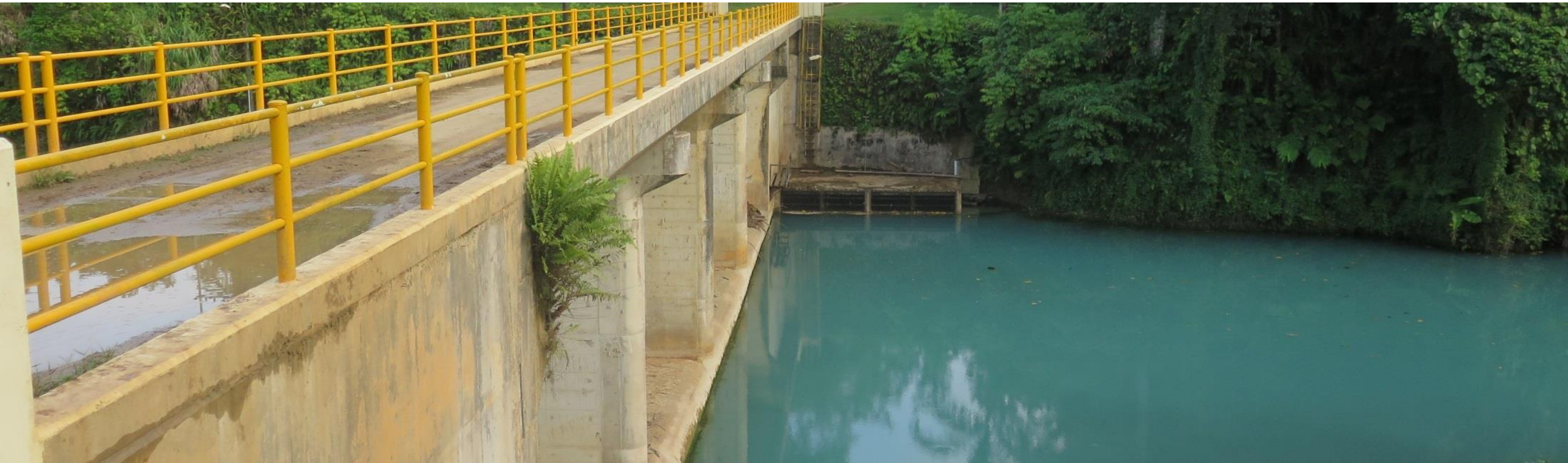
UCL Université catholique de Louvain

LENVI2007

GREENPLUG ENGINEERING

Small Hydro Training – Basics & Case studies

December 2021



GreenPlug Engineering : who we are ?

GreenPlug Engineering is an international consulting and engineering company specialized in design, studies and implementation of renewable energy projects.

Wind • Hydropower • Solar • Storage

Design and studies • Assistance • Strategy

On-grid & Off-grid solutions

GreenPlug Engineering took part at all stages of the project cycle.

Demand & Resources Assessment

Design • Prefeasibilty & Feasibility Studies • Detailed Studies

Owner/Lender'engineering

Technical Due Diligences • Advisory Services

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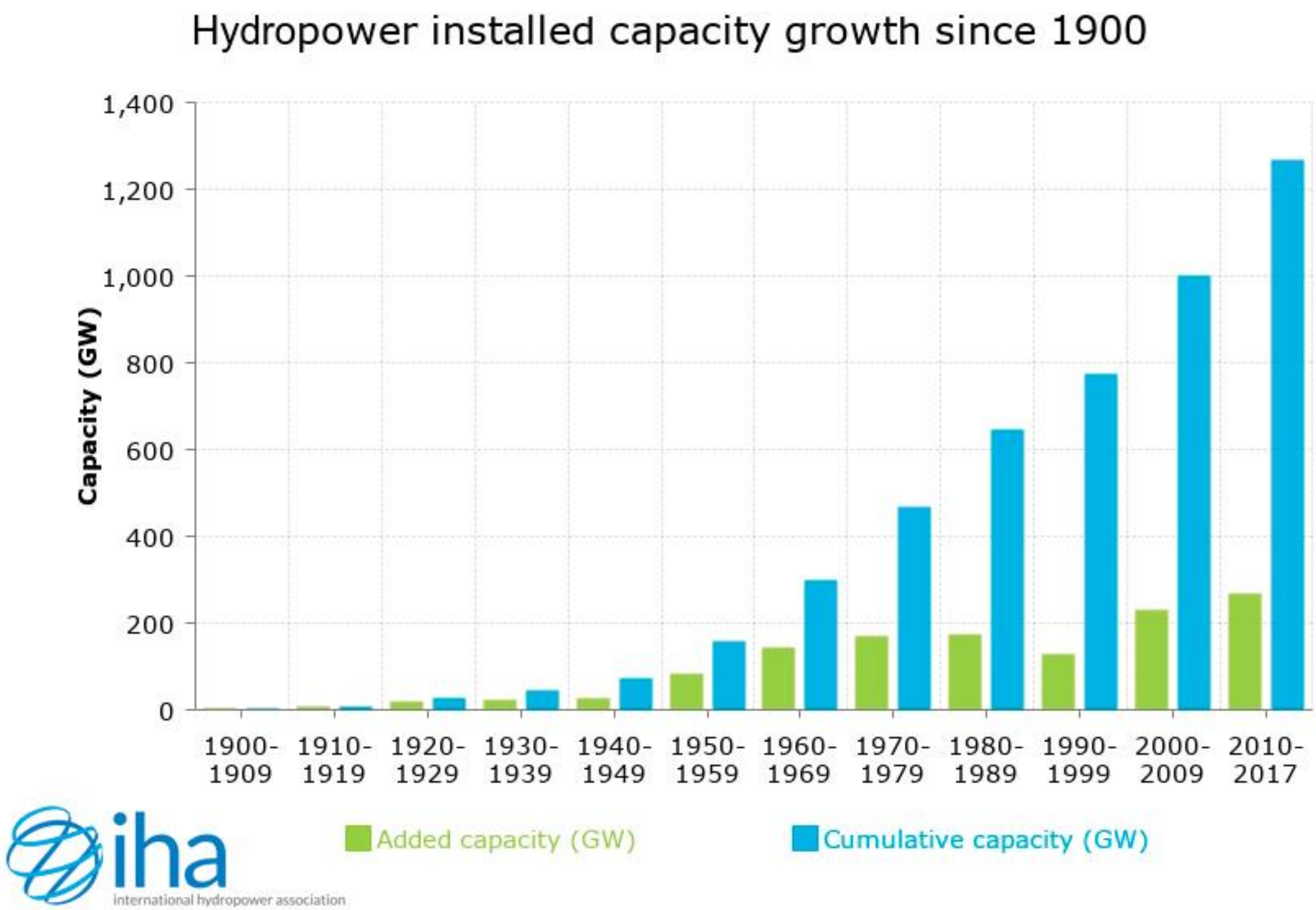
Hydropower basics and design



Each hydropower scheme is unique

Each hydropower plant is unique : There is no standardization

The design is a tailor made solution for the prevailing site conditions. Therefore, contrary to thermal, solar or wind plants, you'll never find any identical project, neither layout nor installed capacity.

- Site conditions required for evaluation:
    - Topography → Head [m]
    - Hydrology → Flow [m^3/s]
    - Geology
    - Seismicity
    - Sediments
    - Social and Ecological conditions

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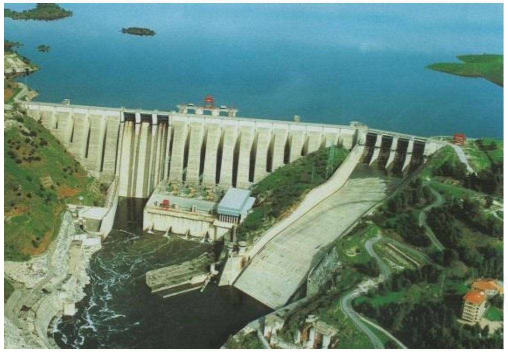
Types of Power Plants

Classification by potential* for hydropower

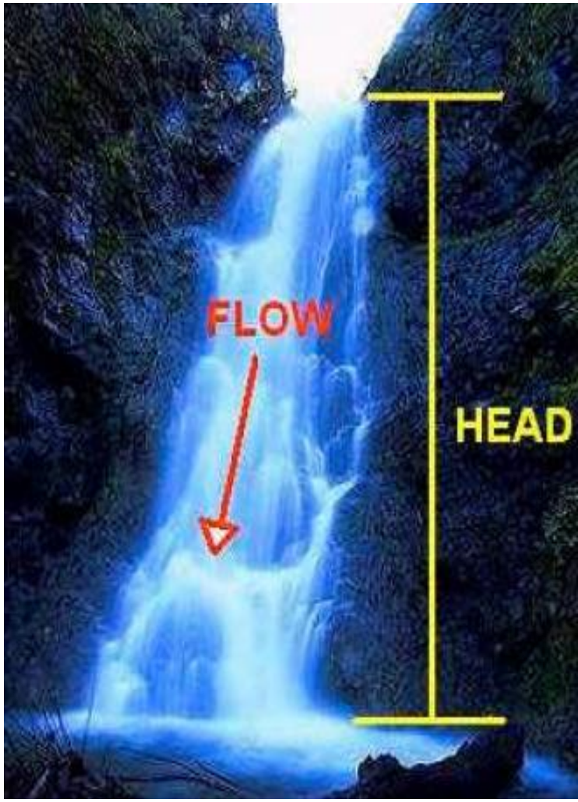
*Definition may vary f.ex.in US and Canada small hydro < 30 MW

Hydro Category	Capacity	No. of homes supplied (demand of industrialized country)
Pico	0 kW – 5 kW	0 – 5
Micro	5 kW – 100 kW	5 – 100
Mini	100 kW – 1 MW	100 – 1,000
Small	1 MW – 20 MW	1,000 – 20,000
Medium	20 MW – 100 MW	20,000 – 100,000
Large	100 MW+	100,000+



Energy of water

$$\mathbf{P} = \boldsymbol{\rho} \times \mathbf{g} \times \boldsymbol{\eta} \times \mathbf{H} \times \mathbf{Q}$$



With:

P = Power [in kW]

P = density of water 1 t/m³ (or 1 g/cm³)

g = acceleration of gravity [m/s²], = 9.81 m/s²

H = net head [m]

Q = discharge [m³/sec] (or flow)

η = Overall equipment efficiency = $\eta_{turbine} \times \eta_{generator} \times \eta_{transformer}$

($\eta_{turbine}$ ~ 0.93; $\eta_{generator}$ ~ 0.97; $\eta_{transformer}$ ~ 0.99)

Simplified: P[kW] = 9 x H [m] x Q [m³/s]

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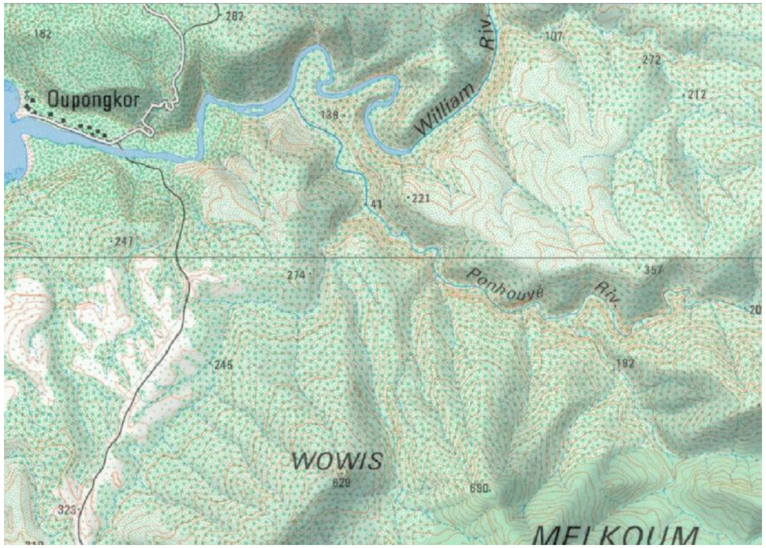
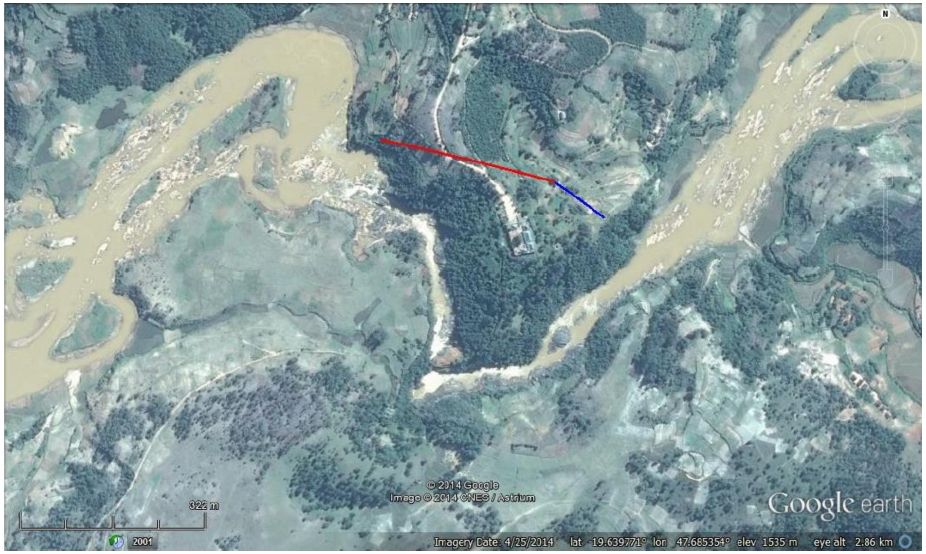
Topography

Preliminary estimate of the available gross head

- Topographic maps with contour lines (equidistance)
- Digital elevation model
- Aerial photos to identify waterfalls or rapids (Google Earth - Drones)
- Site visits are essential to validate the potential of a site





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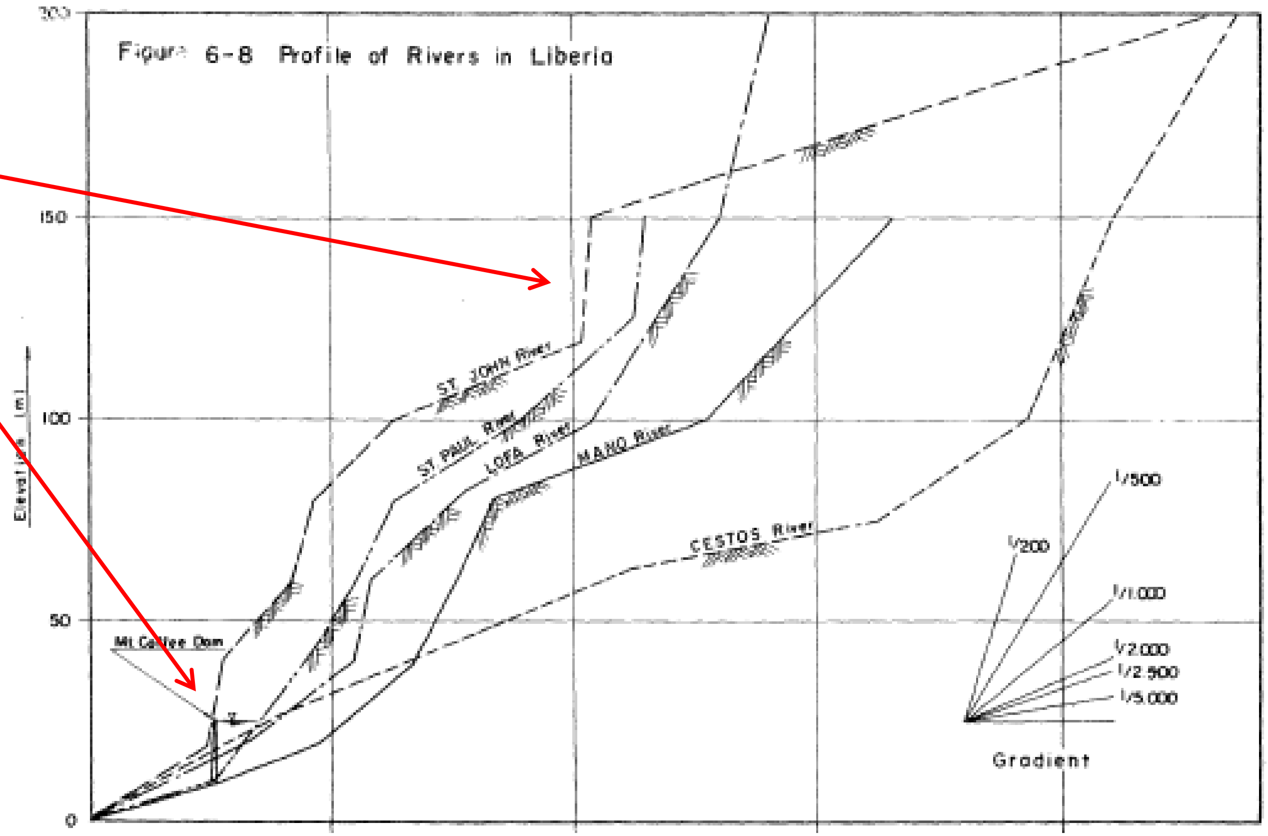
Unit potential exists along a river

Hydropower planning evaluates best sites to develop the maximum of the existing potential by creating corresponding head

Promising location for hydropower sites



Gradients of rivers

Height in 50m, length in 50 km units

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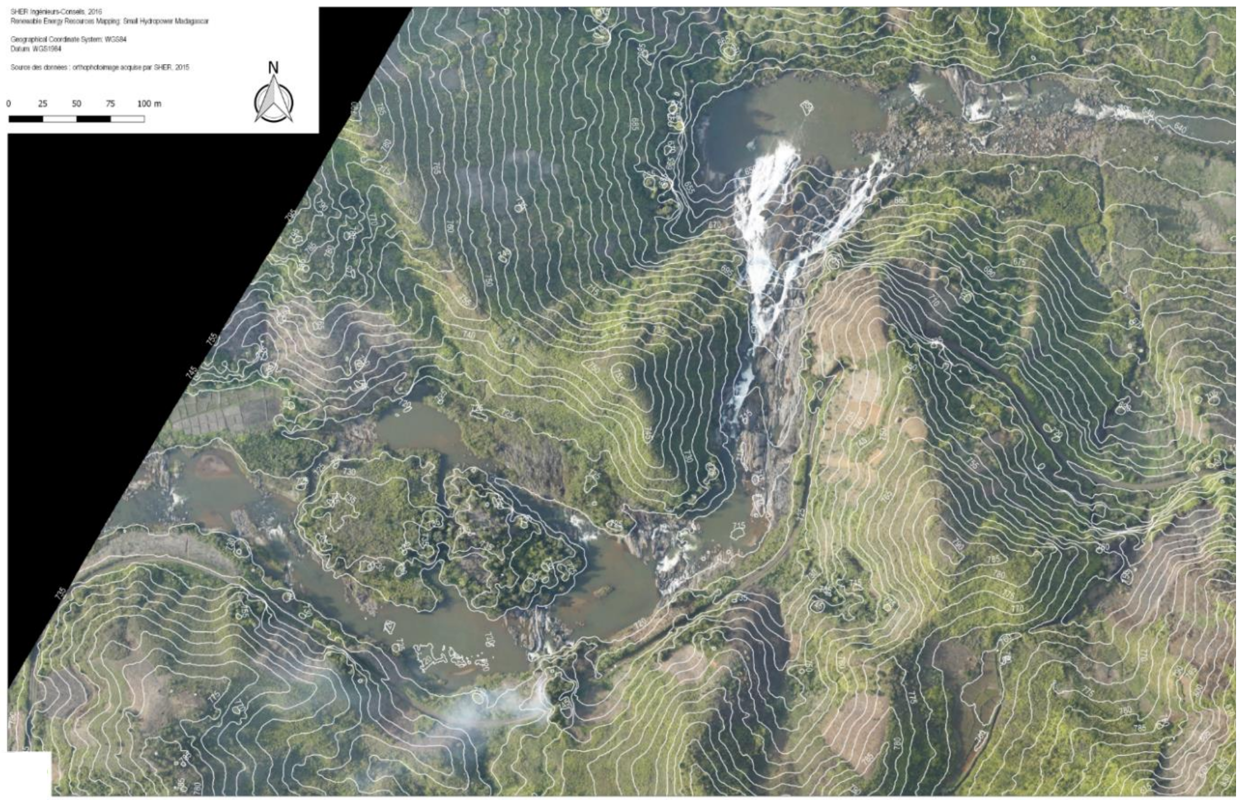
Topography

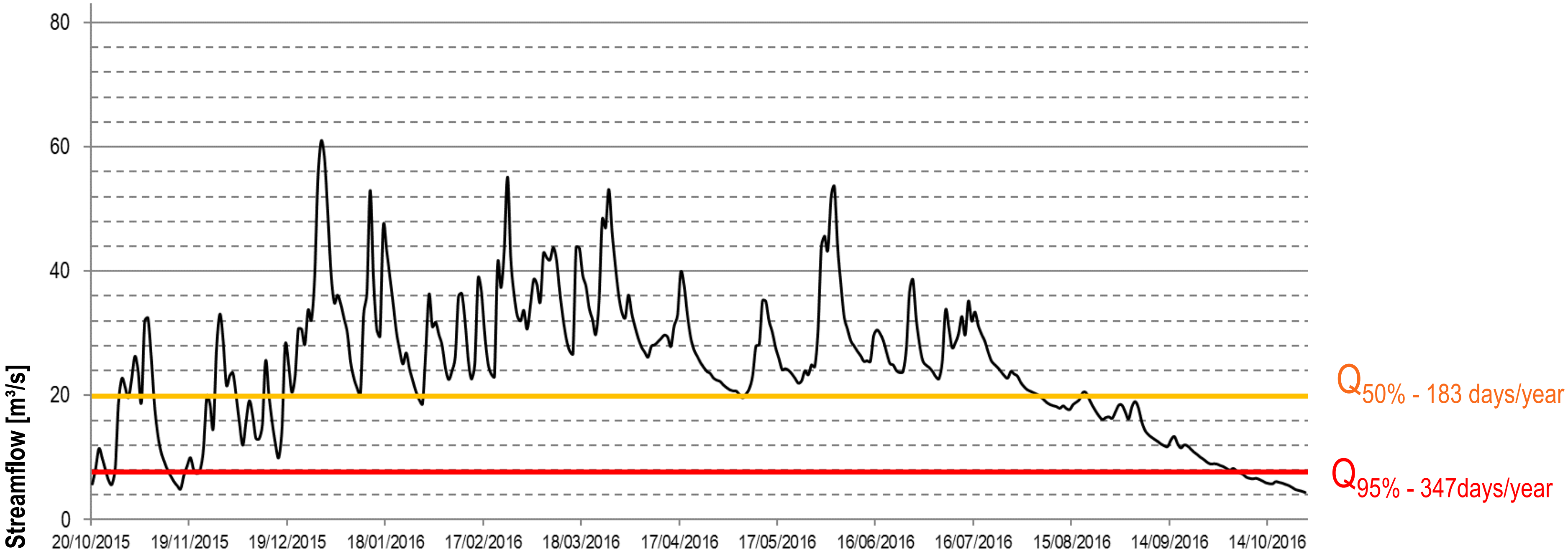
Estimate of the available gross head and sitting of main scheme components. Field survey using :

- DGPS / Total station / Photogrammetry (drone or aircraft) / Lidar
- The accuracy depends on the study stage *(Identification – Prefeasibility – Feasibility – Detail study – Works*) from ~1-2 m to < 1 cm.



Hydrology

Concept of flow duration curve



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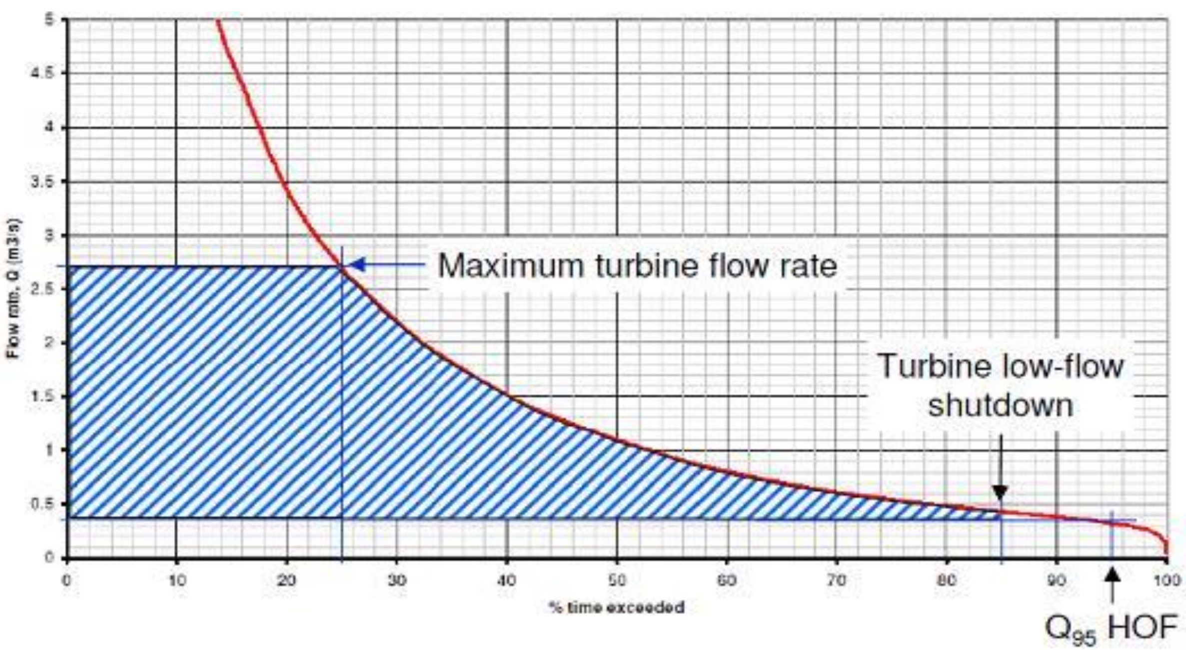
Hydrology

Concept of flow duration curve

- Cumulative distribution function of the streamflow
- Represents the percentage of time that the streamflow is exceeded over a given period of one year
- Turbine max flow rate and low-flow shut down depend on turbine type



For Grid Connected project

- **20% and 40%** exceedance is a common economic approach for dimensioning of hydropower **run-of-river** projects
- A discharge between **15% and 30%** exceedance is a common economic approach for dimensioning **peak projects**

For off-grid project

- 90-95 % exceedance

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Hydrology

Time series of streamflow [m³/s]

- Long term (minimum 15-20 years) recording
- From nearby gauging stations in the same watershed area
- → With this data flow series and frequencies can be developed

Synthetic flow series can be developed based on:

- Rainfall data
- Run-off coefficient
- Watershed area
- → Synthetic flow series must be calibrated by measurements and correlated
- with other stations from similar watershed areas.
- → With synthetic flow series hydrological risk for the project increases

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Hydrology

Information to be collected (as far as available)

- Rainfall series
- River flow measurements (monthly, daily, hourly)
- Calibration of gauging stations (gauging and rating curves)
- If no gauging stations available these should be installed and calibrated as soon as possible in the development process

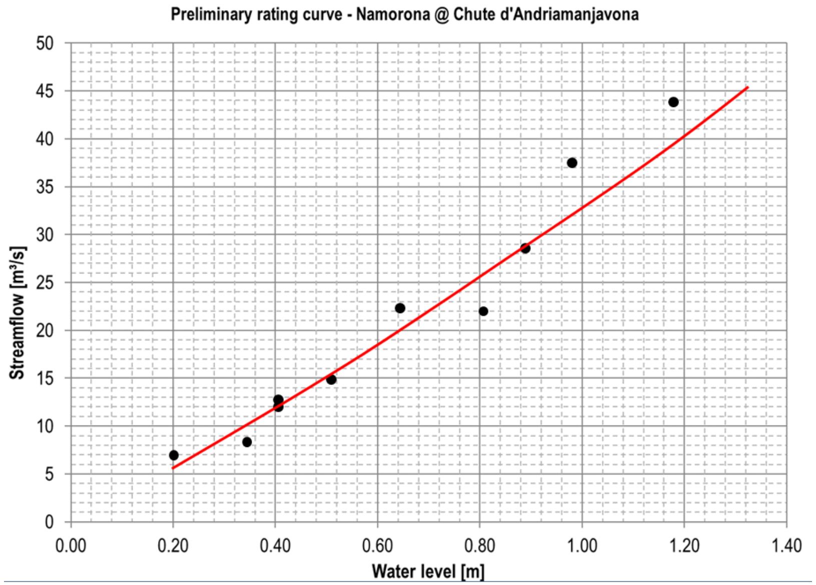
Required for

- Assessment of the hydropower potential of the site
- Design of main structures
- Energy performance assessment
- Safe and appropriate operation

Daily data are preferable (average and max)

Monthly data

- Underestimates flood
- Overestimates average and low flows



Rating curve

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Hydrology

Water level monitoring

Automatic monitoring stations (radar, pressure probe, bubble systems, …)

Non-automatic : staff gauge + regular readings by an observer

- Notebook
- Essential (backup, control)
- Cost-effective

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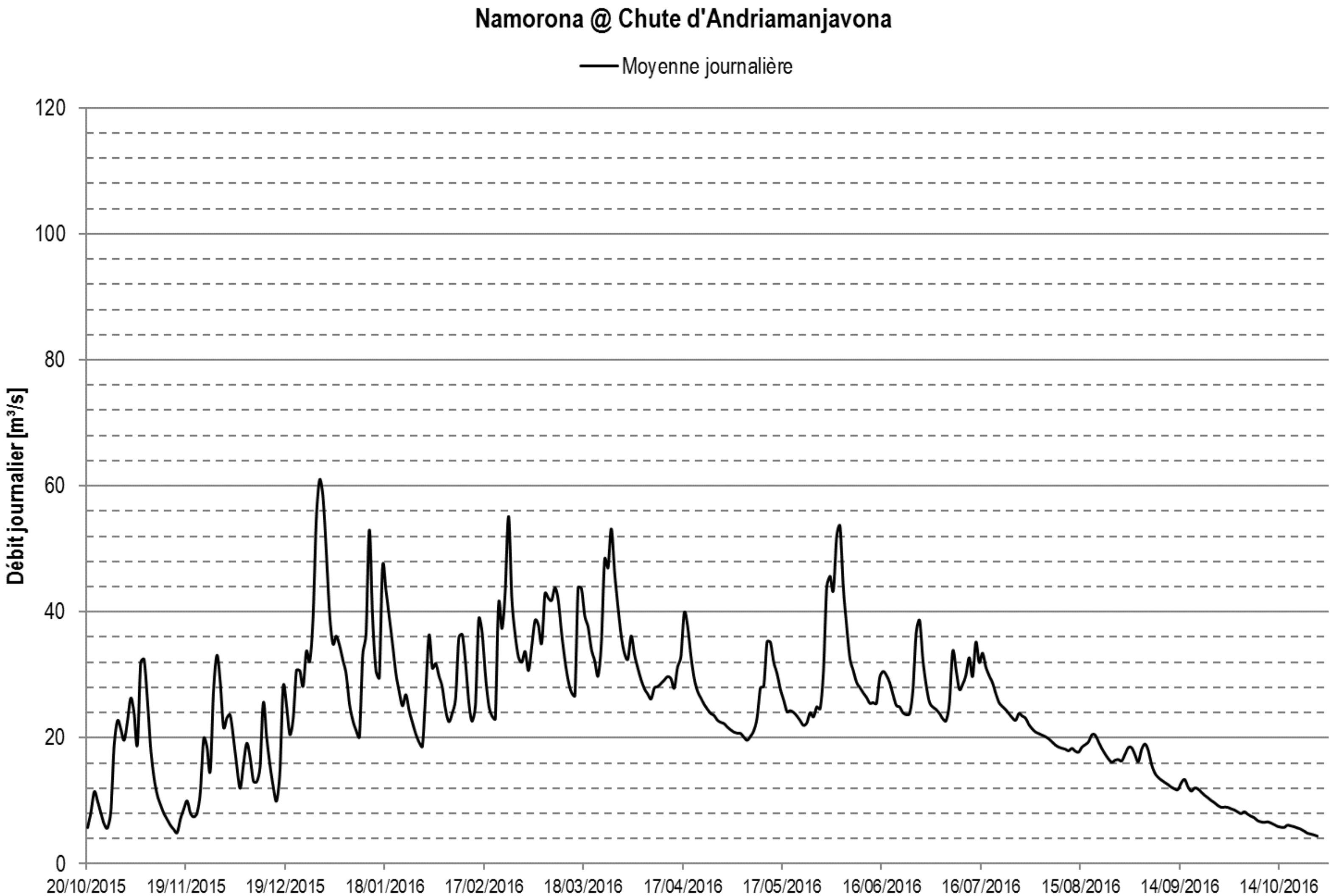
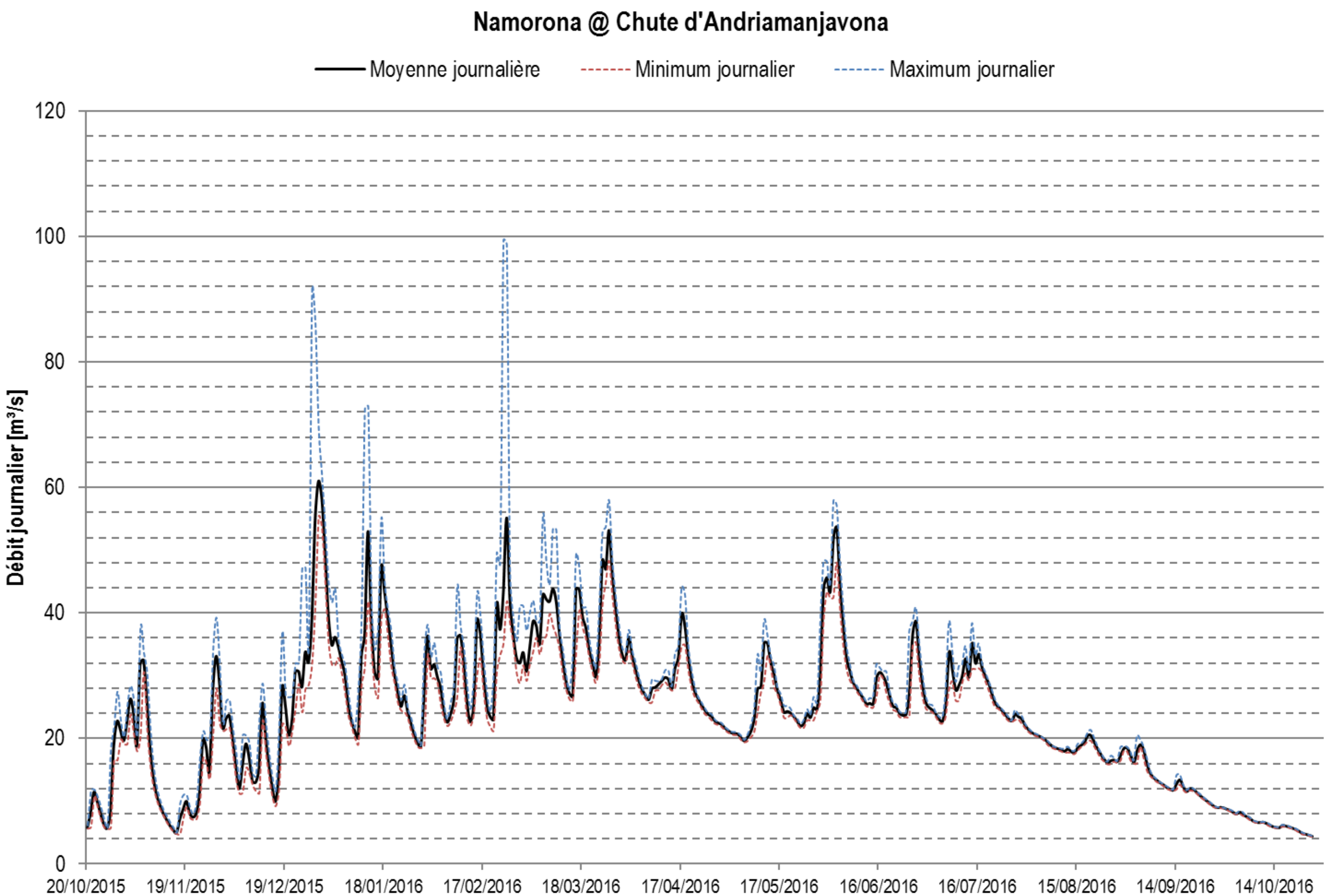
Hydrology



Namorona @ Chute d'Andriamanjavona
Moyenne journalière
Débit journalier [m³/s]
120
100
80
60
40
20
0
20/10/2015
19/11/2015
19/12/2015
18/01/2016
17/02/2016
18/03/2016
17/04/2016
17/05/2016
16/06/2016
16/07/2016
15/08/2016
14/09/2016
14/10/2016

Hydrology



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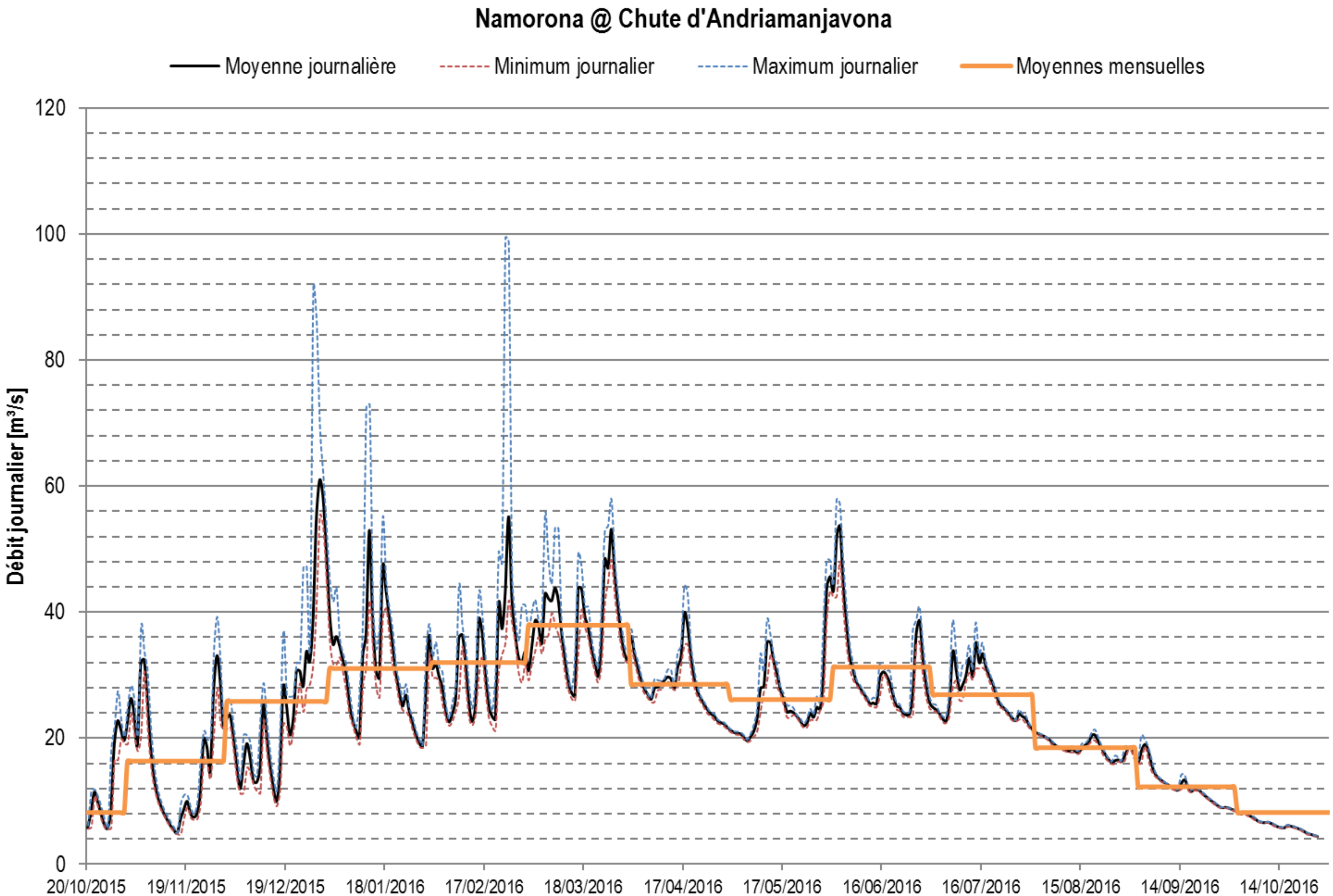
Hydrology



Namorona @ Chute d'Andriamanjavona
Moyenne journalière
Minimum journalier
Maximum journalier
Moyennes mensuelles
Débit journalier [m³/s]
0
20
40
60
80
100
120
20/10/2015
19/11/2015
19/12/2015
18/01/2016
17/02/2016
18/03/2016
17/04/2016
17/05/2016
16/06/2016
16/07/2016
15/08/2016
14/09/2016
14/10/2016

Case Study : Gogo Hydropower Plant redevelopment

Key data

Existing Hydropower plant	
Commissioned in 1958	63 years
Installed capacity	2 MW (11.7 m³/s)
Average production	5.9 GWh/year (historically 13.9 GWh/year)
Reservoir capacity	~ 2 millions m³

Installed Capacity	8.6 MW @ 50m³/s
Yearly energy	32.2 GWh/yr
Basic Project Cost	27.0 MUSD
Daily reservoir capacity	>100,000 m³

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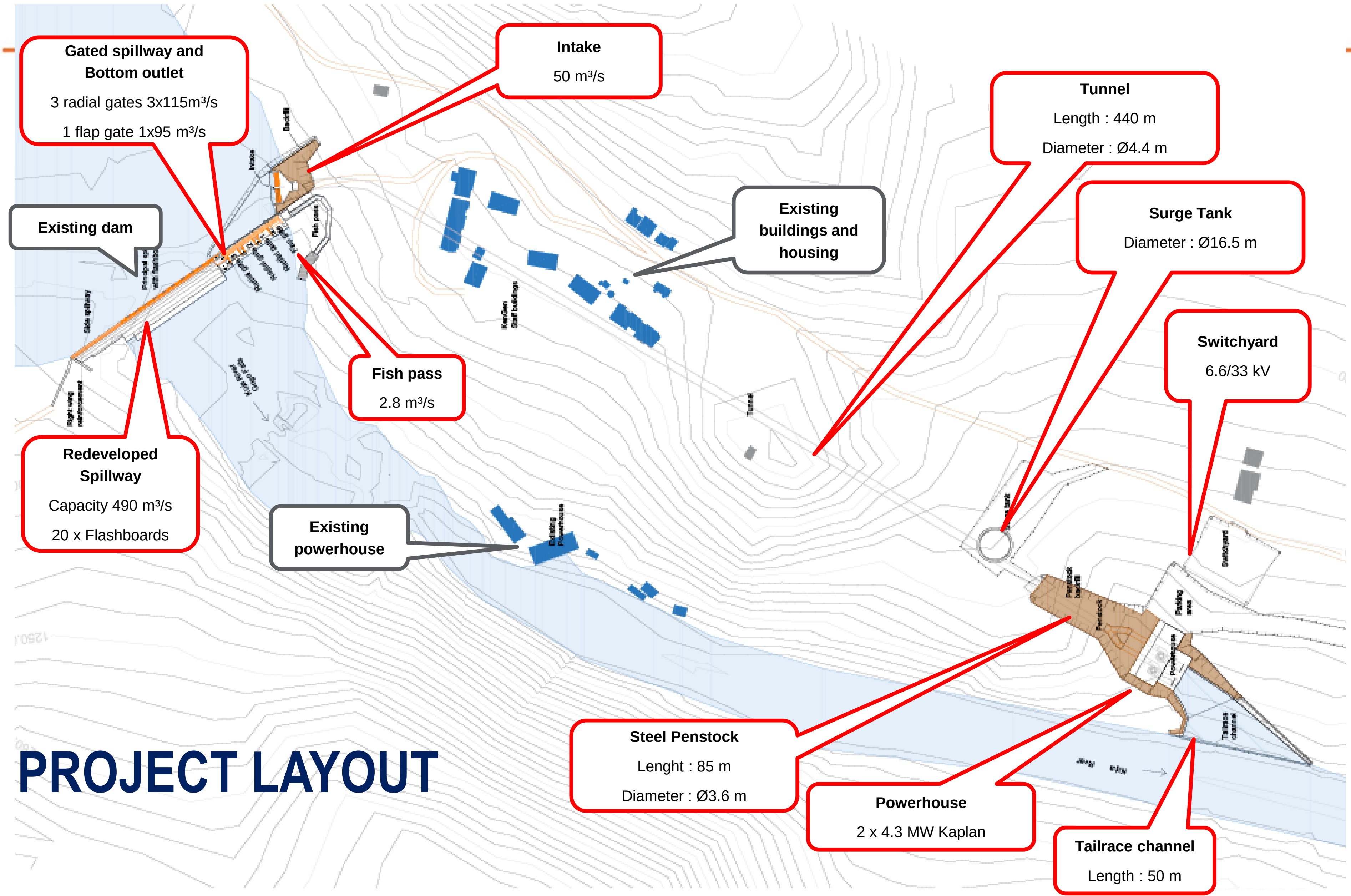
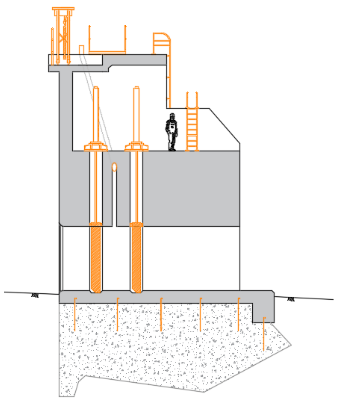
Case Study : Gogo Hydropower Plant



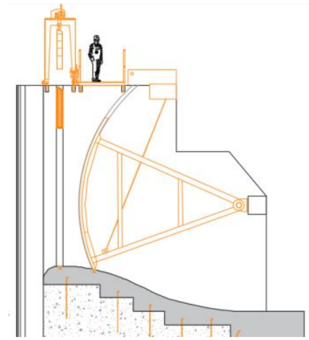
PROJECT LAYOUT

Case Study : Gogo Hydropower Plant redevelopment

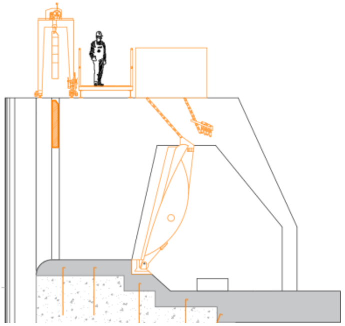
Bottom Outlet



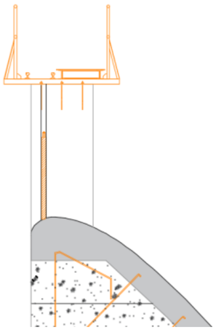
3 x Radial gate(s)



Flap gate

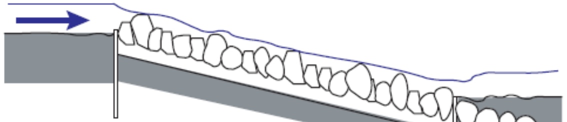


Flashboards



Flood	Water elevation	Radial gate(s)	Flap gate	Combined spilling capacity
100-yr **1010 m³/s**	1235.3 masl	210 m³/s (1x) 630 m³/s (3x)	95 m³/s	725 m³/s
500-yr **1330 m³/s**	1235.9 masl	245 m³/s (1x) 735 m³/s (3x)	115 m³/s	850 m³/s

Fish pass



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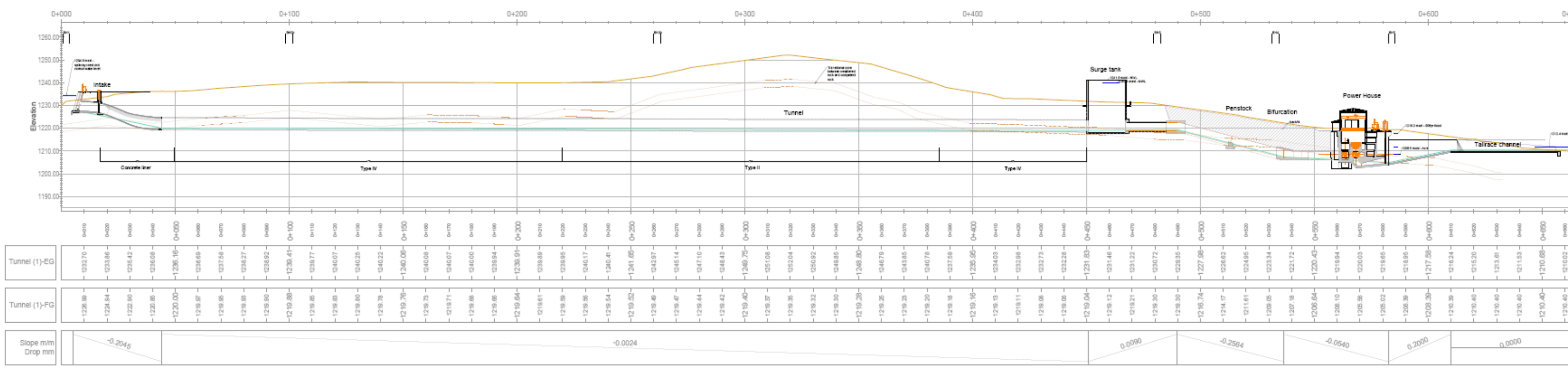
Case Study : Gogo Hydropower Plant redevelopment

Longitudinal Profile

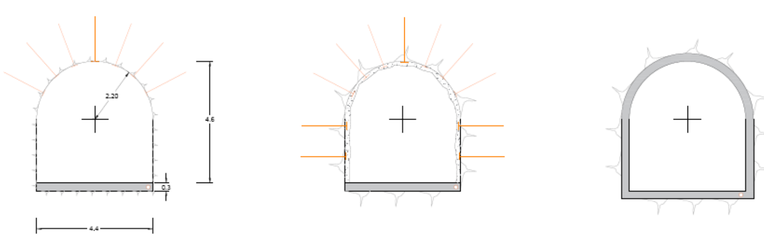


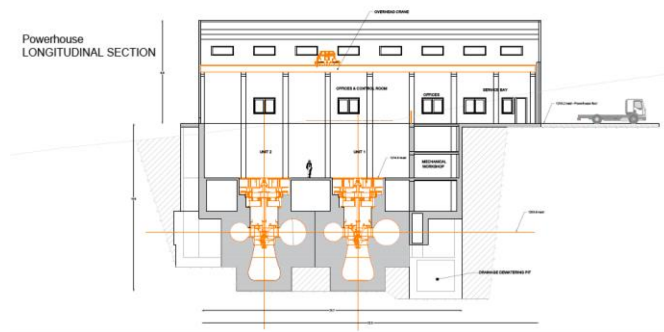
Tunnel Cross section

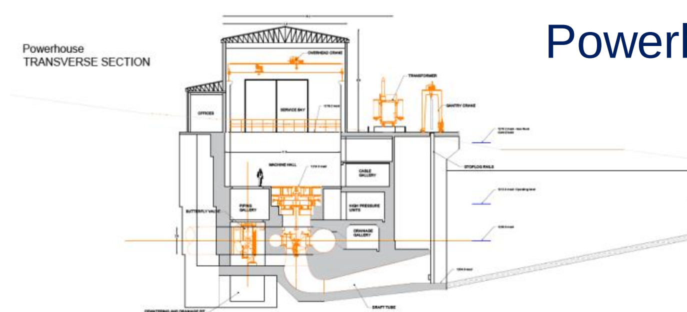
Rock mass class II section

Rock mass class IV section

Concrete liner







Powerhouse

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Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Error in the prefeasibility study for the Gross Head**

The Gross head calculated during the pre-feasibility study was over-evaluated for Medium and redevelopment Options 5a-5aa-5b by a factor of **20%** (20 m instead of 25 m).
The consequence is an overestimation of Capacity and Production.
The source of error is the use of the Airbus DEM instead of a ground survey.

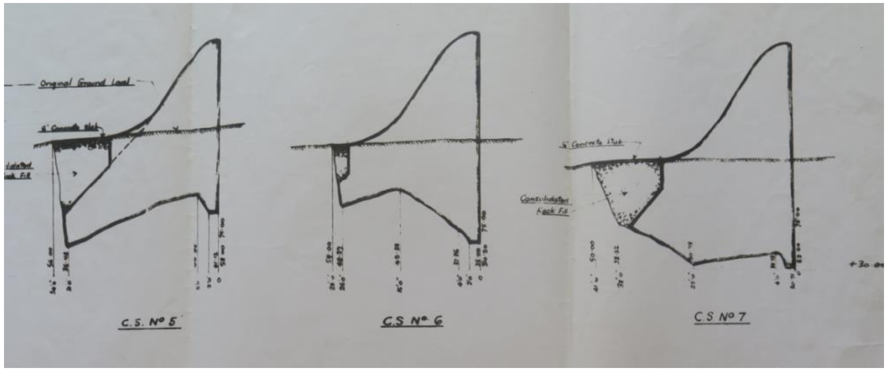
Options	Installed capacity from Prefeasibility study (Tractebel 2020)	Installed capacity after rectification 25m/20m
5a and 5aa	7.2 MW	**~ 5.7 MW**
5b	10.6 MW	**~8.5 MW**

Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Dam stability**

Cross section from as-built drawings + geotechnical investigation



Case Study : Gogo Hydropower Plant redevelopment

Study challenges

Hydrological uncertainties

- ~ 1 year of measurement
- Rating curve not already and completely assessed
- The gauging station was overflowed but the probe level was not known !

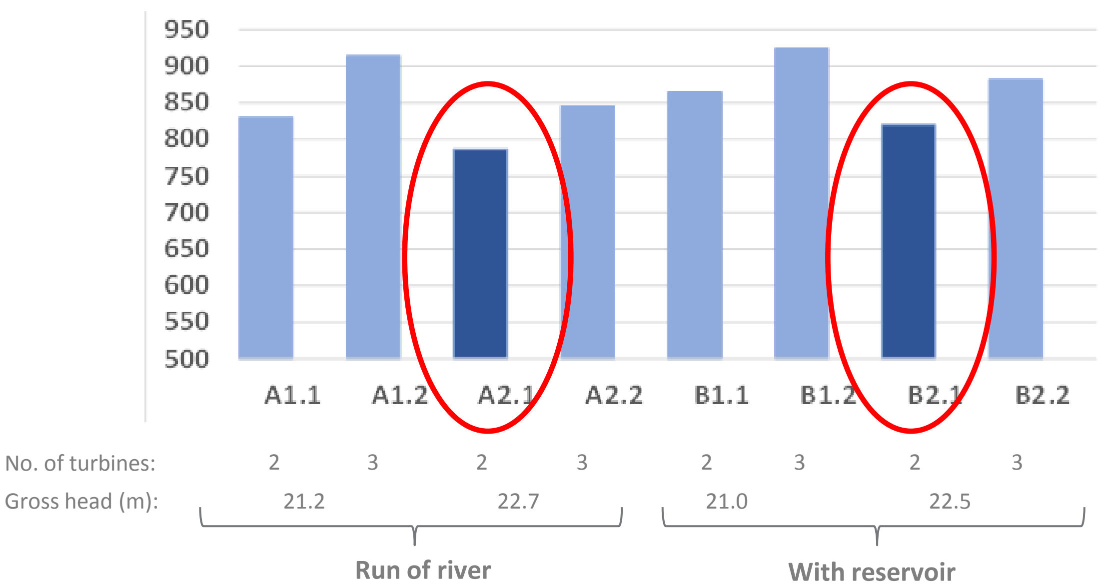
Data are definitively lost

Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Run-of-River** or **Peak capacity** Power Plant **?**
  - Complex problem in a liberalized market
  - Siltation of the dam and cost of desilting

    2 millions m³ of potential volume => 200,000 m³ available by increasing of the dam and desilting (69,000 m³)
  - 8 alternatives (Ranked in USD/MWh)



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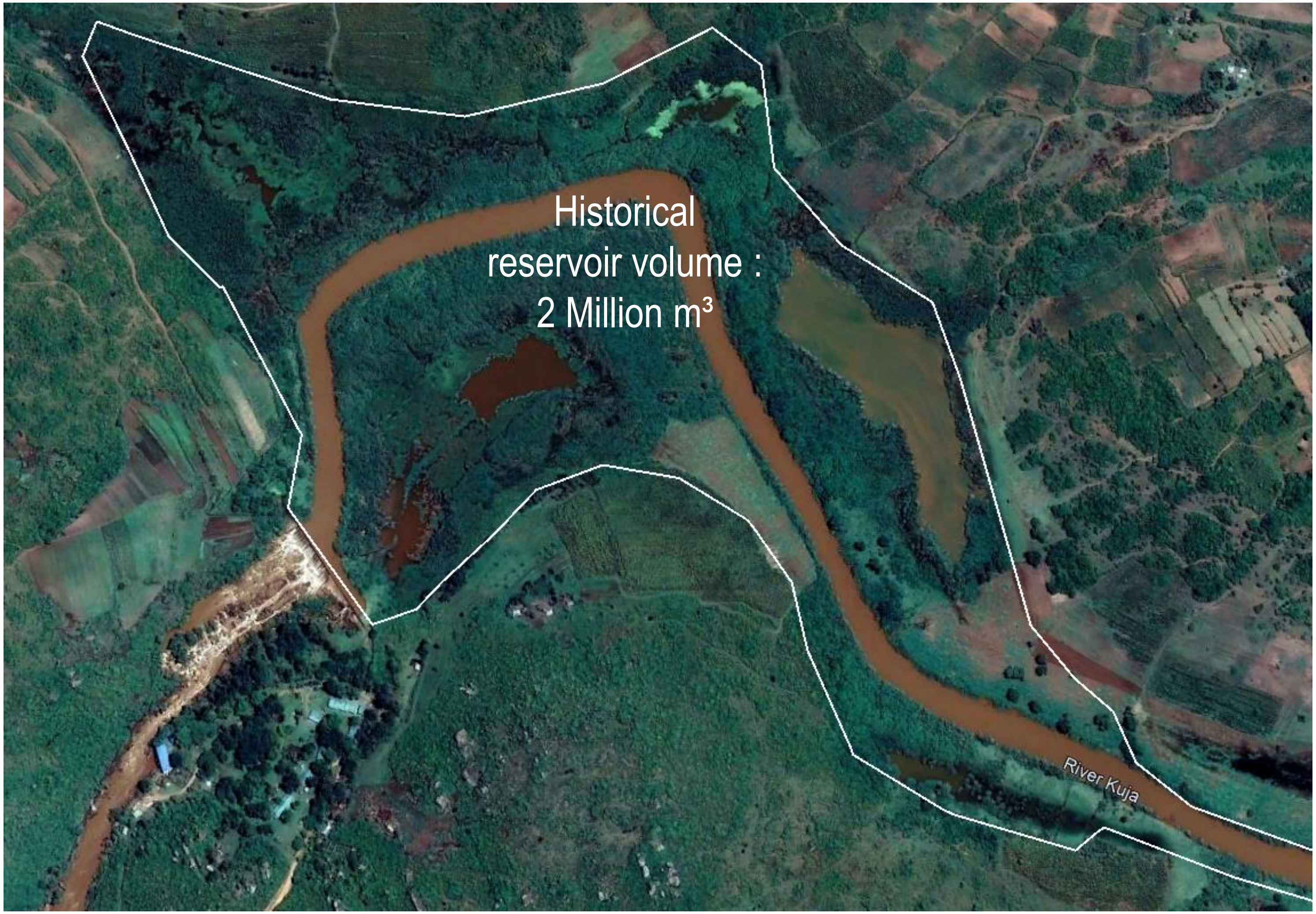
Sediment transport study



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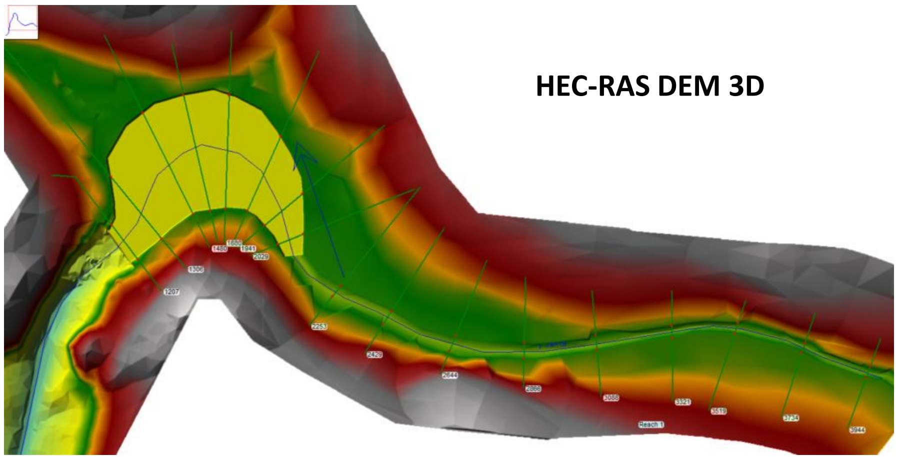
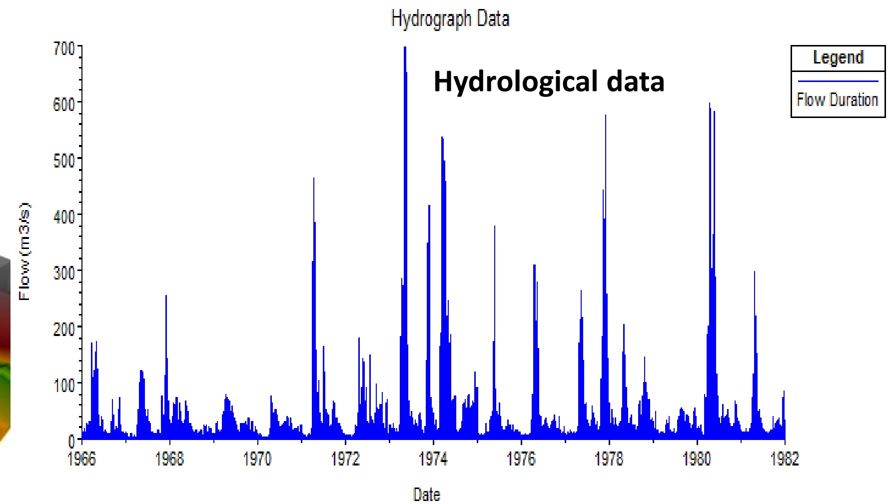
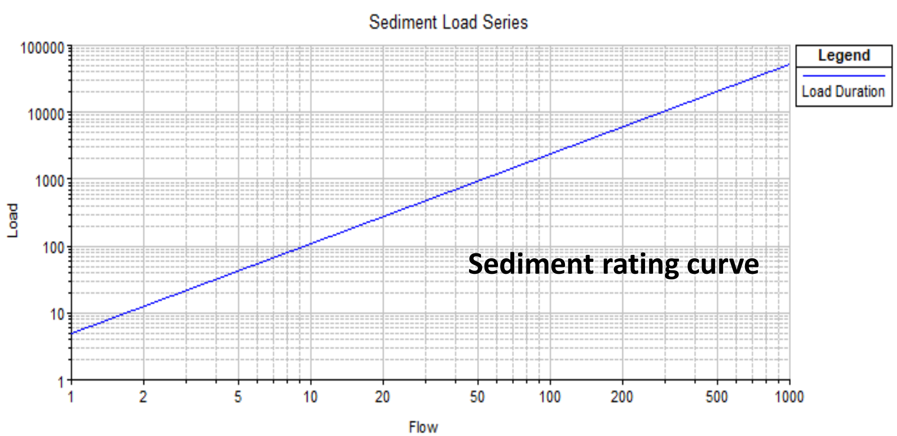
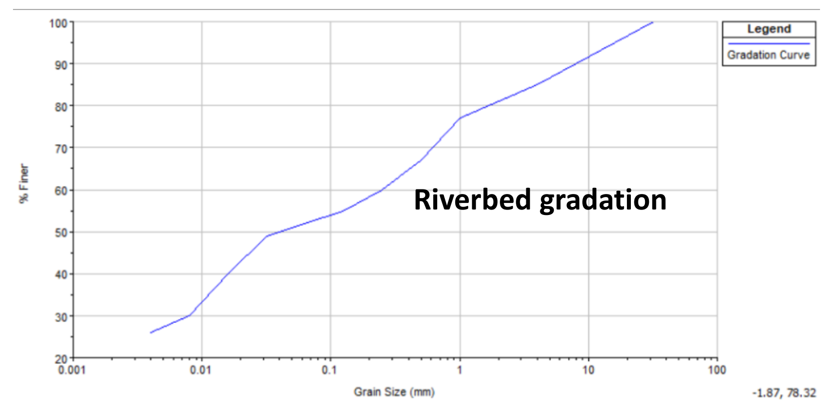
Sediment transport study

- HEC-RAS sediment transport model









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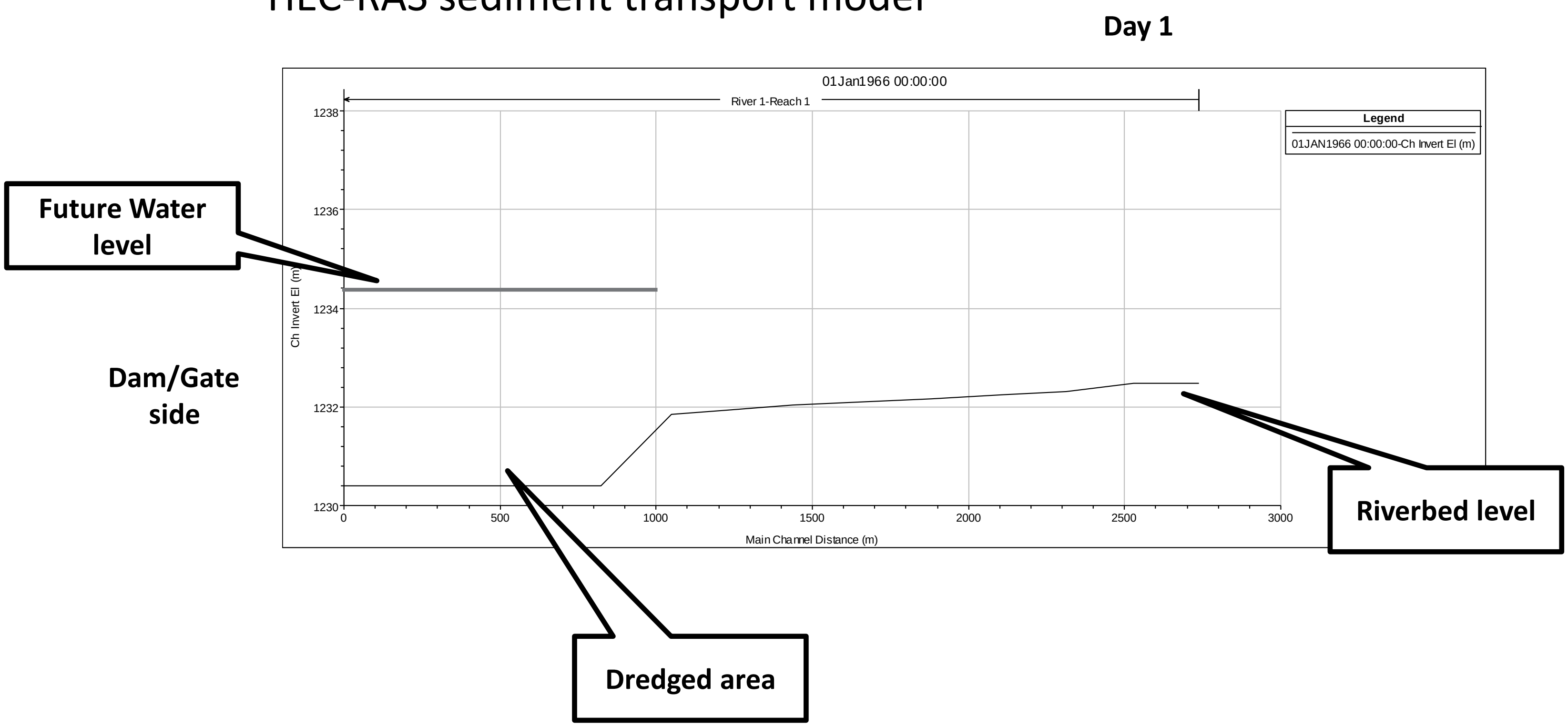
Sediment transport study

- HEC-RAS sediment transport model

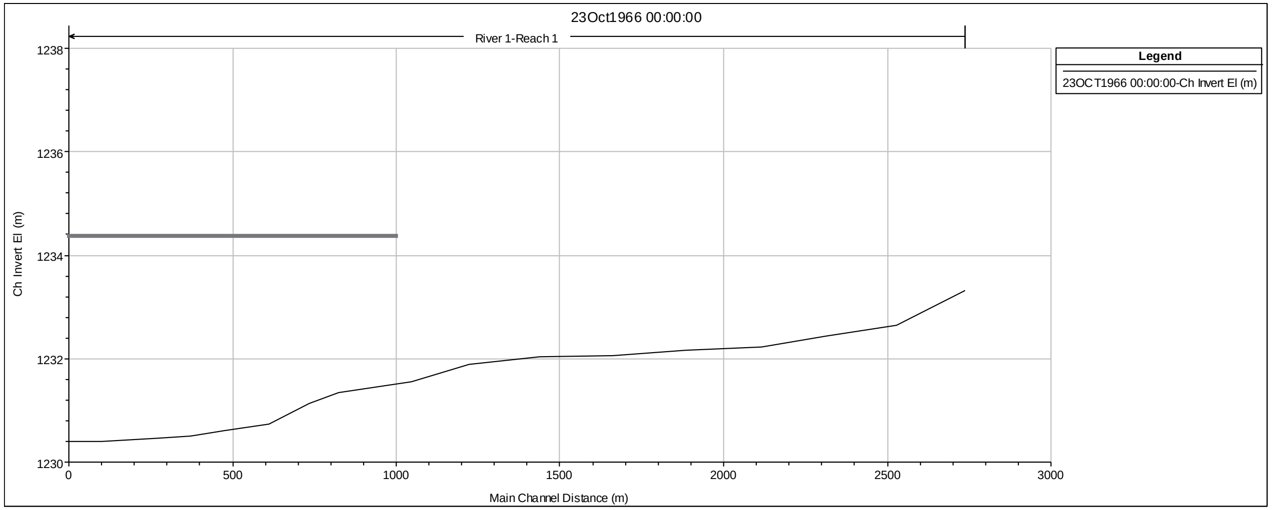


Sediment transport study

- HEC-RAS sediment transport model

Day 285

Dam/Gate side



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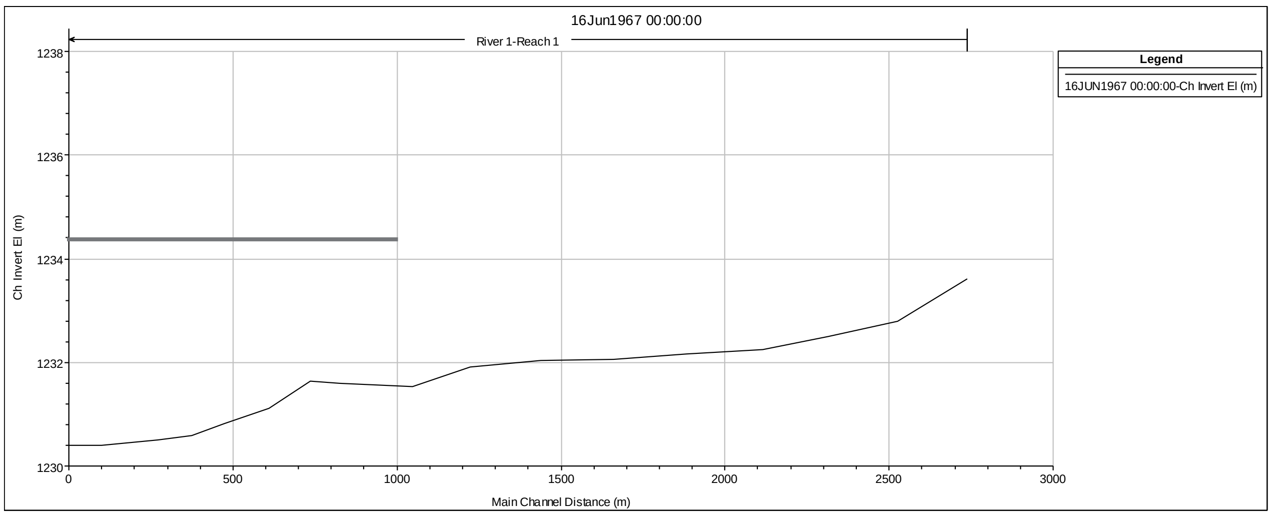
Sediment transport study

- HEC-RAS sediment transport model

Day 521



Dam/Gate side

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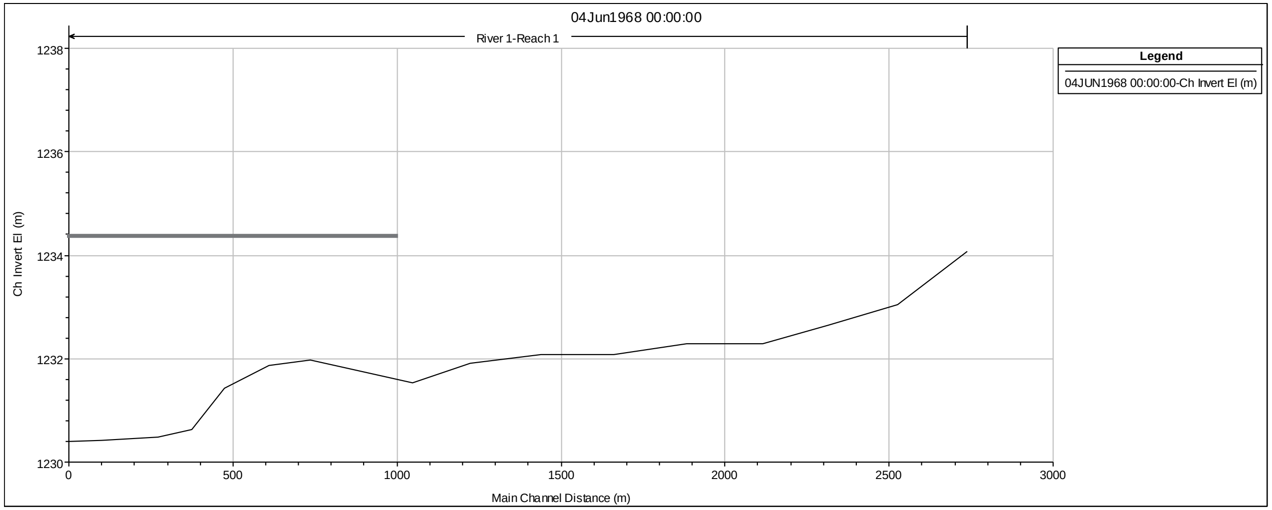
Sediment transport study

- HEC-RAS sediment transport model

Day 875

Dam/Gate side



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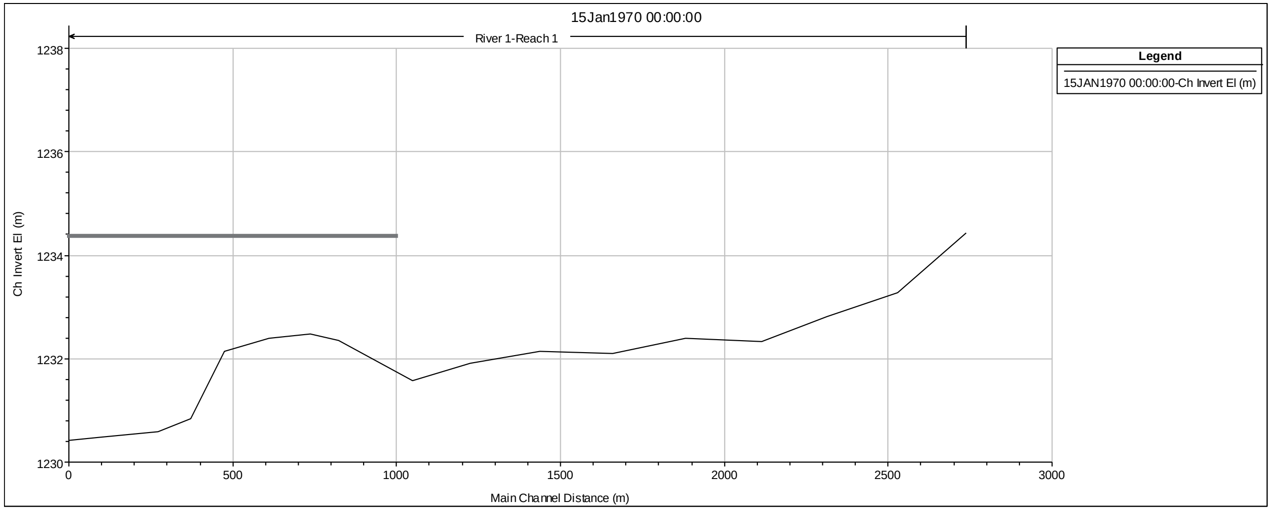
Sediment transport study

- HEC-RAS sediment transport model

Day 1465

Dam/Gate side



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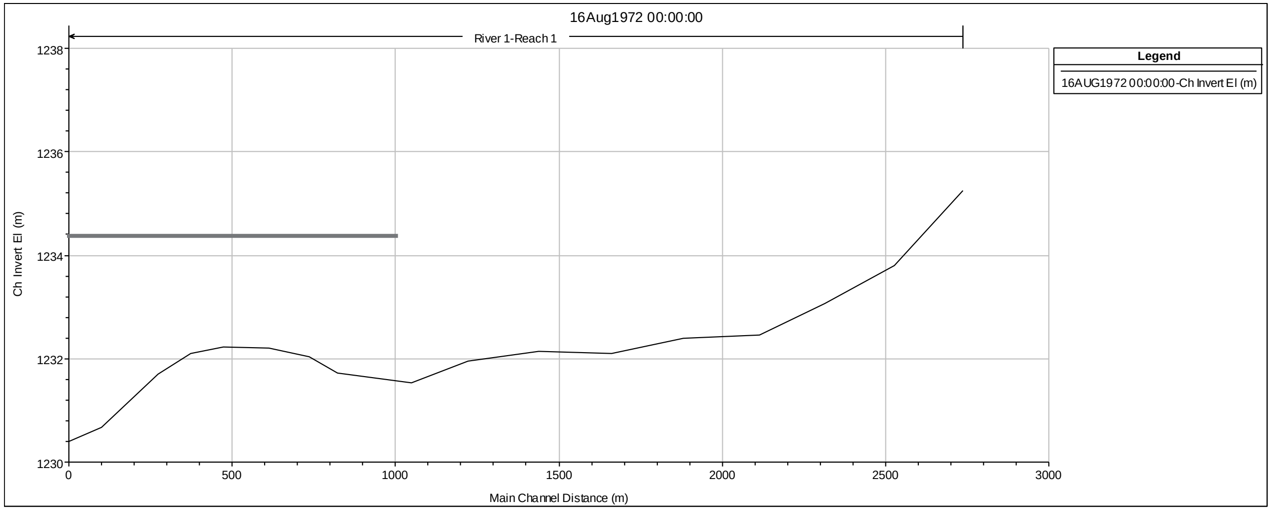
Sediment transport study

- HEC-RAS sediment transport model

Day 2409

Dam/Gate side



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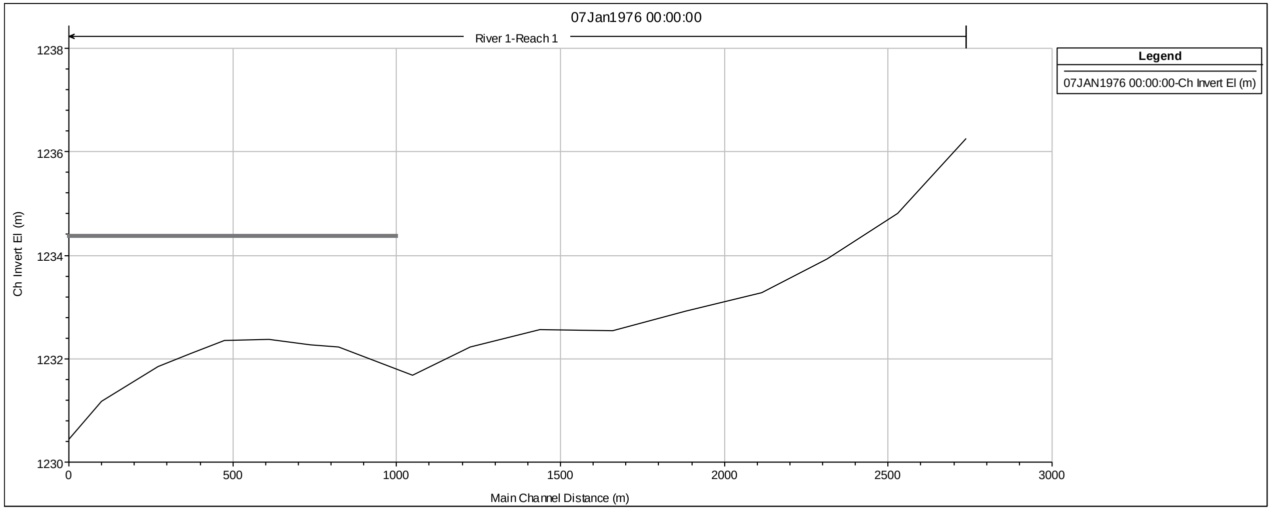
Sediment transport study

- HEC-RAS sediment transport model

Day 3468

Dam/Gate side



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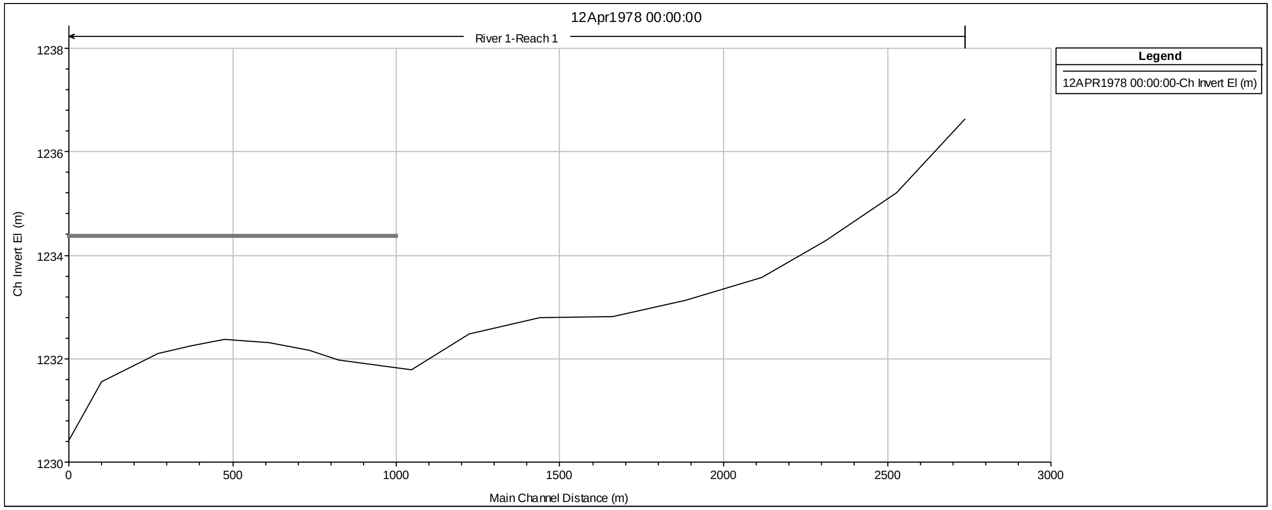
Sediment transport study

- HEC-RAS sediment transport model

Day 4474

Dam/Gate side



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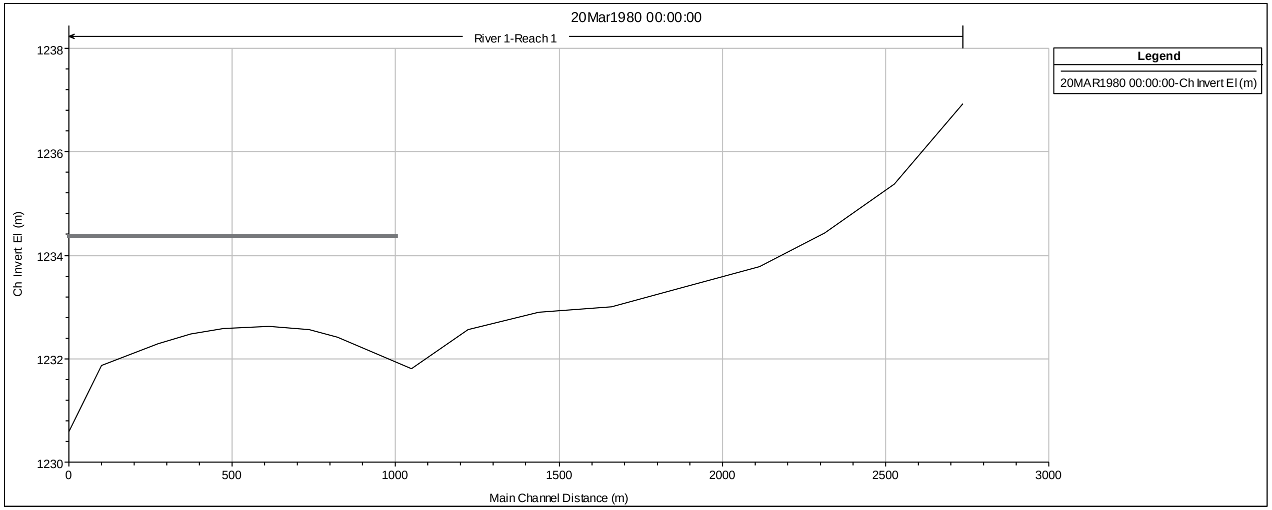
Sediment transport study

- HEC-RAS sediment transport model

Day 5182

Dam/Gate side



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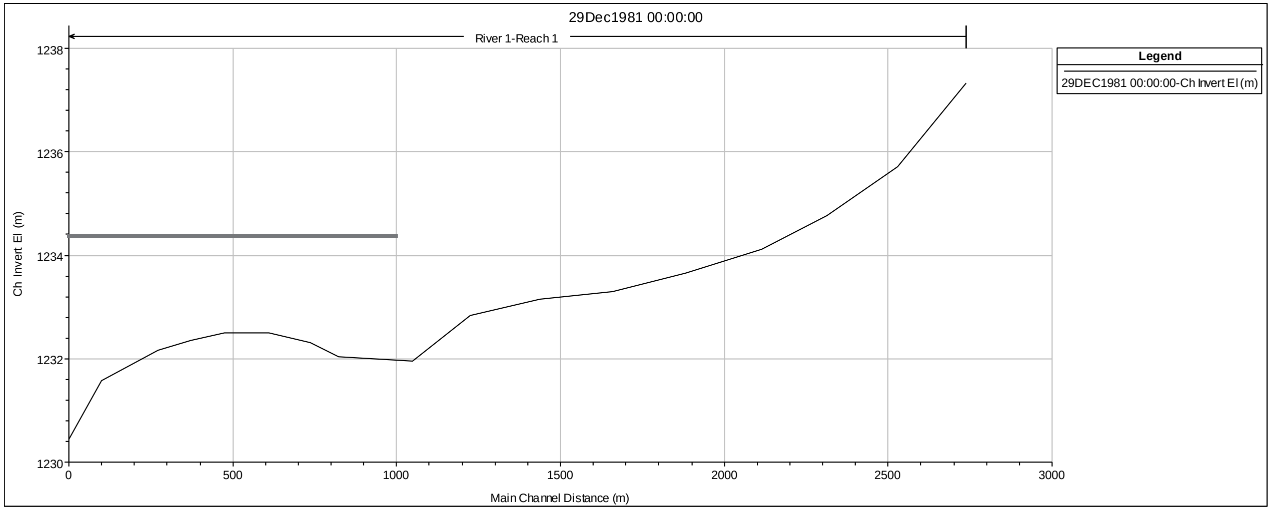
Sediment transport study

- HEC-RAS sediment transport model

Day 5831 - 16 years

Dam/Gate side



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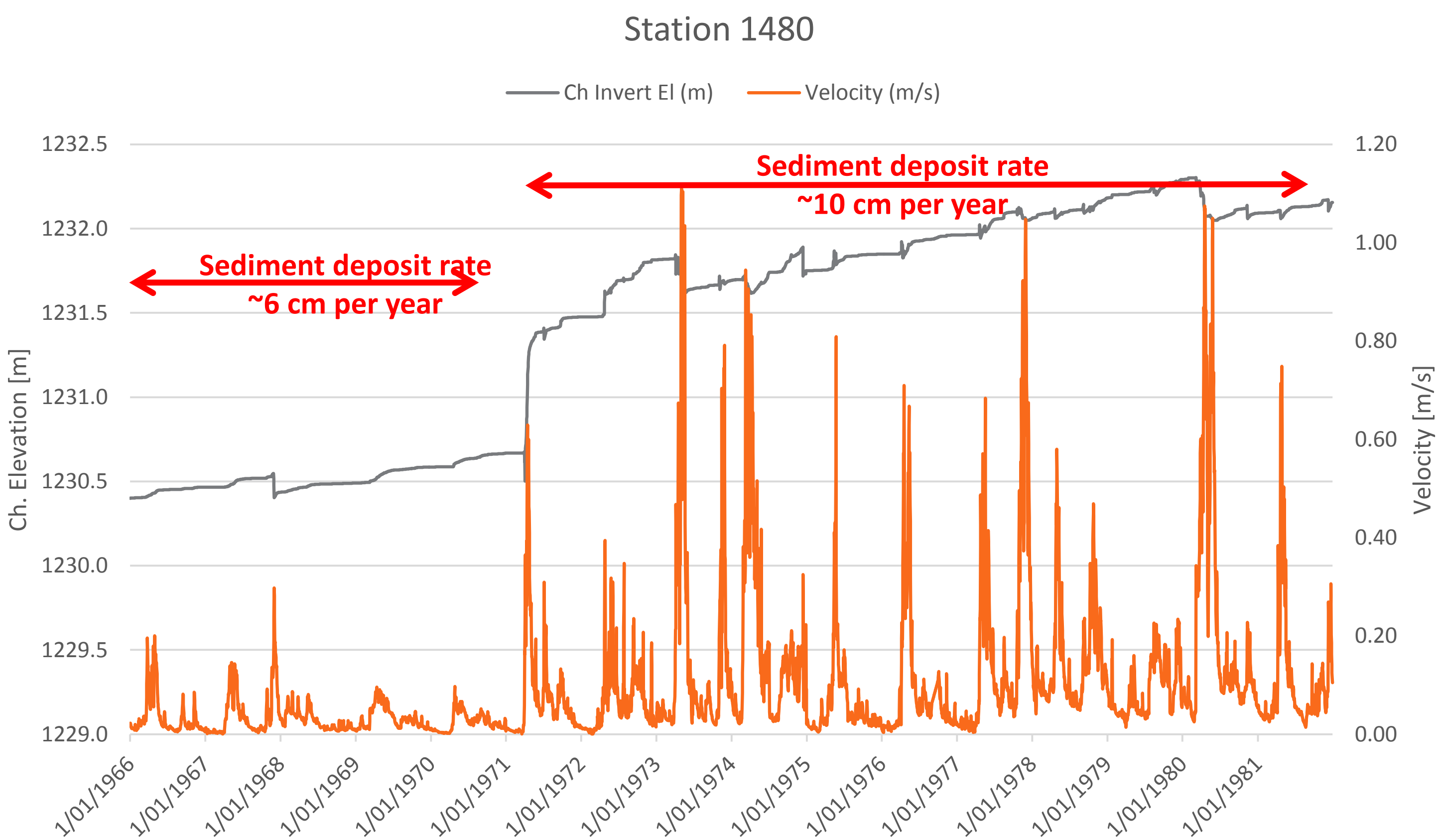
Sediment transport study

- HEC-RAS sediment transport model - Results



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Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Run-of-River or Peak capacity Power Plant ?**

Financial analysis

	A2.1 Run of River, 7.01 MW	B2.1 Reservoir, 8.58 MW	
	Single tariff	Single tariff	Peak & Offpeak**
Without Transmission line			
Equity IRR of 10.5%			
Tariff Offpeak ($/kWh)	0.096	0.101	0.084
Tariff Peak ($/kWh)			0.167
Equity payback period (yrs)	10.4	10.4	10.4
Equity IRR of 15%			
Tariff Offpeak ($/kWh)	0.112	0.117	0.097
Tariff Peak ($/kWh)			0.195
Equity payback period (yrs)	7.9	7.9	7.9
With Transmission line			
Equity IRR of 10.5%			
Tariff Offpeak ($/kWh)	0.104	0.108	0.090
Tariff Peak ($/kWh)			0.179
Equity payback period (yrs)	10.4	10.4	10.4
Equity IRR of 15%			
Tariff Offpeak ($/kWh)	0.121	0.126	0.105
Tariff Peak ($/kWh)			0.210
Equity payback period (yrs)	7.9	7.9	7.9

Economical analysis

Western Kenya has, and is forecast to have, a power supply deficit. The LCPDP forecasts **a 511 MW deficit** to remain even in 2037. Improvement of generation and grid reinforcements were selected as priority projects.

The redevelopment of Gogo is in line with this objective. The benefits will include:

- Reduced load shedding in West Kenya
- Reduced transmission line losses for transportation from other parts of Kenya
- It is therefore important that the wider merits of Gogo are considered, and not just on a stand-alone basis

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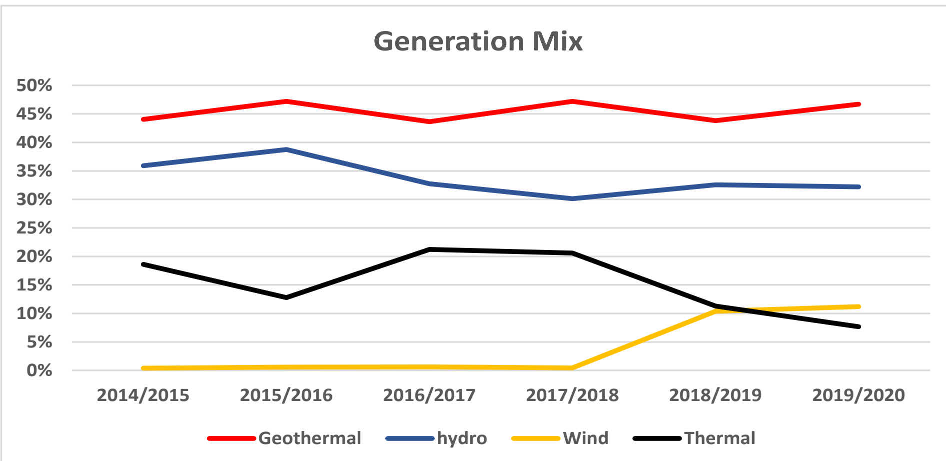
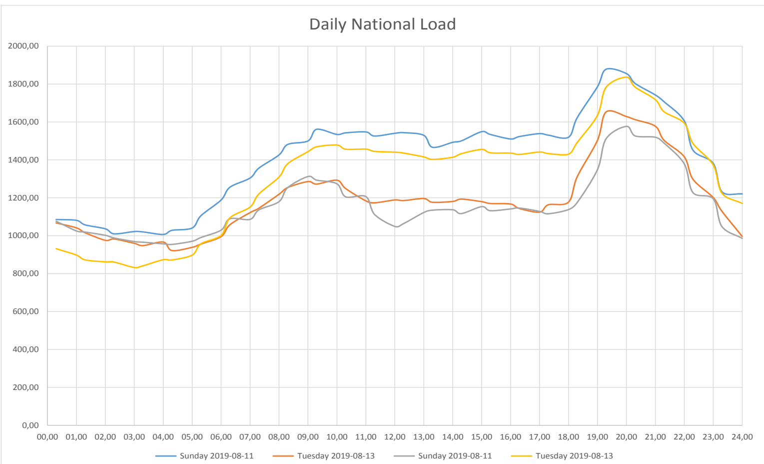
Case Study : Gogo Hydropower Plant redevelopment

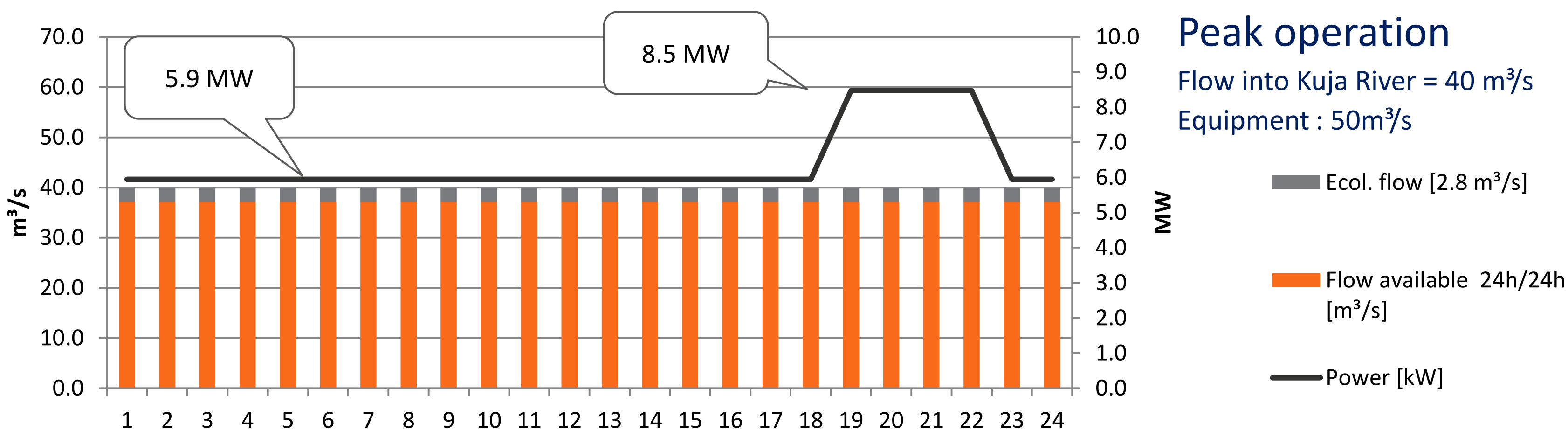
- **Run-of-River or Peak capacity Power Plant ?**

Kenya Generation Mix



Kenya Daily load





Peak operation

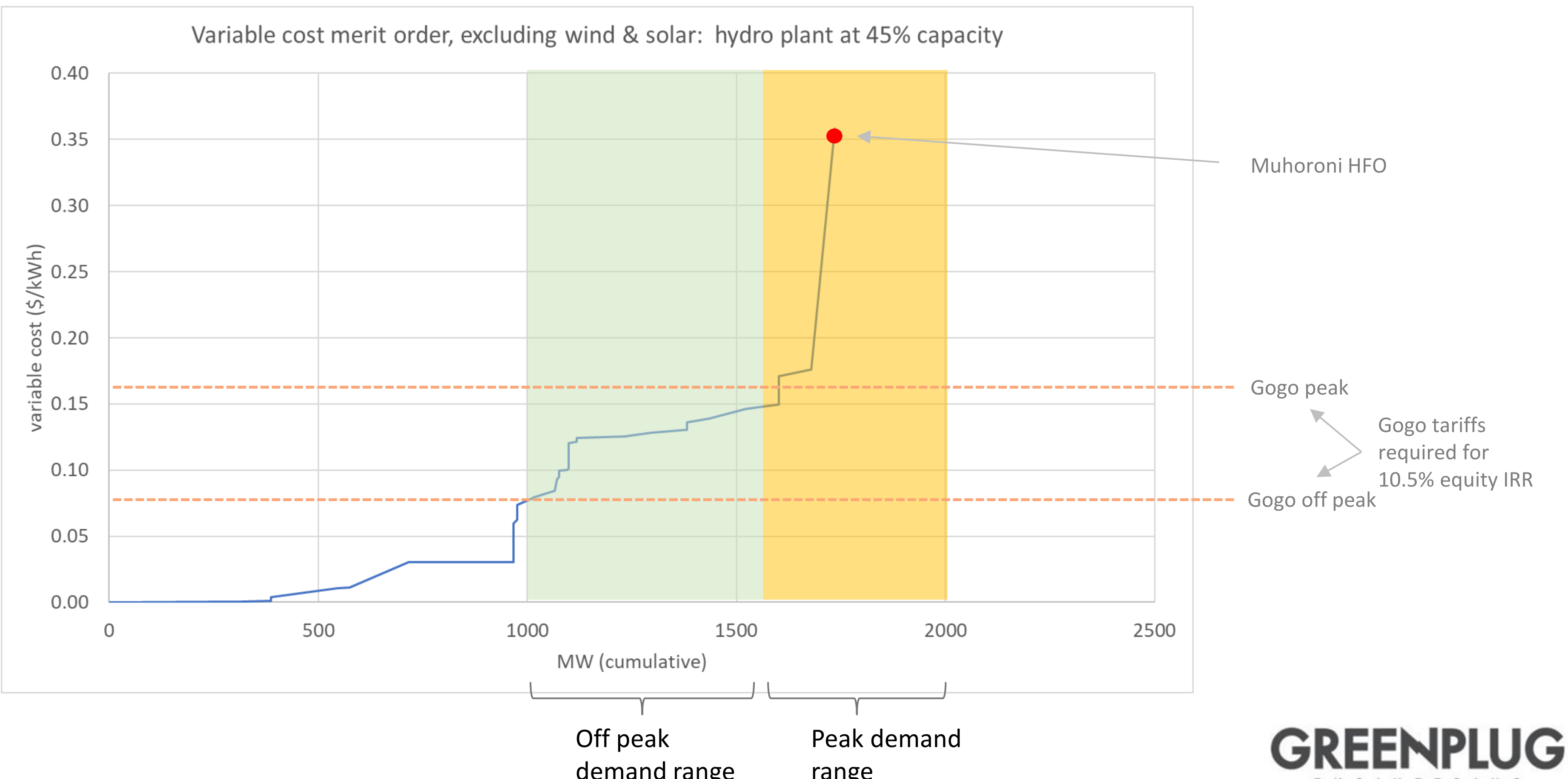
Flow into Kuja River = 40 m^3/s

Equipment : 50m^3/s

Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Run-of-River or Peak capacity Power Plant ? Merit Order**



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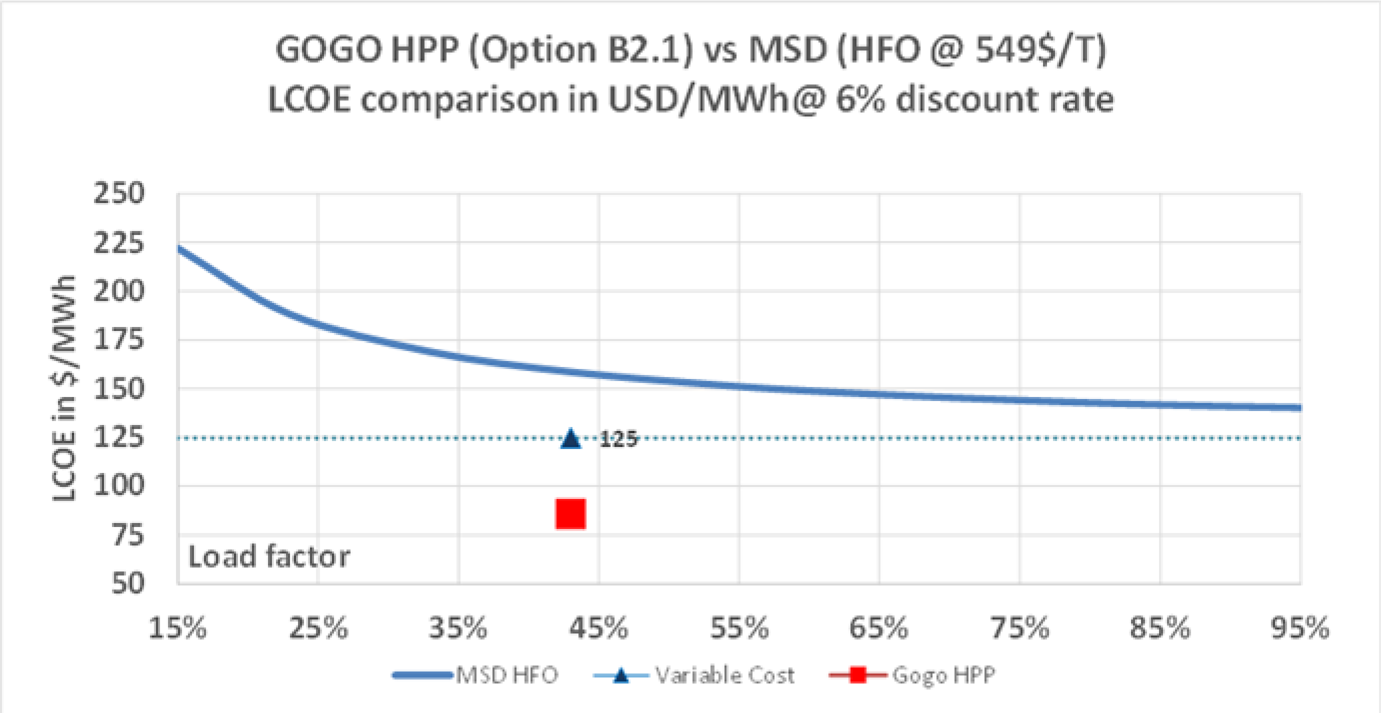
Case Study : Gogo Hydropower Plant redevelopment

Study challenges

- **Avoided Costs of new HFO peaking plant**



- <u>Gogo's LCOE ($92/MWh) is substantially below</u> both the variable and all-in costs of a new HFO plant.
- The HFO price would need to reduce to $370/tonne to give a variable cost equivalent to that of Gogo.

Case Study : Nintulo/Mozambique - High head Project

Study challenges : review of the feasibility study

- **Hydrology**
- **Gauging station**
- Topography
- Institutional and legal aspects

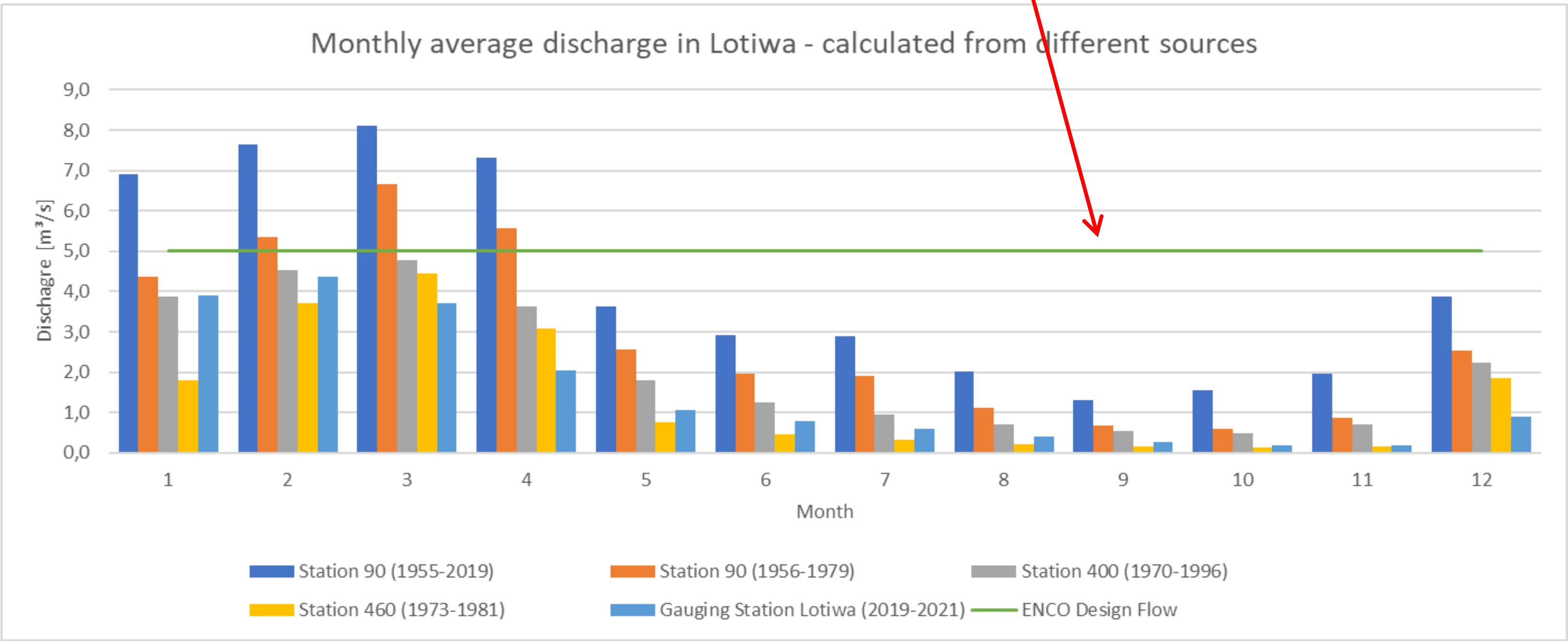
Gross Head:

290 m

Case Study : Nintulo/Mozambique - High head Project

Review of the Hydrology

- The feasibility study recommended a design flow of 5 m³/s => 11.2 MW



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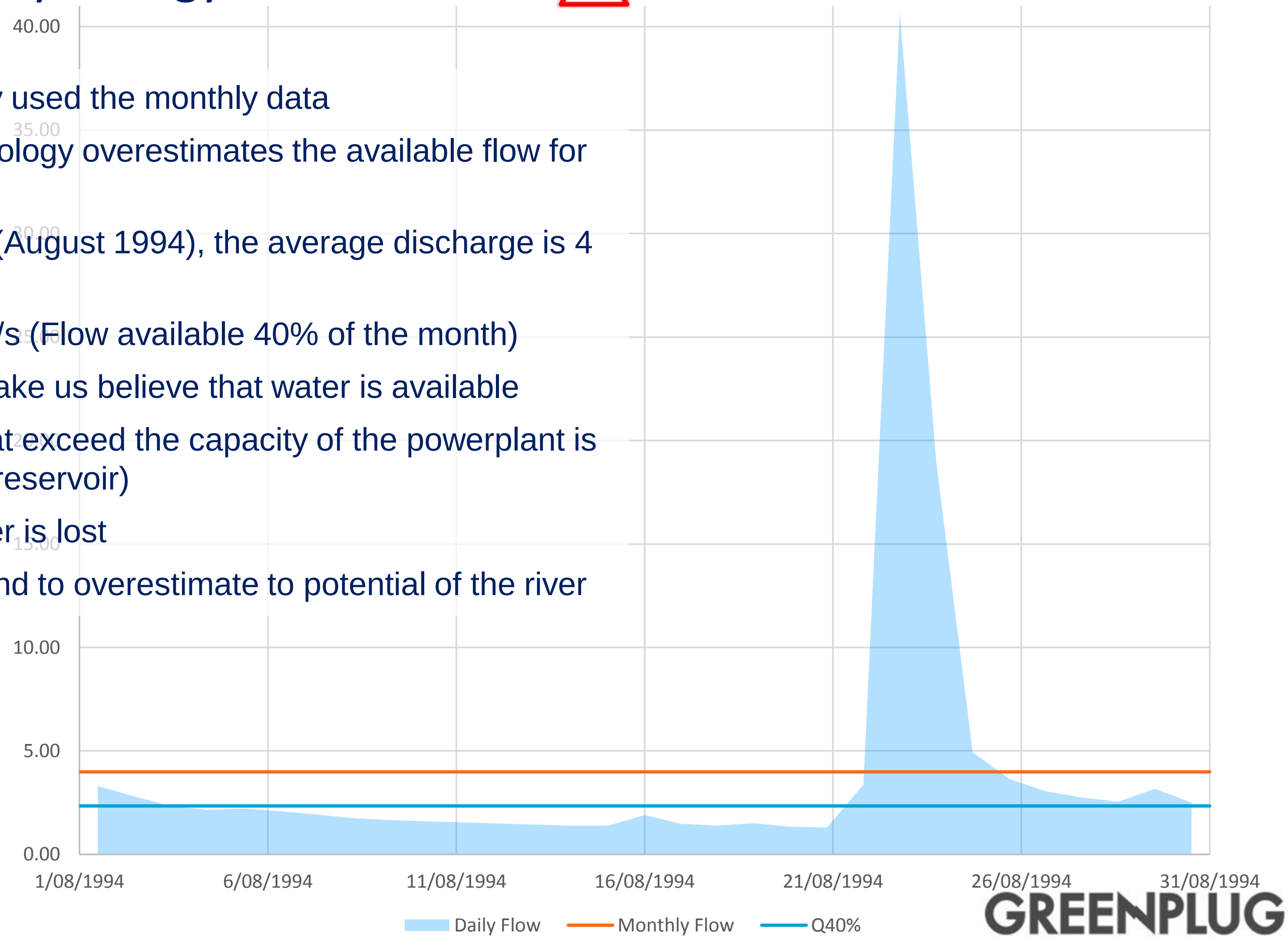
Case Study : Nintulo/Mozambique - High head Project

Review of the Hydrology => First Error ⚠

- Feasibility study used the monthly data
- => This methodology overestimates the available flow for hydropower
- In the example (August 1994), the average discharge is 4 m³/s
- Q40% is 2.3 m³/s (Flow available 40% of the month)
- Monthly data make us believe that water is available
- All the water that exceed the capacity of the powerplant is lost (except for reservoir)
- 47% of the water is lost
- Monthly data tend to overestimate to potential of the river



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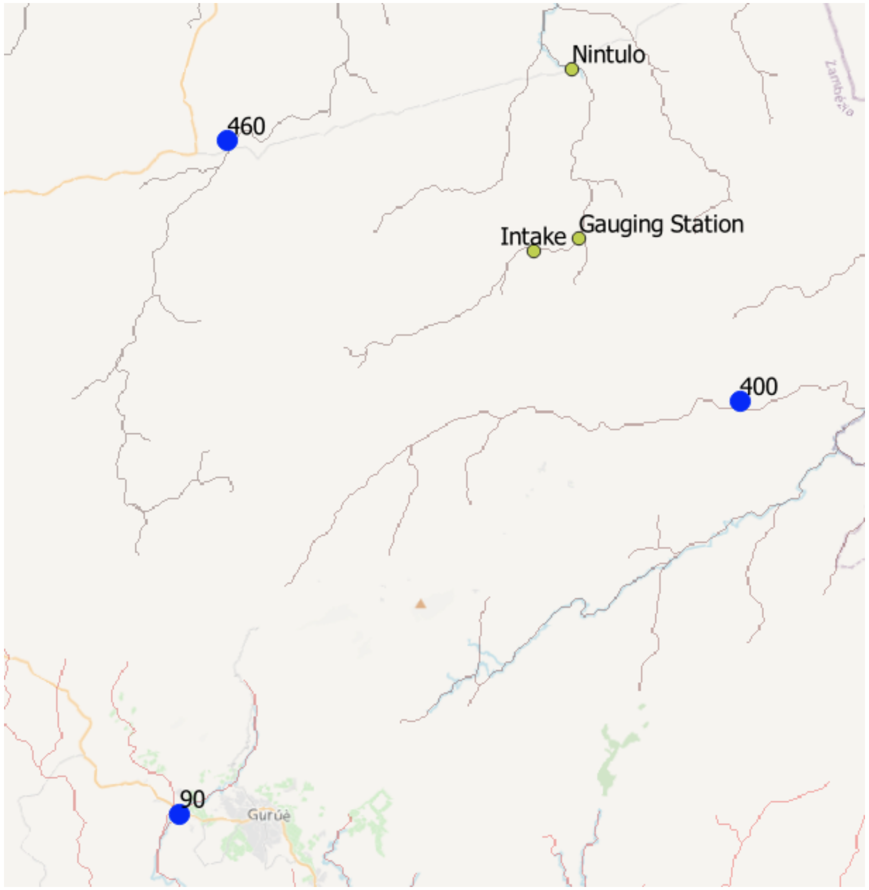
Case Study : Nintulo/Mozambique - High head Project

Review of the Hydrology => Second Error

- Three gauging stations are close and offer historical series of data
  - E90 – 70 km²
  - E400 – 235 km²
  - E460 – 304 km²

- Station E90 has 65 years of data recorded and was used for the feasibility study

- Recent data seem to be biased



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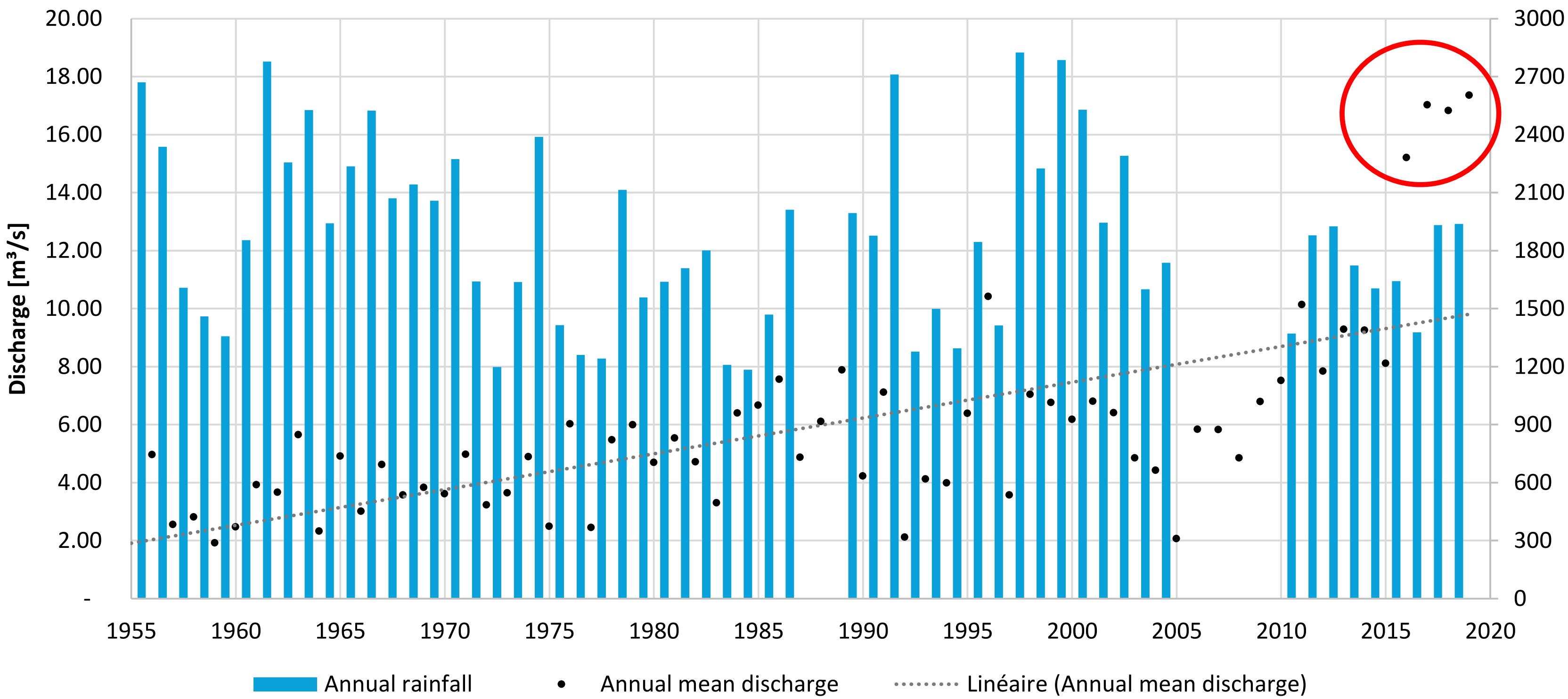
Case Study : Nintulo/Mozambique - High head Project

Review of the Hydrology => Second Error

- Using the monthly discharge of a gauging station with questionnable data
- The annual discharge is increasing while the annual rainfall does not increase.
- This is particulary true for the last 4 years



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Case Study : Nintulo/Mozambique - High head Project

Gauging station : The infrastructure and data collection are appropriate

- The gauge is well located at a proper distance from the weir
- The gauge is readable from the bank
- Protected by rocks
- All data are available

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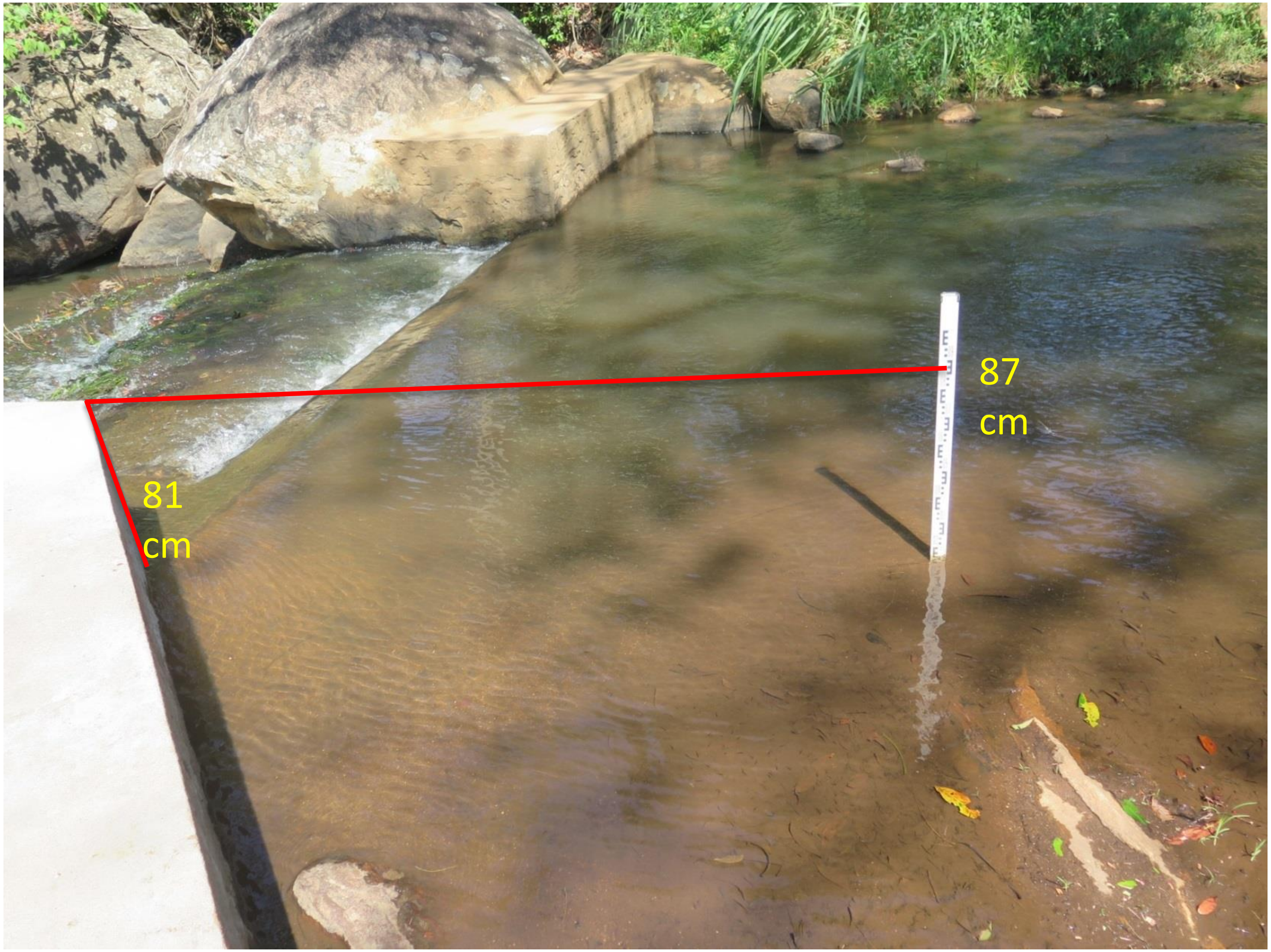
Case Study : Nintulo/Mozambique - High head Project

Levels issue



- Left hand wingwall top reaches 86 cm on the scale
- The weir is 81 cm below the top of the wingwall

→ The zero of the gauging scale is set **6 cm lower** than the weir

↓

If reading 0.15 m at the scale Once should use 0.09 m in calculations

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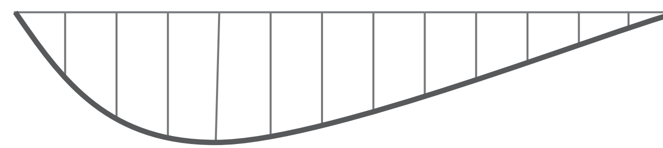
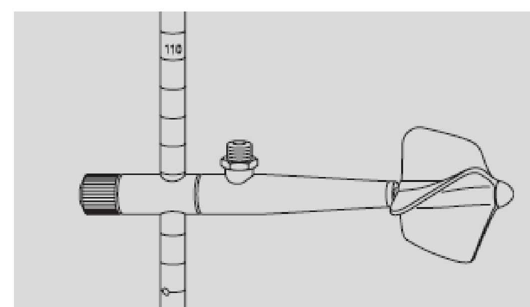
Case Study : Nintulo/Mozambique - High head Project

Discharge verification with a propeller

- Cross section carefully selected (no bypass, no rocks and vegetation…)
- Calibrate propeller to measure water velocity
- Measure in each subsection (1 or 2 depending on water depth)
- Integration of data in the whole section to get the river discharge

→ 28/11 : mean discharge = **233 l/s**
→ 29/11 : mean discharge = **220 l/s**





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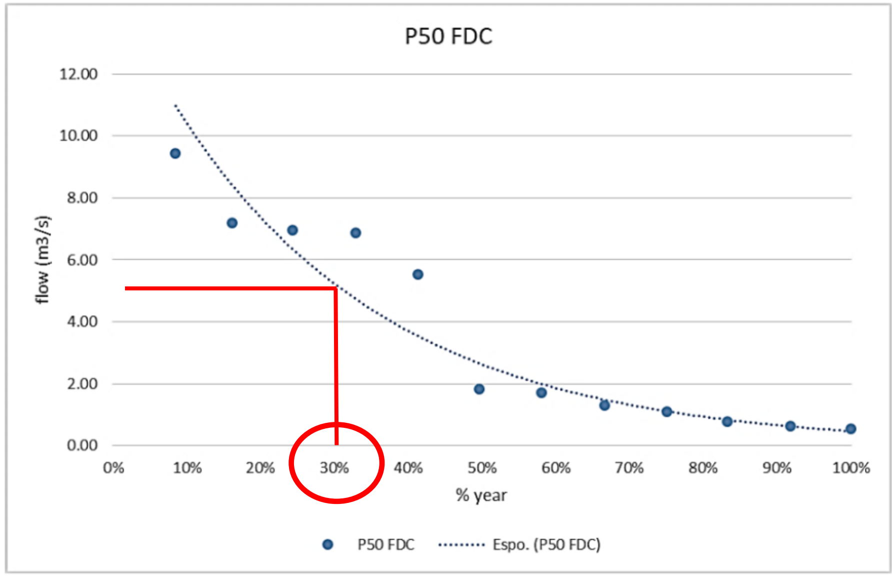
Case Study : Nintulo/Mozambique - High head Project

Review of the FDC (Flow Duration Curve)

Feasibility FDC



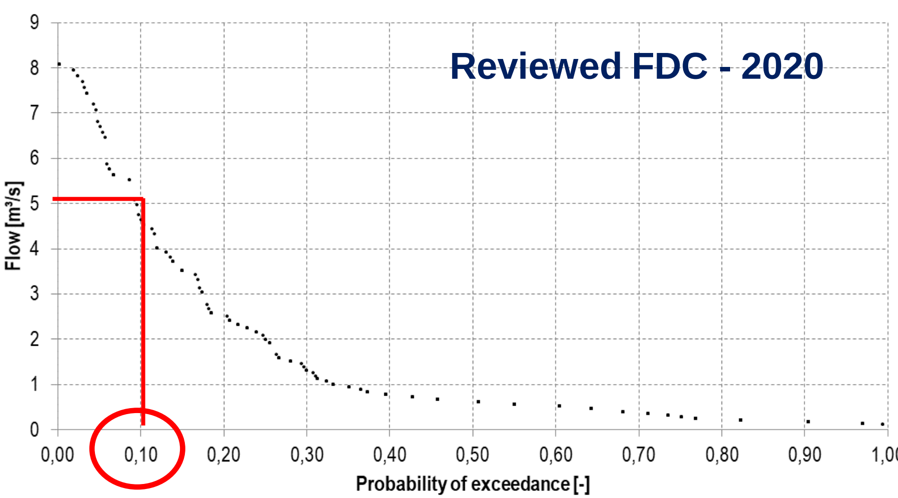
New Proposed discharge :

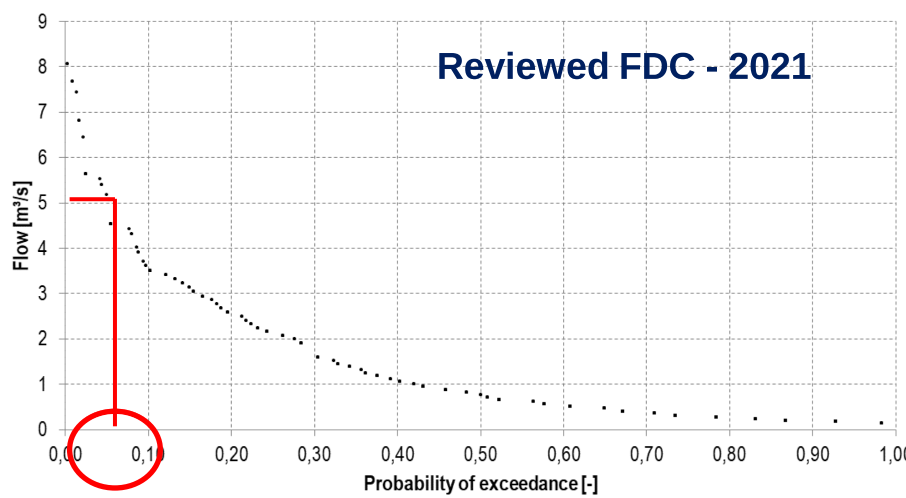
1.5 - 2.0 m³/s

New Capacity :

3.5 - 4.3 MW

We reprocessed the FDC for the two years of gauging





Risques associés à un mauvais engineering

Exemple 1: écrasement de la conduite forcée

Risques associés à un mauvais engineering

Exemple 2: équipements EM de mauvaise qualité

Centrale de NYEMANGA au Burundi:

- 2 Groupes Pelton à axe horizontal Escher Wyss Ravensburg (**1986**)
- 2 groupes Pelton à axe horizontal, Zhejiang Yueqing Machinery Works , Chine (**2008**)

Bride de démontage et vanne groupe 2 (Echer Wyss). On remarque les parties inox et l'absence de corrosion, particulièrement sur la visserie

Bride de démontage et vanne groupe 4 (Zhejiang). On remarque l'absence d'inox et la corrosion, particulièrement sur la visserie

Corrosion au niveau de l'accouplement (Roue Zhejiang)

Roue Escher Wyss. On remarque l'absence de corrosion

Roue Zhejiang. On relève la mauvaise qualité de l'acier et la corrosion sur la roue

Risques associés à un mauvais engineering

Exemple 3: équipements EM de mauvaise qualité

Centrale de RUVYIRONAZA au Burundi:

- 3 groupes de 500 kW (fabrication chinoise 2006)

Roue cassée (défaut de fonderie et de contrôle de qualité)

Usure anormale au niveau du palier d'une turbine (provenant probablement d'un défaut d'équilibrage ou d'un défaut d'alignement)

Générateur hors service remplacé en 2011

Roue corrodée (choix de matière inapproprié)

Importance du <u>contrôle qualité</u> durant le processus de fabrication et de la réception des équipements par des <u>spécialistes indépendants</u>

Risques associés à un mauvais engineering

Exemple 4: Rupture de barrage

Barrage de Teton, USA

Breach of Teton Dam, June 5, 1976

Barrage de Malpasset, France

Quelques conseils

- Utiliser un **cahier de note** (surtout où vous n'irez qu'une fois) et des **traces GPS**
- Pour les dessins et schémas de principe, un **crayon**, une **latte** et un **cahier quadrillé** sont très utiles (avant d'avancer dans les logiciels CAD)
- En hydrologie, toujours doubler les mesures par des **lectures sur échelles**
- Faire appel à des **experts ayant une longue expérience** lorsque la réponse n'est pas immédiatement disponible ou évidente
- Lors d'identification de site, **prenez le temps**, repassez plusieurs fois au même endroit, consultez les autres spécialistes (géologue, géotechnicien, électromécanicien, etc.) et les experts & populations locales sur les étiages, les crues et les aspects EIES. Une étude hydroélectrique c'est avant tout une **équipe multidisciplinaires.**
- Ne **surévaluez** jamais les **puissances** et les **productibles**
- Soyez **prudent** dans les **quantités et budgets**

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Contact

Pierre SMITS
GreenPlug Engineering SRL
Avenue de la Couronne 236B,
1050 Brussels - Belgium
Tel: +32 473 29 29 57
Mail: pierre.smits@greenplug.eu

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