APPLIED ENGINEERING FOR SMALL HYDROPOWER PROJECTS

PRACTICAL TIPS FOR HYDROPOWER PRACTITIONERS

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Georgetown, Guyana

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OUTLINE

- Field measurements for topographic survey of mini and smaller hydro projects
- Different turbine types, their technical qualities and field of usage
- Environmental and Social considerations of hydropower projects
- Hydropower civil design options: differences, advantages and disadvantages
- Optimizing hydropower projects: the difference between grid integrated and island supply

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY OF MINI AND SMALLER HYDRO PROJECTS

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Why is good topographic data so extremely important?

- H is one of three main parameters in the power output equation

$$P = Q * H * \eta * \rho * g$$

Where:

P	-	Power output
Q	-	Discharge
H	-	Head (difference of water levels)
η	-	Plant efficiency
ρ	-	Density of water
g	-	Acceleration constant

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

In last Seminar Spot Light was on:

Q = flow in m^3/s

Depending on

→ Geographic location
(rain forest or desert)

→ Elevation above sea level
(the higher, the wetter)

→ Time of the year
(rainy season or dry season)

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Today:

H_n = net head in m

Gross Head depending on

→ Topography

- Mountain or valley
- Dam, run-off river or diversion

Net Head depending on

→ Friction losses

- Pipe diameter/canal dimensions
- Pipe/canal roughness
- Length of pipe/canal

→ Other hydraulic losses

- Trash rack
- Bends
- Valves

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

- Gross Head is estimated by different means according to required accuracy
- Different approaches
  a) Desktop approaches
  b) Field measurements

Some examples:

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Desktop Approaches:</u>

Read out from Google Earth

Accuracy of elevation: about 3 to 15 m depending on vegetation and relief

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Desktop Approaches:</u>

Read out from contour lines in topographic maps

Accuracy of elevation: about one contour line interval (50 ft = 15 m)

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Des</u>

Rea

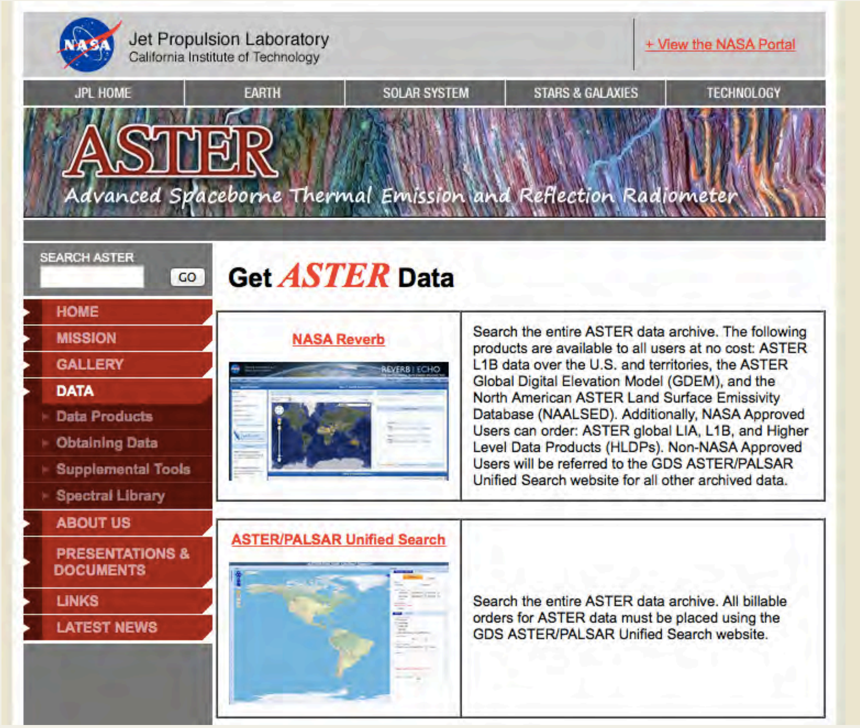
Acc 15 m)

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

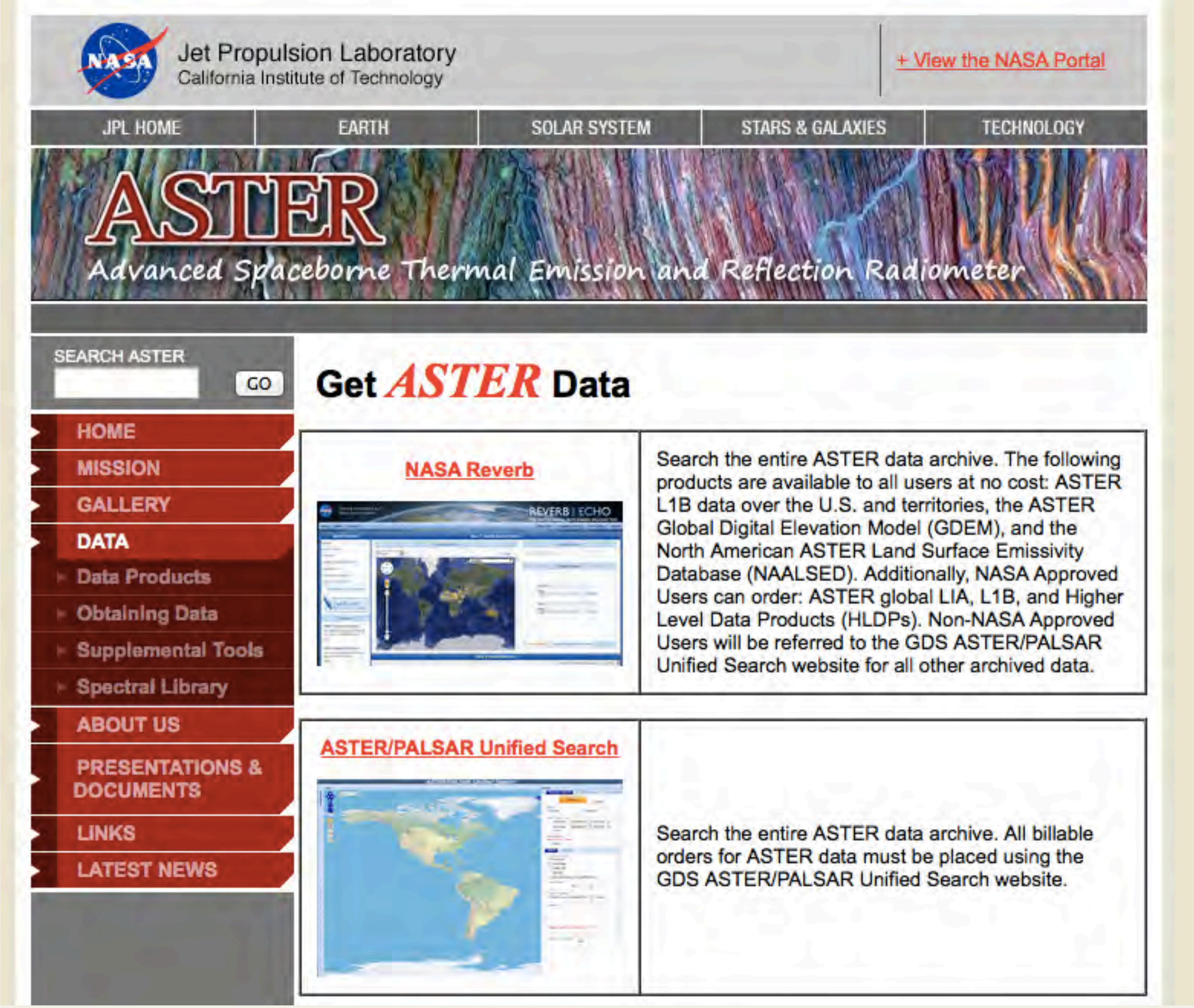
Desktop Approaches:

Global Digital Elevation Models used in GIS, e.g. ASTER

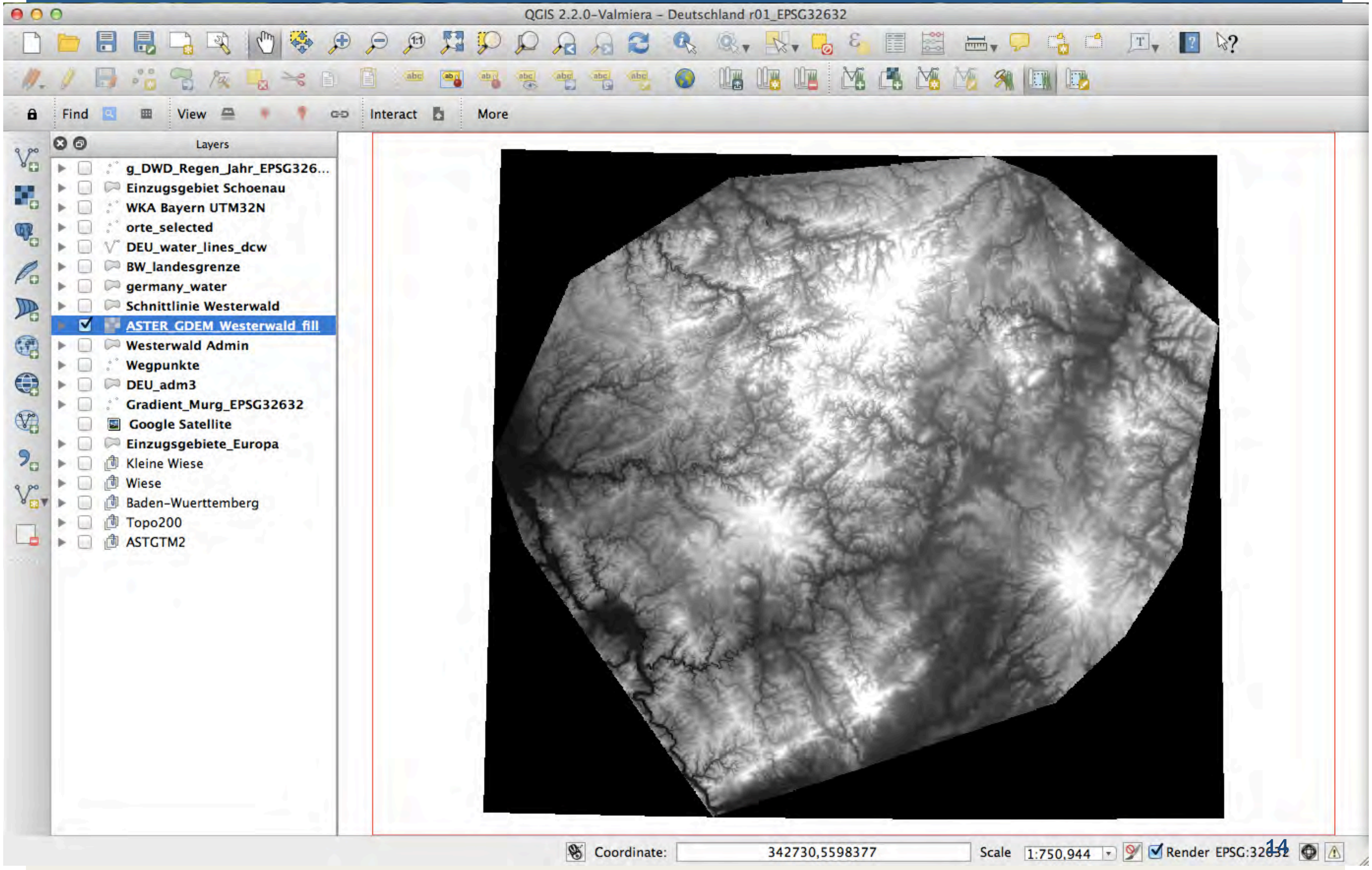
- Several products available, some free of charge, others for fees
- For example: ASTER GDEM >> https://asterweb.jpl.nasa.gov/data.asp



FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY



FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY



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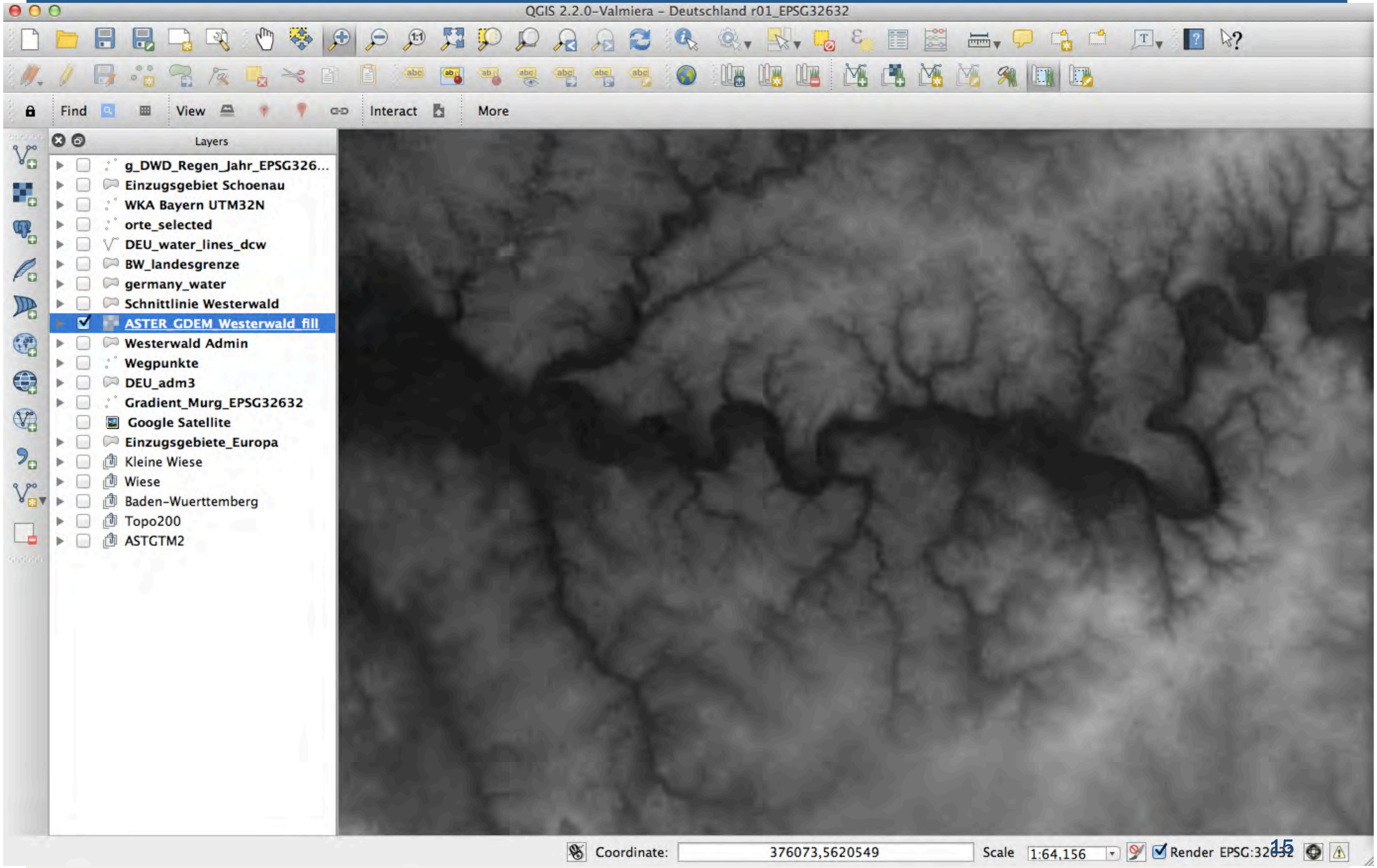
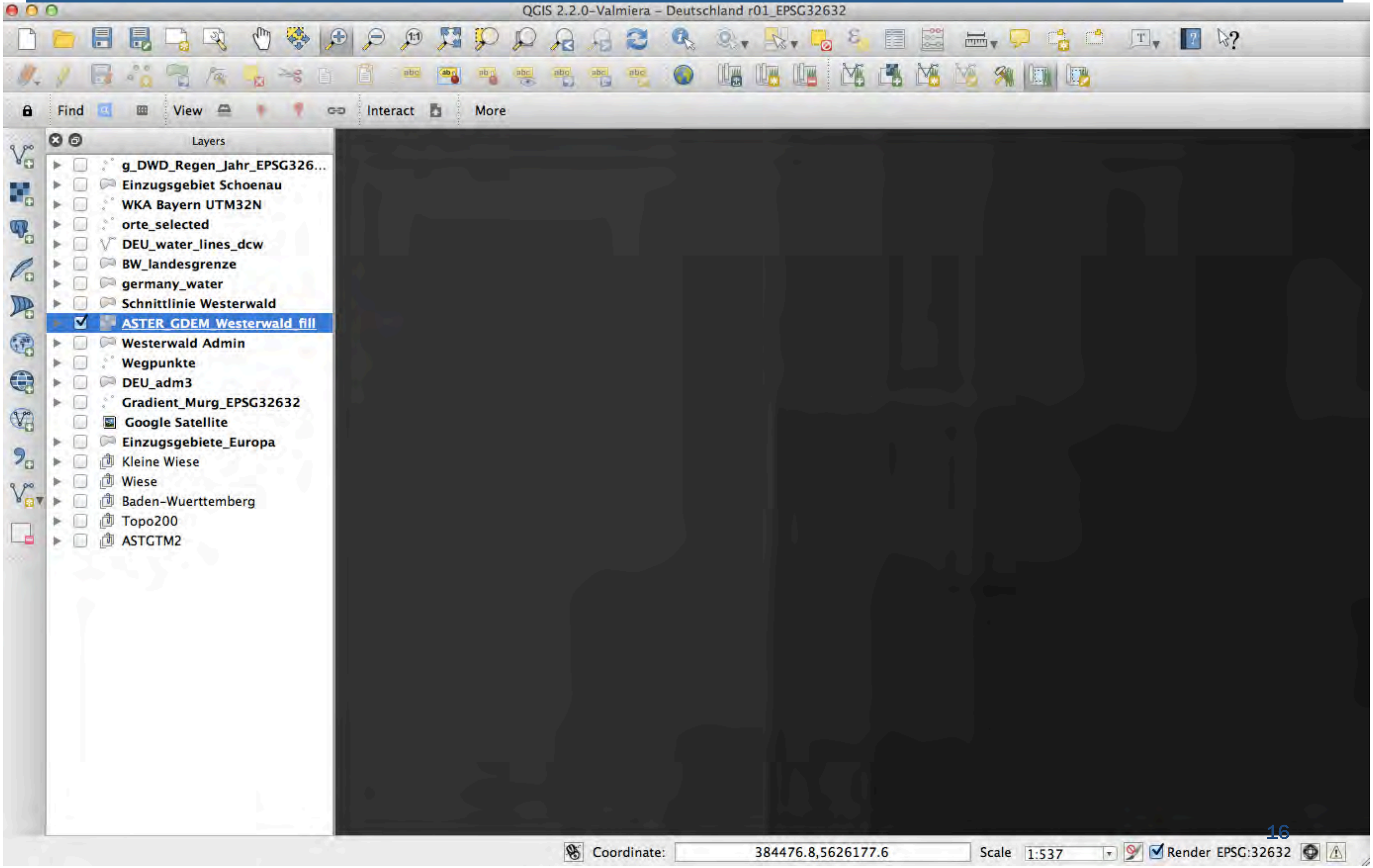


FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

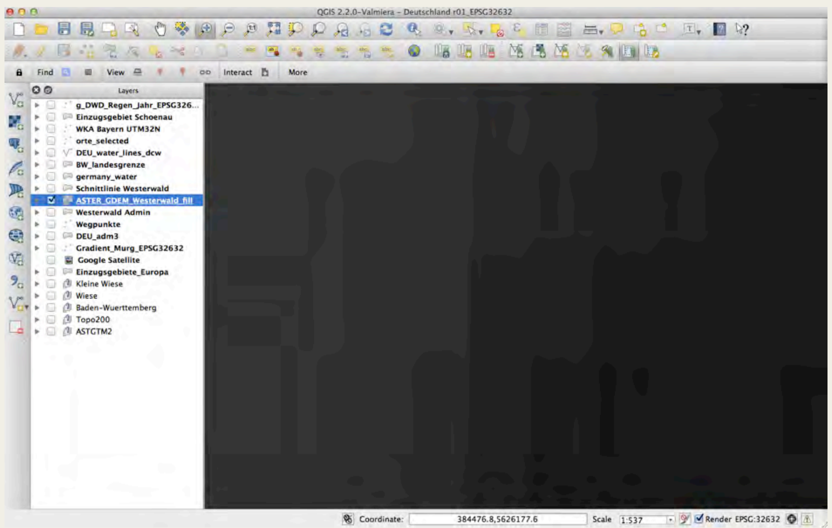


FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Desktop Approaches:

Global Digital Elevation Models used in GIS, e.g. ASTER

- Several products available, some free of charge, others for fee
- For example: ASTER GDEM >> https://asterweb.jpl.nasa.gov/data.asp
- Spatial Resolution: 30 x 30 m
- Vertical Accuracy: RMS Error = 8.68 m, depending on relief structure



FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Conclusion to Desktop Approaches:

(-) Vertical accuracy is quite poor
(+) Data is quickly available for almost all corners of the world
(+) Some data is available for free; more precise data costs money
(+) Usefulness of the desktop approach for
- initial analysis of sites and site identification
- initial analysis of high head projects where the relative error is small compared to the overall head

(-) Method is not suitable for
- analysis of low head sites where every half meter head counts
- detailed analysis of any projects

(+) The desktop approach gives a quick overview on the site
(+) Allows identification of geomorthologic basics such as mountain folding, faults etc.

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Hand held GPS

(+) Easy to handle
(+) Quick results
(-) Poor accuracy for elevations (<5 m at best)
(+) Spatial accuracy: up to 1 m
(-) Not applicable in deep forest

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Water level bubble, line and measuring tape

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

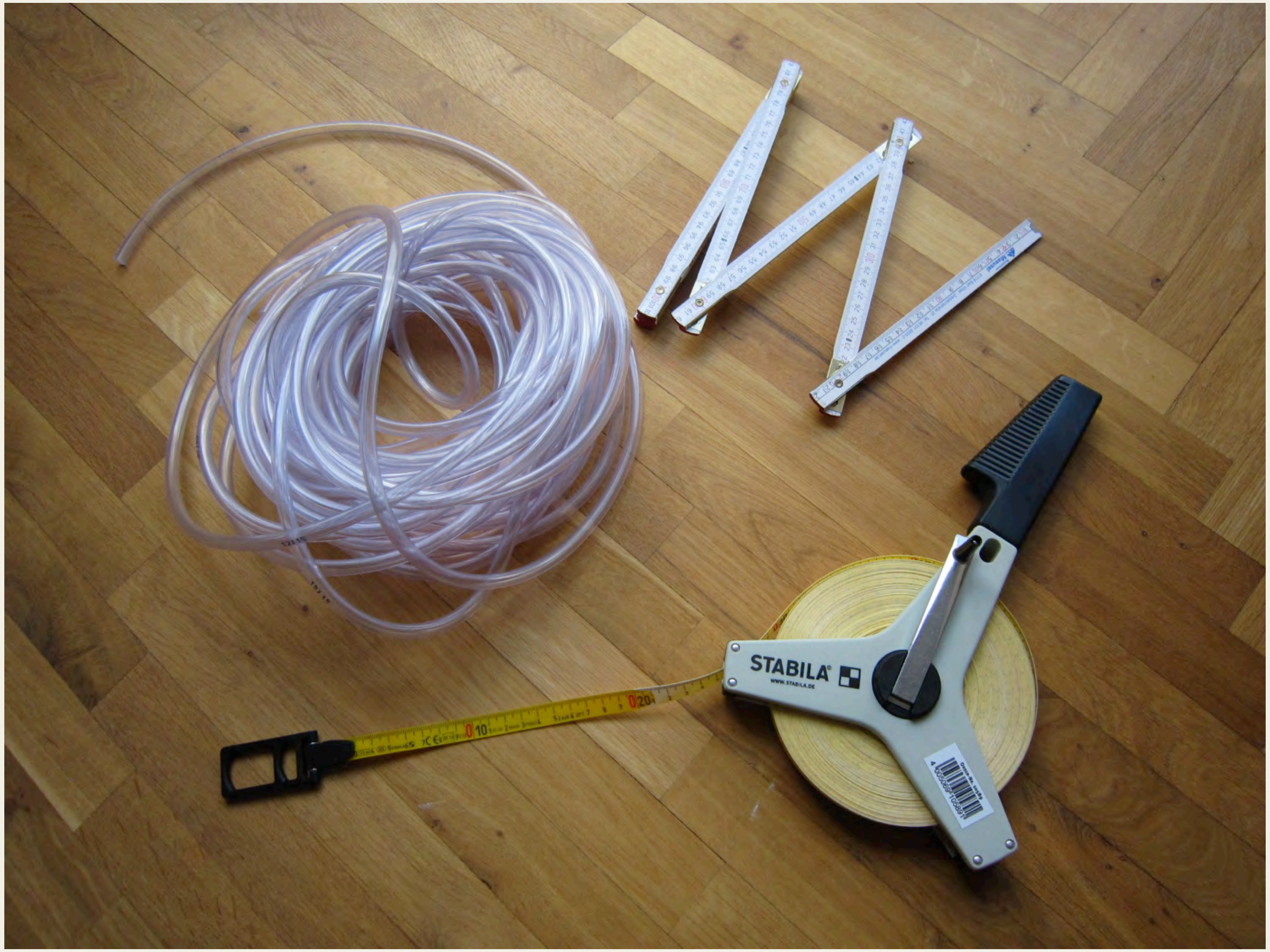
Water level bubble, line and measuring tape

(+) Very cheap tools available in hardware store
(+) Relatively quick for small sites, time consuming for larger sites
(-) Accuracy depends on users' skills; generally around 1 – 2 m per 100 m longitudinal distance
(-) Accuracy of bubble reading needs thorough practice
(+) Best when supplemented with aerial photos, e.g. Google Earth
(+) Applicable nearly everywhere

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Hose water level and measuring tape



FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Hose water level and measuring tape

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Hose water level and measuring tape

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Hose water level and measuring tape

(+) Cheap tools

(+) Relatively quick for small and shallow sites, time consuming for larger and steep sites; can only measure as far as the hose is long

(-) Accuracy depends on users' skills; generally around 0.3 – 1 m per 100 m

(+) Best when supplemented with aerial photos, e.g. Google Earth

(+) Applicable nearly everywhere

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Field Measurement Approaches:</u>

Levelling machine and measuring tape

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Levelling machine and measuring tape

(+) Simple technology, needs only brief introduction
(+) Relatively cheap equipment (Levelling machine: 200 USD; Tripod: 100 USD; Scale bar: 80 USD)
(+) Accurate results of up to 0.001 m
(-) Relatively time consuming
(+) Can measure far distances in shallow areas
(-) Needs at least a team of two persons

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Tachymeter

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Field Measurement Approaches:</u>
Tachymeter (with or without GPS)

(+) High accuracy of 0.005 m horizontal and 0.001 m vertical possible
(+) Measures all spatial coordinates (x, y, z)
(+) Modern machines can be remote controlled → one man station
(-) Expensive equipment (used: USD 10,000 upwards)
(-) Needs thorough training for operator
(-) Needs specialized software for evaluation and visualization of data
(-) Needs local fixed point network

With GPS:
(+) Coordinates available in WGS84
(-) Poor satellite reception in the forest
(-) Very costly equipment

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Survey Drone (= Unmanned Aerial Vehicle)

Multirotor G4 Surveying Robot

Drones were deployed equipped with a camera and various sensors to prepare detailed geo-referenced ortho photos, digital terrain models, contour lines and additional data.

e-bee of Sensefly

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

<u>Field Measurement Approaches:</u>

Survey Drone (= Unmanned Aerial Vehicle)

Drones were deployed equipped with a camera and various sensors to prepare detailed geo-referenced ortho photos, digital terrain models, contour lines and additional data.

How it works:

- Remote controlled drone carries multiple sensors
    - GPS/DGPS
    - Photo camera resolution > 16 Mpix
    - Ground proximity
    - Temperature
    - Altitude
    - Wind velocity and direction
- Flying altitude: about 200 m
- Photos and other data are stored on the device's memory when flying over the investigation area, or are transmitted real-time to a laptop on the ground
- The data is superposed and from each two neighboring photos a digital elevation model is produced by ortho-photogrammetry

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

Survey Drone (= Unmanned Aerial Vehicle)

How it works: (continued)

- The data is evaluated with specialized software
- Terrestrially measured reference points are required to improve the precision
- High density point clouds are generated from the measured data
- One pixel is up to 1.5 cm on the ground
- Accuracy: up to 0.001 m, normally 0.03 to 0.05 m
- Was successfully applied in Ethiopia's Grand Renaissance hydropower project

Drones were deployed equipped with a camera and various sensors to prepare detailed geo-referenced ortho photos, digital terrain models, contour lines and additional data.

FIELD MEASUREMENTS FOR TOPOGRAPHIC SURVEY

Field Measurement Approaches:

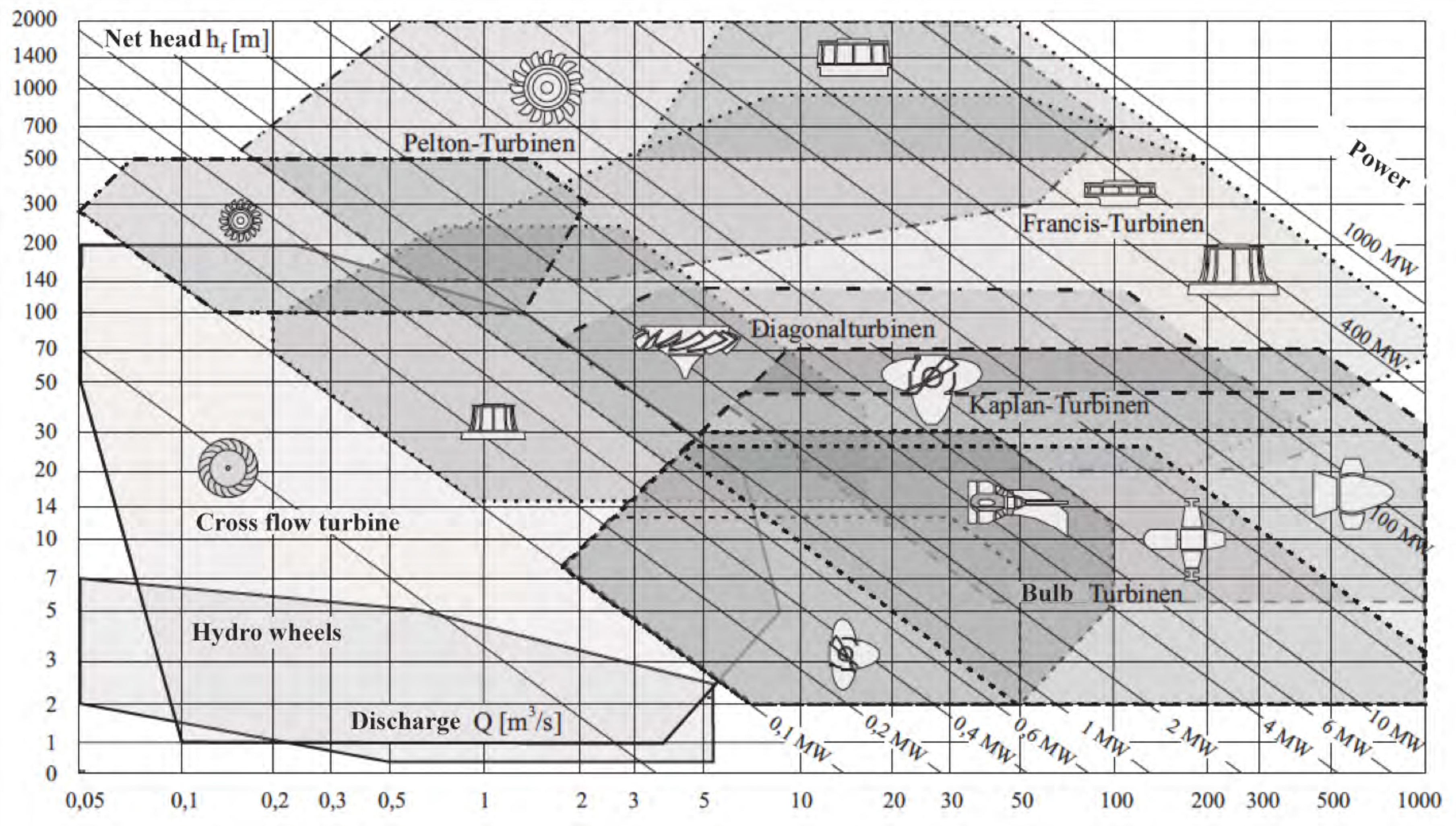
Survey Drone (= Unmanned Aerial Vehicle)

(+) Fast field work over large areas
(+) Produces ortho-photos, contour maps, digital elevation models and other information depending on the deployed sensors
(+) Various models are available and have been tested in practice
(-) Requires high-tech software for data evaluation
(+) Accuracy: 0.01 m horizontal; 0.05 m vertical (if reference points avail)
(-) Very expensive equipment (> USD 25,000) and software (> USD 3,500)
(-) Needs highly specialized skills
(-) Not everywhere applicable without aviation license
(+) Future technology with lots of potential

DIFFERENT TURBINE TYPES, THEIR TECHNICAL QUALITIES AND FIELD OF USAGE

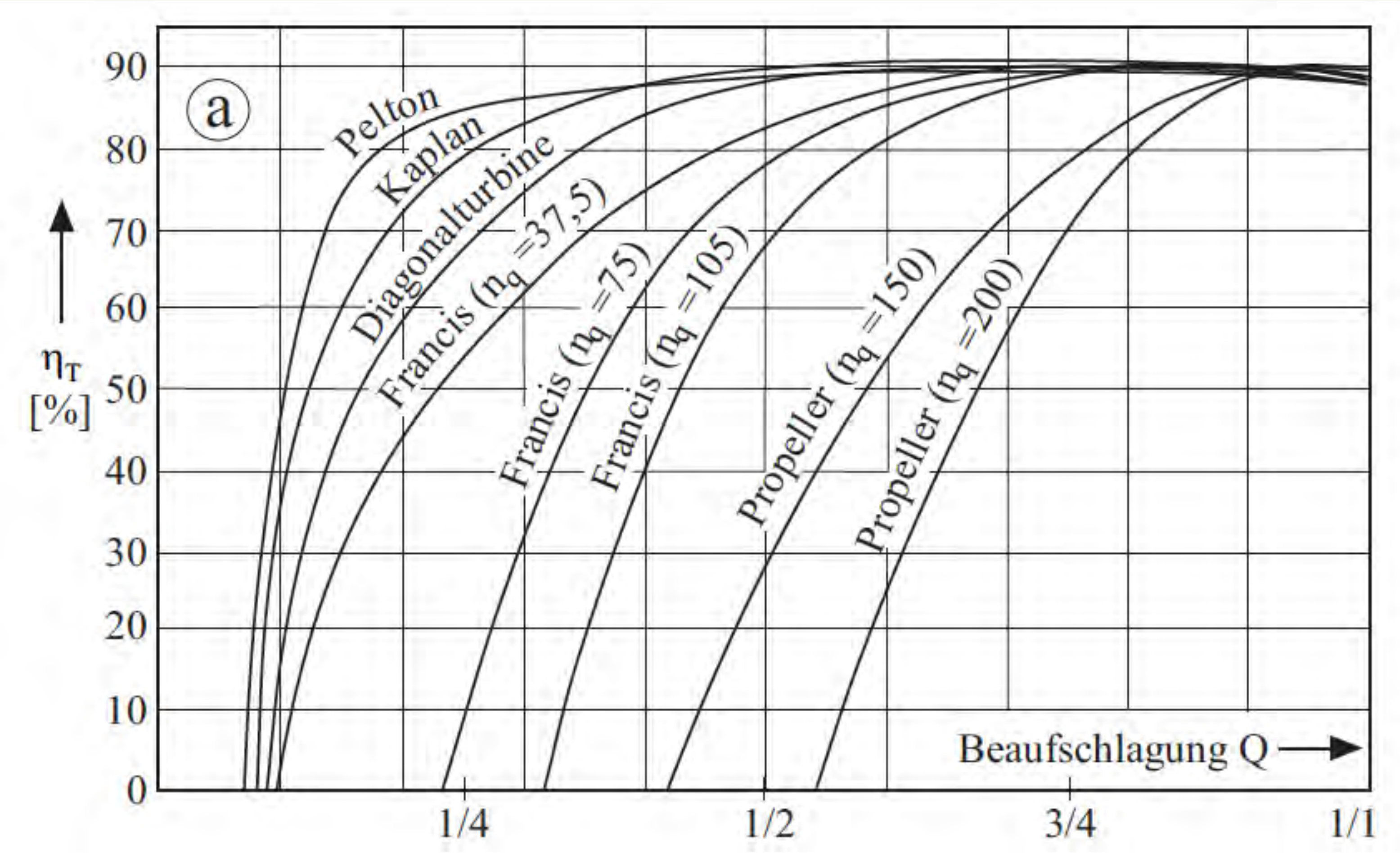
DIFFERENT TURBINE TYPES

Selection of the right turbine type using diagrams:



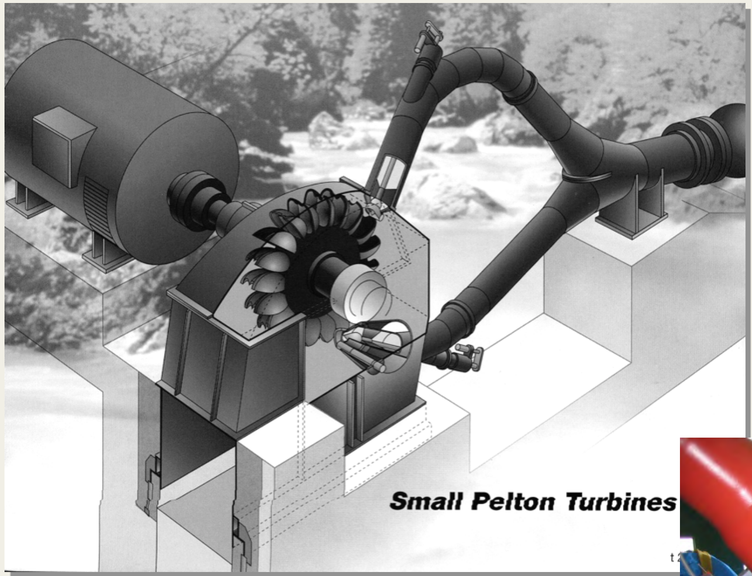
DIFFERENT TURBINE TYPES

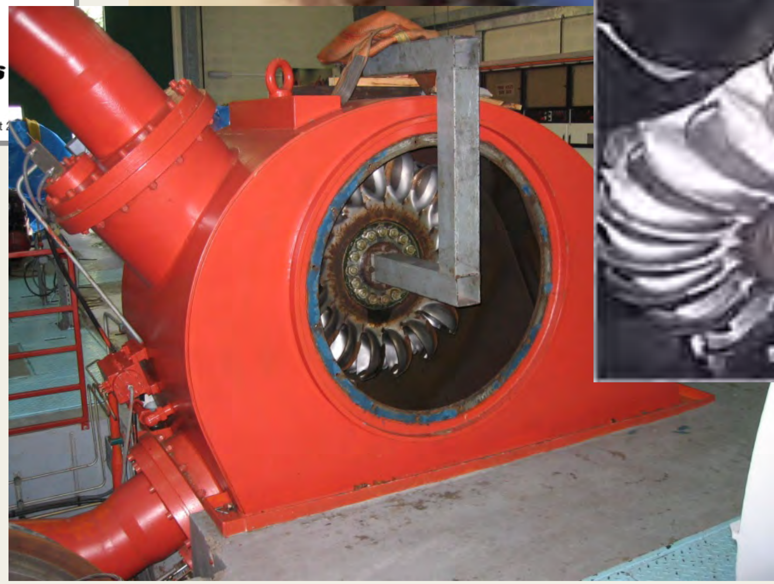
Selection of the right turbine type:



PELTON TURBINE

Pelton turbine: Impulse turbine





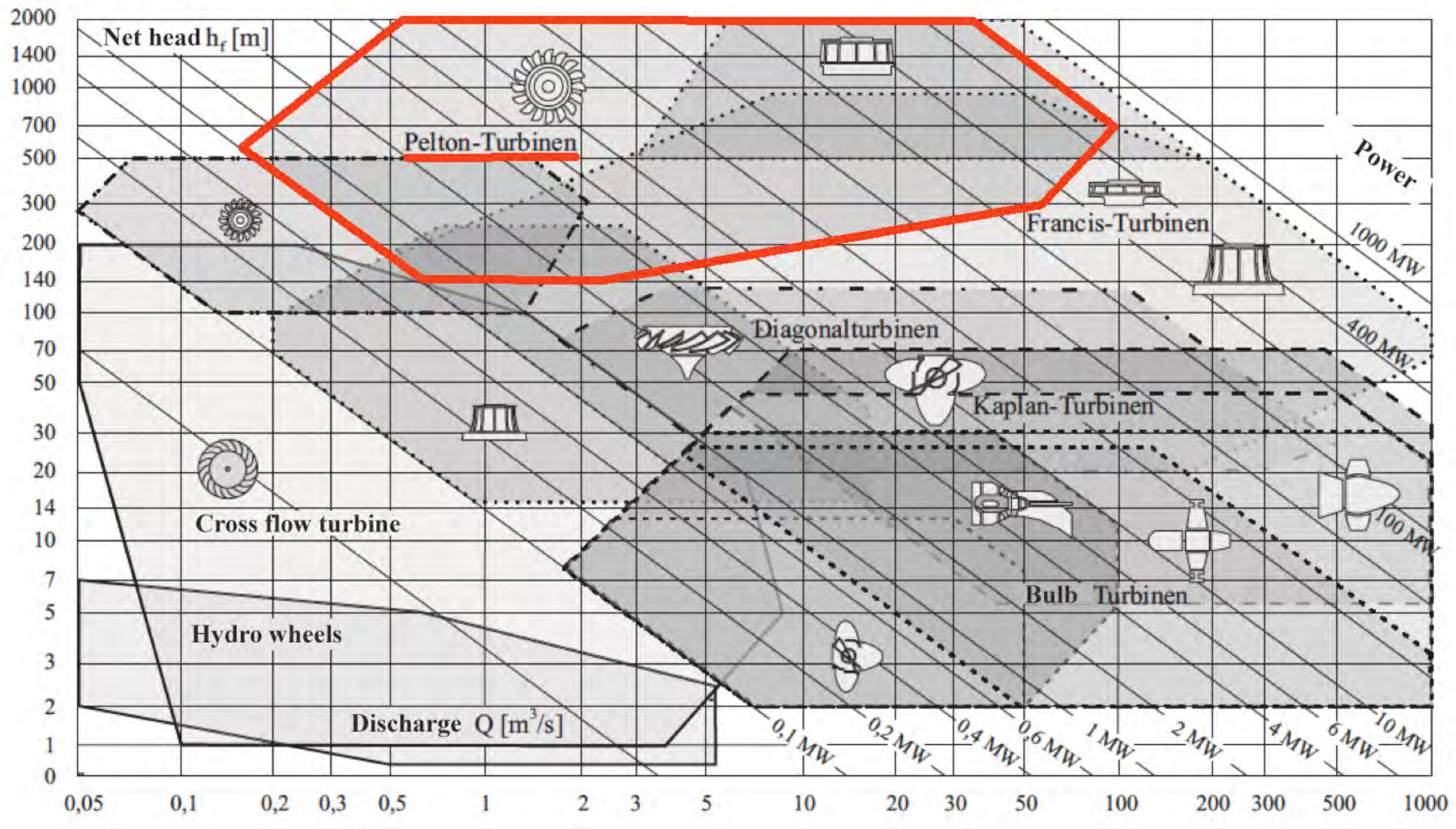
PELTON TURBINE

Pelton turbines key data:

- Impulse turbine for high heads

PELTON TURBINE

Pelton turbines key data:



PELTON TURBINE

Pelton turbines key data:

- Impulse turbine for high heads
- Low and medium discharges
- Between 1 and 6 jets possible
- Quick ability to control power output
- Typically used for storage projects and in peak power plants
- Unit sizes of up to 400 MW each and more
- Sensitive to abrasion through suspended sediments → desanding is very important: up to d = 0.2 to 0.1 mm depending on head
- Baffles divert the jet completely or partially and thus allow fine regulation of the power output
- Turbine efficiencies of up to some 92 % with flat efficiency curves
- Kick-in point at discharges of some 10 % of design discharge
- Easy to maintain technique

PELTON TURBINE

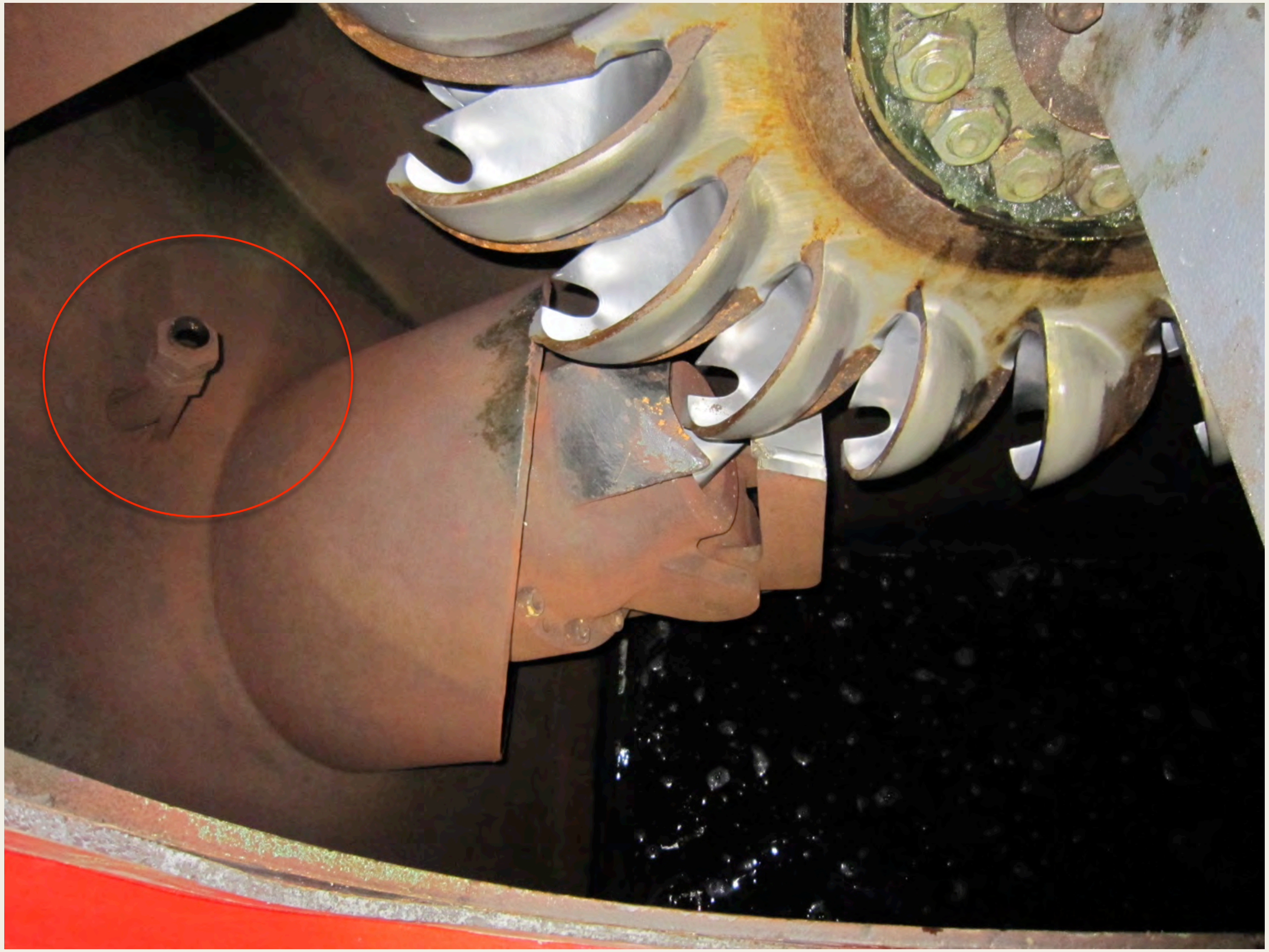
New Trafalgar, Dominica

Needle valve and baffle

PELTON TURBINE

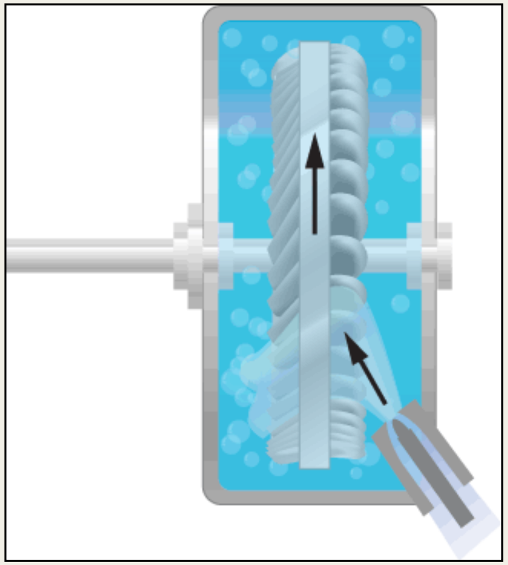
Pelton blades: cups

Break jet



TURGO TURBINE

Turgo turbine: Impulse turbine



TURGO TURBINE

Difference between Turgo and Pelton turbines

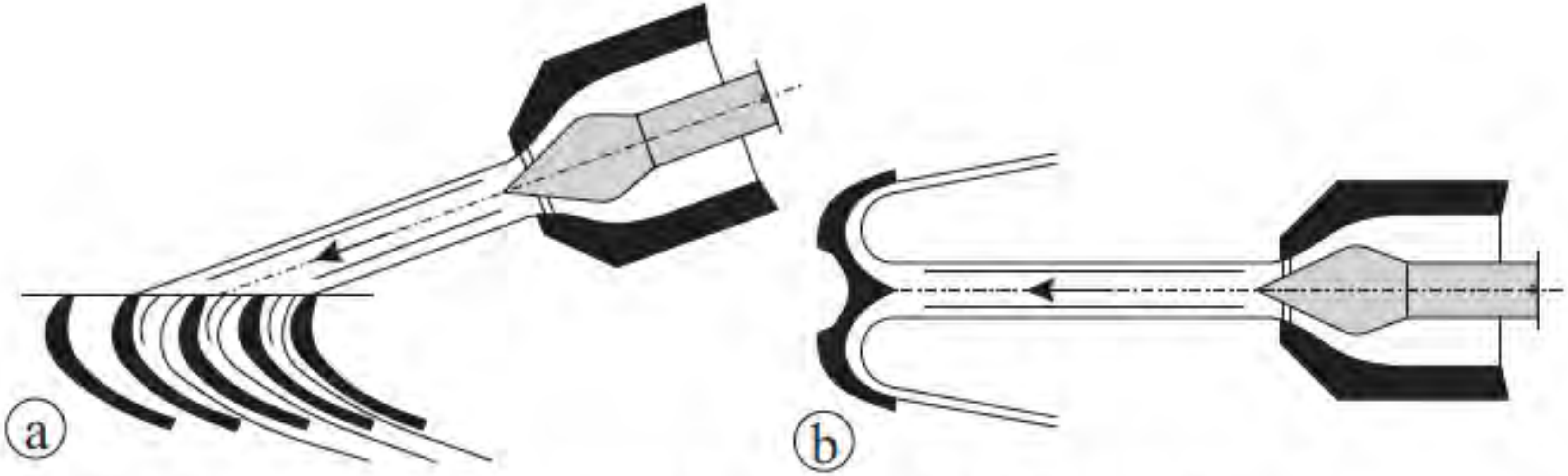


Abb. 15.22: Vergleich zwischen Turgo-Turbine (a) und Pelton-Turbine (b)

The Turgo turbine can process about twice the amount of water than Pelton turbines

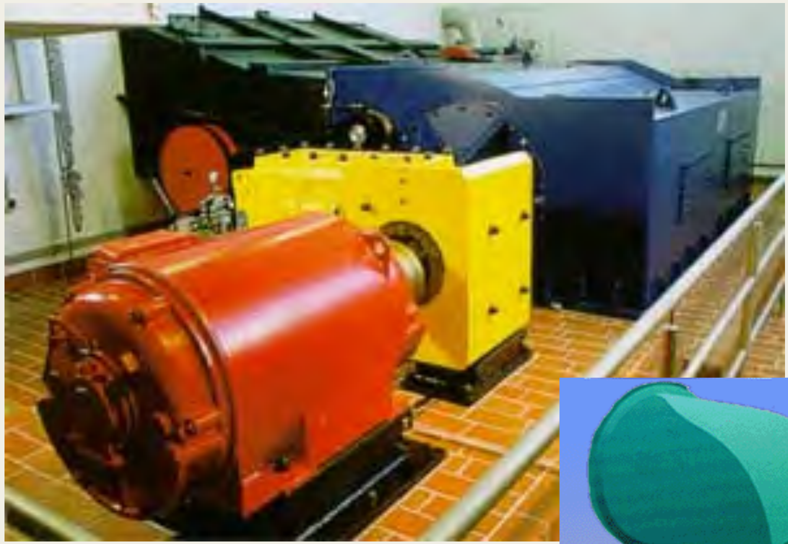
TURGO TURBINE

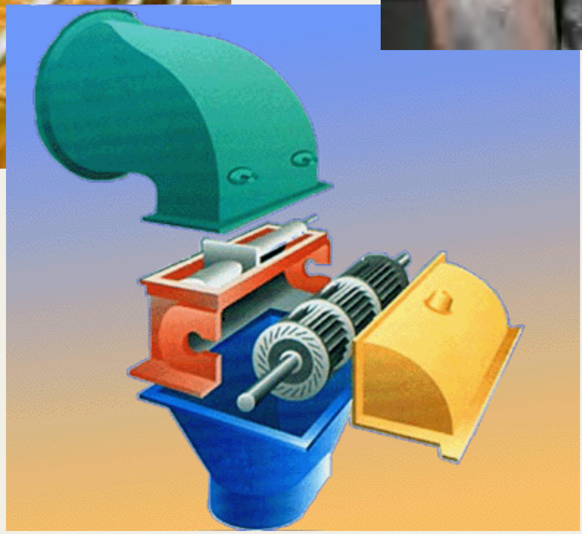
Turgo turbines key data:

- Impulse turbine for medium and high heads > about 30 to 250 m
- Low and medium discharges
- Similar to Pelton but jet hits at 30 to 40° angle
- Quick ability to control power output
- Typically used for small hydropower projects with storage or run-of-river
- Much less sensitive to abrasion through suspended sediments than Pelton turbines → desanding is less costly
- Baffles divert the jet completely or partially and thus allow fine regulation of the power output
- Turbine efficiencies of up to some 90 % with flat efficiency curves
- Kick-in point at discharges of some 10 % of design discharge
- Extremely robust and easy to maintain

CROSS-FLOW TURBINE

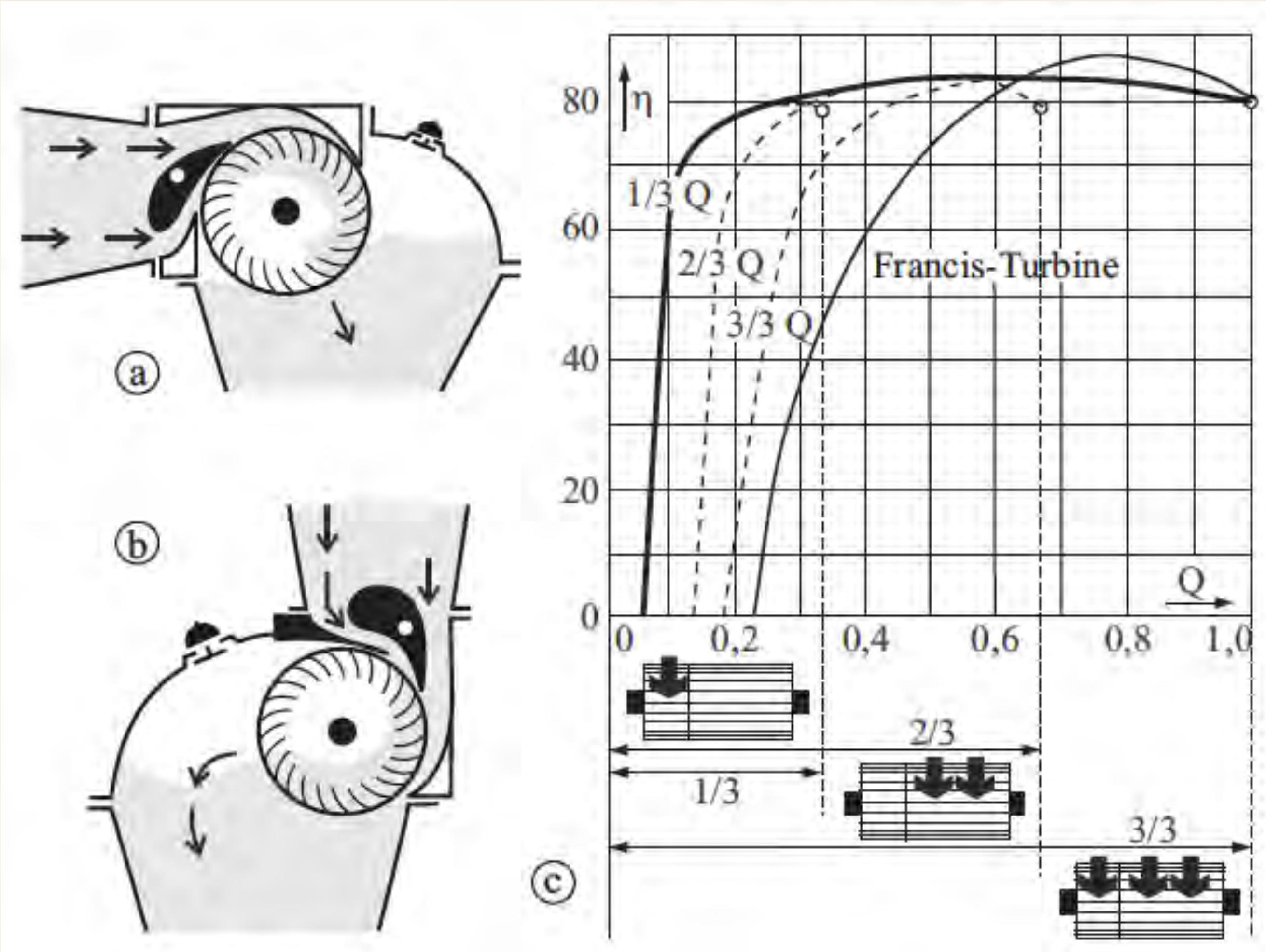
Cross-flow turbine: Impulse turbine when free running, reaction when inundated





CROSS-FLOW TURBINE

Cross-flow turbine: Impulse turbine when free running, reaction when inundated



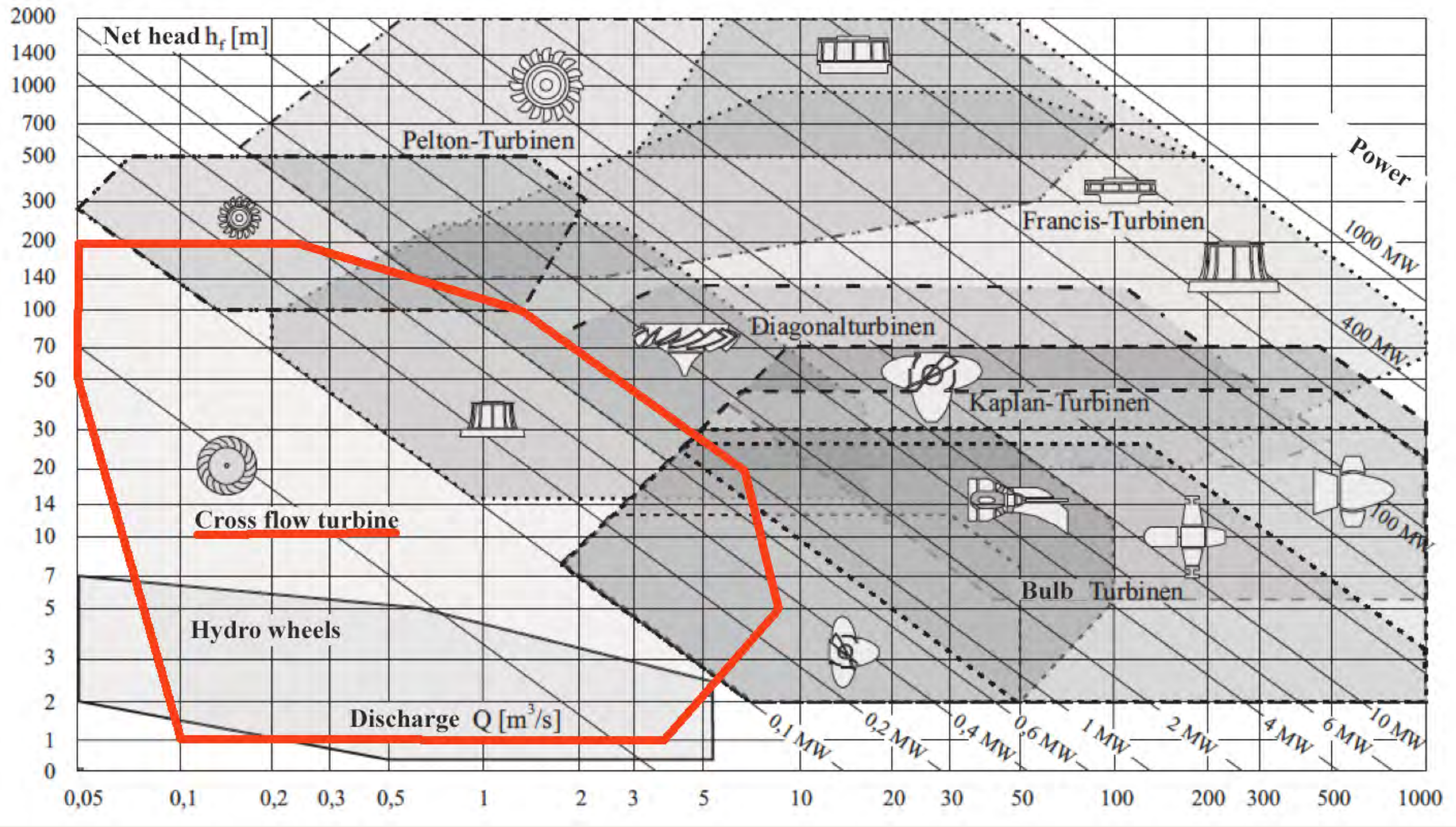
CROSS FLOW TURBINE

Cross flow turbines key data:

- Impulse or reaction turbine depending on operation mode
- Low and medium heads > about 1 to 200 m
- Low discharges: 0.025 to 13 m^3/s

CROSS FLOW TURBINE

Cross flow turbines key data:

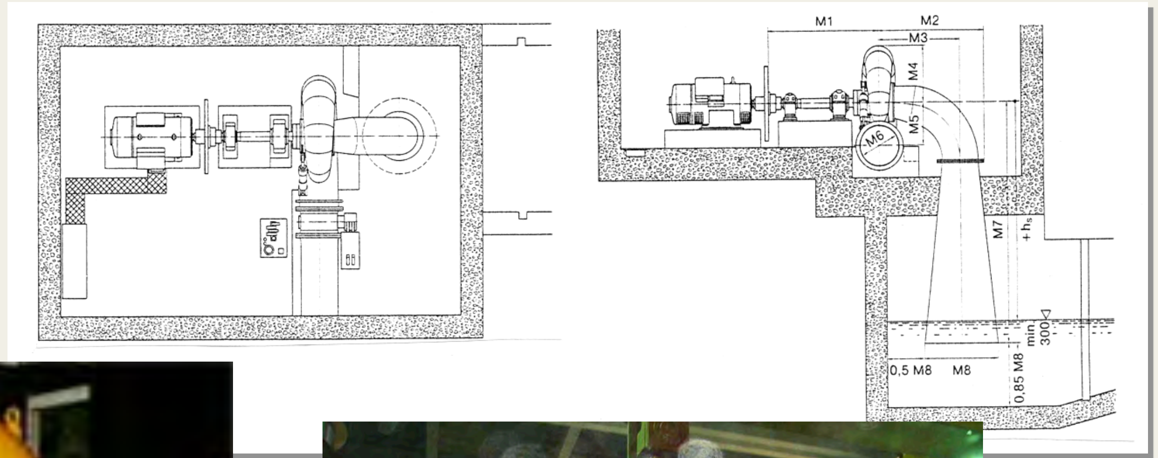


CROSS FLOW TURBINE

Cross flow turbines key data:

- Impulse or reaction turbine depending on operation mode
- Low and medium heads > about 1 to 200 m
- Low discharges: 0.025 to 13 m^3/s
- Capacity up to 1,500 kW
- Typically used for small hydropower projects with storage or run-of-river
- Principle similar to hydro wheels
- Low sensitivity to abrasion through suspended sediments
- Turbine efficiencies of up to some 87 %
- Efficiency curves flat through usage of three cells
- Kick-in point at discharges of some 5 % of design discharge
- With or without draft tube
- Robust and easy to maintain

Francis turbine: Reaction turbine



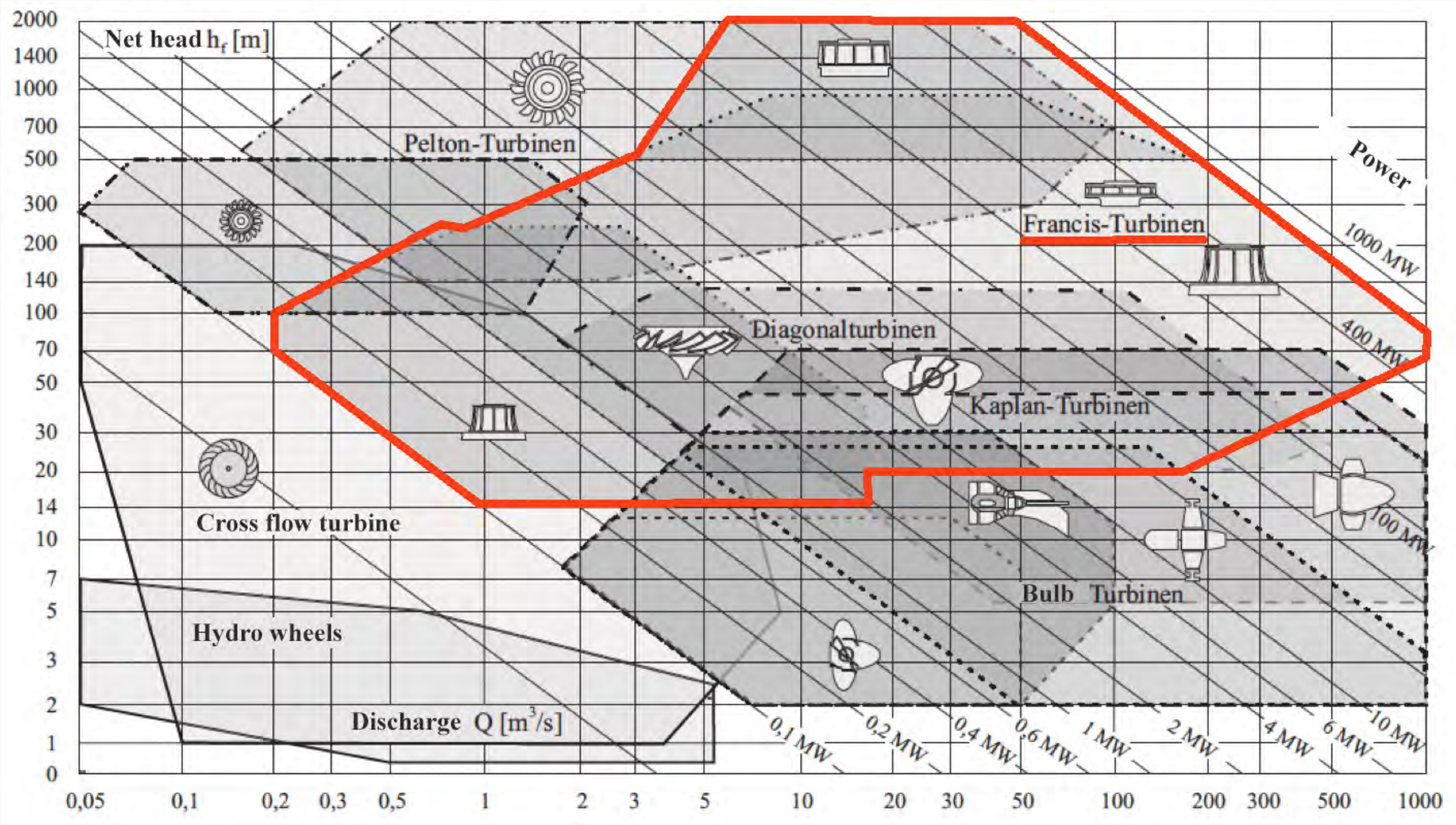
FRANCIS TURBINE

Francis turbines key data:

- Reaction turbine
- Medium and high heads from about 14 to 2,000 m
- Medium and high discharges: 0.2 to 1,000 m^3/s
- Capacity up to 750 kW

FRANCIS TURBINE

Francis turbines key data:



FRANCIS TURBINE

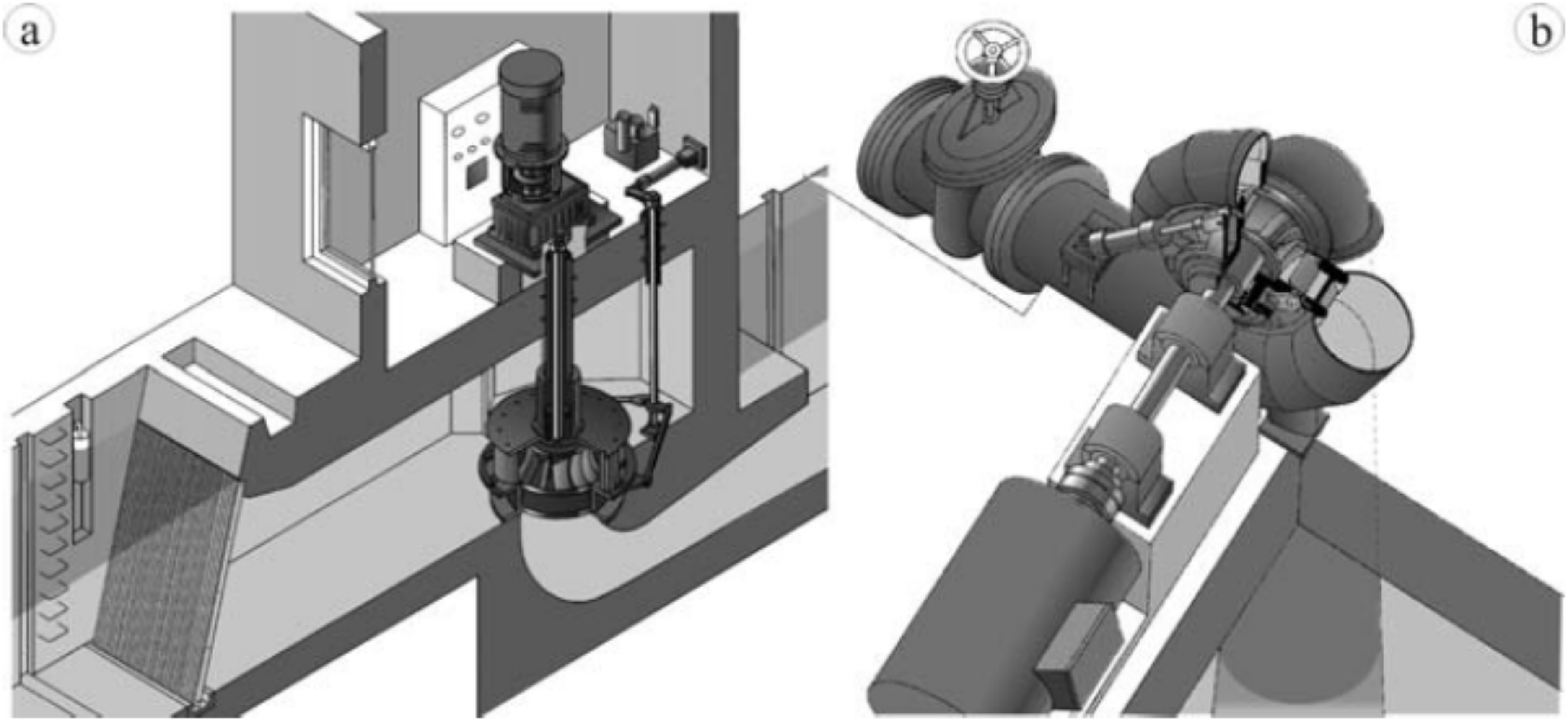
Francis turbines key data:

- Reaction turbine
- Medium and high heads > about 14 to 2,000 m
- Medium and high discharges: 0.2 to 1,000 m^3/s
- Capacity up to 750 kW per unit
- Typically used for small, medium and large hydropower projects with storage or run-of-river, and as pump-turbines
- Low sensitivity to abrasion through suspended sediments
- Turbine efficiencies of up to some 94 %
- Efficiency curves rather pointy
- Kick-in point at discharges of some 30 % of design discharge
- With or without draft tube
- With or without spiral case
- Moderate to maintain

FRANCIS TURBINE

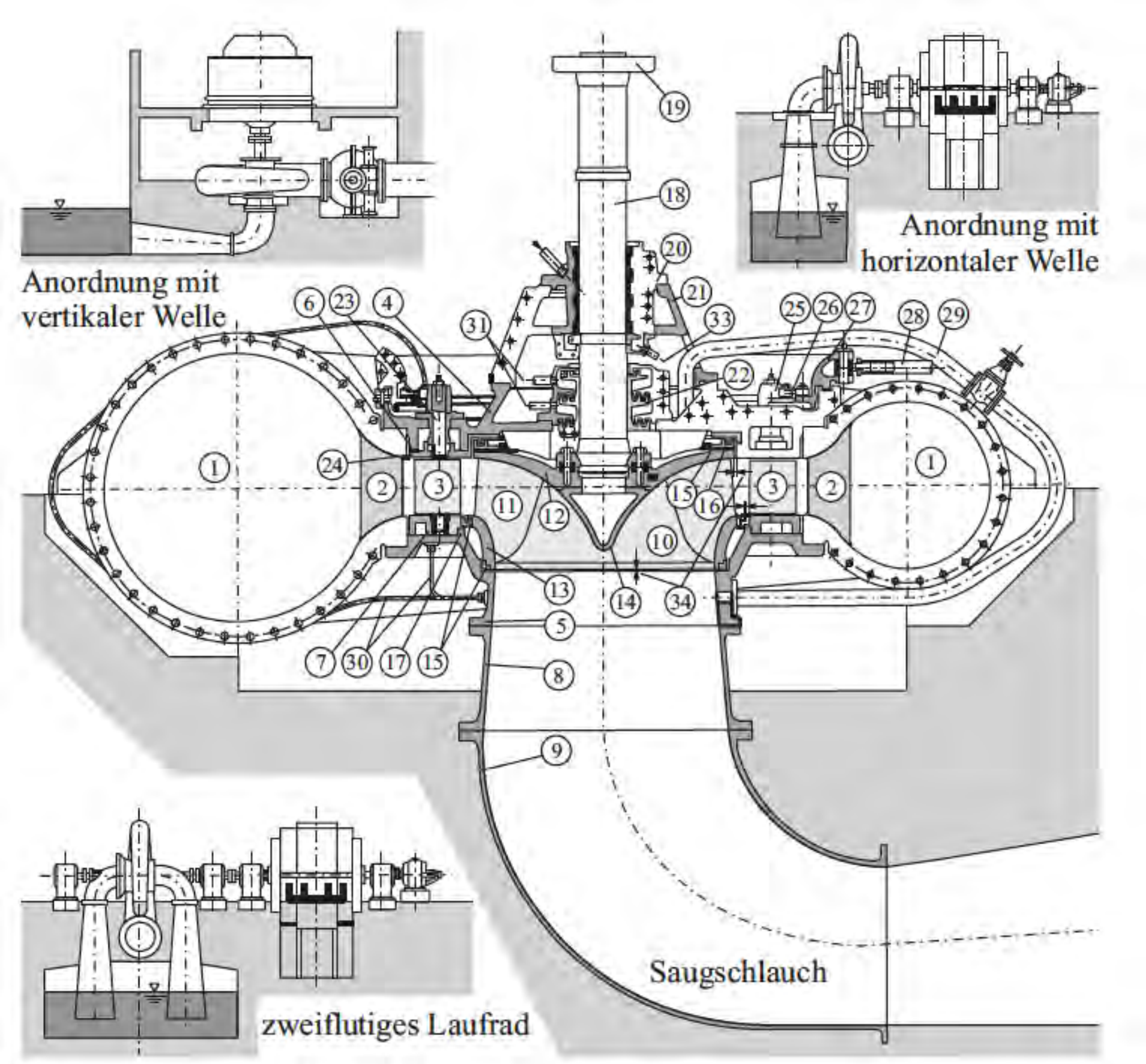
Cumberland, St. Vincent

FRANCIS TURBINE



Francis shaft (a) and spiral (b) turbine arrangements

FRANCIS TURBINE



Top left: vertical shaft arrangement;

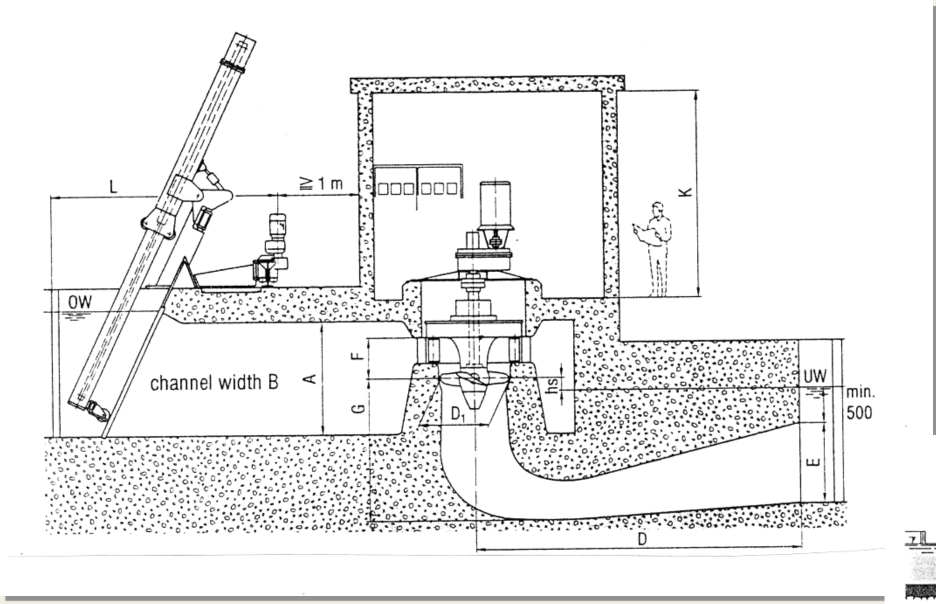
Top right: horizontal shaft alignment;

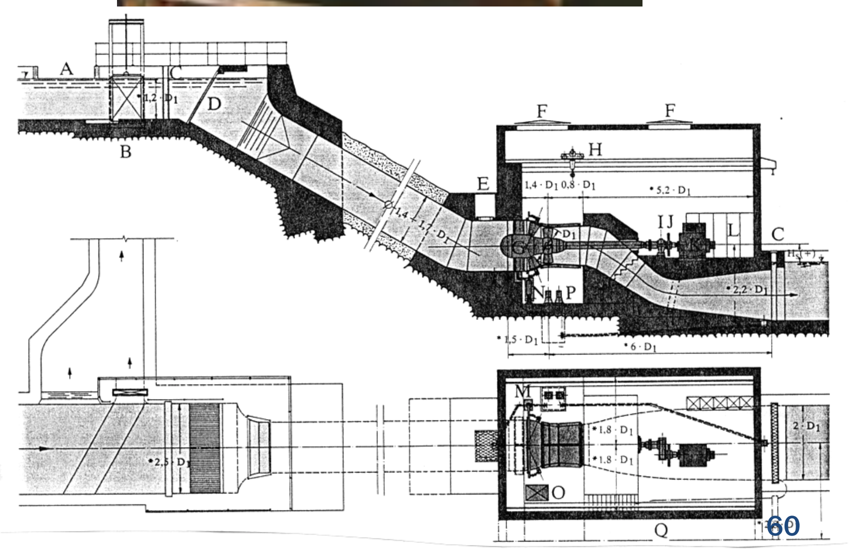
Bottom left: double flooded turbine;

Center: elements of a Francis turbine

KAPLAN TURBINE

Kaplan type turbine: Reaction turbine





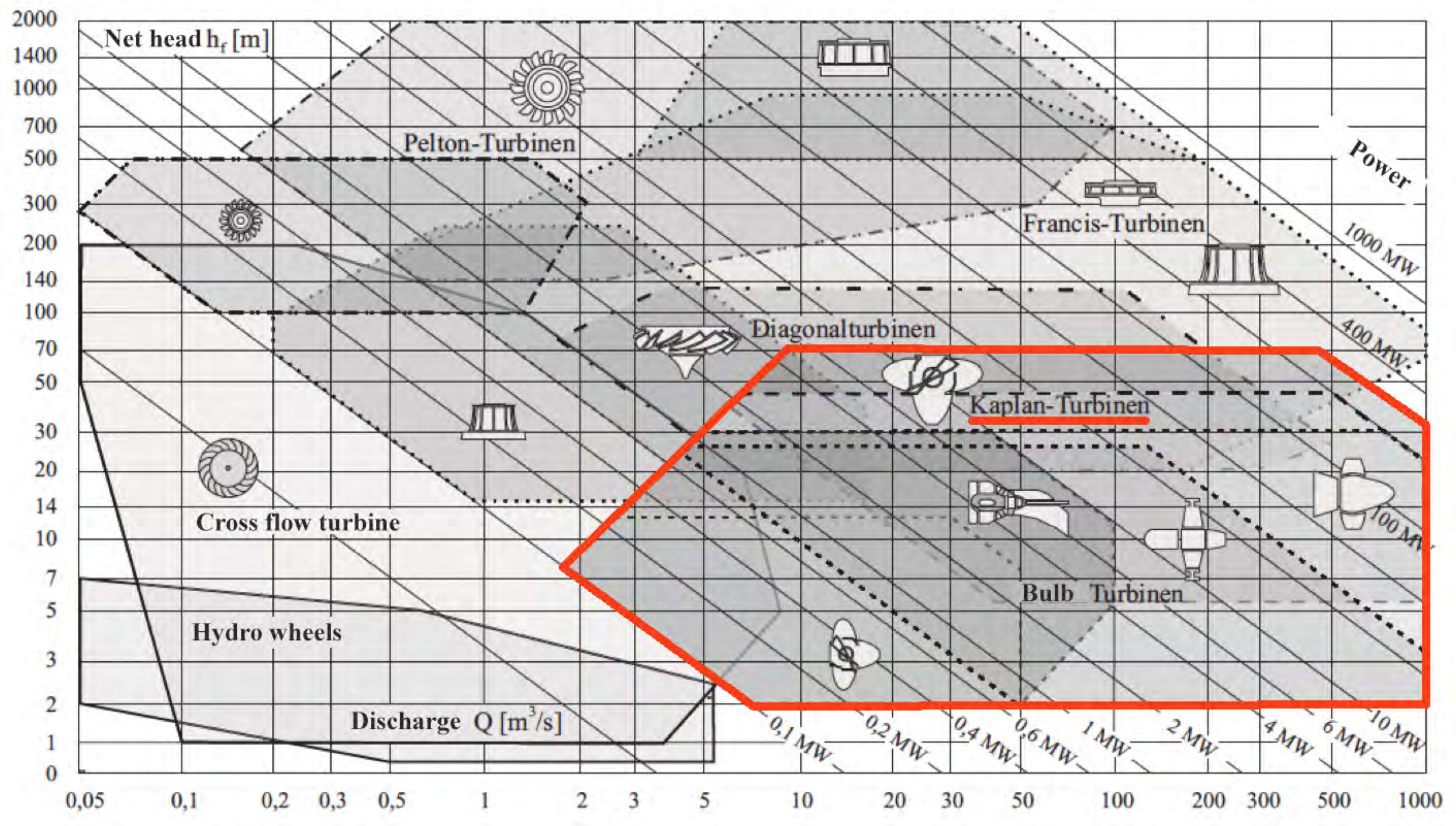
KAPLAN TURBINE

Kaplan turbines key data:

- Reaction turbine
- Low and medium heads < about 80 m
- Medium and high discharges: 1.5 to 1,000 m^3/s
- Capacity up to 350 kW per unit

KAPLAN TURBINE

Kaplan turbines key data:



KAPLAN TURBINE

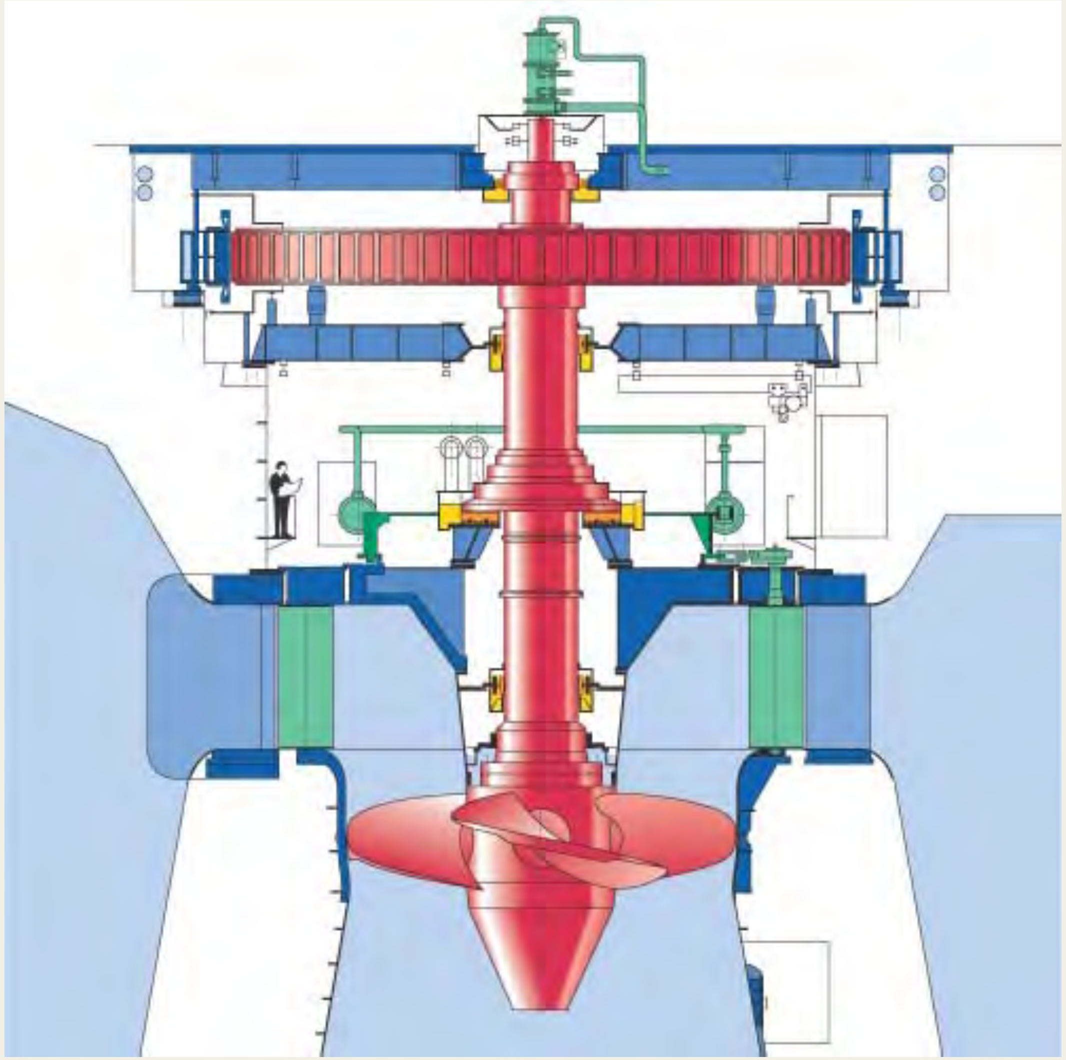
Kaplan turbines key data:

- Reaction turbine
- Low and medium heads < about 80 m
- Medium and high discharges: 1.5 to 1,000 m^3/s
- Capacity up to 350 kW per unit
- Typically used for small and medium hydropower projects with small storage or run-of-river
- Low sensitivity to abrasion through suspended sediments
- Turbine efficiencies of up to some 95 %
- Efficiency curves flat through double regulated blades/guide vanes
- Kick-in point at discharges of some 20 % of design discharge
- With or without draft tube
- With or without spiral case
- High maintenance

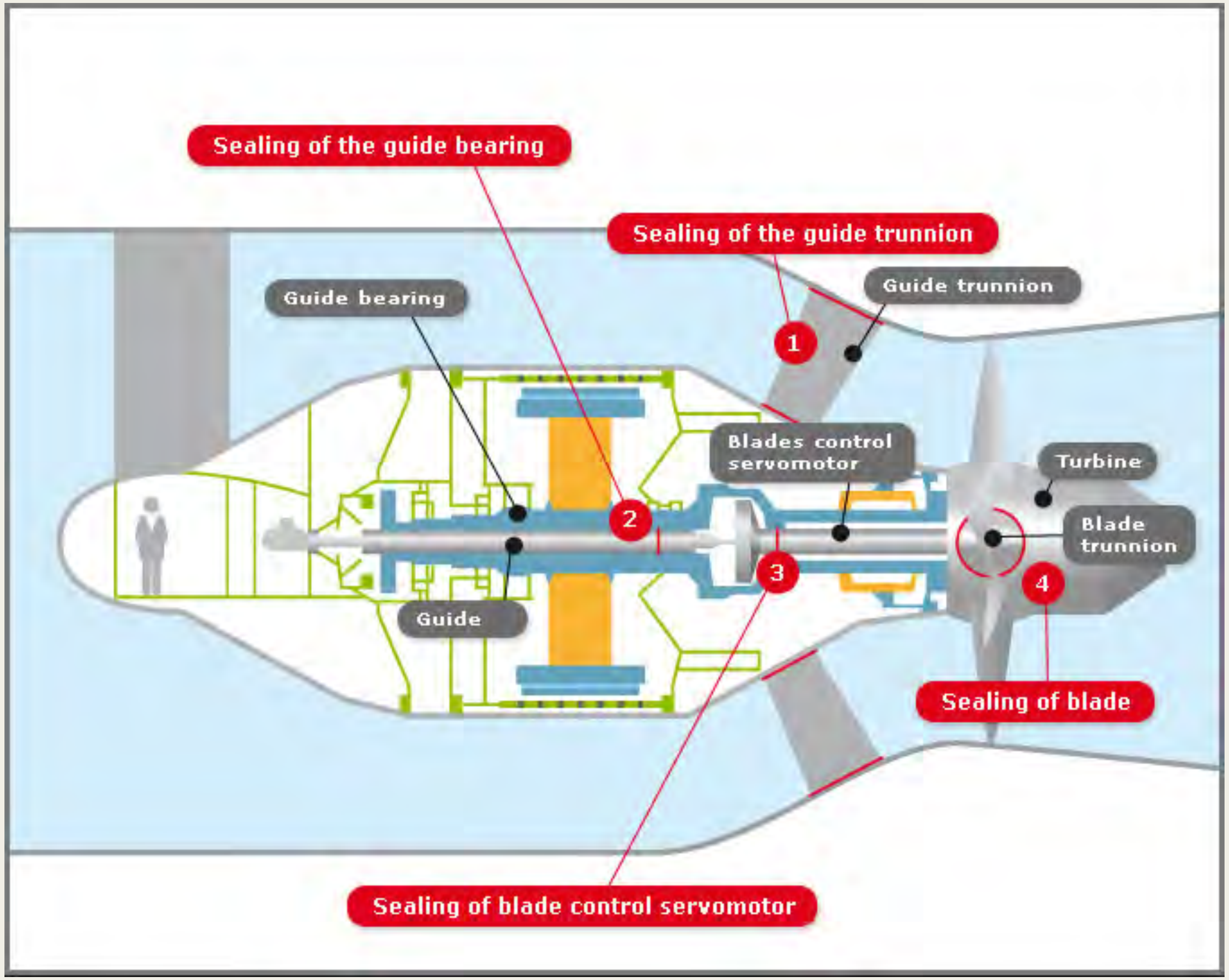
KAPLAN / PROPELLER TURBINE

Kaplan turbine: guide vanes and blades can be regulated;

Propeller turbine: only guide vanes can regulate flow



Related turbine types: Bulb turbine



KAPLAN / PROPELLER TURBINE

Related turbine types: HydroMatrix™

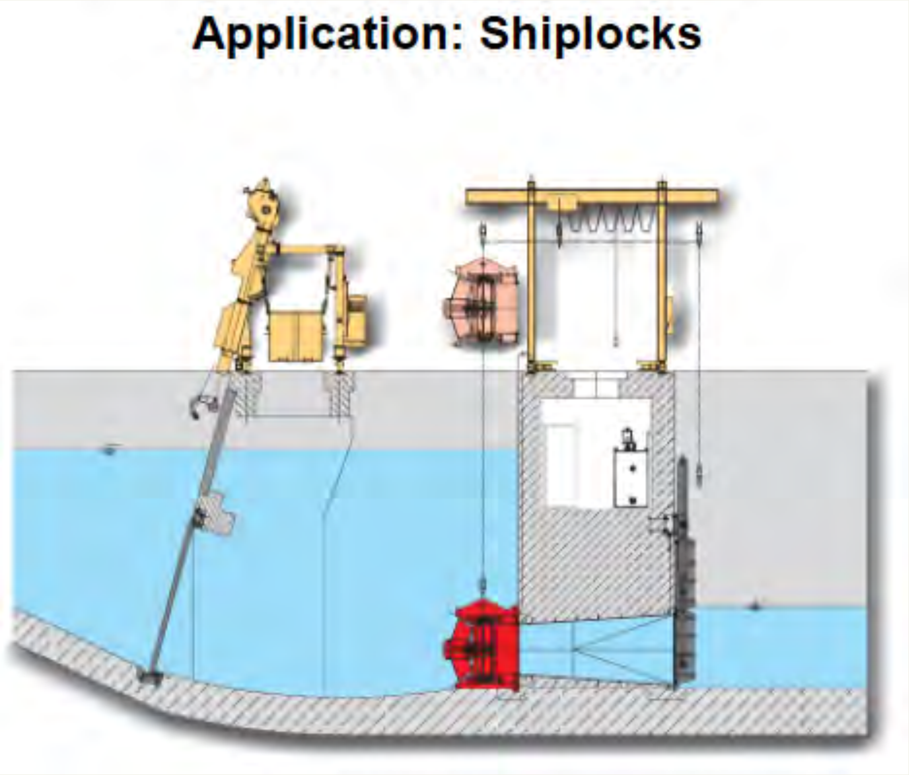
HYDROMATRIX® Experience

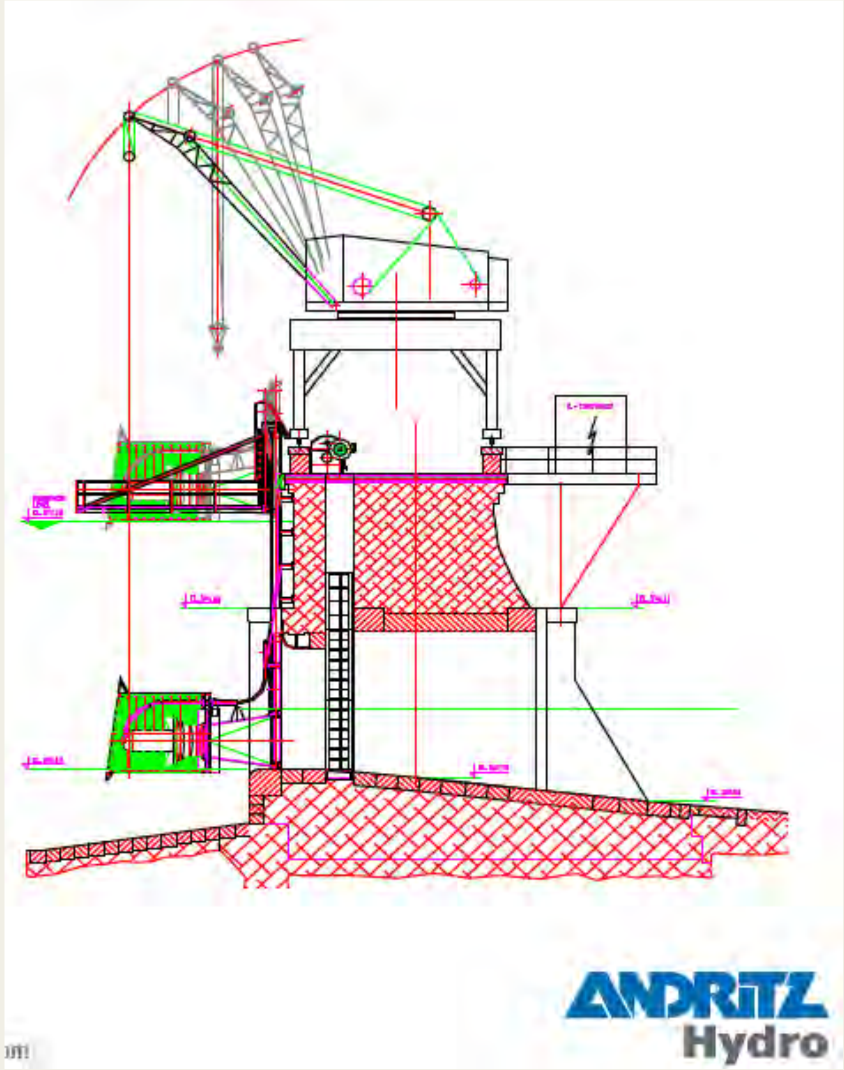
Irrigation Dams – JEBEL AULIA /Sudan

Status November 2003

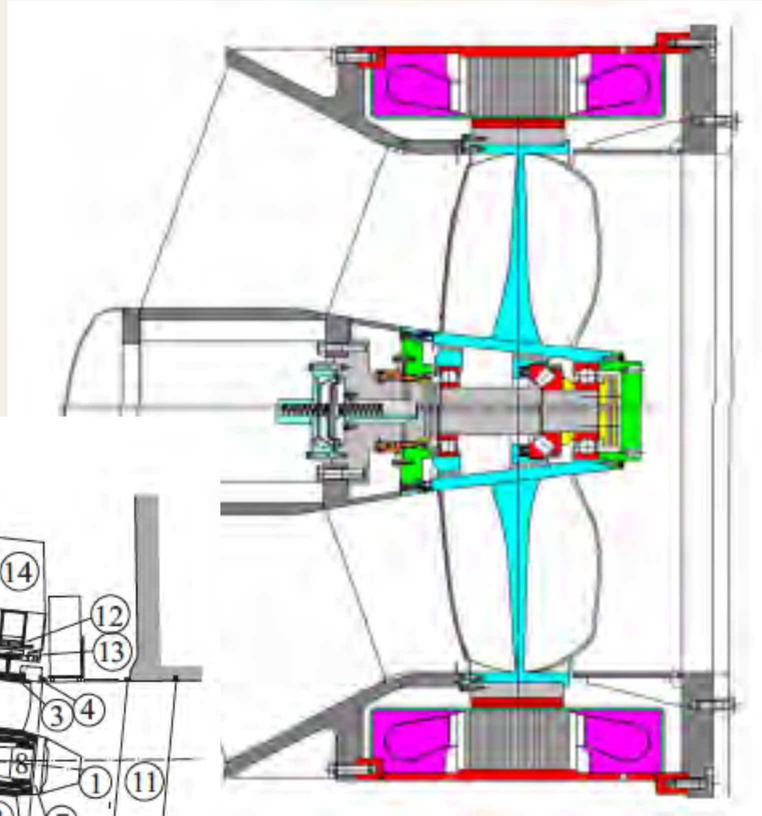
KAPLAN / PROPELLER TURBINE

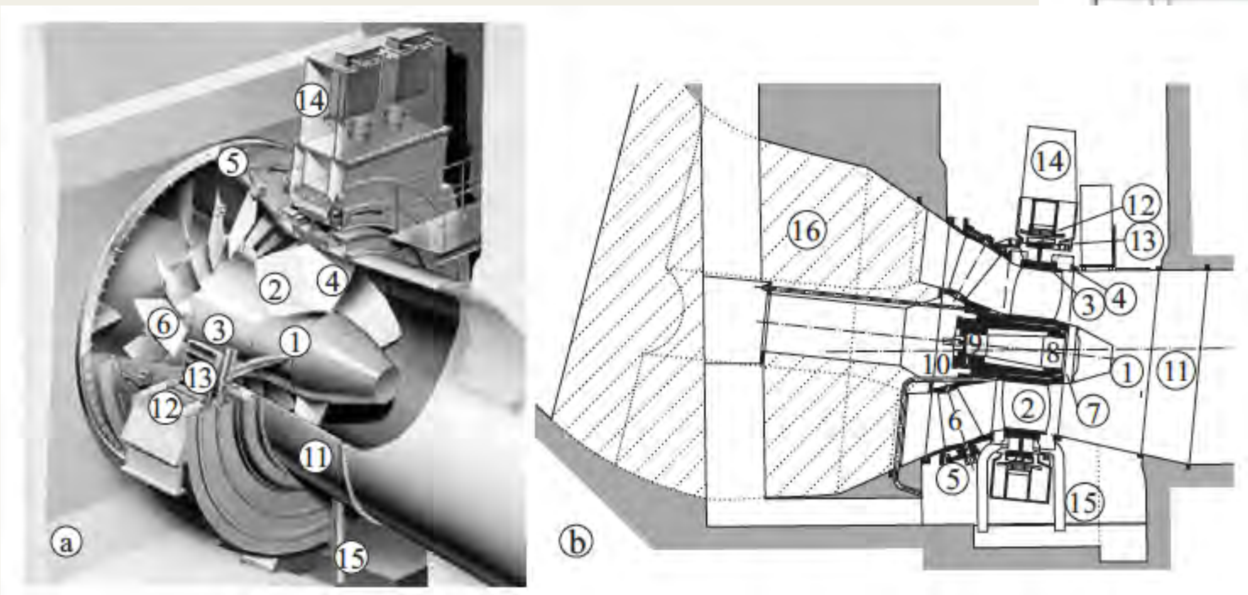
Related turbine types: HydroMatrix™
Some 7 % less efficient than Bulb turbines





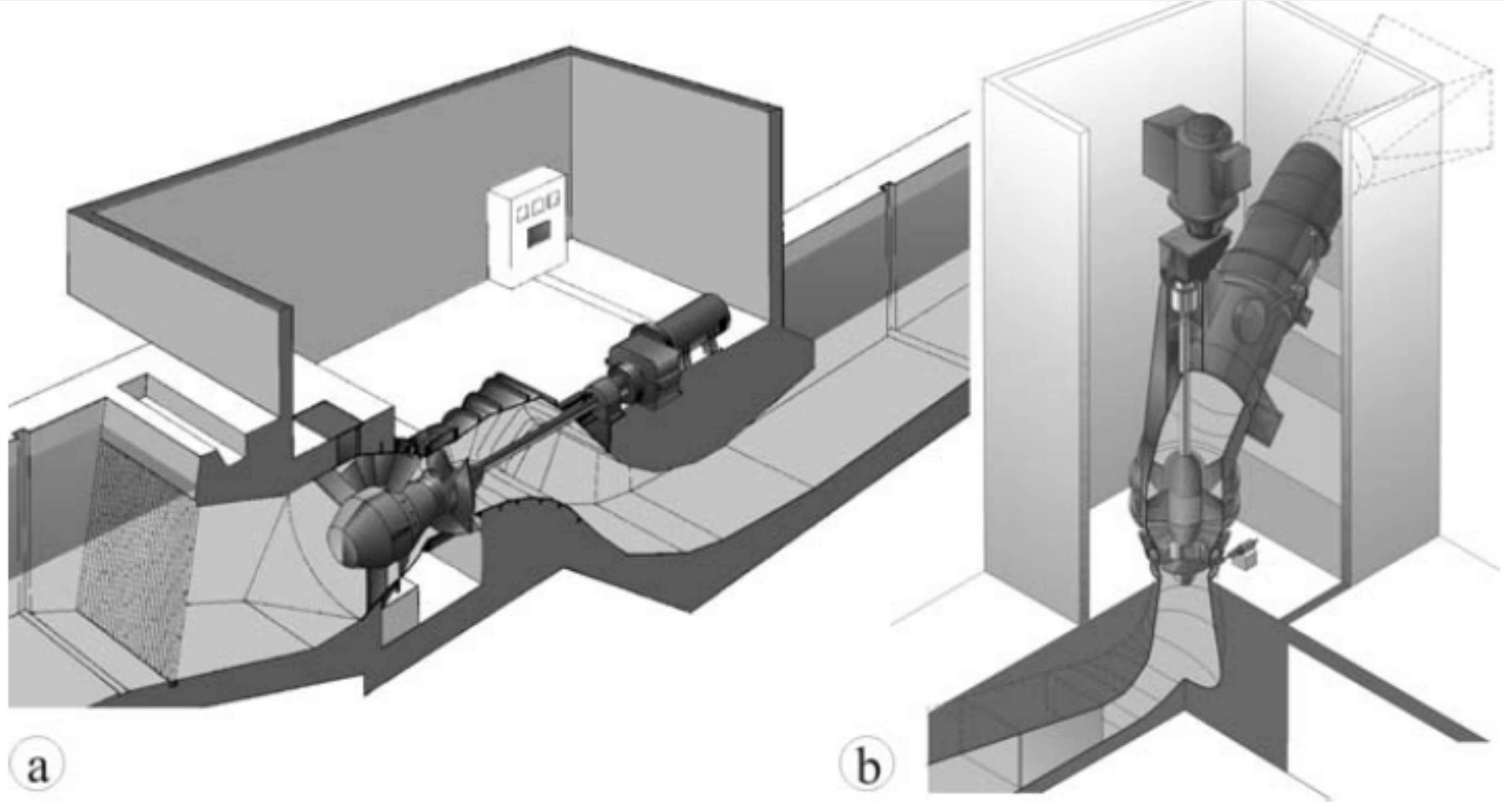
Related turbine types: Straflo Turbine





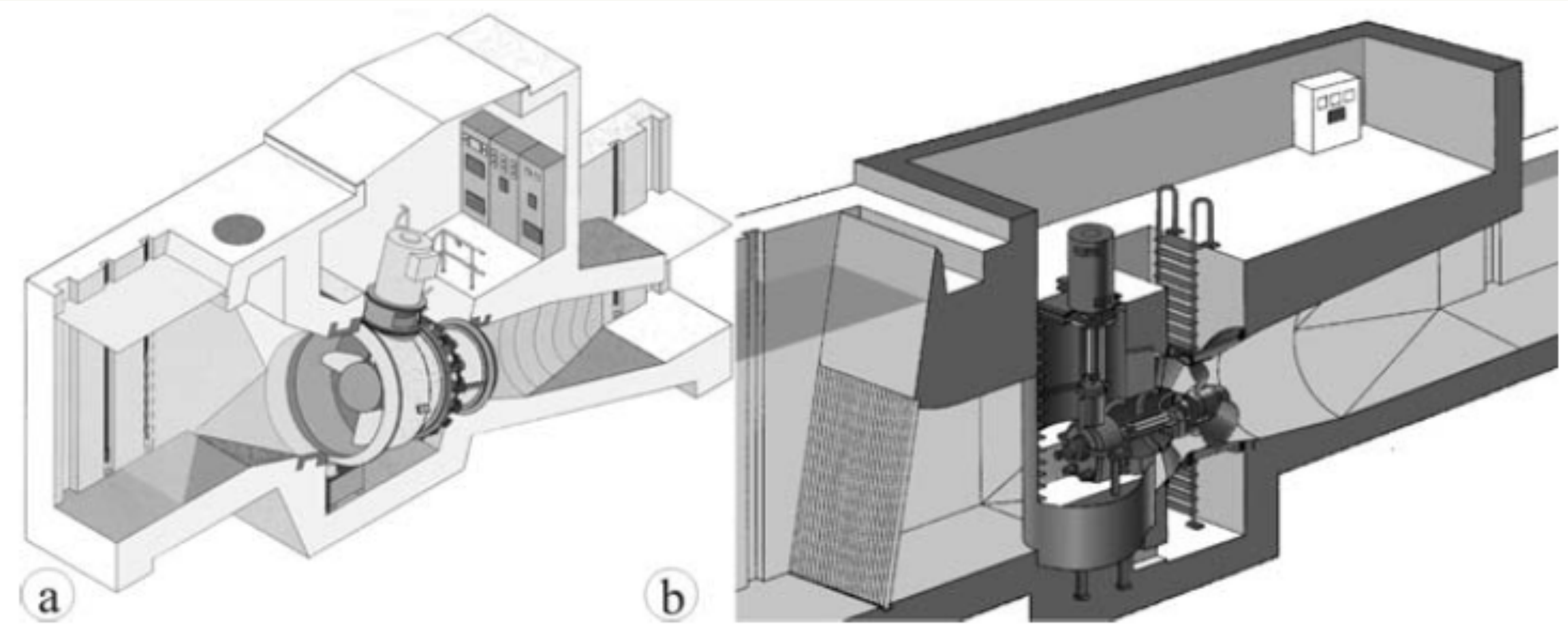
KAPLAN / PROPELLER TURBINE

Related turbine types: S-Bulb turbines



KAPLAN / PROPELLER TURBINE

Related turbine types: Cone-gearbox (a) and Gearbox (b) turbines



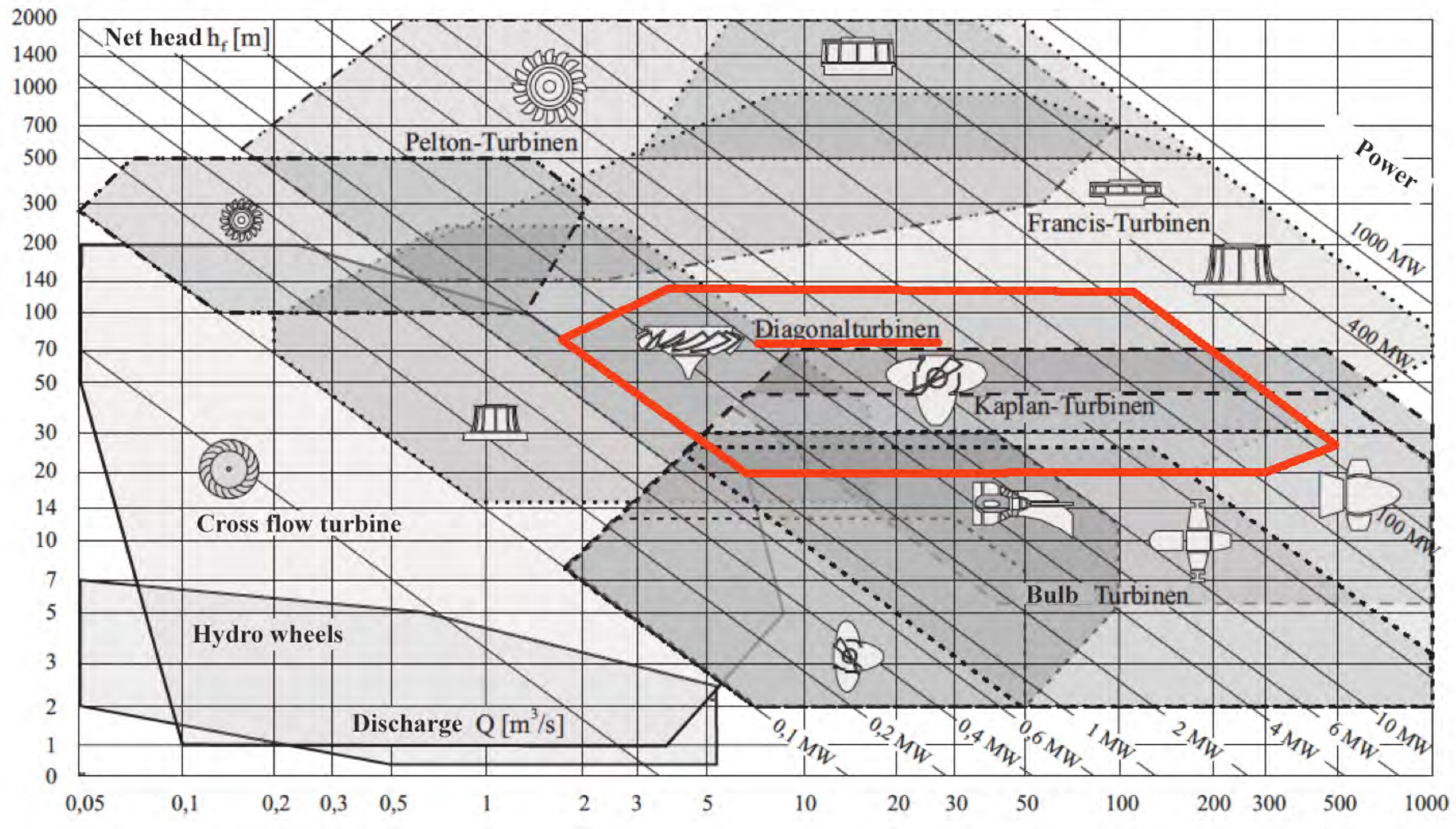
DIAGONAL (OR DERIAZ) TURBINE

Diagonal (Deriaz) turbines: Mix between Kaplan and Francis Turbine

- Reaction turbine
- Shape similar to Francis Turbines
- Double regulated: guide vanes and blades are adjustable
- Medium heads 20 to about 140 m
- Medium and high discharges: 1.8 to 500 m^3/s
- Capacity up to 100 MW per unit

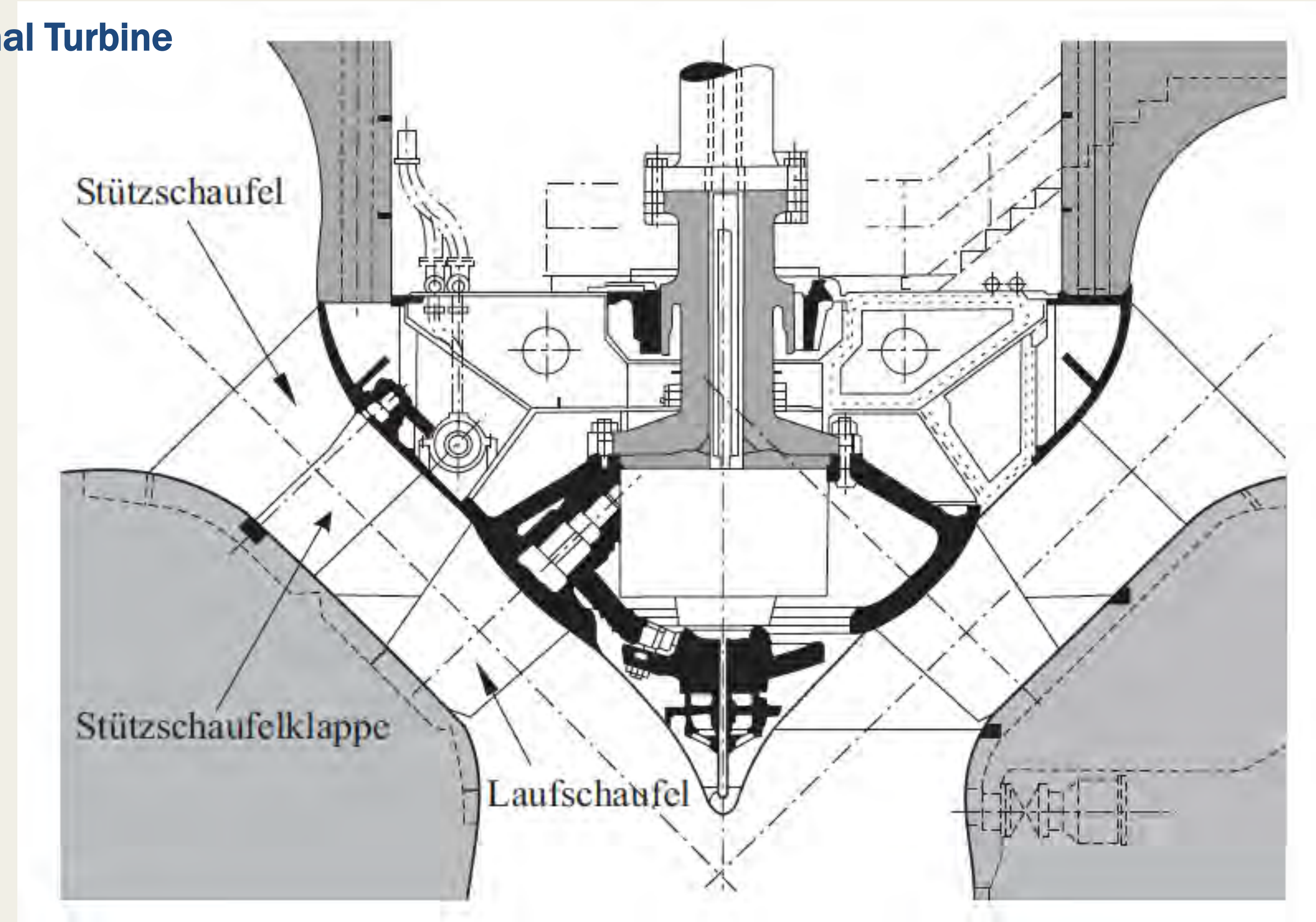
DIAGONAL (DERIAZ) TURBINE

Diagonal (Deriaz) turbines: Mix between Kaplan and Francis Turbine



DIAGONAL (OR DERIAZ) TURBINE

Diagonal Turbine

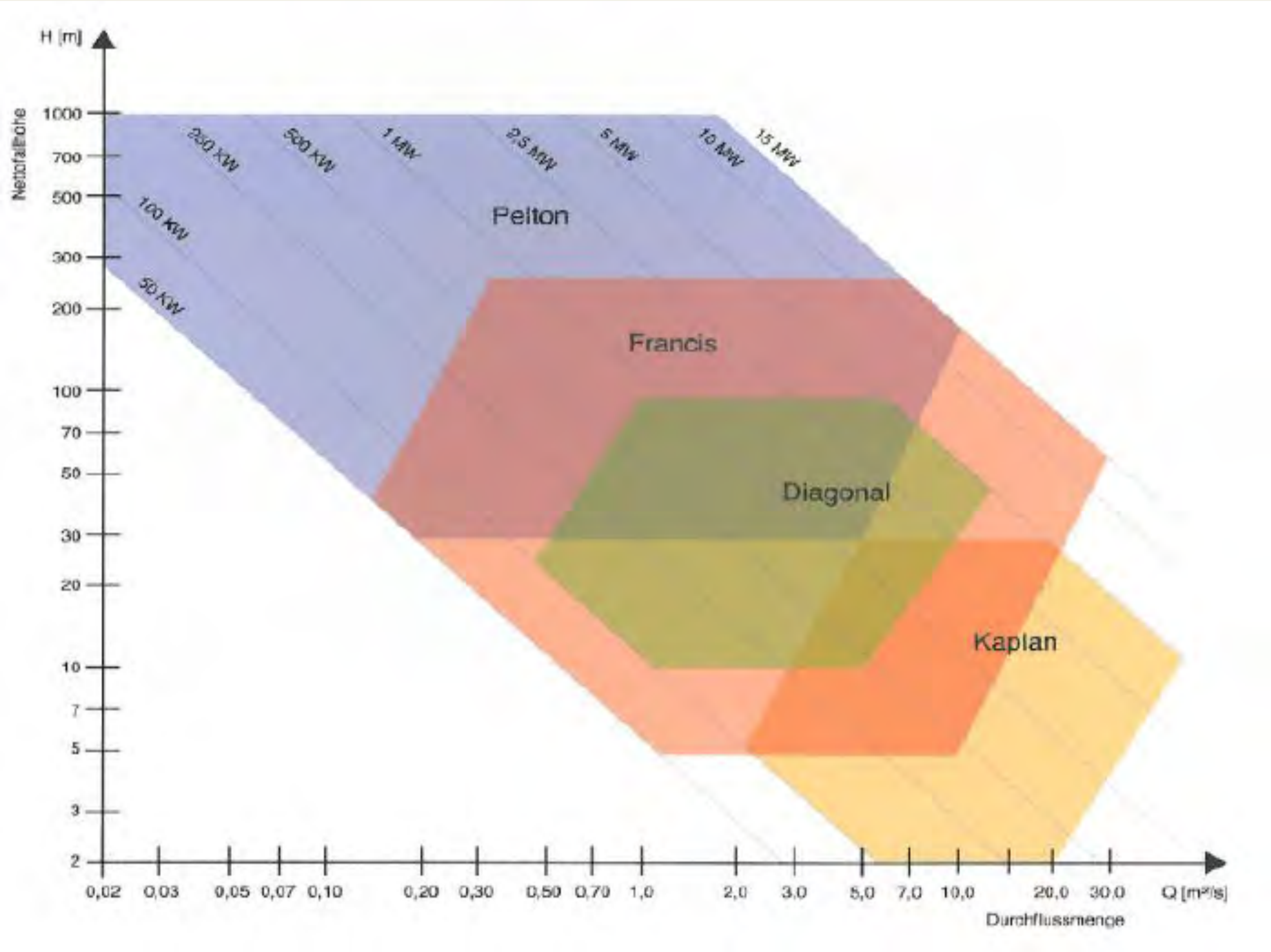


DIAGONAL (OR DERIAZ) TURBINE

Diagonal Turbine

DIAGONAL (OR DERIAZ) TURBINE

Diagonal Turbine efficiencies, Geppert GmbH (Austria)



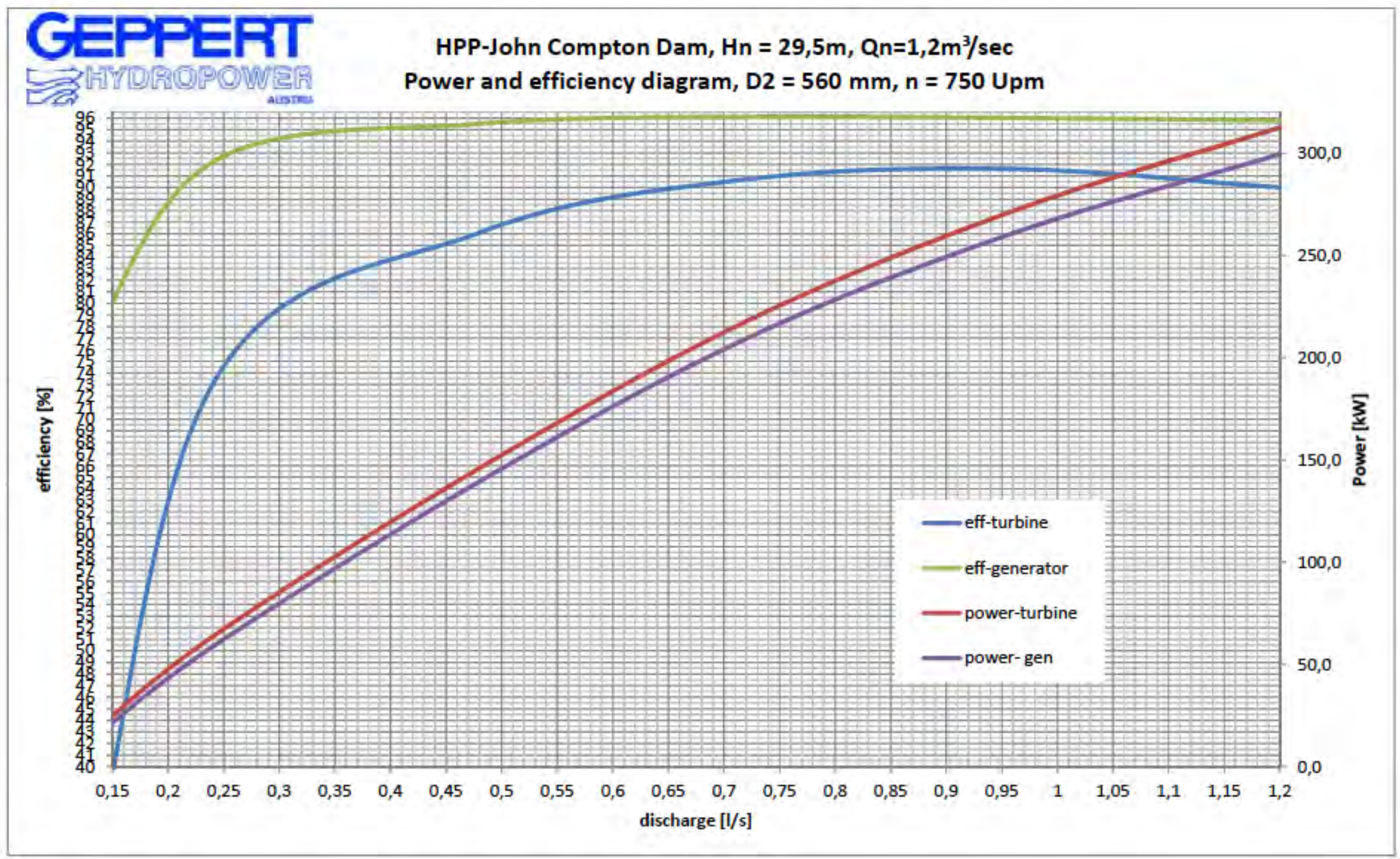
DIAGONAL (OR DERIAZ) TURBINE

Diagonal (Deriaz) turbines: Mix between Kaplan and Francis Turbine

- Reaction turbine
- Shape similar to Francis Turbines
- Double regulated: guide vanes and blades are adjustable
- Medium heads 20 to about 140 m
- Medium and high discharges: 1.8 to 500 m^3/s
- Capacity up to 100 MW per unit
- Typically used for small and medium hydropower projects with storage or run-of-river and high flow variability
- Moderate sensitivity to abrasion through suspended sediments
- Turbine efficiencies of up to some 95 %
- Efficiency curves flat through double regulated blades/guide vanes
- High maintenance

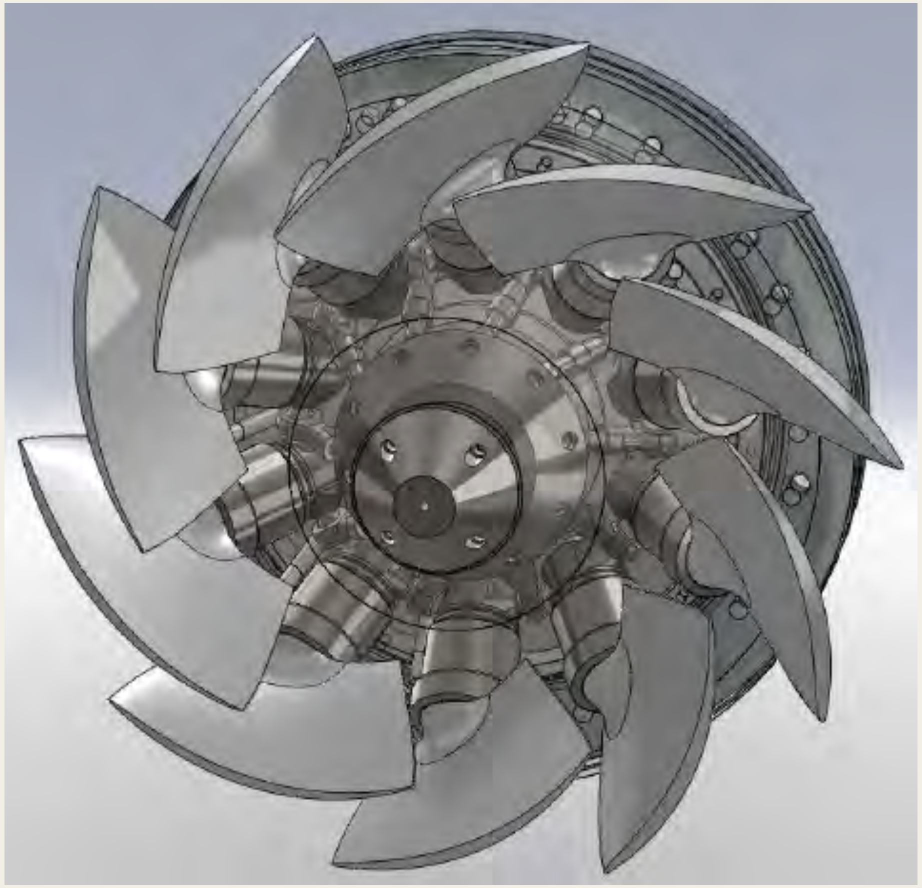
DIAGONAL (OR DERIAZ) TURBINE

Diagonal Turbine



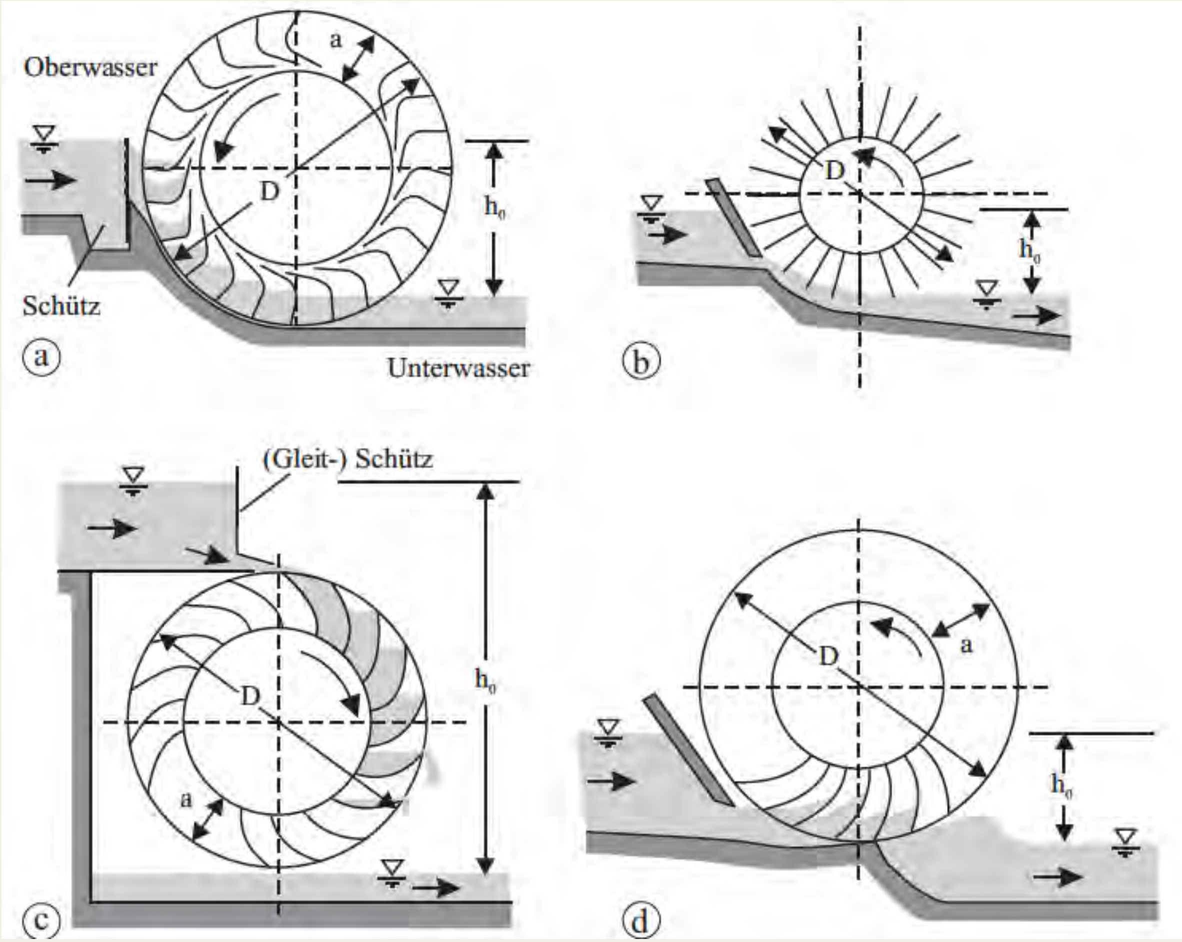
DIAGONAL (OR DERIAZ) TURBINE

Diagonal Turbine



HYDRO WHEELS

(a) Breast wheel with cells
(b) Breast wheel with blades
(c) Overshot wheel
(d) Undershot wheel



HYDRO WHEELS

Breast shot hydro wheel

HYDRO WHEELS

Overshot hydro wheel

HYDRO WHEELS

Breast shot hydro wheel type Zuppinger
$Q = 1.2\ m^3/s$
$H = 1.3\ m$
$P = 10 – 11\ kW$

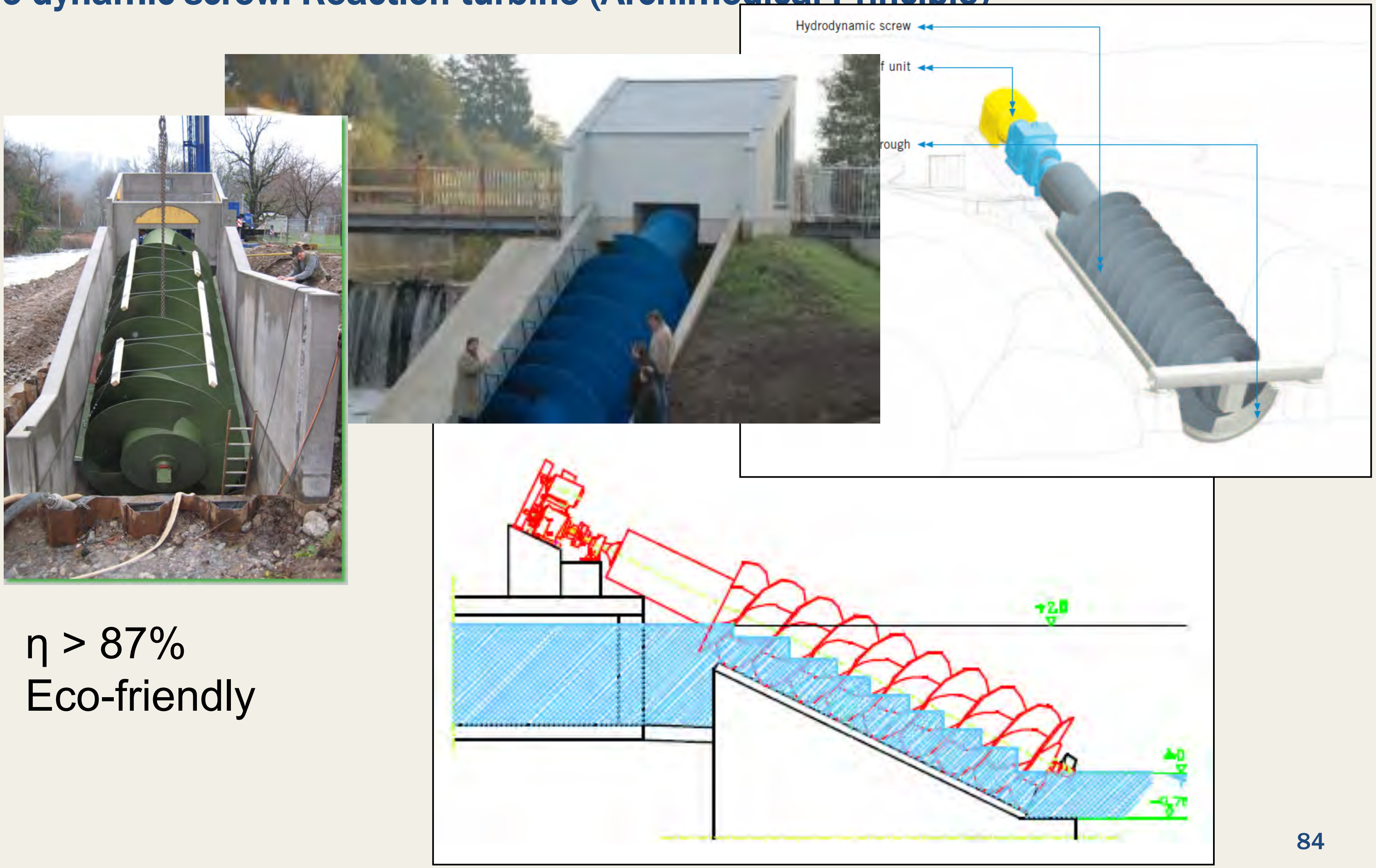
HYDRO WHEELS

Hydro Wheels key data:

- Low heads < about 7 m
- Low discharges up to 5 m^3/s
- Capacity up to 100 kW per unit
- Typically used for small run-of-river hydropower projects, rarely with small storage pond
- Very low sensitivity to abrasion through suspended sediments through slow rotation speed
- Efficiencies of 50 % to some 82 %
- Efficiency curves generally flat with **good partial load efficiency due to slow rotational speed**
- Requires gear box
- Kick-in point at discharges of some 10 % of design discharge
- **Eco friendly**

HYDRODYNAMIC SCREW

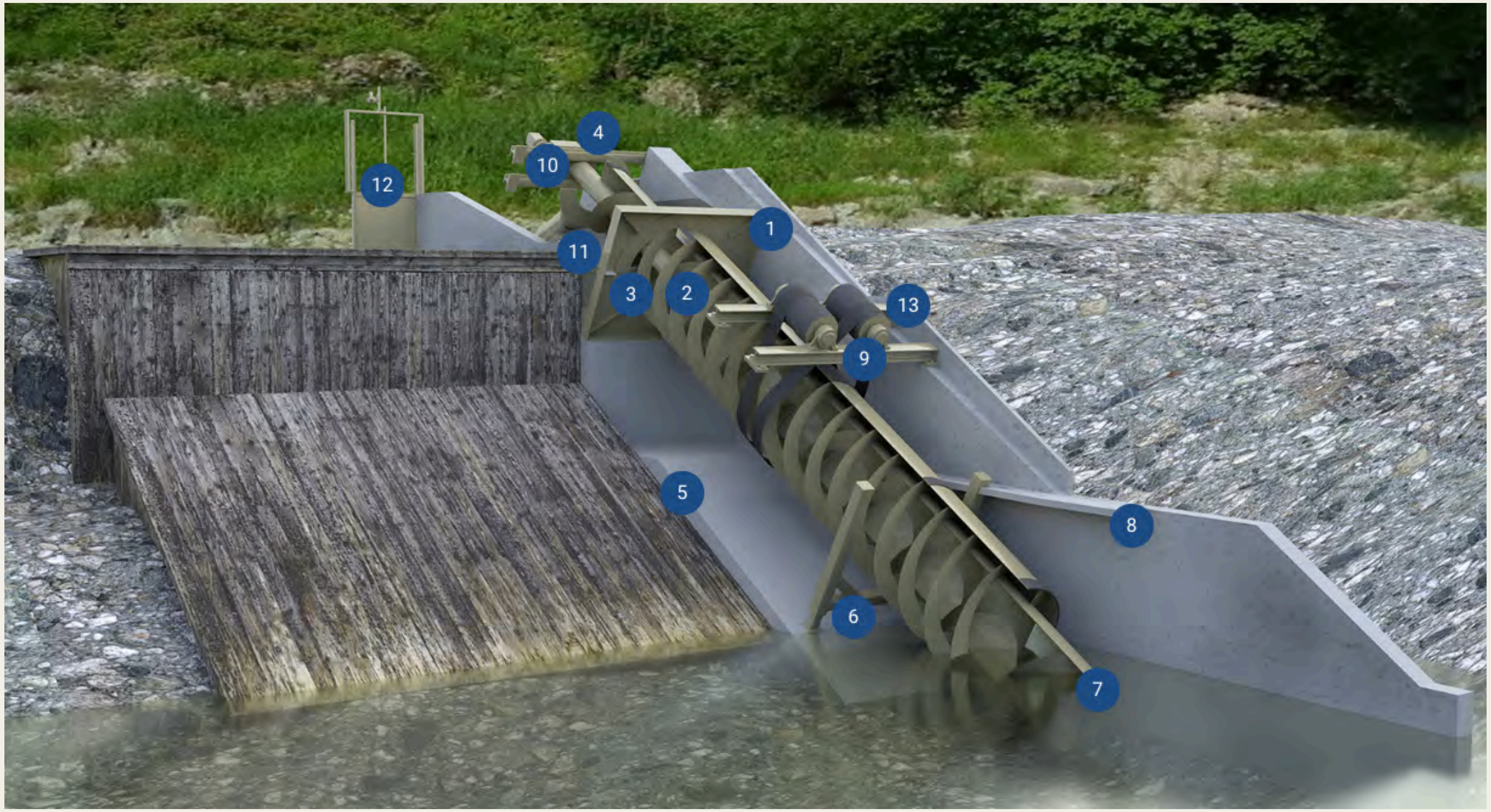
Hydro-dynamic screw: Reaction turbine (Archimedical Principle)



η > 87%
Eco-friendly

HYDRODYNAMIC SCREW

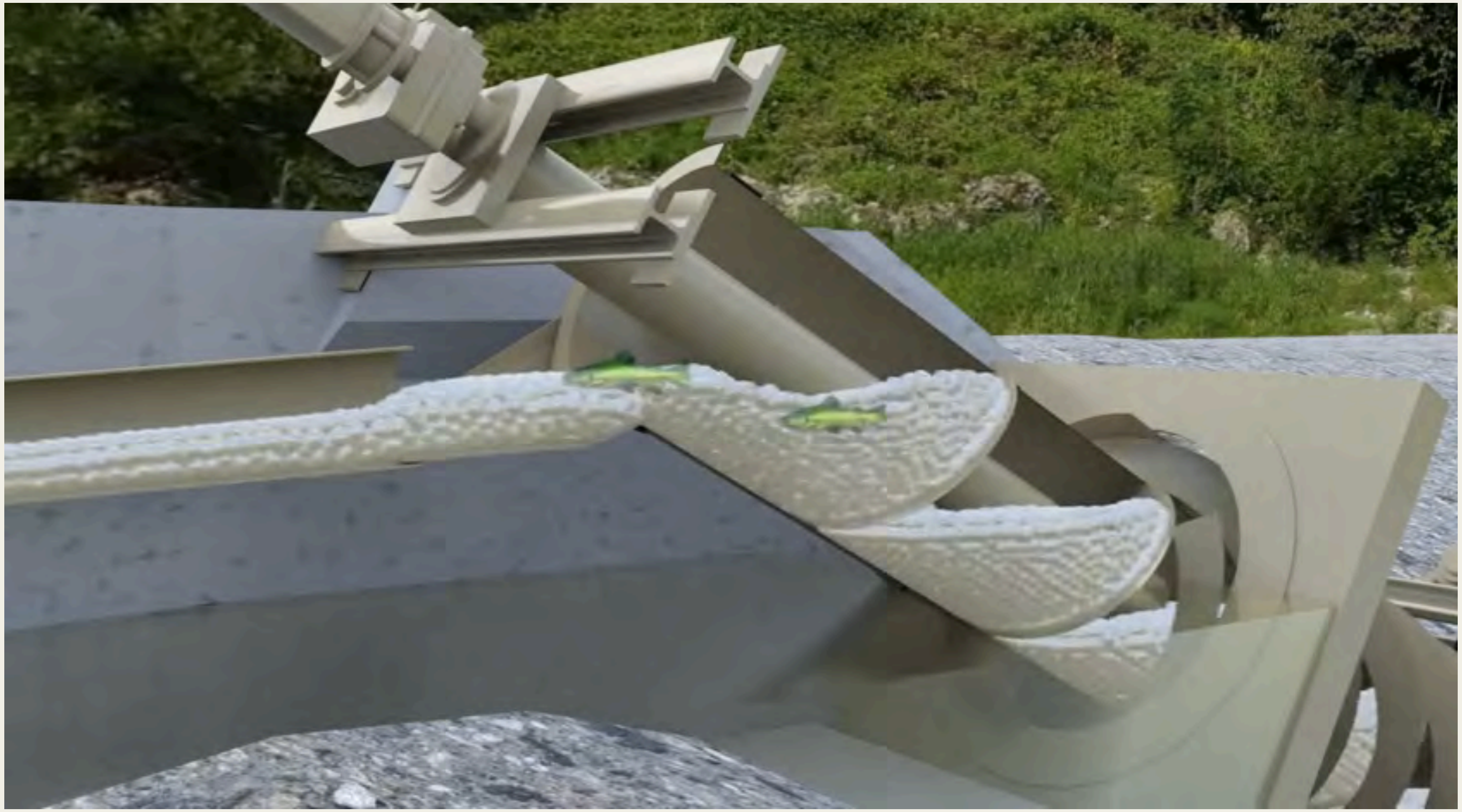
Hydro-dynamic screw also available with integrated fish pass



https://www.youtube.com/watch?feature=player_embedded&v=geh2c0kbfqs

HYDRODYNAMIC SCREW

Hydro-dynamic screw also available with integrated fish pass



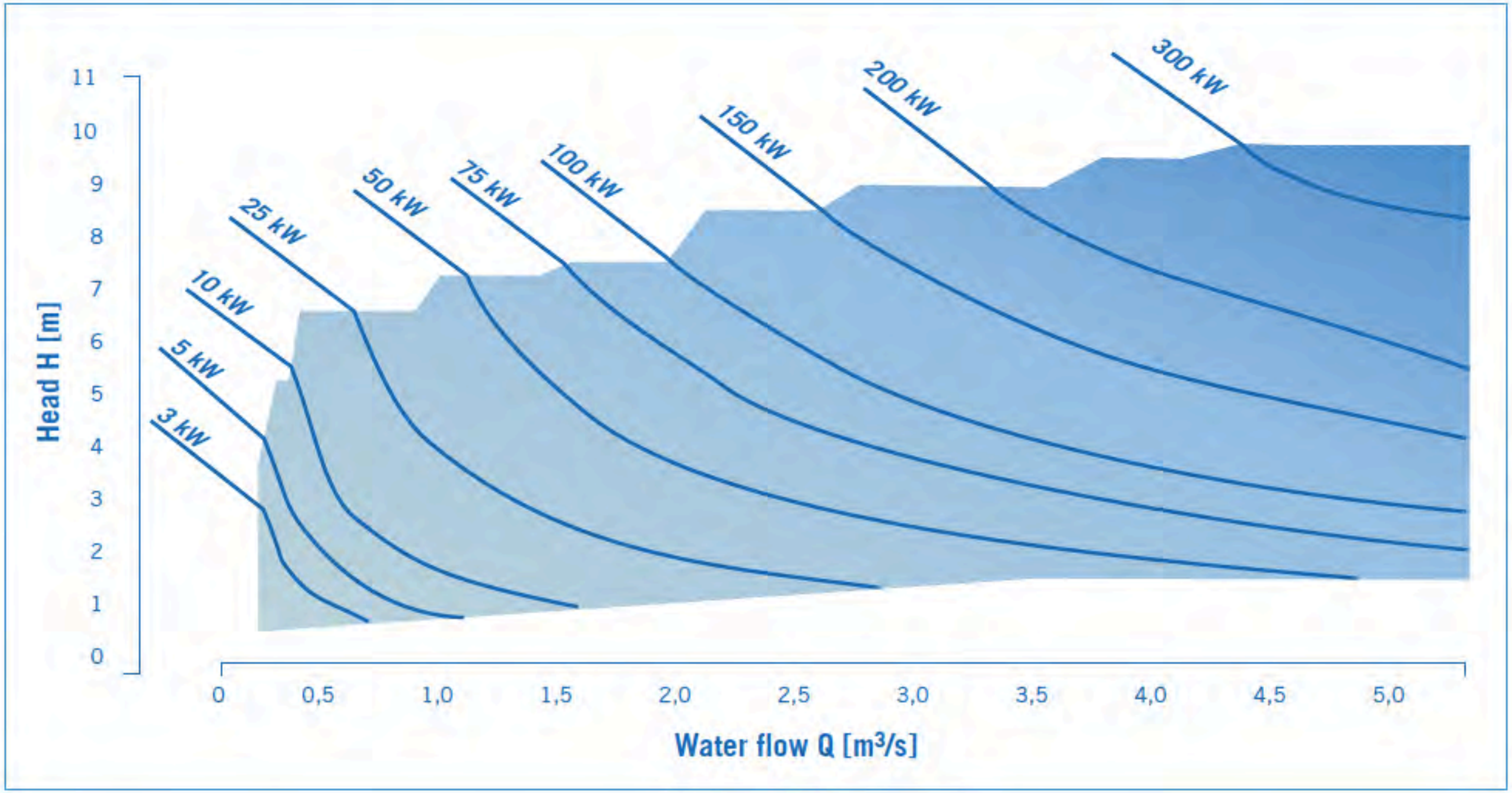
https://www.youtube.com/watch?feature=player_embedded&v=geh2c0kbfqs

HYDRODYNAMIC SCREW

Hydrodynamic Screw key data:

- Low heads of 1.5 to about 10 m
- Low discharges up to 5.5 m^3/s
- Capacity up to 300 kW per unit

Electric power provided to terminals
(Generator Power)



HYDRODYNAMIC SCREW

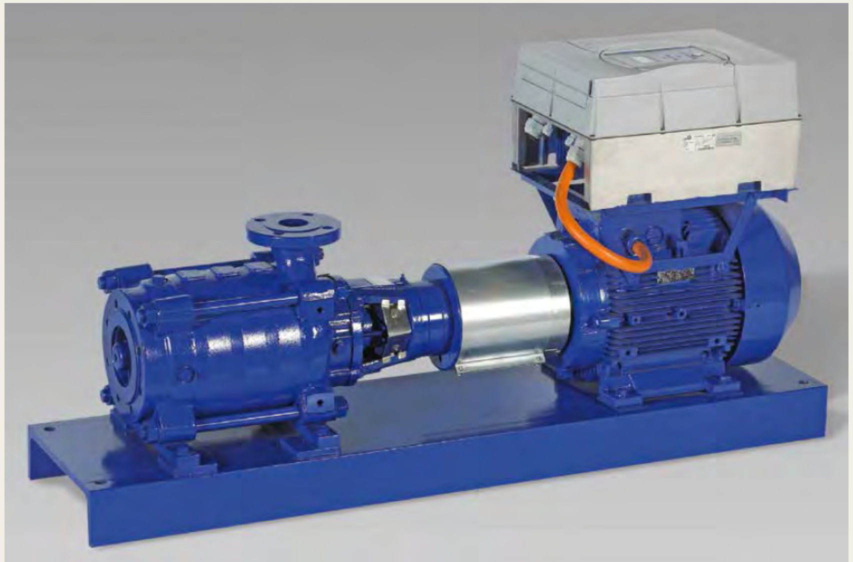
Hydrodynamic Screw key data:

- Low heads of 1.5 to about 10 m
- Low discharges up to 5.5 m^3/s
- Capacity up to 300 kW per unit
- Typically used for small run-of-river hydropower projects
- Very low sensitivity to abrasion through suspended sediments through slow rotation speed
- Efficiencies of up to some 87 %
- Efficiency curves generally flat with **good partial load efficiency due to slow rotational speed**
- **Eco friendly, optional with integrated fish lift**

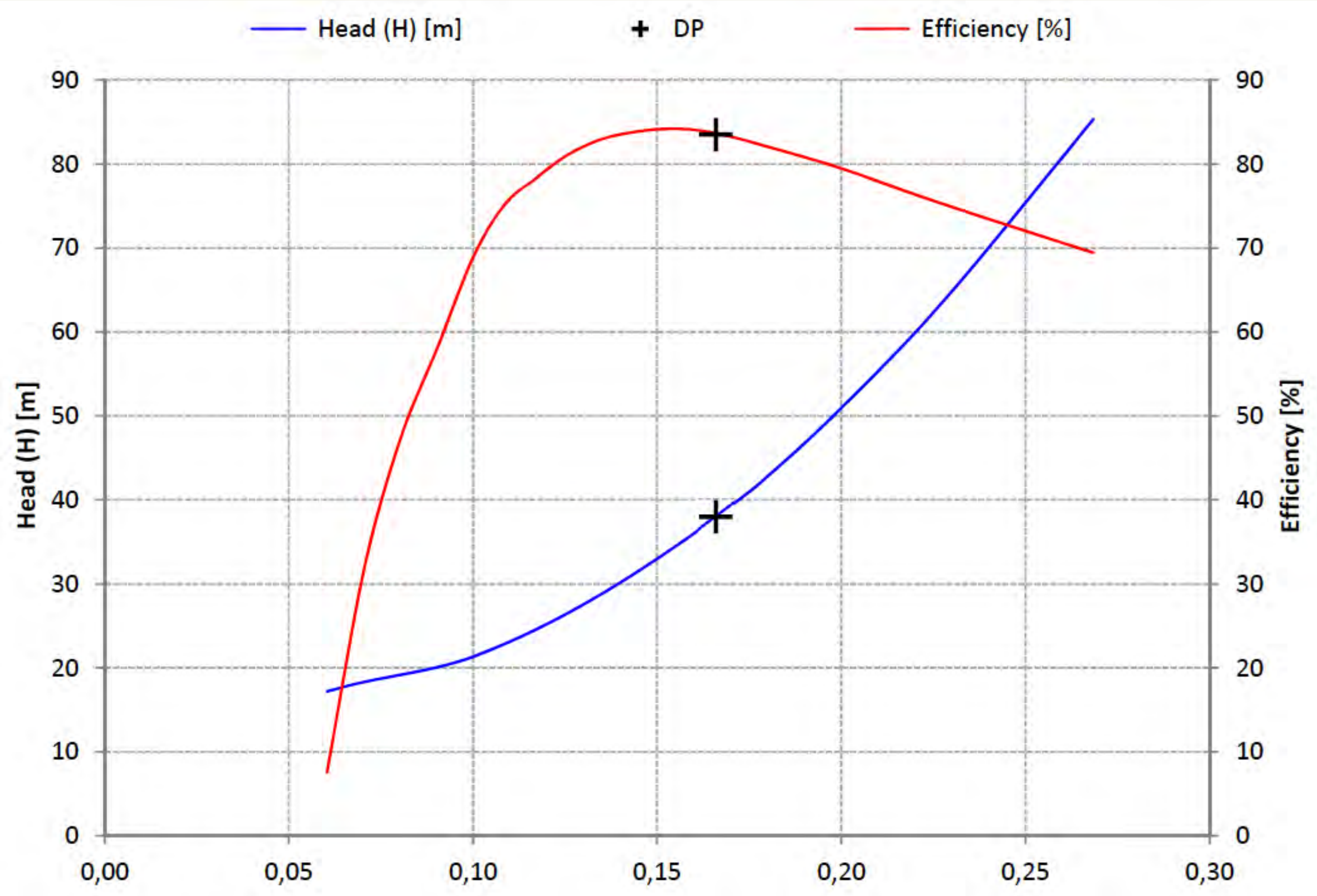
PUMPS AS TURBINES

What is Pumps as Turbines?

- Centrifugal pumps are similar to Francis turbines with fixed guide vanes
- Pumps operated in reverse mode generate electricity
- Disadvantage: efficiency decreases quickly when operation point moves out of optimum

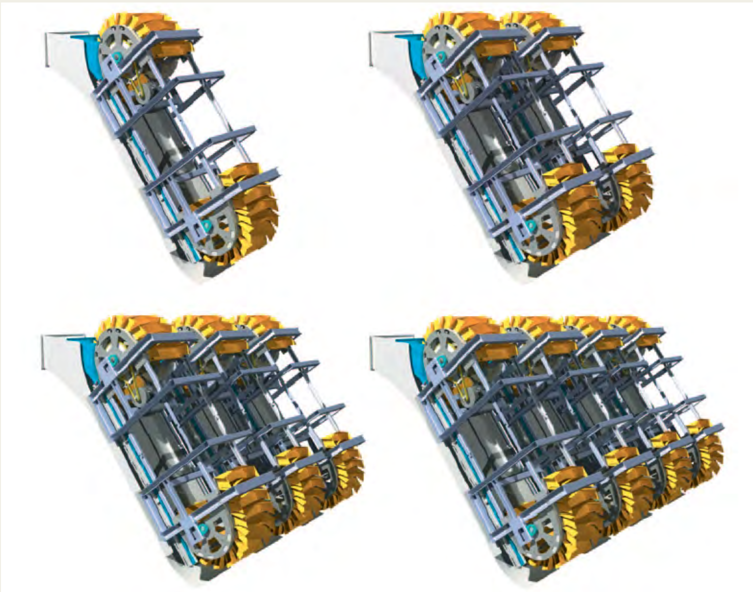


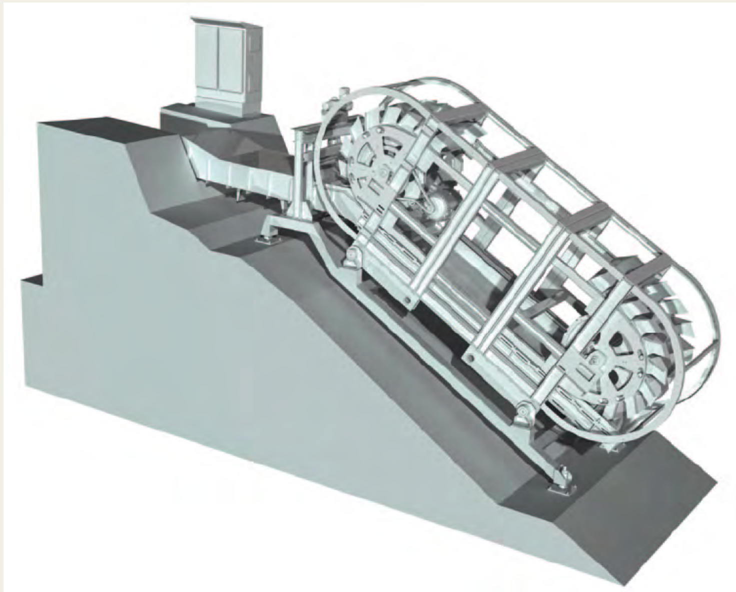
PUMPS AS TURBINES



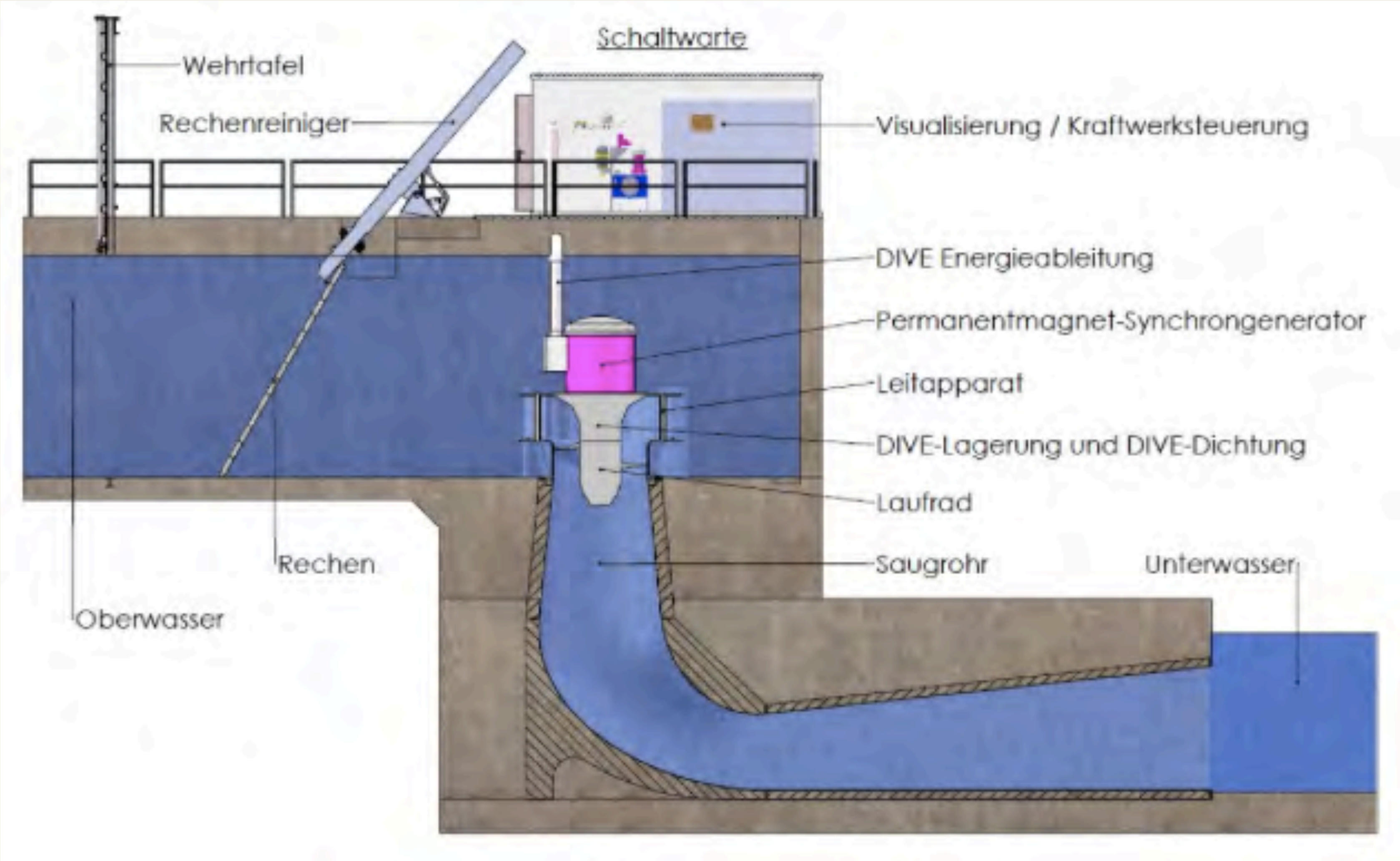
STEFF TURBINE

Steff Turbine





DIVE TURBINE

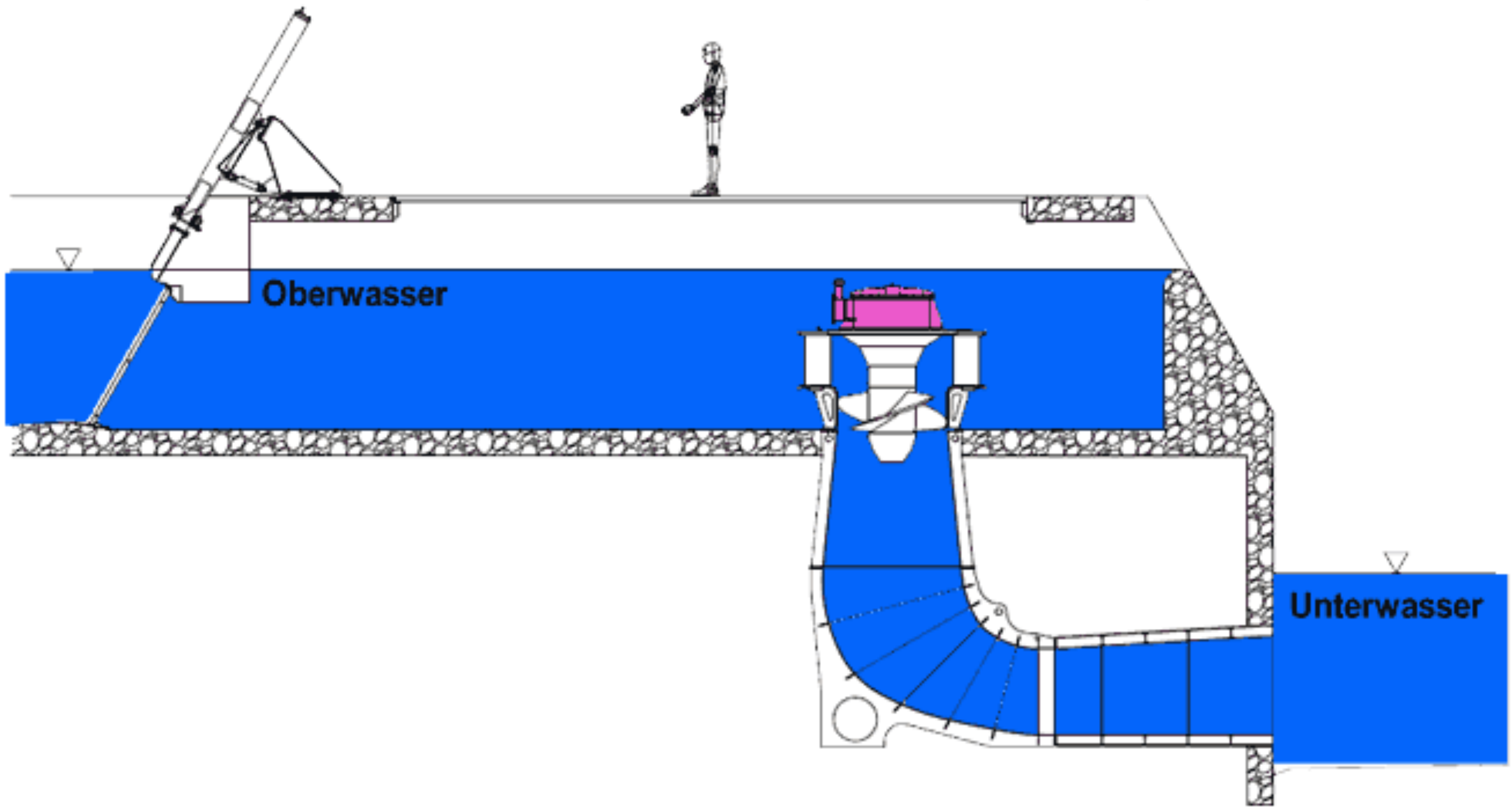


DIVE TURBINE

Dive Turbine key data:

- Principle of a Kaplan Turbine
- Low heads of 2 to about 25 m
- Low to medium discharges of 0.6 to 40 m^3/s
- Capacity of 30 kW to 2 MW per unit
- Permanent magnet generator with frequency converter
- Variable speed drive
- Typically used for small run-of-river hydropower projects
- Submersible design → no need for powerhouse
- Medium sensitivity to abrasion through suspended sediments
- Efficiencies of up to some 87 %

DIVE TURBINE



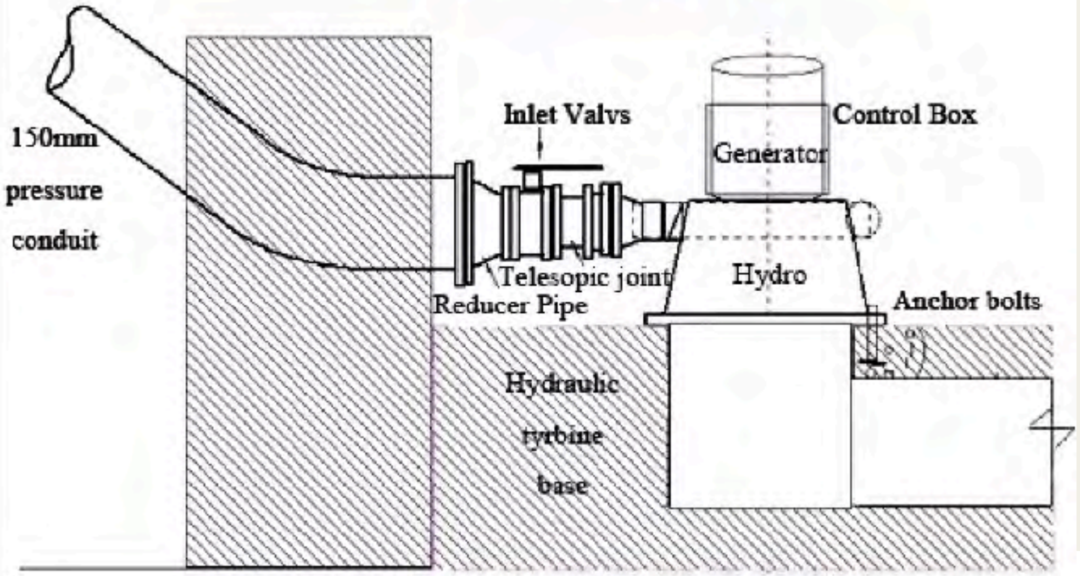
MICRO TURBINE COMPACT SYSTEMS

For very small projects compact turbine packages exist.

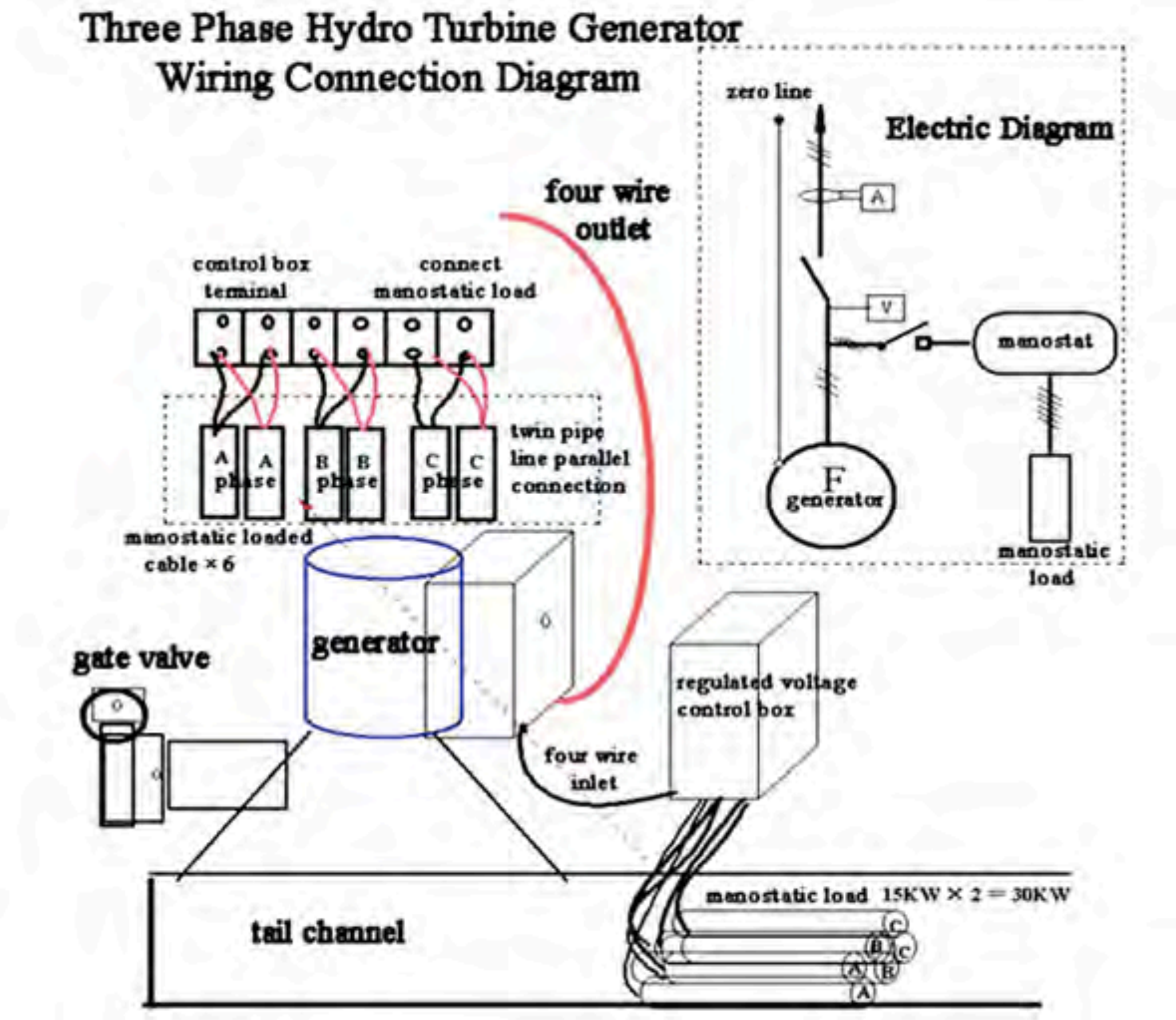
Example: Fuchun Industry from Shenzhen, China

- Turgo and propeller type turbines
- Turgo:
  - H between 12 m and 45 m;
  - Q between 0.003 and 0.120 m^3/s;
  - P between 0.3 and 300 kW
  - One or two nozzles
  - One or three phase permanent magnet generator
- Propeller:
  - H between 4 m and 11 m;
  - Q between 0.045 and 0.165 m^3/s;
  - P between 3.0 and 10.0 kW
- See web-page: http://www.fuchunind.com

MICRO TURBINE COMPACT SYSTEMS



MICRO TURBINE COMPACT SYSTEMS



MICRO TURBINE COMPACT SYSTEMS

Example: IREM Ecowatt Hydro, Torino, Italy

- Pelton and cross flow type turbines
- Pelton:
  - H between 10 m and 350 m;
  - Q between 0.001 (?) and 0.080 m^3/s;
  - P between 0.5 and 100 kW
  - Between one and six nozzles
  - One or three phase permanent magnet generator
- Cross flow:
  - H between 5 m and 60 m;
  - Q between 0.008 and 1.000 m^3/s;
  - P between 1.0 and 100.0 kW
- See web-page: http://www.irem.it/ENG/lines/hydro.html

MICRO TURBINE COMPACT SYSTEMS

The models

Turbine-Generator Group

■ TPS024 ■ TPA024

Pelton turbine with 6-nozzle distributor and 3 regulation valves. Single-phase, brushless, self-exciting synchronous generator, with 2 poles, 230 Volt, 50Hz.

TPA model is equipped with three-phase, asynchronous generator with 2 poles, 400 Volt 50/60Hz. Main ball valve with electric actuator.

Turbine-Generator Group

■ TPS041 ■ TPA041

Pelton turbine, with 6-nozzle distributor and 3 regulation valves. Three/single-phase synchronous, self-exciting, brushless generator, with 4 poles, 400/230 Volt, 50/60 Hz.

TPA model is equipped with three-phase, asynchronous generator with 4 poles, 400 Volt 50/60Hz. Automatic or manual main valve with 3 to 6 manual or automatic regulation valves.

MICRO TURBINE COMPACT SYSTEMS

When ordering packaged systems:

- Is the control system included or not?
- How much civil works are required?
- Warranty period?
- Supply of spare parts and delivery time?
- Labeling of the control system: English, Chinese, Italian,...?
- Easy to operate?
- Shipping costs?
- Online or telephone support available?

ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

ENVIRONMENTAL IMPACT ASSESSMENT

Importance:

- Requirement (legal in most countries and/or for financiers)
- For macroeconomic cost-benefit analysis
- For microeconomic viability of the project
- Anticipated irreversible adverse impacts on the environment may result in the discontinuation of projects!

ENVIRONMENTAL IMPACT ASSESSMENT

<u>Main issues:</u>

- Loss of natural resources, habitats, biodiversity, ecosystem services
- Alteration of the natural environment and its consequences
- Pollution and environmental degradation during construction phase
- Noise pollution from power house (and other noisy equipment)

ENVIRONMENTAL IMPACT ASSESSMENT

<u>Special issues for (large) dams:</u>

- Sediments and nutrients are trapped in dams if there are no low-level outlets
- Reduced oxygen levels in water due to decomposing vegetation in dams
- Release of methane and carbon dioxide from rotting organic matters into the atmosphere
- Mercury contamination in dams
- High rates of water evaporation in tropical climate may lead to significantly reduced water levels downstream
- Reduced water levels downstream might cause loss of floodplains and mangrove forests

ENVIRONMENTAL IMPACT ASSESSMENT

Special issues for (large) dams: (continued)

- Seasonal variations of water levels in the river as well as water temperature are lost through the regulation of the dam's outflow
- Change of air flow patterns have an influence on air quality and subsequently on local flora
- Colonization by aquatic plants
- Dams provide ideal breeding grounds for disease vectors
- Change of fish habitat from river to lake
- Lakes might pose barriers to wildlife migration

ENVIRONMENTAL IMPACT ASSESSMENT

Questions to be answered by an EIA:

Are mitigation measures for all issues possible?

How much do they cost?

SOCIAL IMPACT ASSESSMENT

Importance:

- Requirement in some countries and for some financiers
- For macroeconomic cost-benefit analysis
- For microeconomic viability of the project
- Information, communication and consultation with affected people is essential for a successful project! People who are angry because they feel their concerns are ignored may find ways to stop the project.

SOCIAL IMPACT ASSESSMENT

Main issues and mitigation measures to consider:

- Communication, information and consultation
  - Establish good communications channels with affected people from the start of the project (and keep complaints management in place after construction is completed)
  - Hold open information and consultation meetings for the affected people at the beginning of the project and in regular intervals thereafter; involve the affected people in the project planning
  - Manage expectations carefully: ensure the local population benefits from the project but does not create expectations the project cannot fulfill

SOCIAL IMPACT ASSESSMENT

<u>Main issues and mitigation measures to consider: (Continued)</u>

- Resettlement:
  - Negotiate fair deals with communities that have to be resettled
  - Transparent decision-making processes and consultations with the communities are essential
  - Pay attention to the following:
    - Land rights (customary and statutory land rights might be overlapping, people might not have official land titles)
    - Water rights
    - Gender equality
    - Indigenous people's rights

SOCIAL IMPACT ASSESSMENT

Main issues and mitigation measures to consider: (Continued)

- Compensation:
  - For loss of houses and land, livelihoods, cultural/ religious goods and places, community services
  - Also consider communities downstream whose livelihoods might be endangered through changes in the ecosystems
  - Might include training and initial resources for uptake of new livelihoods

SOCIAL IMPACT ASSESSMENT

<u>Main issues and mitigation measures to consider: (Continued)</u>

- Health issues
- Loss of cultural heritage sites
- Noise pollution
- Social disruptions
- Large, especially cross-border projects add political component and issues with water rights and water usage on a national level

SOCIAL IMPACT ASSESSMENT

Positive social impacts might include:

- Development impulses through access to electricity
- Education benefits through access to electricity
- Health benefits through access to clean water

SOCIAL IMPACT ASSESSMENT

The positive and negative impacts must be put in relation to one another!

SOCIAL IMPACT ASSESSMENT

<u>Assessment of the Ability and Willingness to Pay for Electricity:</u>

For electrification of unserved areas, including communities affected by the hydropower plant

Importance:

- Serves to project electricity demand
- Informs electricity tariff setting
- Projection of electricity sales and income important for the economic analysis of a project
- Projected demand, increase in demand and purpose of electricity use should inform the grid design

SOCIAL IMPACT ASSESSMENT

Data to be collected:

- **Demographic data** (population and growth rate, migration patterns, seasonal variations)
- **Economic data** (livelihoods, economic growth, possibilities to increase cash income)
- **Electricity-specific data** (types of users: residential/ commercial/ industrial and their relative share; projected initial and overall connection rate; projected amount of electricity demanded; projected increase in the electricity demand over time; types of electrical equipment to be used)
- **Training needs among the population**

INTERRELATION OF EIA AND SIA

- Social and environmental impacts are closely related, especially in developing countries, as people often depend on the environment for their livelihoods
- People who are adversely affected by the project and feel they do not benefit enough from the project might find environmental impacts as reasons to stop the project!
- Access to electricity and clean water for communities affected by the project should be ensured

ENVIRONMENTAL & SOCIAL IMPACT ASSESSMENT

Conclusions:

- The importance of ESIAs must not be underestimated
- ESIAs should not be viewed as additional bureaucratic hurdles to overcome, but as an instrument to inform the debate about the costs and benefits of a proposed project and its viability
- Impact mitigation costs must be considered in the economic viability analysis of a project
- Local population must participate in the benefits of the project and not just bear the costs

ENVIRONMENTAL & SOCIAL IMPACT ASSESSMENT

Conclusions (continued)

- Expectations, concerns and grievances of affected population must be considered and managed carefully; otherwise conflicts will arise, which is very costly: angry people might find ways to stop projects
- High adverse environmental or social impacts may be a reason to discontinue a project
- But: environmental and social costs should not be compared to status quo (zero development) but instead to costs of realistic alternatives

HYDROPOWER CIVIL DESIGN OPTIONS: DIFFERENCES, ADVANTAGES AND DISADVANTAGES

Characteristic ciphers of hydropower projects

Development factor
Is the ratio of mean river discharge and plant design discharge;

Plant Factor
Is the ratio of the average power load of a plant to its rated capacity; (kW)

Capacity factor
The net capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it was possible for it to operate at full nameplate capacity continuously over the same period of time. (kWh)

Availability factor
The availability factor of a power plant is the amount of time that it is able to produce electricity over a certain time period.

Characteristic ciphers of hydropower projects

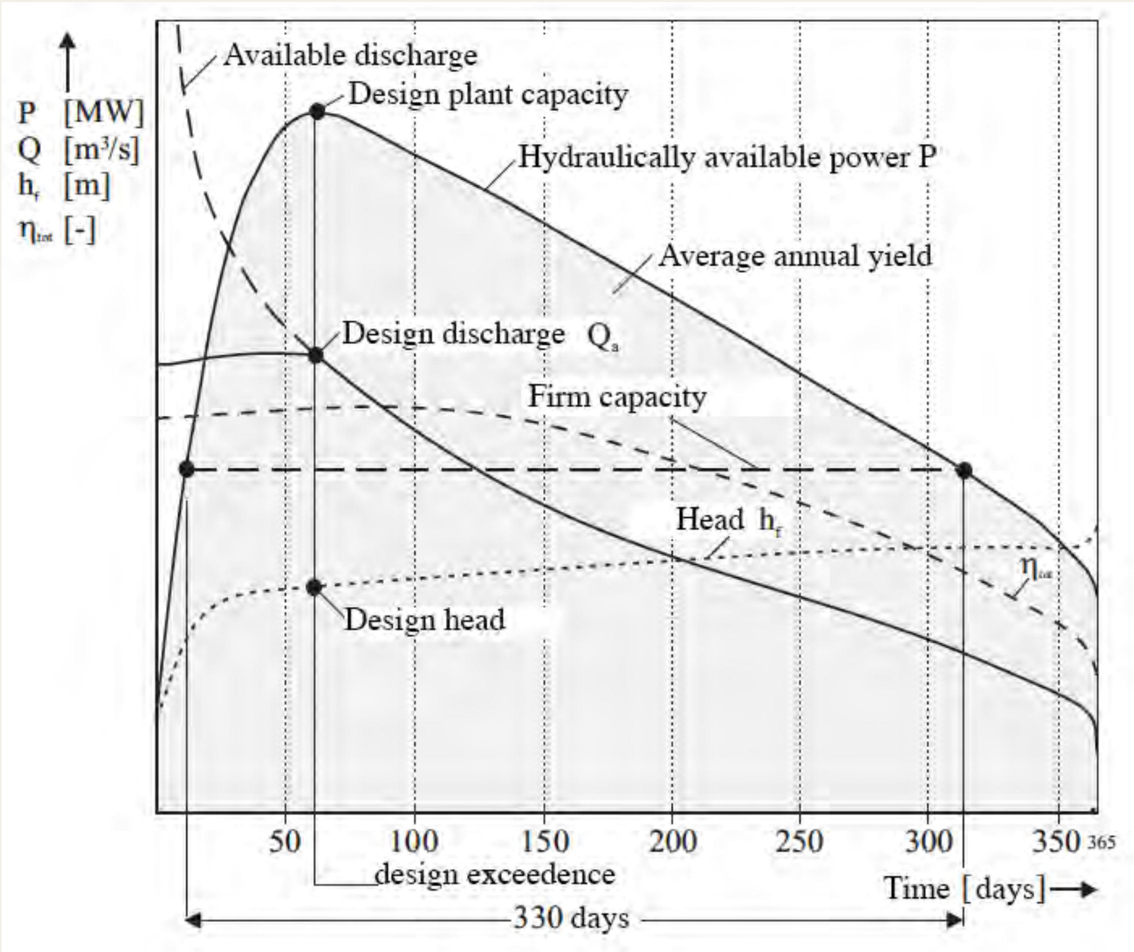
Load factor

Load factor for a power plant is the ratio between average load and peak load.

Operational efficiency

Is the ratio of the total electricity produced by the plant during a period of time compared to the total potential electricity that could have been produced if the plant operated at 100 percent in the period.

Yield diagram of a hydropower project



Power and energy calculations

Purpose: to estimate annual electricity generation and annual benefits.

Input parameters:

- Available flow
- Residual flow
- Hydraulic characteristics of the waterway
- Tailwater level
- Turbine operational characteristics (cut-in and cut-out points)
- Turbine efficiency function
- Generator efficiency function
- Transformer efficiency function

(Excel Spreadsheet)

Plant optimization and design criteria

Hydropower projects can be optimized for different criteria:

- Maximum power output;
- Minimum electricity generation cost;
- Maximum power availability and reliability;
- Maximum flexibility;
- Provision of grid system services;
- Pumped storage;
- Other parameters that deem fit.

Depending on optimization objective the structural design will change.
More details in a later session.

Plant optimization and design criteria

Each individual element of a hydropower plant is optimized using value engineering criteria:

“Value engineering (VE) is systematic method to improve the "value" of goods or products and services by using an examination of function.
Value, as defined, is the ratio of function to cost. Value can therefore be increased by either improving the function or reducing the cost.
It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements.”
(Source: Wikipedia)

Plant design criteria

For design criteria of hydraulic structures refer to:
"Hydraulic Design Criteria, Volume 2" of the US Army Corps of Engineers, 1987

- Powerhouse design criteria are mainly governed by the data provided by the equipment manufacturer.
- The electricity grid operator provides design criteria for electrical equipment.
- Other design criteria may apply depending on the project.

PRINCIPLES OF GOOD PROJECT LAYOUT DESIGN

- When visiting a site for the first time, or watching a topo map, an initial project layout should be visualized
- Logically: Upstream = water in; Downstream = water out
- Dam and reservoir or Run-Off River?
- Pressure head
  - High head (h > 50 m)
  - Medium head (15 m < h < 50 m)
  - Low head (h < 15 m)
- Water availability
- General geology
  - Solid rock
  - Soil and rock
  - Soil and sand
- Look for good geology for the various structures!

PRINCIPLES OF GOOD PROJECT LAYOUT DESIGN

- Try to avoid areas of high population density for project design → avoid need for resettlement and lengthy disputes
- Try to maximize the hydropower potential of each site with the layout design. If the potential is more than the power needed for supply, a stage wise construction can be envisaged.
- Integrate environmental considerations (fish ladders, minimum flow donation, and so on) in your design to avoid additional cost when these items are required later in the process
- Consider sediment handling to be a serious aspect
- Do not omit the bottom outlet at dams and reservoirs
- Design with realistic redundancy: black start hydropower plant instead of diesel generators
- Do not save on safety aspects

WATERWAY HYDRAULICS

Important design aspect: Reducing Hydraulic Losses

Remember:

H_n = net head in m

Gross Head depending on

→ Topography

- Mountain or valley
- Dam, run-off river or diversion

Net Head depending on

→ Friction losses

- Pipe diameter/canal dimensions
- Pipe/canal roughness
- Length of pipe/canal

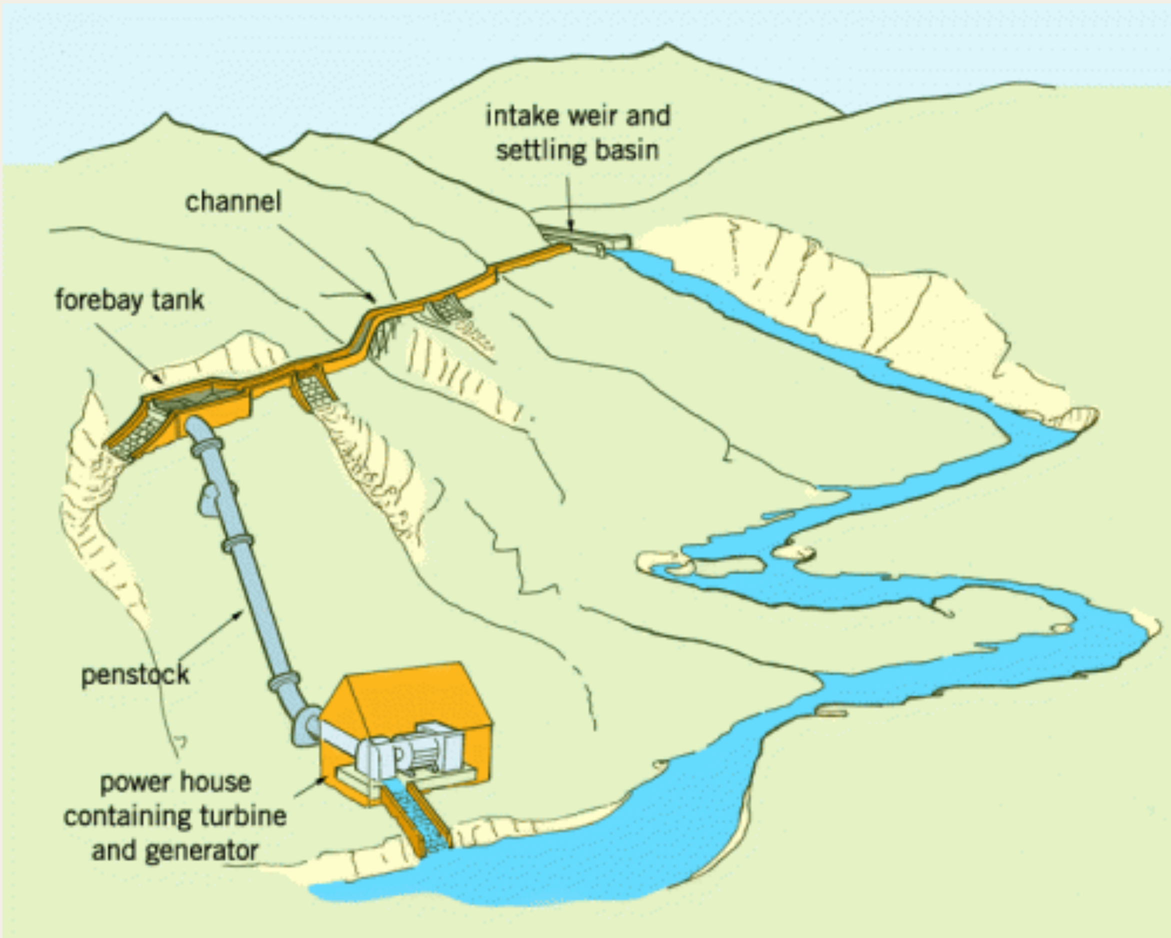
→ Other hydraulic losses

- Trash rack
- Bends
- Valves

Net Head???

WATERWAY HYDRAULICS

Hydraulic losses occur due to water moving over surfaces or along or against structural elements in the waterway.



WATERWAY HYDRAULICS

Losses are caused mainly by the water’s viscosity.

Inner friction converts loss energy into

- heat,
- turbulence, and
- sound energy

WATERWAY HYDRAULICS

Hydraulic losses typically originate from:

- Water intake
- Trash rack
- Friction losses in open channels
- Desilting chamber due to deceleration of water velocity
- Pipeline intake, forebay
- Friction losses in pipelines
- Valves and other fittings
- Bends in pipes and channels
- Changes in cross section size
- Bifurcations and merging y-pieces and similar
- Losses in the turbine itself; these are usually included in the turbine efficiency
- Draft tube
- Tailrace channel turbulence

WATERWAY HYDRAULICS

- Calculation of the hydraulic losses → hydromechanics principles
- Main sources of hydraulic losses: friction losses in open channels and pipelines, bend losses and valve losses
- Poorly designed structures: also desilting basin losses and changes in cross section area are significant

→ good understanding of the hydraulic principles is important to establish good hydropower designs

Generally, hydraulic losses are quantified as loss head h_v in [m]

$$h_{v,i} = \zeta \cdot \frac{v^2}{2g}$$

Where

$h_{v,i}$ = loss head resulting from origin "i"

ζ = loss coefficient, in other literature also named "K"

v = water velocity

g = earth acceleration constant

Considering individual loss causing components:

$$h_{net} = h_{gross} - \sum_{i=0}^{n} \zeta_i \cdot \frac{v_i^2}{2g}$$

Important: use water velocity "*v*" where the losses occur!

WATERWAY HYDRAULICS

Where to get loss coefficients from?

→ Established from physical experiments for a multitude of fittings, intake shapes and surfaces
→ Good practical guide is "Internal Flow Systems" by D.S.Miller (Volume 5 in the BHRA Fluid Engineering Series)

The loss head depends on the discharge through the waterway and is proportional to the square of the discharge.

Remember: $Q = v * A \rightarrow v = Q/A$ and $v^2 = Q^2/A^2$

Basic variables for hydraulic calculations

Reynolds Number: Re
= dimensionless cipher to describe similar flow processes in different fluid flow situations

$$\mathrm{Re} = \frac{UD}{\nu}$$

where U is the mean velocity
D is the hydraulic diameter (4 × area/perimeter)
ν is the kinematic viscosity

Kinematic viscosity is temperature dependent → See next table

Medium	t °C	ϱ t/m³	γ N/m³	η N · s/m²		ν m²/s		p_D bar	E N/m²	
Ice at atmospheric pressure	−20	0,9202	9024							
	−10	0,9186	9008							
	0	0,9167	8990							
Water	0	0,9998	9805	1,78		1,78		0,0061	2,01	
	4	1,0000	9807							
	10	0,9996	9803	1,30	$\cdot 10^{-3}$	1,30	$\cdot 10^{-6}$	0,0123	2,12	
	20	0,9982	9789	1,00		1,00		0,0233	2,20	
	30	0,9956	9764	8,02		8,06		0,0425	2,26	
	40	0,9922	9730	6,52		6,57		0,0738	2,29	$\cdot 10^{-9}$
	50	0,9880	9689	5,44	$\cdot 10^{-4}$	5,50	$\cdot 10^{-7}$	0,1234	2,29	
	60	0,9832	9642	4,70		4,78		0,1992	2,26	
	80	0,9718	9530	3,56		3,66		0,4736	2,19	
	100	0,9583	9398	2,82		2,94		1,0132	2,08	
Sea water, Salt concentration: 35 ‰	10	≈ 1,027	≈ 10072							
Water of very high turbidity		≈ 1,020	≈ 10003							
Water vapor at atmospheric pressure	100	0,000598	5,864	1,27		2,12				
	200	0,000467	4,580	1,65		3,53				
	300	0,000384	3,766	2,03	$\cdot 10^{-5}$	5,29	$\cdot 10^{-5}$			
	400	0,000326	3,197	2,42		7,42				
	500	0,000284	2,785	2,81		9,89				

t Temperature
$t = 0$ °C $\widehat{=}$ $T = 273{,}15$ K
ϱ Density

γ Weight
η dynamic viscosity
ν kinematic viscosity

p_D Steam pressure, boiling pressure
E Modulus of elasticity (Young's M.)

Basic variables for hydraulic calculations

Froude Number

Is the ratio between inertia and gravity force:

$$Fr = \frac{v}{\sqrt{g \cdot h}} \quad [-]$$

Where

ν = kinematic viscosity

g = gravity constant

h = water depth

The Froude Number is mainly used in open channel flow calculations.

Pipe losses

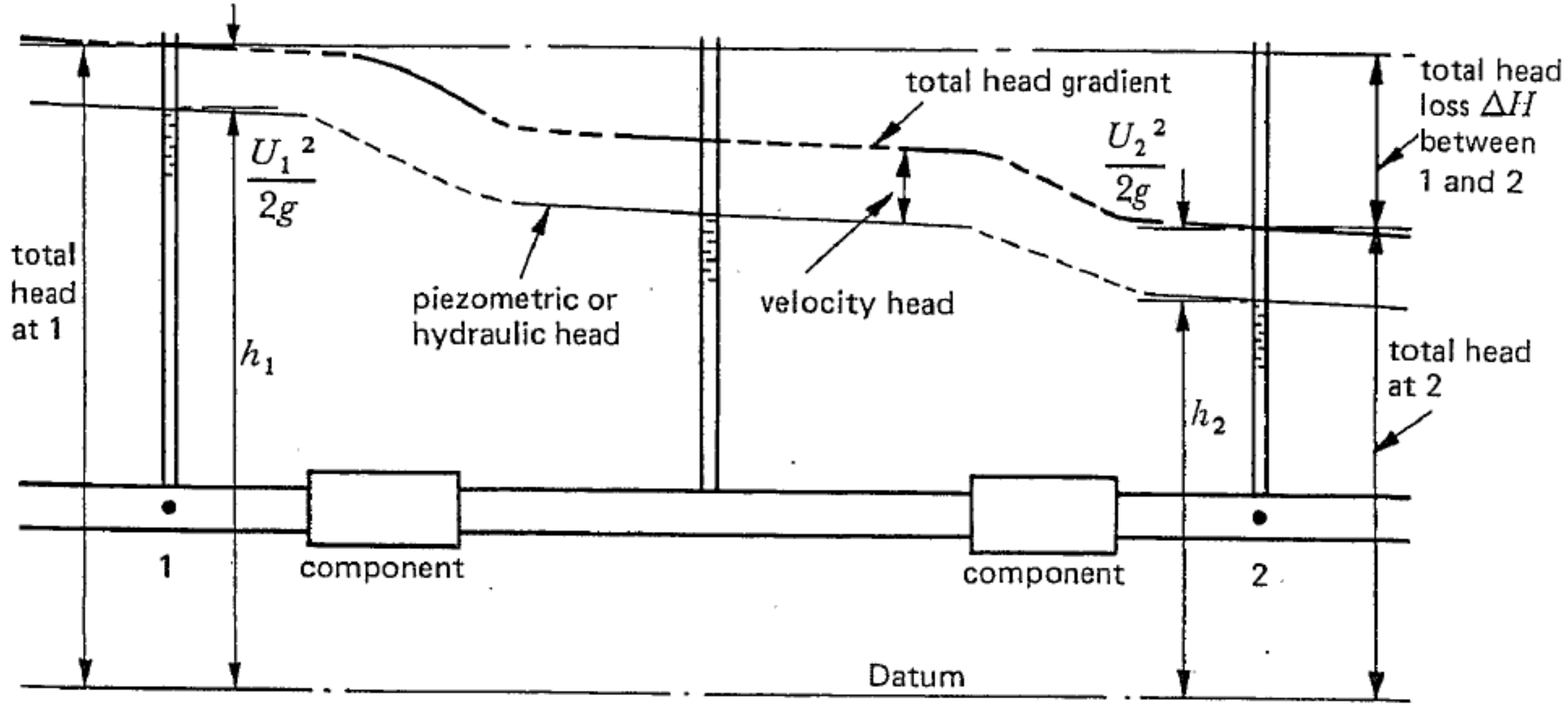


Fig. 1.3. Total head loss

Pipe losses

The formula for friction losses is

$$h_{v,r} = \lambda \cdot \frac{L}{d_{hy}} \cdot \frac{v^2}{2g} = \lambda \cdot \frac{L}{d_i} \cdot \frac{8 \cdot Q^2}{g \cdot \pi^2 \cdot d_i^4} = \frac{8 \cdot \lambda \cdot L \cdot Q^2}{g \cdot \pi^2 \cdot d_i^5} \quad [\mathrm{m}]$$

Where
$h_{v,r}$ = friction loss
λ = loss coefficient
L = length of pipe
d_{hy} = hydraulic diameter (=4 x hydraulic radius; hydraulic radius r_{hy} = A/L_u)
d_i = diameter of pipeline

The loss coefficient λ

The loss coefficient λ is calculated by means of a recursive formula by COLEBROOK-WHITE:

$$\frac{1}{\sqrt{\lambda}} = -2\log\left[\frac{C_1}{Re\sqrt{\lambda}} + \frac{\varepsilon}{C_2}\right] \quad [-]$$

Where
C_1/C_2 = constant factors according to the following table
Re = Reynolds number

$$\varepsilon = {}^{k}\!/_{d_{hy}} \quad [-]$$

		Form factor f	$C_1 = 2,51/f$	$C_2 = 3,71 \cdot f$
Rectangular profile	h/b			
	0	(0,520-) 0,600	(4,83-) 4,18	(1,93-) 2,23
	0,25	0,791	3,17	2,93
	0,50	0,869	2,89	3,22
	0,75	0,893	2,81	3,31
	1,00	0,897	2,80	3,33
Circular profile	h/d			
	0	0,328	7,65	1,22
	0,25	0,763	3,29	2,83
	0,50	0,922	2,72	3,42
	0,75	0,951	2,64	3,53
	1,00	1,0	2,51	3,71
Trapezoidal profile		$f = \left(1,629 \cdot r_{hy}/b_{Sohle}\right)^{0,25}$		
Triangular profile		$f = \left(2,539 \cdot \tan\alpha\right)^{0,15}$		

The loss coefficient λ

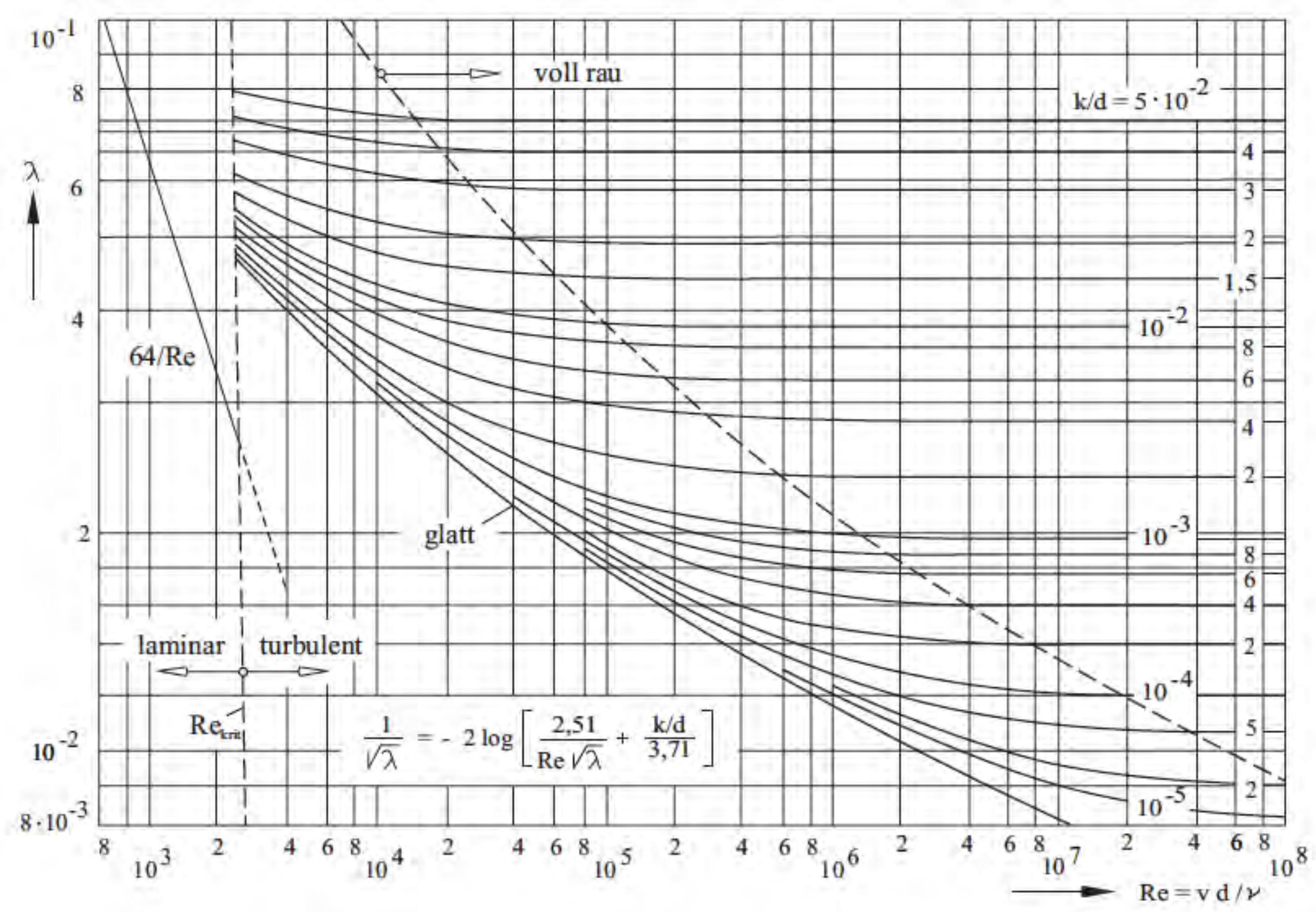
For completely filled circular pipelines the loss coefficient λ is calculated by

$$\frac{1}{\sqrt{\lambda}} = -2\log\left[\frac{\varepsilon}{3,71}\right] = -2\log\left[\frac{k/d_{hy}}{3,71}\right] \quad [-]$$

Where
k = hydraulic roughness in mm
d_{hy} = hydraulic diameter in mm (!)

For simplicity, λ can be obtained from the MOODY-Diagram:

The MOODY-Diagram



Bend losses

Bend losses are calculated by

$$h_{bend} = \zeta_{bend} \cdot \frac{v^2}{2g}$$

Values for ζ_{bend} can be obtained from literature, such as “Internal Flow Systems” by Miller.

(Note: instead of ζ_{bend} in the following figures the symbol K_b was used but has the same meaning.)

$$\Delta H = K_b \frac{U^2}{2g}$$

$$\mathrm{Re} = \frac{Ud}{\nu}$$

where U is the mean inlet velocity
and ν is the kinematic viscosity

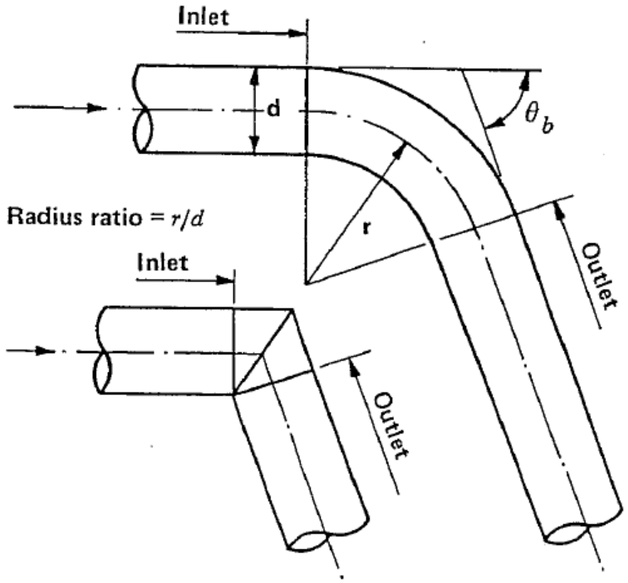


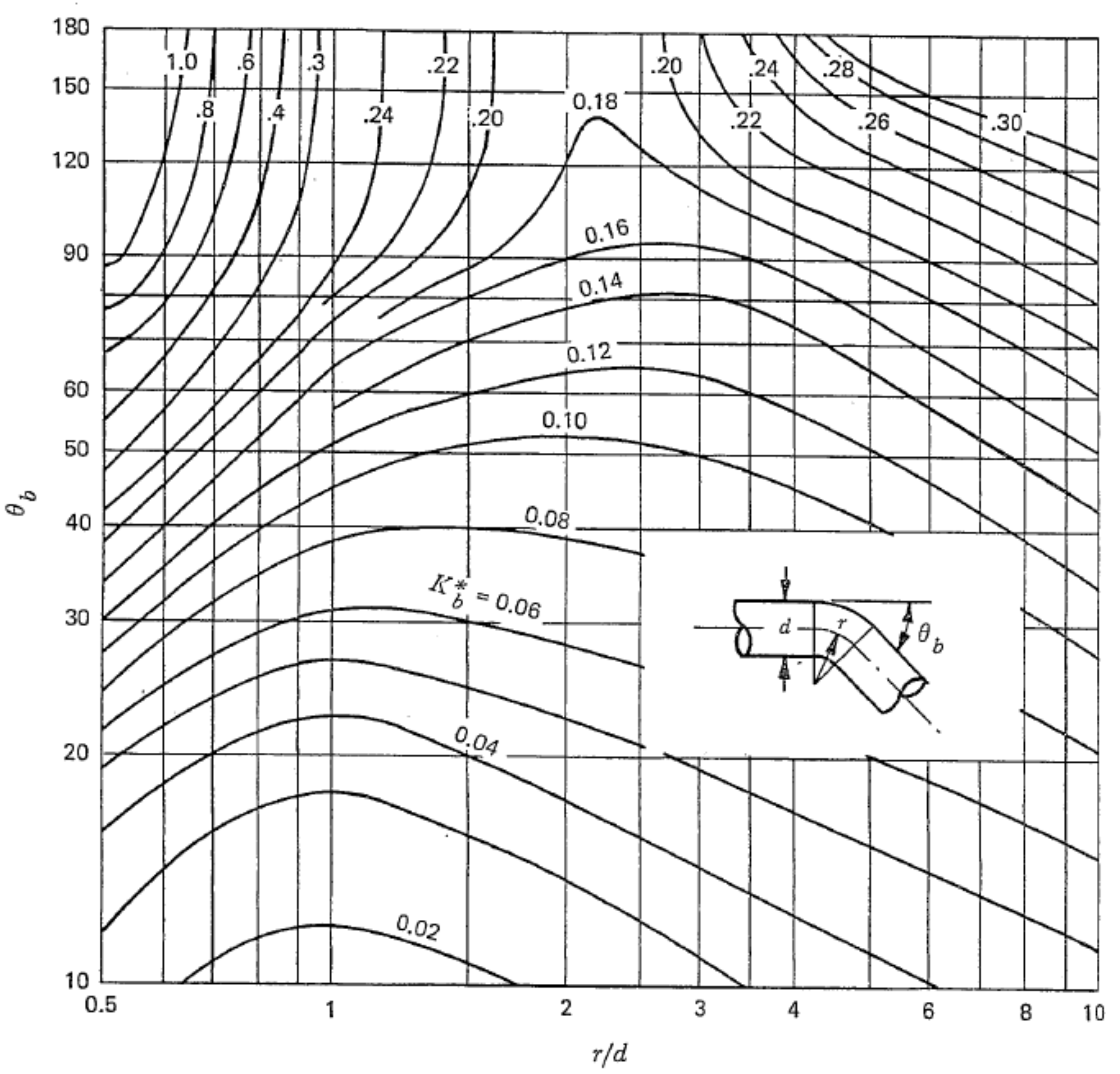
Fig. 9.1. Circular cross-section bend geometries

Bend losses

K^*_b is the basic coefficient
→ modified by other factors considering, e.g.

- Reynolds number,
- outlet pipe length
- etc.

For estimates at design level it is sufficient to use K^*_b straight for ζ in the above formula.

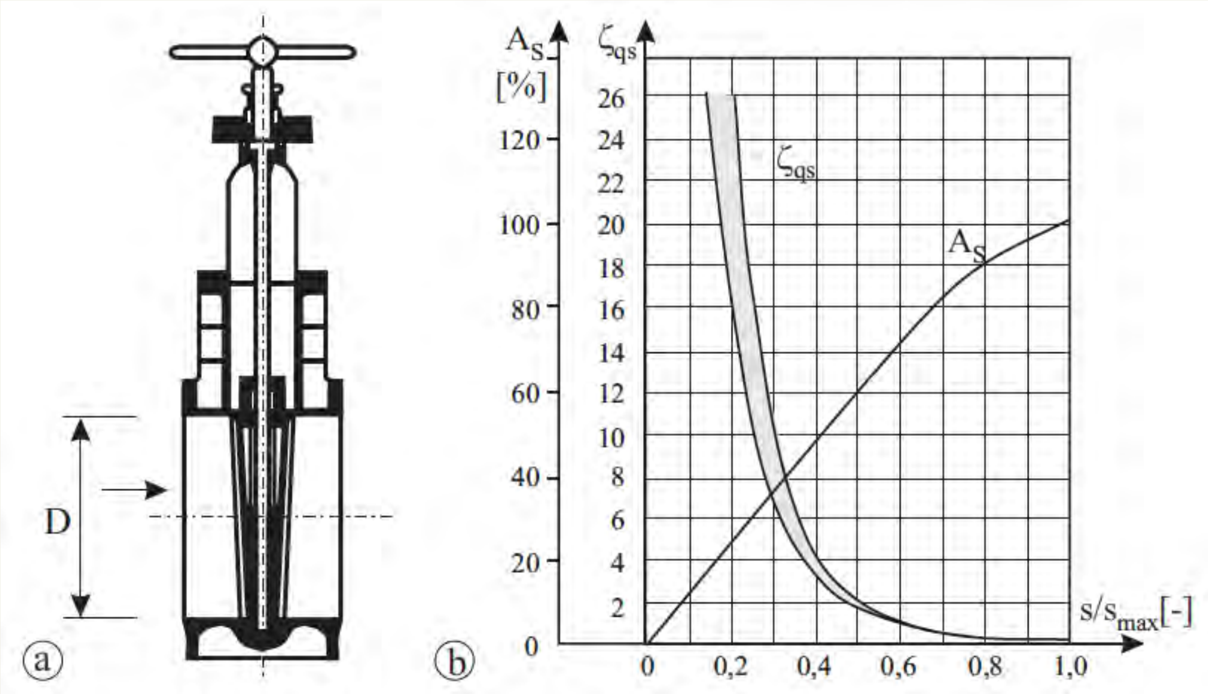


Valve losses

Valve losses are calculated by

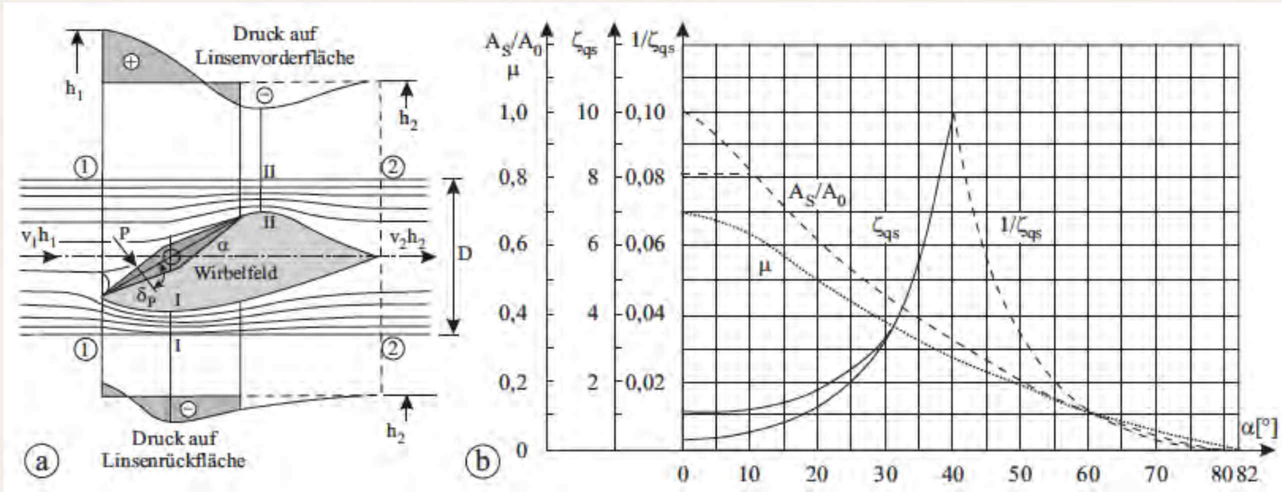
$$h_{valve} = \zeta_{valve} \cdot \frac{v^2}{2g}$$

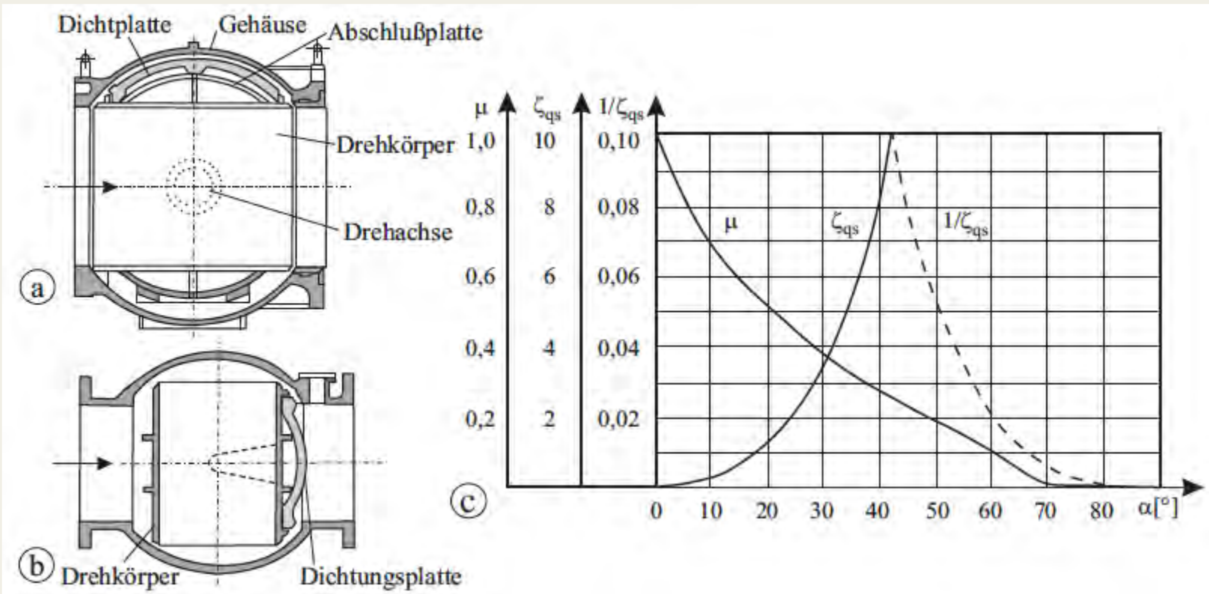
Values for ζ_{valve} can be obtained from literature, such as "Internal Flow Systems" by Miller.



Here, s and s_{max} are the opening width; A_s is the cross section area.

Valve losses



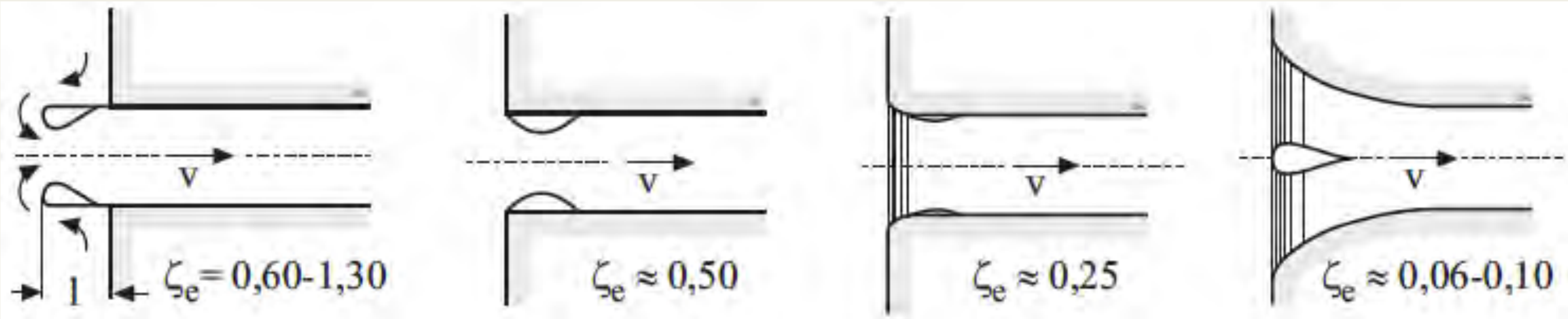


Intake losses

Intake losses are calculated with the same formula as above.

$$h_e = \zeta_e \cdot \frac{v^2}{2g}$$

Some intake coefficients are given below:



Hydraulic Transients - Water Hammer Effect

- Water has a mass $m = \rho * V$

Where
m = mass
ρ = density
V = volume

- Closing or opening a valve causes change of velocity
- Change of velocity causes an impulse with impulse force
- The impulse force shows as pressure change (up or down)
- The resulting transient process is known as "Water Hammer"

- The magnitude of pressure rise depends on the time it takes to close a valve
- Generally speaking, it depends on the deceleration rate $\partial v/\partial t$

Hydraulic Transients - Water Hammer Effect

The magnitude of pressure variation in the pipe depends on:

- Density of the water or liquid;
- Length of the pipeline;
- Diameter of the pipeline, which defines the water velocity;
- Modulus of elasticity of the pipe wall or tunnel wall;
- Difference between initial and final velocity;
- Time to reduce the speed from its initial to its final value.

- Generally: softer pipe walls → lower sound propagation speed in water → slower propagation of the pressure waves.
- Higher water velocities → greater pressure modifications

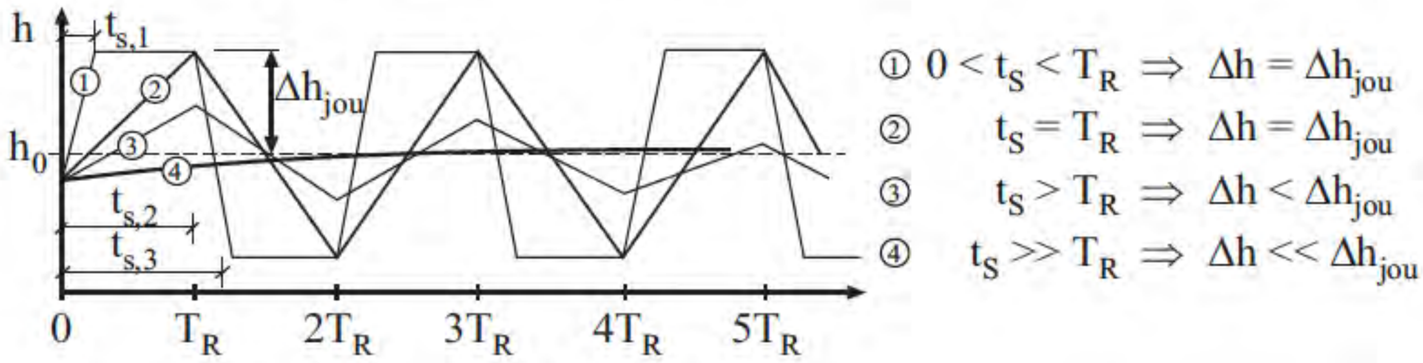
Hydraulic Transients - Water Hammer Effect

To calculate the pressure rise, various methodologies are applied:

- Finite element and finite difference methods;
- “Characteristics method” using simple differential equations
- Theory of elastic water column
- For rough estimates the formula according to Joukowsky is commonly used:

$$\max h_a \approx \frac{a \cdot \Delta v}{g} \cdot \frac{T_R}{t_S} \text{ für } t_S > T_R \quad [\text{m}] \tag{8.24b}$$

h_a	Druckstoßhöhe	[m]
t_S	Schließzeit des Verschlussorganes	[s]



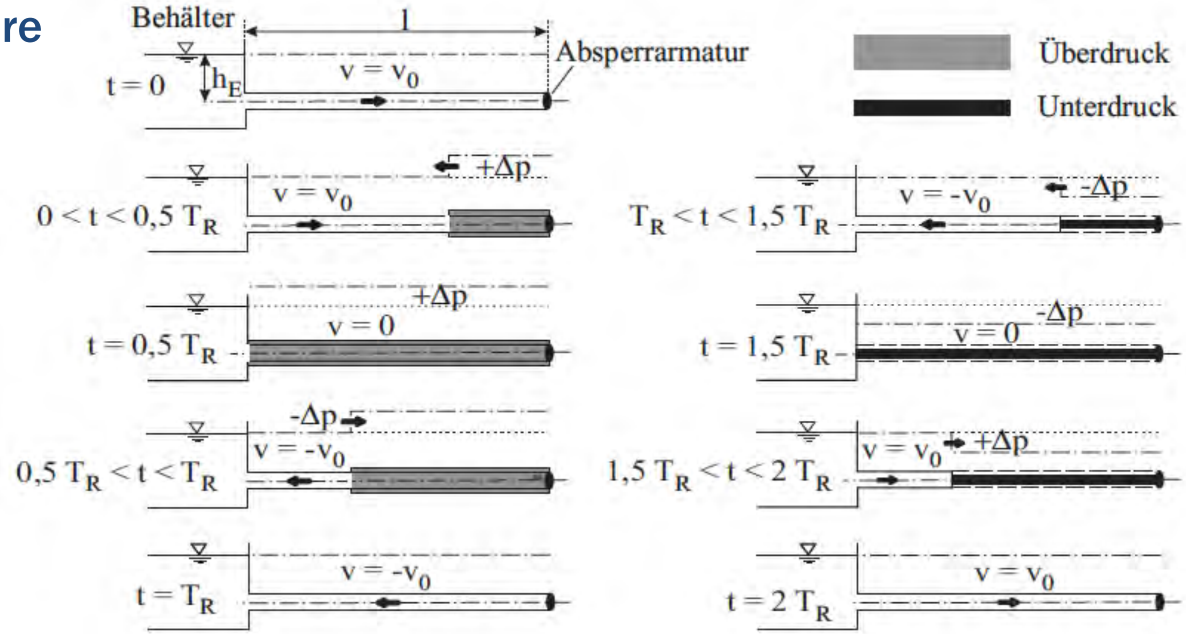
Where

max h_a	= Maximum pressure head from water hammer
a	= Shock wave propagation speed
Δv	= Difference between final and initial velocity
g	= gravity constant
T_R	= reflection time of the wave in the pipe
t_s	= time to close the valve

$$max\, h_{a,jou} = \pm \frac{a \cdot \Delta v}{g} \quad [m] \qquad (8.24a)$$

$max\, h_{a,jou}$ maximale Druckstoßhöhe infolge Joukowsky-Stoß [m]

Where
Überdruck = positive pressure
Unterdruck = negative pressure
Absperramatur = valve

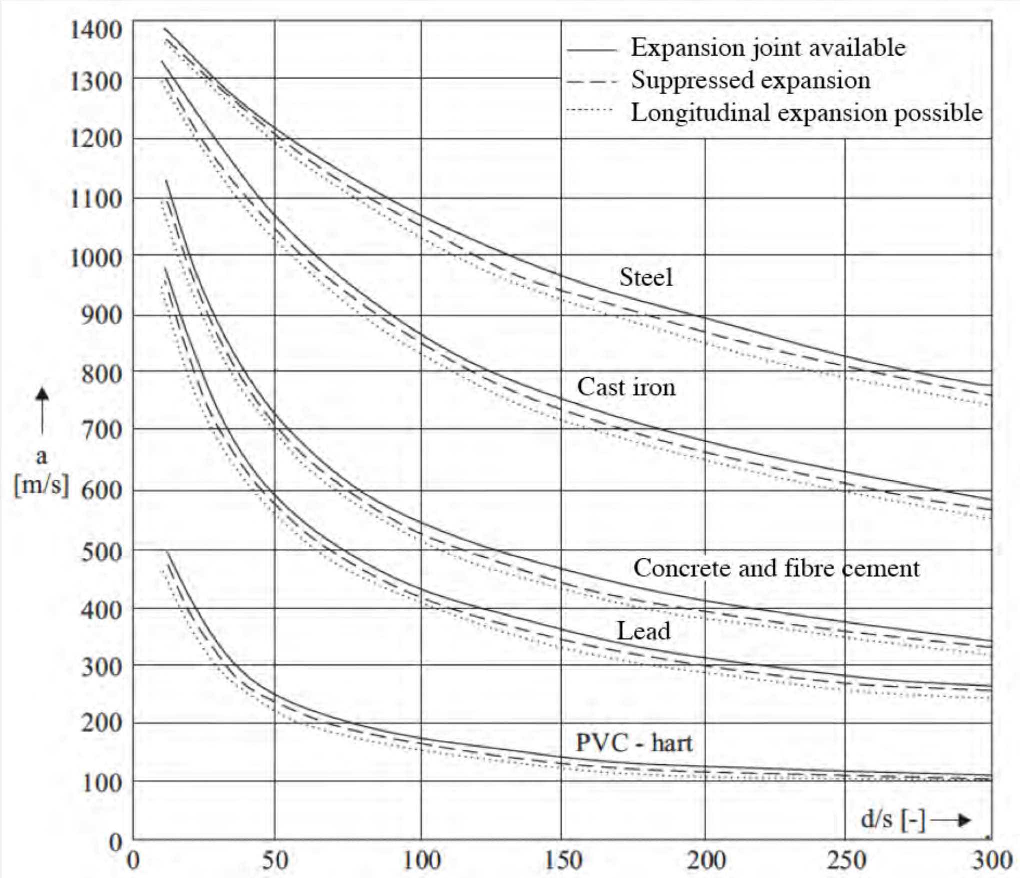


The reflexion time is calculated by

$$T_R = 2 \cdot T_L = {}^{2 \cdot l}/_{a} \quad [s]$$

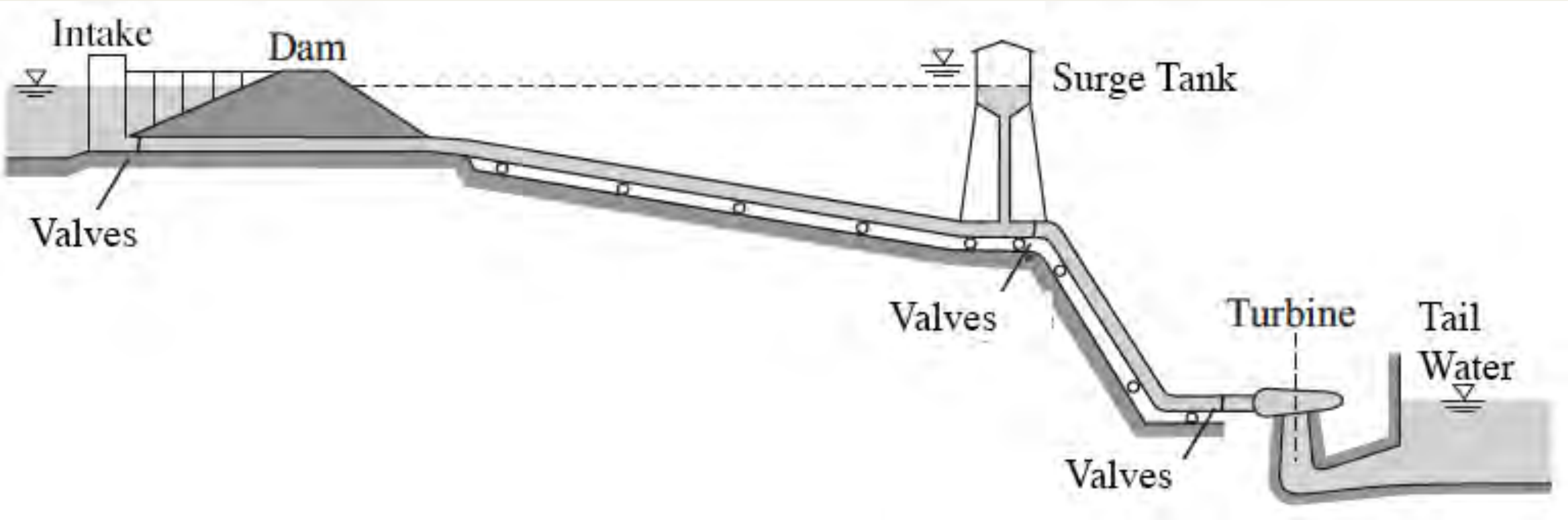
Where
T_L = Running time of the shock wave in one direction
l = Length of pipeline
a = Propagation speed of sound in the medium, depending on pipe material and bedding conditions

Shock wave propagation speed is depending on the bedding situation and the pipe material.
The following figure gives an indication for different pipe materials installed without bedding:



To reduce the water hammer effect, different measures can be taken:

- Reduce the speed of closing the valve;
- Change pipe and bedding material;
- Increase the pipe diameter to reduce the flow velocity;
- Installation of pressure release valves or bypasses (high risk of failure!)
- Reduce the pipe length;
- Installation of an air pressure cushion;
- Installation of a surge shaft to reduce the pipe length;



DRAWING CONCLUSIONS FROM THE RESULTS, QUESTION AND ANSWER SESSION

Questions? Comments?

THANK YOU FOR YOUR ATTENTION!

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REFERENCES

- Magazine „Hydro Review Worldwide, edition July-August 2015“
- https://www.sensefly.com/drones/ebee-rtk.html
- www.wikipedia.com
- „Wasserkraftanlagen“; Giesecke; Mosonyi; 2003; ISBN 3-540-44391-6
- „Hydraulik fuer Bauingenieure“; Heinemann/Paul; ISBN 3-519-05082-x
- http://www.hydroconnect.at
- http://www.wasserradfabrik.de/wasserkraftraeder.html
- http://goecke.de/Produkte/