INTRODUCTION TO HYDROPOWER CONCEPTS

TECHNICAL BASICS OF HYDROPOWER PROJECTS

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Georgetown, Guyana

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OUTLINE

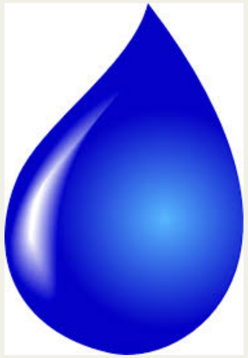
- What is Hydropower?
- Hydropower Classification
- Brief History of the Turbine
- Hydropower and the Environment
- Hydropower Physics
- Electrical Generators for Turbines
- The various Turbine Types
- Elements of Hydropower Plants
- Hydropower Examples/Lessons Learned

WHAT IS HYDROPOWER?

WHAT IS HYDROPOWER?

Thesis:

HYDROPOWER is SOLAR POWER



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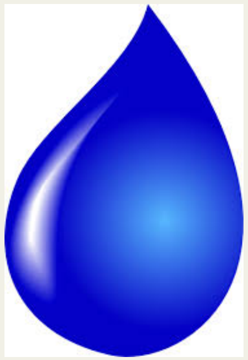
Right or Wrong...?

WHAT IS HYDROPOWER?

Thesis:

HYDROPOWER is SOLAR POWER



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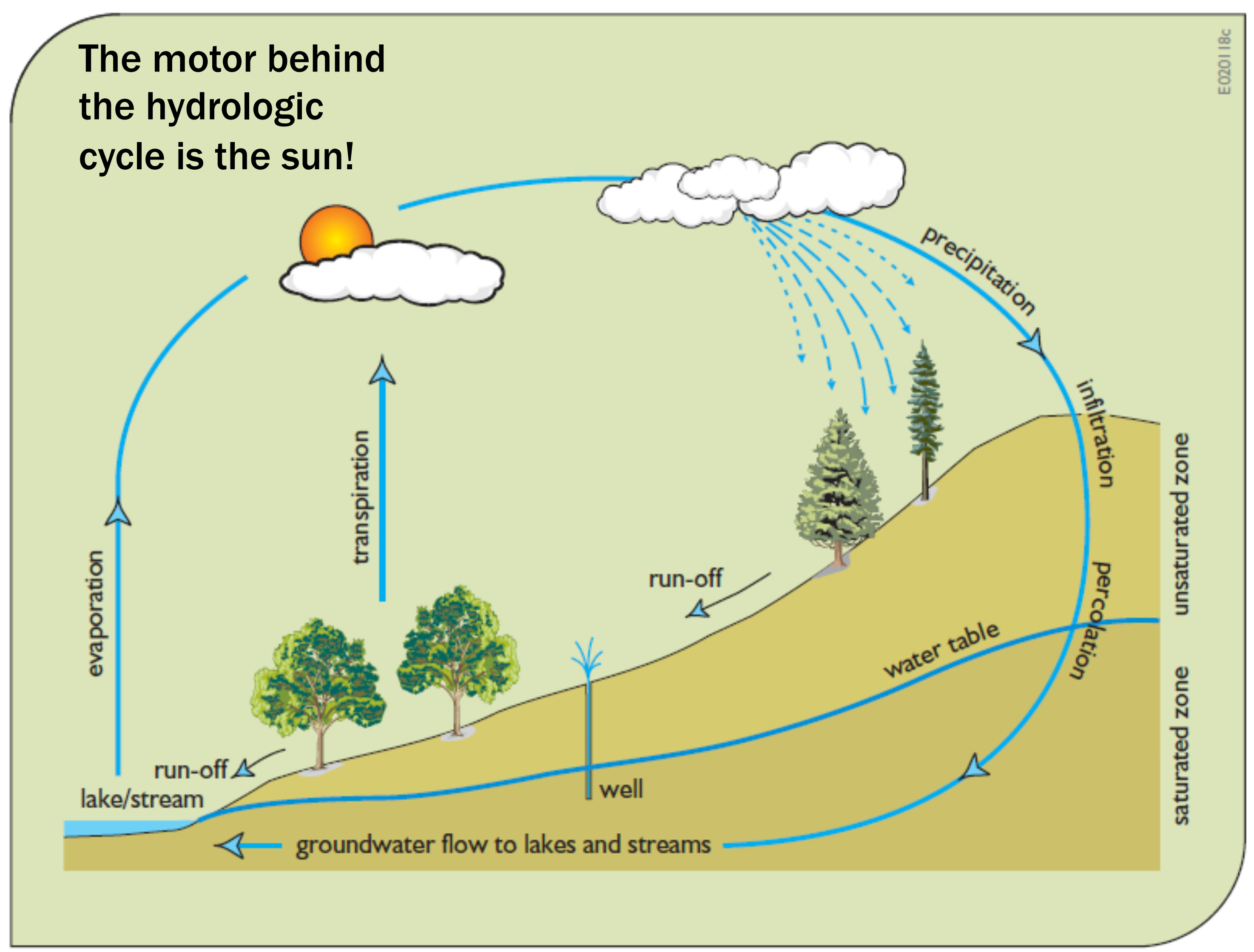
<u>Right !</u>

HYDROLOGIC CYCLE



RAINFALL HEIGHTS

Average annual rainfall heights for selected areas:

Source: www.gaisma.com

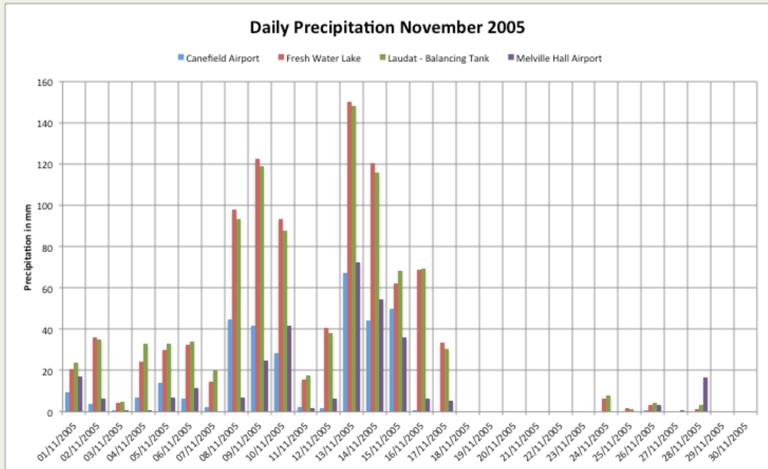
Georgetown	2,315 mm
Bartica	2,300 mm
Kato	2,680 mm
Linden	2,620 mm
Lethem	1,715 mm

For comparison:

New York City	1,155 mm
Iguazu	1,765 mm
Niagra Falls	954 mm

PRECIPITATION…

- …is one of the two most important inputs for hydropower
- …is usually not constant but underlies fluctuations (hydrographs)

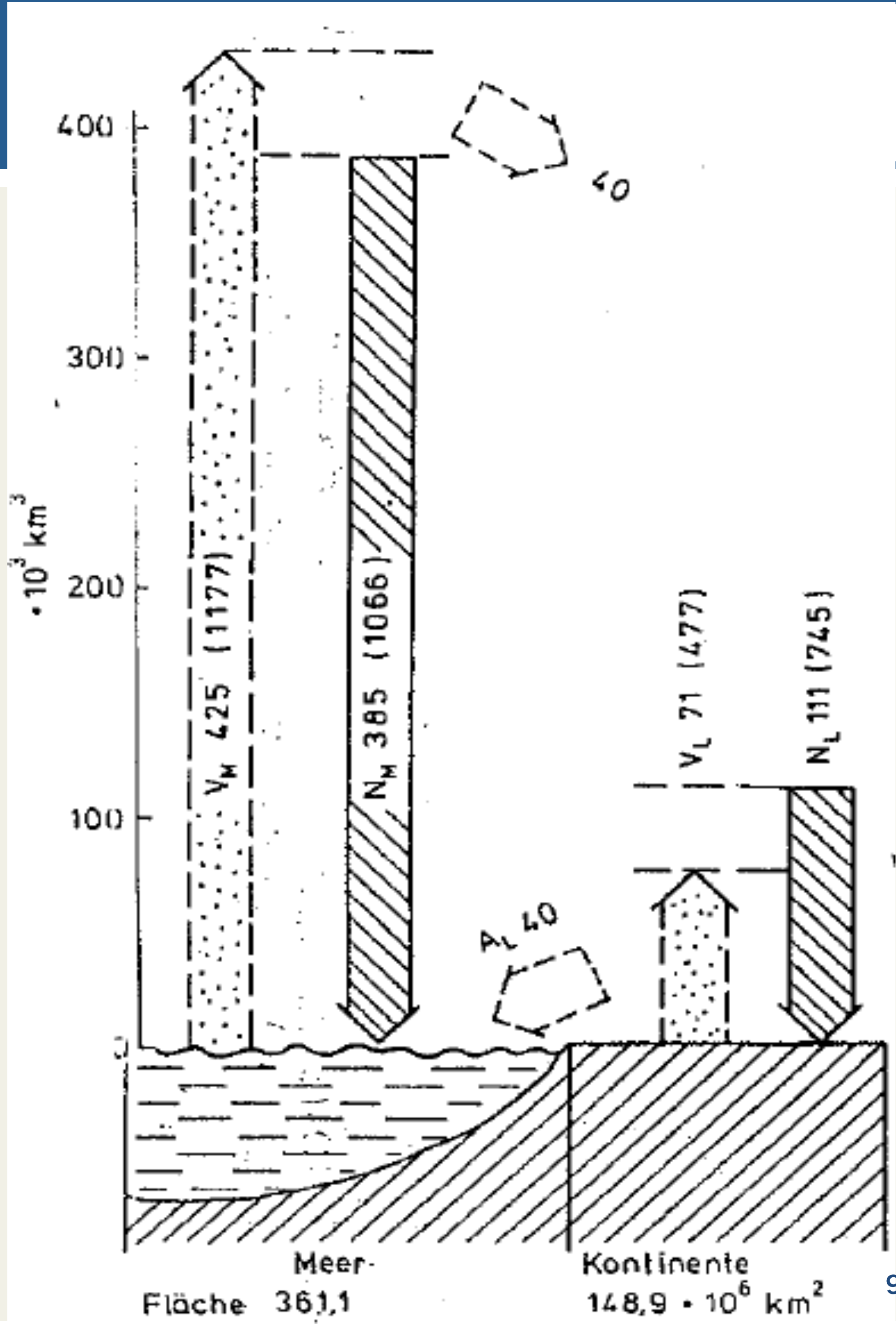


- …may be as rain or snow -> snow leads to storage effects
- …cannot 100% be used for hydropower: losses & floods

PRECIPITATION

How much water

is there in the world?



PRECIPITATION-RUN OFF PROCESS

What happens after a rain drop hits the ground?

- Some water evaporates directly back in the air
- Some water enters the upper soil layers and is transpired by plants
- Both effects together are known as "evapo-transpiration"
- Water in the ground that seeps in deeper soil layers will end in aquifers as ground water, which provides base flow for rivers
- Water that does not enter the ground runs off into creeks, ravines, rivers, streams and finally lakes or the sea

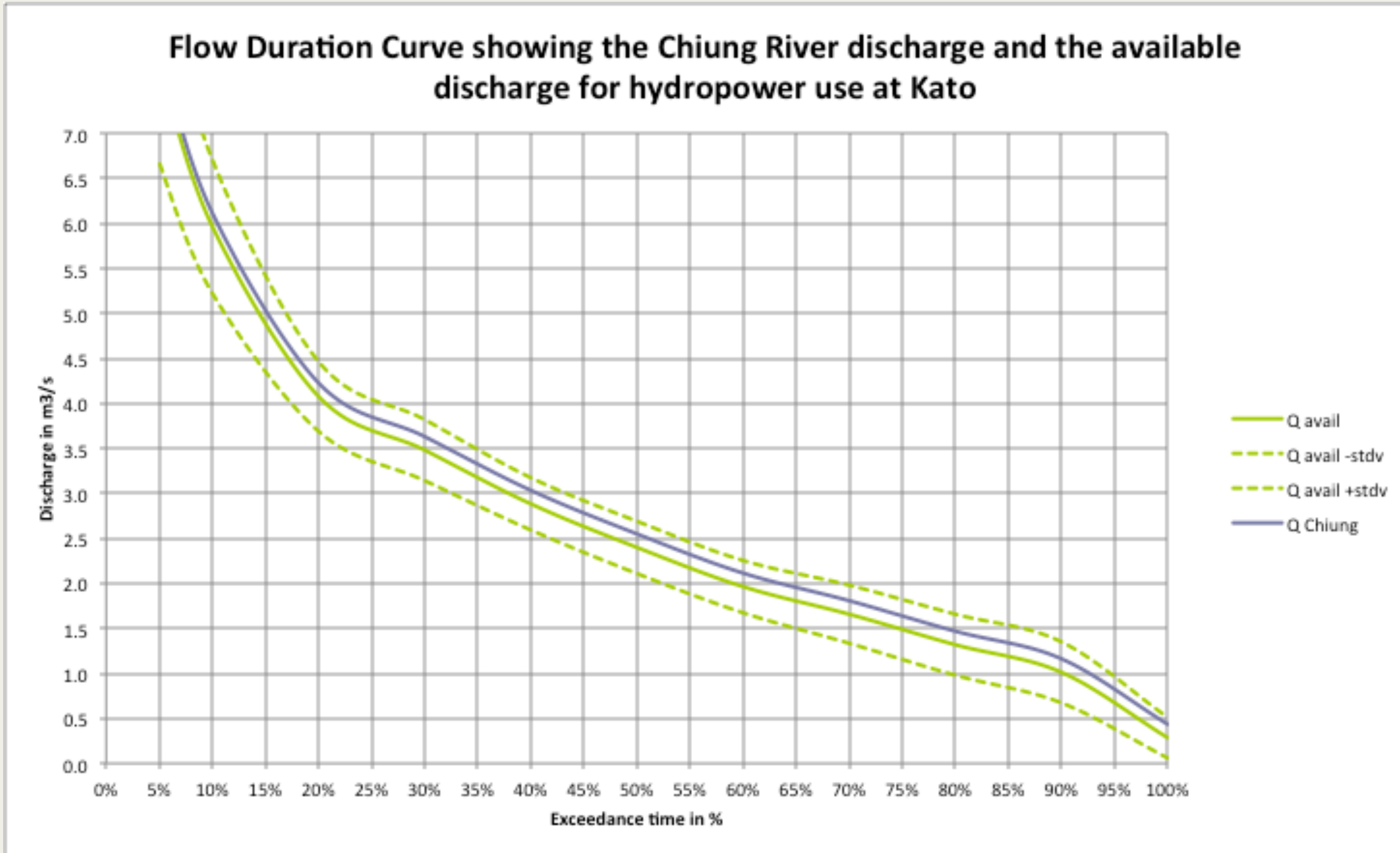
WHAT HYDROLOGIC DATA IS NEEDED?

What hydrologic data is needed to plan a hydropower project?

- The central question to answer is “How much electricity can be generated from the plant?”
- To answer this question, one must look at the availability of water: “how much?” and “when?”
- Therefore, long term hydrologic records are required, ideally stream flow discharge on daily basis
- The length of the records must be between 3 and 20 years, depending on the project size
- The daily data gives information about the average amount of water that has been available in the past and will allow projections in the future

FLOW DURATION CURVE

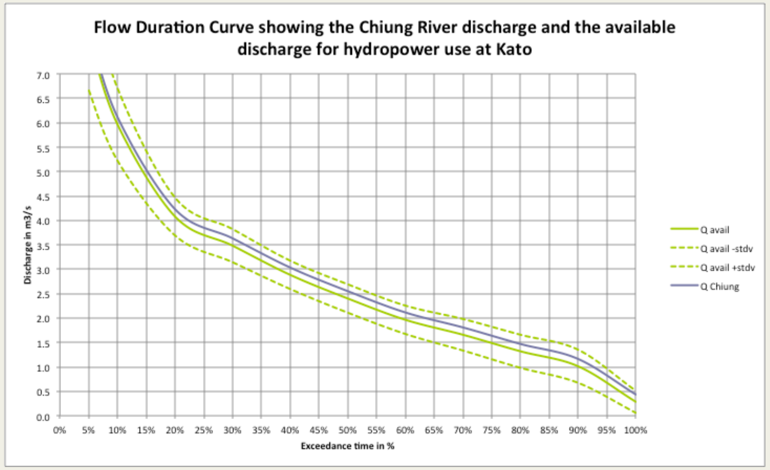
The daily values are sorted to get the flow duration curve:



FLOW DURATION CURVE

The daily values are sorted to get the flow duration curve:

- The FDC tells for who long what amount of water will be available
- The FDC is the basis to select the design (turbine) discharge for the project



As a rule of thumb:

- Rural electrification → E = approx. 80%
- Small HPP → E = approx. 30%

WHAT HYDROLOGIC DATA IS NEEDED?

More hydrologic data needs?

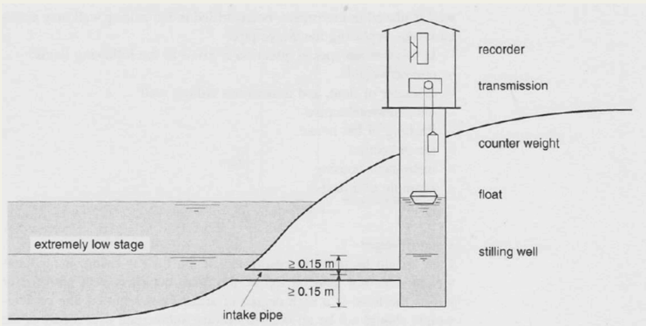
- The flood discharge plays the second significant role in hydropower planning:
  - How large to design flood releasing hydraulic structures to safely evacuate the design flood?
- The flood design is a safety relevant issue and hence of high importance
- Flood event discharges must be collected for a number of flood events to create statistical data
- Statistical analysis is done with the data to obtain design values
- There are lots of manuals and guidebooks available on flood discharge estimation, including software tools, for example from the Hydrologic Engineering Center of the US Army Corps of Engineers

PRECIPITATION-RUN OFF PROCESS

How do we know how much water is available?

1. Measuring the run-off in rivers directly <u>(first best)</u>

- **Stationary**



- **Spot measurements**

PRECIPITATION-RUN OFF PROCESS

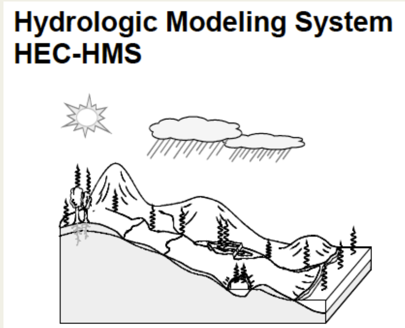
How do we know how much water is available?

2. Measuring rainfall and concluding to run-off data <u>(second best)</u>

PRECIPITATION-RUN OFF MODELS

- If no discharge data is available, precipitation-run off models are used to calculate the discharge.
- A free of charge PRO model is HEC-HMS of the US Army Corps of Engineers, for example

US Army Corps of Engineers®
Hydrologic Engineering Center



- There are many more models available, including ARC GIS applications of ESRI
- Also manual run-off modelling is possible, using interpolation and isohyets methods
- Disadvantage of PRMs: Accuracy is limited and loads of input data is needed
- Better: stream flow discharge records. → Invaluable data!

HYDROPOWER CLASSIFICATION

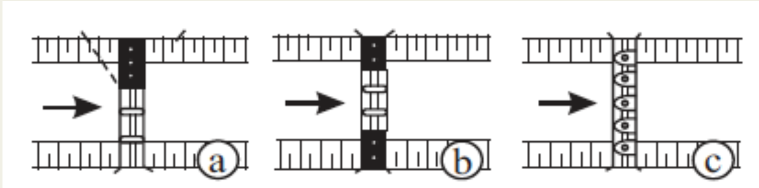
HYDROPOWER CLASSIFICATION

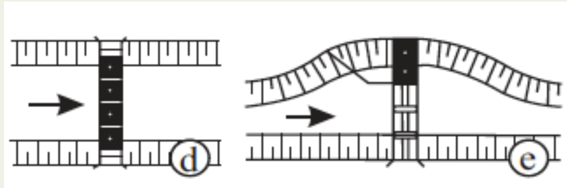
Classification can be done by

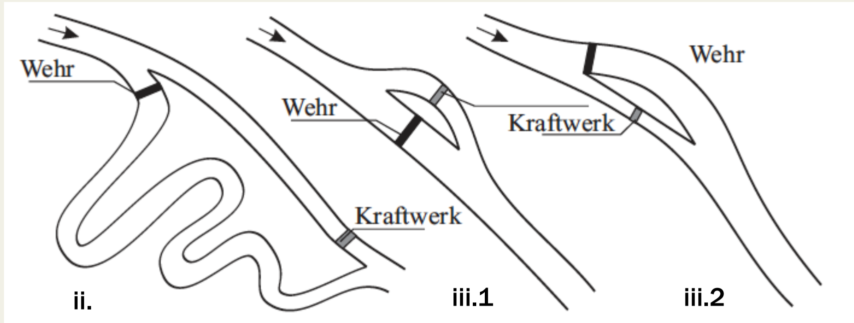
- Technical (river engineering) aspects
- Topographical aspects
- Energy head
- Energy market aspects
- Operational aspects
- Installed capacity
- Water resource management aspects

TECHNICAL (RIVER ENGINEERING) ASPECTS

1. Run-off river
   i. River plants
      a. Block design
      b. Twin design
      c. Pier design
      d. Overtopable design
      e. Bay design
   ii. Diversion design
   iii. Loop/river bend design
2. Storage hydropower
3. Pumped storage hydropower
4. Tidal power plants
5. Wave power plants
6. Depression power plants
7. Glacier hydropower

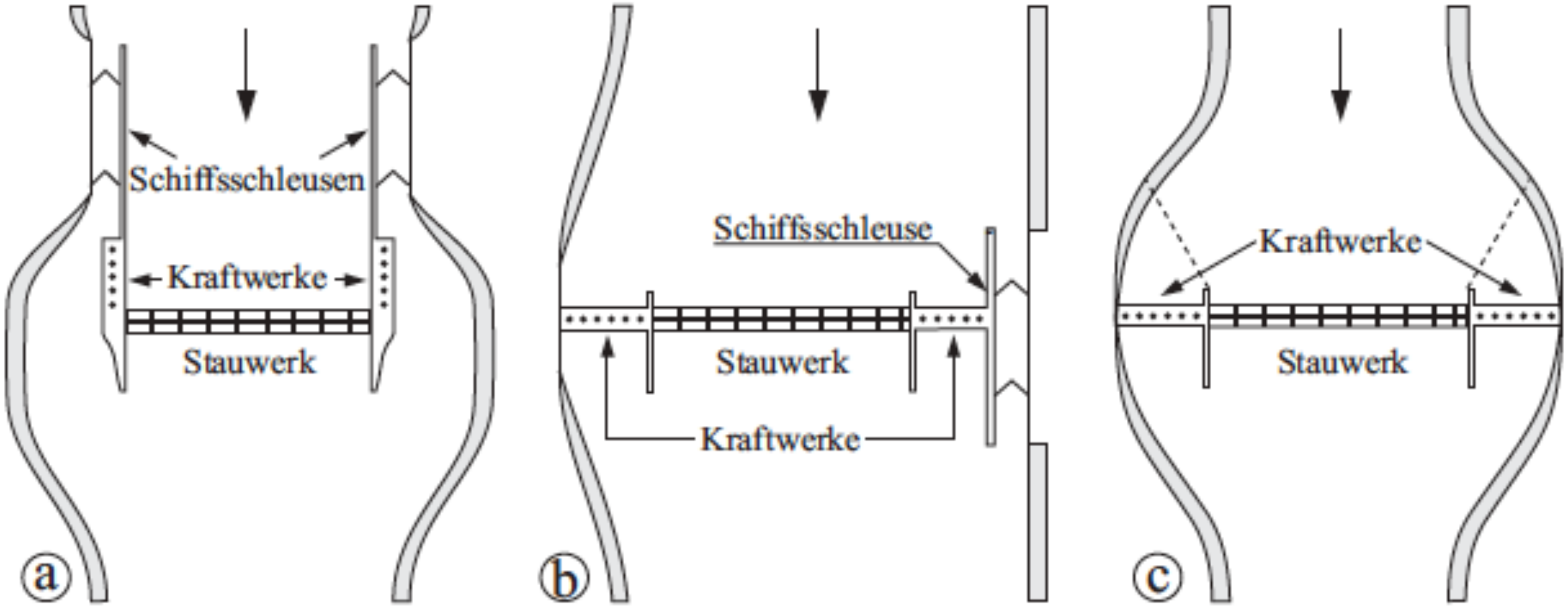






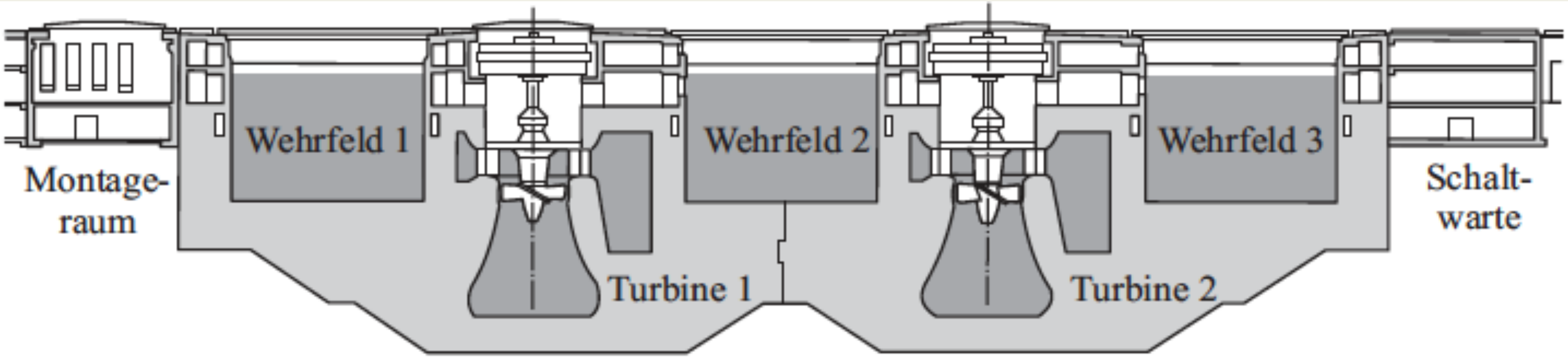
TECHNICAL (RIVER ENGINEERING) ASPECTS

Twin design options



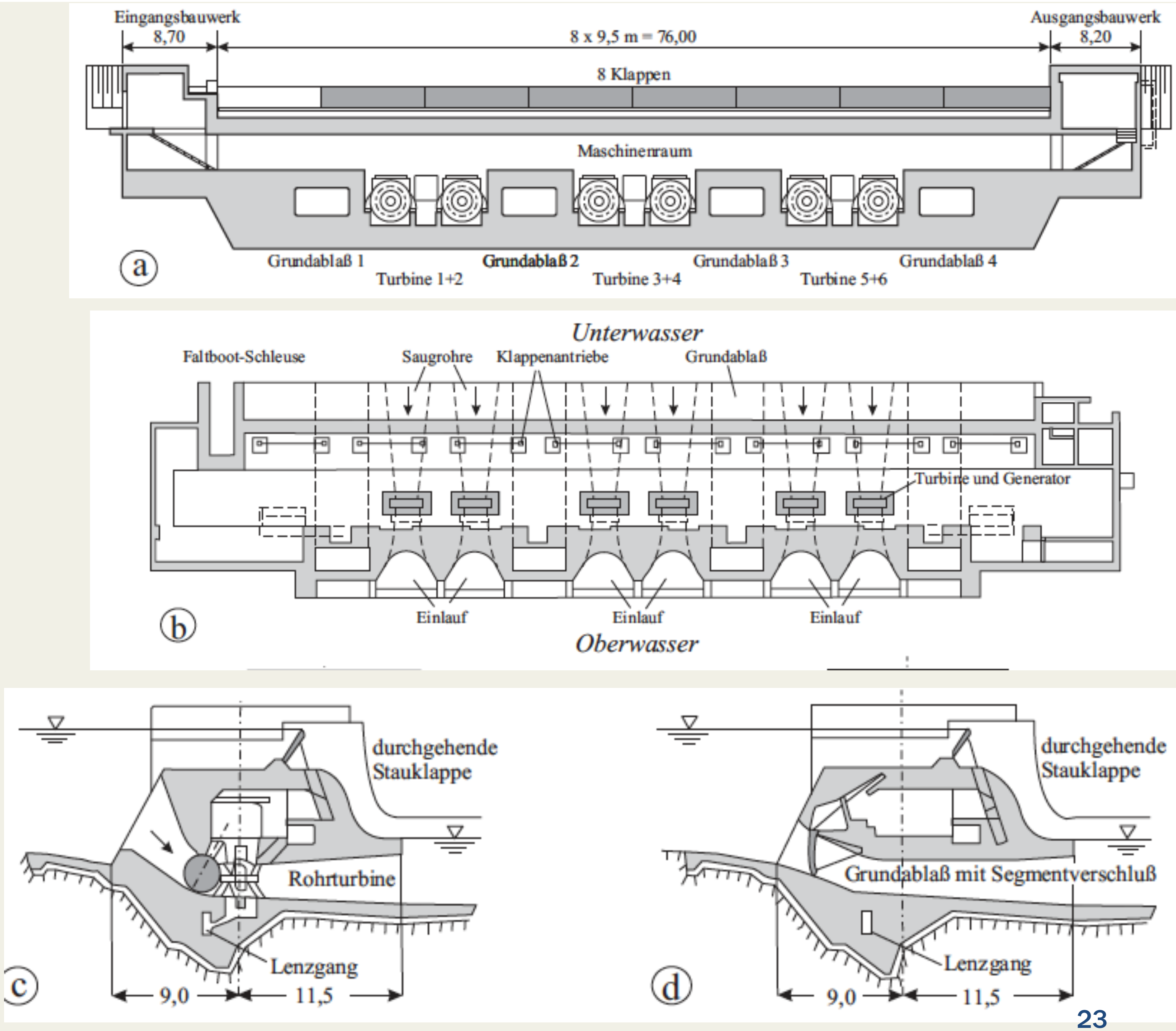
TECHNICAL (RIVER ENGINEERING) ASPECTS

Pier design option



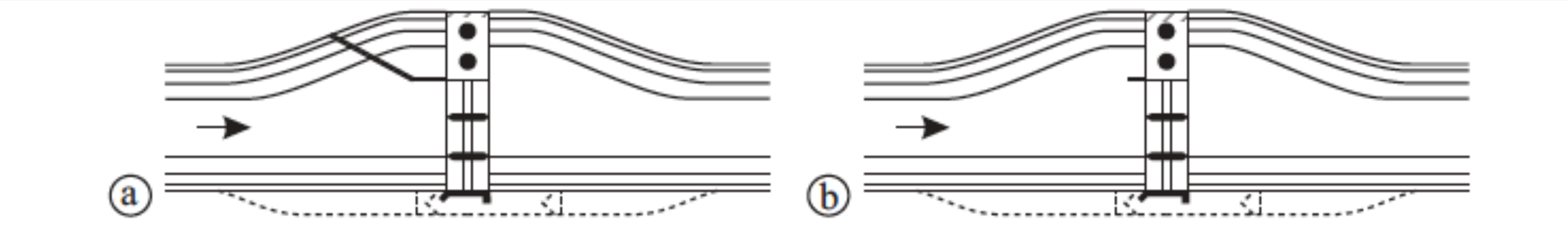
TECHNICAL (RIVER ENGINEERING) ASPECTS

Overtopable design



TECHNICAL (RIVER ENGINEERING) ASPECTS

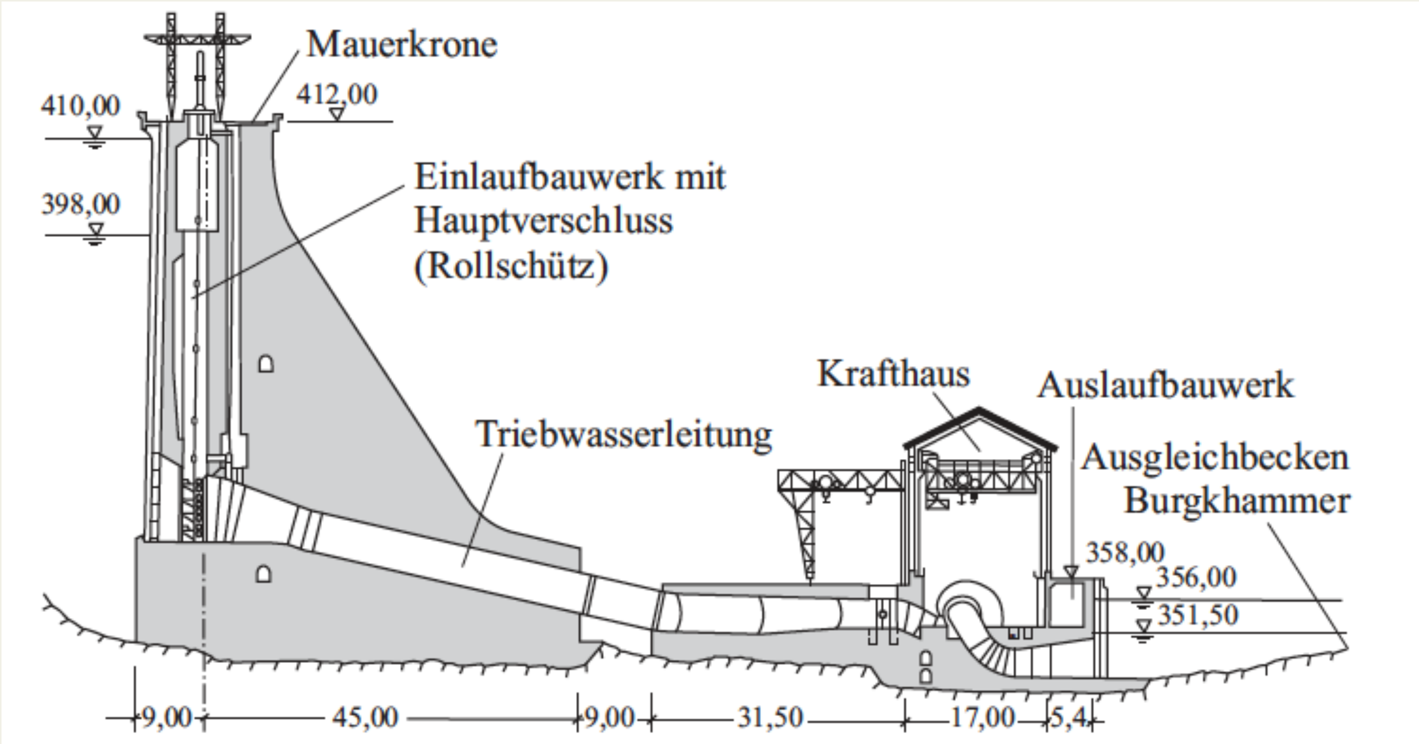
Bay design options



a) With and b) without separate intake structure, and potential ship lock

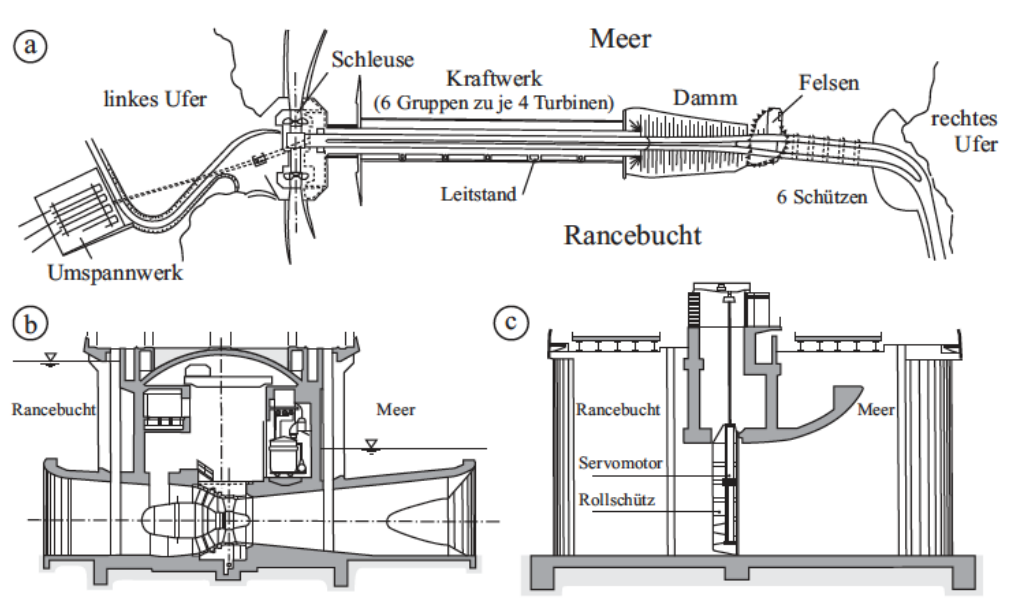
TECHNICAL (RIVER ENGINEERING) ASPECTS

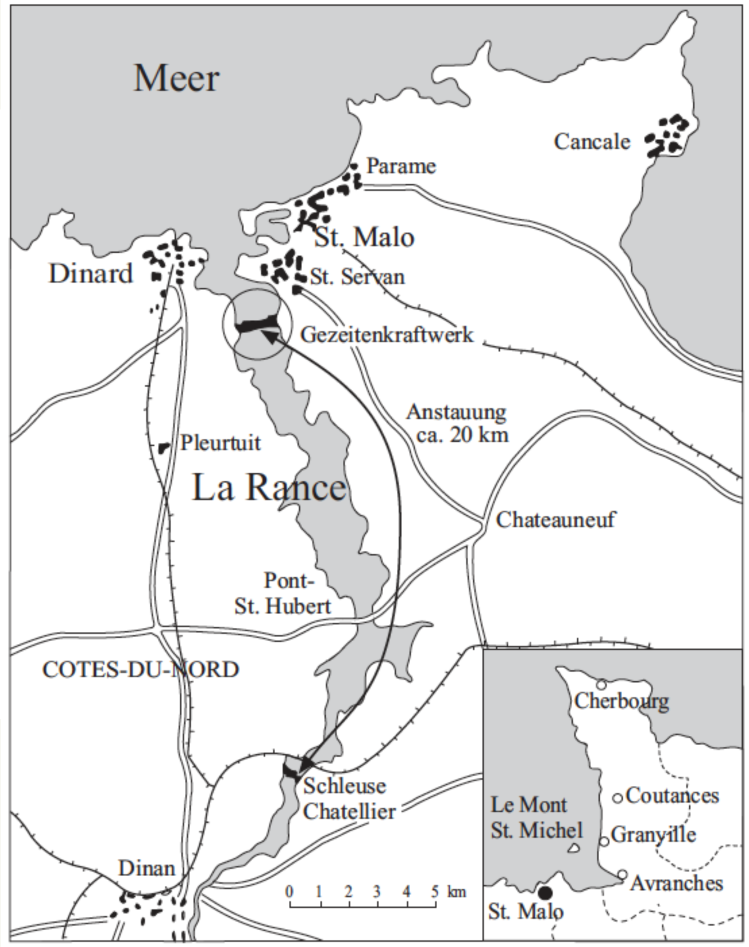
Storage plant



TECHNICAL (RIVER ENGINEERING) ASPECTS

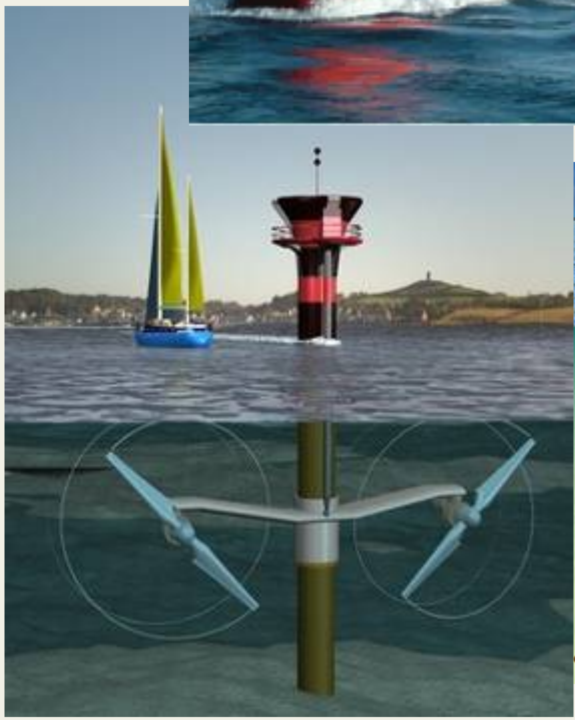
Tidal power plant

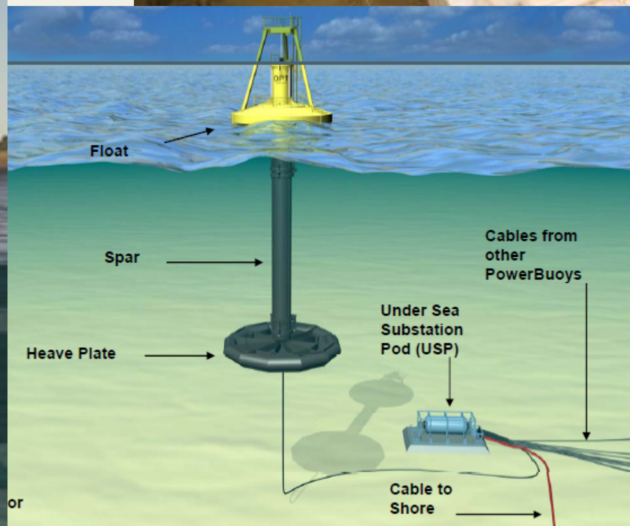




TECHNICAL (RIVER ENGINEERING) ASPECTS

Wave power plant



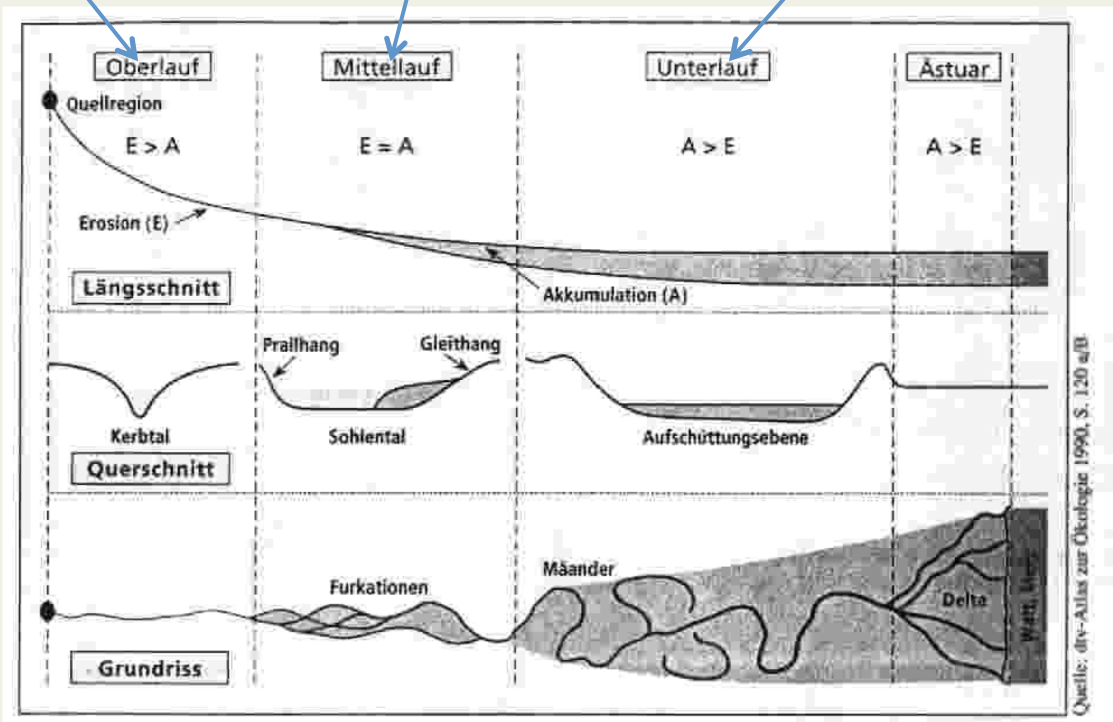


TOPOGRAPHICAL ASPECTS

Topographically, hydropower plants are distinguished:

Hydropower plants in…

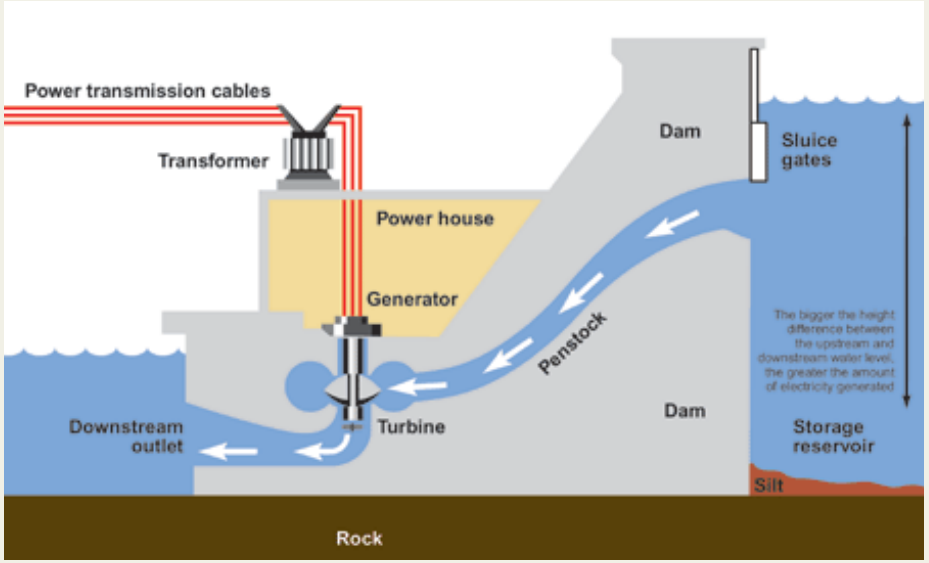
…upper reach | …middle reach | …lower reach



ENERGY HEAD

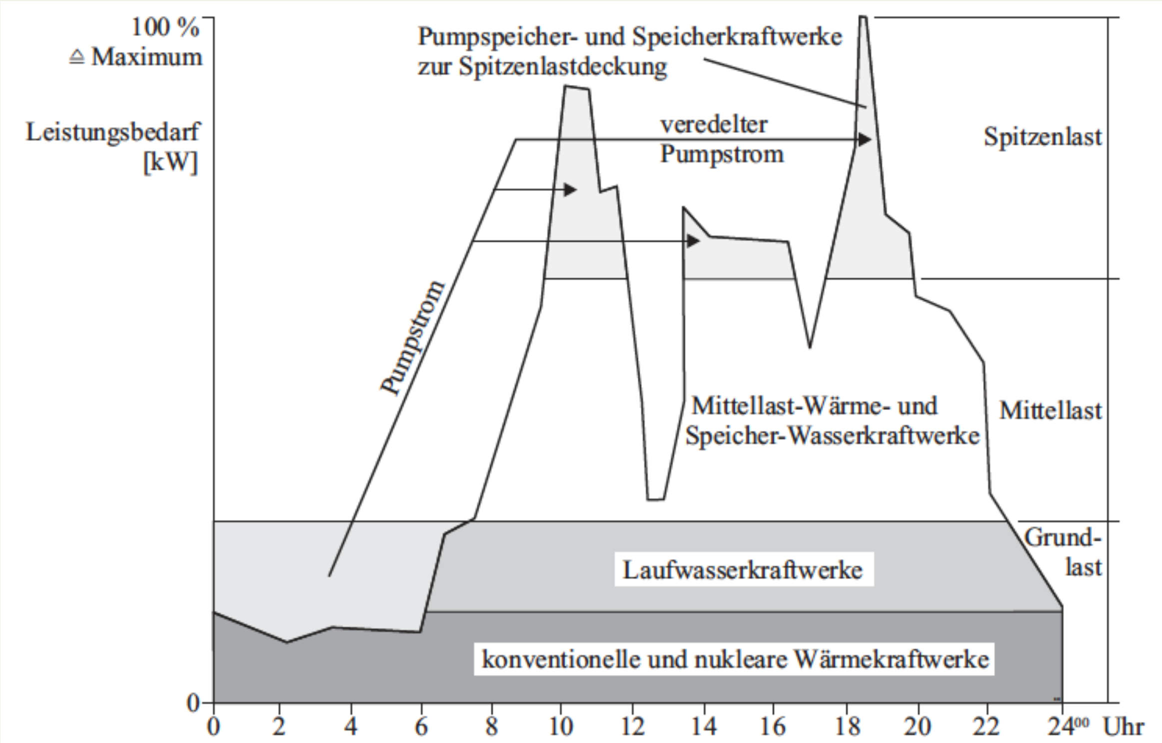
Classification by useful head at design parameters:

- Low head plants
  - Head <15 m
- Medium head plants
  - Heads between 15 and 50 m
- High head plants
  - Heads > 50 m



ENERGY MARKET ASPECTS

Classification by market aspects:



1. Peak load plants
2. Mid-load plants
3. Base load plants

OPERATIONAL ASPECTS

<u>Island operation</u>

The hydropower plant or set of hydropower plants supply a confined amount of customers

<u>Grid integrated operation</u>

The hydropower plant is integrated in a larger electricity generation system, for example the national electricity grid

INSTALLED CAPACITY

Classification by installed capacity:

- Small hydropower
  - < 1 MW
- Medium hydropower
  - < 100 MW
- Large scale hydropower
  - >100 MW

- Mini hydropower
  - < 100 kW
- Micro hydropower
  - < 10 kW

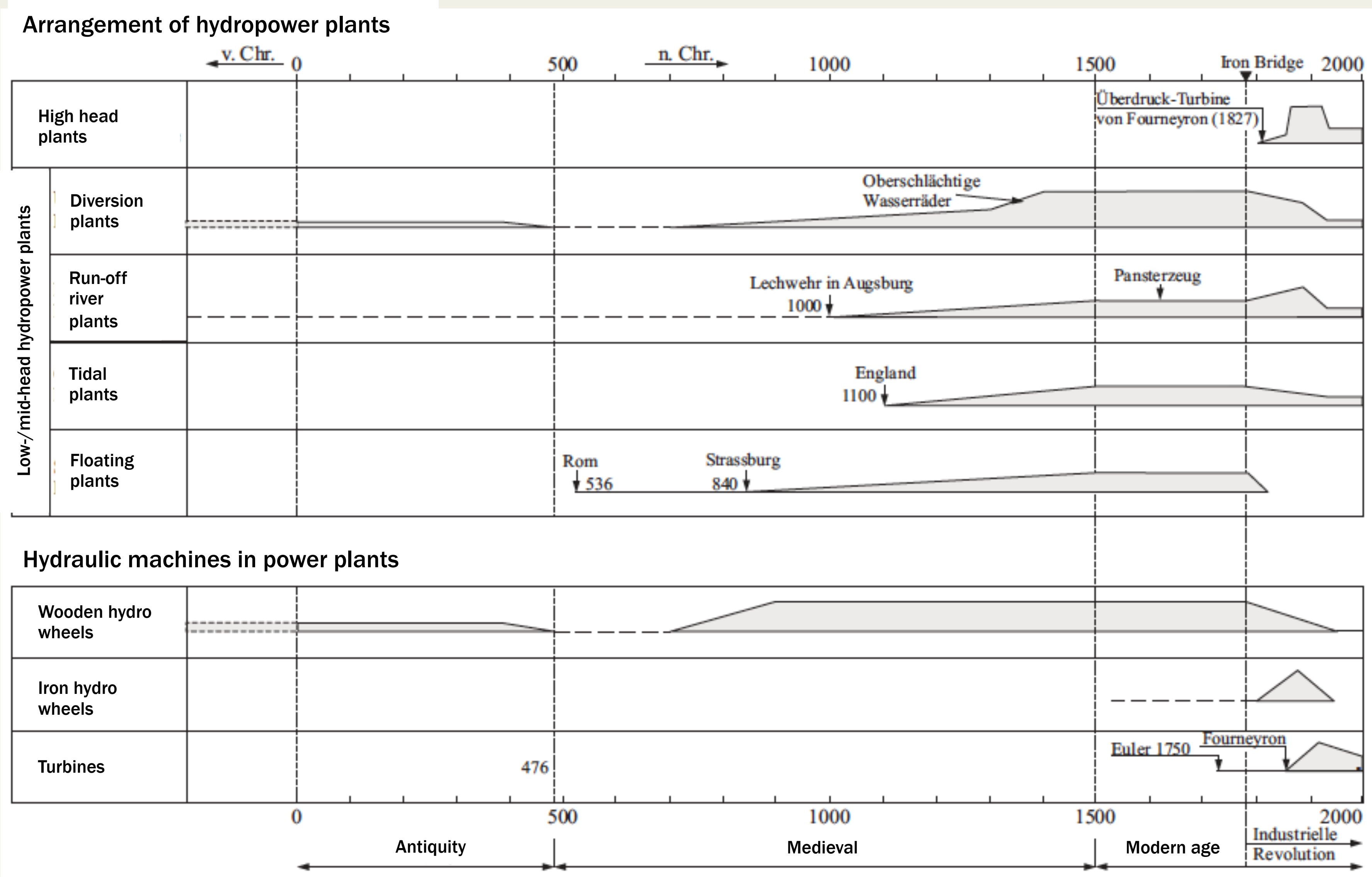
WATER RESOURCE MANAGEMENT ASPECTS

Classification by water resource management aspects:

1. Plants exclusively for hydropower generation
2. Plants serving more purposes than hydropower alone: Multi-purpose projects
3. Plants whose primary purpose is not hydropower, such as water supply or recreational purposes

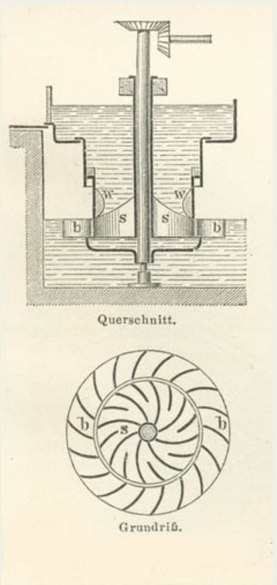
BRIEF HISTORY OF THE TURBINE

HISTORY OF THE TURBINE



HISTORY OF THE TURBINE

- Water as source of power is known to mankind since around 2,000 B.C., which is around 1,000 years later that wind power was used on sailing boats
- In around 300 B.C. hydro wheels were used for pumping water
- In the first 1,000 years AD floating and ship mills were used for processing grains and other food



- In central Europe hydro wheels were widely used till mid of the 20th century for direct use of mechanical energy
- In 1827 Benoit Fourneyron invented the prototype of a turbine, as his response to a technical competition
- In 1849 James B. Francis invented the Francis turbine that in principal is still used today. This invention marked the modern turbine era

HISTORY OF THE TURBINE

- 1879: Lester Pelton invented the Pelton turbine
- 1903: Anthony Michell receives the patent for his Michell-turbine, a predecessor of the cross-flow turbine
- 1913: Victor Kaplan invented the Kaplan turbine
- 1933: Fritz Ossberger receives a patent for the cross-flow, or Ossberger turbine, as it is still used today

- Recent times: new and re-invented technologies emerge on the hydropower market

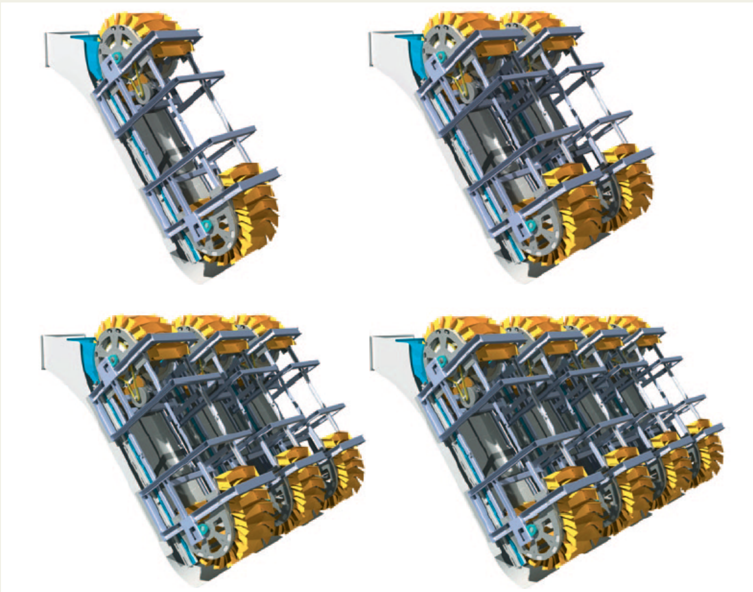
SOME EXAMPLES OF RECENT TECHNOLOGIES

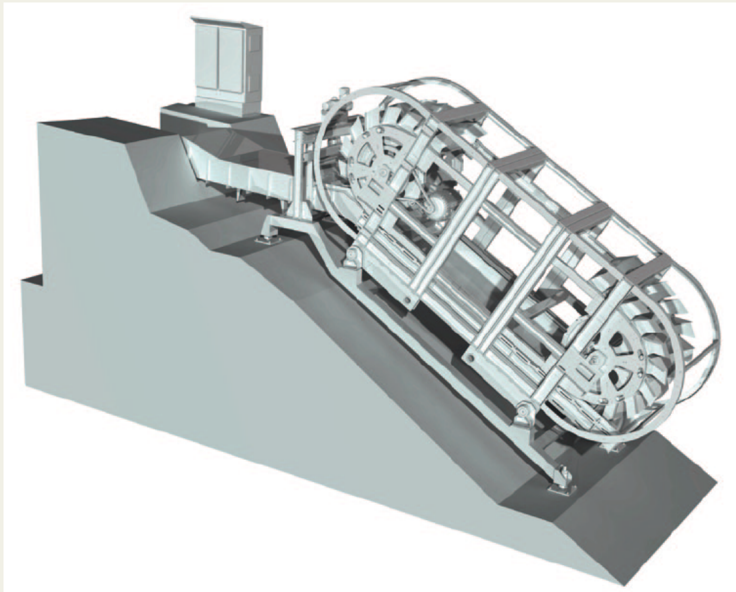
Hydrodynamic Screw




SOME EXAMPLES OF RECENT TECHNOLOGIES

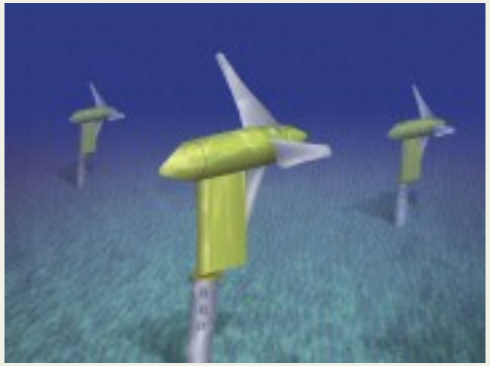
Steff Turbine



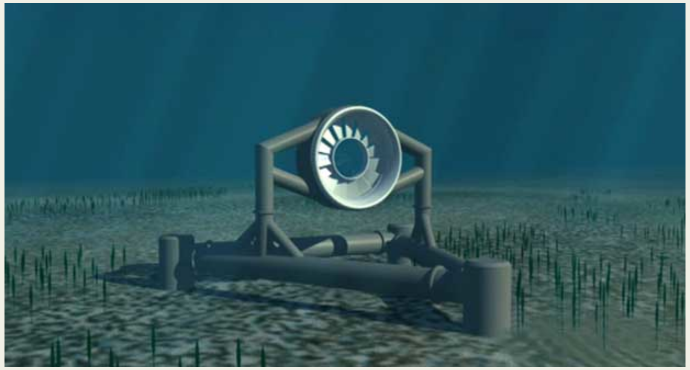


SOME EXAMPLES OF RECENT TECHNOLOGIES

Hydro-kinetic Turbines



Axial flow turbine



Open center fan turbine

Helical turbine

Free flow power generator

Gravitation water vortex power

HYDROPOWER AND THE ENVIRONMENT

ENVIRONMENTAL HYDROPOWER ASPECTS

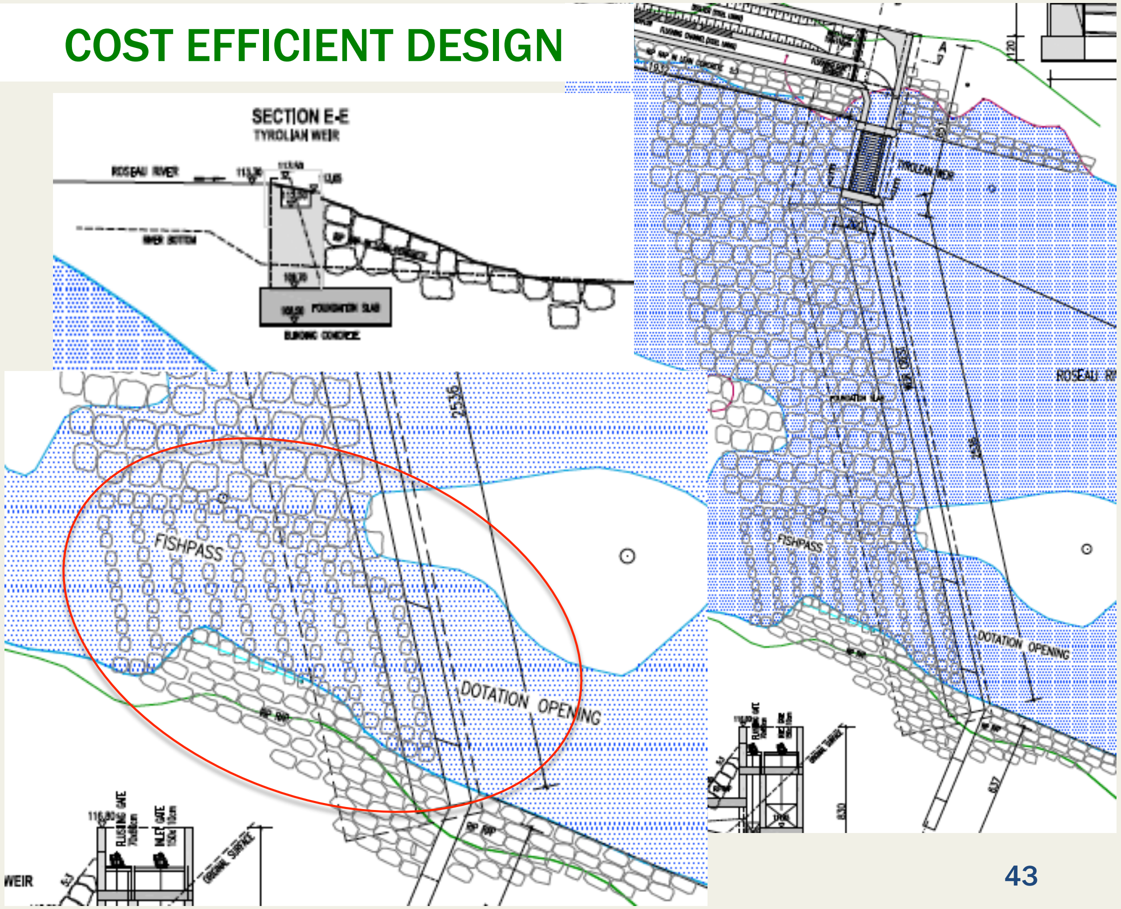
- Hydropower has the potential to be a clean and environmentally friendly energy – if developed wisely!
- The environmental consciousness in the context of hydropower development was taken serious only from the end 1980'ies when environmental standards were developed
- Since then, many hydropower plants, in particular small scale developments built in rivers, were refurbished with environmental support measures
- Omission of environmental aspects in the design of a hydropower plant are always a boomerang that returns to you at one point in time

ENVIRONMENTAL HYDROPOWER ASPECTS

- Environmental measures have huge cost implications when built after plant completion, but cost can be controlled when these measures are included in the design from the beginning

EXPENSIVE SOLUTION

COST EFFICIENT DESIGN



ENVIRONMENTAL HYDROPOWER ASPECTS

What aspects to consider?

Generally, environmental issues can be broken down in:

1. Real issues
2. ASB issues – Artificial Stumbling Block

While real issues need real solutions, ASB issues must not be under estimated as they can kill projects.

Typical ASB issue: Protection of individual old trees!

Solution: identify those issues early and design around them.

ENVIRONMENTAL HYDROPOWER ASPECTS

Real issues:

- Fish related issues
  - Fish migration: upstream and downstream
  - Fish damage when passing through the turbine
  - Fish damage in front of trash racks
  - Changing of fish habitat from river to lake (stenoecious types)
- Migration of invertebrates (shrimps, cray fish, etc)
- Creation of stagnant water bodies → mosquito breeding grounds; source of vector related hazards
- Lakes create barriers for wild life migration
- Destruction of wild life habitats, in particular of endangered species
- Removal of vegetation, in particular prime forest
- Creation of GHG sources from inundated trees

ENVIRONMENTAL HYDROPOWER ASPECTS

Real issues: (continued)

- Changing of air flow patterns → influence on air quality
- Noise pollution by powerhouse and other noisy equipment
- Destabilization of slopes
- Impact on water quality
  - Stagnant water → temperature, oxygen, pollutant accumulation
  - Pollutants from the plant (oil leaks…)
  - Positive impact possible: removal of garbage through trash rack
- Reduction of flow in a section of the river
- Changing of sediment regime of the river by weir or dam
  - The sediment topic is an integral topic connecting ecology and sustainability and longevity of a project
- Impact on riparian and river flora

ENVIRONMENTAL HYDROPOWER ASPECTS

Social issues to be considered:

- Resettlement
- Noise pollution
- Conflict with usage of water and water rights (e.g. Nile Water Treaty)
- Territorial conflicts (land issues)
- Lack of benefits for affected people
- Cultural conflicts, in particular with native population
- Cross-border projects add a political component

ESIA

Environmental and social aspects must be studied in an

Environmental and Social Impact Assessment (ESIA)

- International banks request ESIA as obligatory part of a project document
- ESIA analyses the existing environmental and social situation, compares it with the situation with project and identifies the project's impact
- ESIA forms the basis for the Environmental and Social Impact Mitigation Plan
- Impact mitigation can eat up significant project budget. Even more so if not done with appropriate care!!

ESIA

A good project development considers environmental and social aspects right from day 1 !

PHYSICAL HYDROPOWER BACKGROUND

PHYSICAL HYDROPOWER BACKGROUND

What is Hydropower?

"Hydropower, hydraulic power or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes."

(Wikipedia)

Forms in which Energy is stored in water:

Pressure Energy

Potential Energy

Kinetic Energy

Heat Energy

Chemical Energy

PHYSICAL HYDROPOWER BACKGROUND

How is power expressed in mathematical terms?

Power P in Watts [W], or multiples of it (kW, MW, mW,…)

So: what is the difference between Power and Energy?

Answer: The “h”!

Energy E is expressed in Watt hours [Wh]

Energy is the ability to provide the power P over a time interval t [in h].

Here, power is the electrical equivalent of physical work.

PHYSICAL HYDROPOWER BACKGROUND

Work is a force multiplied by distance along a path C:

$$W = \int_C F \cdot ds$$

So, power is the equivalent to providing a force along a way.

For example: lifting a mass *m* the distance Δz

PHYSICAL HYDROPOWER BACKGROUND

<u>Potential, Pressure and Kinetic Energy in physical terms</u>

The law of energy conservation applies:

Energy can neither be created (produced) nor destroyed by itself. It can only be transformed.

PHYSICAL HYDROPOWER BACKGROUND

Total energy is the sum of kinetic, potential and pressure energy

$$E_{total} = E_{kin} + E_{press} + E_{pot}$$

And:

$$E_{kin} = 1/2 * m * v^2$$

$$E_{press} = m * p / \rho$$

$$E_{pot} = m * g * h$$

Where:

m = mass

g = earth acceleration

v = velocity

p = pressure

ρ = density

h = height

PHYSICAL HYDROPOWER BACKGROUND

The total energy can be expressed by energy heads using weight instead of mass in the former equations:

$$H_{total} = H_{kin} + H_{press} + H_{pot}$$

And:

$$H_{kin} = v^2 / (2*g)$$

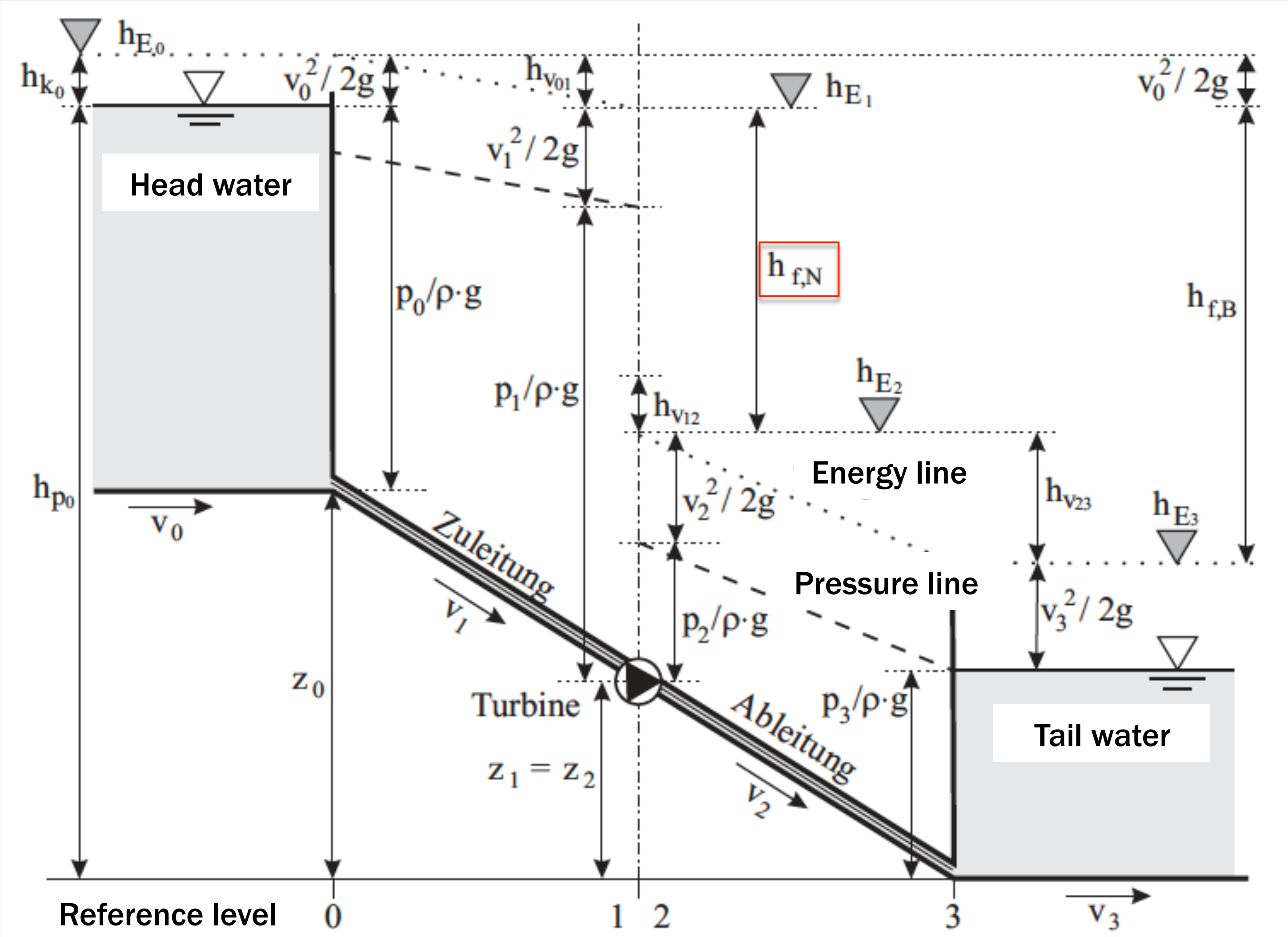
$$H_{press} = p / (\rho*g)$$

$$H_{pot} = z$$

Why is that important?

- Energy heads can easily be illustrated as water depth!

PHYSICAL HYDROPOWER BACKGROUND



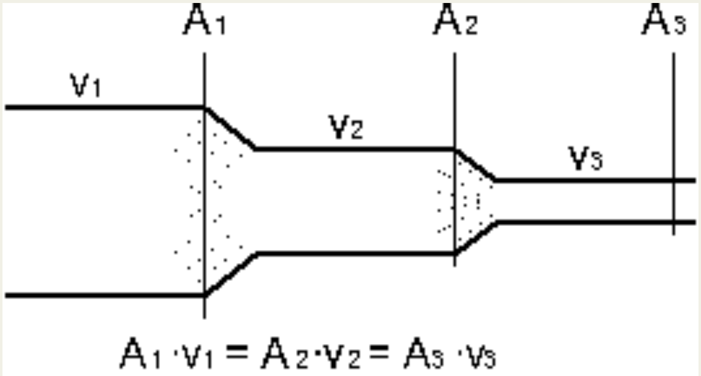
PHYSICAL HYDROPOWER BACKGROUND

Two underlying physical laws:

1. **Law of Continuity**

2. **Bernoulli's Law**

1. Law of Continuity

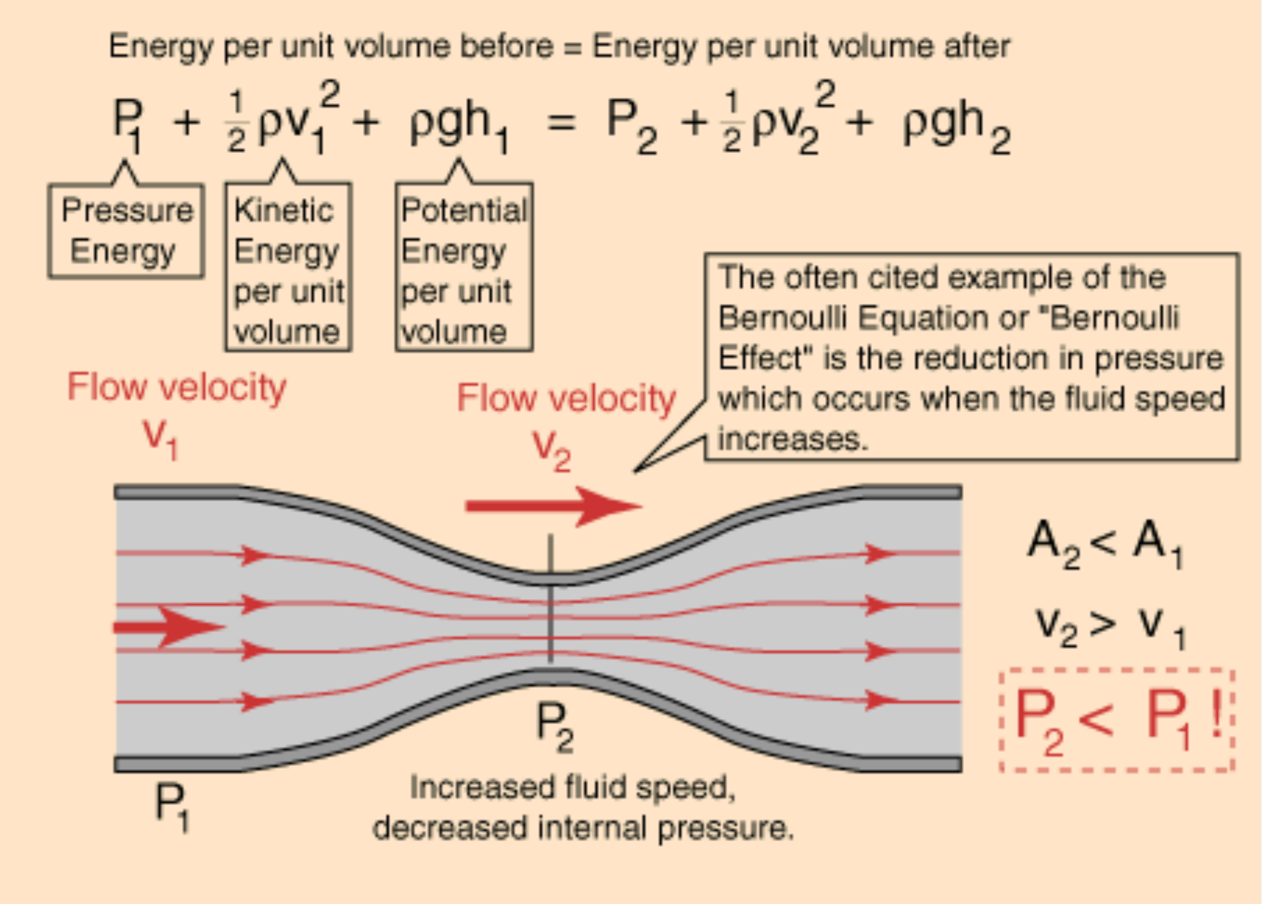


$$Q = A \cdot v = const$$

Assumption: Liquid is incompressible

2. Bernoulli's Law

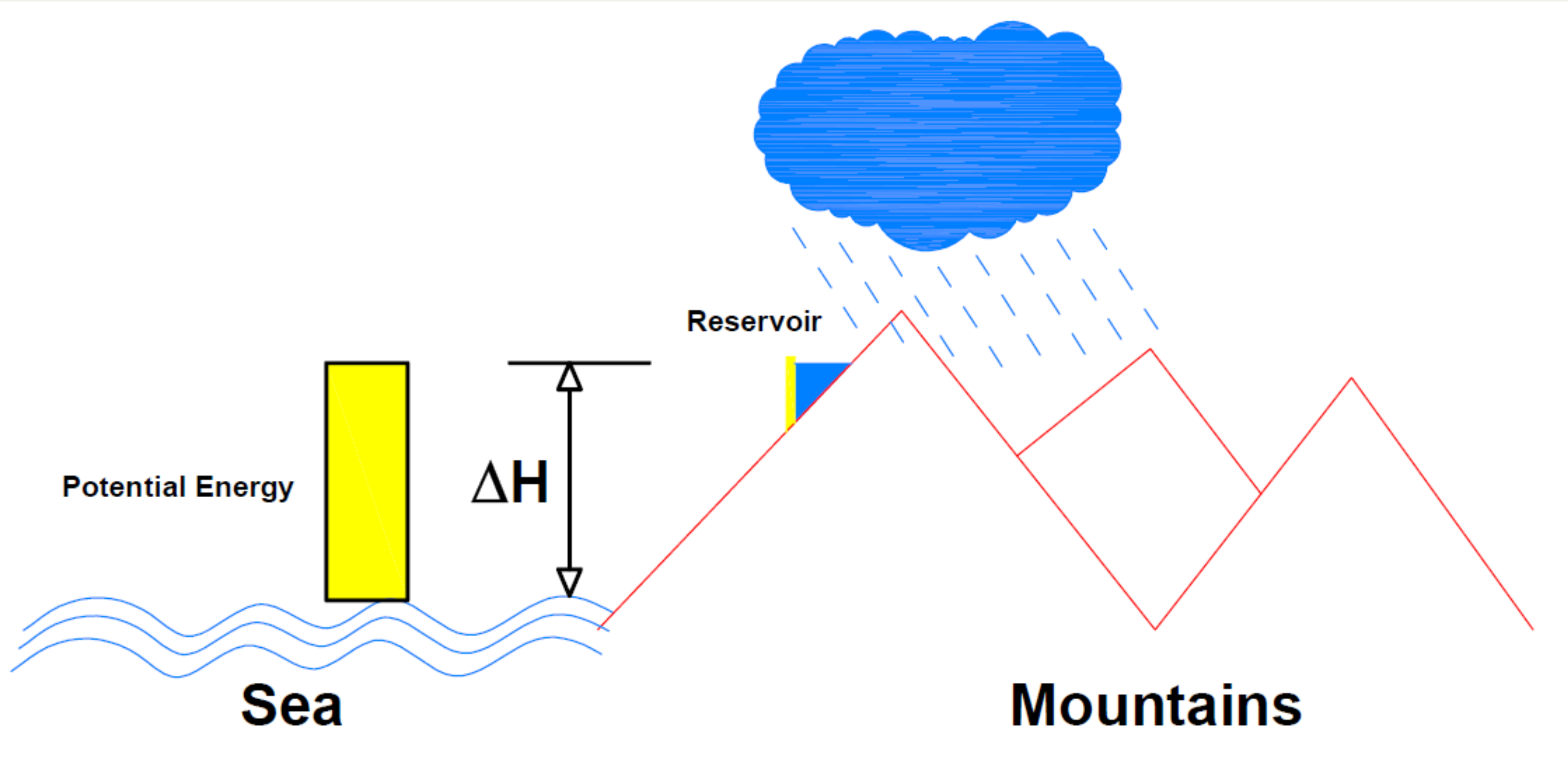
Here energy is expressed in pressure terms which are obtained from the former energy head terms by multiplying with (ρ*g)



[Bernoulli calculation]

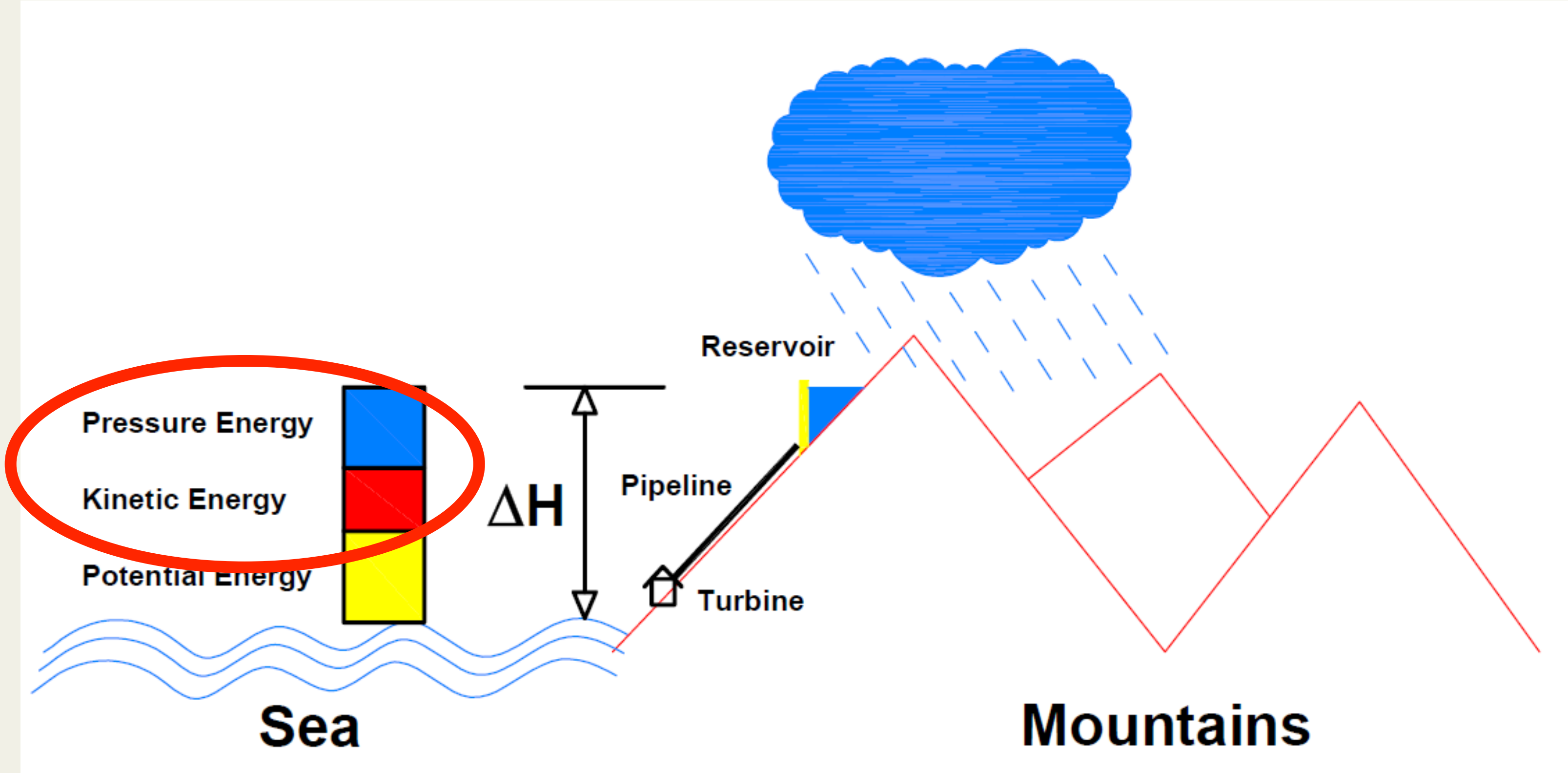
How to make use of water as source for energy?

Example: Reservoir



Until further use: Potential Energy

Example: Reservoir



Converted: Kinetic and Pressure Energy

PHYSICAL HYDROPOWER BACKGROUND

Governing parameters of a hydropower site:

→ **Head H**
Potential energy of the water

→ **Discharge Q**
Amount of water per time unit (e.g. 1 m^3/s)

Calculate power output at the selected site

$$\boxed{P_{el} = \rho * g * Q * H_n * \eta}$$

P_{el} = electrical power output in Watts
ρ = density of water (1000 kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
Q = flow in m^3/s
H_n = net head in m
η = overall efficiency

PHYSICAL HYDROPOWER BACKGROUND

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)

PHYSICAL HYDROPOWER BACKGROUND

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

PHYSICAL HYDROPOWER BACKGROUND

η = efficiency

Efficiency of

→ Turbine runner

- Depending on turbine type, size and speed, quality, wear

→ Generator

- Depending on type, size, speed, voltage level, age

→ Transformer

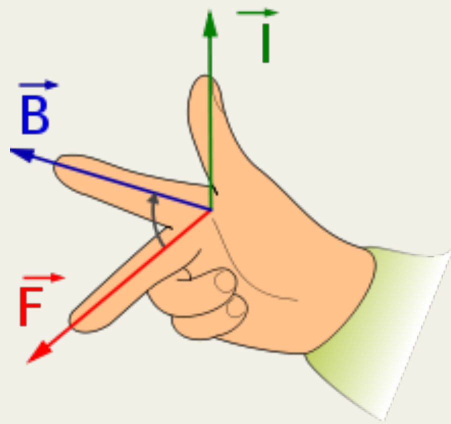
- Depending on type, size, cooling system, voltage level, age

Usually: $\eta_{total} \approx$ 70 to 85 % for small hydropower

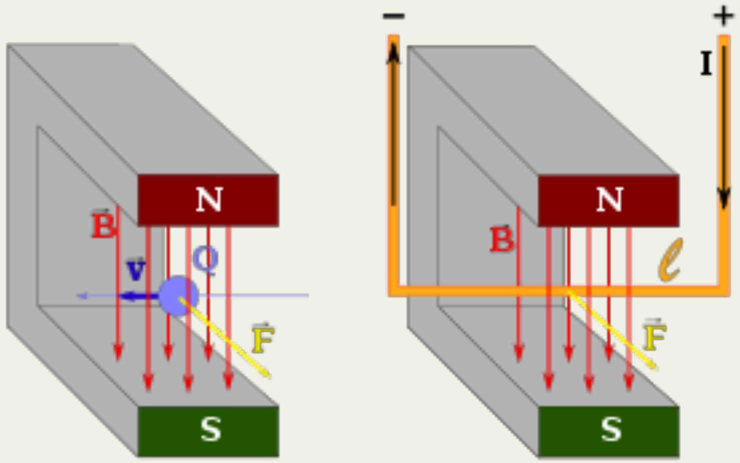
ELECTRICAL GENERATORS FOR TURBINES

PRINCIPLE OF AN ELECTRICAL GENERATOR

- A quantity of electricity that moves through a magnetic field experiences a force perpendicular to the direction of the magnetic field and the direction of movement of the electricity (Lorentz force, illustrated with the 3-finger-rule)

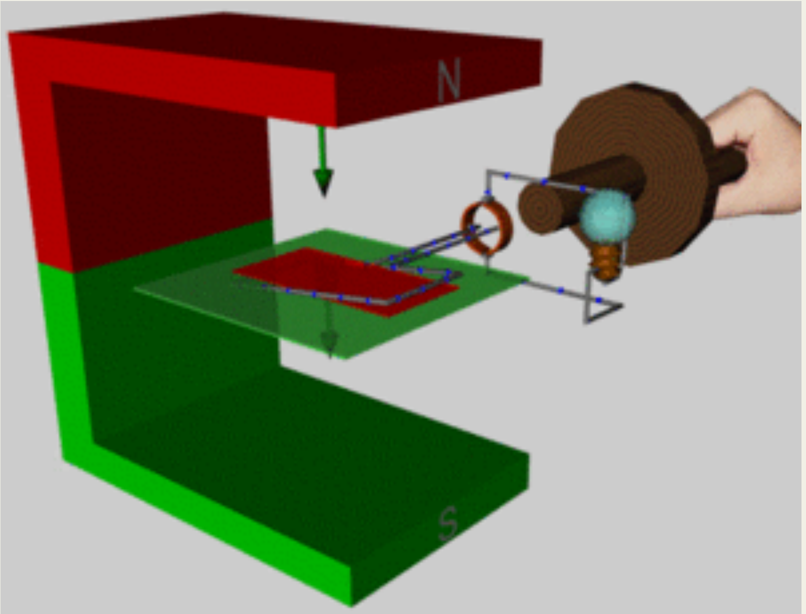


- The same applies also backwards: If a conductor is moved through a magnetic field, electricity flows

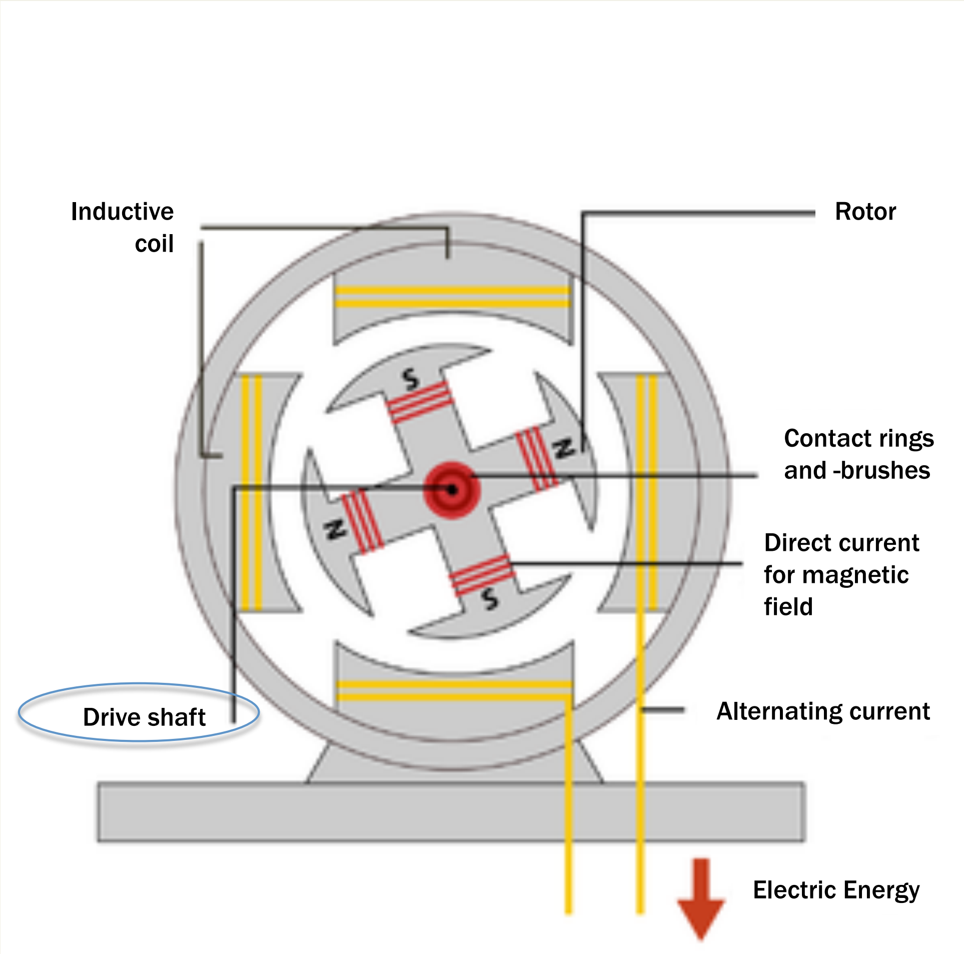


PRINCIPLE OF AN ELECTRICAL GENERATOR

- This effect is used in generators that generally – but not necessarily – rotate around a shaft



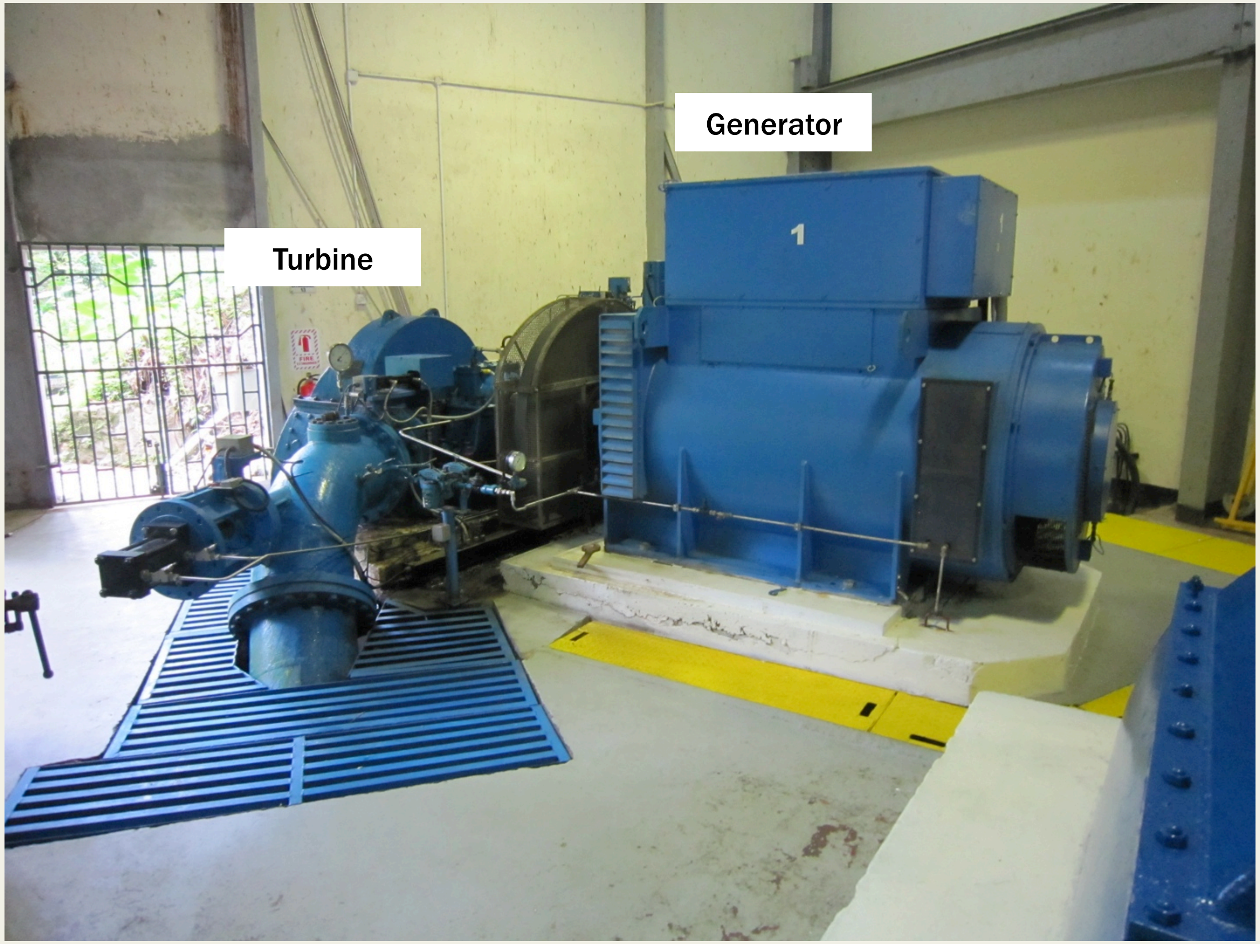
PRINCIPLE OF AN ELECTRICAL GENERATOR



- In the case of a hydropower plant, the drive shaft is connected to the turbine

PRINCIPLE OF AN ELECTRICAL GENERATOR

- Example of a 940 kW Pelton turbine with synchronous generator and flywheel



COMPARISON SYNCHRONOUS VERSUS ASYNCHRONOUS GENERATOR

What is the difference between synchronous and asynchronous generators?

- Synchronous generators generate their own magnetic field
  - The magnetic field can either be created by electric coils or by permanent magnets
- Asynchronous generators use a magnetic field that is induced by an external source, e.g. grid power

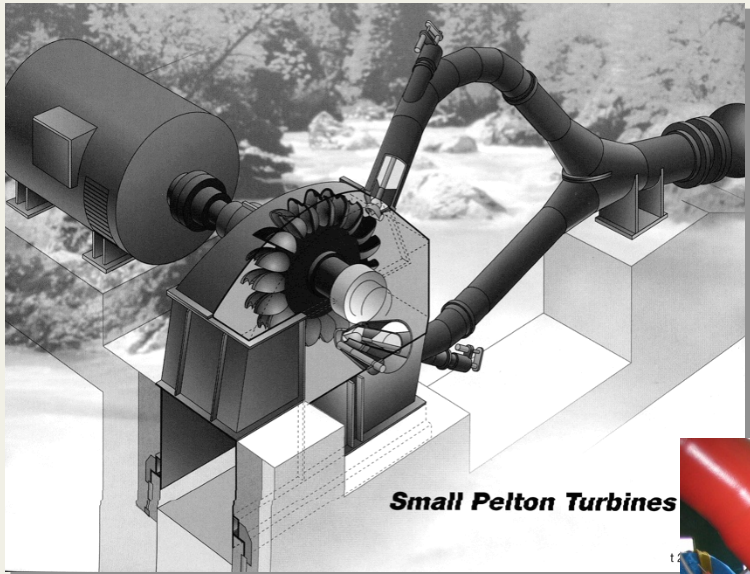
- Synchronous generators are used for island operation and to provide grid power services
- Asynchronous generators are not suitable to provide these grid power services

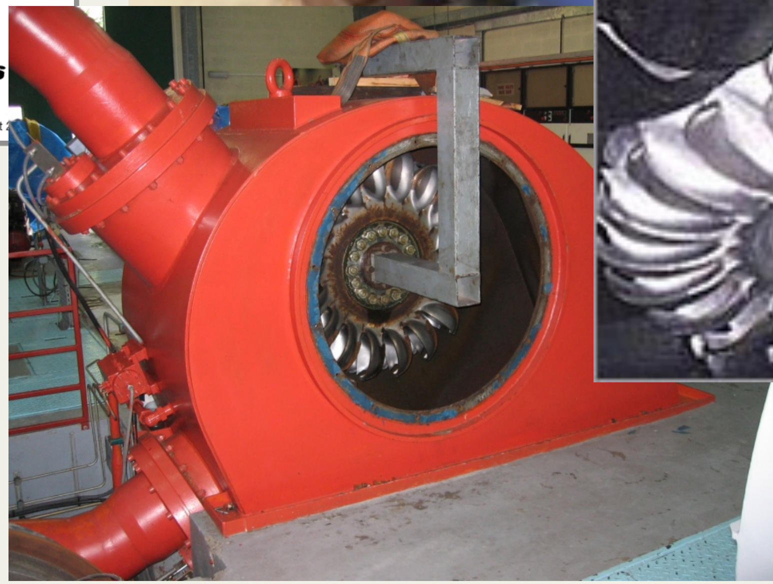
COMPARISON SYNCHRONOUS VERSUS ASYNCHRONOUS GENERATOR

Quality	Synch.	Asynch.
Requires runner regulation	yes	no
Self starting from stand-still	no	yes
Voltage regulation possible	yes	no
Active power regulation possible	yes	yes
Reactive power regulation possible	yes	no
Feeding-in into public grid possible	yes	yes
Feeding-in into island grid possible	yes	exceptionally
Synchronizing necessary when connecting to grid	yes	no
Overall efficiency	higher	lower
CAPEX / OPEX	higher	lower
Construction	complicated	simple
Space requirement	high	low

THE VARIOUS TURBINE TYPES

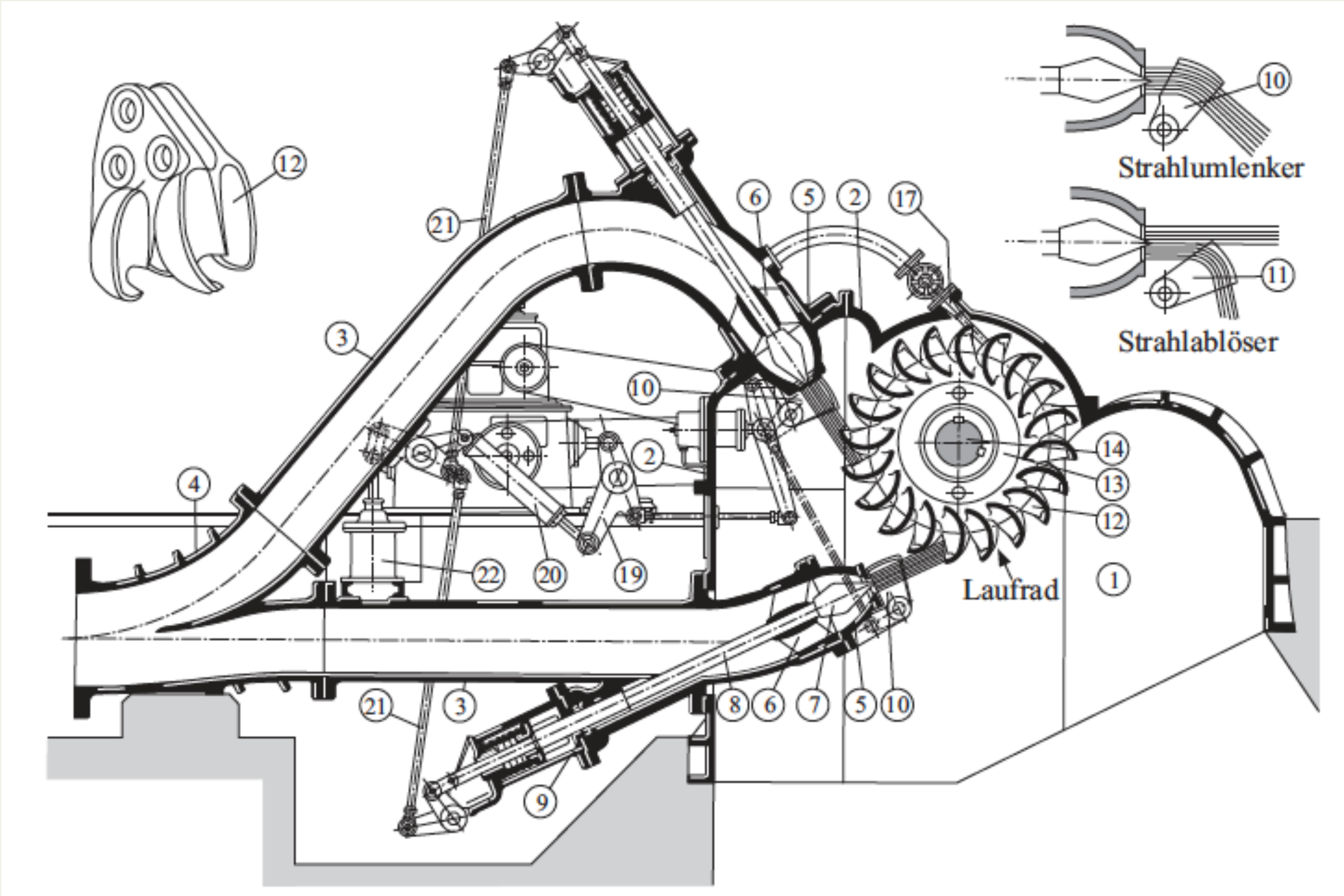
Pelton turbine: Impulse turbine





η up to 92%
(High efficiency at
partial flow down to10%)

Pelton turbine: Impulse turbine



PELTON TURBINE

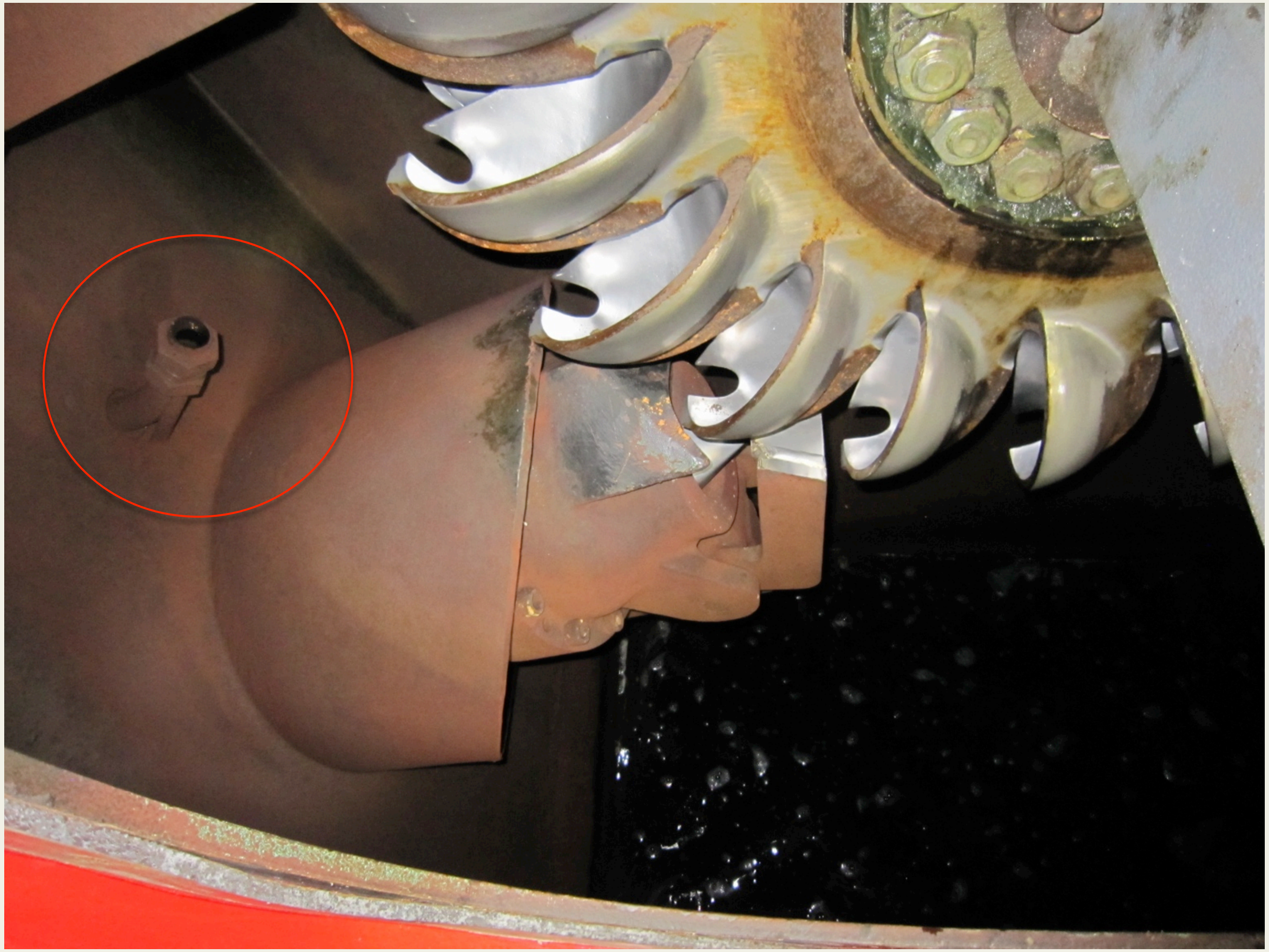
New Trafalgar, Dominica

PELTON TURBINE

Needle valve and baffle

Pelton blades: cups

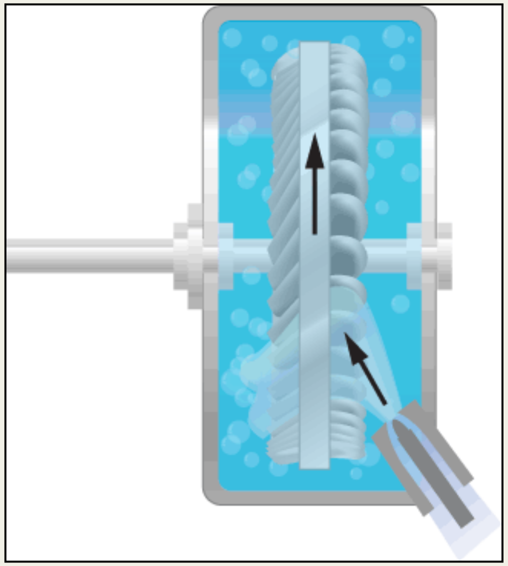
Break jet



TURGO TURBINE

Turgo turbine: Impulse turbine

η up to 90%
(High efficiency at
partial flow down to10%)



TURGO TURBINE

Difference between Turgo and Pelton turbines

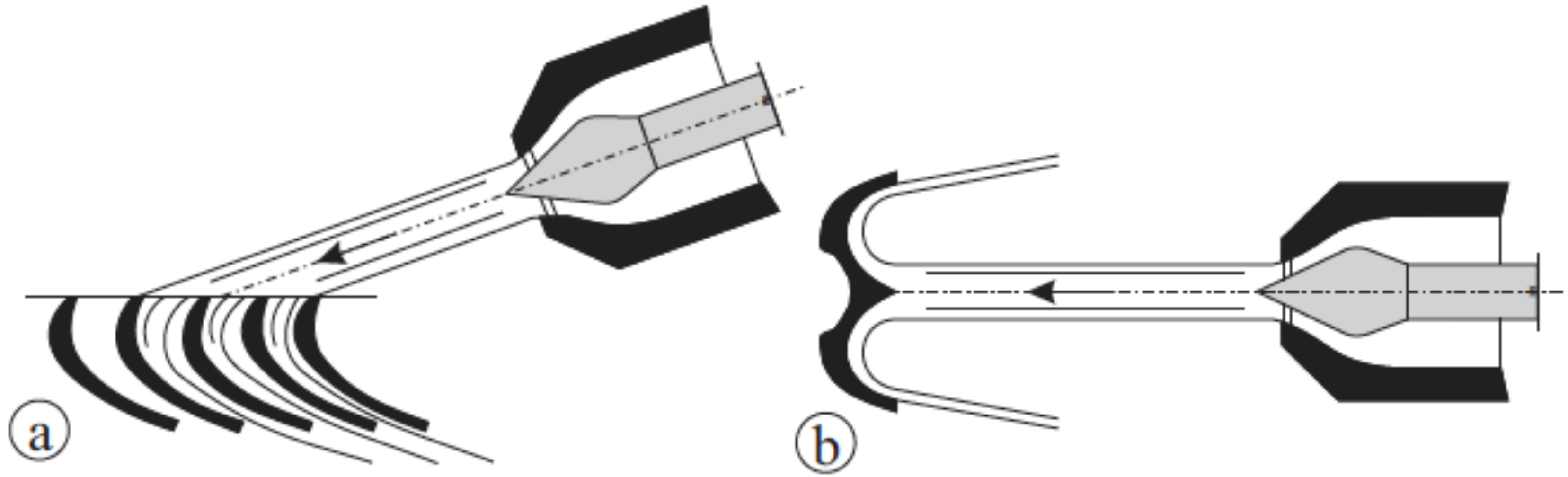
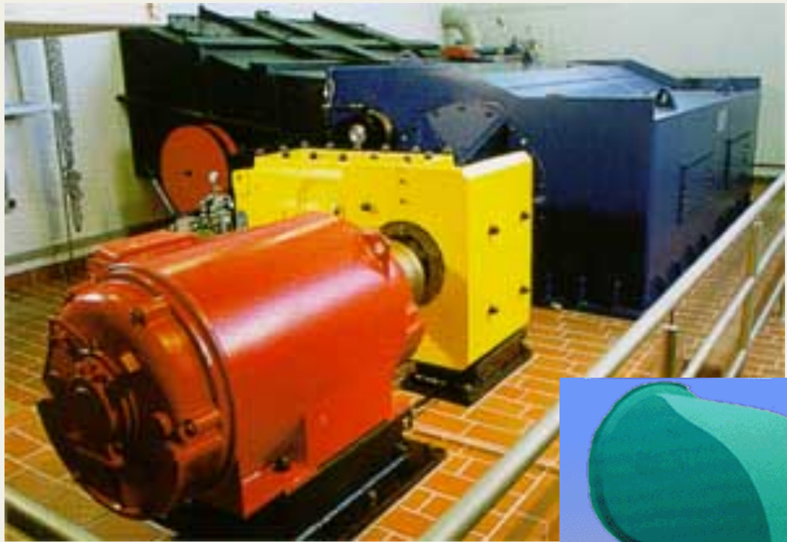


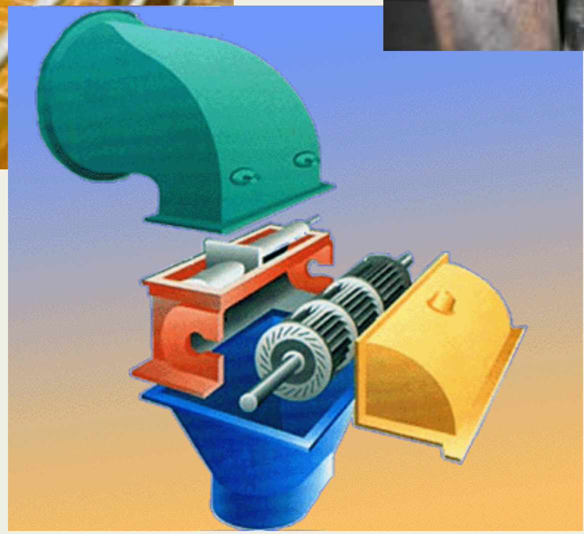
Abb. 15.22: Vergleich zwischen Turgo-Turbine (a) und Pelton-Turbine (b)

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

CROSS-FLOW TURBINE

Cross-flow turbine: Impulse turbine

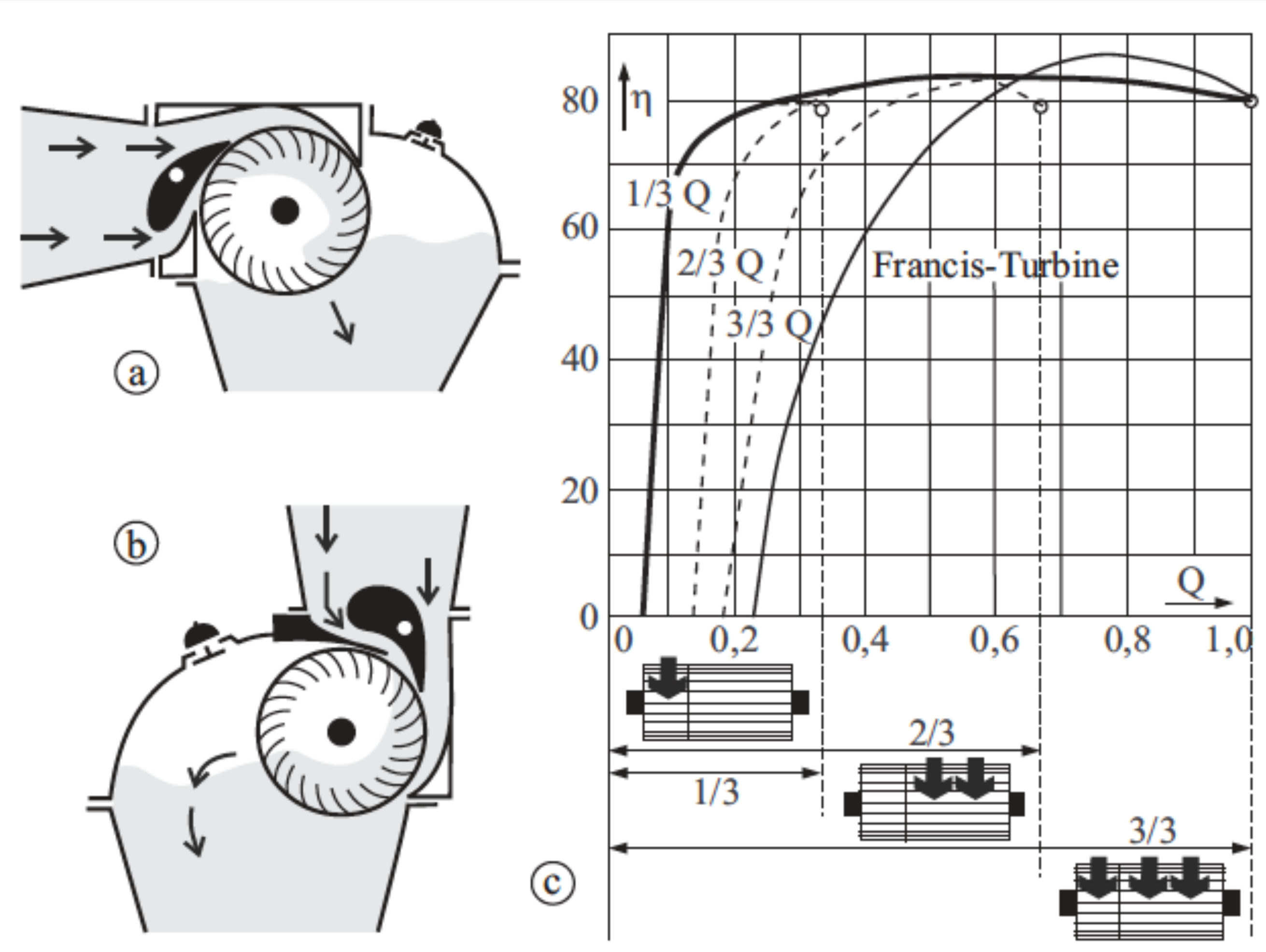




η up to 80%
(less efficient at
partial flow)

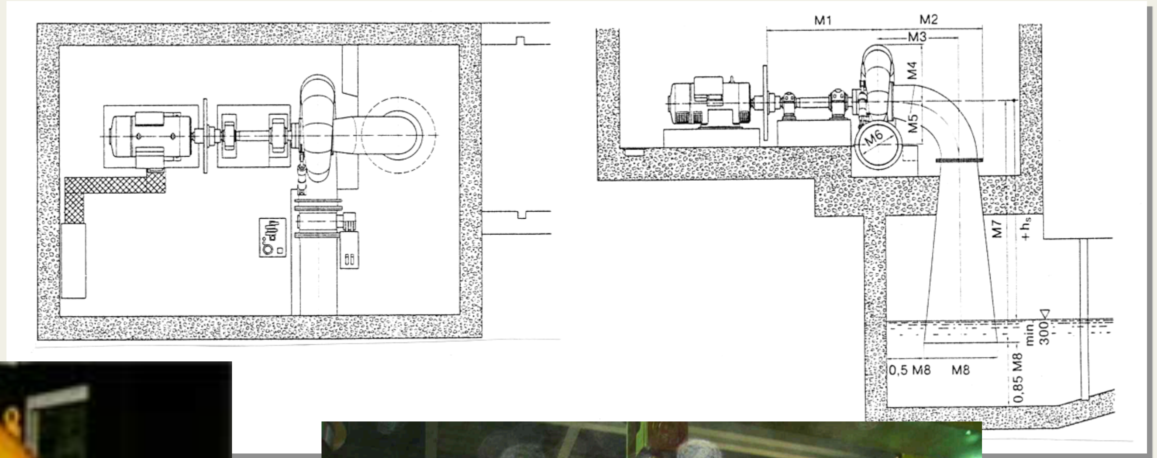
CROSS-FLOW TURBINE

Cross-flow turbine: Impulse turbine



Francis turbine: Reaction turbine

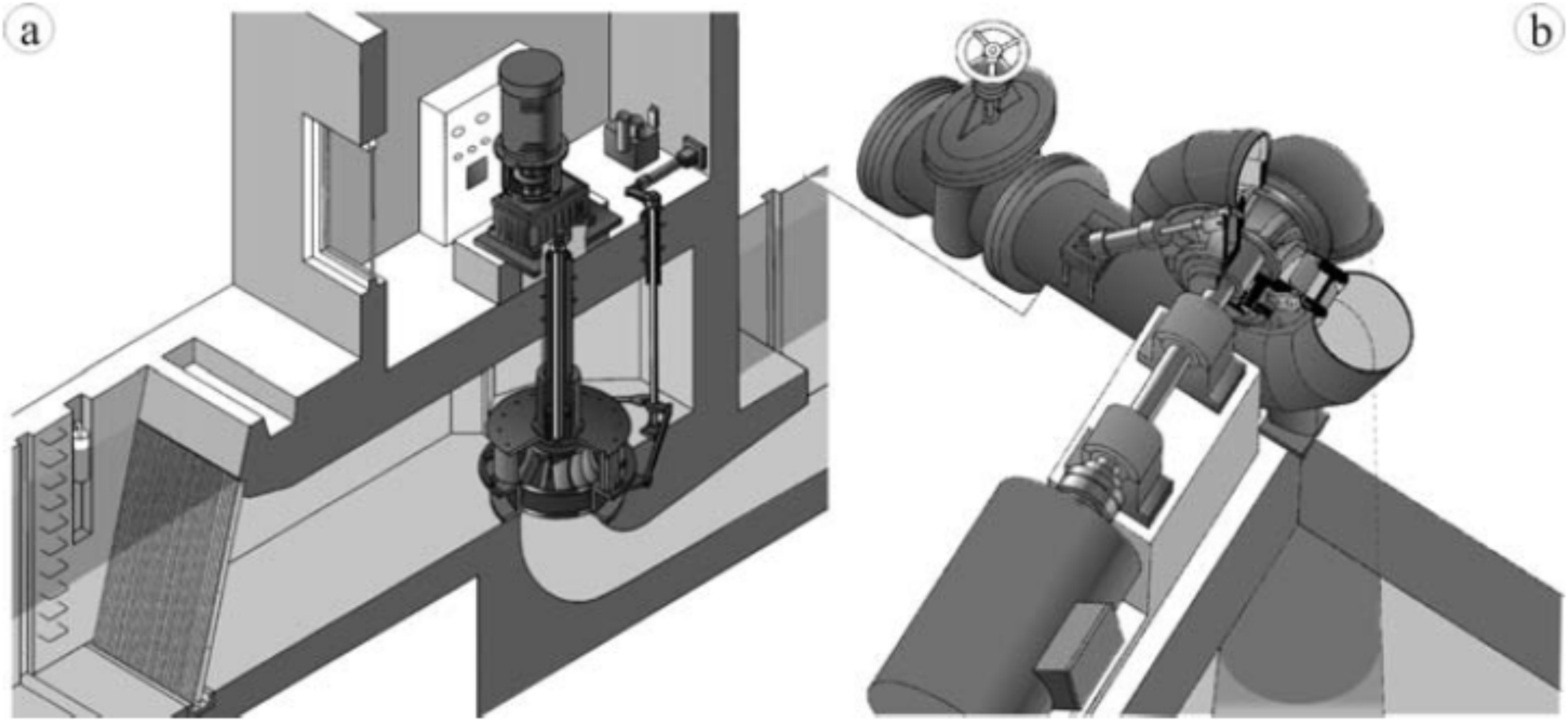
η up to 93%
(Applicable as
pump turbine)



FRANCIS TURBINE

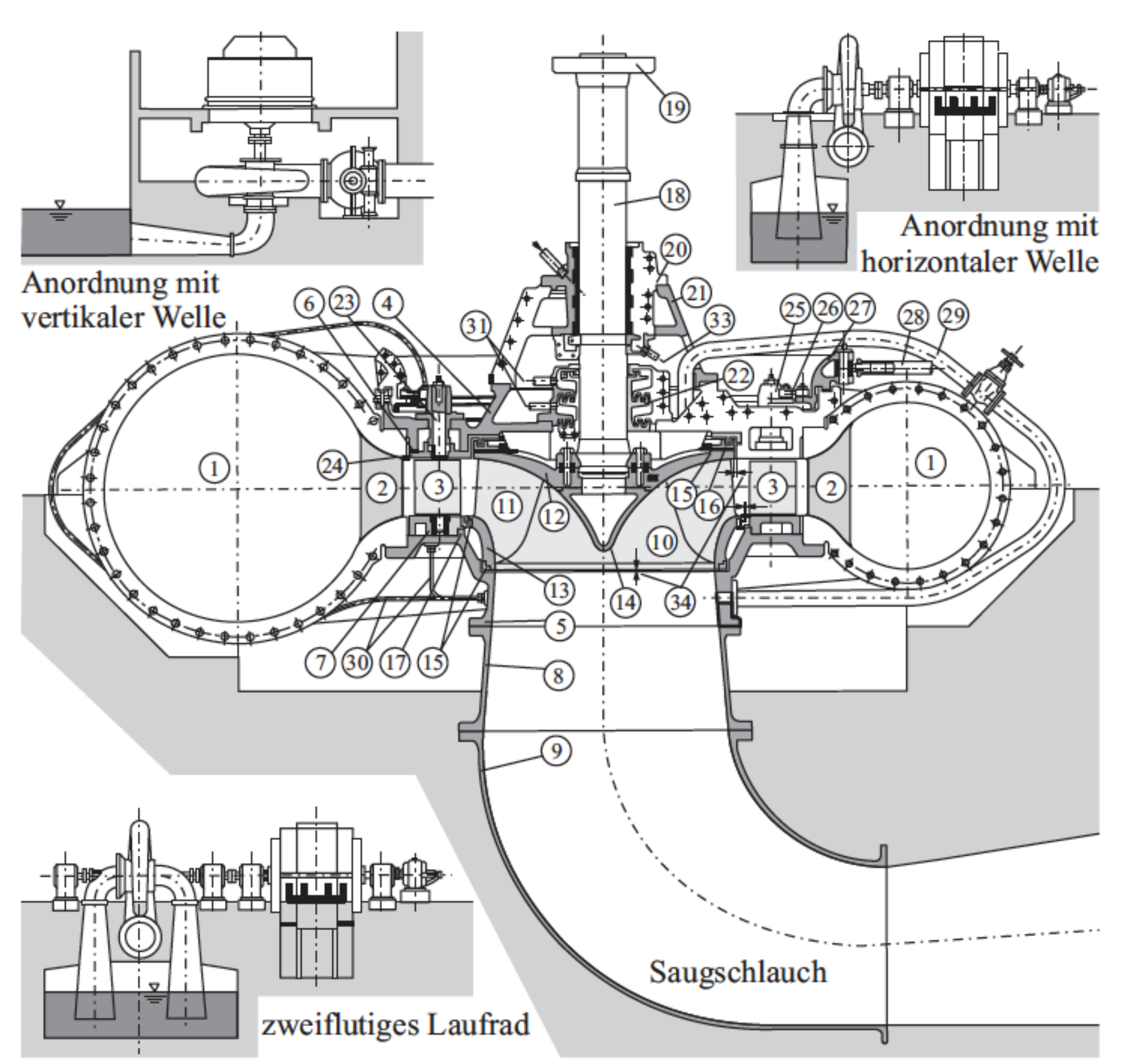
Cumberland, St. Vincent

FRANCIS TURBINE



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

FRANCIS TURBINE



Top left: vertical shaft arrangement;

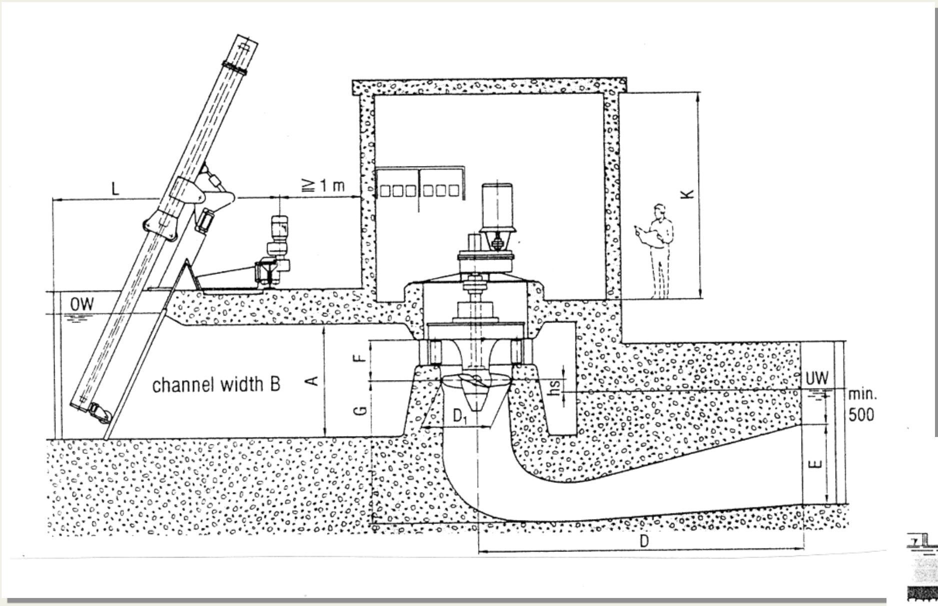
Top right: horizontal shaft alignment;

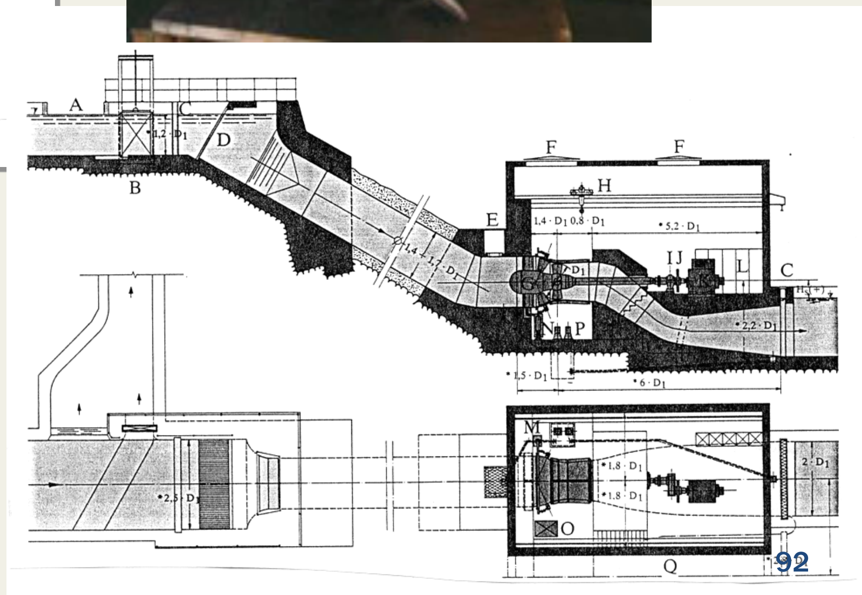
Bottom left: double flooded turbine;

Center: elements of a Francis turbine

KAPLAN TURBINE

Kaplan type turbine: Reaction turbine



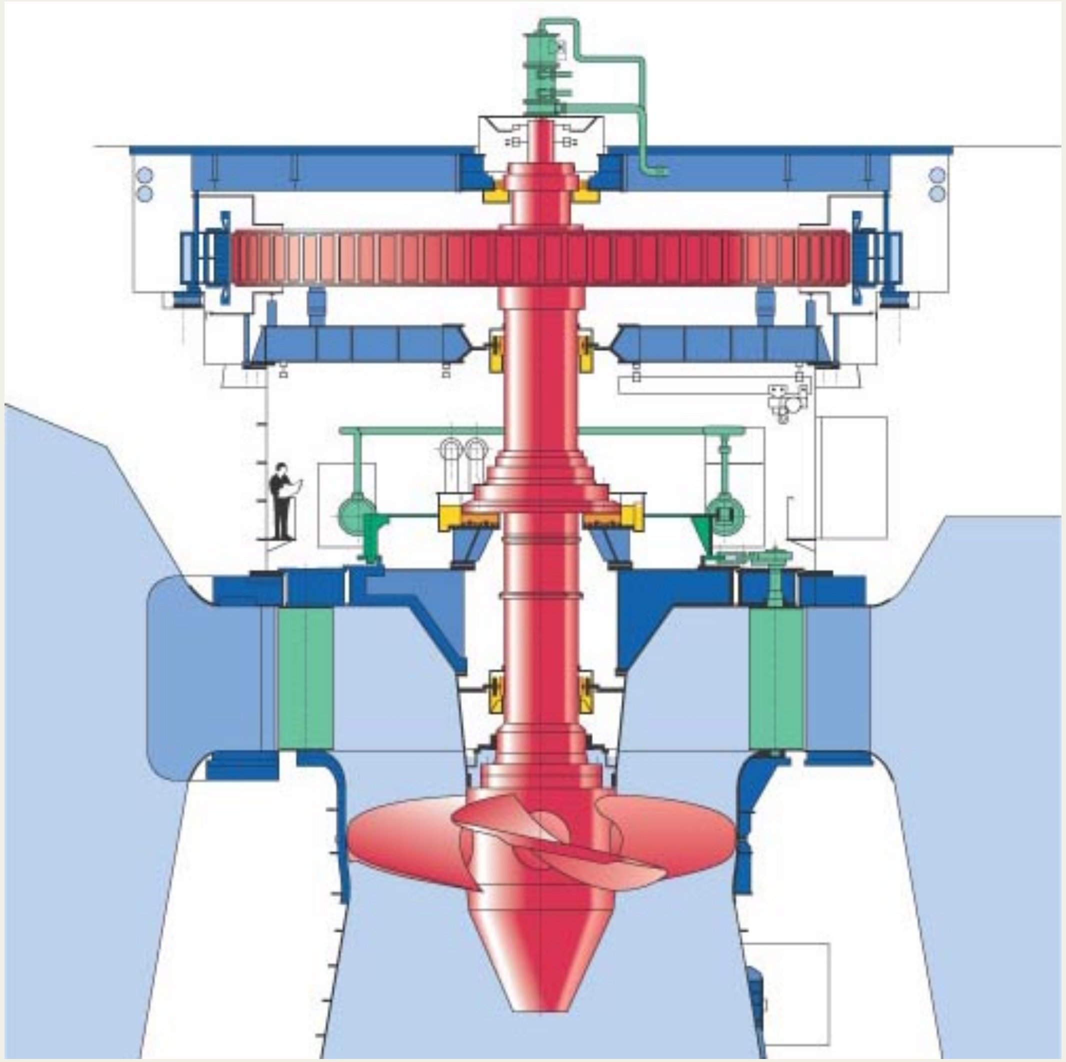


η > 90%
(High efficiency at
partial flow)

KAPLAN / PROPELLER TURBINE

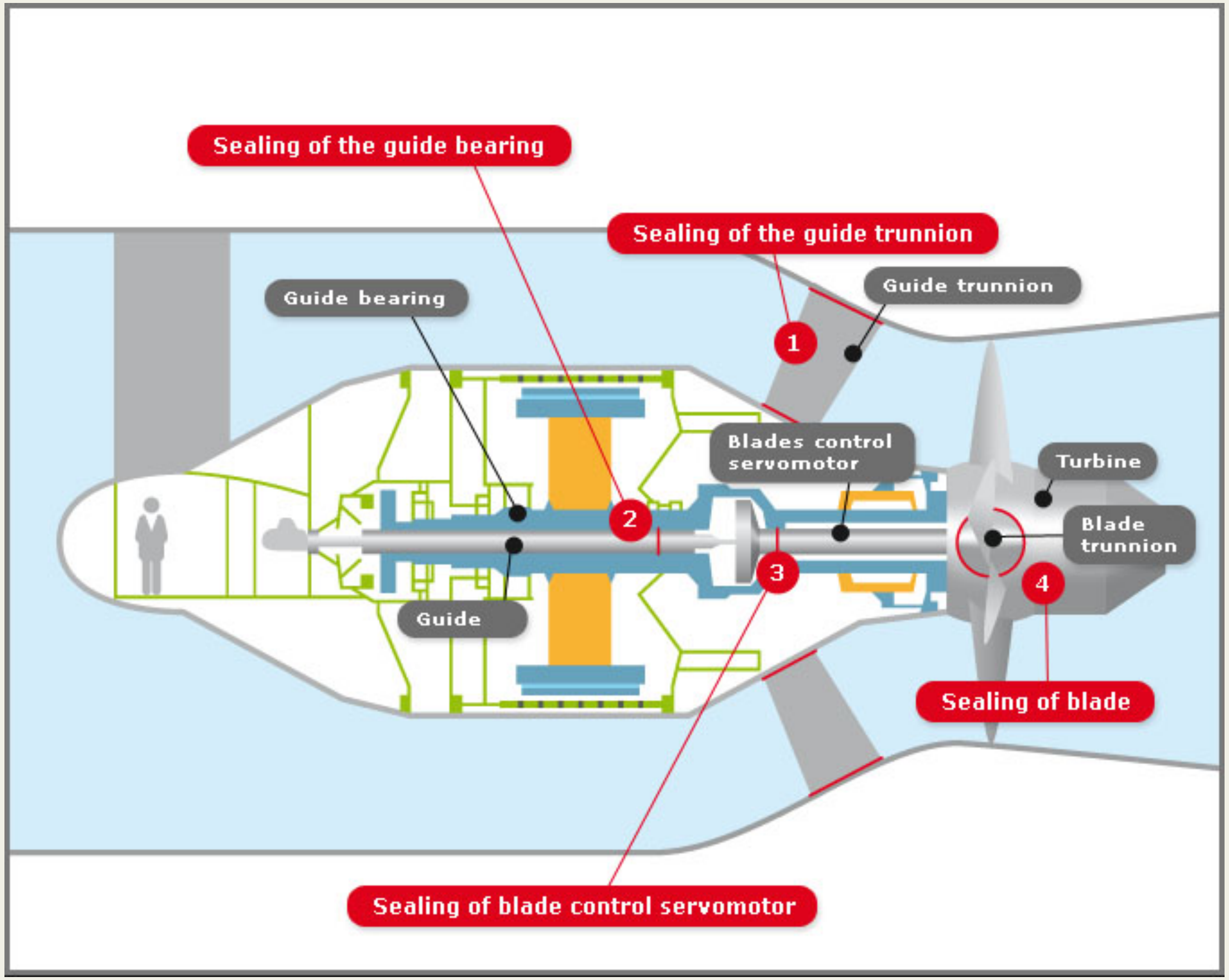
Kaplan turbine: guide vanes and blades can be regulated;

Propeller turbine: only guide vanes can regulate flow



KAPLAN / PROPELLER TURBINE

Related turbine types: Bulb turbine



KAPLAN / PROPELLER TURBINE

Related turbine types: HydroMatrix™

HYDROMATRIX® Experience

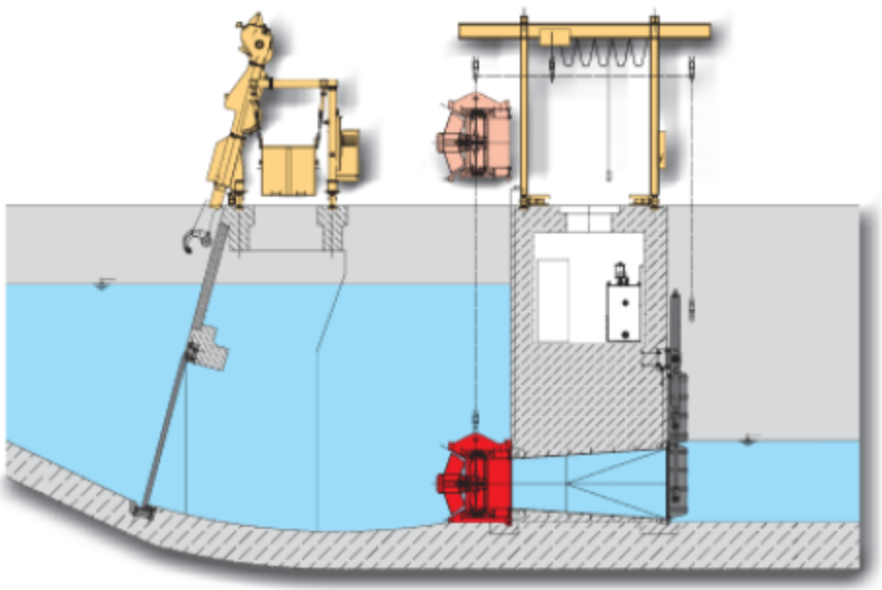
Irrigation Dams – JEBEL AULIA /Sudan

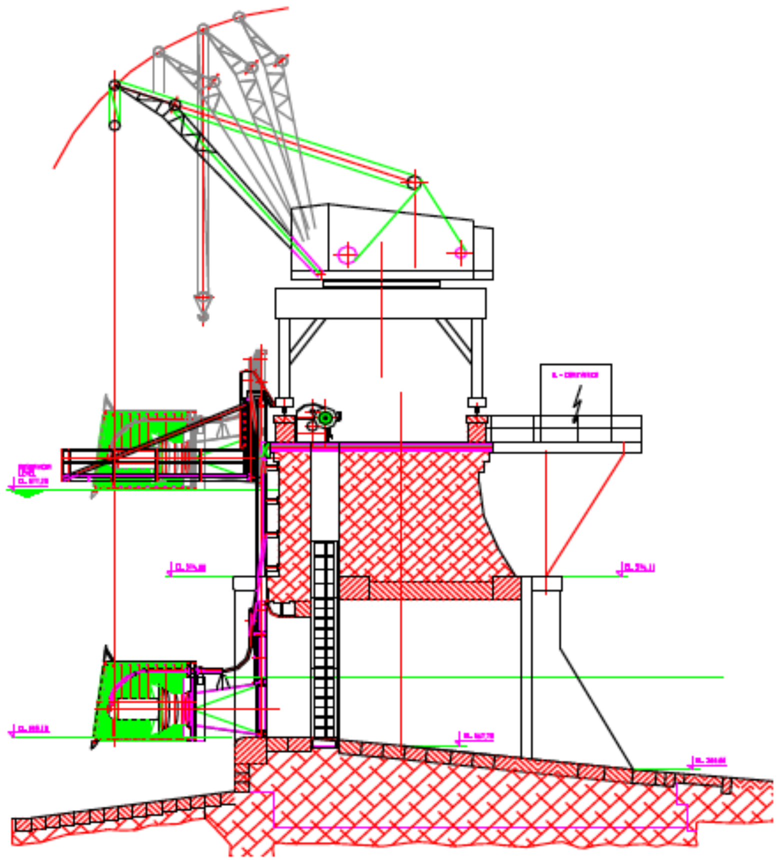
Status November 2003

KAPLAN / PROPELLER TURBINE

Related turbine types: HydroMatrix™

Application: Shiplocks

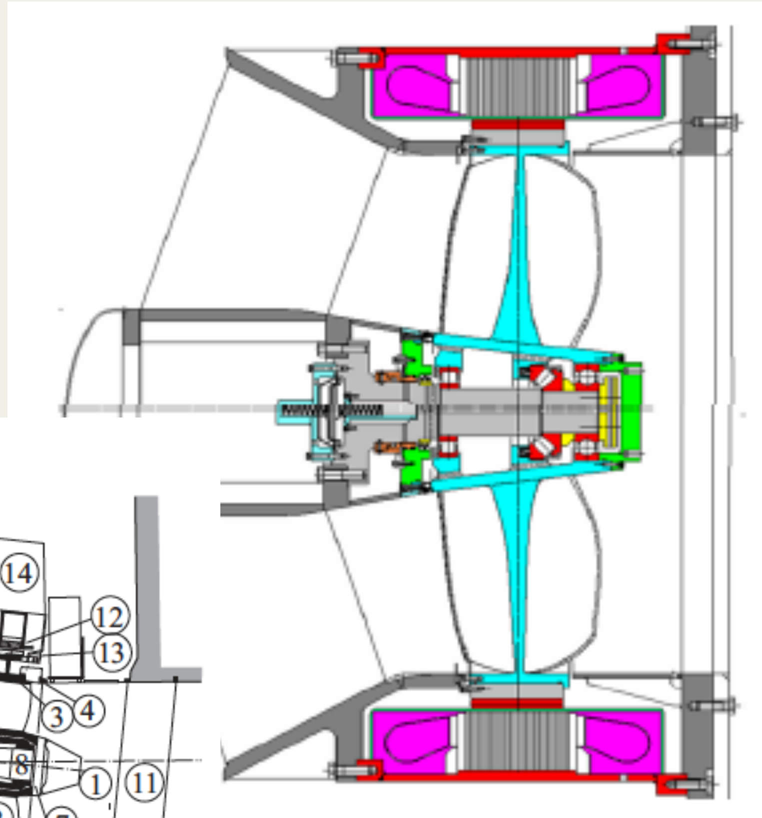


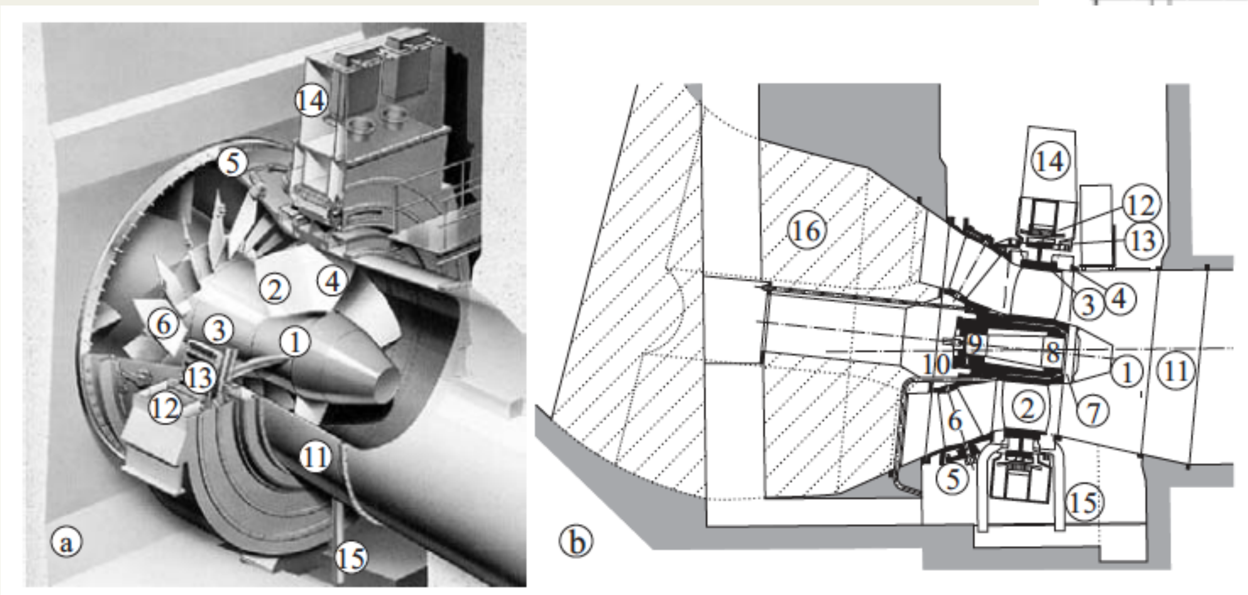


ANDRITZ Hydro

KAPLAN / PROPELLER TURBINE

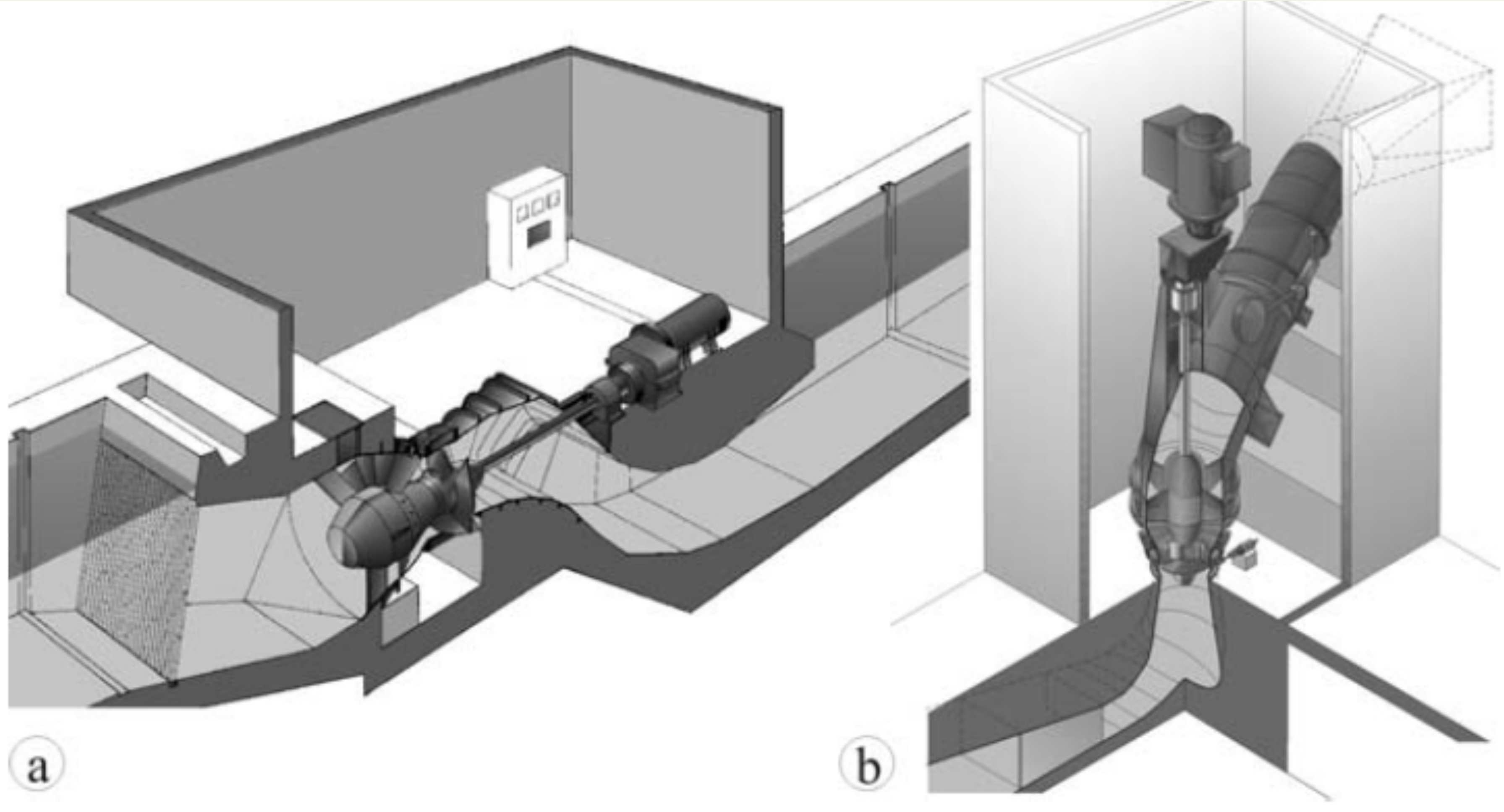
Related turbine types: Straflo Turbine





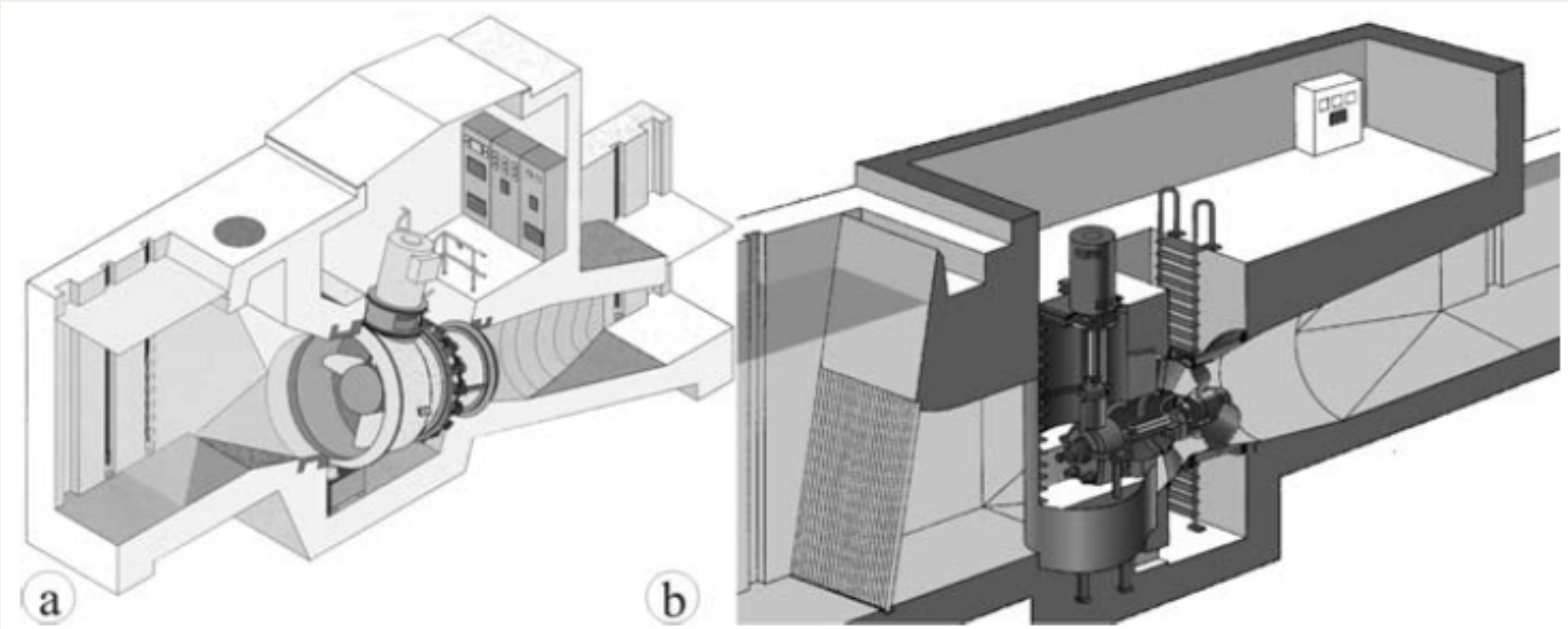
KAPLAN / PROPELLER TURBINE

Related turbine types: S-Bulb turbines



KAPLAN / PROPELLER TURBINE

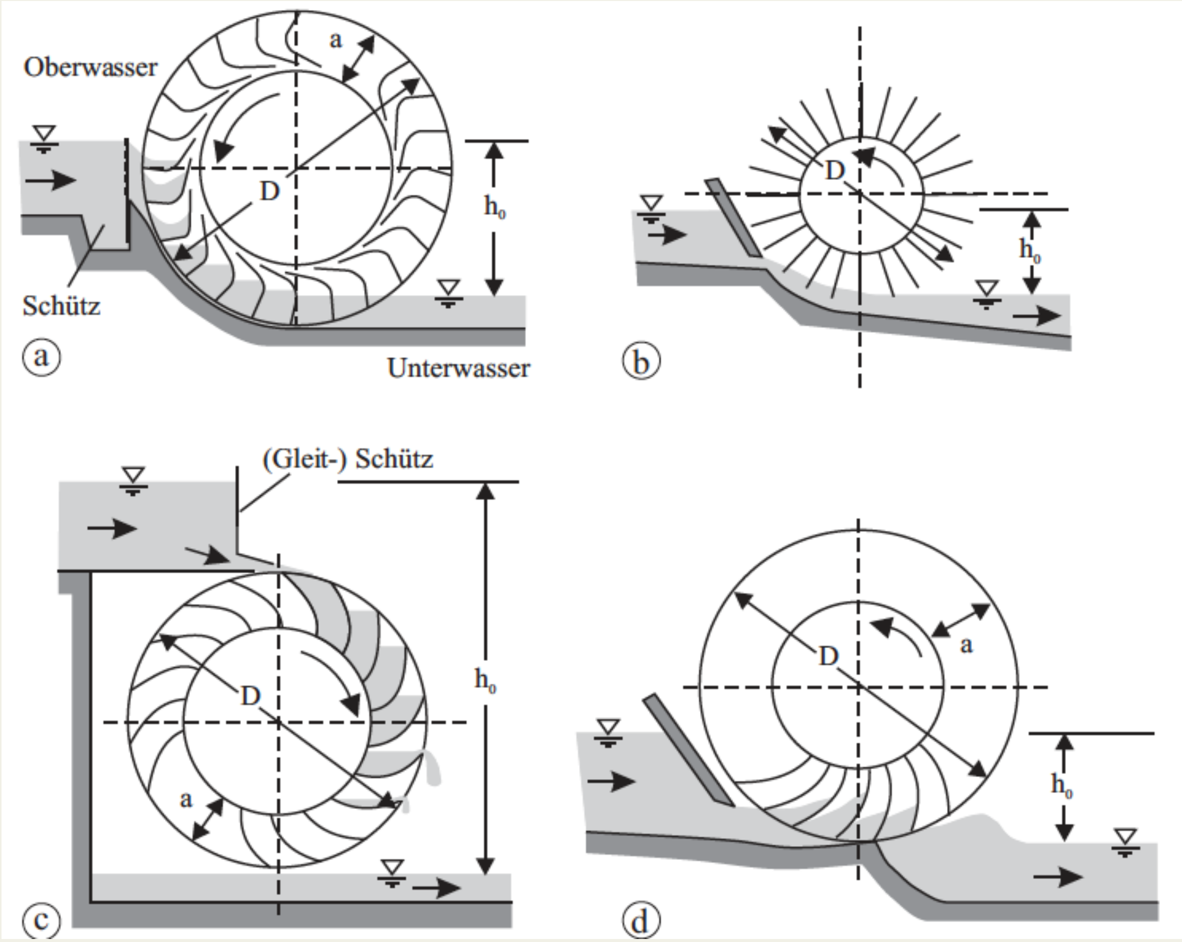
Related turbine types: Cone-gearbox (a) and Gearbox (b) turbines



HYDRO WHEELS

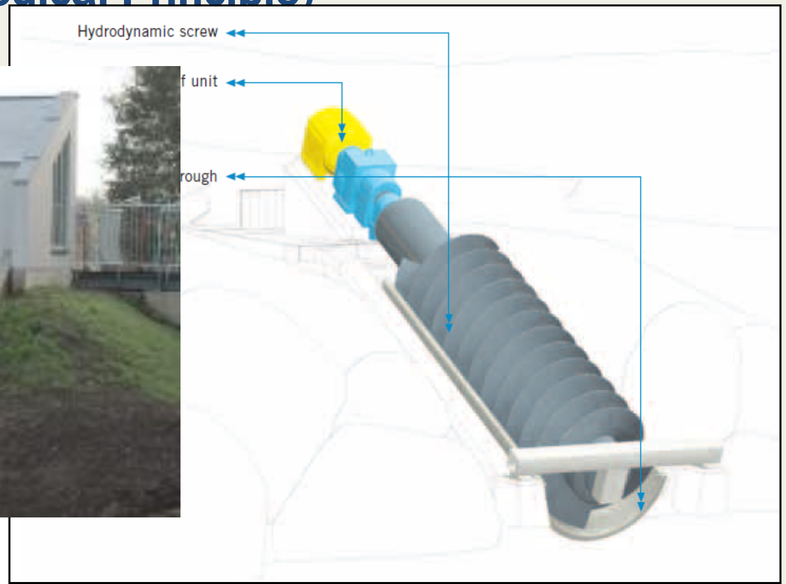
(a) Breast wheel with cells
(b) Breast wheel with blades
(c) Overshot wheel
(d) Undershot wheel

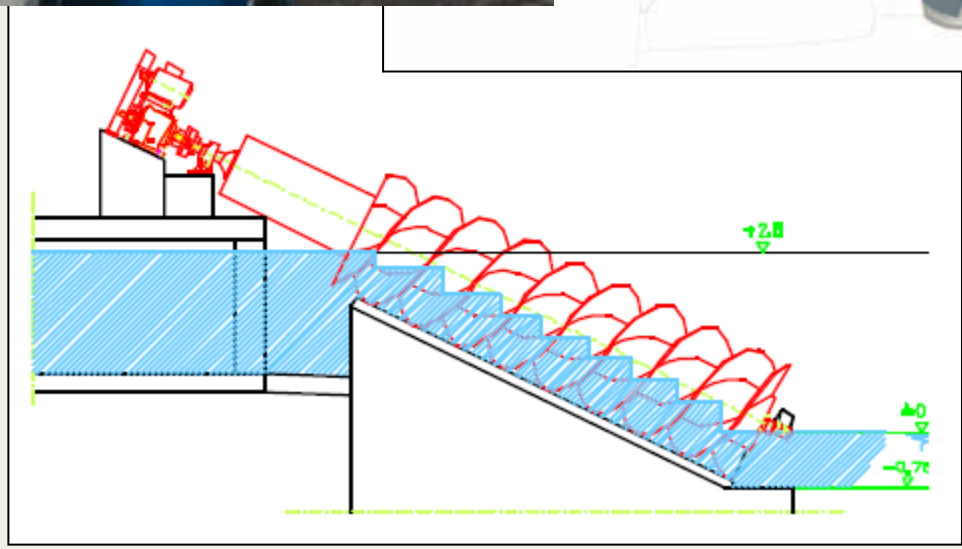
- Efficiency between 50 and 82%
- Good partial load efficiency due to slow rotational speed
- Eco friendly



HYDRODYNAMIC SCREW

Hydro-dynamic screw: Reaction turbine (Archimedical Principle)





η > 80%
Eco-friendly

ELEMENTS OF HYDROPOWER PLANTS

ELEMENTS OF HYDROPOWER PLANTS

Diversion Weir and Intake

Trash Rack

If required:
Trash rack cleaner

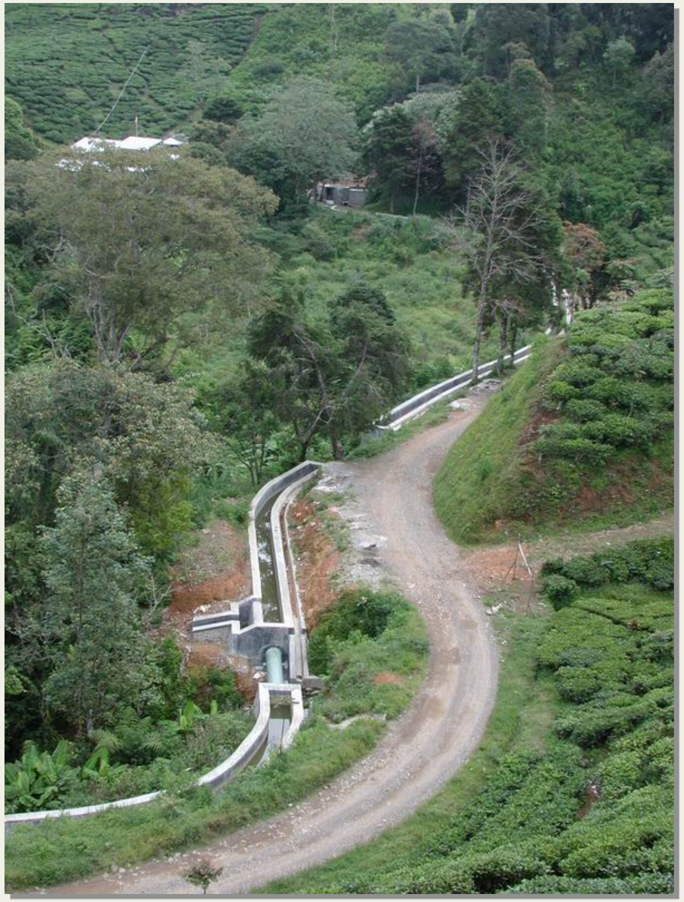
Dam and Spillway

ELEMENTS OF HYDROPOWER PLANTS

Desilting Basin / Sand Trap

Forebay / Storage Pond

Headrace Channel / Pipeline



ELEMENTS OF HYDROPOWER PLANTS

Penstock

ELEMENTS OF HYDROPOWER PLANTS

Tunnel

ELEMENTS OF HYDROPOWER PLANTS

Powerhouse with substation

ELEMENTS OF HYDROPOWER PLANTS

Ship lock

Schleuse Kachlet

HYDROPOWER EXAMPLES AND LESSONS LEARNED

TOTORA PAMPA, BOLIVIA

Totora Pampa, Bolivia

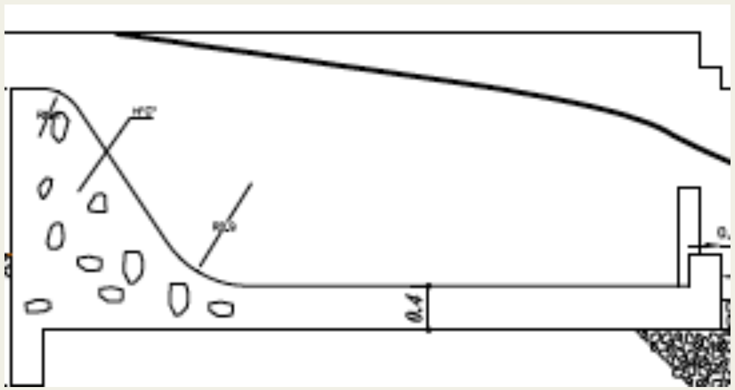
TOTORA PAMPA, BOLIVIA

Collapse of the stilling basin:

Project details

- Small scale hydropower plant: 200 kW
- Located in the Andes mountains in Bolivia

Problem: weir was built on the alluvial sand of the river bed



Consequence: downstream river bed erosion

TOTORA PAMPA, BOLIVIA

TOTORA PAMPA, BOLIVIA

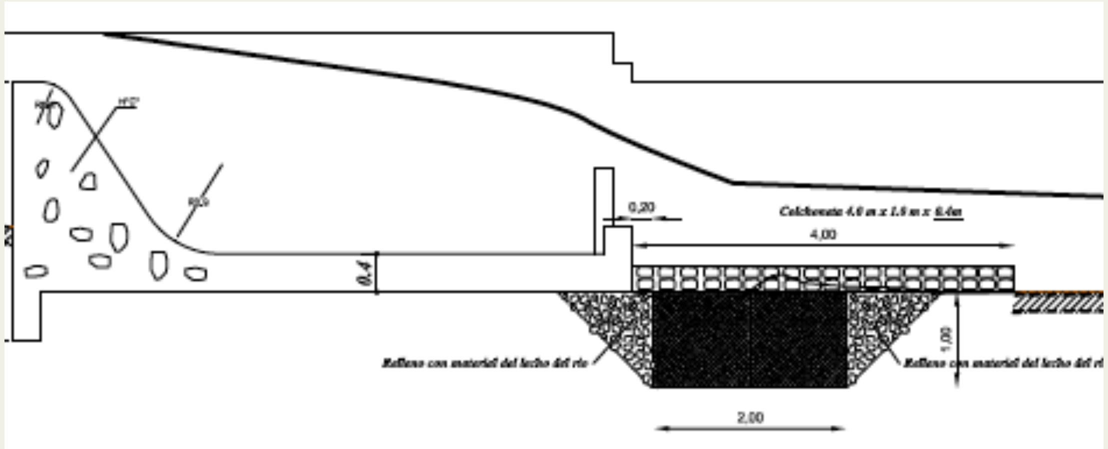
TOTORA PAMPA, BOLIVIA

TOTORA PAMPA, BOLIVIA

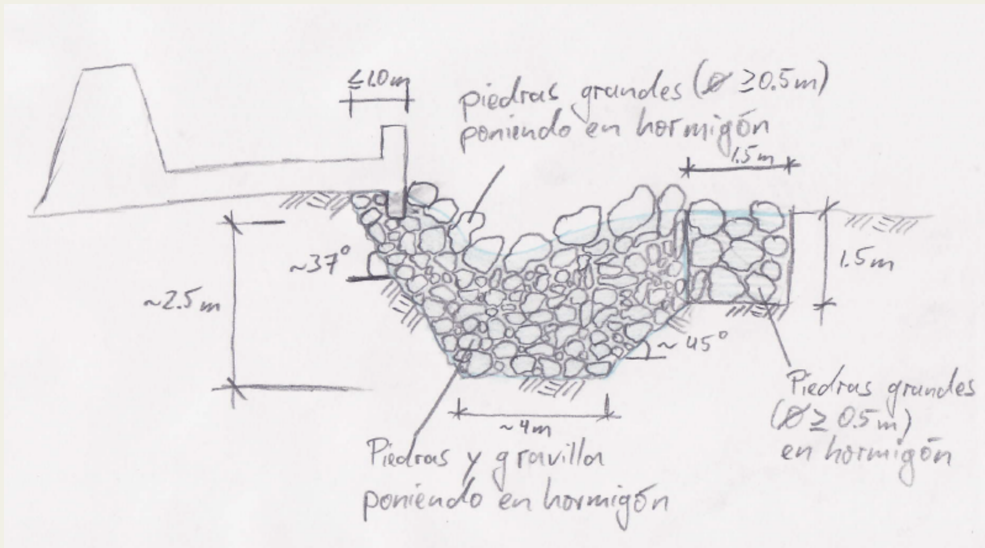
TOTORA PAMPA, BOLIVIA

Proposed solution:

Temporary → Gabion basket protection



Permanent → cut-off wall construction



SAYANO SHUSHENSK, RUSSIA

Sayano Shushensk, Russia

SAYANO SHUSHENSK, RUSSIA

Sayano Shushensk Hydropower Plant

- Installed capacity 6,400 MW (world's sixth largest plant)
- 10 x 640 MW Francis turbines
- Hd = 194 m; Qd = ~385 m^3/s
- Construction between 1961 and 1978
- Supplying about 10% of Sibiria's power
- Located at the Jenisei River in Khakassia

- Severe accident with considerable loss of life on 17th August 2009, 8:13 am

SAYANO SHUSHENSK, RUSSIA

What happened?

- Between 2007 and 2011, modernization works were under way to install modern control and protection system
- On 17th August 2009 a fire in a communication room in the nearby Bratsk hydropower station occurred
- Consequently, the operators of Sayano were asked to operate their plant for grid regulation
- Unit 2, recently modernized, was selected as lead unit
- All units suffer from substantial draft tube pressure pulsations and cause vibrations in part load operation
- Particularly bad: range between 250 and 450 MW, thus normal operation was outside that range

SAYANO SHUSHENSK, RUSSIA

What happened? (continued)

- Due to its enforced frequency control mode, Unit 2 entered the critical range many times that day
- Operating the units in the critical zone for limited time was done many times during the units' life time – without problems

SAYANO SHUSHENSK, RUSSIA

What happened? (continued)

- At 8:13 am the head cover of unit 2 broke away due to excessive vibrations, freeing the generator-turbine unit
- The water pressure lifted the 1,600 ton heavy turbine and generator unit in the air

SAYANO SHUSHENSK, RUSSIA

What happened? (continued)

- At 8:13 am the head cover of unit 2 broke away due to excessive vibrations, freeing the generator-turbine unit
- The water pressure lifted the 1,600 ton heavy turbine and generator unit in the air
- Consequently, water flooded the powerhouse, damaging the other units
- A transformer exploded, all control to the other units was lost and part of the powerhouse roof collapsed
- Consequence: total destruction of units 2, 7 and 9; part destruction of units 3, 4 and 5
- As cause for the failure of Unit 2 was found that the head cover retaining bolts were corroded, fatigued and failed due to excessive load

SAYANO SHUSHENSK, RUSSIA

What happened? (continued)

SAYANO SHUSHENSK, RUSSIA

Lesson to be learned:

- Every turbine-generator unit has ranges in which they operate “noisy”
- Problems may not occur under normal operation conditions, but are very likely to happen under extreme stress conditions
- When selecting equipment check the unit’s properties and take the worst case scenario into account
- If necessary for operational flexibility, foresee rather more than less units
- Don’t rely on goodwill but always take human error into consideration
- This applies also for the Amaila Falls hydropower project!

MOCO MOCO, GUYANA

Moco Moco, Guyana

MOCO MOCO, GUYANA

Basic information:

- The hydropower plant of Moco-Moco was built in 1996
- Supply of electricity for Lethem and Moco-Moco
- Installed capacity: 500 kW (2 x 250 kW Pelton units)
- The plant was financed by the Chinese Government as a grant and built by a Chinese contractor who installed equipment of Chinese make.
- Q_d = 0.166 m^3/s per unit; H_d = 210 m

MOCO MOCO, GUYANA

- Heavy rainfalls in 2003 caused the head pond to overflow and a land slide to happen along the penstock

MOCO MOCO, GUYANA

- Heavy rainfalls in 2003 caused the head pond to overflow and a land slide to happen along the penstock
- The landslide damaged the penstock like bending a straw

MOCO MOCO, GUYANA

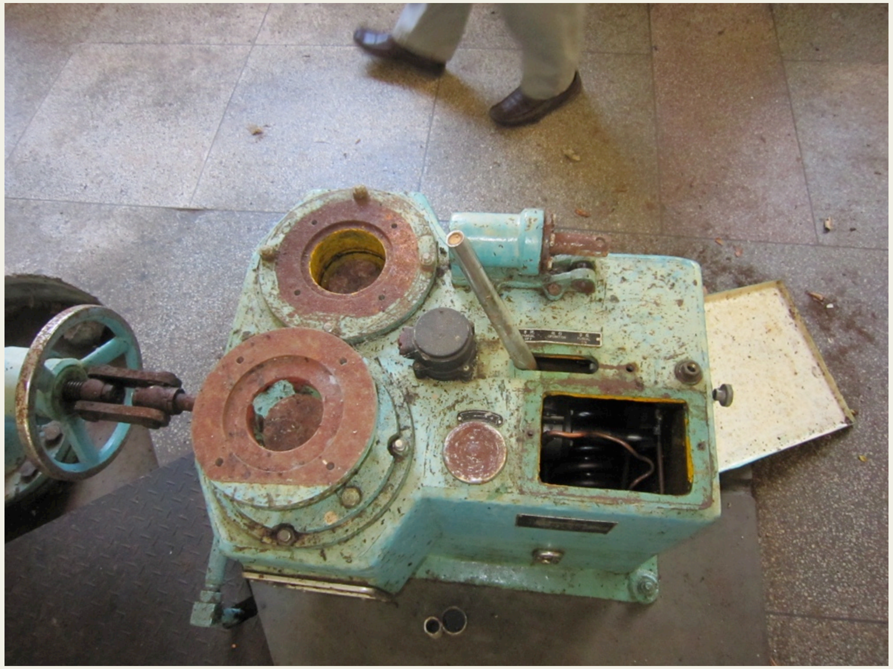
- Heavy rainfalls in 2003 caused the head pond to overflow and a land slide to happen along the penstock
- The landslide damaged the penstock like bending a straw
- Consequently, a diesel generator was installed in Lethem to supply the electricity needs
- The electricity was fed back towards the hydropower powerhouse
- Due to the lack of load side over voltage protection a short circuit occurred in the control board of the HPP and a fire destroyed the control system

MOCO MOCO, GUYANA

- Due to the lack of load side over voltage protection a short circuit occurred in the control board of the HPP and a fire destroyed the control system

MOCO MOCO, GUYANA

- Due to the lack of load side over voltage protection a short circuit occurred in the control board of the HPP and a fire destroyed the control system
- Consequently, the security team let the site and vandalism lead to theft of all copper wires and other relevant parts in the powerhouse



MOCO MOCO, GUYANA

Prime cause of the damage:

- Overestimation of the underground stability, presumably due to the lack of geotechnical investigations during the design phase

MOCO MOCO, GUYANA

Prime cause of the damage:

- Overestimation of the underground stability, presumably due to the lack of geotechnical investigations during the design phase
- → Lack of drainage along the penstock alignment

MOCO MOCO, GUYANA

Prime cause of the damage:

- Overestimation of the underground stability, presumably due to the lack of geotechnical investigations during the design phase
- → Lack of drainage along the penstock alignment
- → Lack of other protection measures to prevent the slope from slipping

MOCO MOCO, GUYANA

Lessons learned:

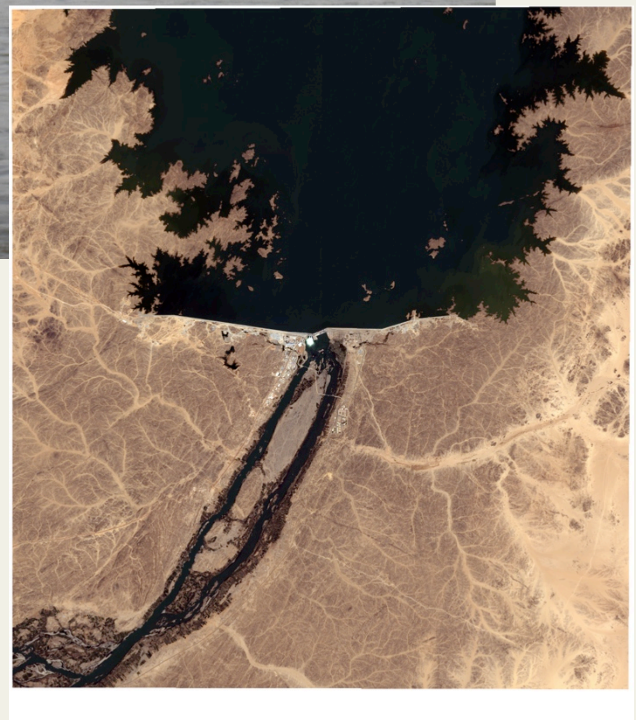
- Don’t compromise the integrity of a design for cost reasons
- Proper assessment of underground conditions is of utmost importance!
- While a wrong hydrological assessment may lead to an oversized turbine, a wrong geotechnical assessment may lead to the loss of an entire hydropower plant
- Use experienced designers for projects with high risk potential

MEROWE, SUDAN

Merowe, Sudan

MEROWE, SUDAN

- At the river Nile in North Sudan
- 1,250 MW installed capacity, doubling Sudan's supply
- 10 x 125 MW Francis turbines
- Q_d = 300 m^3/s (each turbine); H_d = ~48 m
- Dam is 67 m high and about 10 km long, multi-type
- Construction from about 2003 to 2009



MEROWE, SUDAN

Turbine runner wheel

MEROWE, SUDAN

Spiral case

MEROWE, SUDAN

Wicket gates

MEROWE, SUDAN

Concrete pouring in spillway bay

MEROWE, SUDAN

Spillway in test operation

THANK YOU FOR YOUR ATTENTION!

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Web: http://www.credp-giz.org

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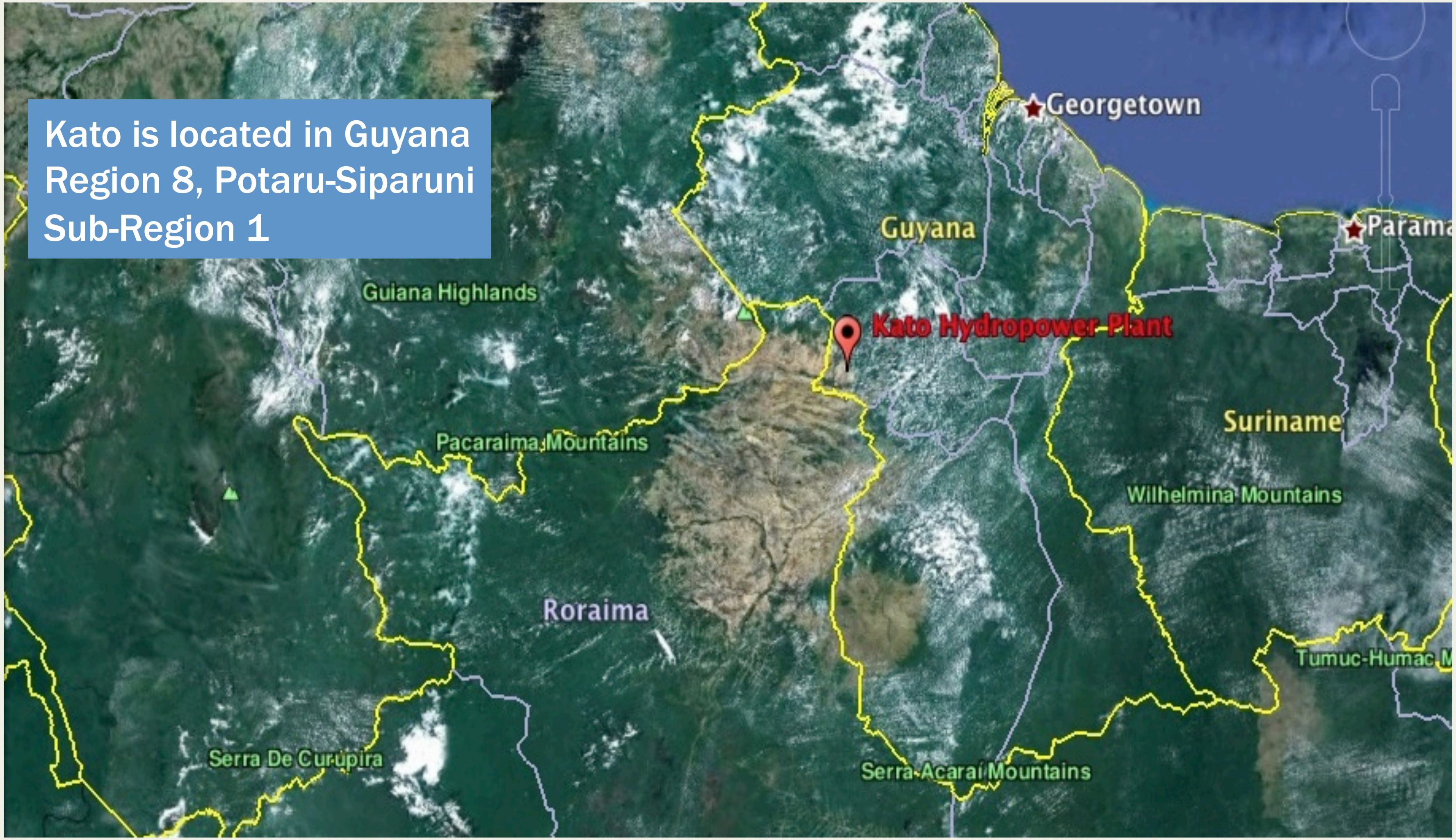
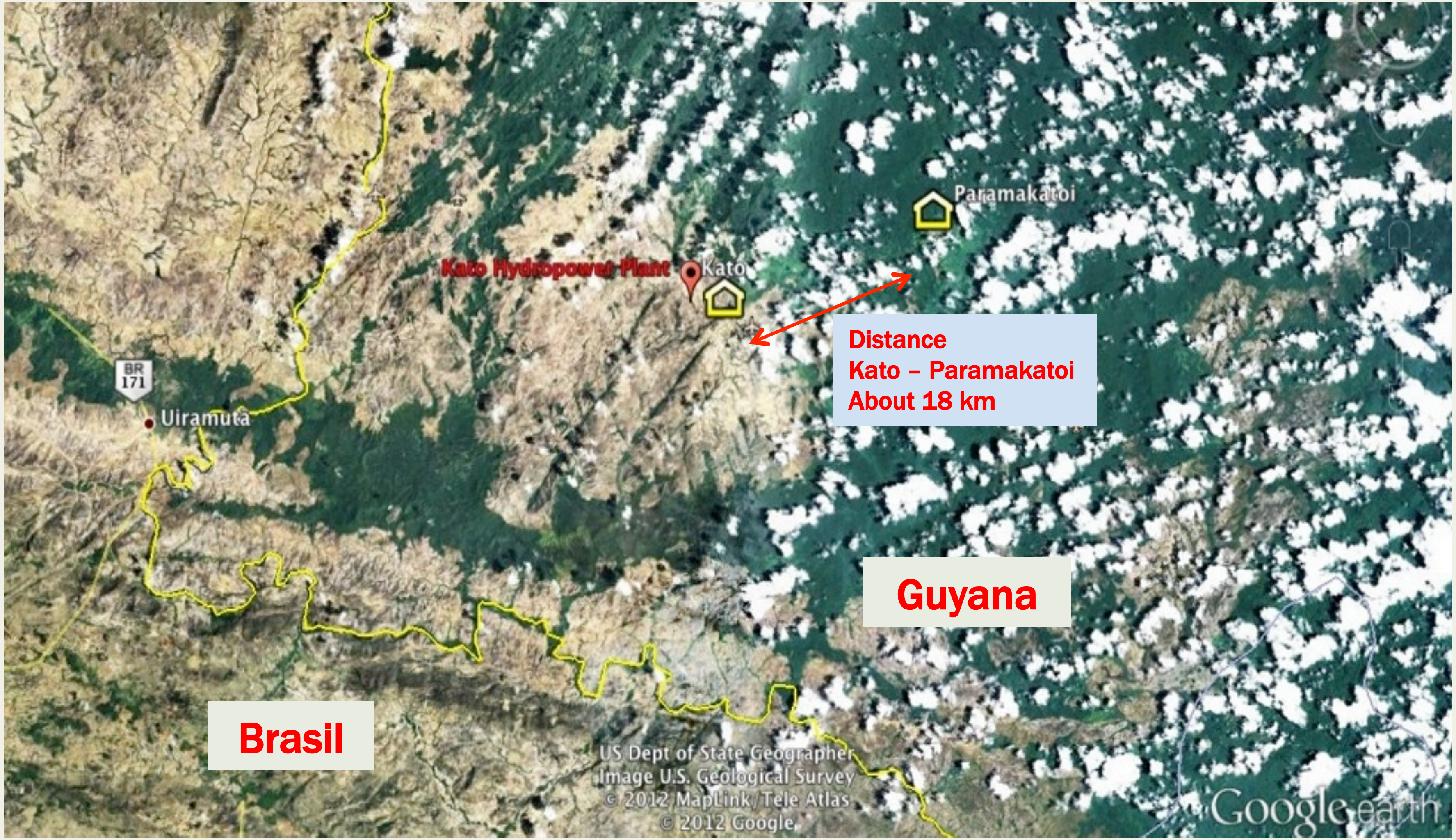
INTRODUCTION TO THE KATO PROJECT

LOCATION OF THE PROJECT

Kato is located in Guyana Region 8, Potaru-Siparuni Sub-Region 1



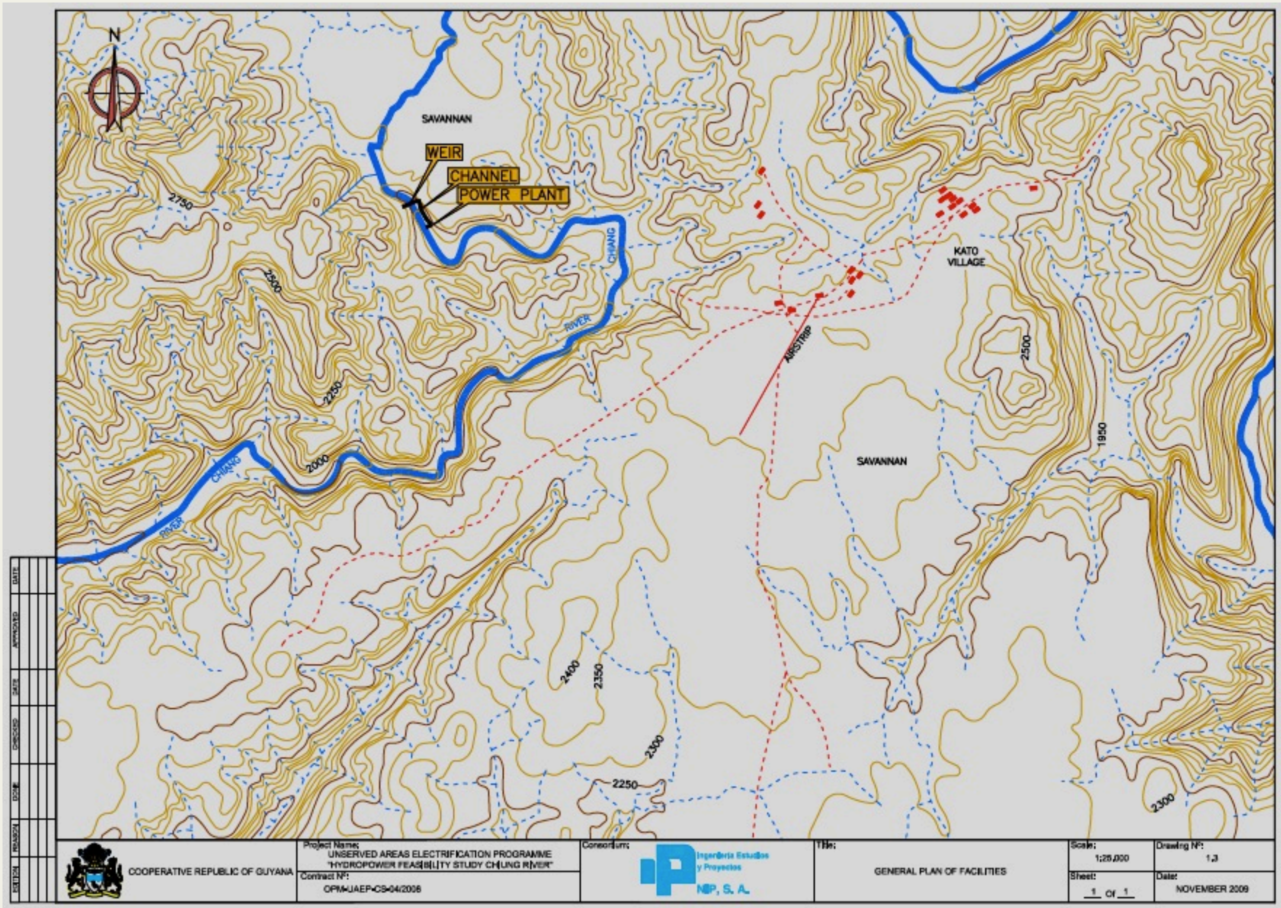
LOCATION OF THE PROJECT



LOCATION OF THE PROJECT

Today, Kato's economy is nearly purely subsistence.

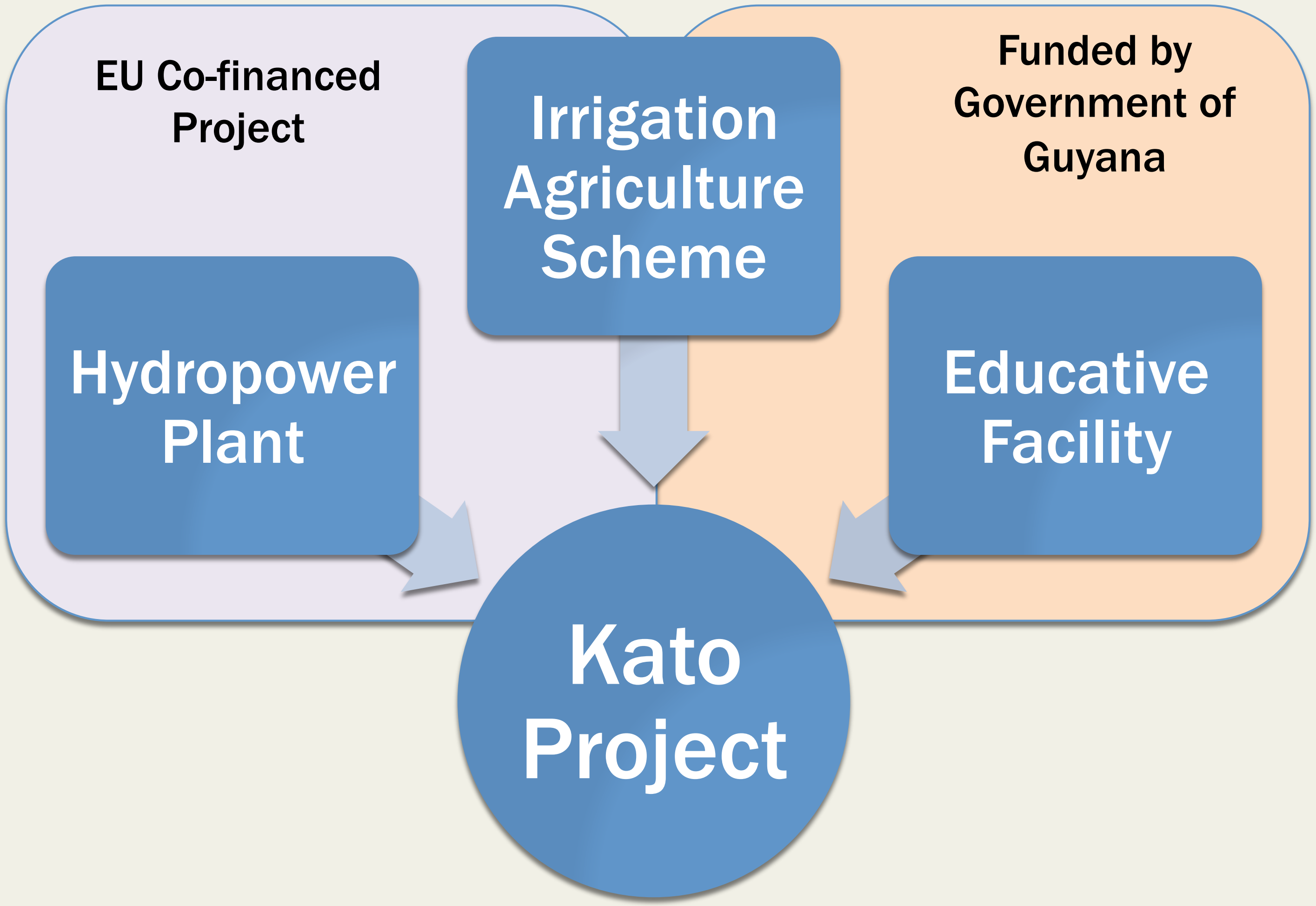
Required goods, such as clothing, are brought in by traders on small scale



PROJECT OBJECTIVES

1. To administer permanent electricity supply to the villages of Kato and Paramakatoi
2. To displace the current generation of electricity with the 3.5 and 16 kW diesel generators in Kato and Paramakatoi, respectively, and save 20 t CO_2 annually
3. To facilitate irrigation agriculture in Kato through the provision of electricity for irrigation water pumping
4. To facilitate the operation of a secondary and vocational school to be built in Kato
5. To facilitate productive use of electricity in the villages of Kato and Paramakatoi

PROJECT SETUP



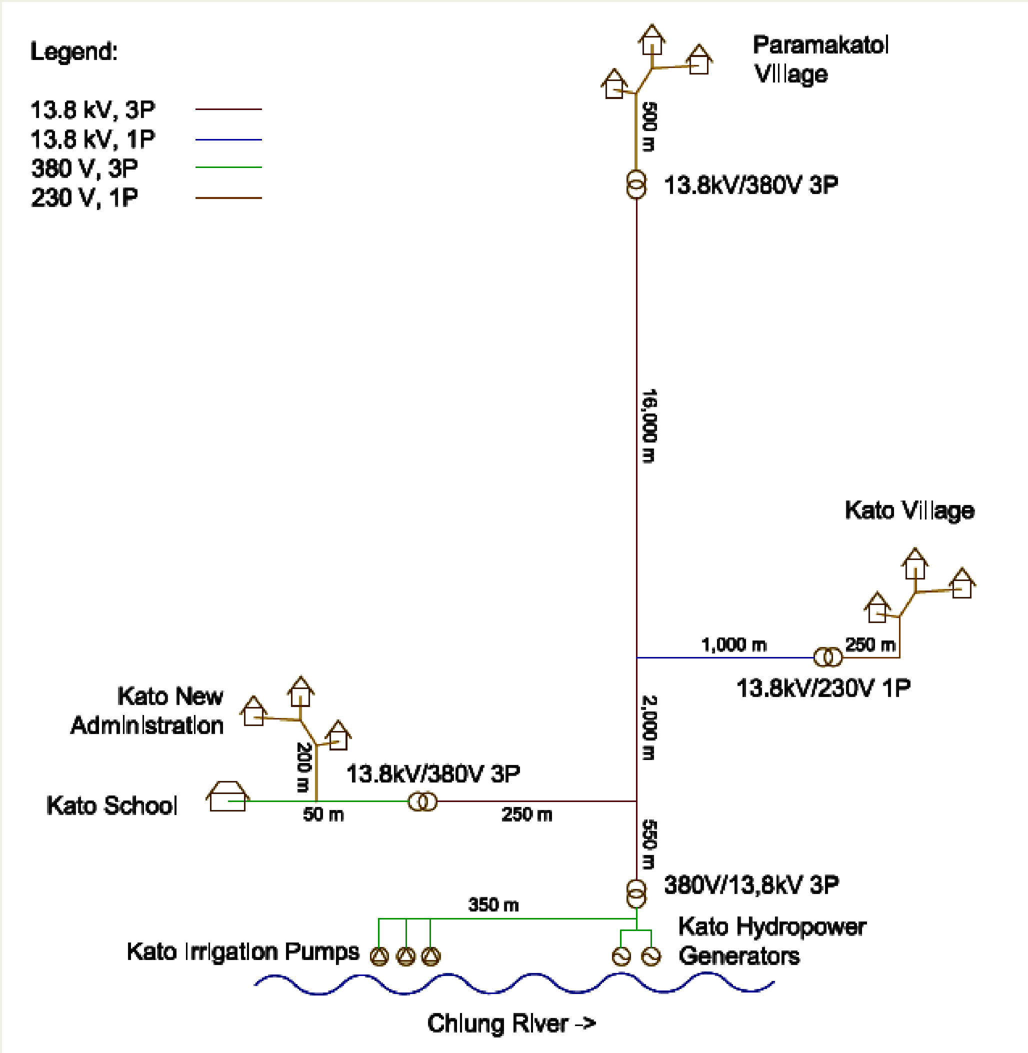
THE HYDROPOWER COMPONENT

USING THE CHIUNG RIVER WATERFALL

TECHNICAL DATA HYDROPOWER

- Using the Chiung River Waterfall for Hydropower
- Available head: about 36 m
- Design discharge: 1.16 m^3/s
- Installed capacity: 330 kW at the turbine, 305 kW at the generator
- Turbine type: 2 x Cross Flow (Ossberger/Mitchel-Banki) turbine
- 18 km long 13.8 kV transmission line between Kato and Paramakatoi
- About 2 km LV cable

SINGLE LINE DIAGRAM



ADDITIONAL CONTRACT CONTENT

Also included in the hydropower contract are:

- Irrigation weir and pumping station
- 7,600 m^3 large irrigation water storage reservoir
- Pipeline between pumping station and reservoir

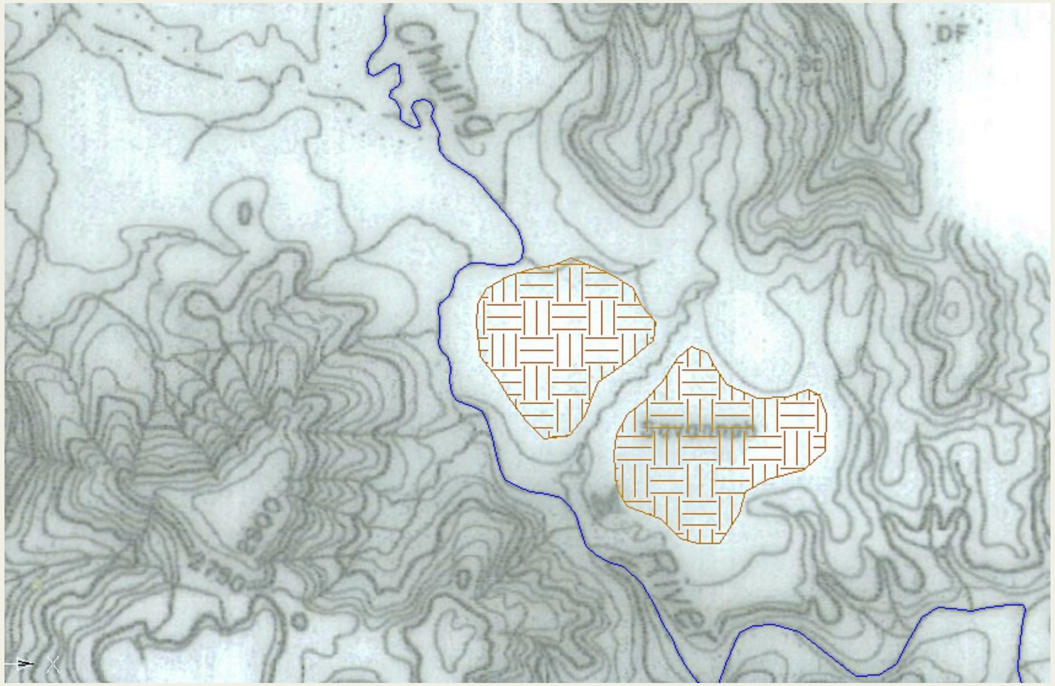
Contract type: Design and build contract

Expected construction period: 18 months

THE IRRIGATION COMPONENT

IRRIGATION AREA

- Agricultural area separated in two section of up to 40 ha each



THE EDUCATION COMPONENT

SECONDARY SCHOOL

- The Ministry of Education plans to build a secondary school in Kato to replace the one in Paramakatoi
- School in Paramakatoi has no more potential for expansion due to water supply constraints
- Kato school complex will host students from Kato, Paramakatoi and some more surrounding villages
- In total 1,000 students and teachers are expected
- Paramakatoi secondary school has no qualified teachers today; this is expected to change with the new school in Kato
- Primary school in Paramakatoi will continue

VOCATIONAL TRAINING

- The secondary school is planned to contain also a section for vocational training, such as carpentry, processing of agricultural produces, sewing of clothing, etc.
- The electricity from the hydropower plant will be used to operate the electro tools for the training of the students
- In particular training in relation to agricultural activities and food processing can be done “on the job”