

SHERPA

new Solutions for Hydropower plants to Enhance operational Range, Performance
and improve environmental impAct

Modernising Hydropower For Flexibility and Environmental Performance

Ademir Suárez – Head of Electromechanical Engineering (Iberdrola Generación)

Diego Castejón – Hydroelectric Power Plants Engineer (Iberdrola Generación)



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INDEX

1. Objective
2. Consortium & Key figures
3. Background
4. Actions
5. SHERPA's WP & Methodology
6. Pilot plants

Objective

Main objective: Developing and validating innovative technologies leading to operation at production or discharge levels below design specifications, operating in accordance with ecological flow requirements, thereby improving environmental conditions as we generate energy.



Ecological flow: refers to the minimum quantity, timing, and quality of water that must be released from dams or hydropower plants to maintain the ecological integrity of downstream aquatic ecosystems, support biodiversity, and ensure the sustainability of ecosystem services for local communities.



Consortium & Key figures

Total Budget: 3.8 M

Project duration: 42 months

Consortium: 7 partners



Figure: SHERPA Consortium partners

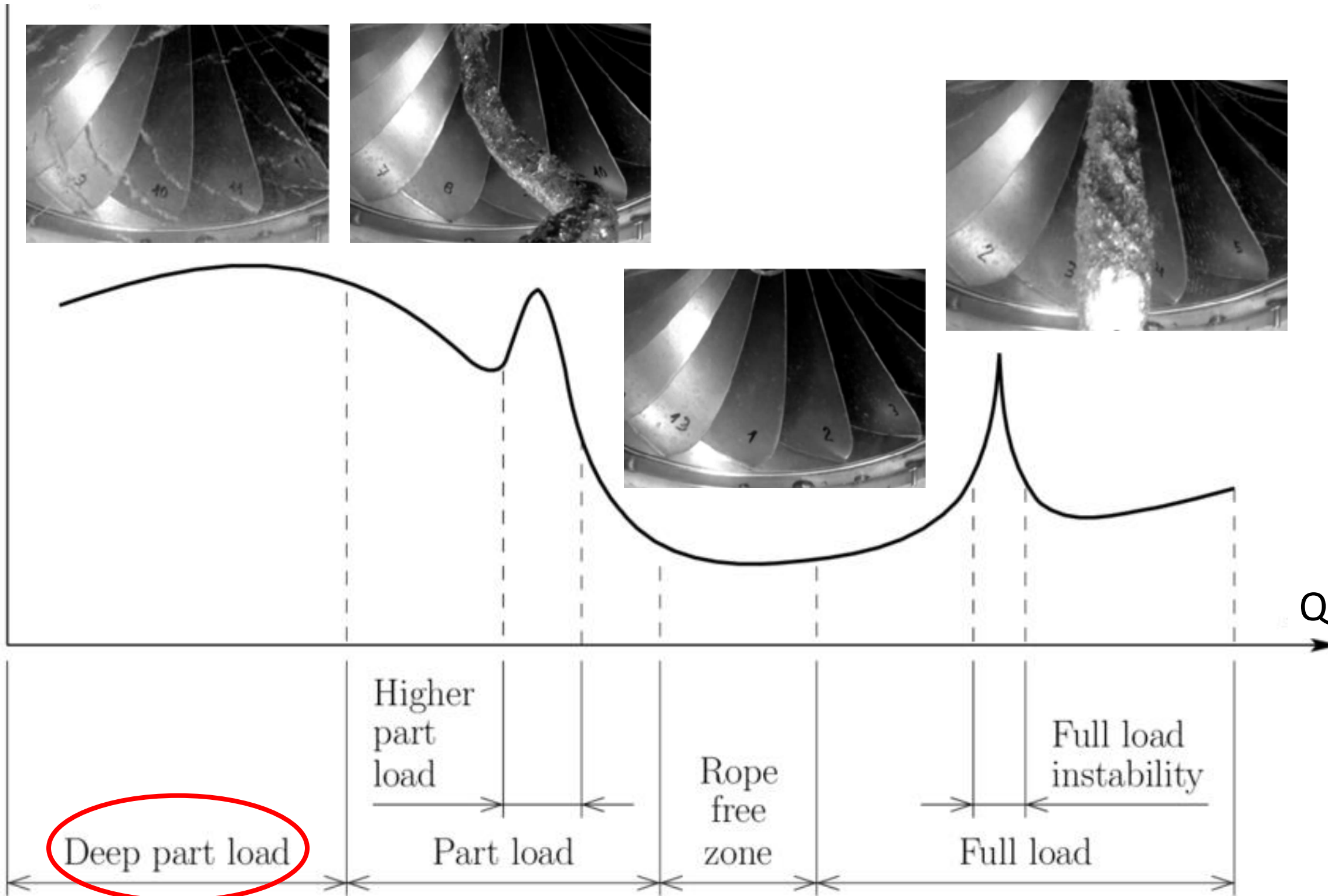
Background

Magnoli M & Maiwald, M (2014) - Influence of Hydraulic Design on Stability and on Pressure Pulsations in Francis Turbines at Overload, Part Load and Deep Part Load based on Numerical Simulations and Experimental Model Test Results **27th IAHR Symposium on Hydraulic Machinery and Systems (IAHR 2014)**.

<https://doi.org/10.1088/1755-1315/22/3/032013>

$dh/$

$/H$



Actions

Main objective: **develop and validate innovative technologies** for refurbishing current HPPs through:



AM METALLIC PATCHES AND COATINGS TO MINIMIZE DAMAGE AND ENHANCE RESISTANCE TO CAVITATION



NEW STRATEGIES TO ADAPT ROTATIONAL SPEED DEPENDING ON THE FLOW RANGE.

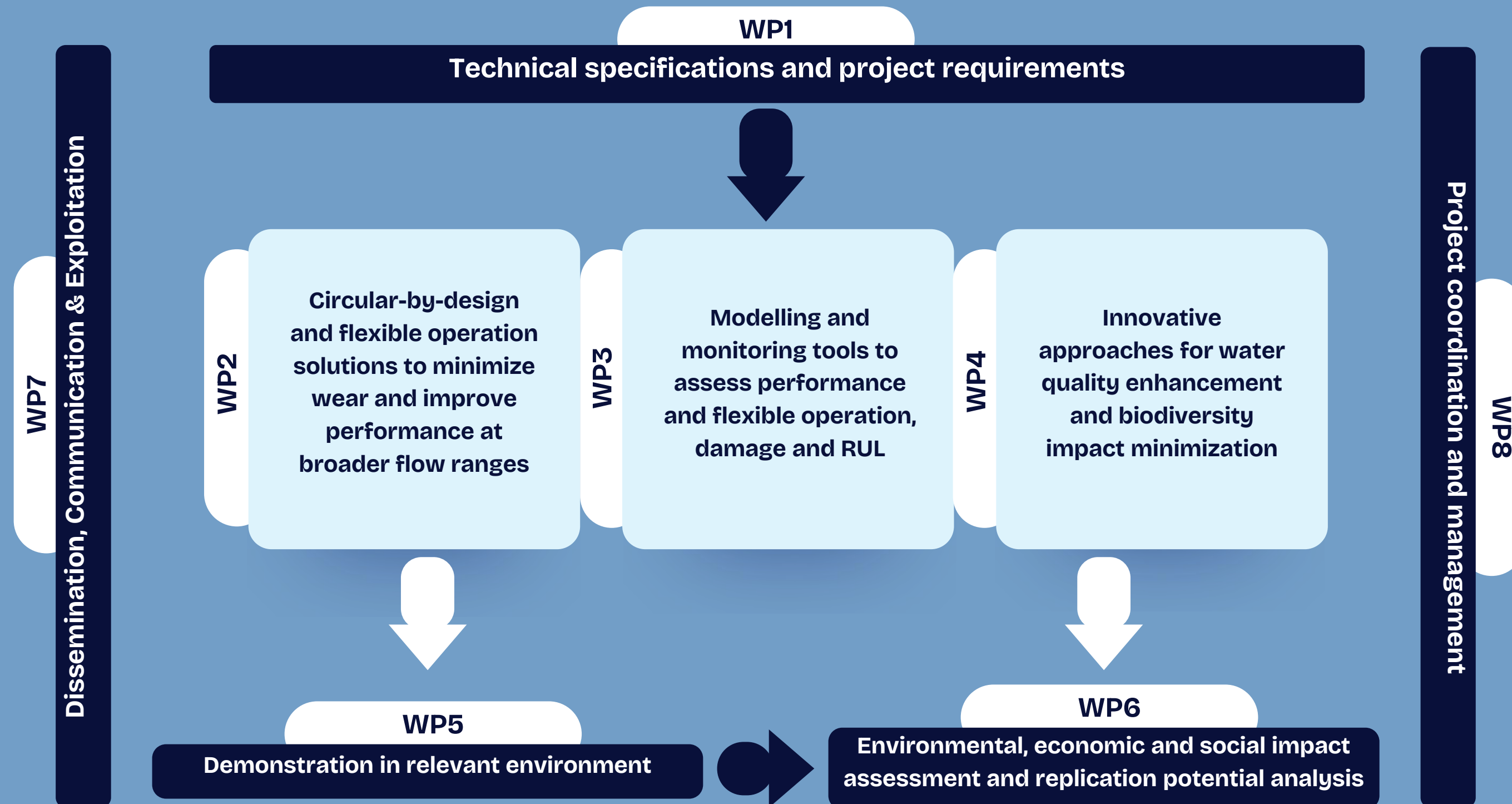


ADVANCED AIR INJECTION SYSTEMS TO IMPROVE WATER QUALITY AND EFFICIENCY



NEW RUNNER DESIGNS ADAPTED TO E-FLOWS INCREASING PERFORMANCE.

SHERPA's WP and methodology



Pilot plants

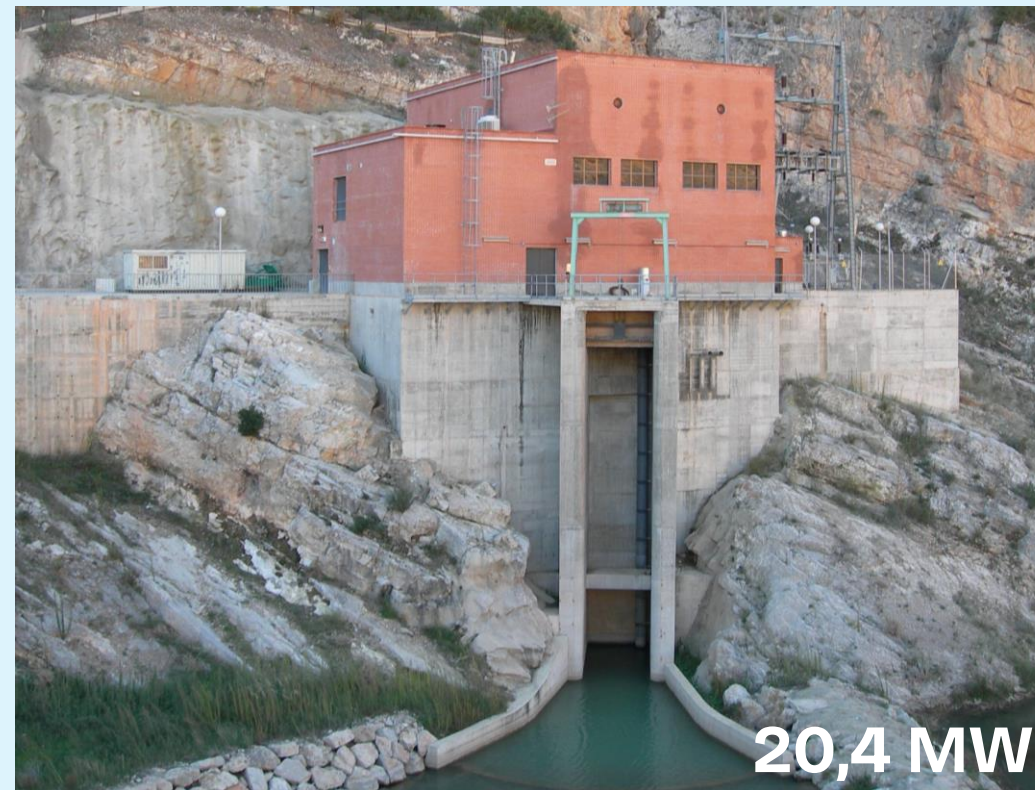
At the Mediterranean Basin



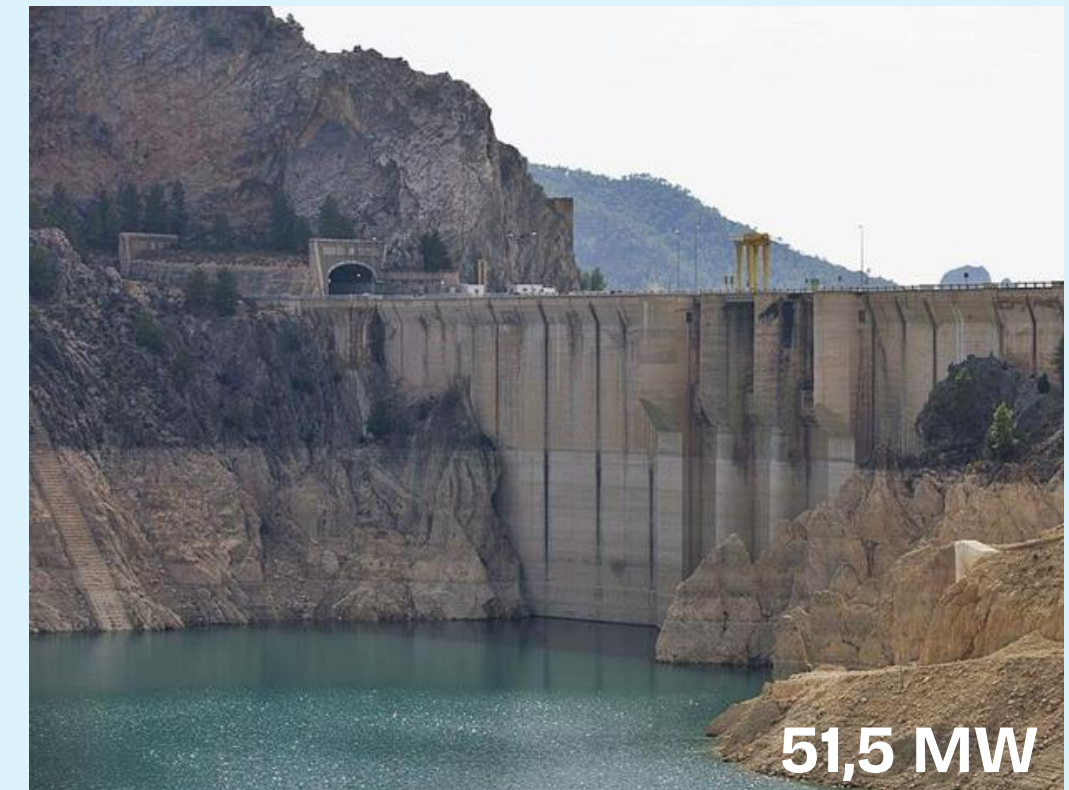
BENAGÉBER



DOMEÑO



CONTRERAS II



ALARCÓN



LORIGUILLA



Pilot plants

At the Sil Basin



ALTO TÁMEGA



DAIVOES



SAN ESTEBAN II



Innovations in Turbine Refurbishment

Jorge Deus – Senior CFD Engineer (AIMEN)

Jorge Arias – Senior Researcher Advanced Laser Processes (AIMEN)

Joerg Necker – Head of Hydraulic Development (Voith Hydro)



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INDEX

1. Aimen – CFD Simulation
2. Aimen Additive Manufacturing
3. Voith Hydro

Innovation in Turbine Refurbishment

01

Aimen - CFD

Patch design to improve runner performance under low-flow conditions

02

Aimen - AM

Patch fabrication by laser additive manufacturing
Wear- and corrosion-resistant coatings

03

Voith Hydro – Turbine manufacturer

Flexibility towards part load:
“0 – 100 % load” – operation

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AM-PATCH DESIGN

MOTIVATION:

Modify runner geometry to operate in a different point they were originally designed for.

- **CFD design methodology** was created to evaluate efficiency and cavitation risk in different geometries.
- **Automatic generated geometries** were evaluated to find the optimum design.



METHODOLOGY

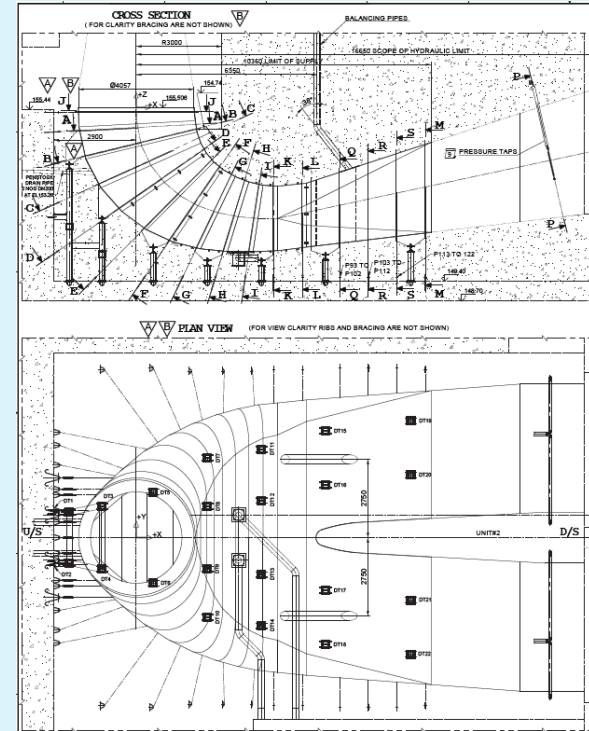
- **Steady-state solution** of fluid motion equations (Navier–Stokes)
- **MRF** applied to the runner (solved in a moving coordinate system)
- **Two-phase model**: water and water vapor (Eulerian model)
- Vapor sources modelled using **cavitation model** (Zwart–Gerber–Belamri)
- **Vapor pressure** set at 3540 Pa (absolute)
- **5 Cases of study** 15°, 20°, 25°, 30°, 35° wicket gate opening

DAIVÕES GEOMETRY CREATION

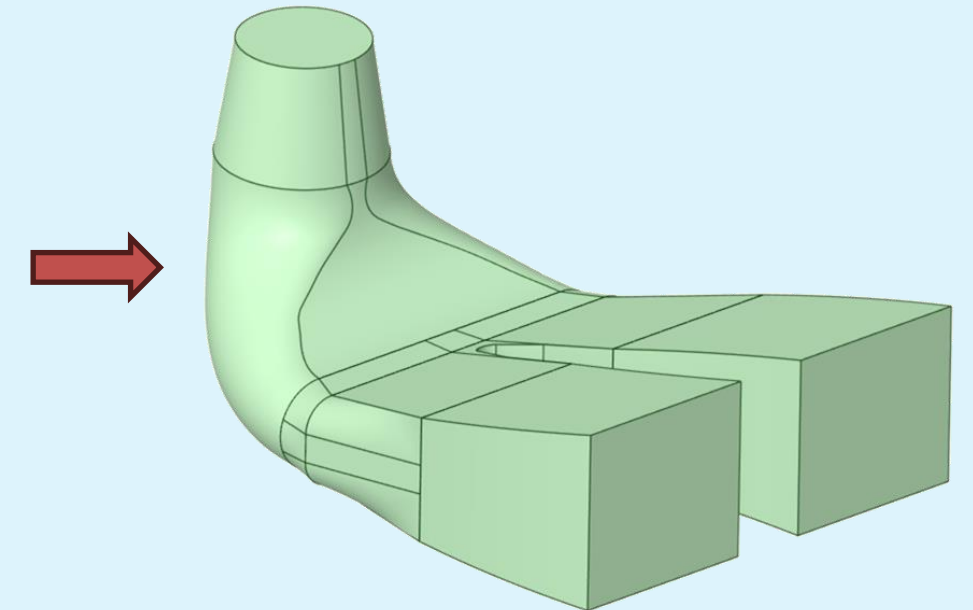
Geometry was obtained from **Blueprints** and **point cloud** obtained by a 3D scan procedure.



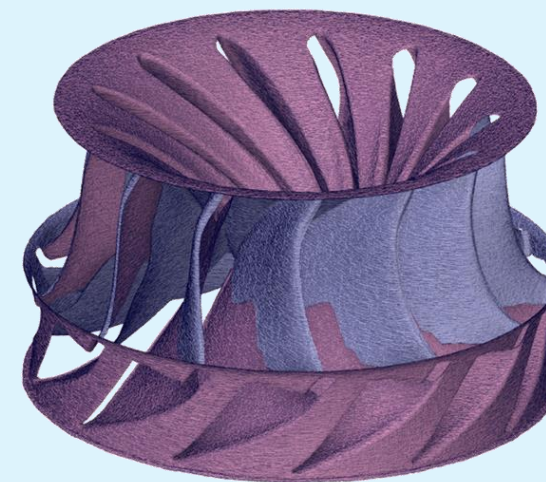
BLUEPRINTS



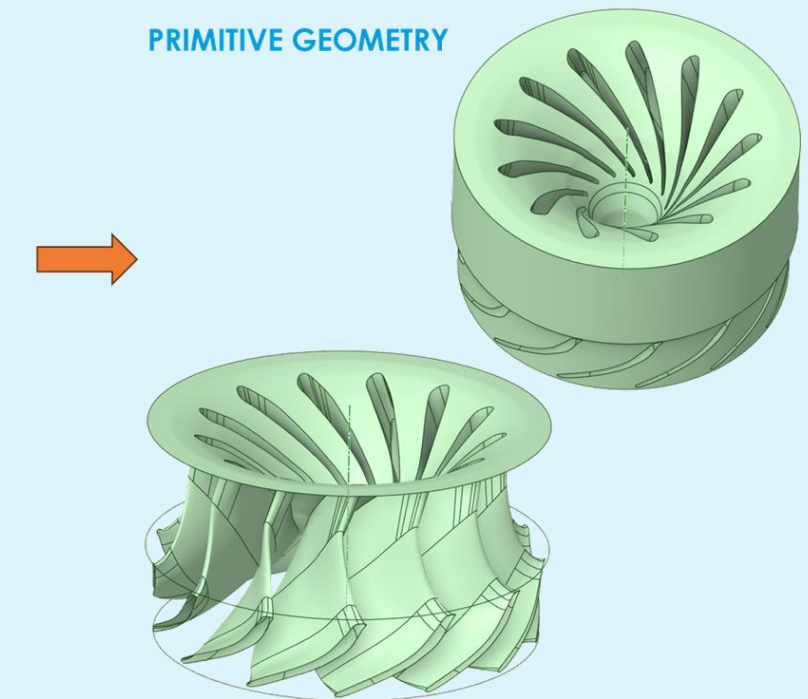
PRIMITIVE GEOMETRY



POINT CLOUD

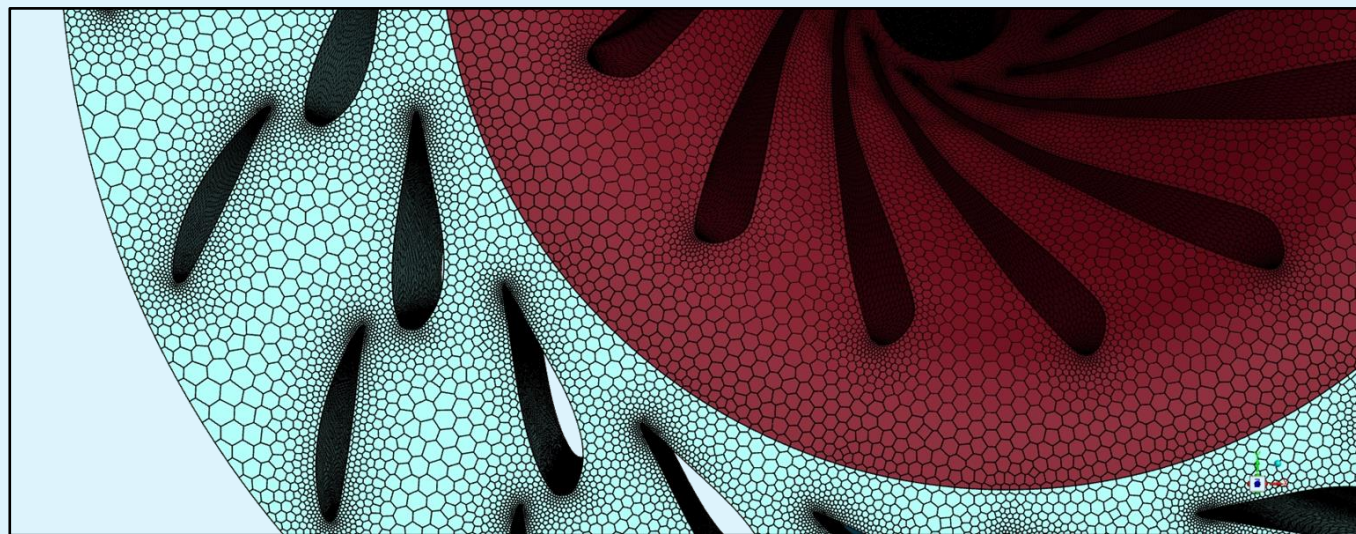
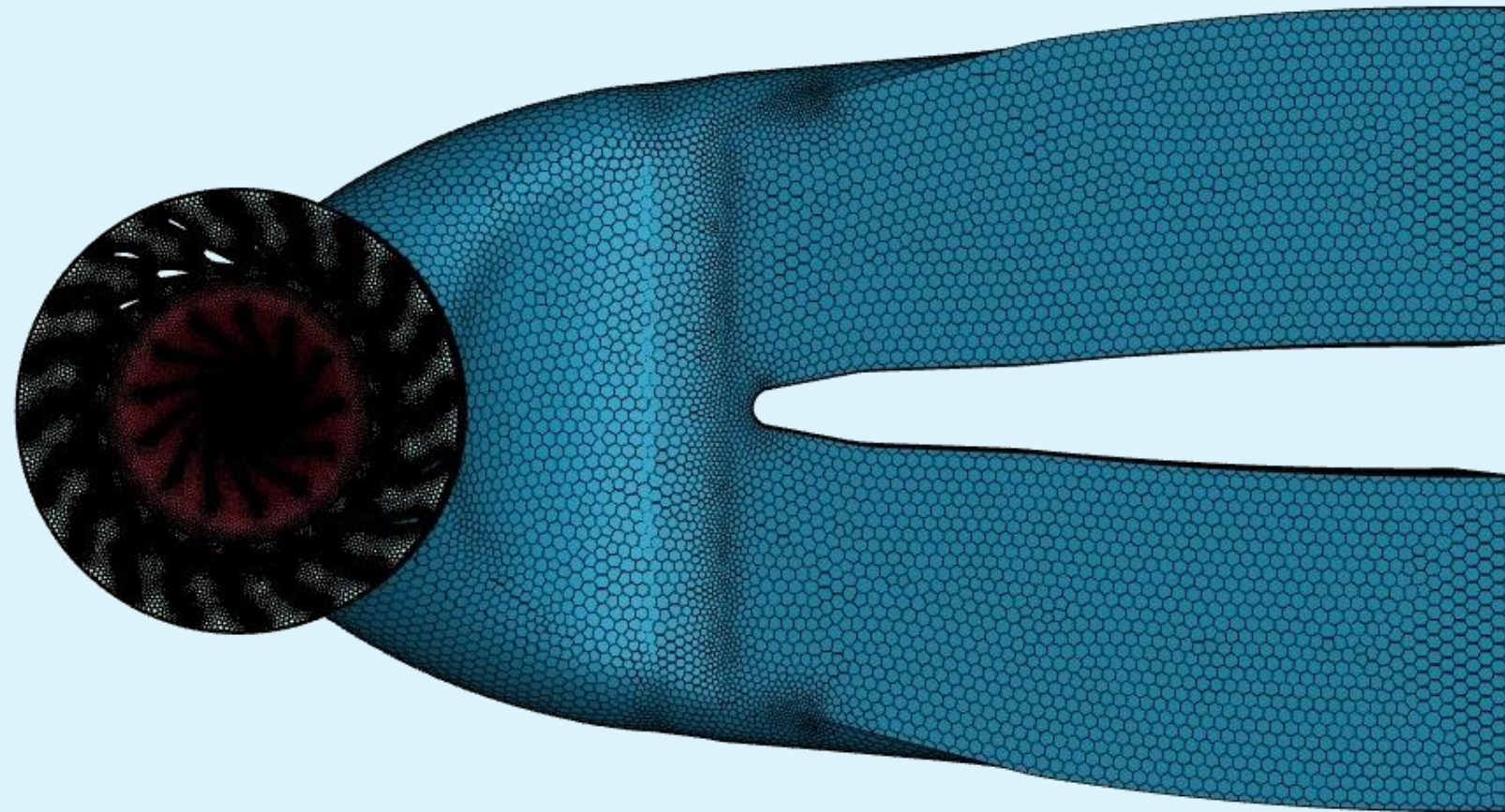


PRIMITIVE GEOMETRY

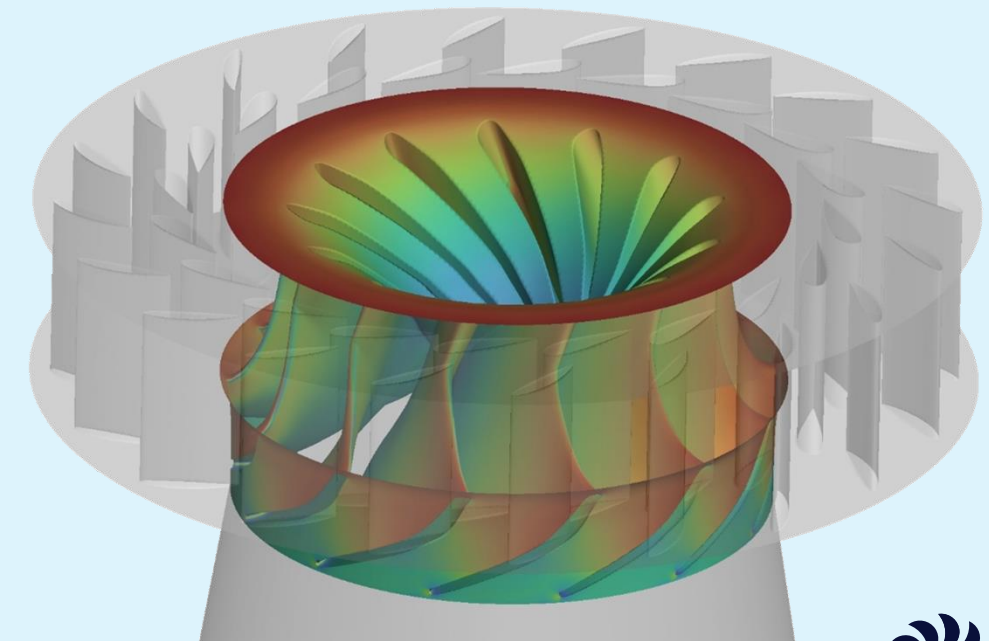
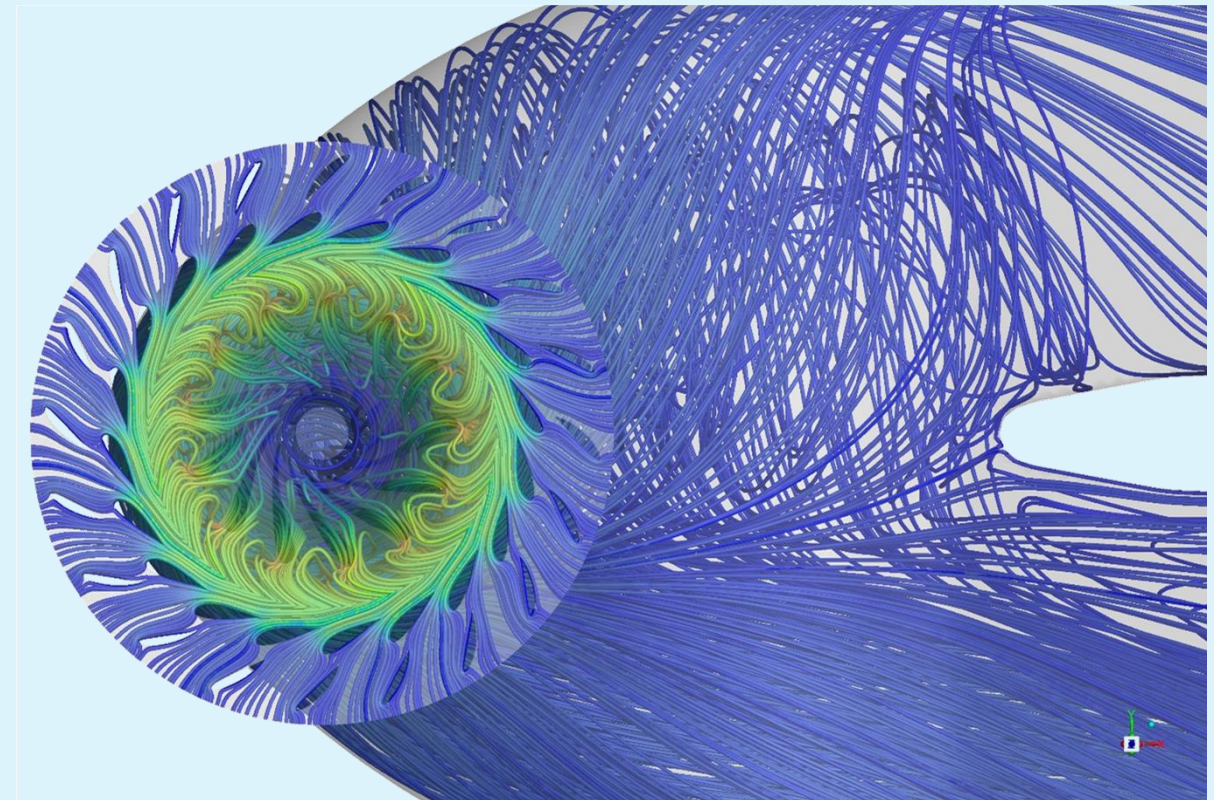


CFD SIMULATION

MESH DETAIL

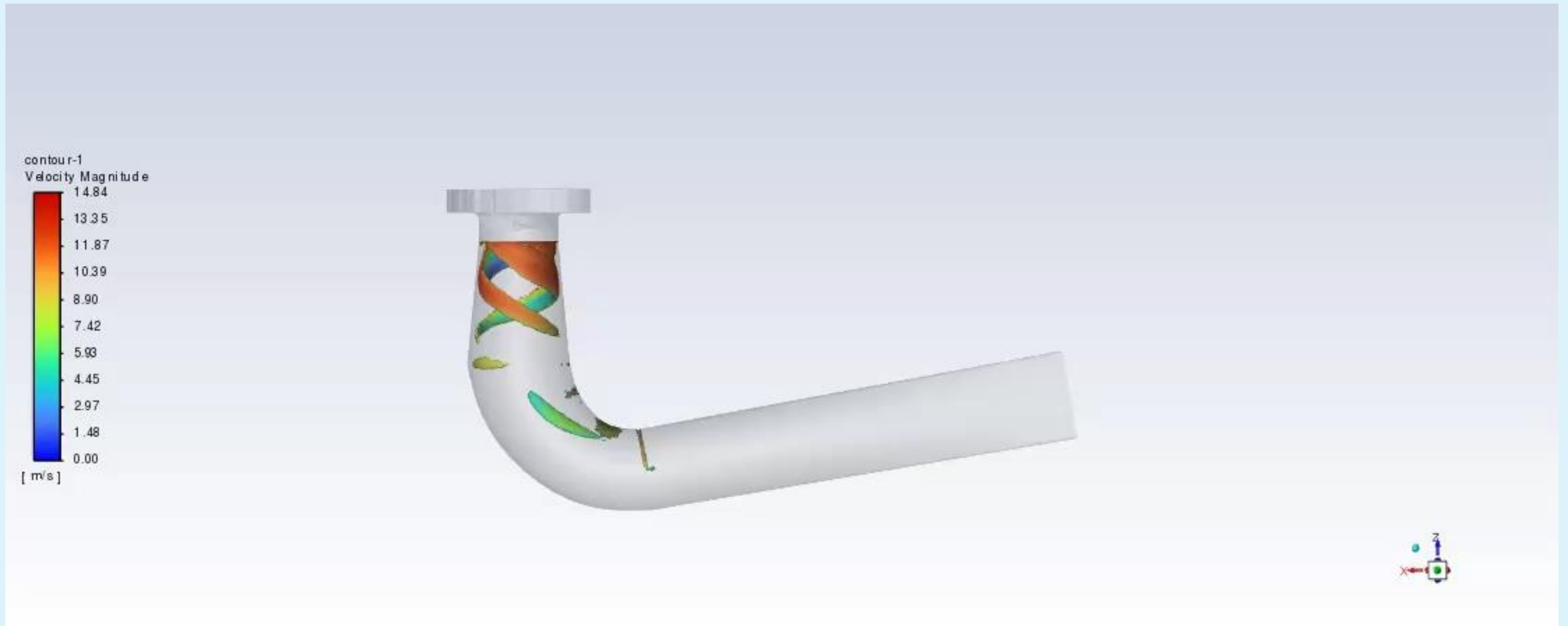


CFD RESULT

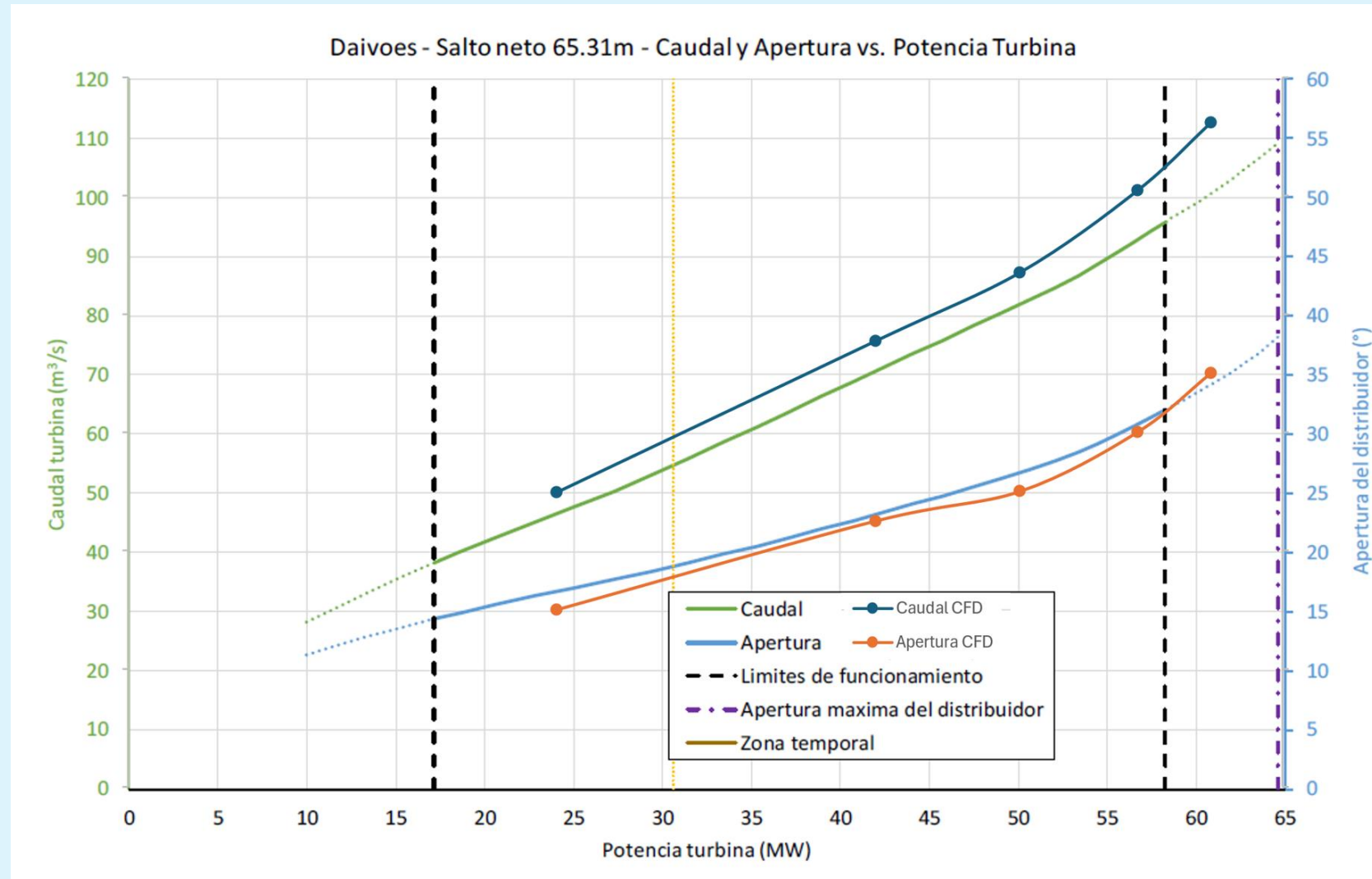


CFD SIMULATION

TRANSIENT

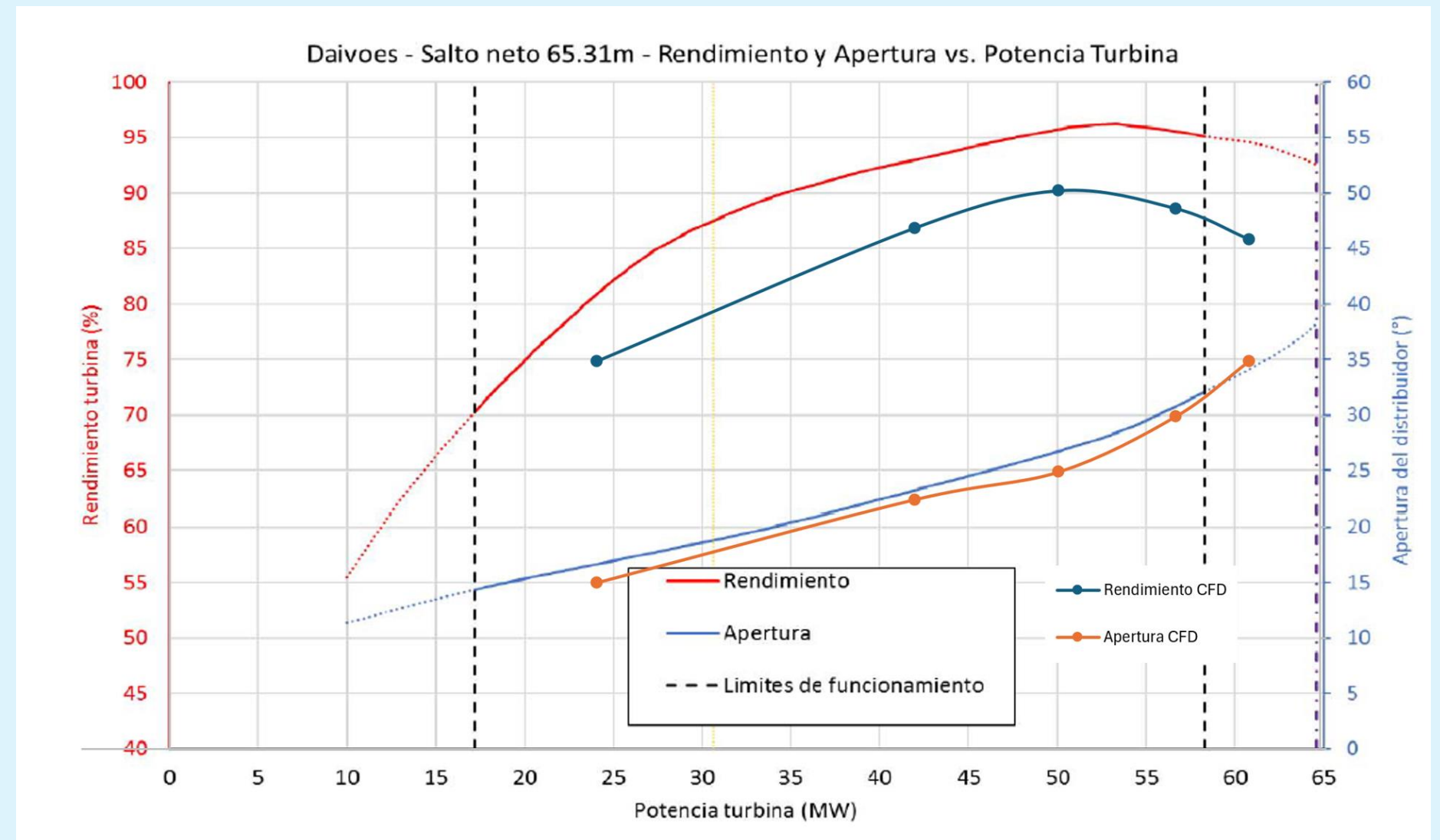


CFD CORRELATION



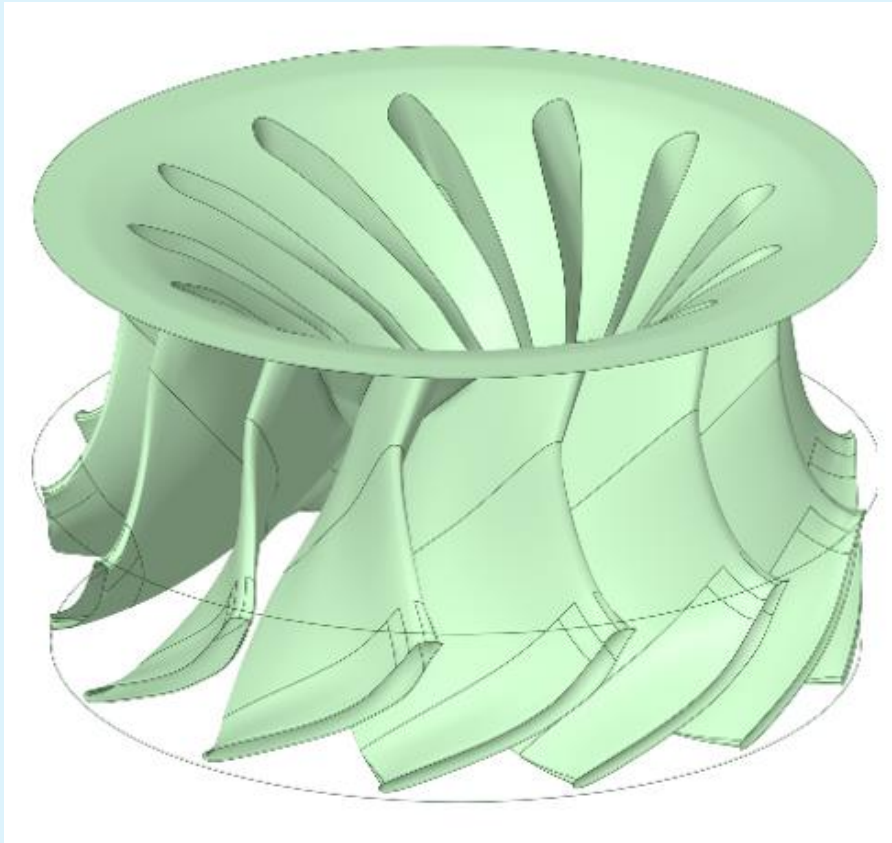
CFD results predicts the efficiency of the runner with an error of around a 5%

CFD results accurately predict the **Volume flow** and **wicket gate opening** shown in the Hill Chart

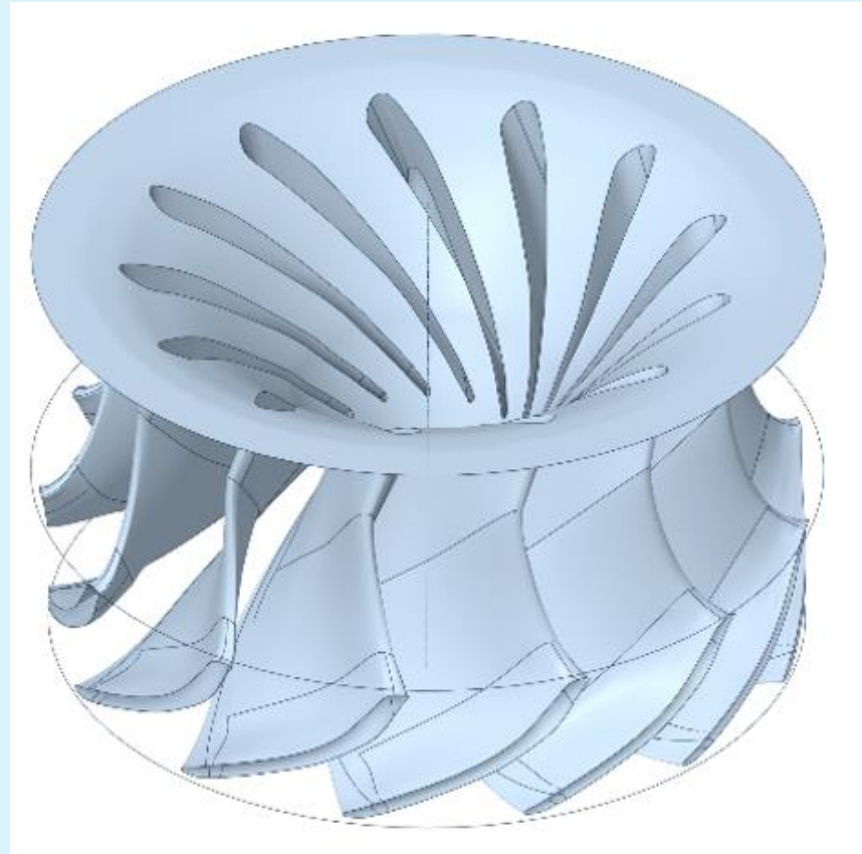


PATCH DESIGN

ORIGINAL GEOMETRY



PATCH GEOMETRY

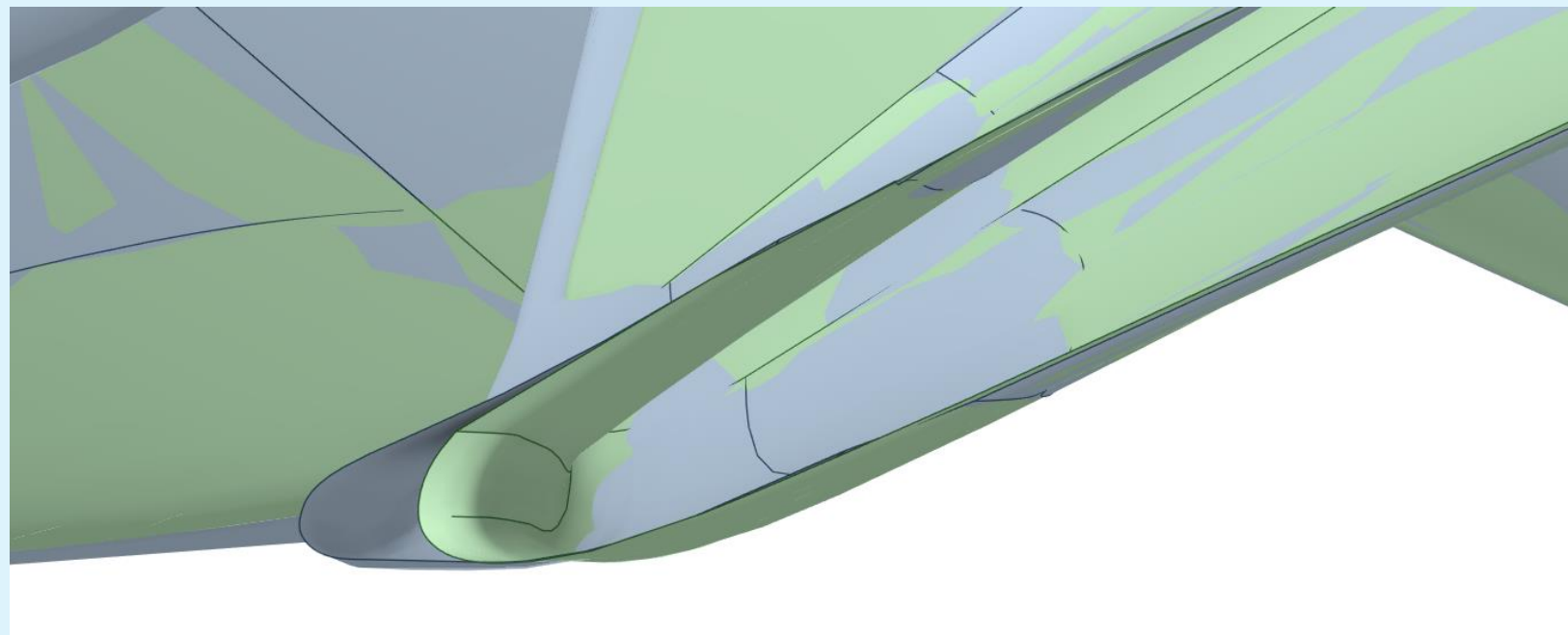


PATCH MODIFICATION

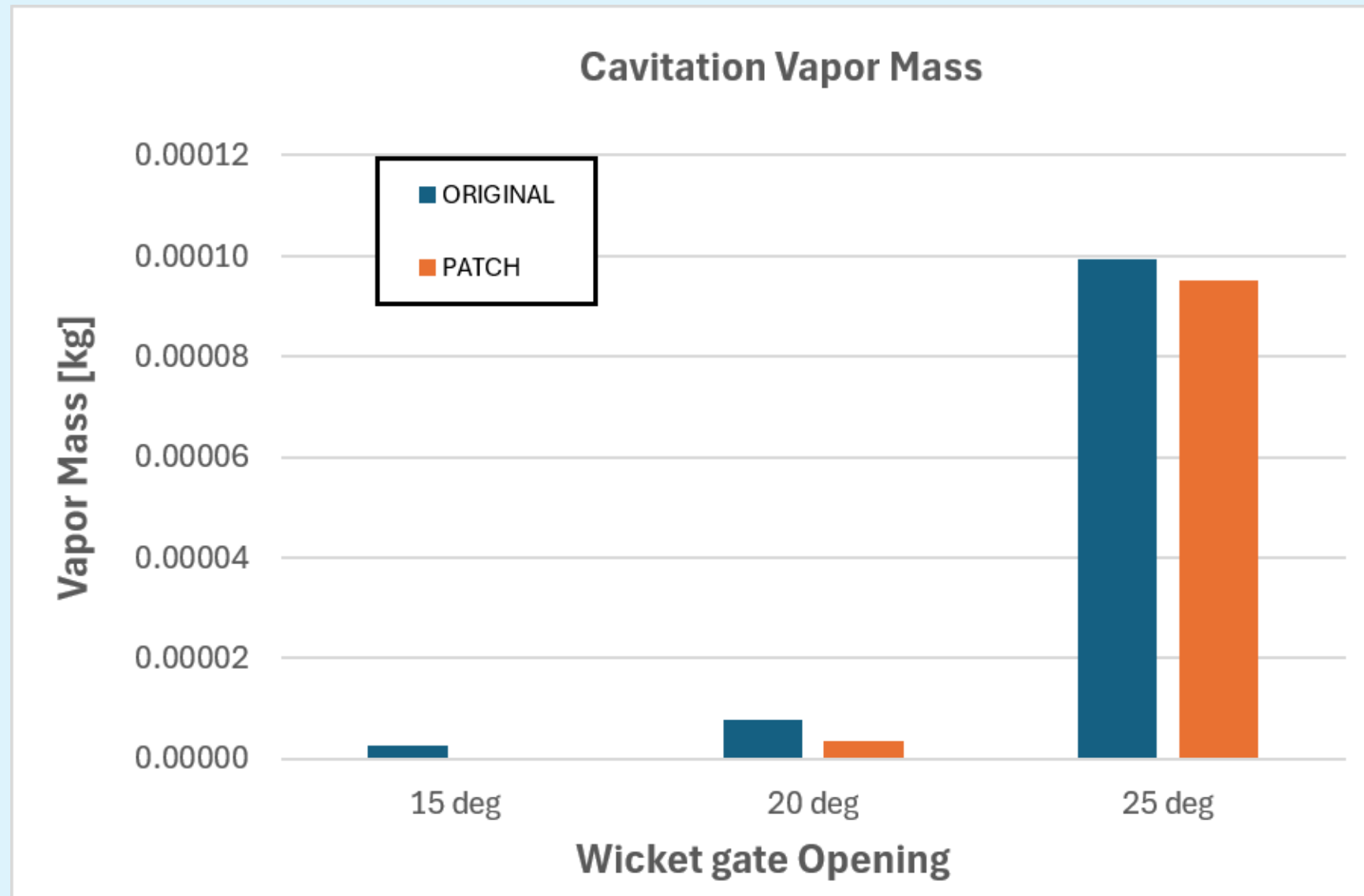
- Extending the trailing edge
- Reducing the outlet angle

OBJECTIVES

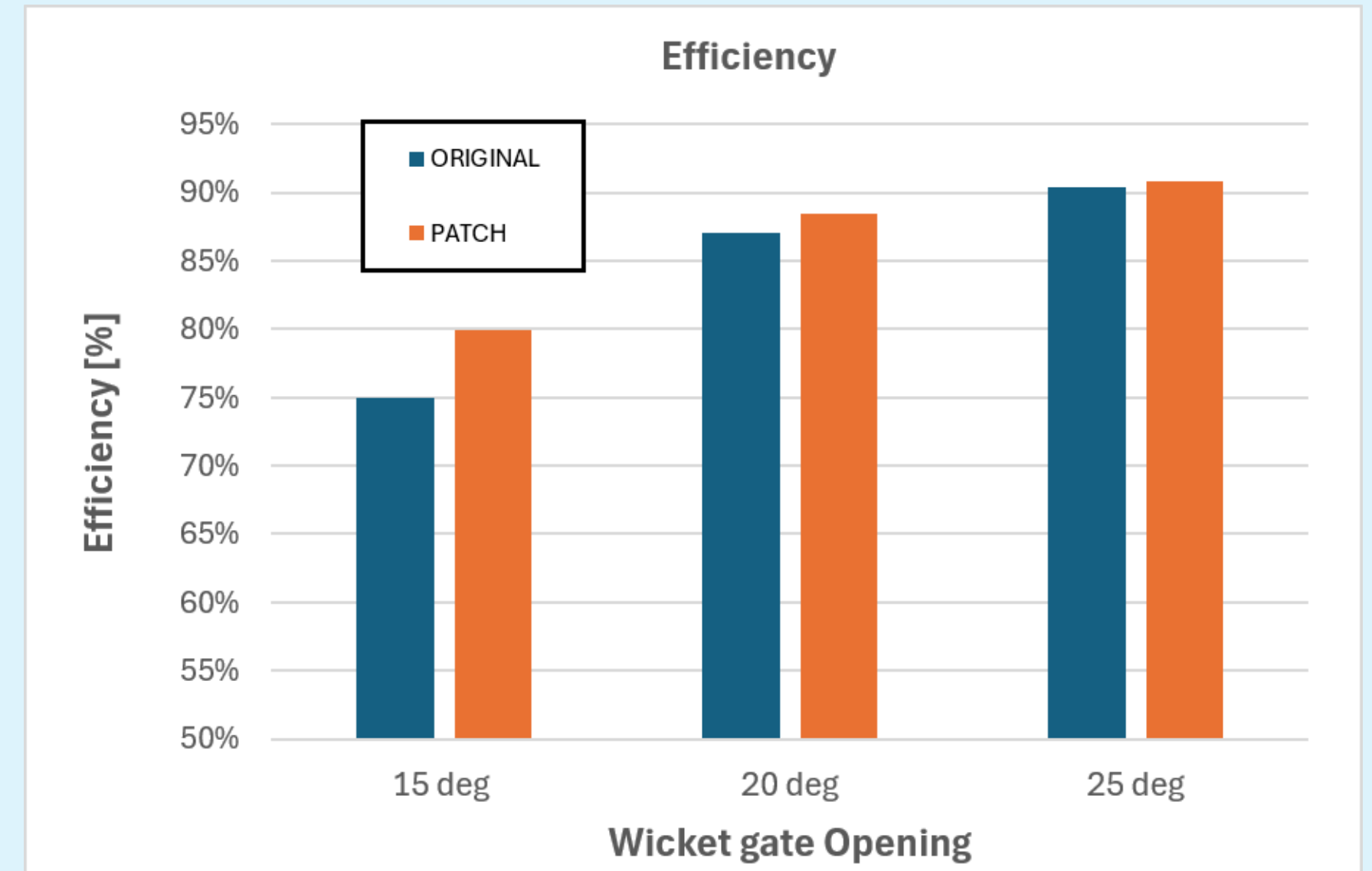
- **Smooth the pressure recovery** downstream of the blade.
- **Reduce local pressure gradients**, lowering the risk of pressure dropping below vapor pressure.
- **Improve flow alignment** at discharge, minimizing flow separation and vortex formation near the blade exit.



PATCH DESIGN



The PATCH design reduces cavitation in a 95% for a 15° opening, a 55% for a 20° opening and a 5% for a 25° opening



The PATCH design improves runner efficiency in a 5% for the 15° opening, 1.5% for the 20° opening and 0.5% for a 25° opening

Innovation in Turbine Refurbishment

01

Aimen - CFD

Patch design to improve runner performance under low-flow conditions

02

Aimen - AM

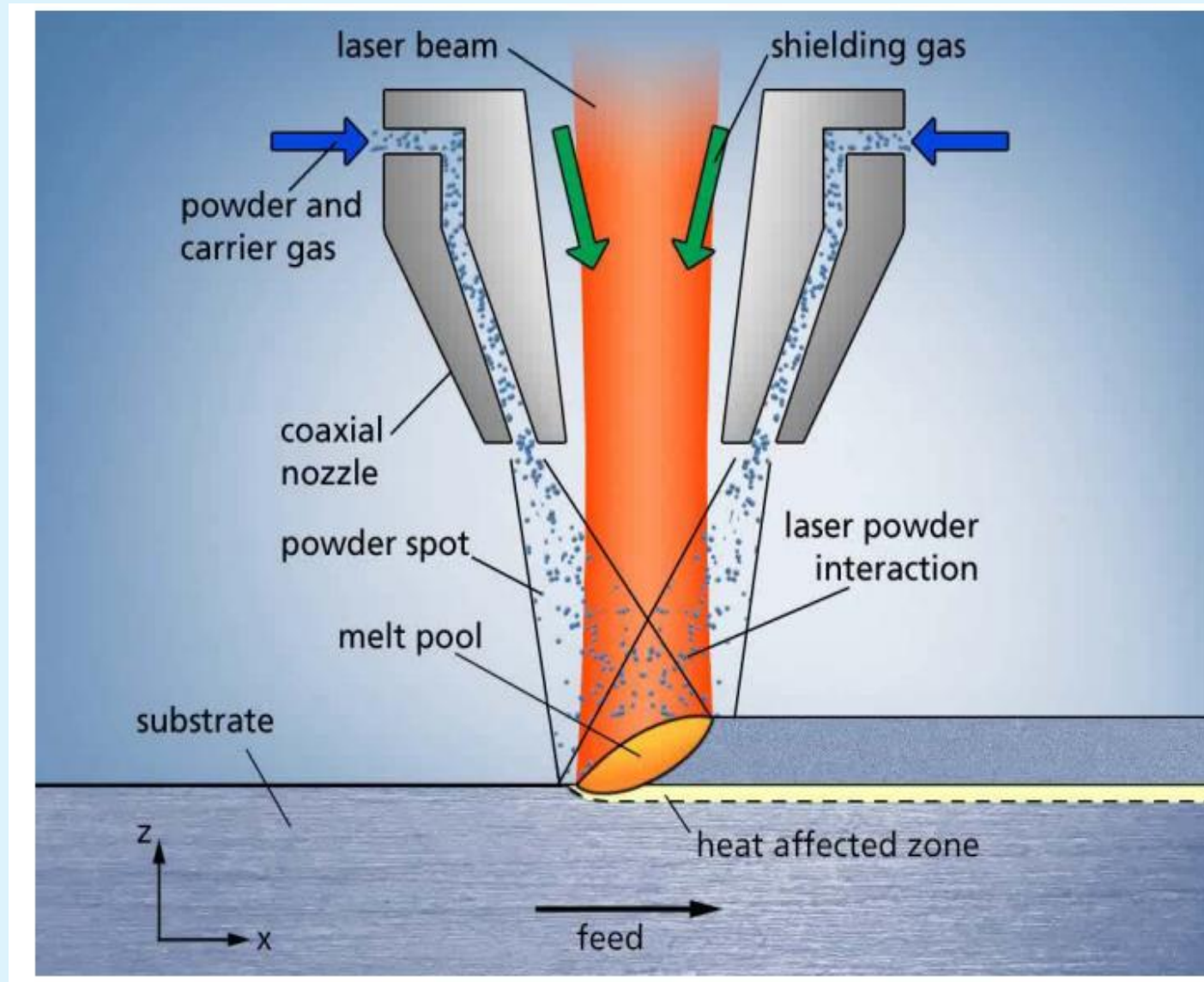
Patch fabrication by laser additive manufacturing
Wear- and corrosion resistant coatings

03

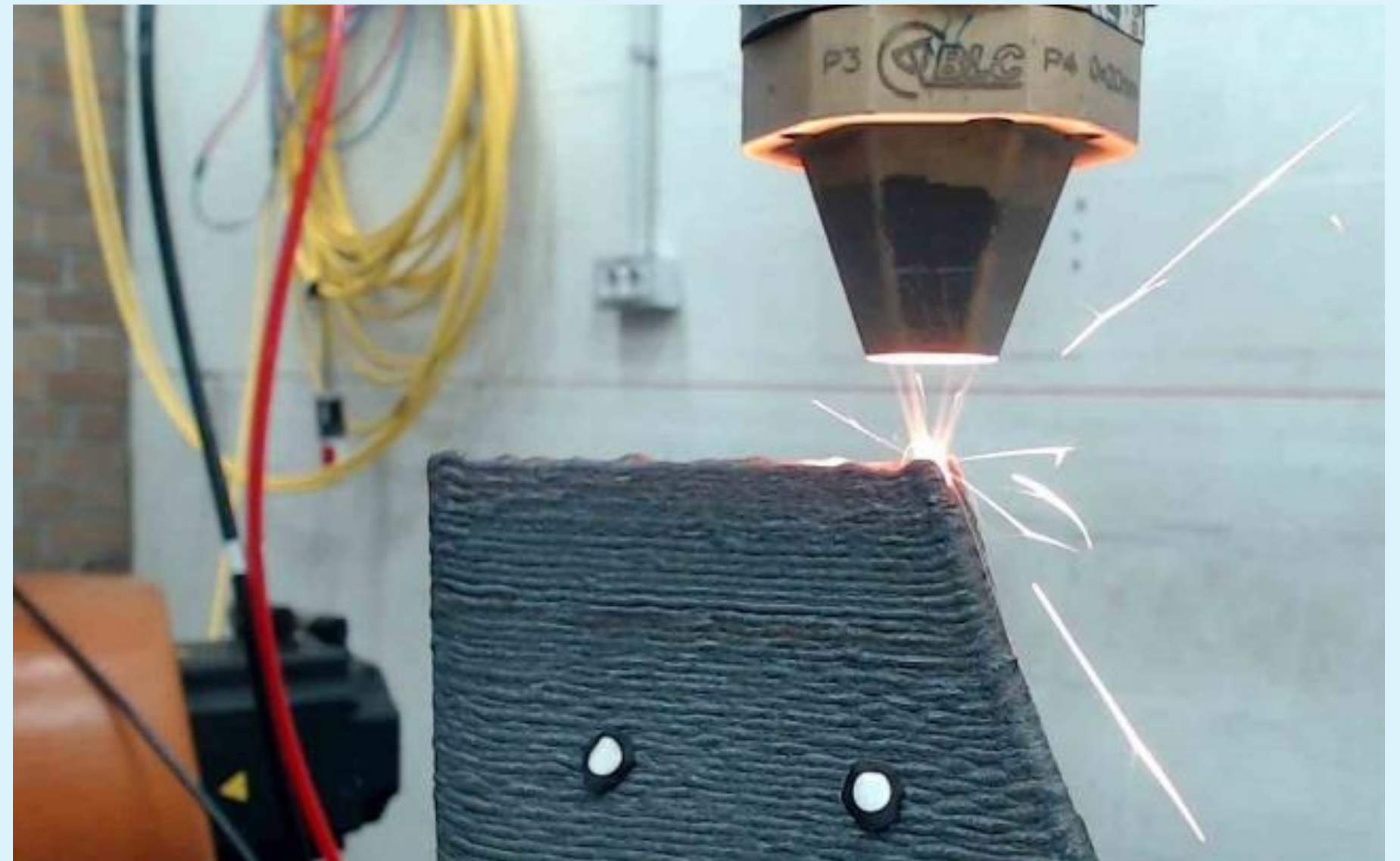
Voith Hydro – Turbine manufacturer

Flexibility towards part load:
“0 – 100 % load” – operation

DIRECTED ENERGY DEPOSITION BY LASER (DED_LB)



Fuente: Fraunhofer IWS

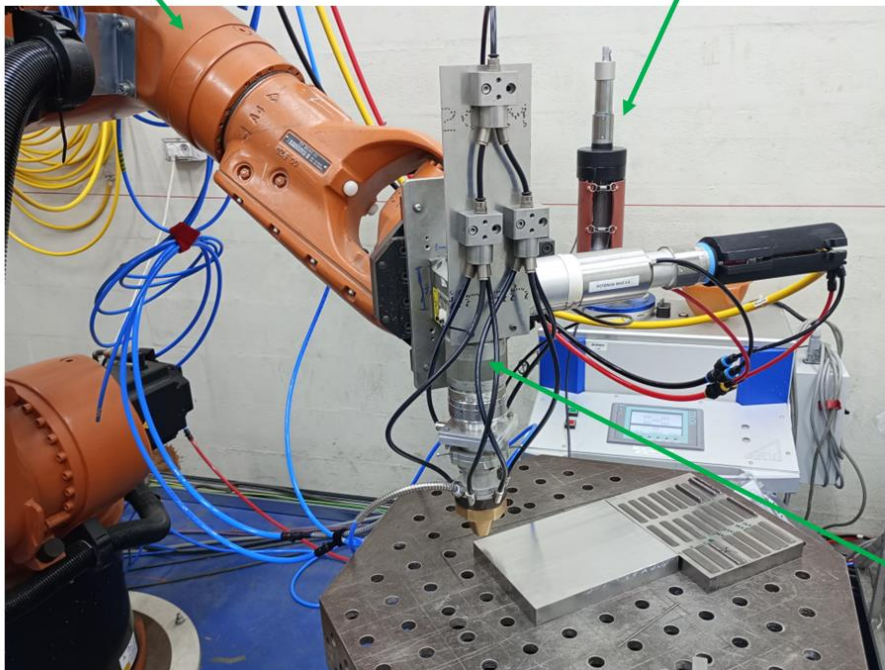


1. Additive manufacturing of patches
2. Wear- and corrosion-resistant coating application

ADITIVE MANUFACTURING + COATINGS

Robot

Powder feeder



Direct Energy Deposition by Laser (DED-L):

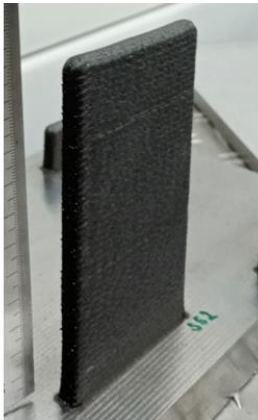
Laser Power (W)	Processing speed (mm/s)	Powder flow (g/min)	Laser beam diameter (mm)	Shielding gas (l/min)	Gas
900 - 1500	8 - 20	5 - 20	1 - 3	12	Argon

DED-L processing tool

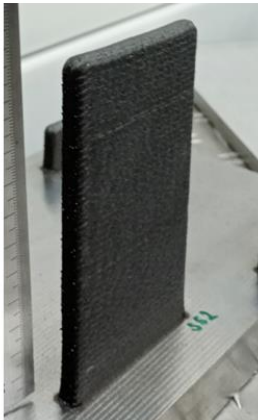
Small coatings (6 overlapped beads)



DED-L beads



AM walls (N layers / n beads per layer)



Large coatings (100 x 150 mm)





Inconel 625



Stellite 6



WC - Co



NiCrBSi alloy

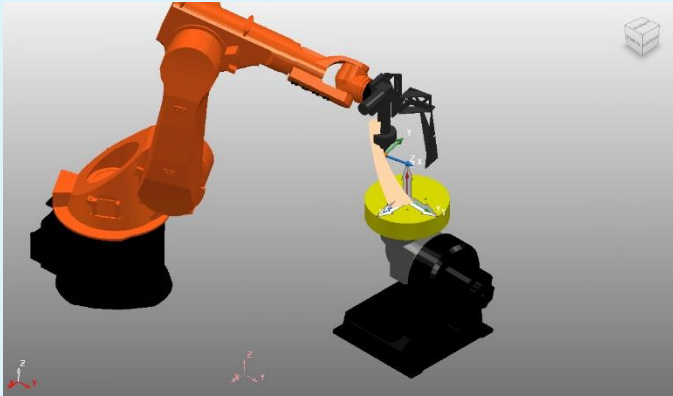


AISI 410 steel

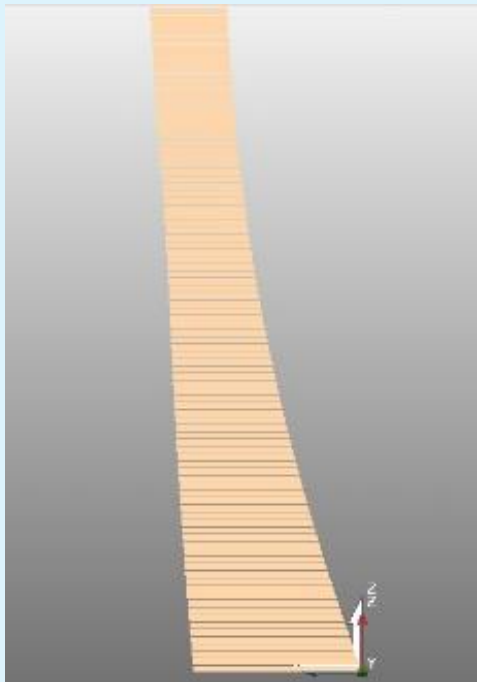
FABRICATION OF AM METALLIC PATCH



CAD design



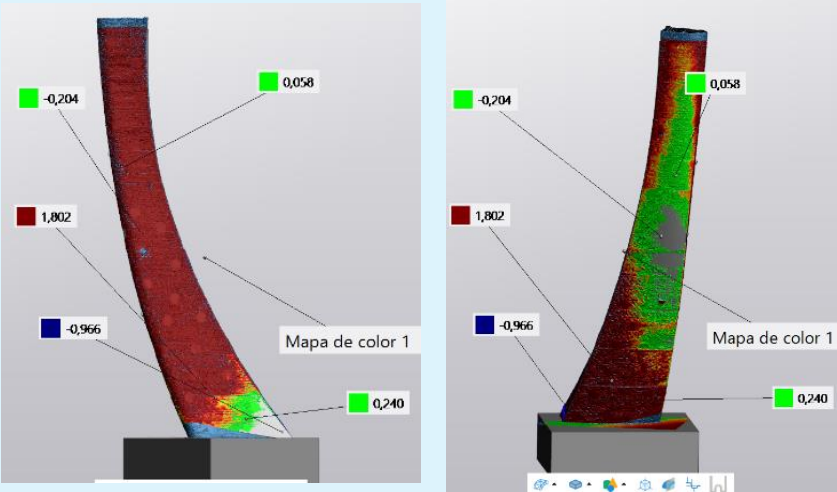
AM path
planning



Manufacturing



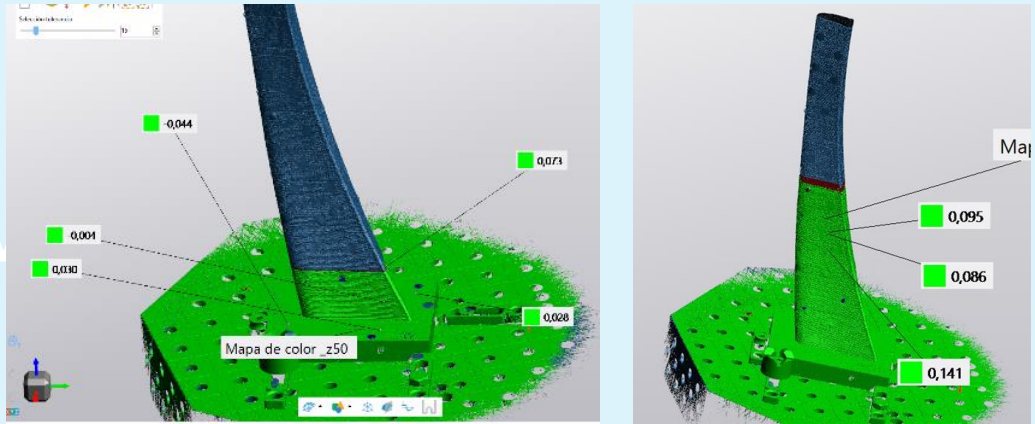
CAD vs. Final AM patch



118 MW

Intermediate vs. Final

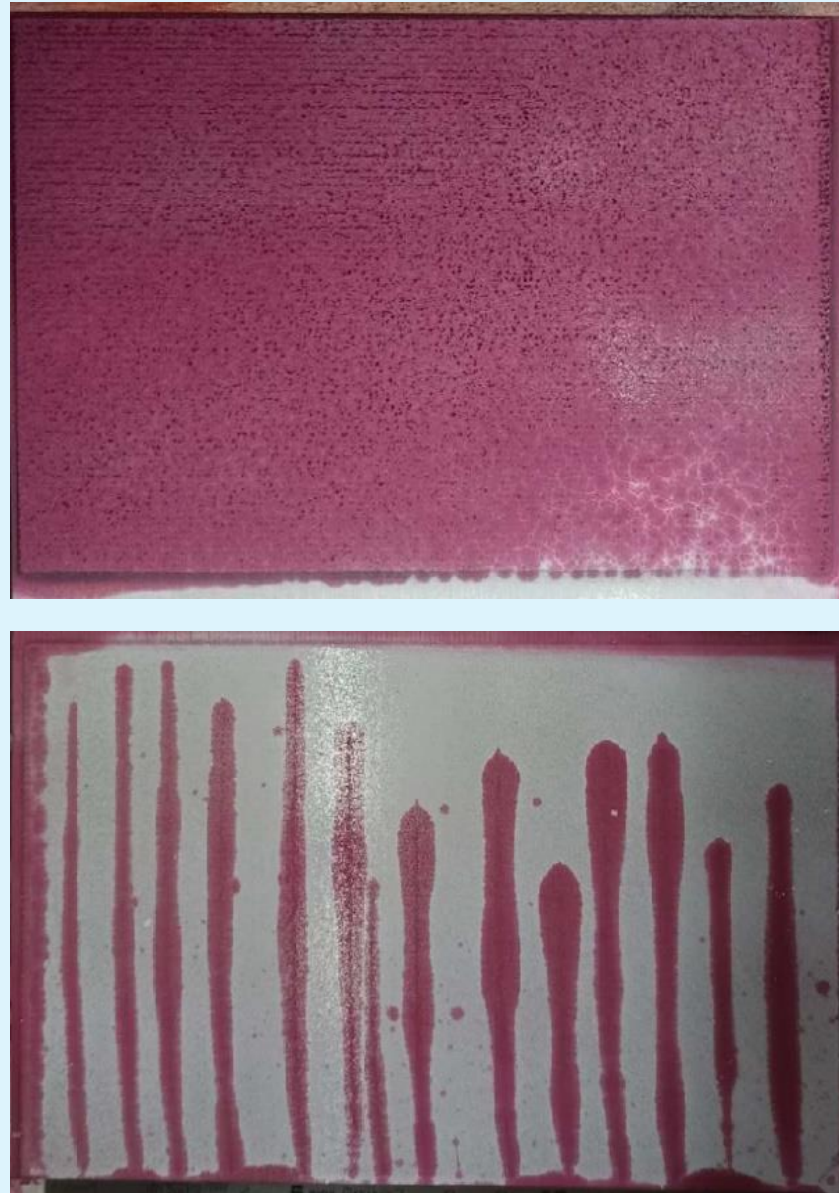
118 M



Inspection

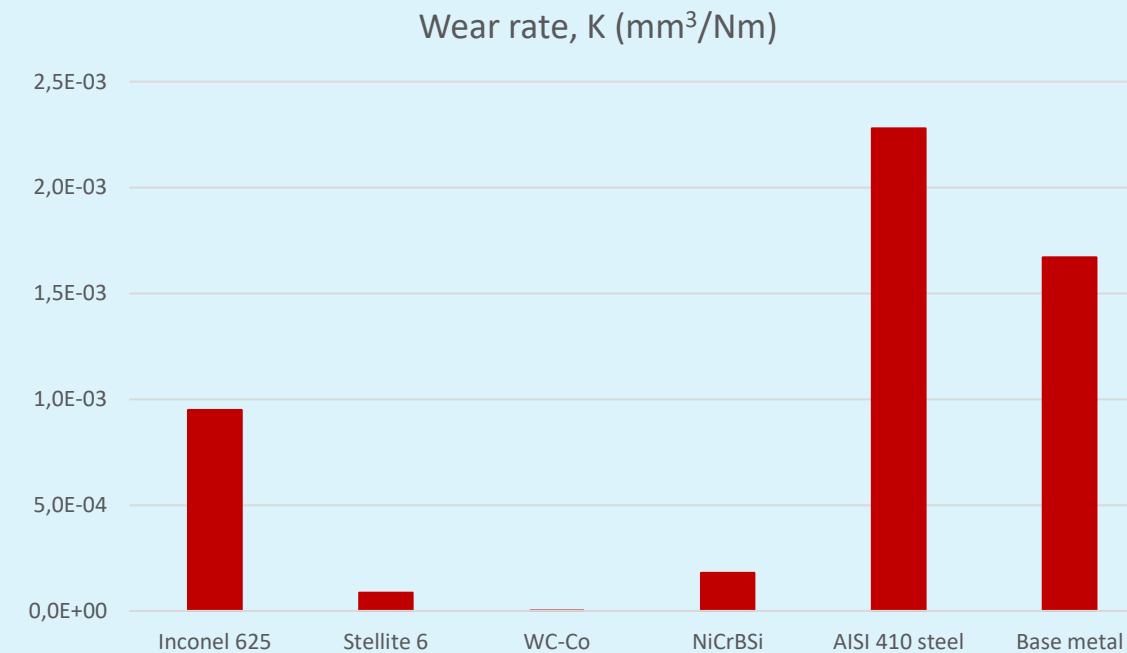
CORROSION- AND WEAR-RESISTANT COATING

NDT inspection



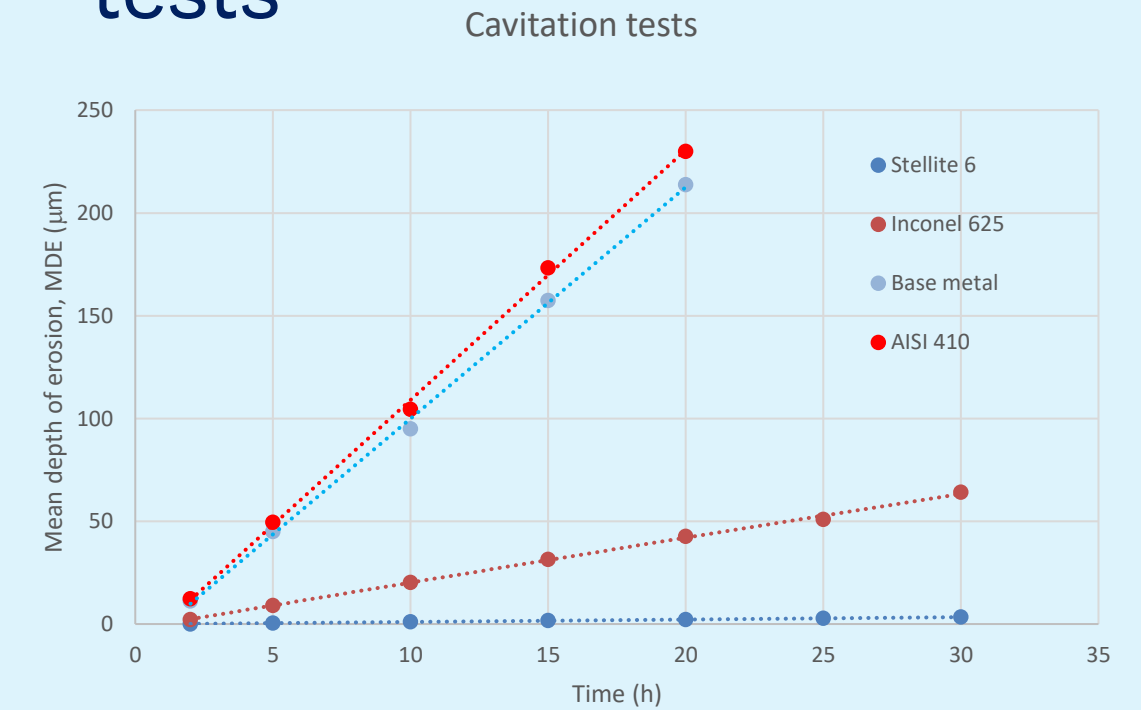
- WC-Co >> extensive porosity
- NiCrBSi >> extensive cracking

Wear tests



- All coatings show better wear behaviour than base metal, except AISI 410 steel

Cavitation corrosion tests



- Stellite 6 and Inconel 625 meet the required improvement in cavitation performance than base metal.
- AISI 410 steel shows similar behaviour.

Innovation in Turbine Refurbishment

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Patch design to improve runner performance under low-flow conditions

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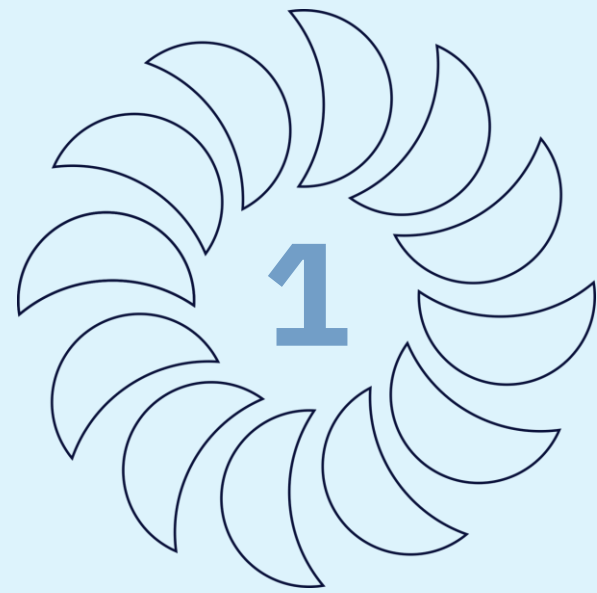
Patch fabrication by laser additive manufacturing
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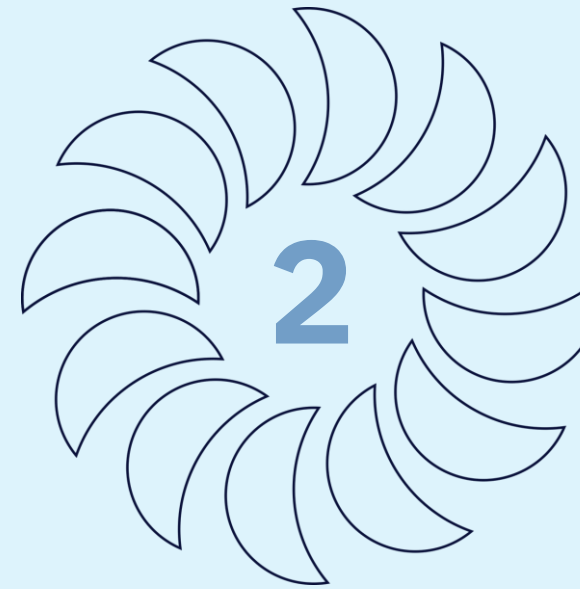
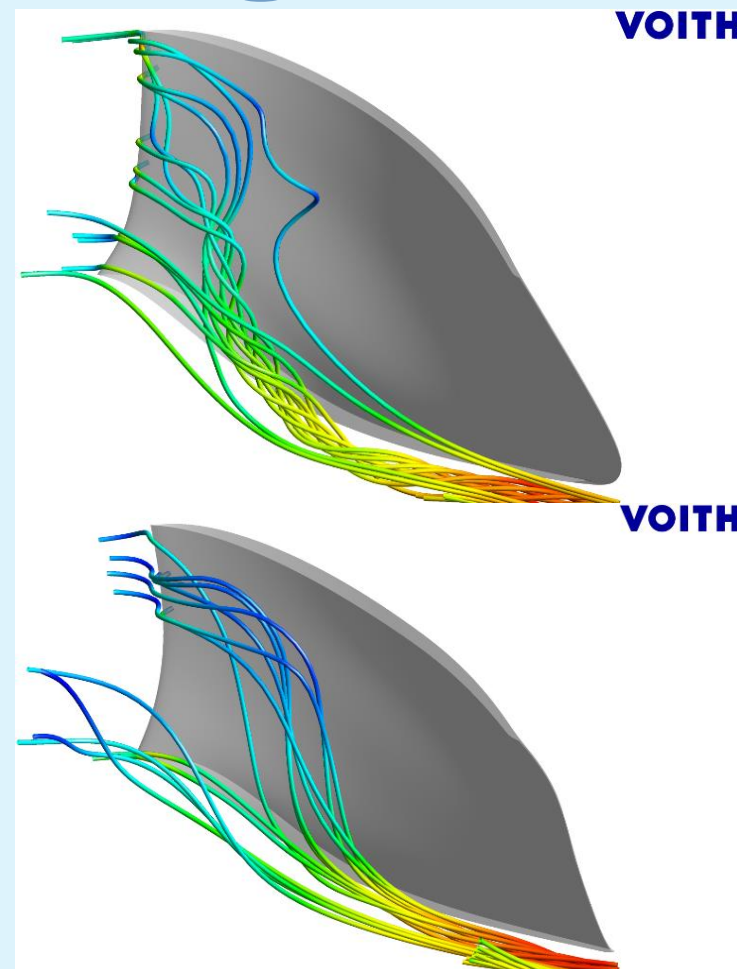
Voith Hydro – Turbine manufacturer

Flexibility towards part load:
“0 – 100 % load” – operation

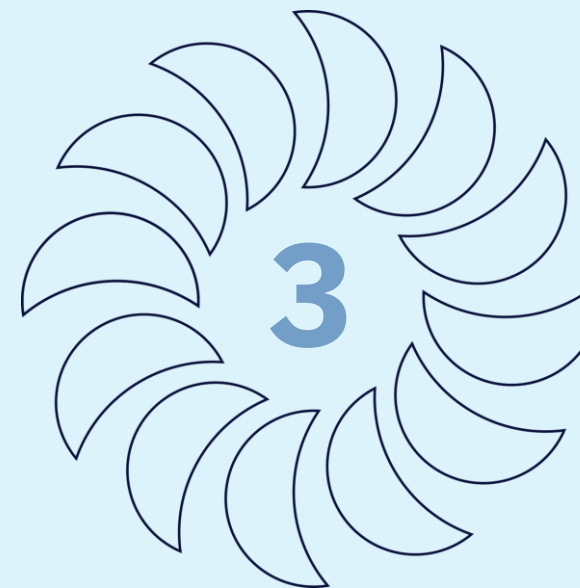
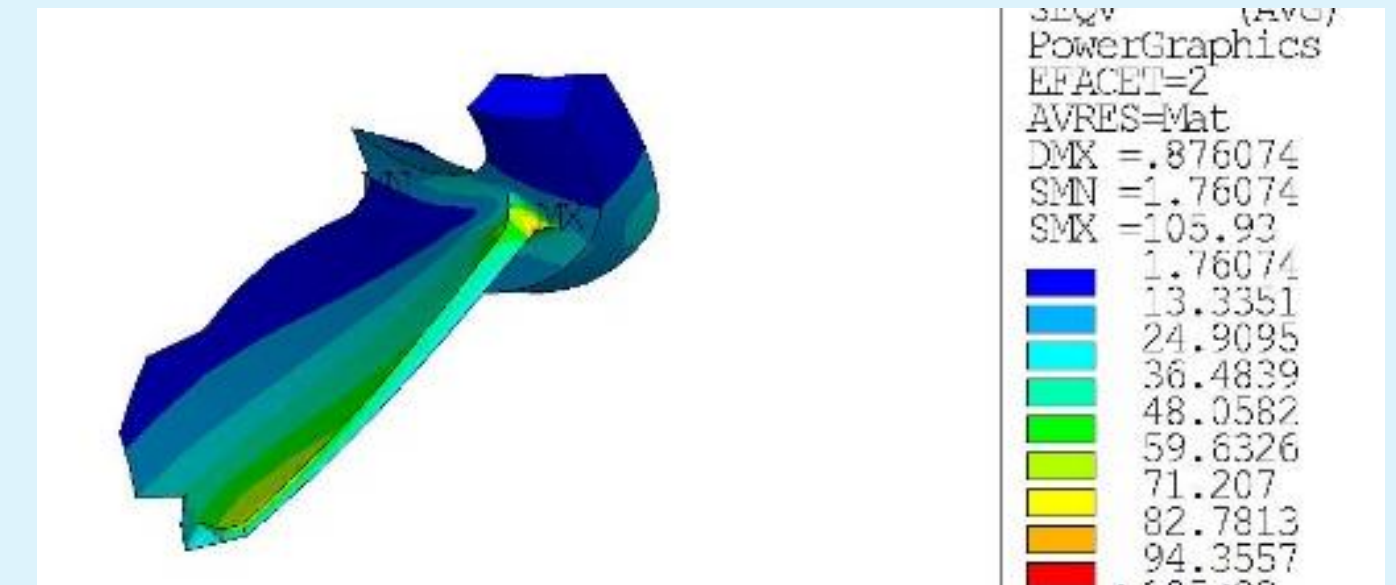
Voith Hydro's approach towards 0 – 100 % load:



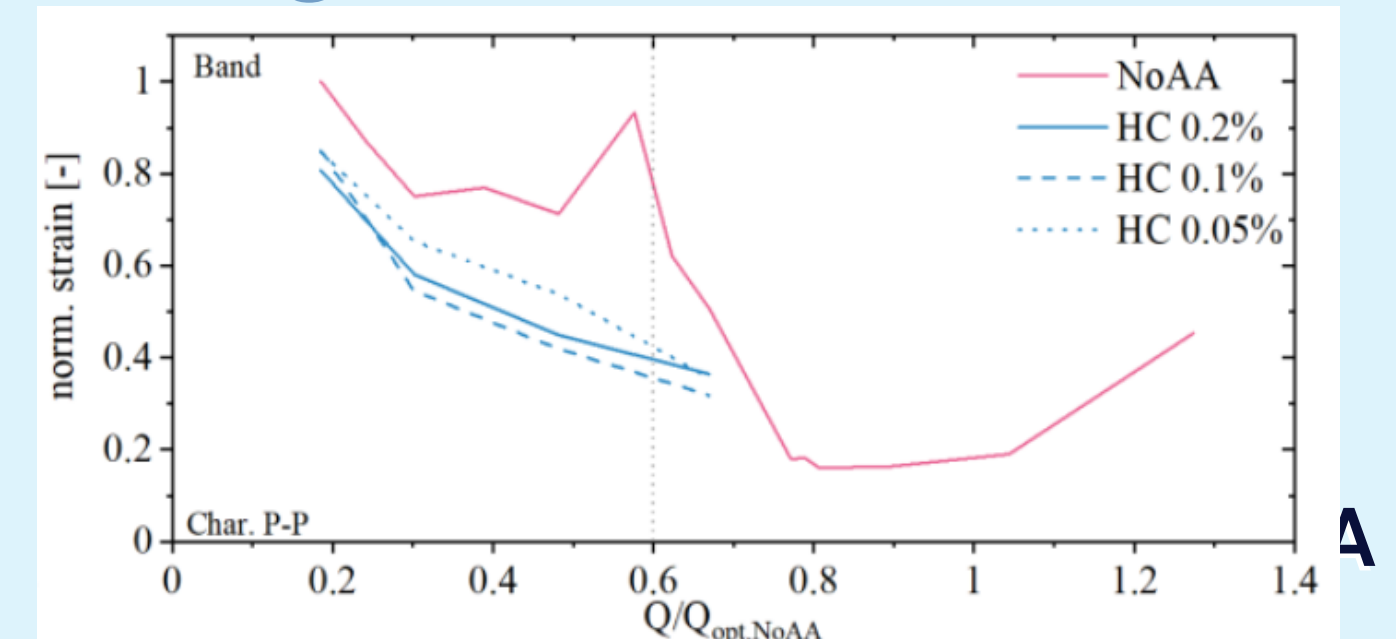
Hydraulic tailored design



Structural robust design

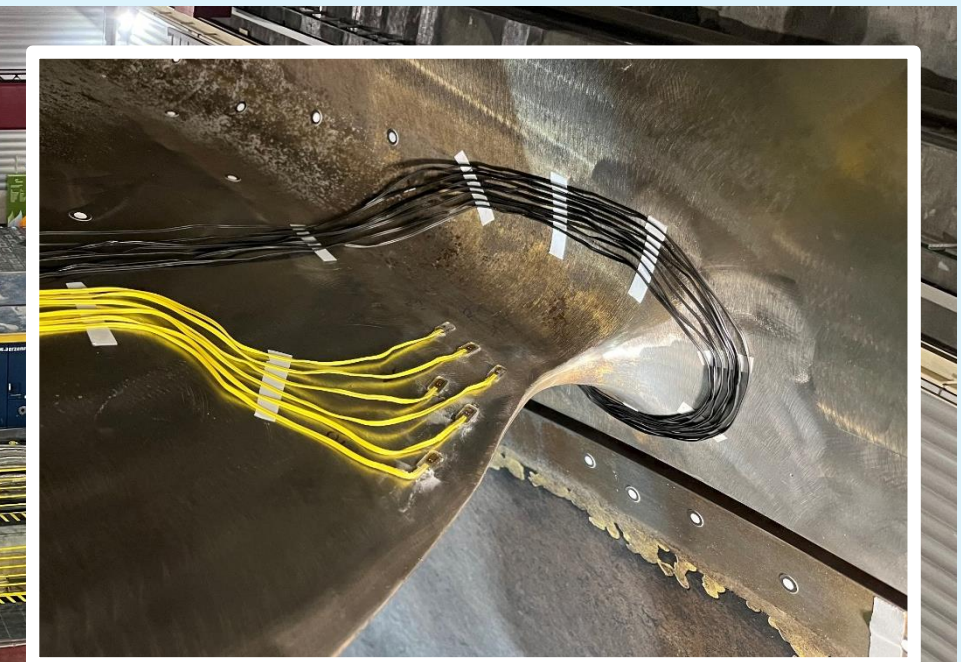
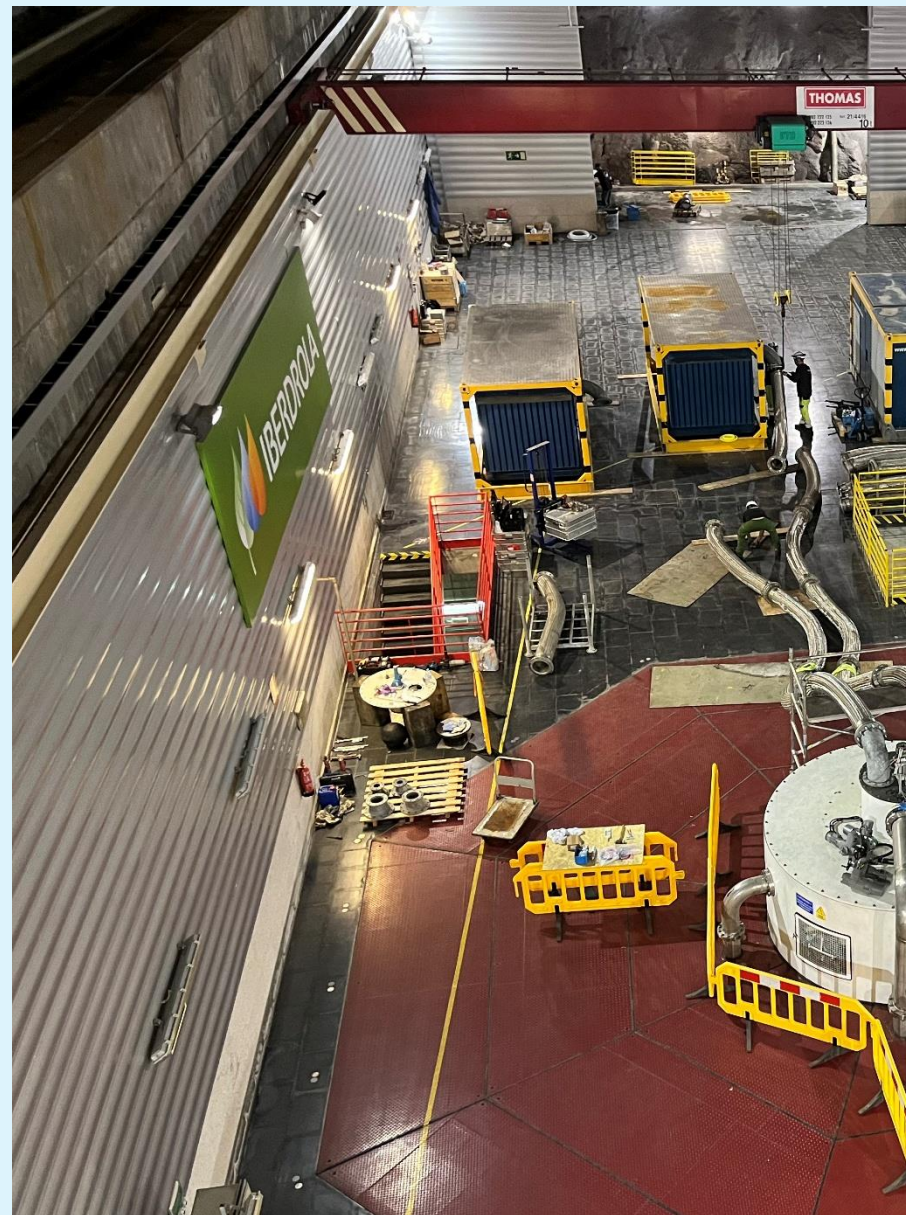
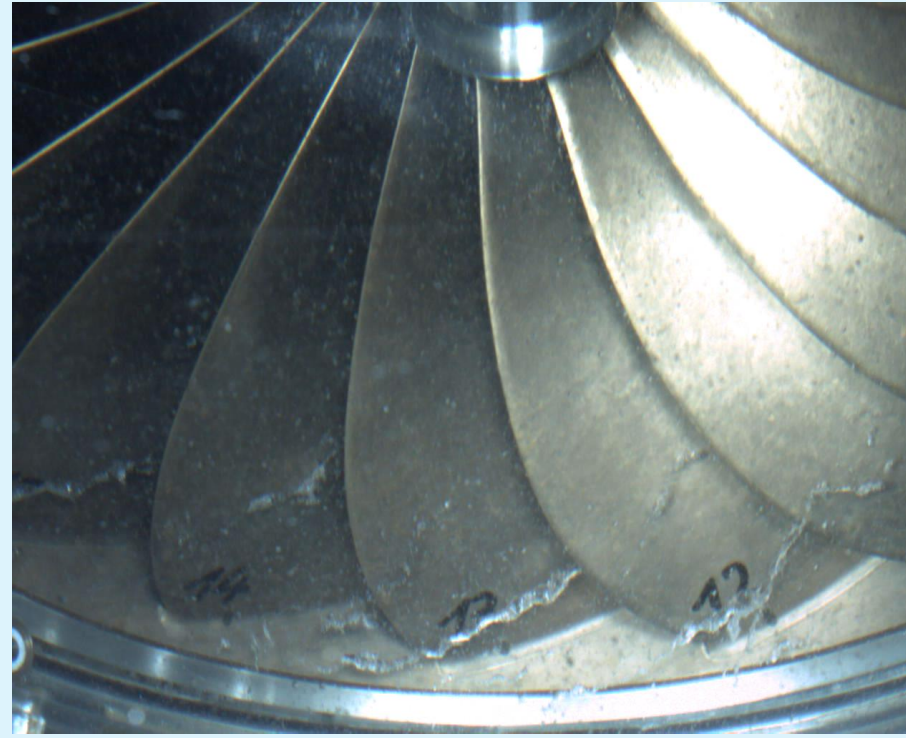


Prototype mitigations



SHERPA covers these three aspects:

1. Model design development for 0 – 100 % runner
2. Correlation of measurements from prototype and model
3. Influence of aeration in prototype



Take aways

- Voith Hydro with intensive Research and Development on flexible operation
- Comprehensive approach:
 - Hydraulic AND Structural Design
 - Prototype AND Model tests
- SHERPA as ideal environment



Smarter Hydropower: Digital Twins in Operation

Alberto González de la Torre – Mechanical Engineer (Innomerics)



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INDEX

1. Innometrics in SHERPA
2. Application overview
3. 3D Models
4. Data Repositories
5. Sensor Data
6. Digital Twin

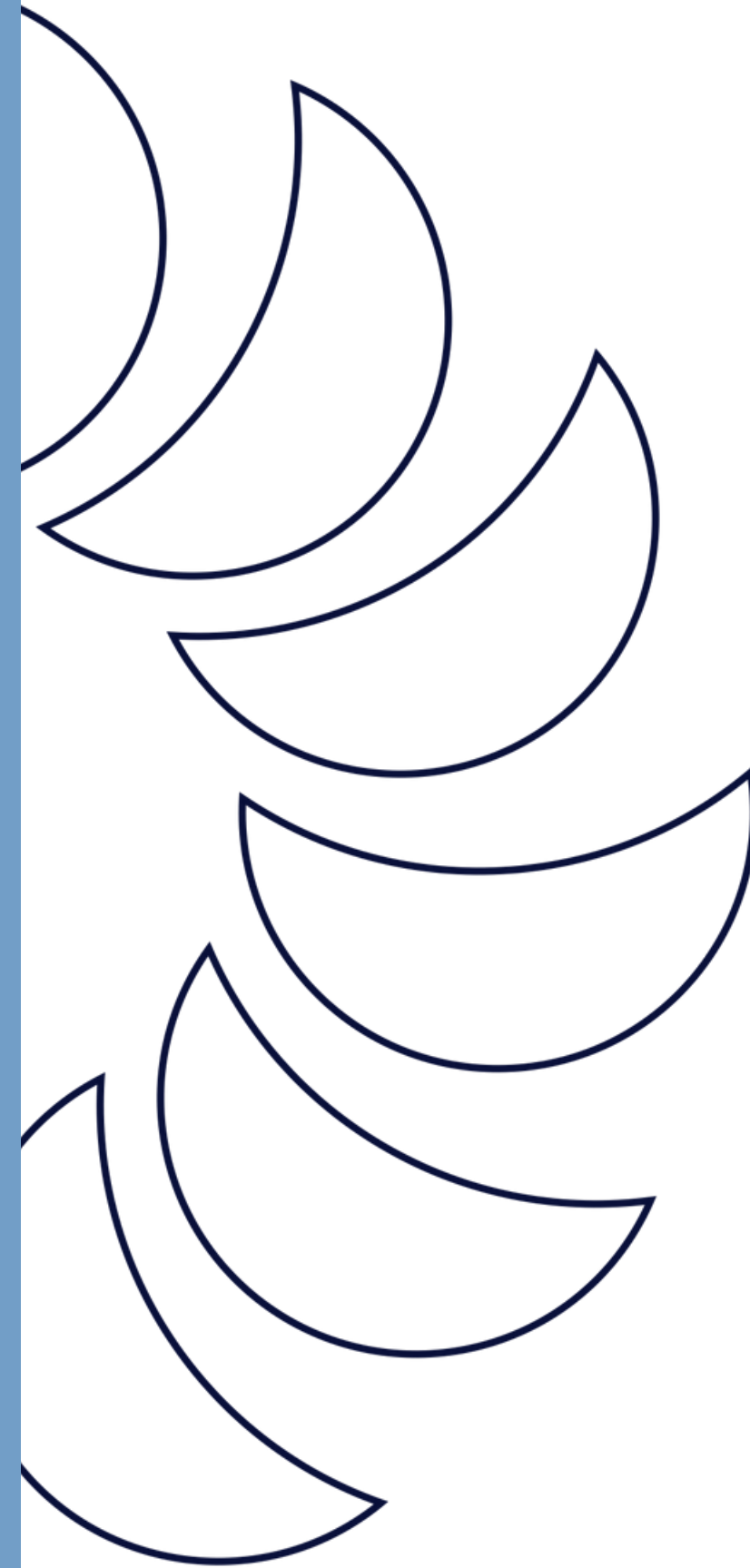


Innomerics in SHERPA

Innomerics' work in SHERPA is centered on the behavior of Francis turbines operating far from their design point.

Two lines advance in parallel: high-fidelity simulation of the flow through the machine, and instrumentation able to measure what happens inside it while the unit is generating.

Both converge in pamONE, the Innomerics application in which models, measurements and technical information of the plant are handled from a single interface. The work is being carried out on one of the main units of the Daivões hydroelectric power plant.



Application overview

pamONE is a modular, 3D model-based web platform that integrates different types of information about a power plant: its geometry, its technical documentation, sensor data acquired during operation, and the physics-based simulation of its behavior.

At the Daivões hydroelectric power plant, it is being used to monitor and simulate the behavior of one of the main turbines when it operates far from its design point. The platform is built on four blocks, each covered in the rest of this presentation.

3D Models

High-fidelity representation of the geometry of the plant and its components.

Data Repositories

Static data that characterize the design of the machine.

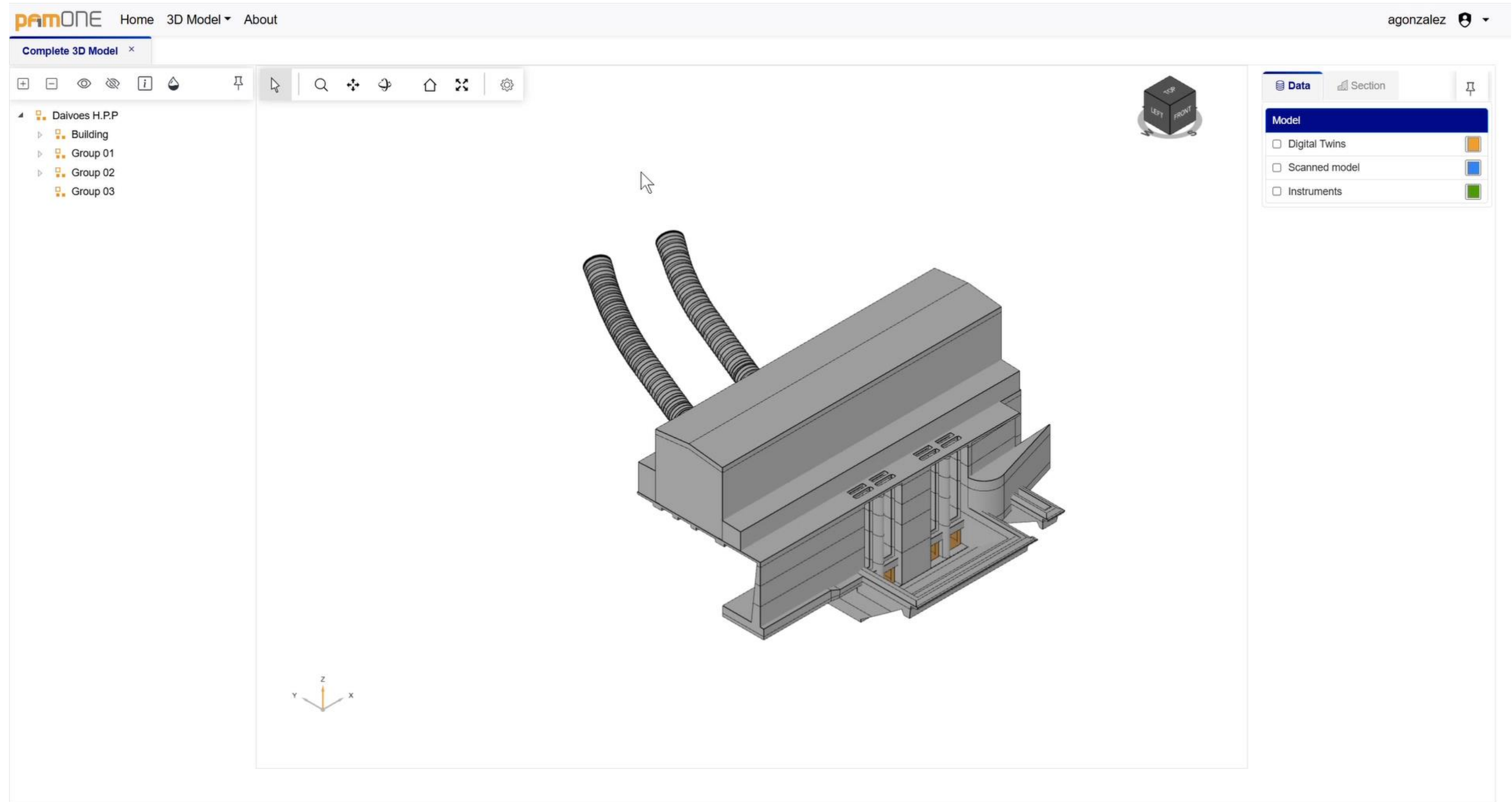
Sensor Data

Dynamic data that characterize its state during operation.

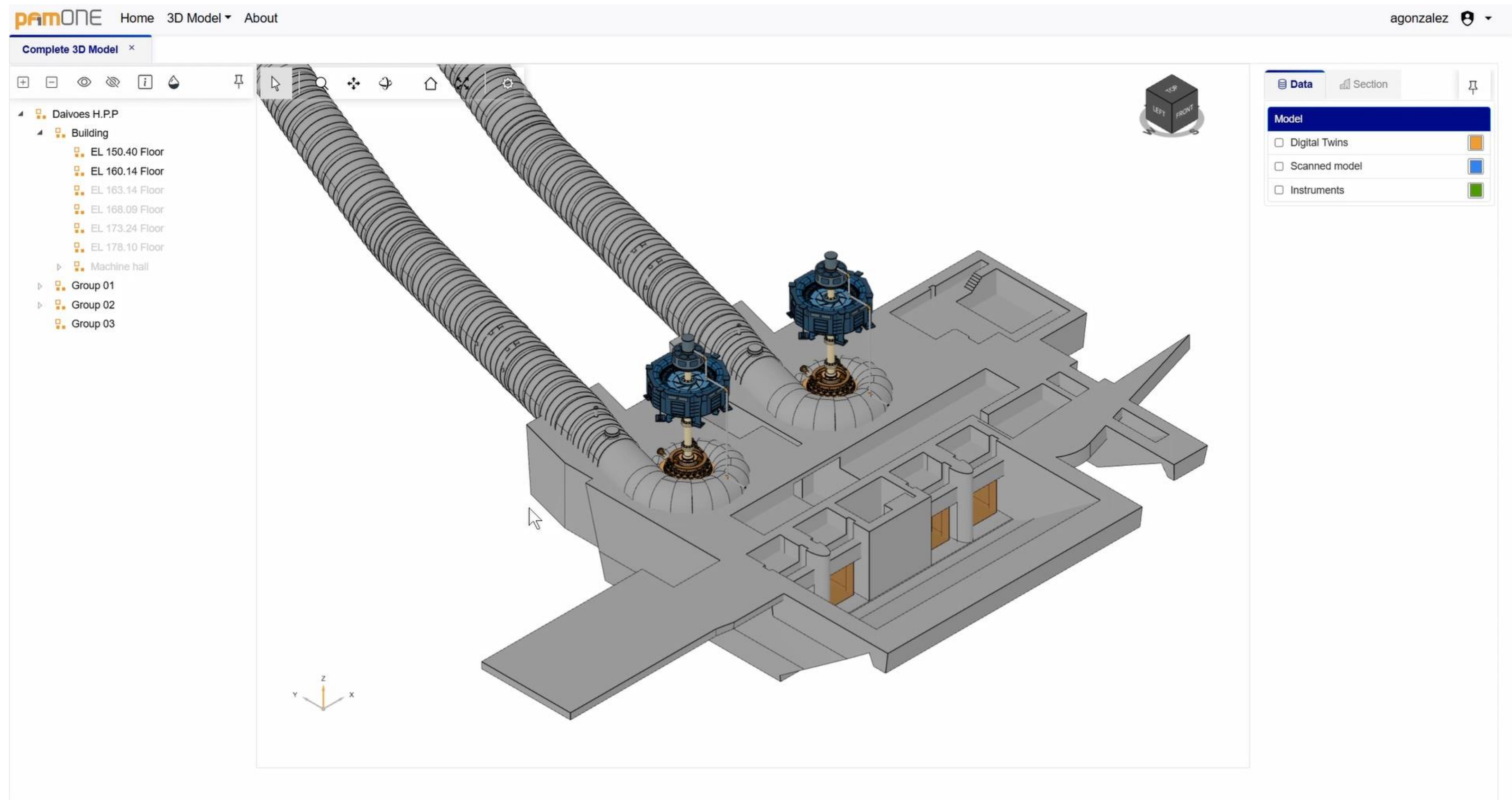
Digital Twin

Physics engine that reproduces its behavior and calculates variables that are not measured directly.

3D Models



Data Repositories



Sensor Data

Non-invasive monitoring system

Innomerics has developed and installed at the Daivões hydroelectric power plant a non-invasive monitoring system that complements the data already available from the plant's instrumentation.

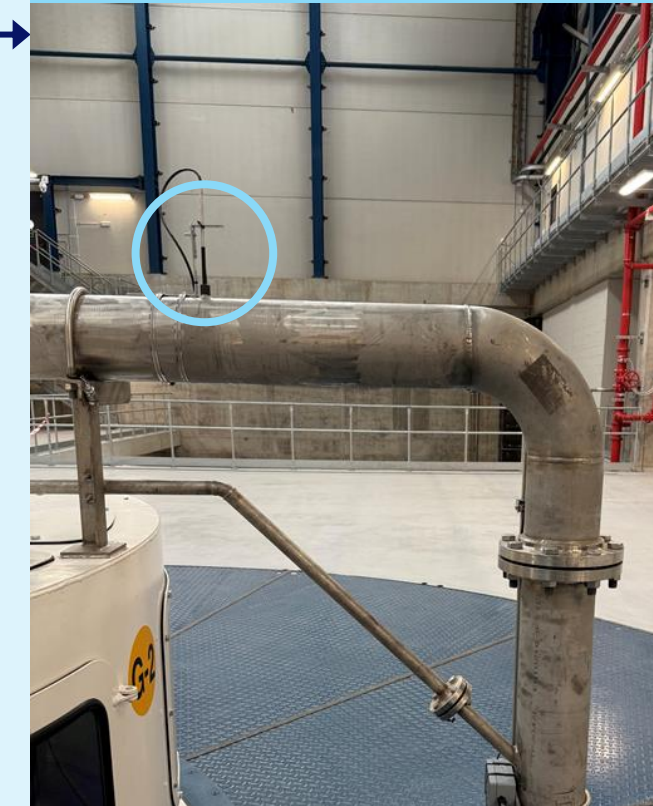
The system adapts to any plant and any environment, it is compatible with any type of sensor, and its satellite connection allows the recorded data to be transferred out of the plant in real time. These measurements are incorporated into pamONE, where they feed the physics-based digital twin simulations.



Generator Accelerometers



Aeration flow rate Sensor



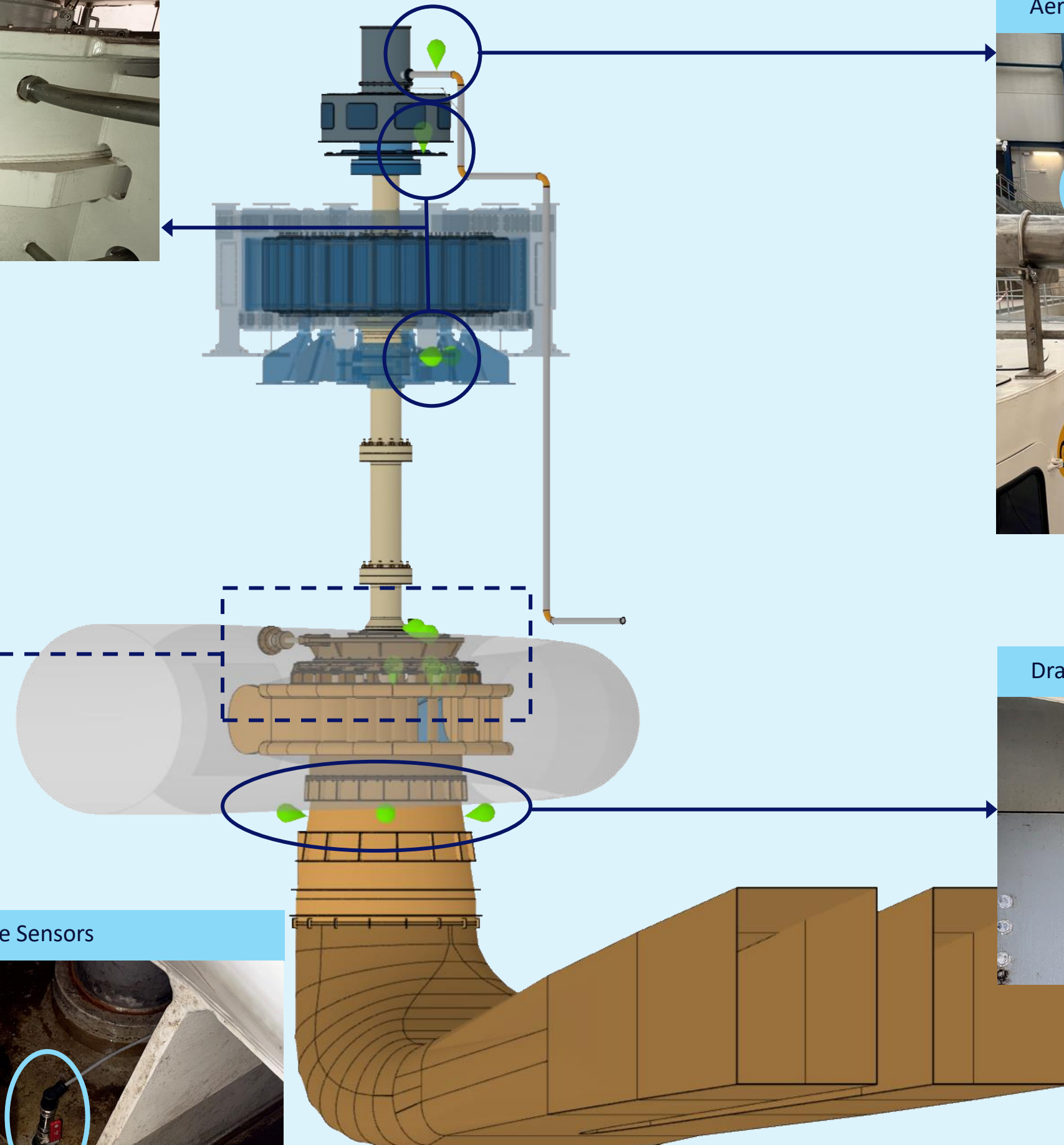
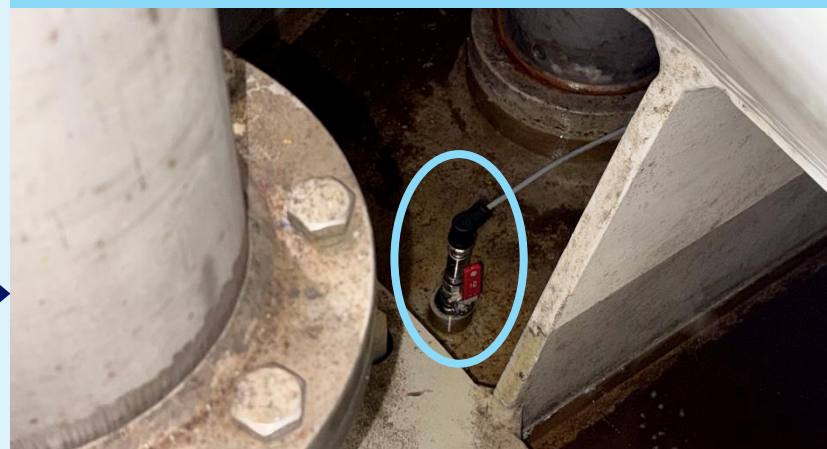
Head Cover Accelerometers



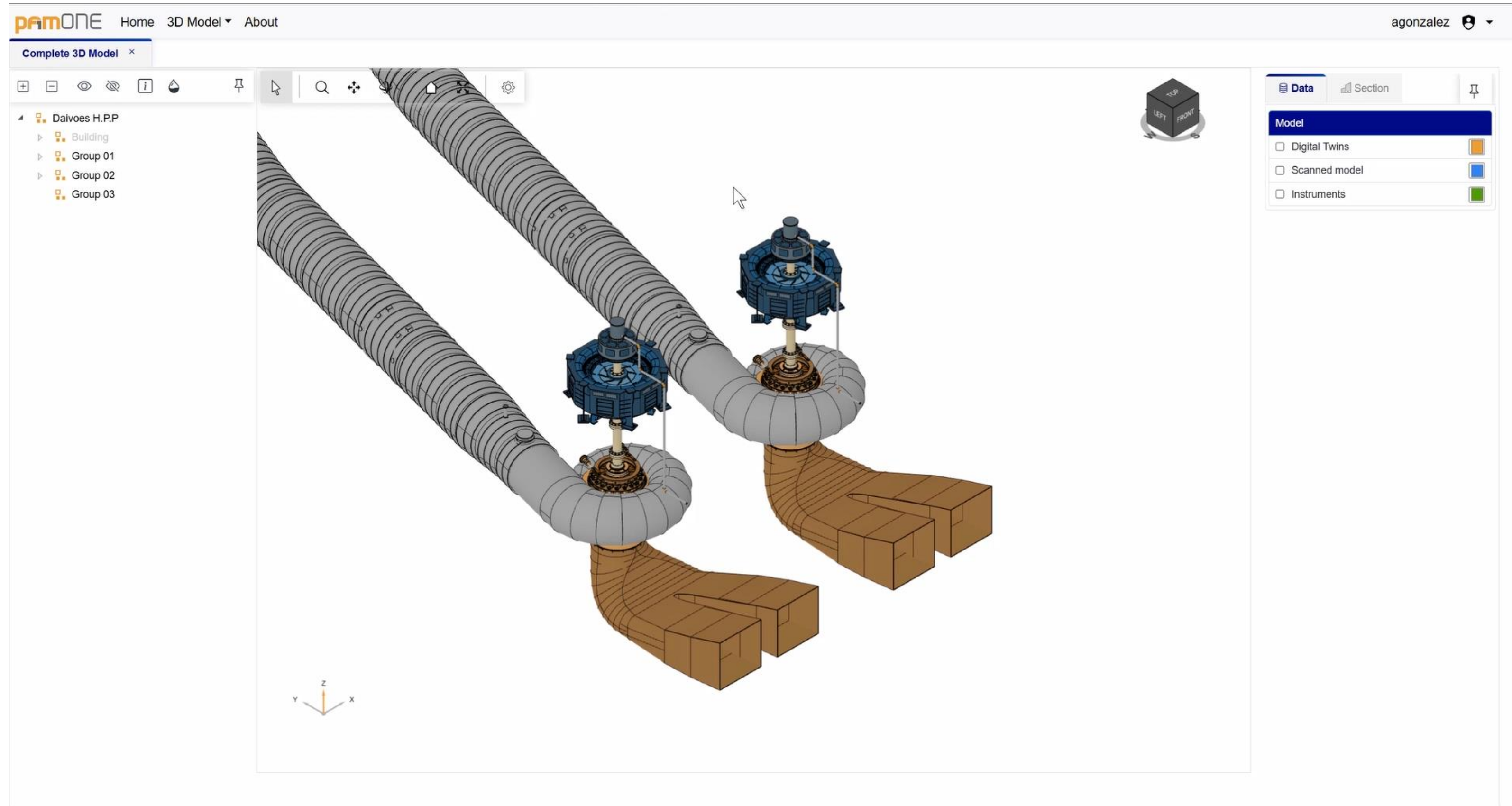
Draft Tube Cone Pressure Sensor



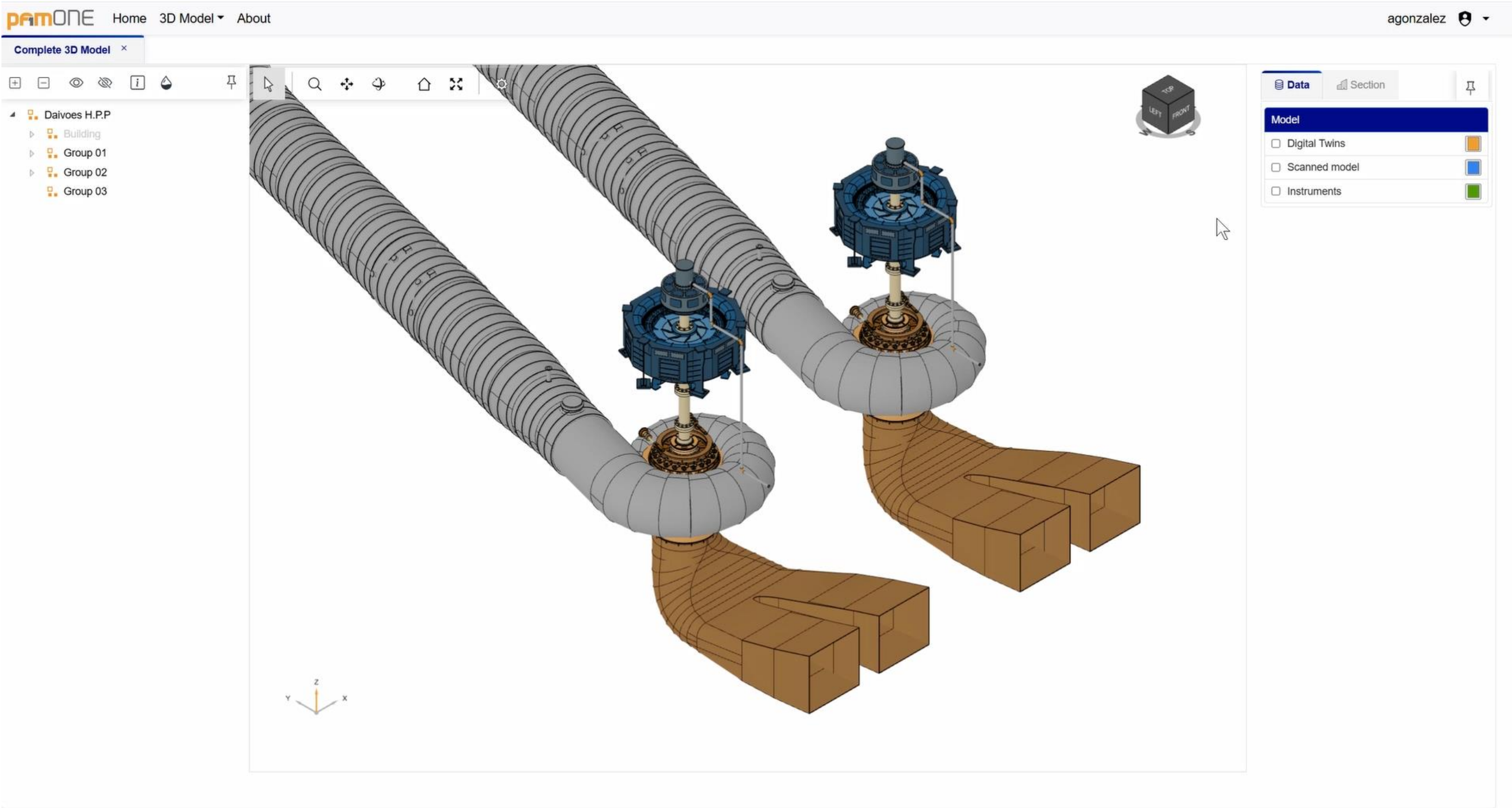
Head Cover Pressure Sensors



Sensor Data



Digital Twin





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Enhancing Biodiversity and Ecosystem Services

Nicolás Marx – EU Renewables Technology Leader (EPRI Europe)

Marta Arenas Romasanta – Senior Environmental and Social Impact Advisor (AECOM)

Montserrat Real – Technical Director of the Aquatic Ecology Laboratory (AECOM)



AECOM



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INDEX

1. Dissolved oxygen optimization as a key ecological driver
2. Biological responses to oxygen conditions
3. Modelling and monitoring to assess oxygen content
4. Long-term effect on biodiversity, ecosystem services and the society



Dissolved Oxygen



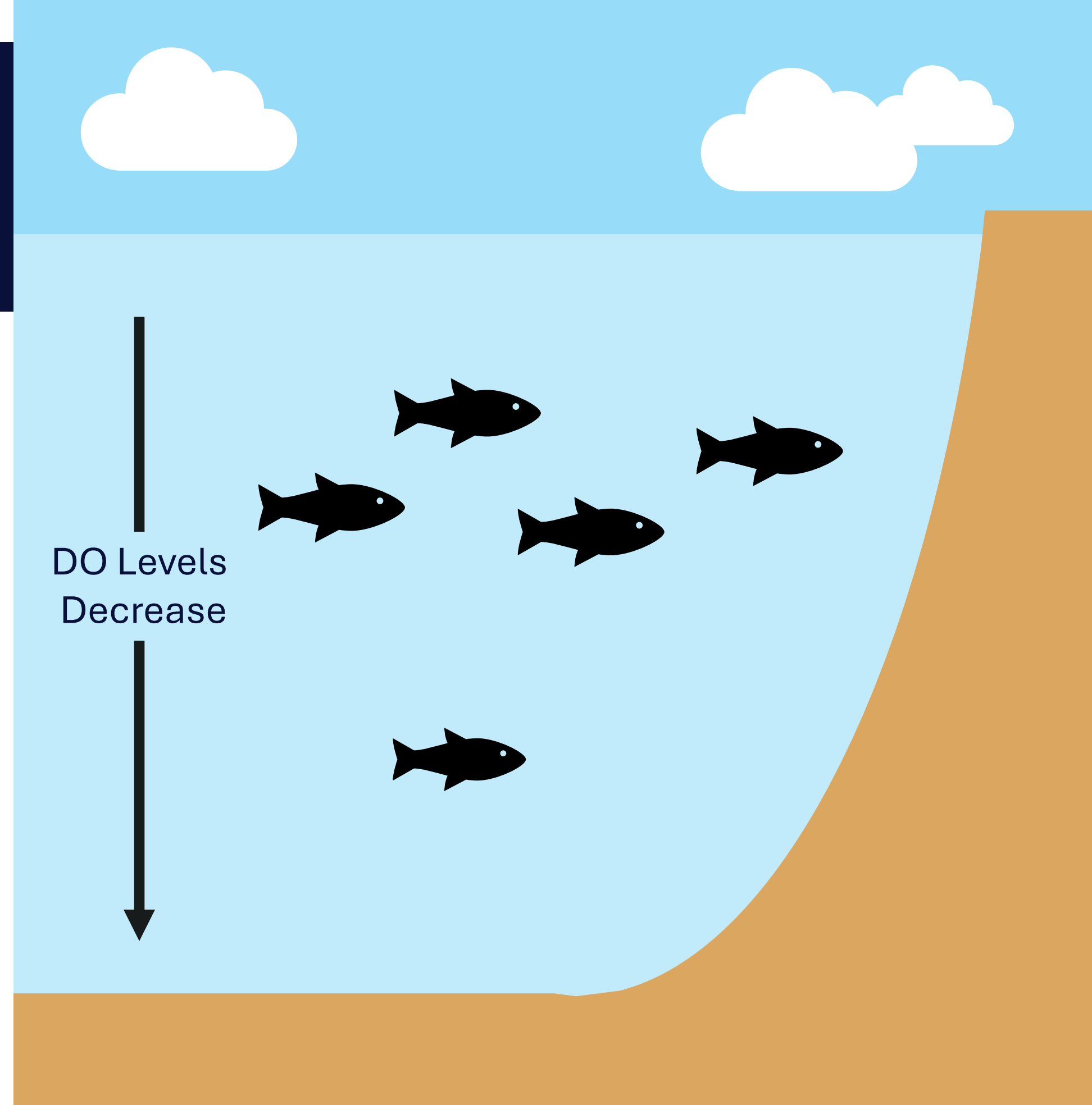
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What is Dissolved Oxygen?

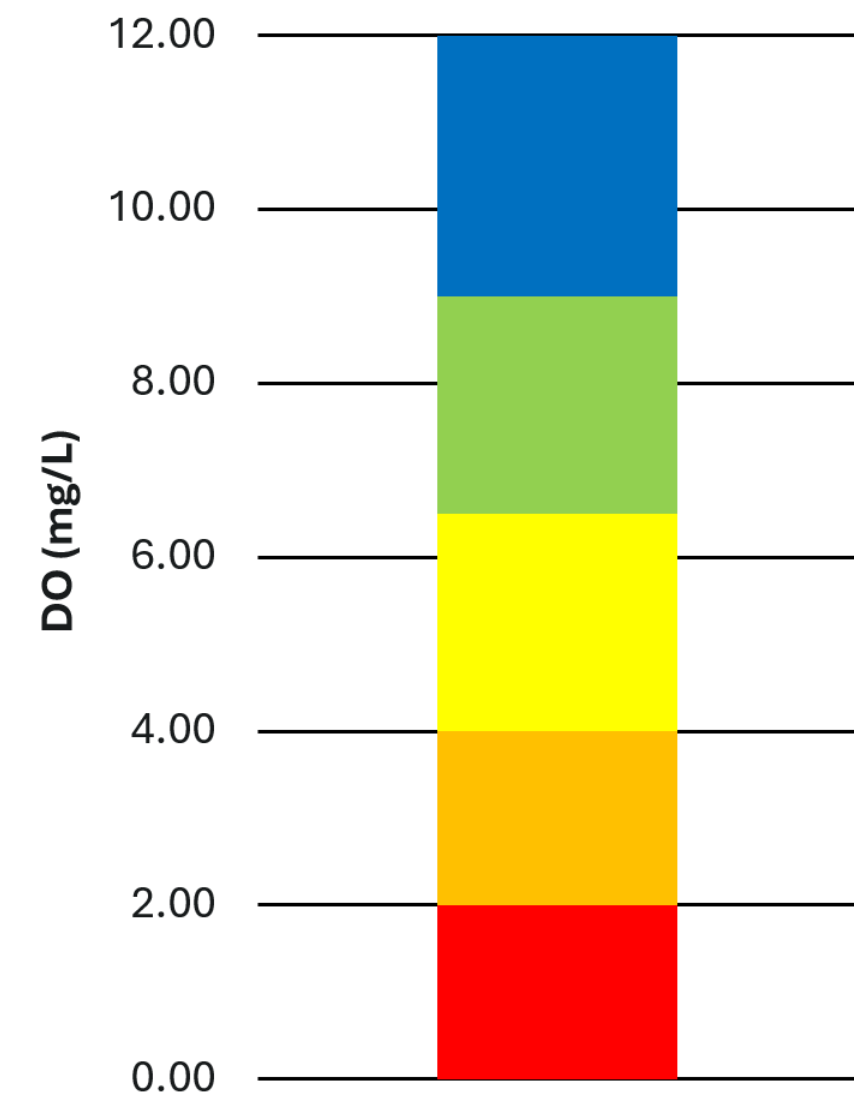
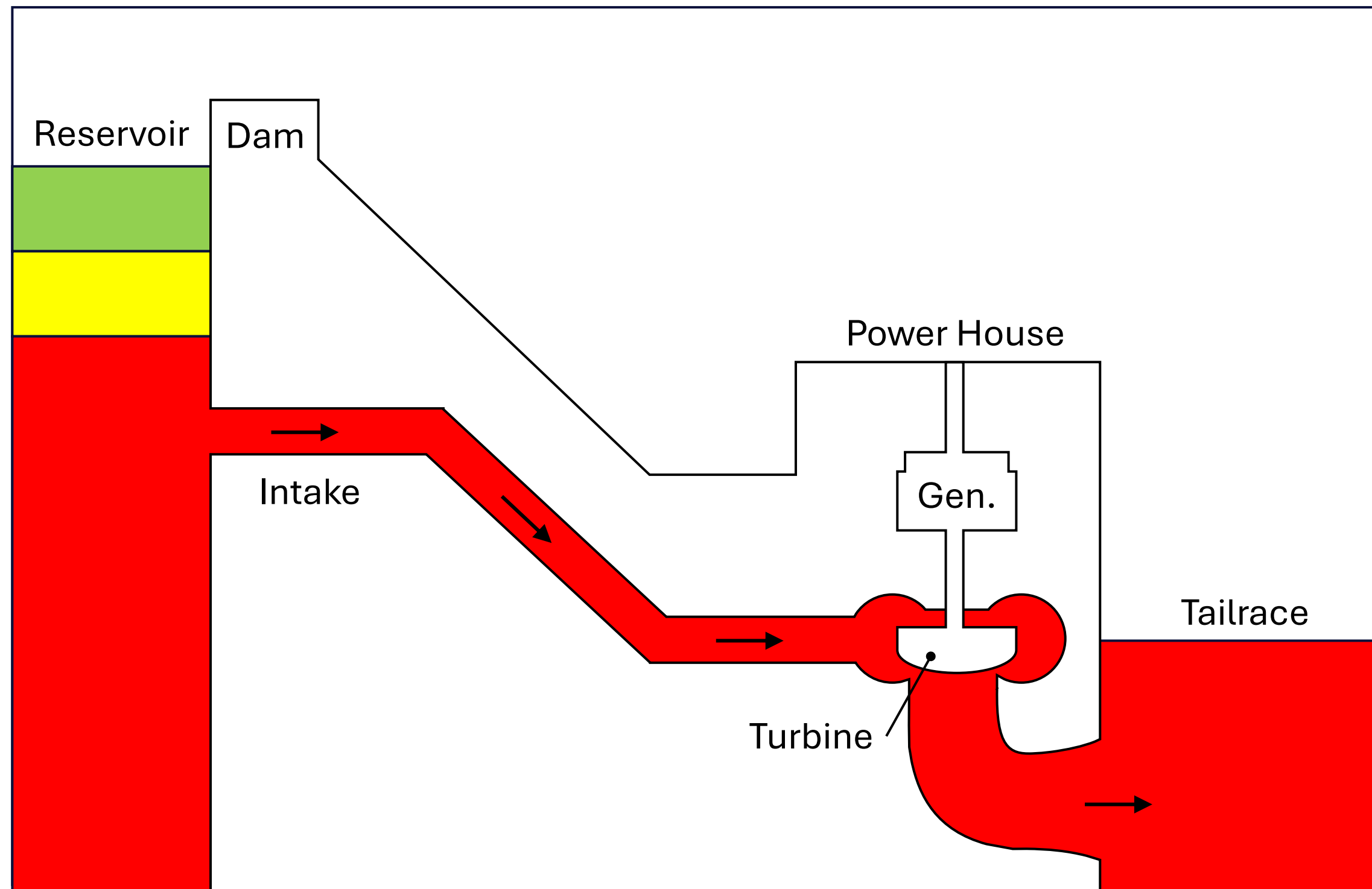
Dissolved oxygen (DO) is the free oxygen (O_2) present in water.

It is the oxygen aquatic organisms use for respiration.

DO is a core indicator of water quality and ecosystem health.



Hydropower and its Effect on DO Levels





Aeration and Oxygenation Strategies



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15 technologies
assessed



Aspirating Aerator



Floating Surface Aerator



Speece Cone



Line Diffuser



Membrane Diffuser



Weirs



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Three Criteria for Classifying Strategies

01 Location



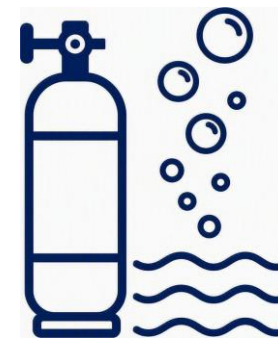
Where the technology is installed

Upstream in the reservoir, above the dam

Powerhouse within the turbine passage

Downstream in the tailrace or receiving river

02 Gas Type

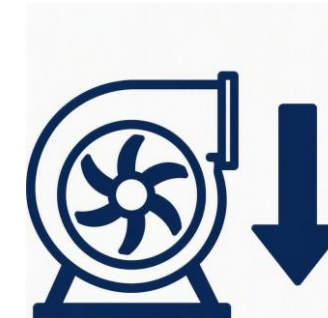


Which gas is delivered to the water

Air – aeration ambient air, no gas supply needed. Limited by Nitrogen concentration.

Oxygen – oxygenation higher transfer efficiency, requires an oxygen supply

03 Driving Force



How the gas is moved into the water

Natural driven by existing head or sub-atmospheric pressure, no added energy

Forced blowers, compressors or pumps supply the gas

THE PROBLEM WE TRY TO SOLVE

Which strategy raises dissolved oxygen most effectively at this specific hydropower plant?

Every site differs in DO deficit, head, geographical constraints, hydraulics, operating regime and economics –no single best technology or combination.

No common framework

Owners and operators have no consistent way to evaluate DO enhancement options.

Site-specific complexity

Stratification, hydraulics, plant design and local constraints all shape what works.

Need for unbiased comparison

Technologies must be assessed comprehensively and on equal terms, not case by case.



Aeration System Optimization Framework

An multi-step optimization tool under dynamic constrains that identifies the optimal combination of aeration technologies for a given plant.

Site characteristics

Head, flow, DO deficit, plant layout and operating regime define what is feasible on site. Account for multiple constrains.

Technology interactions

Strategies used together influence each other's transfer efficiency, so they are assessed as a system.

Optimal combination

The mix of technologies that meets the DO target at the lowest total cost.

Biological responses to oxygen conditions



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Oxygen impacts downstream of dams

Hydropower transforms river ecosystems

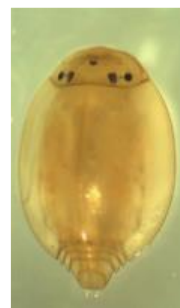
- Changes in oxygen conditions and habitats

Biological responses downstream of dams

- Low oxygen conditions → diversity ↓ tolerant species ↑



Outlet withdrawal



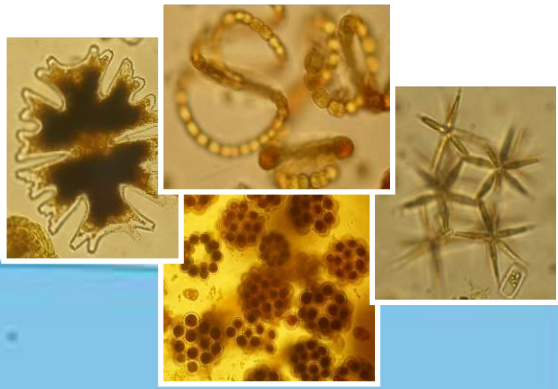
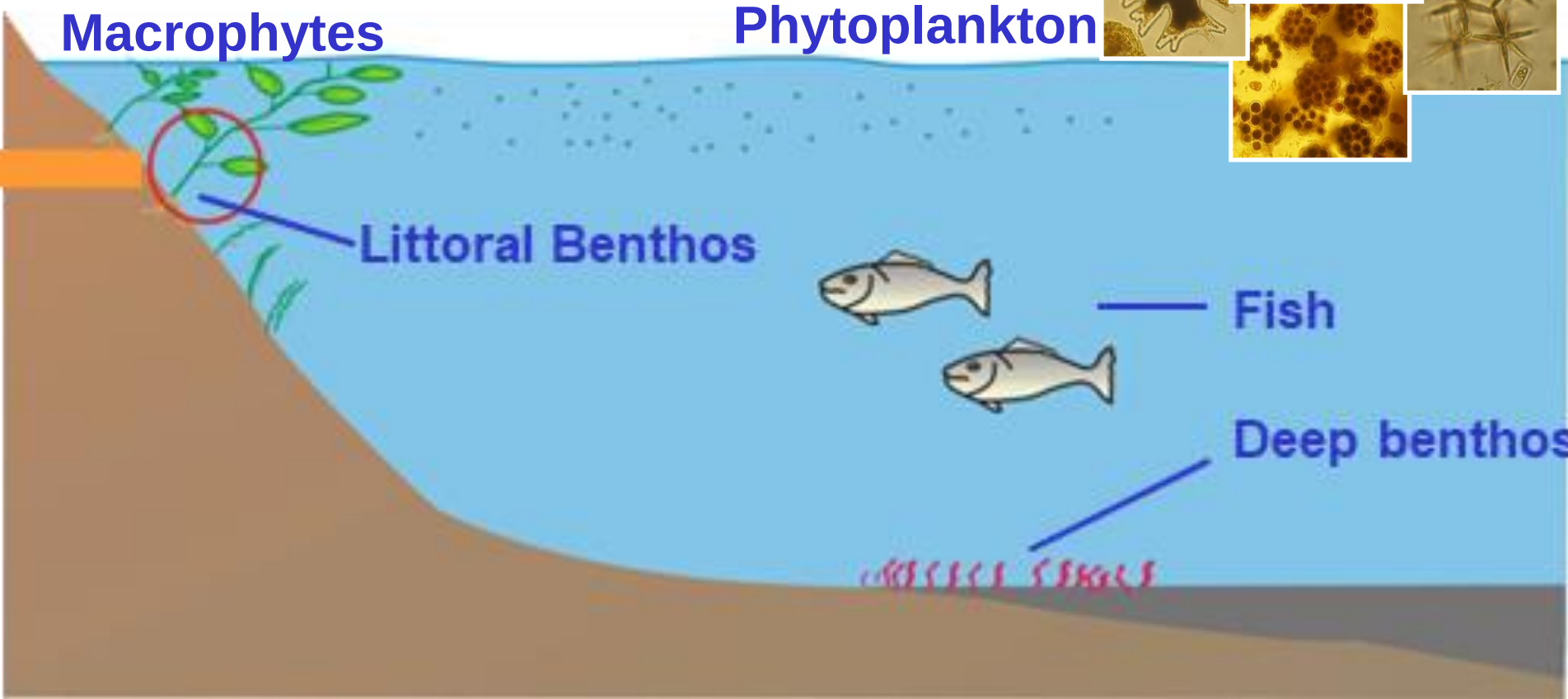
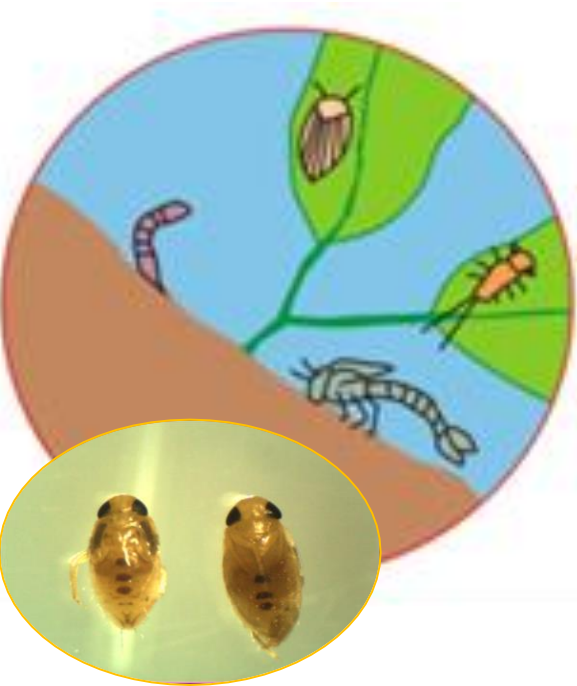
Sensitive species



Tolerant species

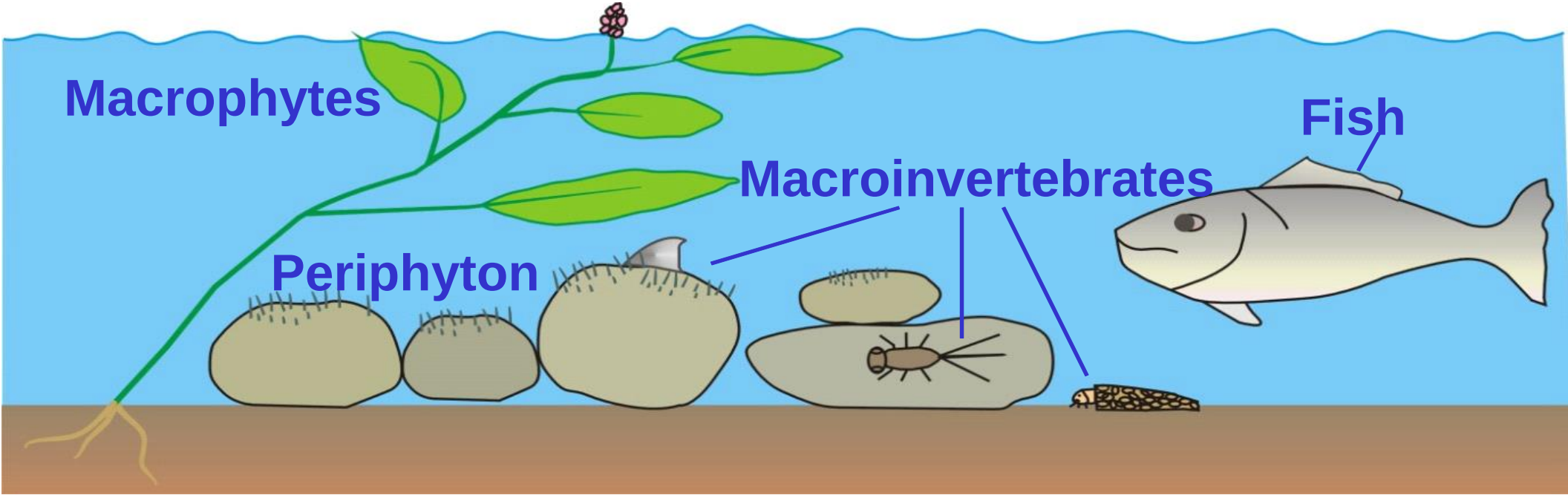


Biological indicators of oxygen conditions

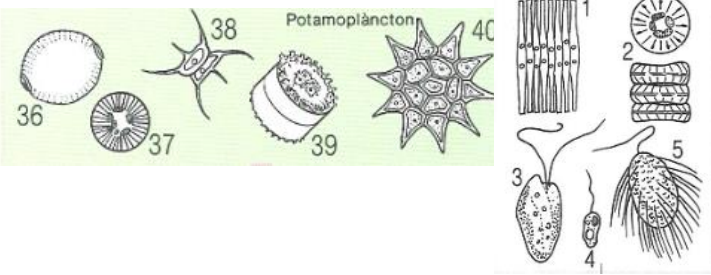


Zooplankton

Reservoir



Potamoplankton



Downstream river



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Modelling and monitoring to assess oxygen content



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Integrating Monitoring, Biology and Modelling

Telemetry

- Autonomous floating devices, real-time, continuous, multi-depth data, at key locations
- Key parameters: oxygen, temperature, turbidity

Field surveys

- Detailed snapshots in time to validate telemetry data

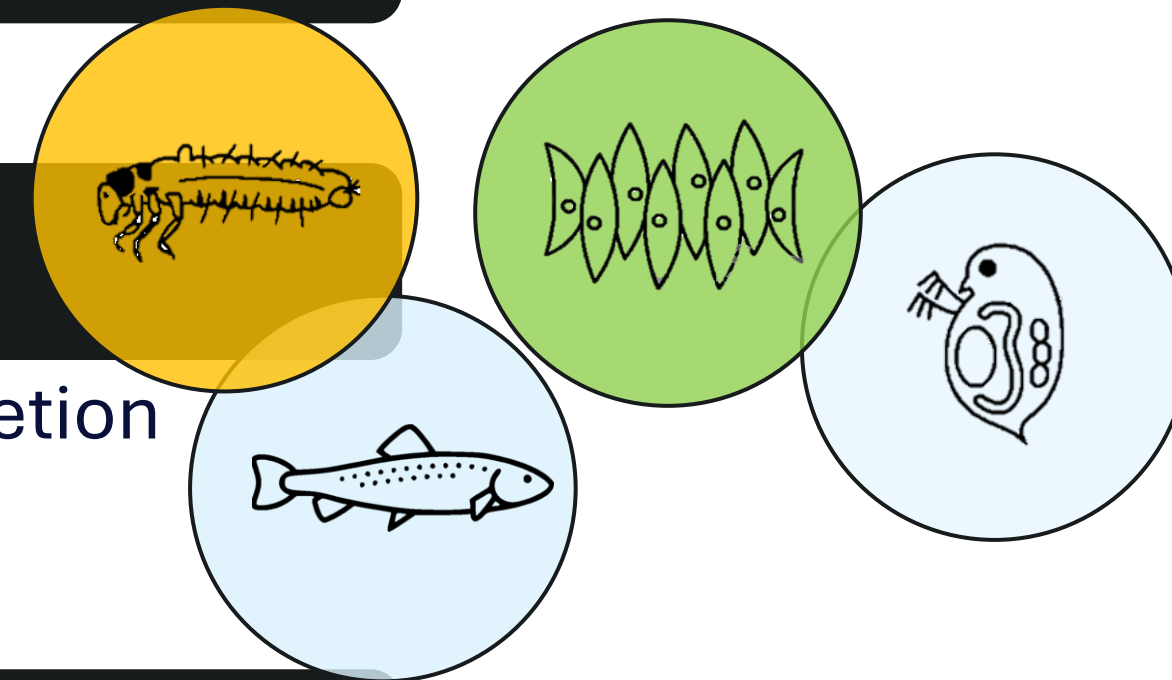
Biological monitoring

- Seasonal comparison: well-oxygenated (early spring) vs oxygen depletion conditions (late summer)
- Assess biological response (metrics, indexes, eDNA)

Modelling

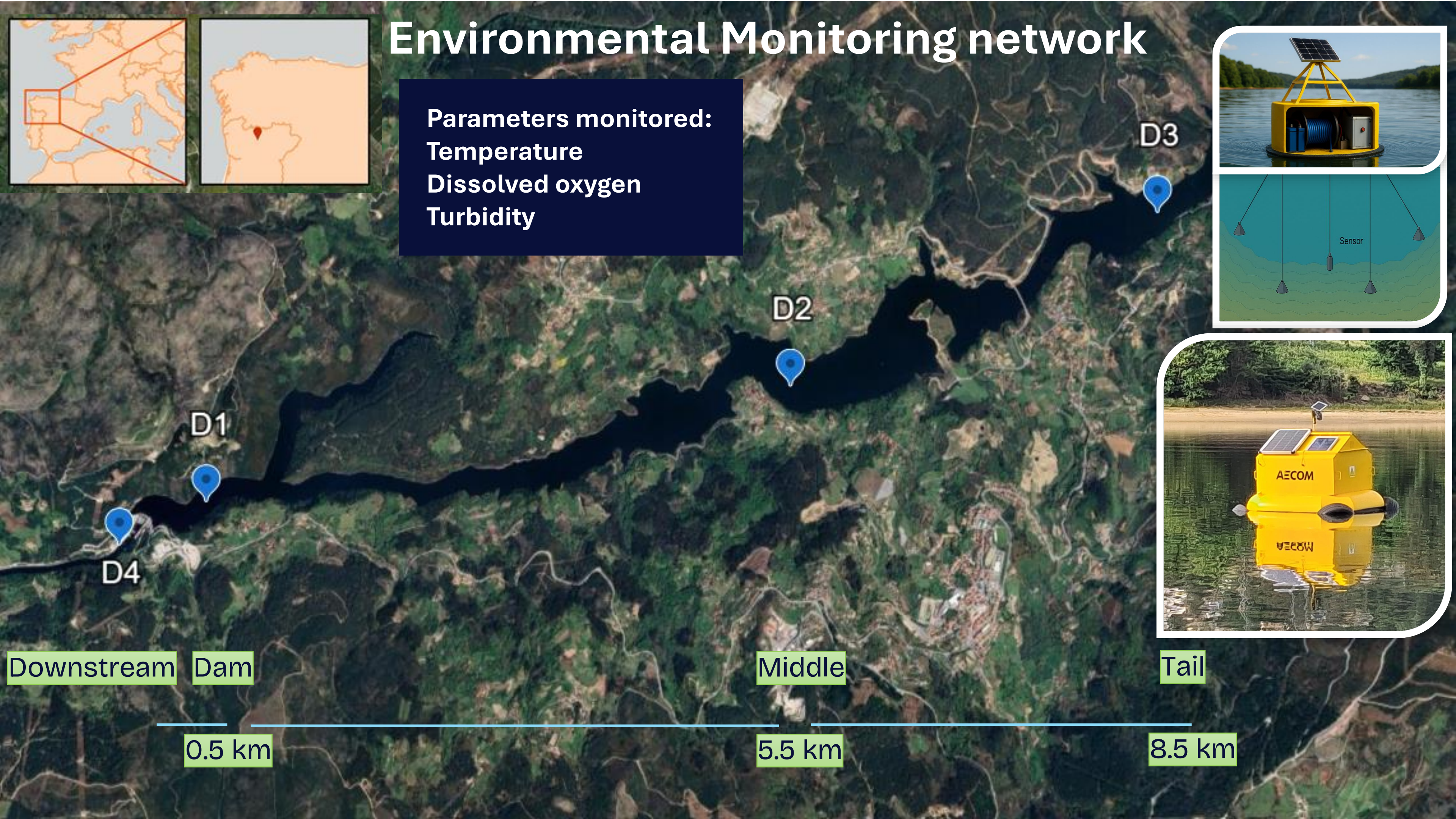
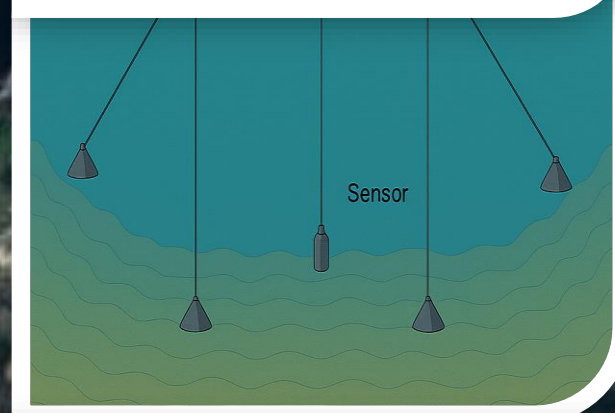
- Supports operations & management
- Improves: oxygen management strategies

**Combining monitoring +
biology + modelling:
ecosystem response to
oxygen dynamics**



Environmental Monitoring network

Parameters monitored:
Temperature
Dissolved oxygen
Turbidity



D4

D1

D2

D3

Downstream

Dam

Middle

Tail

0.5 km

5.5 km

8.5 km

Forecasting Oxygen Conditions

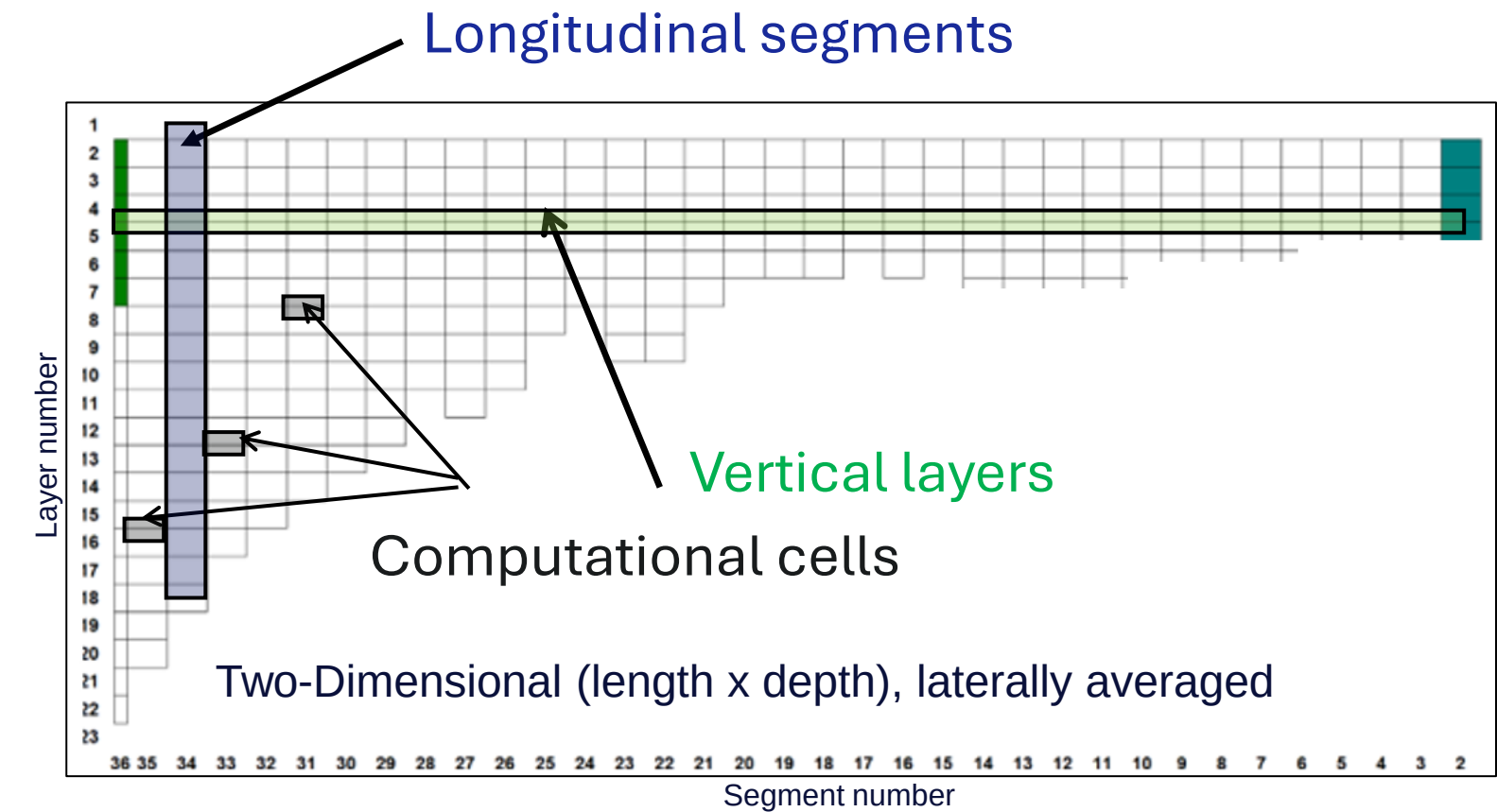
Model: CE-QUAL-W2

2D model to simulate O₂ distribution under different operations

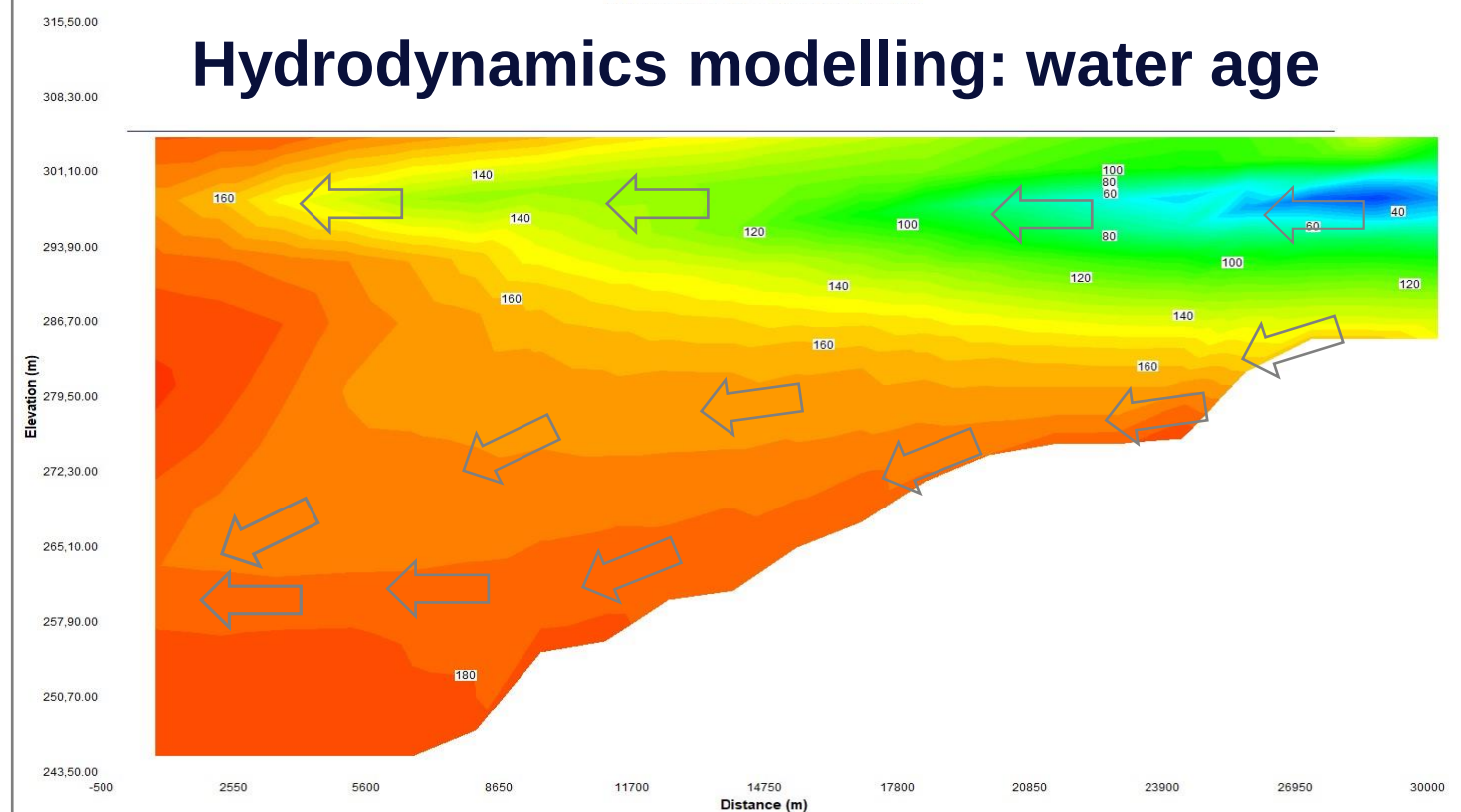
Boundary conditions:

bathymetry
oxygen consumption
hydrology
meteorology
operational conditions

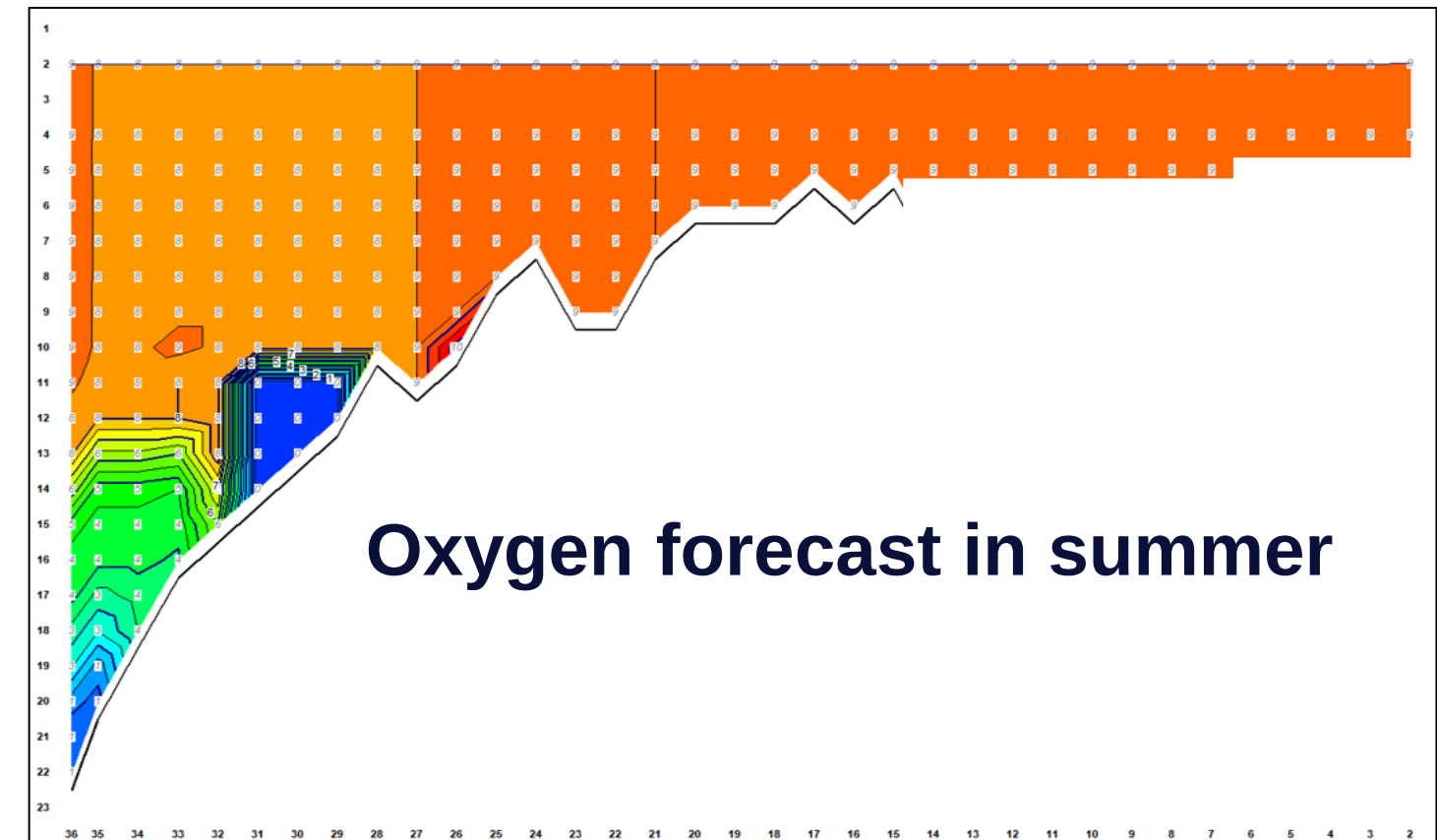
Telemetry
Hydrodynamic model
Oxygen forecast
Operational scenarios
Decision support



Hydrodynamics modelling: water age



Oxygen forecast in summer



From monitoring to decision support

Monitoring and modelling enable proactive environmental management

- Telemetry data, field data validation, existing datasets

Biological indicators reveal ecosystem responses

- Fish, invertebrates, diatoms, bacteria and eDNA
- Metrics and indexes
- Biodiversity indexes

Oxygen management can support both biodiversity and flexible hydropower operation

- Integrate oxygen into hydropower operations
- Support biodiversity and regulatory compliance
- Align energy production with environmental goals

**Monitoring, modelling,
measuring biological
responses to support
environmentally informed
hydropower management**



Biodiversity & Society



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WP6: Environmental, economic and social impact assessment and replication potential analysis

- 01 Stock, flow and ESS

Identify ecosystem services (ESS) involved in the operation of HPP (case study)
- 02 Net Positive Impact

Assessment of the effect of SHERPA on the provision and demand of ESS and social benefits

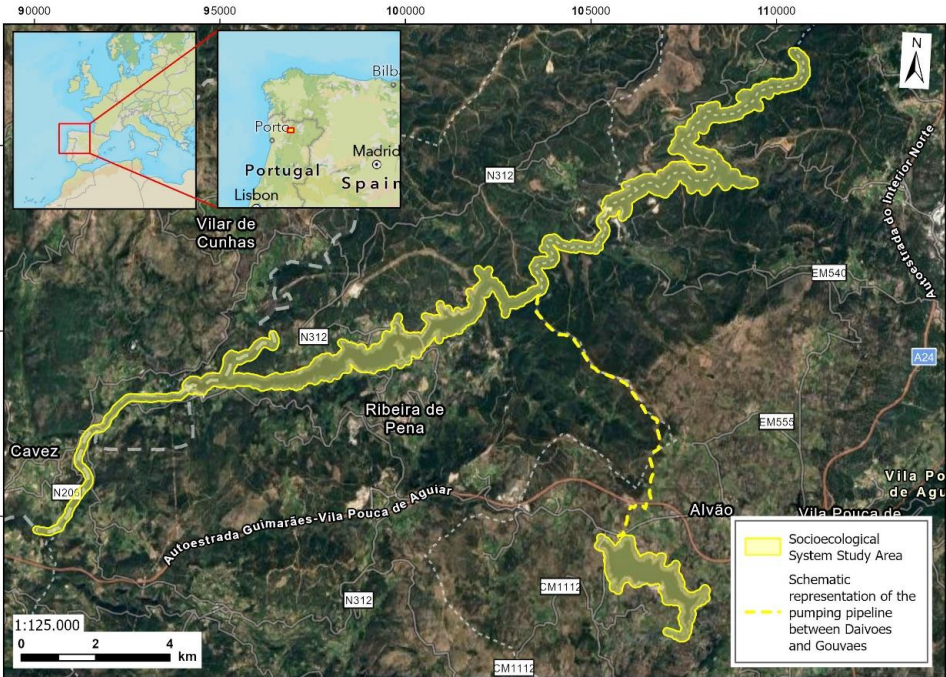
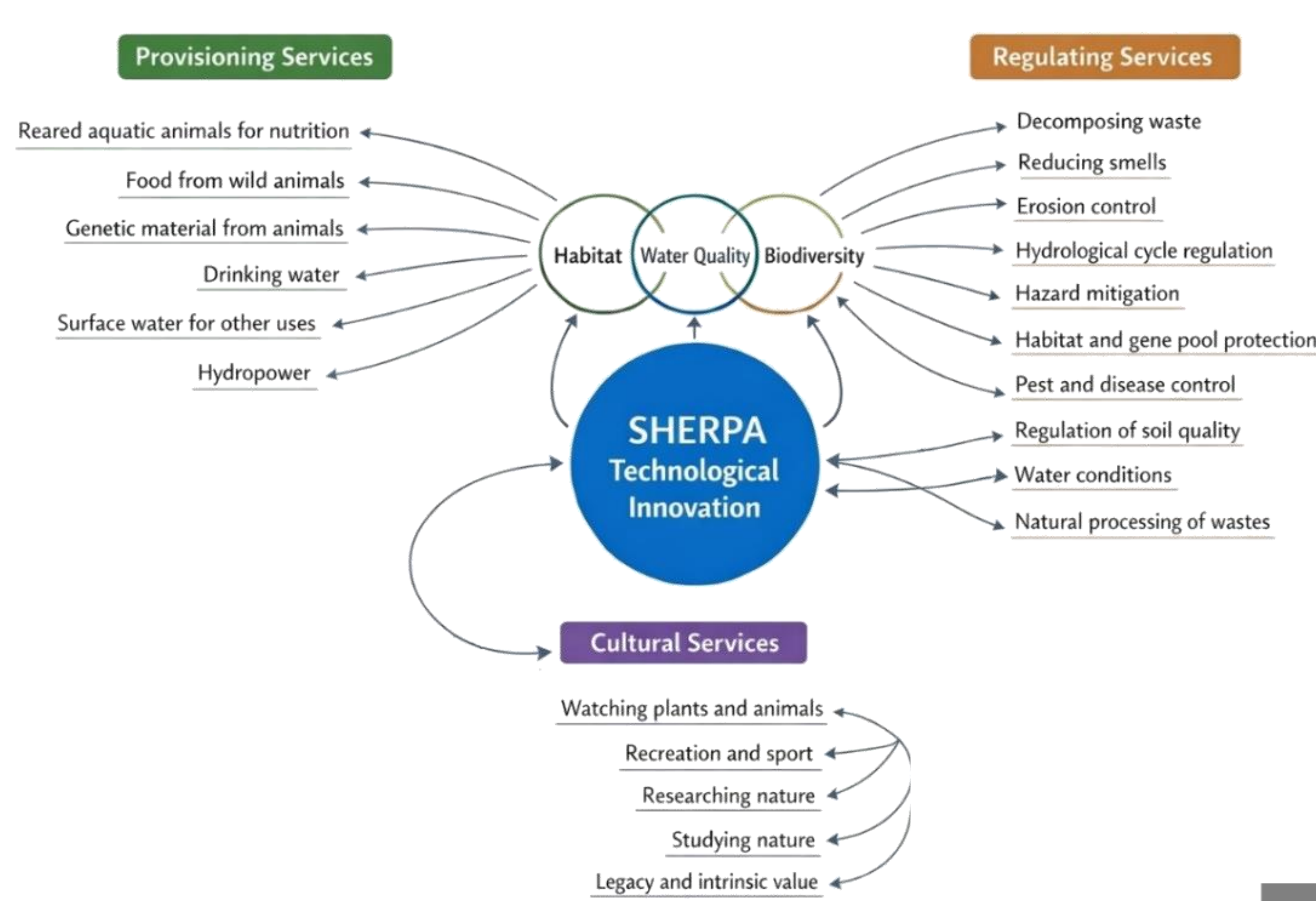


Figure 73: Overview of the study methodology process



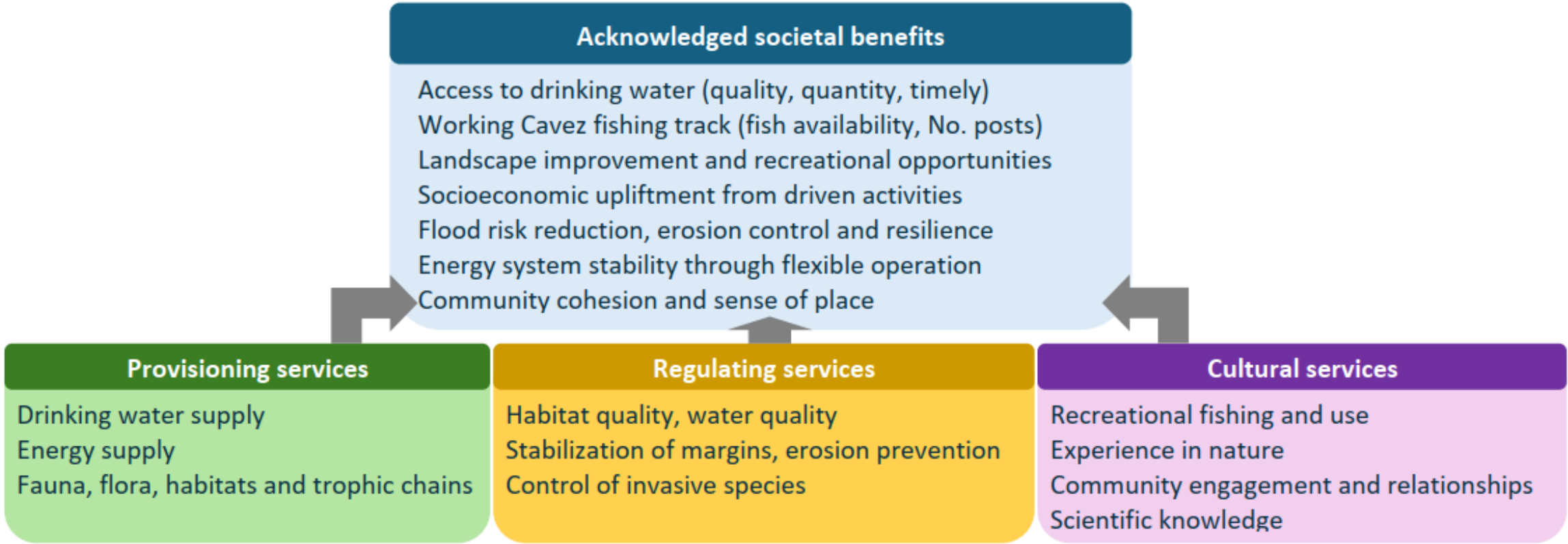
1A - Theoretical approach: Meta-analysis



Next steps (currently):

- Modelling from field data
- Valuation
- New broader validation

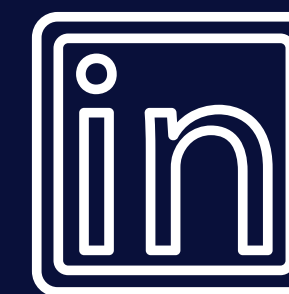
1B – Validation workshop: social value for the local community





SHERPA KoM Meeting (Brussels-September 2024)

Thank you!



SHERPA, new
solutions
for hydropower
plants



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