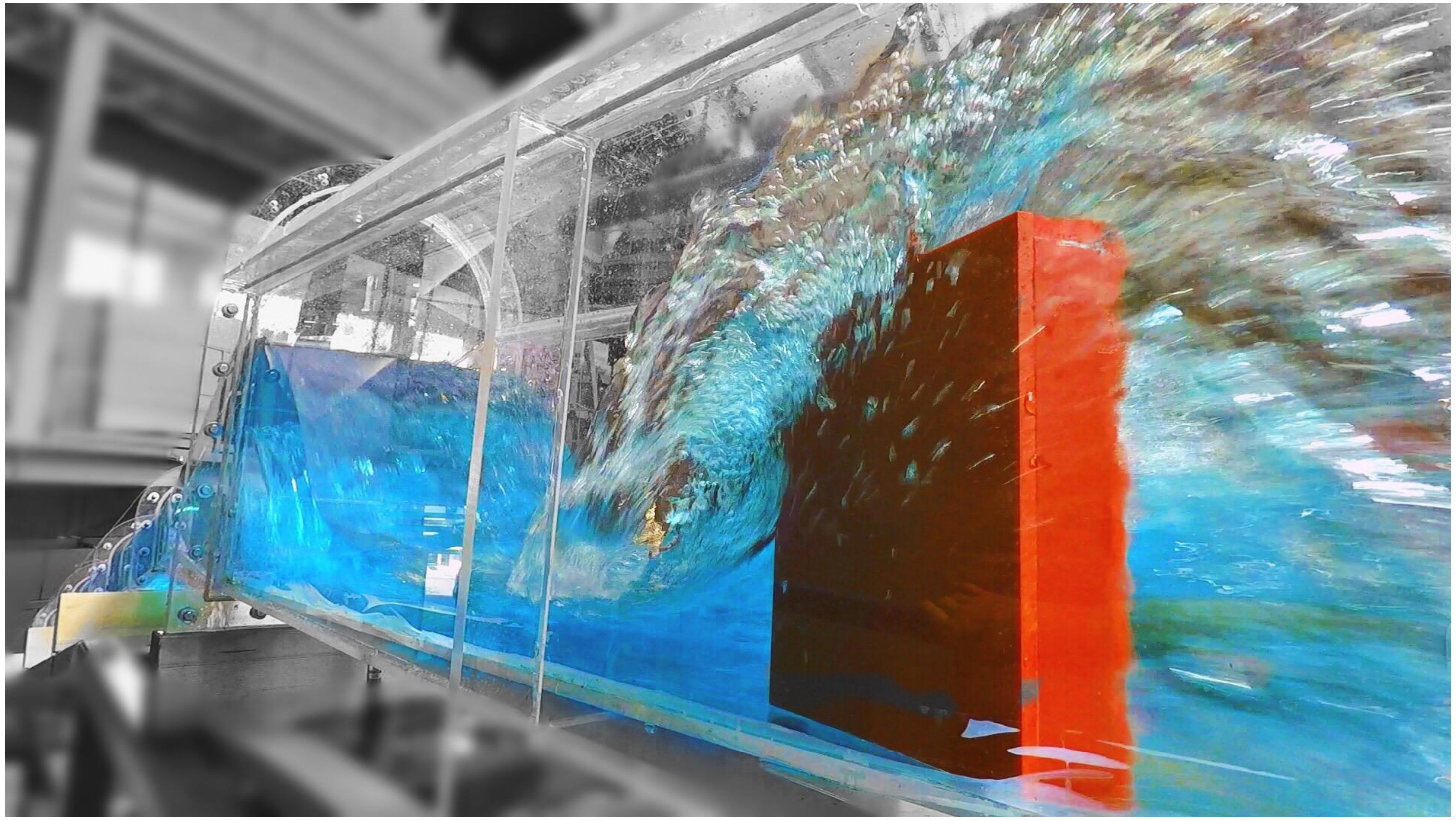
Surge tank design for safe penstock and pressure tunnel

Wolfgang Richter - Graz University of Technology



European ICOLD Club

Working Group

Penstocks, pressure shafts & pressure tunnels

Autumn

2022

ITCOLD

RSE Ricerca Sistema Energetico

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Goal

- Prosperity
- Energy safety
- Energy sovereignty
- Low costs of energy
- No climate catastrophe
- Clean, renewable Energy transition
- …

Problem

- Addicted to fossil fuels
- Fossil energy driven inflation
- Pollution of fossil fuels
- Wars for fossil fuels
- Dependency of imports of fossil fuels
- Inefficiency of combustion
- …
  - Will
  - Slow integration
  - Demand of Transmission
  - Variable Production

Solution

- 100 % Renewable Energy system
- Electrification
  - Wind
  - Water
  - Sun
  - Geothermal
- Power grid expansion
- Balance power
- Energy storage - PSH
  - **Surge tank design**

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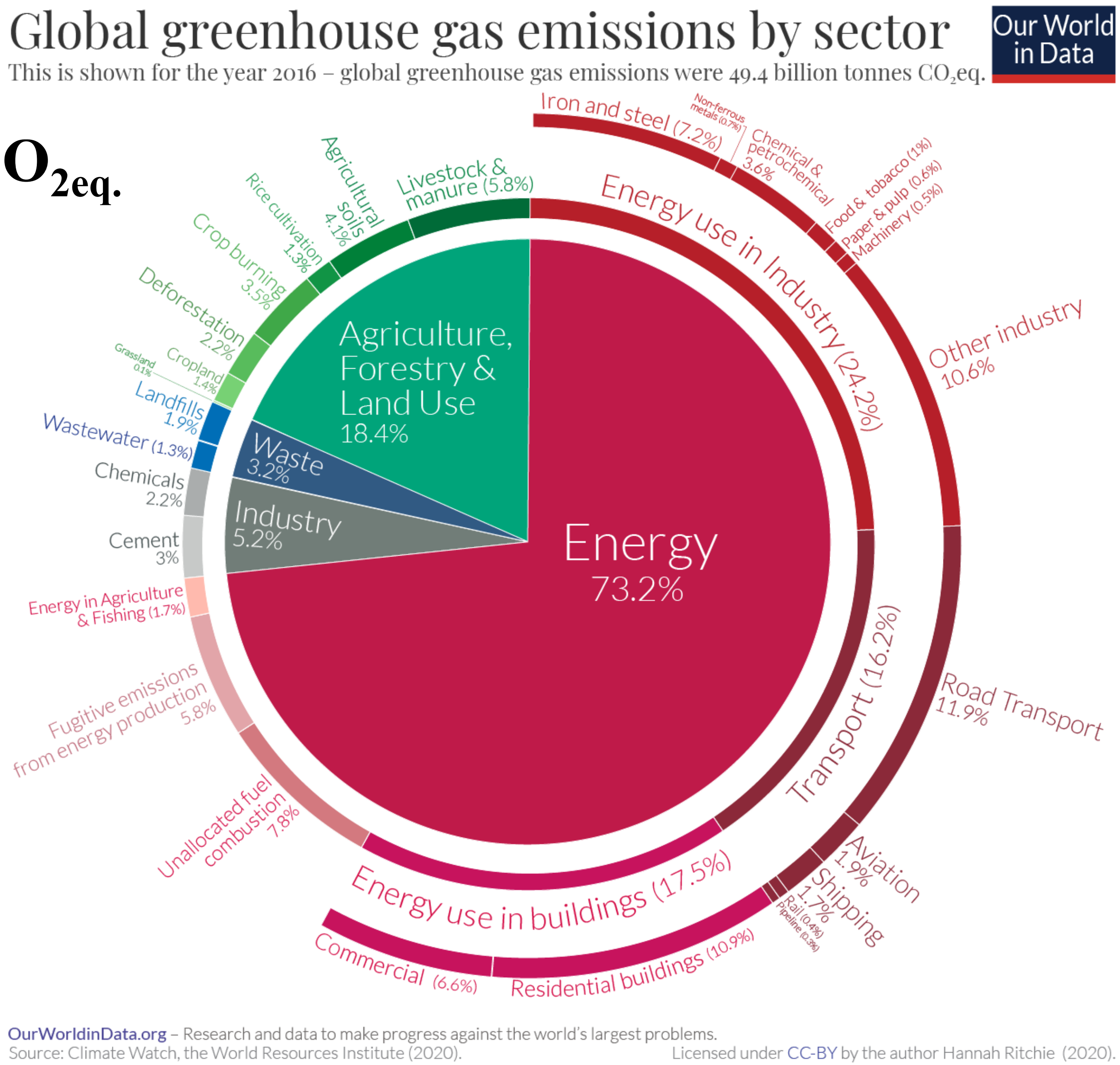
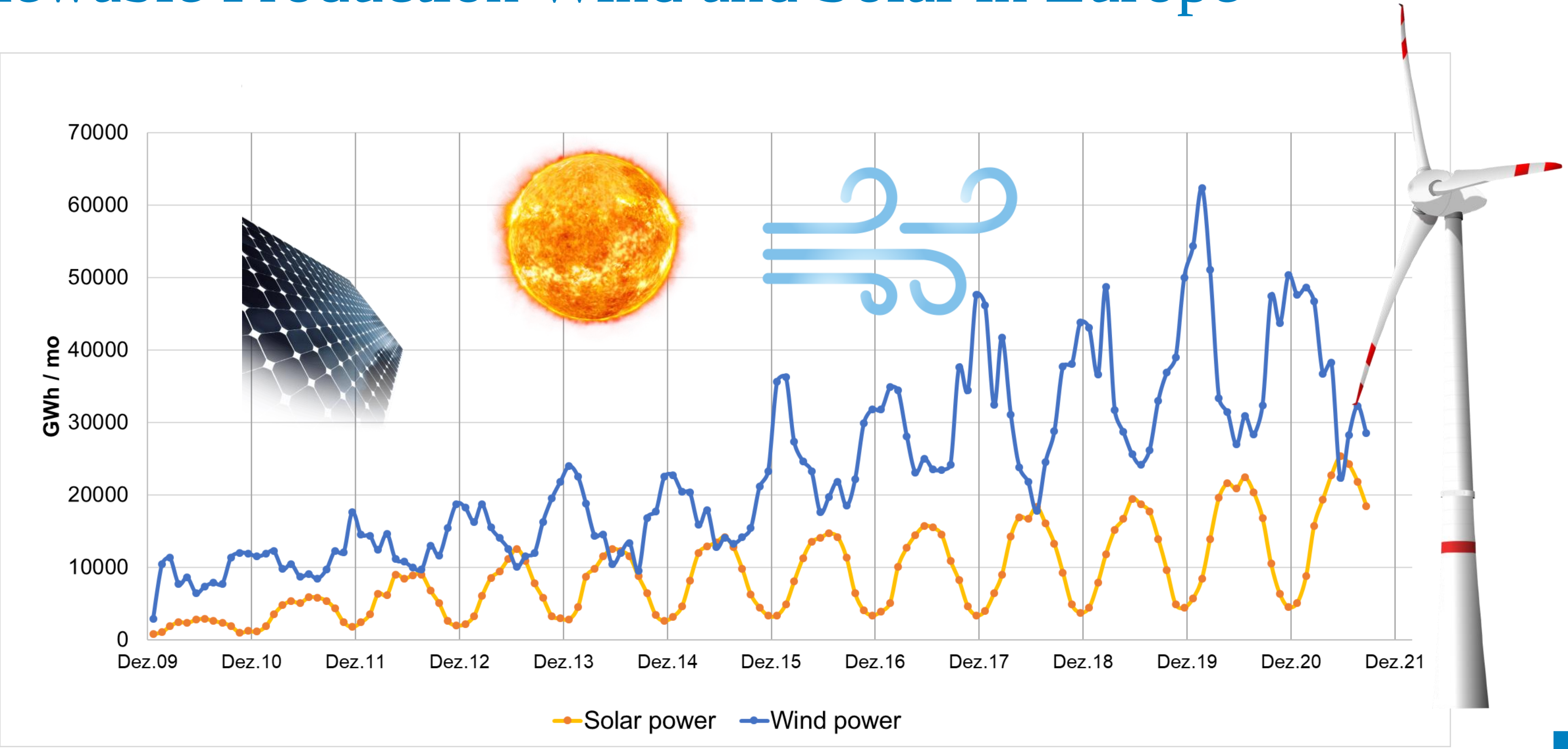


Goal:
fading out of Fossil energy → transformation to 100% Renewable Energy

- → Electrification
- → Massive saving by high Efficiency
- → Energy sovereignty

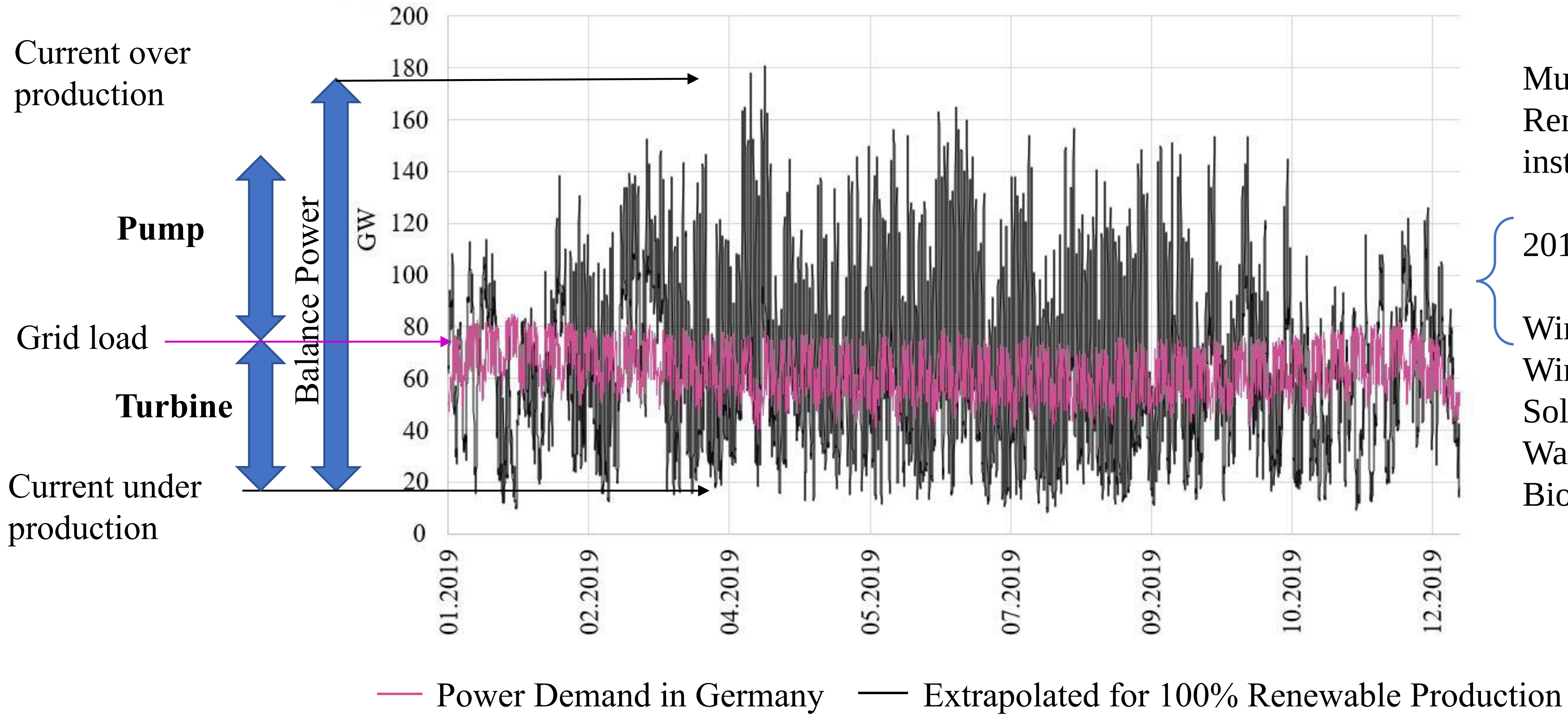
Renewable Production Wind and Solar in Europe



Quelle: https://www.iea.org/reports/monthly-electricity-statistics-overview

Study to convert the power production Germany (~540 TWh) to 100% renewables

Ideal Storage and Balance Technology: **Pumped-Storage Hydropower (PSH)**



Multiplicator of Renewable power installation

2019:

Wind onshore: **1.9** [-]
Wind offshore: **5** [-]
Solar PV: **3.5** [-]
Wasserkraft: **1.0** [-]
Biomasse: **1.0** [-]

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Surge Tanks – Why - When

To handle the large inertia in the water way

Indicator: Tw

- Machine regulation
- Quick start-up – Lower level
- Emergency shut-down – Upper level
- Pressure surges mitigation
- Site specific prototypes
- Flexible to boundary conditions
- Safe design → Resonance load cases
  - Safety Philosophy → Friction and local losses

    → Multiple Loading and Reloading

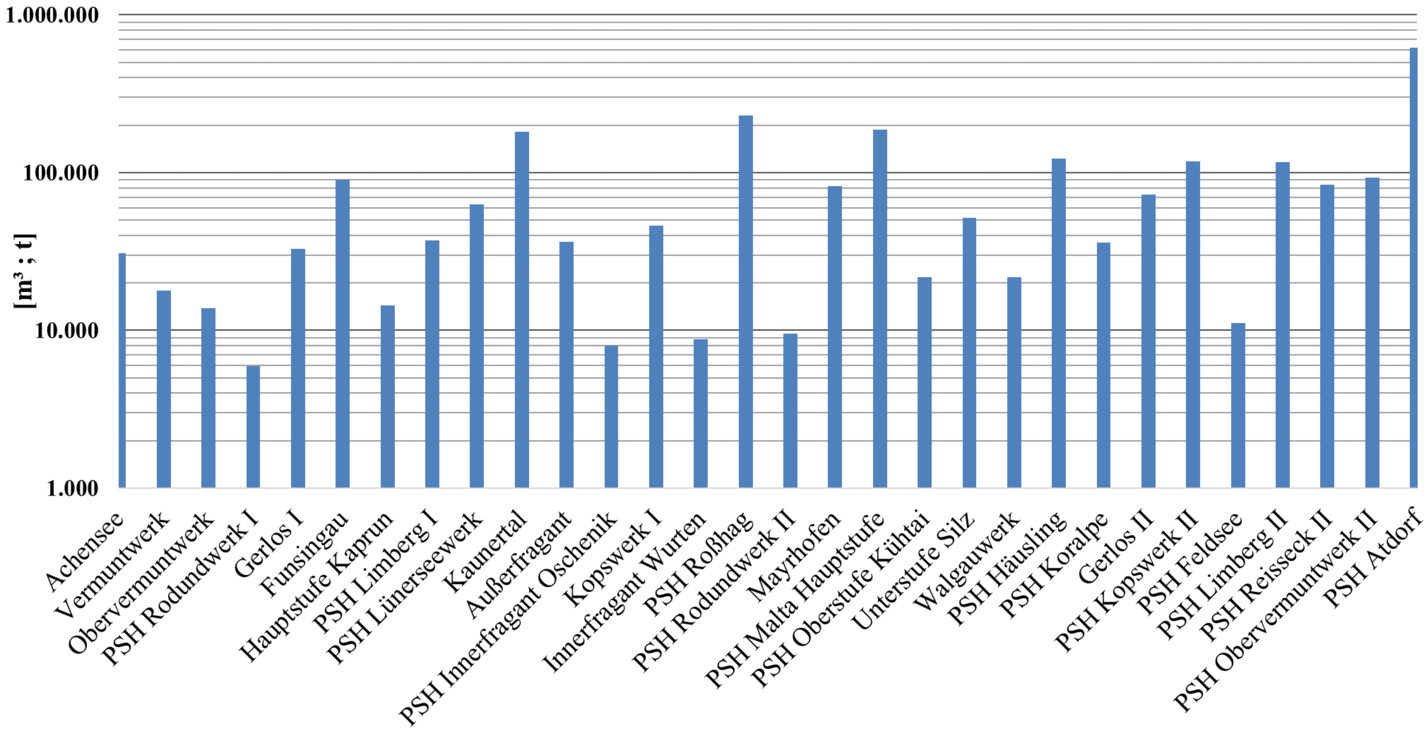
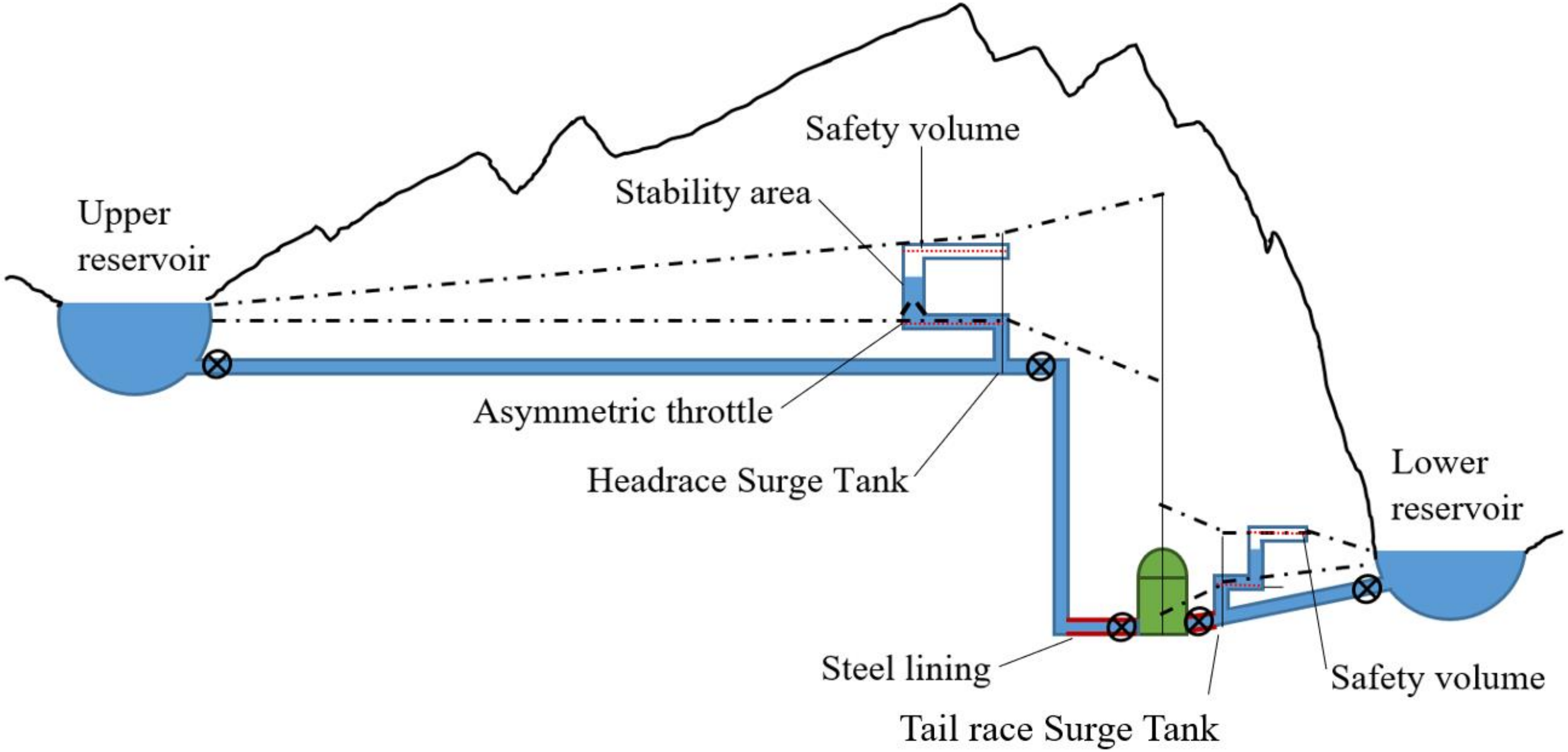
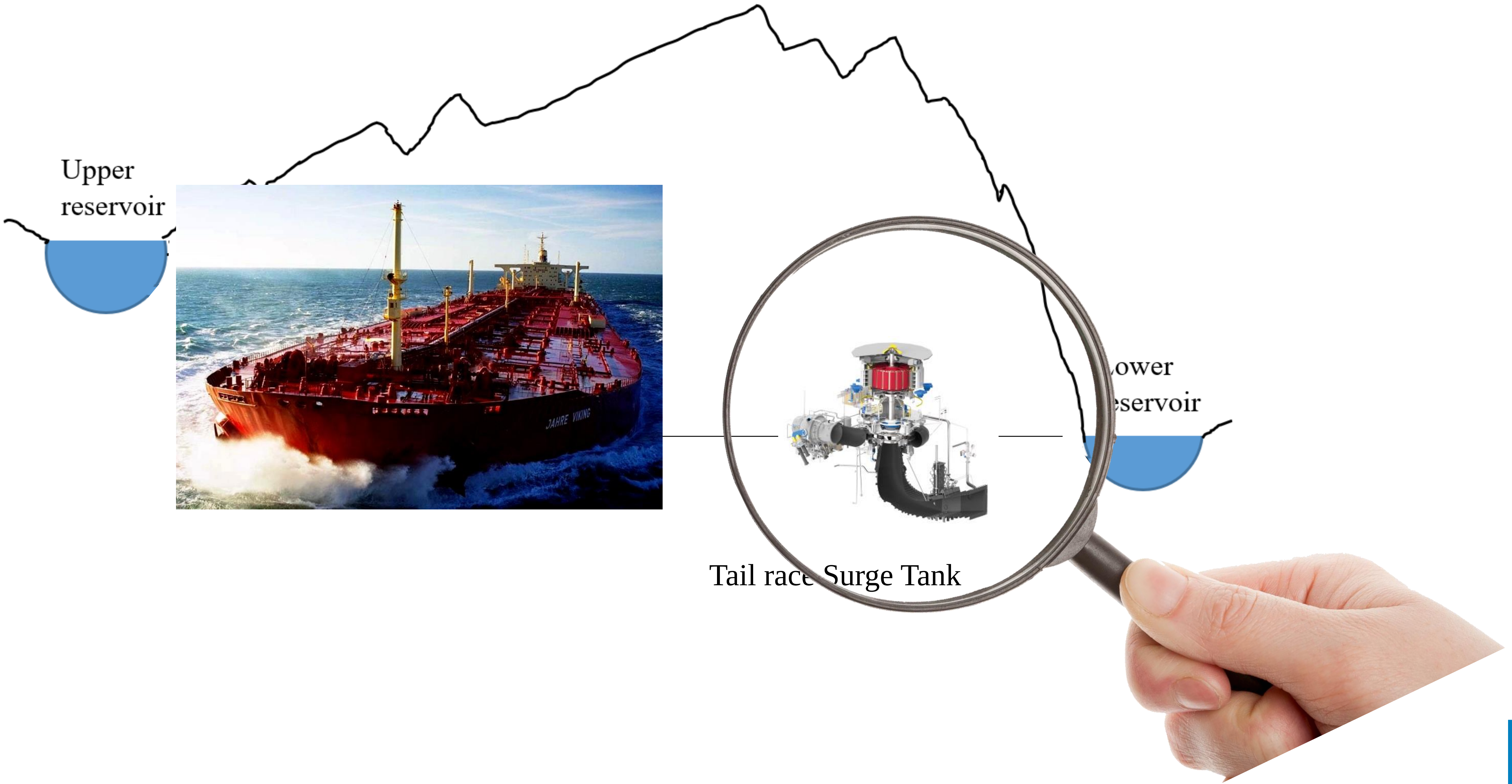


Fig: Internal water volume of pressure tunnels in large Austrian HPPs

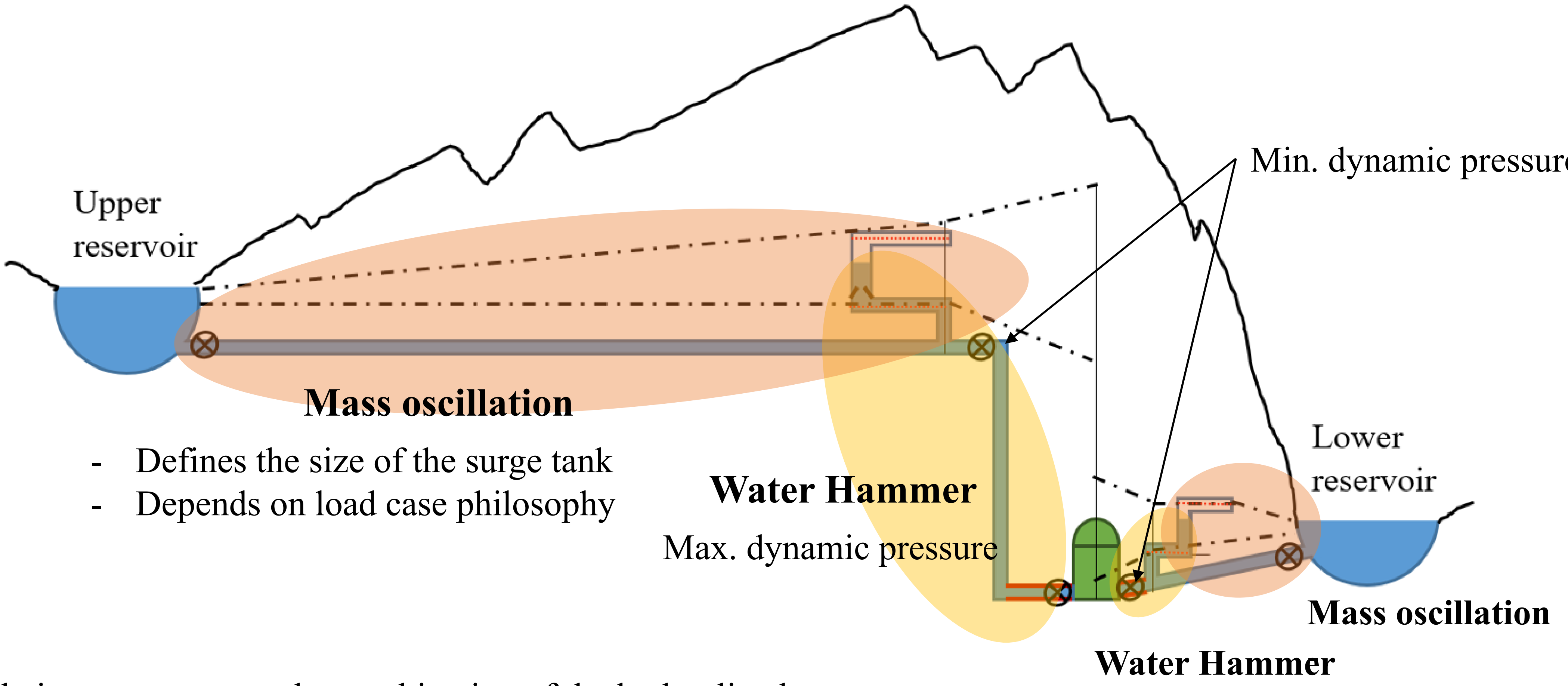
Surge Tank - operation



Surge Tank - operation



Principal transient phenomena



- Defines the size of the surge tank
- Depends on load case philosophy

Final 1D simulation must capture the combination of the hydraulic phenomena

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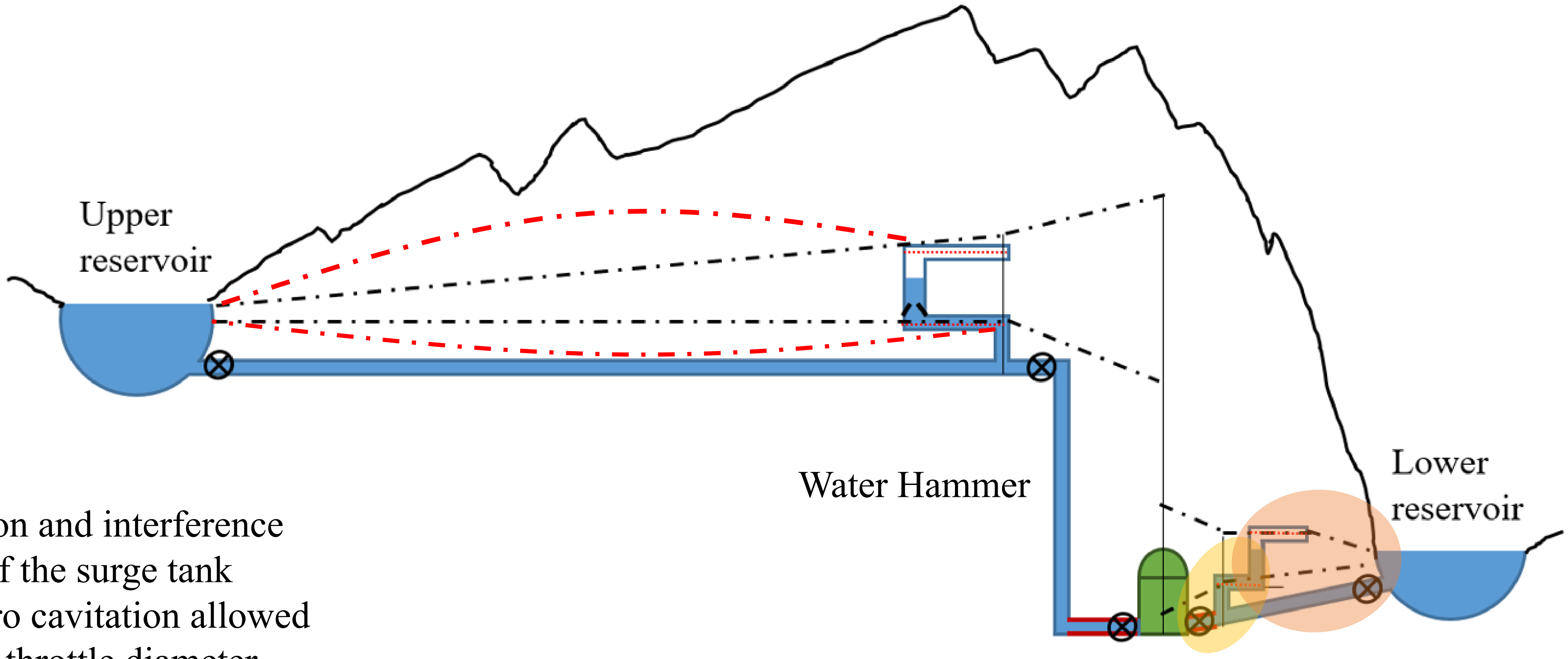
Water hammer in pressure tunnel



- Reflection and interference
- Inertia of the surge tank
- No macro cavitation allowed
- Limit of throttle diameter
- Effect of adits and brook inlets

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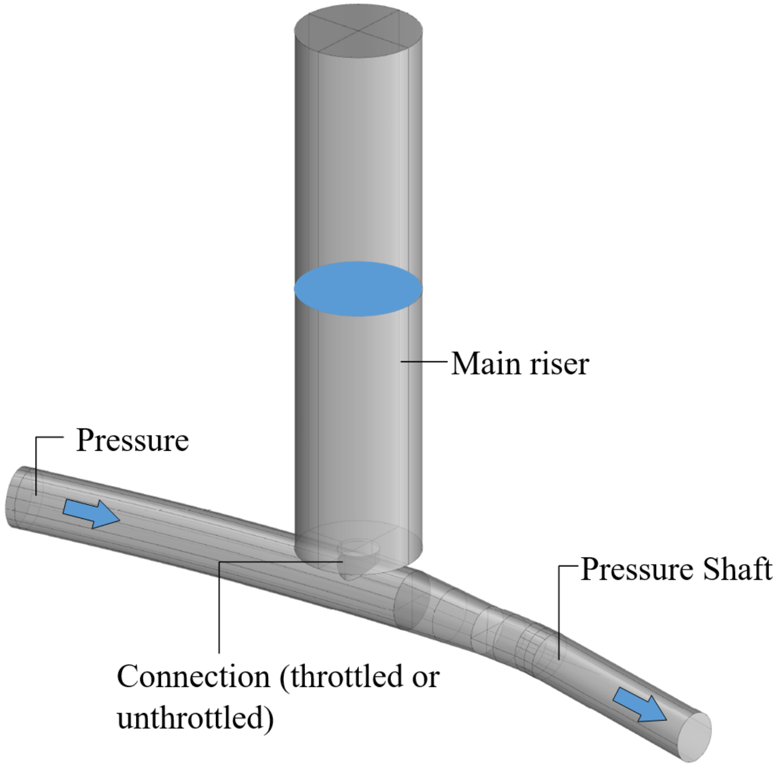
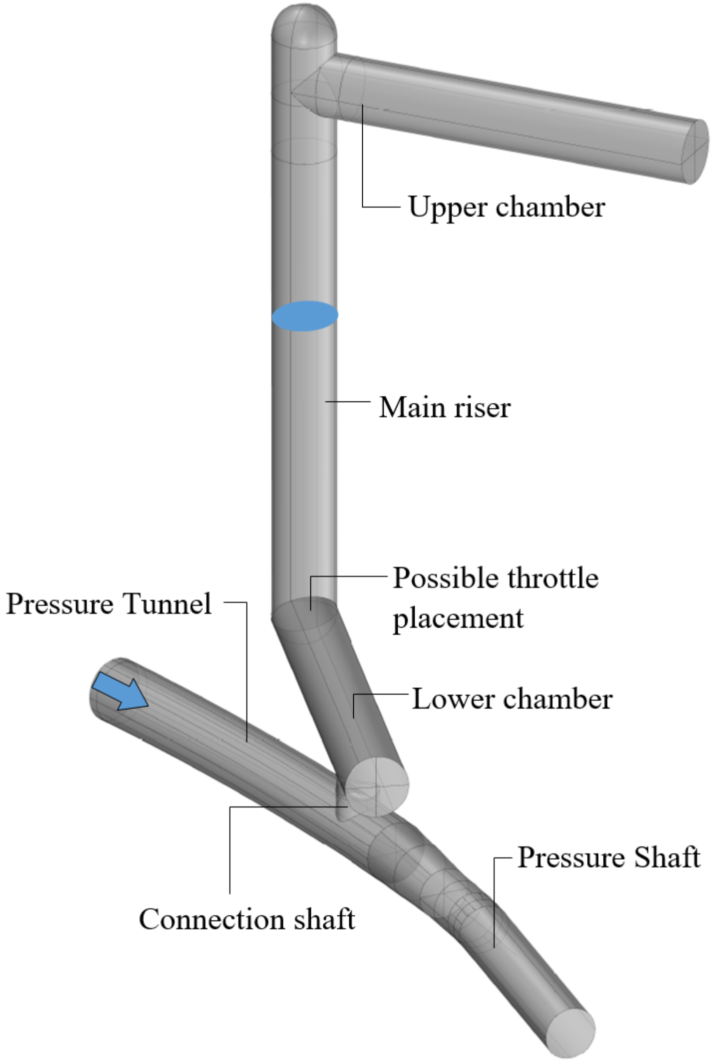
Surge Tank Design

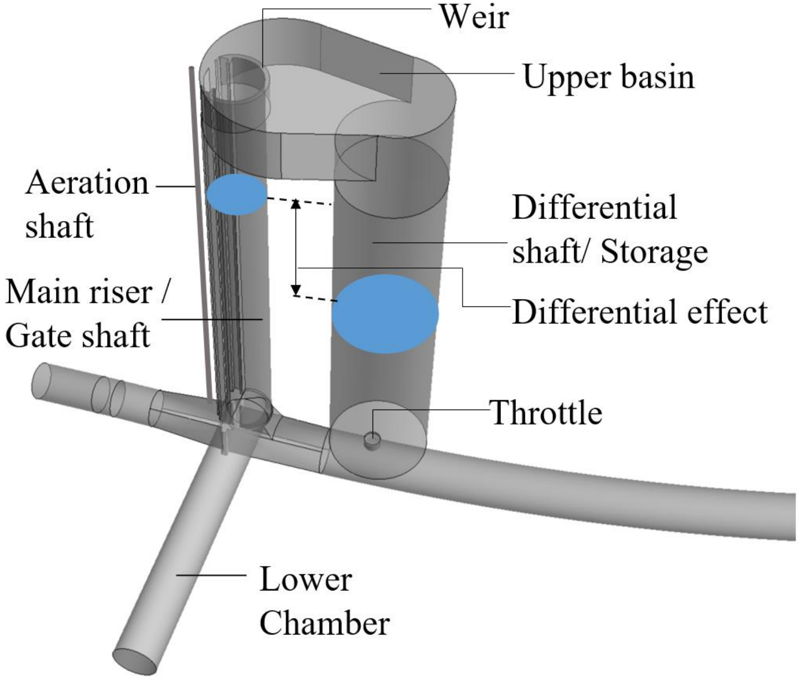
Shaft Surge Tank



Chamber Surge Tank



Differential Shaft Surge Tank with Gate



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Many design types - Why?

Flexibility to boundary conditions

Differential surge tanks

Minimizes excavation volume

Differential throttle:
Hydraulic loss up-surge vs. downsurge

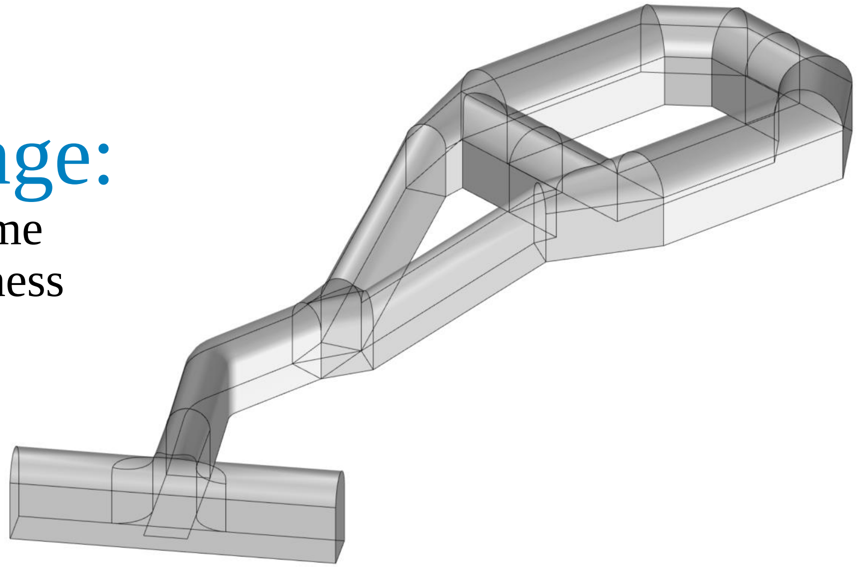
~1:3 – Orifice throttle
~1:20 – vortex throttle

Air cushion surge tanks

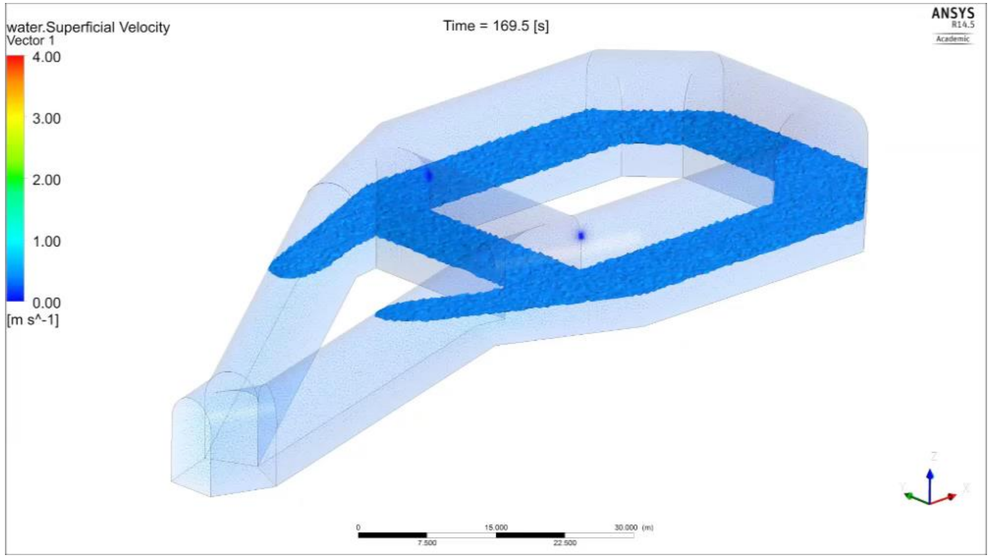
- Ideal inertia response
- No adits required
- For steep and high mountains

Challenge:

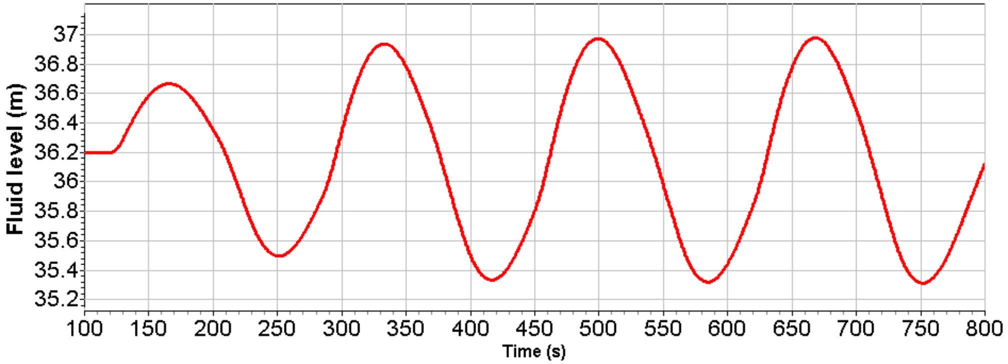
- Filling time
- Air tightness

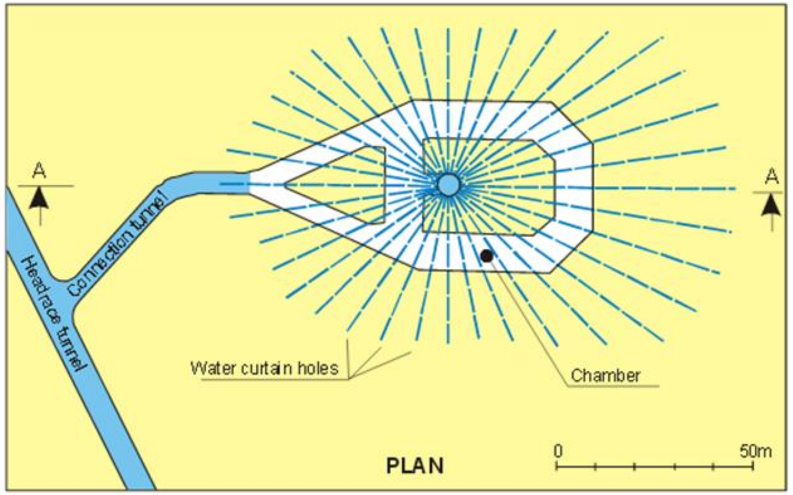


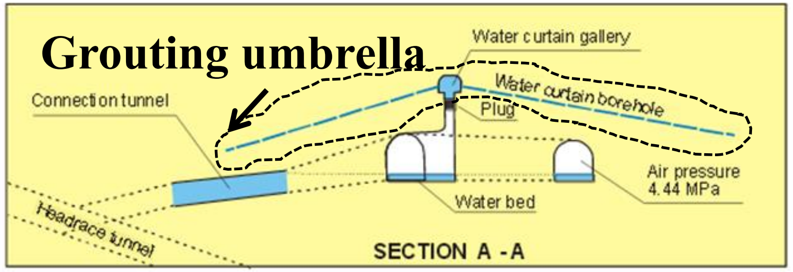
Air cushion surge tank Torpa



Resonance case QA = 35,5 m³/s







Source: Palmström A. *AIR CUSHION SURGE CHAMBER a cost-effective solution in hydropower design*, www.rockmass.net, 2008

Water pressure in the water curtain > ~ 20 mwc above static internal pressure in ACST

Limit demanding grouting & water curtain		
κ =	1E-14	[m²]
kf=	7,55E-08	[m/s]

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Accelleration time constant

Recommended range: of Tw < 1s – 2s

Time constant of Hydraulic inertia:

Tuning:
Diameter of pressure shaft, distance to surge tank

$$T_W = \frac{Q_0}{g\,H_0} \sum_{i}^{n} \frac{L_i}{A_i} \,[s]$$

Q_0	…	Reference flow rate at turbine
H_0	…	Mean reference head at turbine
L_i	…	Length of pipe section
A_i	…	Cross-sectional area of pipe section

Time constant of Rotating inertia:

$$T_A = J\,\frac{\omega^2}{P_{max}}$$

J	…	Inertia of the rotating mass
ω	…	Angular speed
P_{max}	…	Full power output

Recommended ratio:

Also defines if surge tank is needed.

$$\frac{T_A}{T_W} > 6$$

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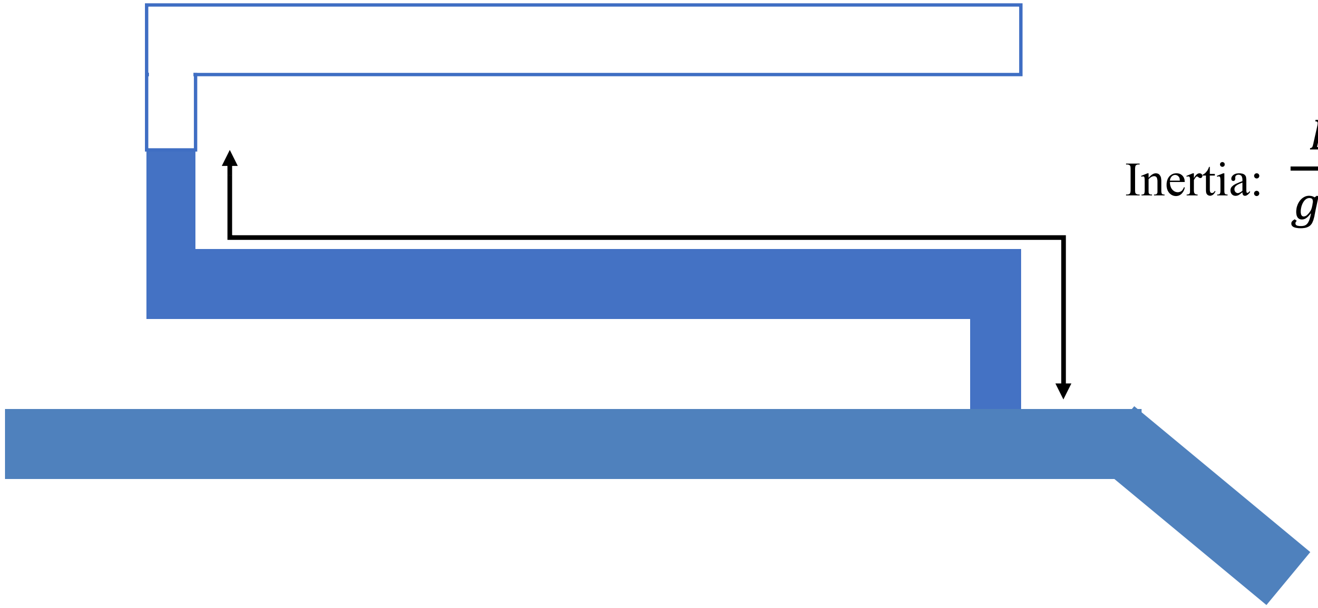
Long Lower chamber

- Inertia regarding water hammer reflection
- Pumped storage plants with pump turbines (S-curve characteristic)
- Degassing length for air
- Pressure peaks at filling



Inertia: $\frac{L}{gA}$ [m²/s²]

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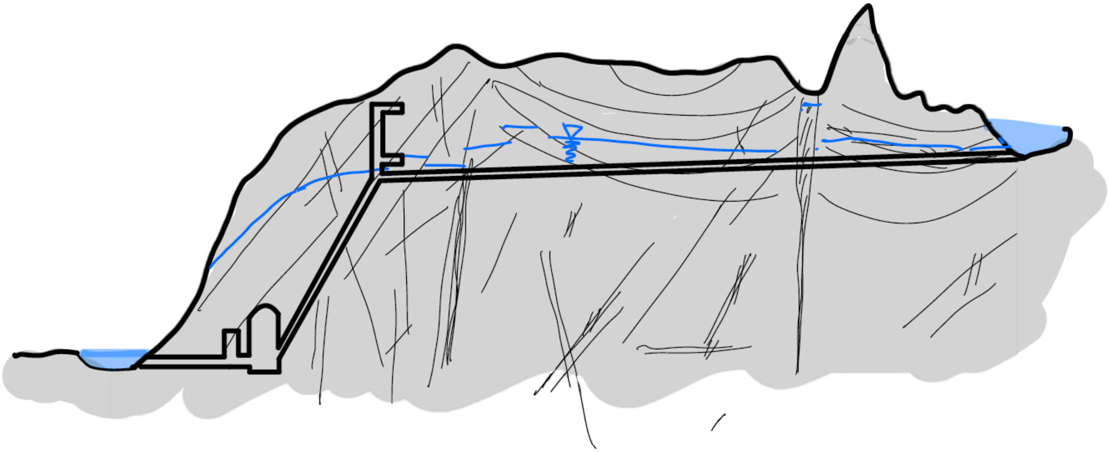
Surge Tank design recipe

- Iterative process - water way design – hydraulics - construction
  - Position of surge tank is given by boundary conditic
  - Type of surge tank
- Stability Criterion
  - *Thoma*, *Svee* (Air cushion), *Svee* (Tailrace)
  - 1D transient calculation
  - Complex systems
- Definition of power plant Flexibility
- 1D transient mass oscillation → definition of the size
- 1D transient water hammer calculations with hydraulic machine characteristics
  - List of load cases
  - Definition of worst case – e.g. pump turbine blocking at ESD
- Physical model test at a University hydraulic laboratory
  - Avoiding surprises
  - Water-air behaviour
  - Joint inspection
  - Research output
  - Education



Interdisciplinary Team!

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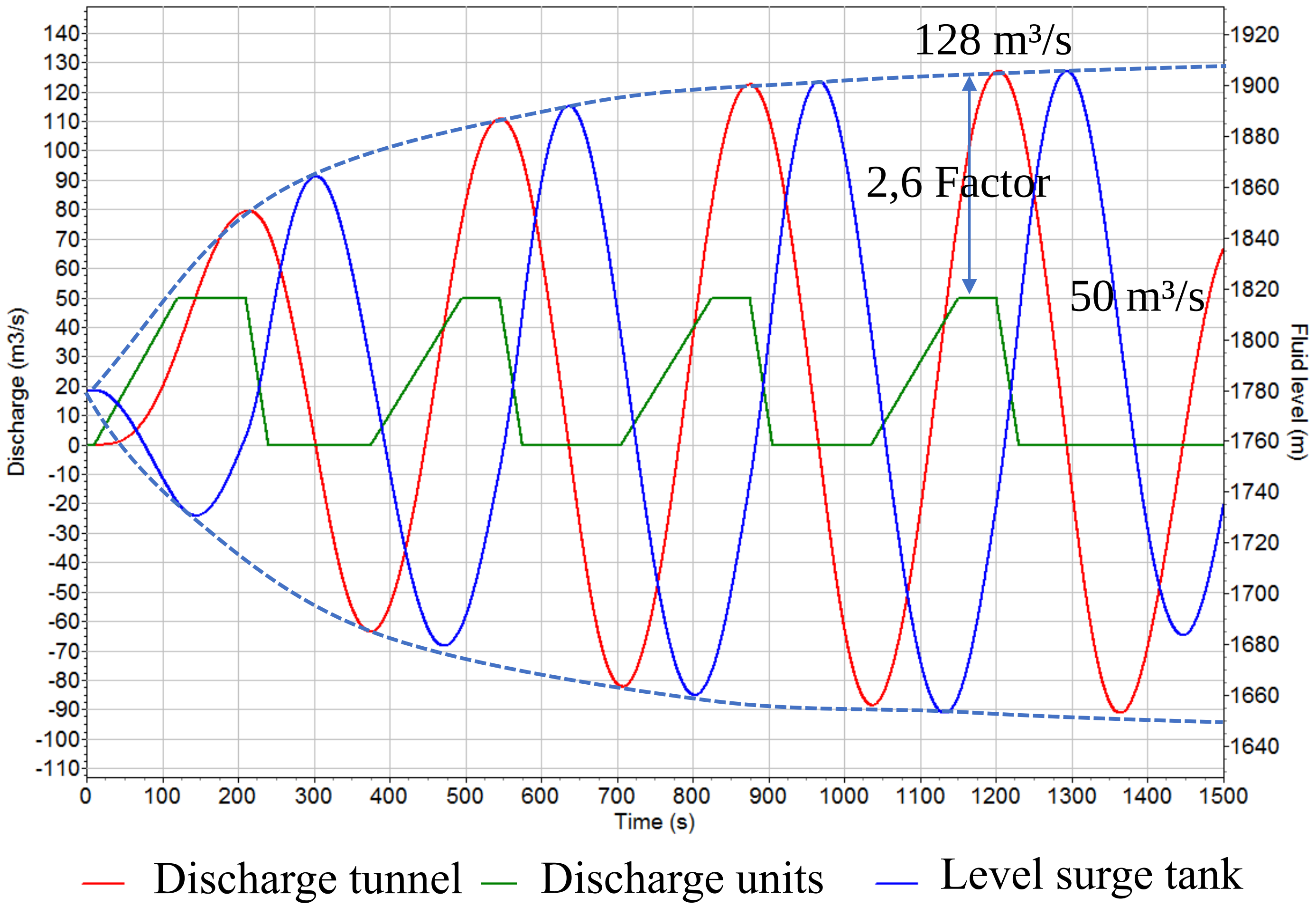
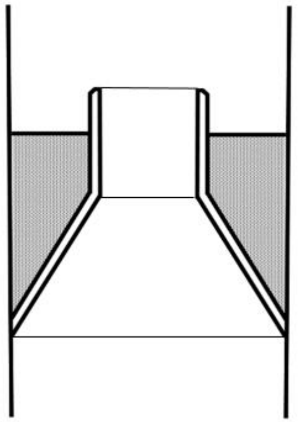
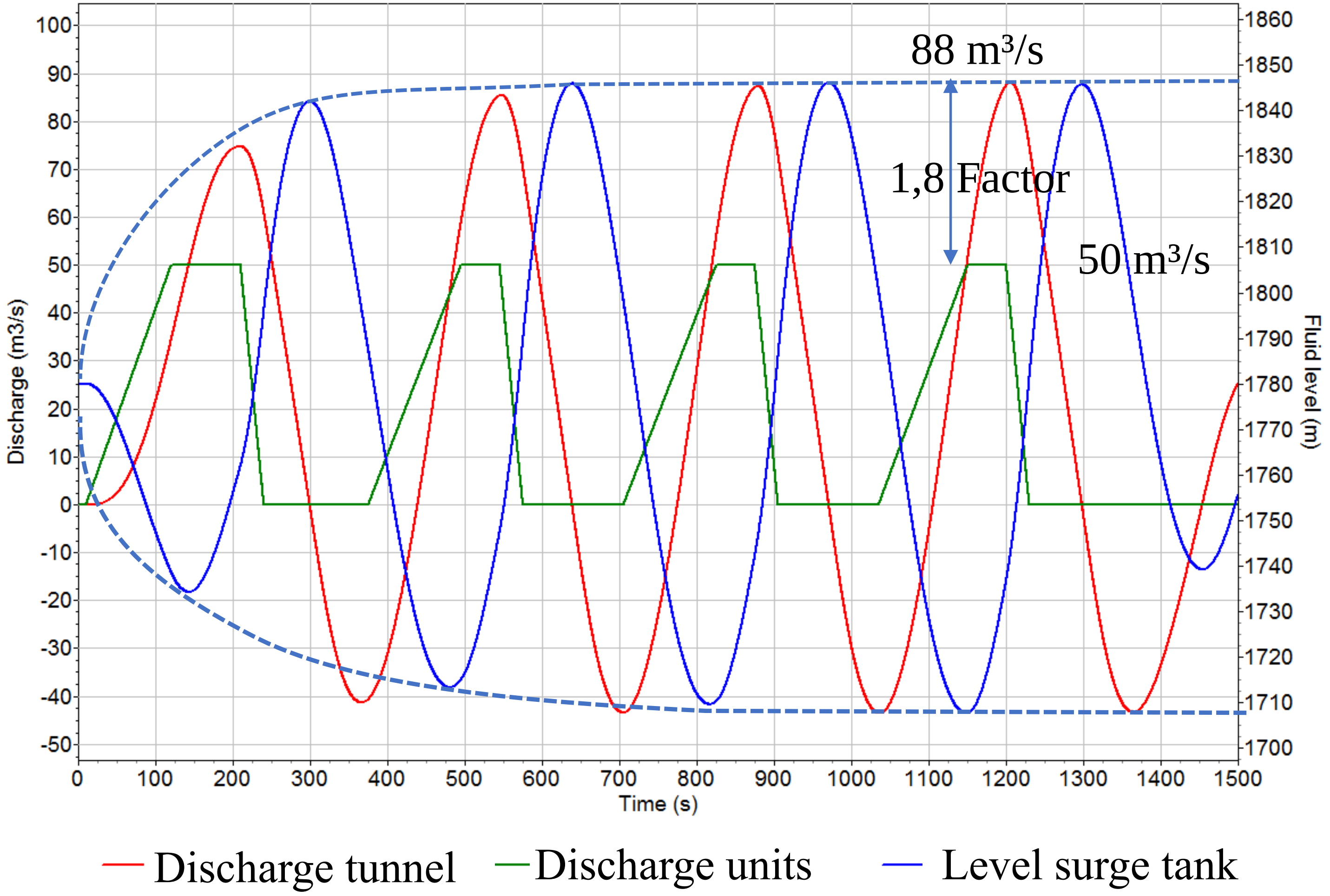
Resonance load cases
No throttle in shaft surge tank – generic case



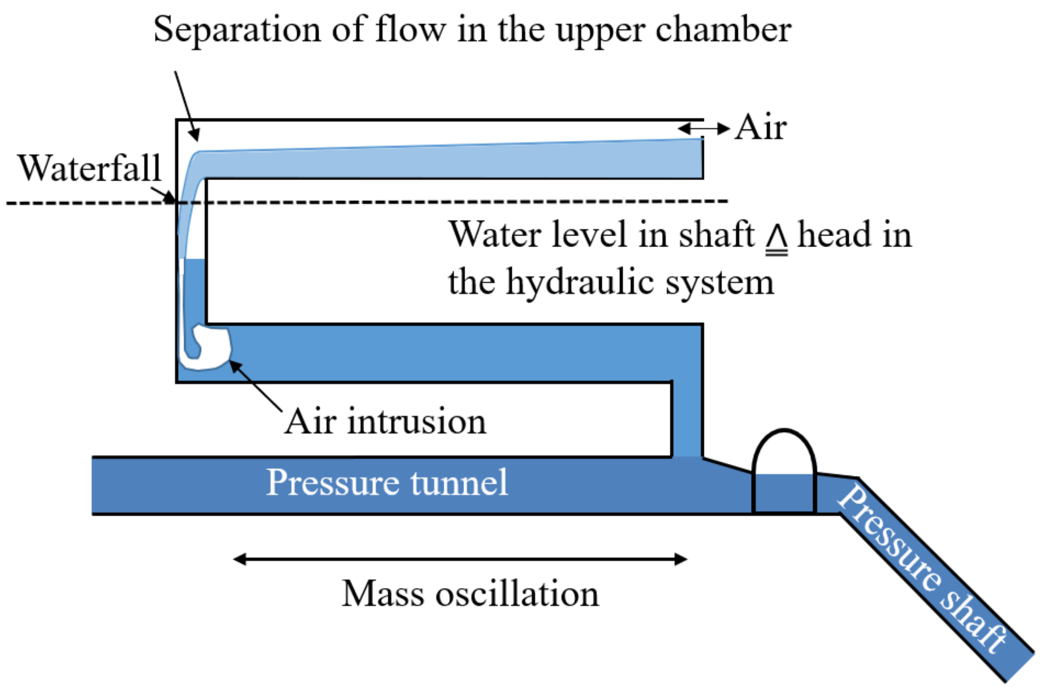
Resonance load cases
With throttle in shaft surge tank – generic case

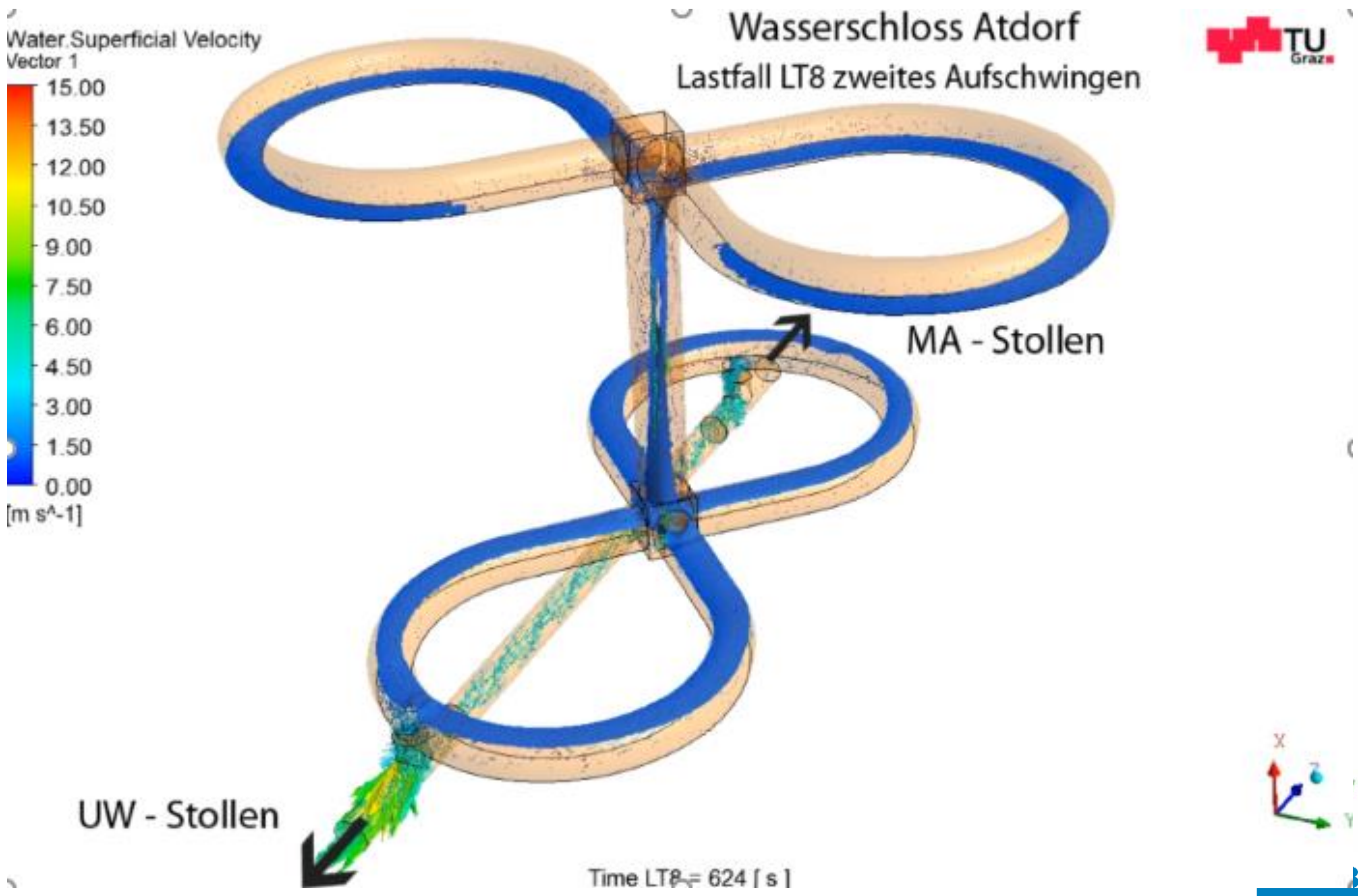
Differential orifice throttle





Waterfall Issue in Surge Tanks





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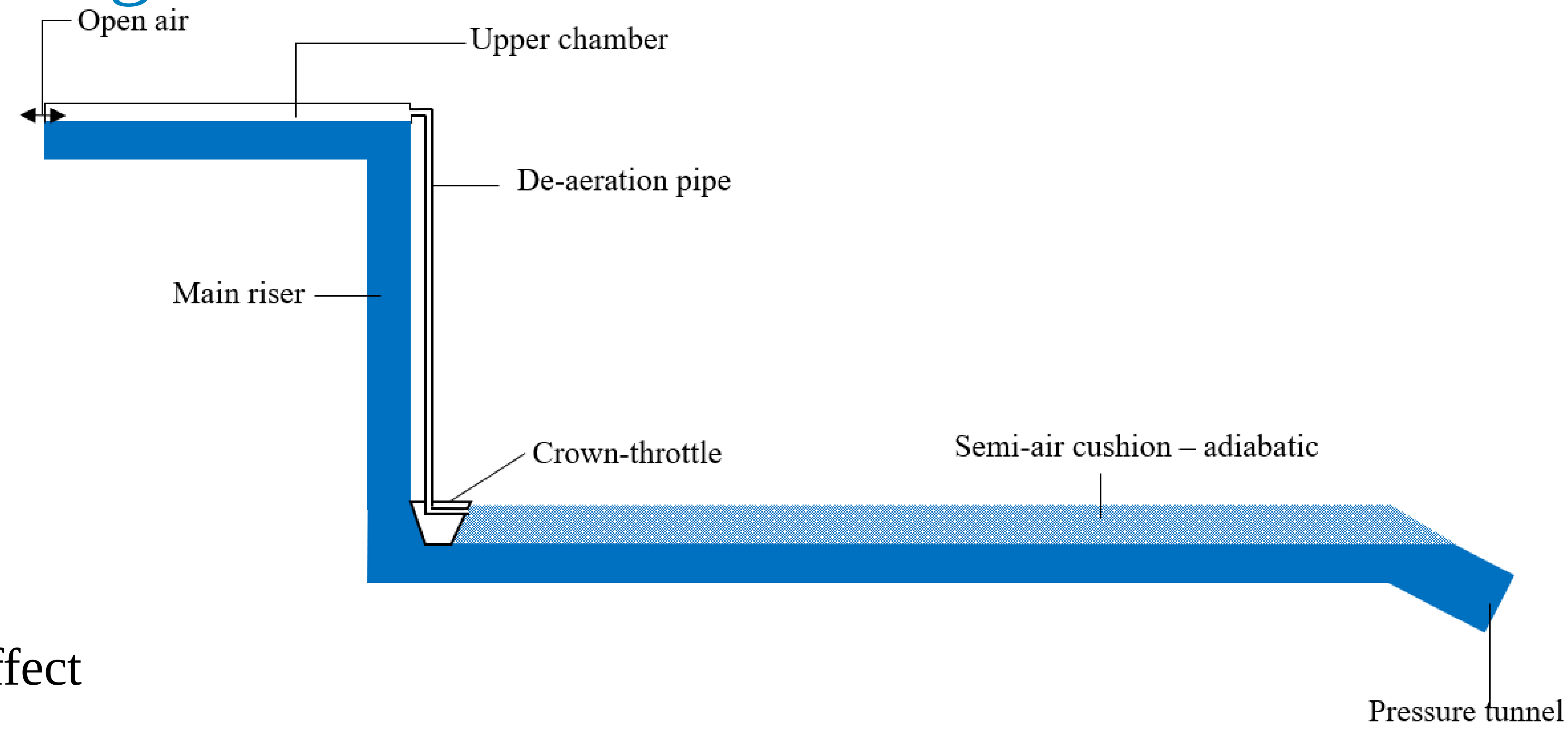
Semi-Air cushion surge tank to decrease volume demand



- Upgrades
- Improved differential effect
- Lower volume demand
- Implementation into 1D-numerical code - outlook
- Physical model tests - outlook
- Thermodynamic behaviour of the air throttle - outlook

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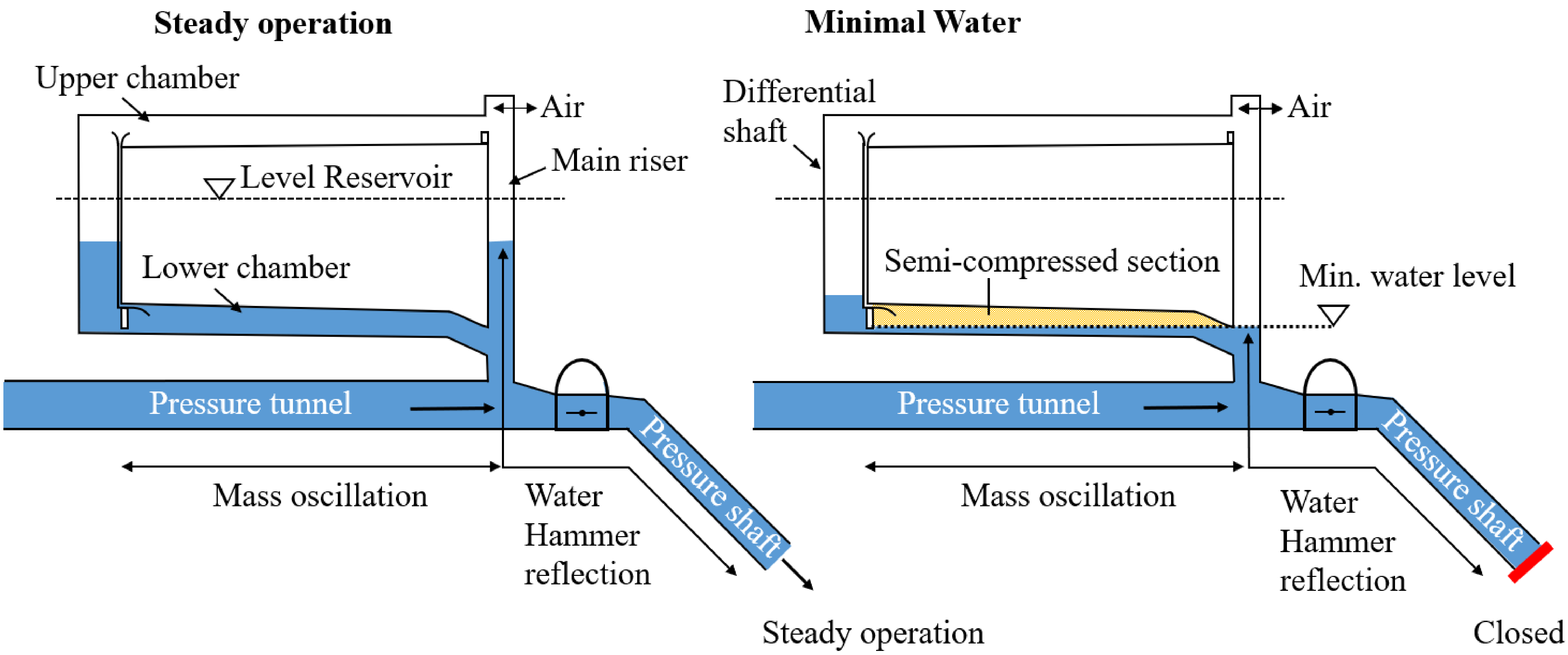
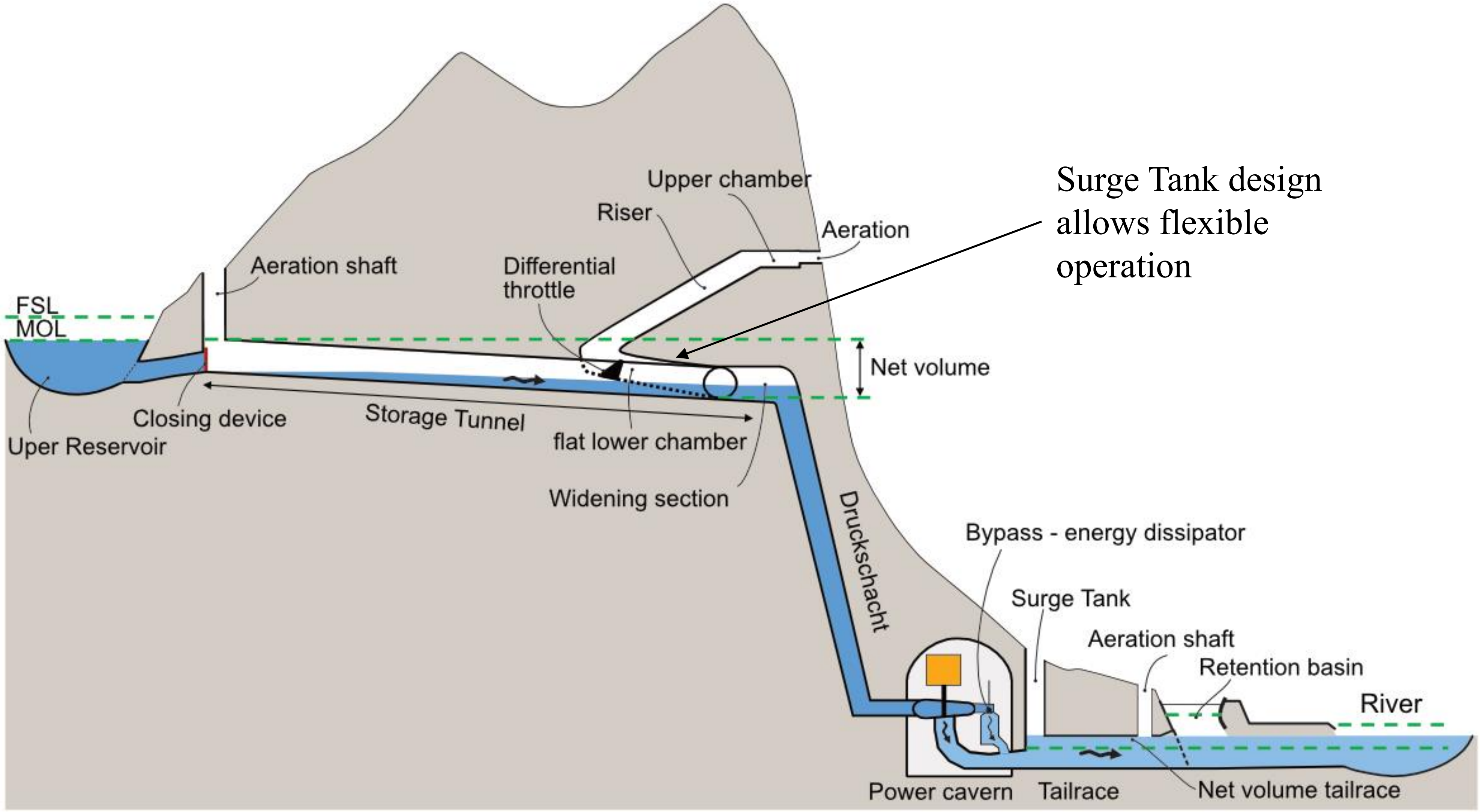
Semi-Air Cushion Surge Tank



Storage Tunnel concept – Hydropeaking mitigation



Surge Tank design allows flexible operation

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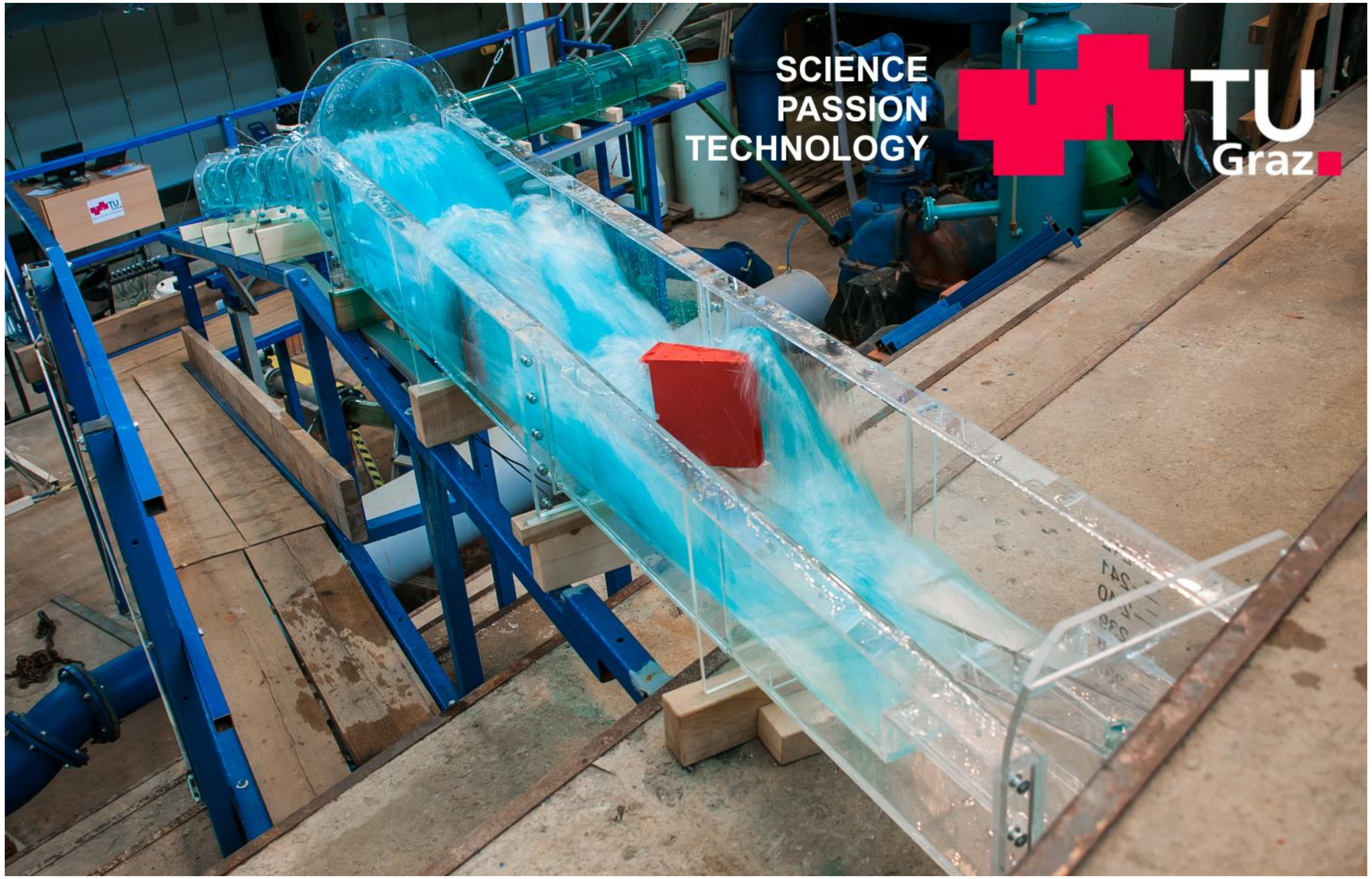
Thank you very much for your attention! ☺



Picture: F G Pikl

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