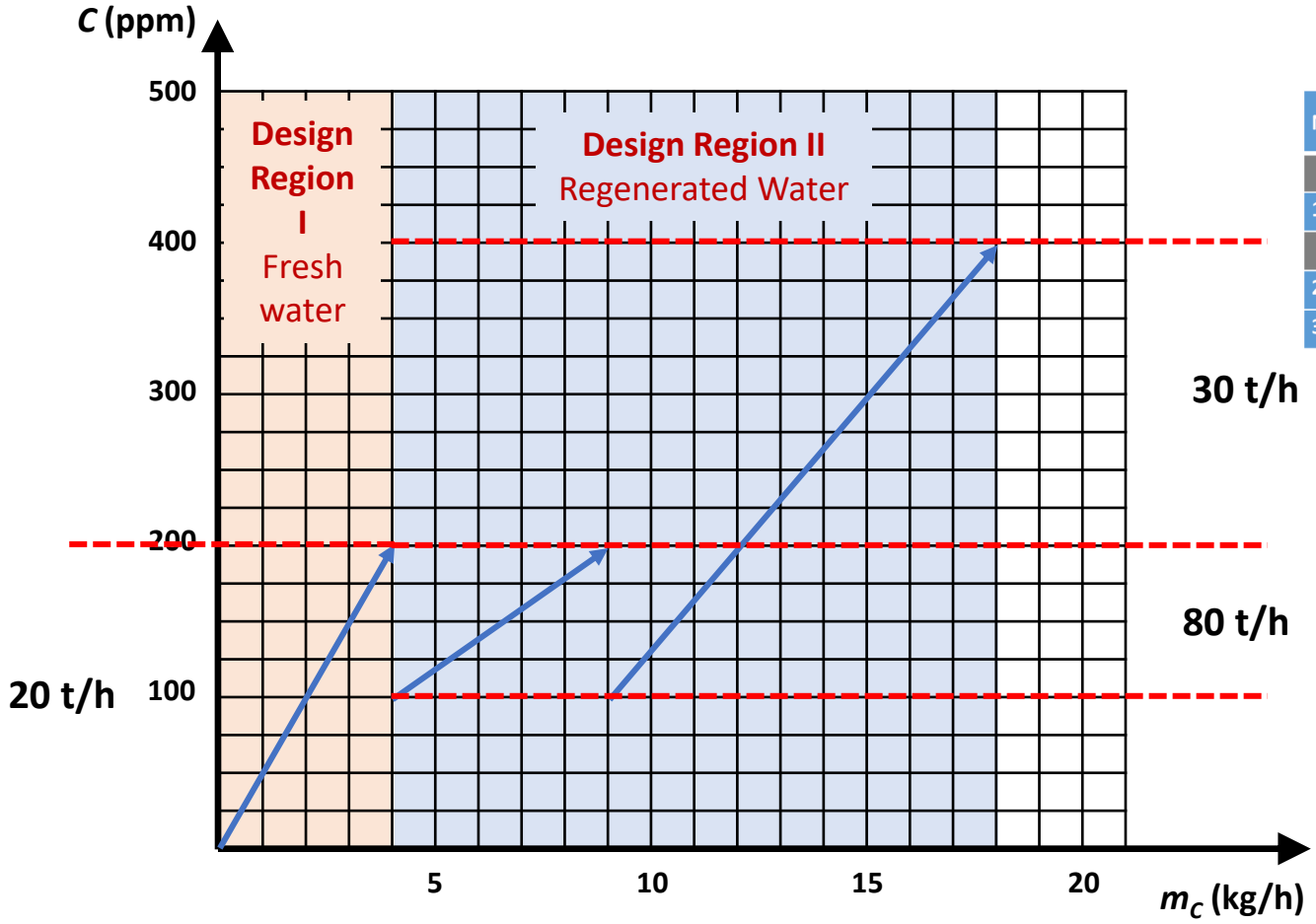
Distribute the processes based on the specifications

- In this case, one process must use freshwater (Process 1), whereas the other two can use regenerated water

No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
Freshwater				
1	4000	0	200	20
Regenerated Water				
2	5000	100	200	50
3	9000	100	400	30

Wastewater Regeneration Recycling

Draw the Limiting Water Profiles for the two design regions



No	Contaminant Mass (g/h)	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)
Freshwater				
1	4000	0	200	20
Regenerated Water				
2	5000	100	200	50
3	9000	100	400	30

Wastewater Regeneration Recycling

Calculate the concentration intervals for both design regions

Design Region I – Freshwater

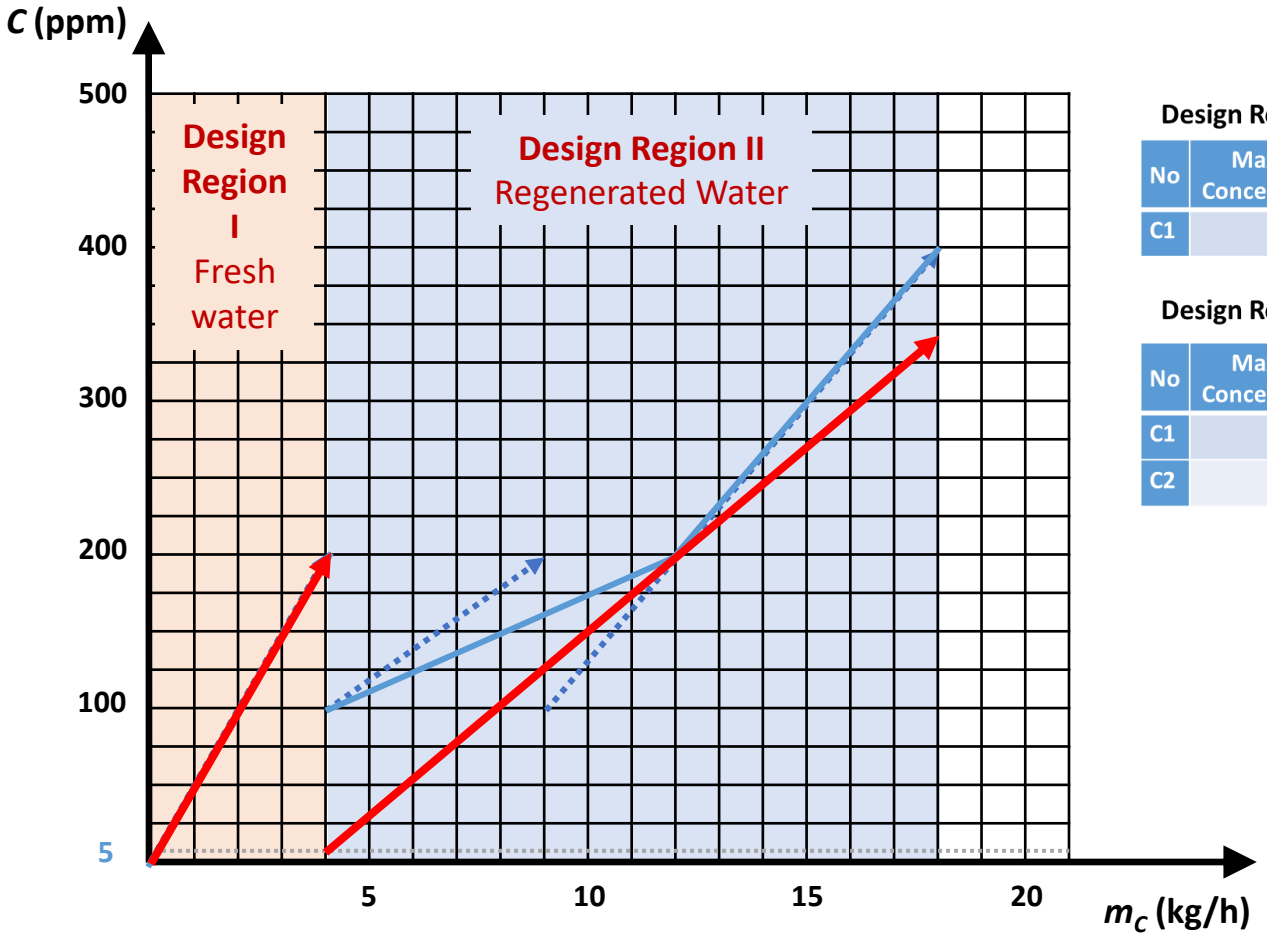
No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	200	20	4000

Design Region II – Regenerated Water

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	100	200	80	8000
C2	200	400	30	6000

Wastewater Regeneration Recycling

Draw the composite curve and the minimum flowrate water supply line



Design Region I – Freshwater

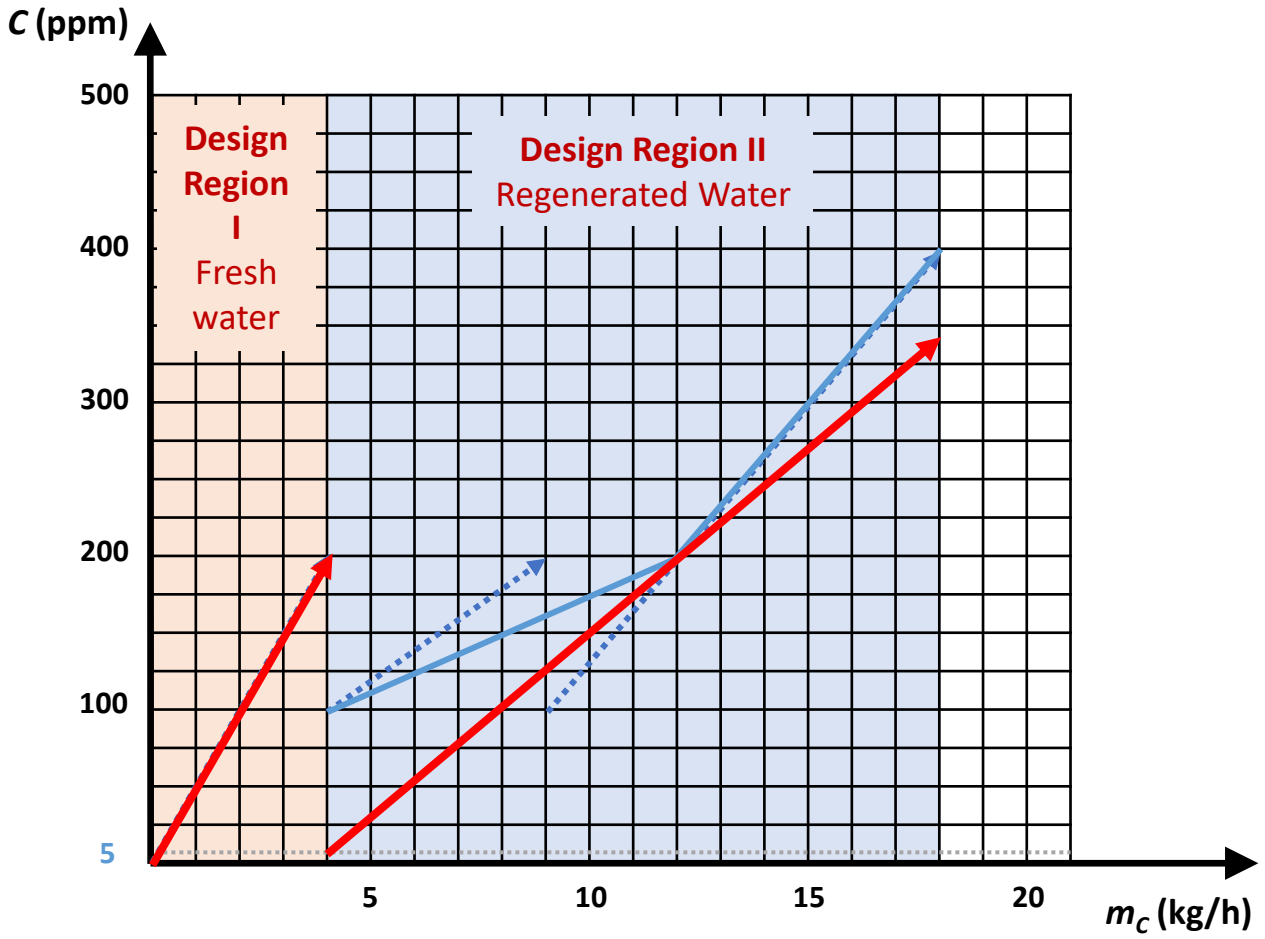
No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	0	200	20	4000

Design Region II – Regenerated Water

No	Maximum Inlet Concentration (ppm)	Maximum Outlet Concentration (ppm)	Limiting Water Flowrate (t/h)	Contaminant Load (g/h)
C1	100	200	80	8000
C2	200	400	30	6000

Wastewater Regeneration Recycling

Draw the composite curve and the minimum flowrate water supply line



Minimum Flowrate for Freshwater

$$m_{FW} = \frac{4000}{200 - 0} = 20 \text{ t/h}$$

Minimum Flowrate for Regenerated Water

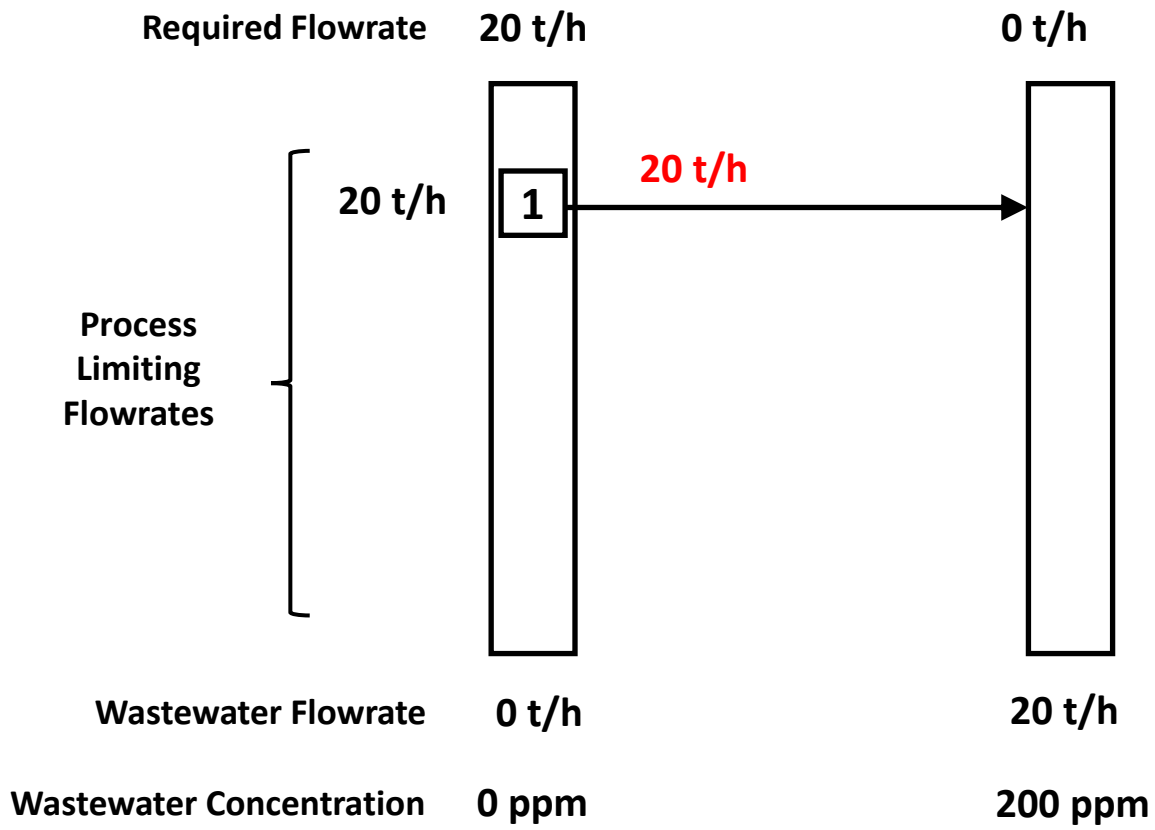
$$m_{RW,I} = \frac{12000 - 4000}{200 - 5} = 41 \text{ t/h}$$

Minimum Flowrate for Regenerated Water Above the Pinch

$$m_{RW,II} = \frac{18000 - 12000}{400 - 200} = 30 \text{ t/h}$$

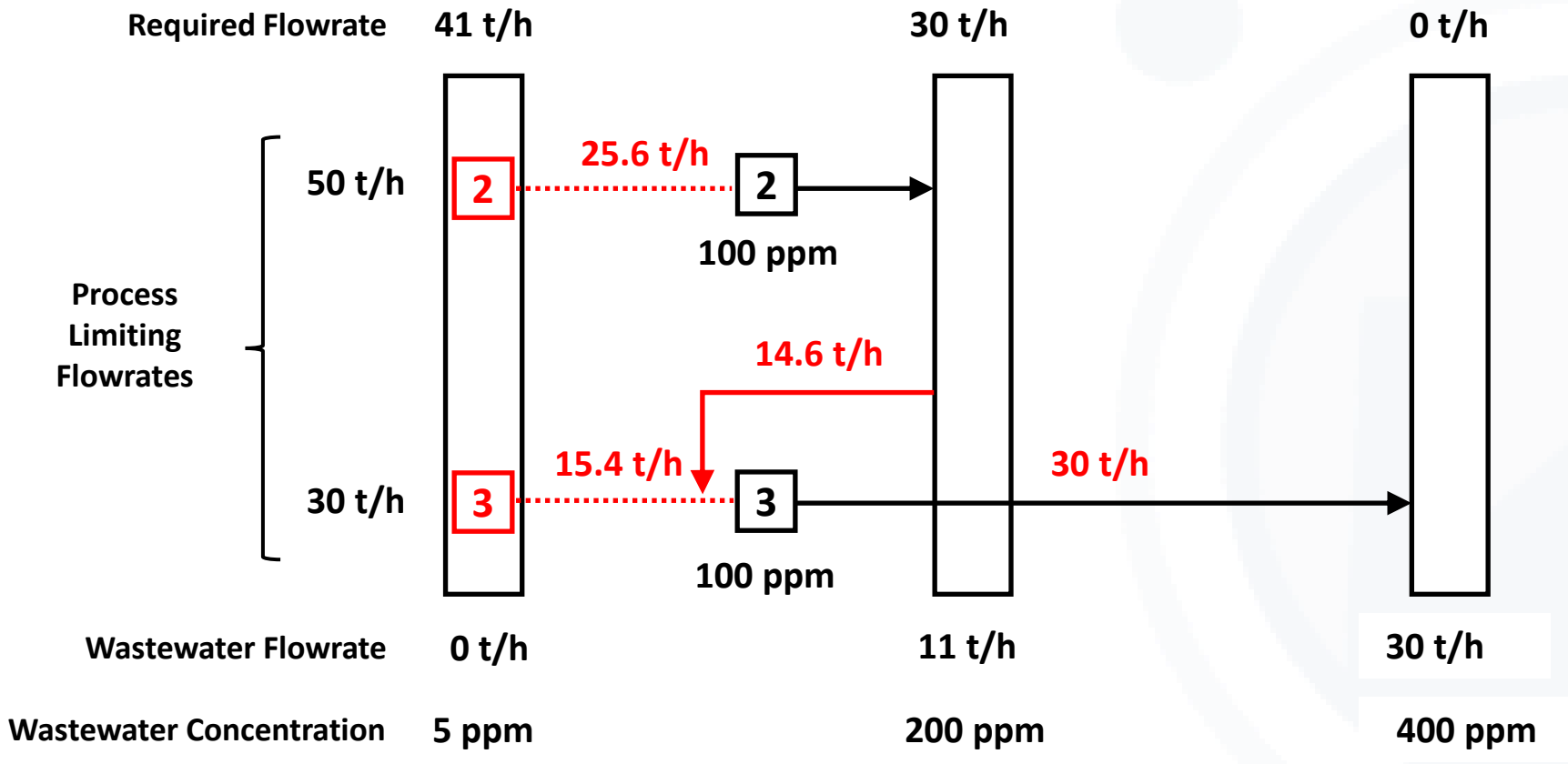
Wastewater Regeneration Recycling

Set up the design grid for Design Region I – Freshwater Use



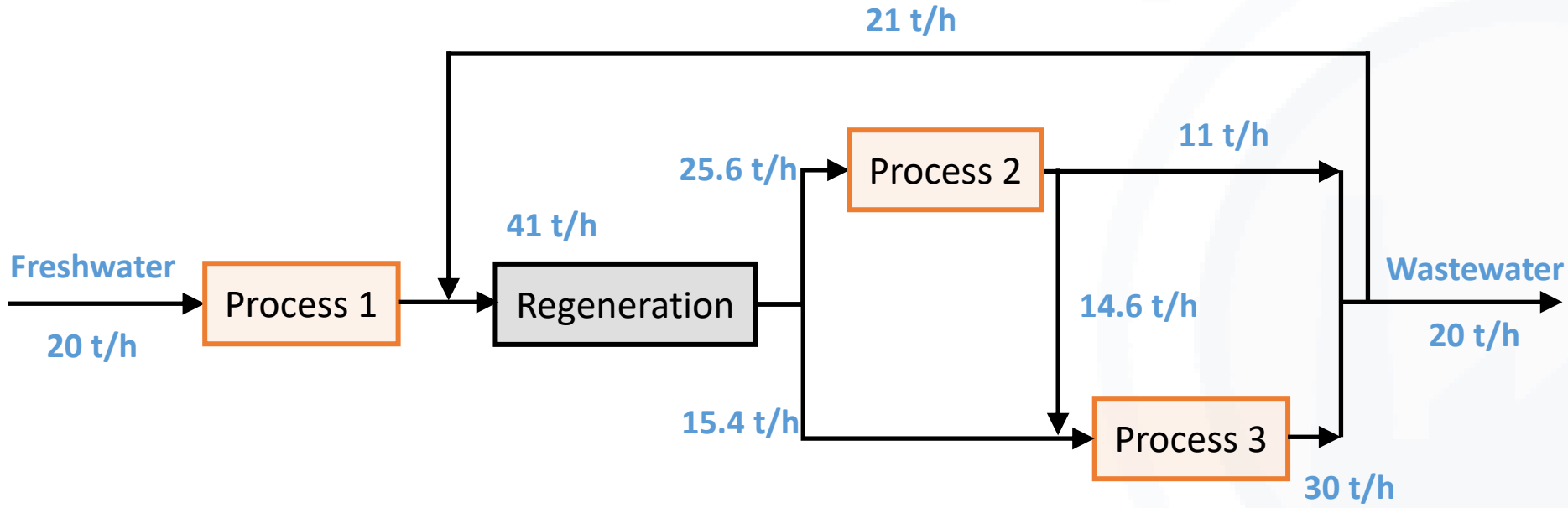
Wastewater Regeneration Recycling

Set up the design grid for Design Region II – Regenerated Water



Wastewater Regeneration Recycling

Process Flow Diagram



Total Freshwater Use: 20 t/h

Comparison of alternative configurations

Scheme	Freshwater Use	Water Savings	New Unit
Freshwater Only	67.5 t/h	-	No
Water Reuse	60 t/h	11.1%	No
Regeneration Reuse	35 t/h	48.1%	Yes
Regeneration Recycling	20 t/h	70.4%	Yes

- 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.