ENERGY OPTIMISATION IN WATER SUPPLY NETWORKS

INFRAWATT WEBINAR "SMARTE TRINKWASSERREGELUNG

Khalid Essyad | 11.19.2025

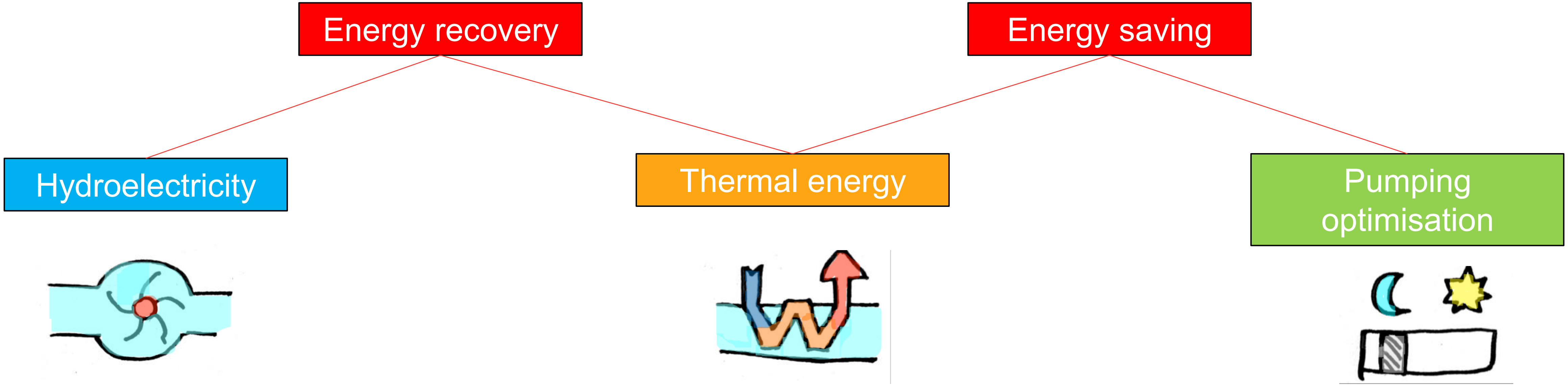
Introduction

Water-energy nexus has been a central theme for over 20 years:

- **Energy is necessary for all stages of the water cycle (intake, treatment, transport, heating, etc.)**
- **Water is used in all types of electricity production, from the process and cooling to the production of electricity itself.**

Today, the aim is to focus on this link in drinking water supply networks.

Introduction



Introduction : stages

3 successive stages

1. **Screening :**

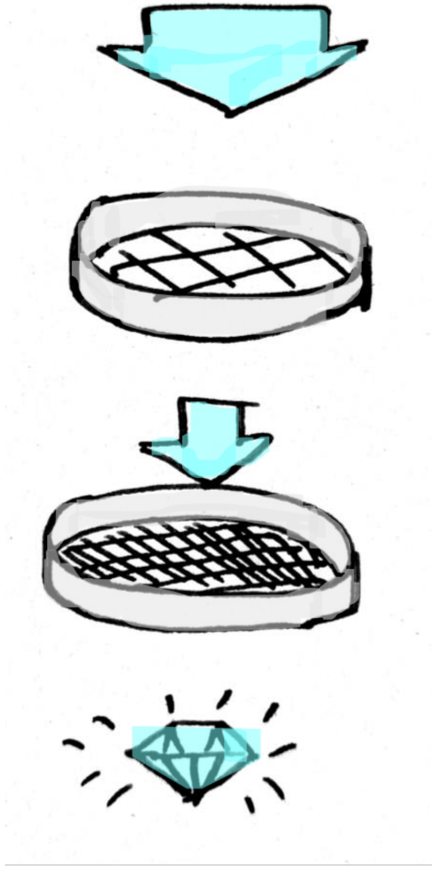
   identification of sites/head/infrastructure to be potentially valorised

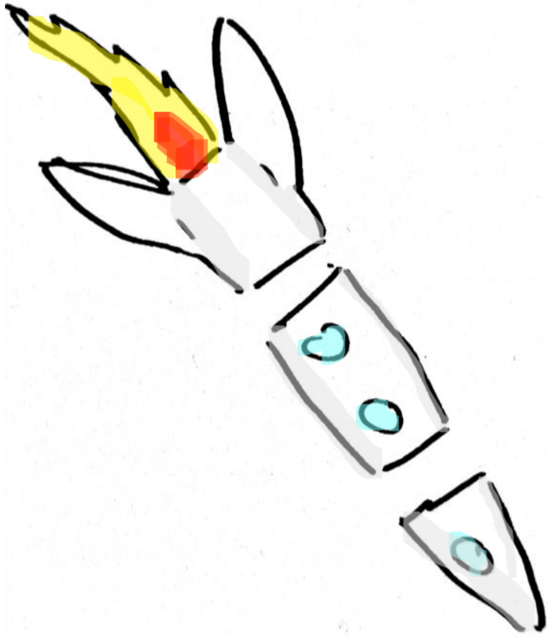
2. **Feasibility:**

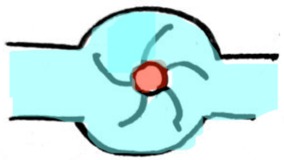
   Site constraints, estimation of feasibility and return of investment.

3. **Implementation :**

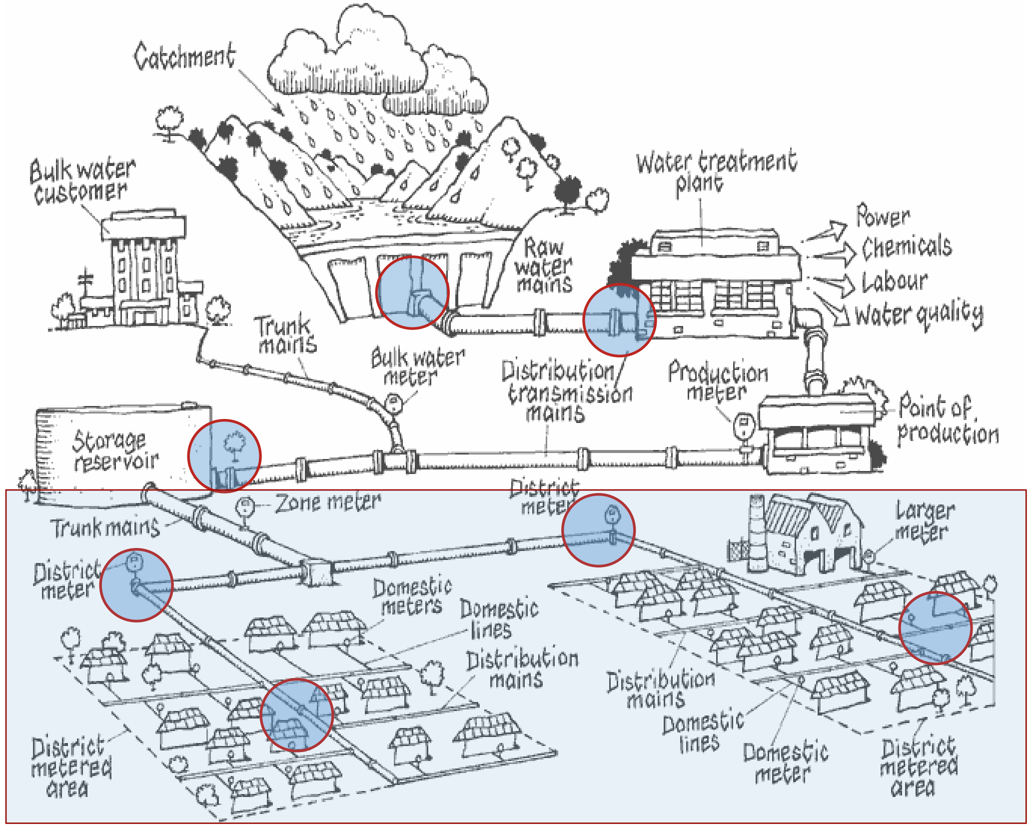
   Project, realisation, commissioning, follow up







Hydroelectricity – mini and micro



Mini

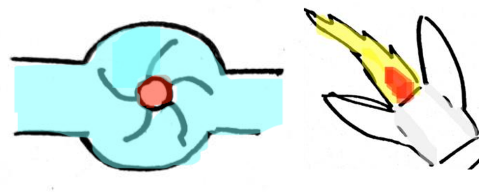
Micro (pico)

Source: Queensland Environmental Protection Agency and Wide Bay Water Corporation (2004): Managing and Reducing Losses from Water Distribution Systems. A series of 10 manuals

Challenges for small and micro hydroelectric plants

- Depend on the demand
- Minimum pressure requirements in the network
- Networks are often meshed
- Pressure requirements always respected

Priority remains the distribution of water to the population, which must be guarantied in quantity as well as quality.



Hydroelectricity – Technologies

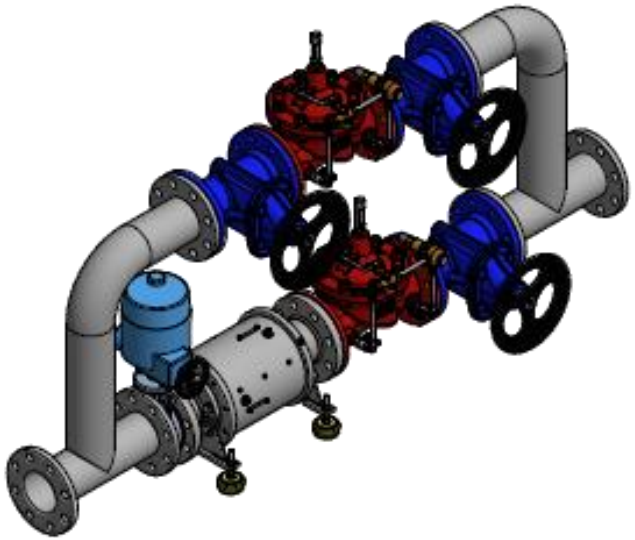
Technologies for water supply networks

- Crossflow turbines
- Pumps as turbines (PAT)
- Mini-peltons
- Specific micro turbines

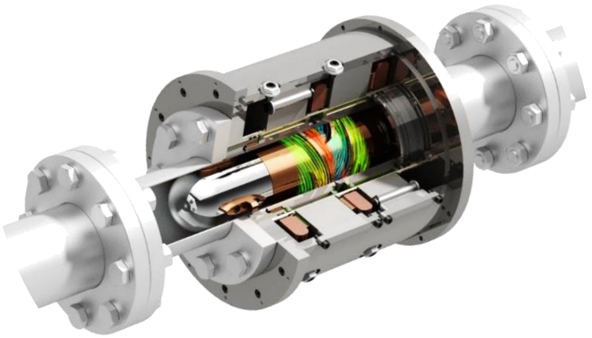
Choice depends on :

- The head (available pressure)
- And its variability
- Discharge availability
- And its variability

Example: TUNE project in Pully (VD), turbine conception and realisation VS



DuoTurbo



WSP

Hydroelectricity – order of magnitude of the income

Daily recoverable energy with a turbine : E (J/j)= ρ * g * Vj * H * η * Cj

With :

- **ρ** = water density= 1000 *kg/m³*
- **g** = gravity = 9.81 *m/s²*
- **q** = mean supply of water per inhabitant per day = 0.15 *m³/d/hab* (estimation)
- **X** = number of inhabitants
- **H** = head (in *m*)
- **η** = efficiency of turbine system ~ 0.5
- **Cj** = ratio of the flow that can be turbined during the day~ 0.7
- **p** = sale price of kWh

Potential income in *CHF/d* : **Rtj**(X, p, H) = p * Cj * E * 10^{-3} ~ **0.00014** *kWh/m/d/hab* * **p** * **X** * **H**

Hydroelectricity – order of magnitude of the income

Example with :

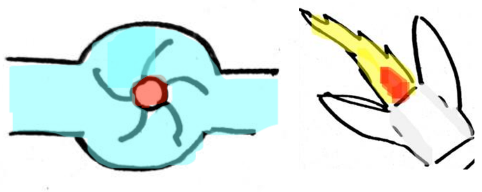
- **H** = 100 *m*
- **X** = 5000 *hab*
- **p** = 0.20 *CHF/kWh*

Income in *CHF/year* : ***f***(X, p,H) = p * X * H * α = 0.20 * 5000 * 100 * **0.00014** * 365 = 5000 CHF/year

With :

- **H** = 50 *m*
- **X** = 1000 *hab*
- **p** = 0.20 *CHF/kWh*

Income in *CHF/d* : ***f***(X, ΔC,H) = ΔC * X * H * α = 0.10 * 1000 * 50 * 0.00014 * 365 j = 500 CHF/year



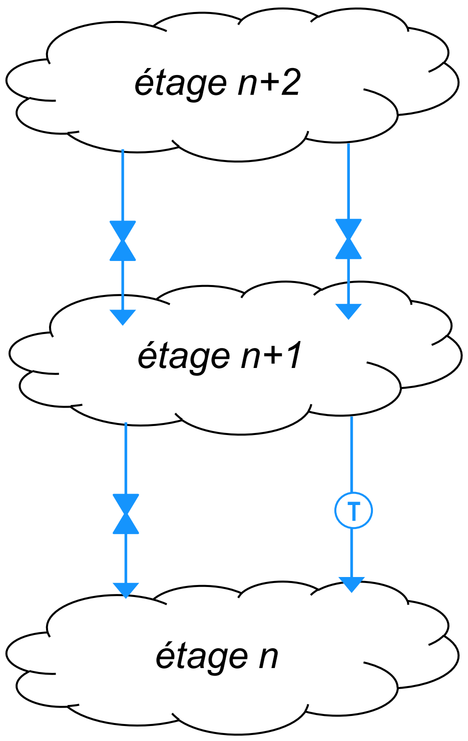
Hydroelectricity - phase 1 : screening

→ **Energy optimization searches for the highest flows in the networks**

→ **Economical optimisation favours existing sites (pressure maintaining valves between levels)**

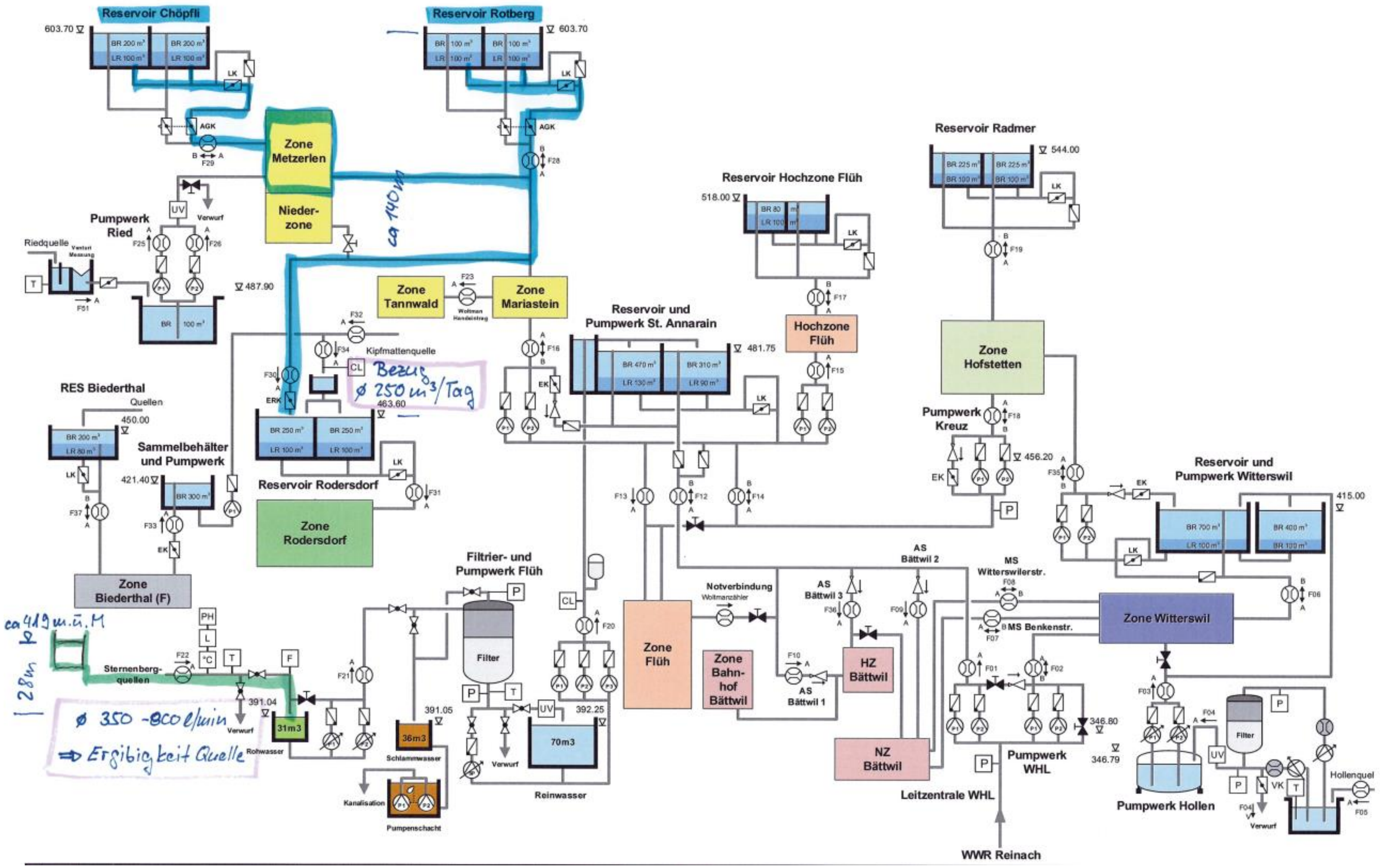
To perform an efficient and quick assessment of the potential of hydroelectric recovery in a distribution unit :

- **Simplify the network into sub-sectors, in function of the pressure levels**
- **Identify the existing pressure maintaining valves, generally between the pressure levels and upstream of the reservoirs.**
- **Assess the available manometric height and flow, both in quantity and in variability**



Hydroelectricity - phase 1 : example

Synopsis

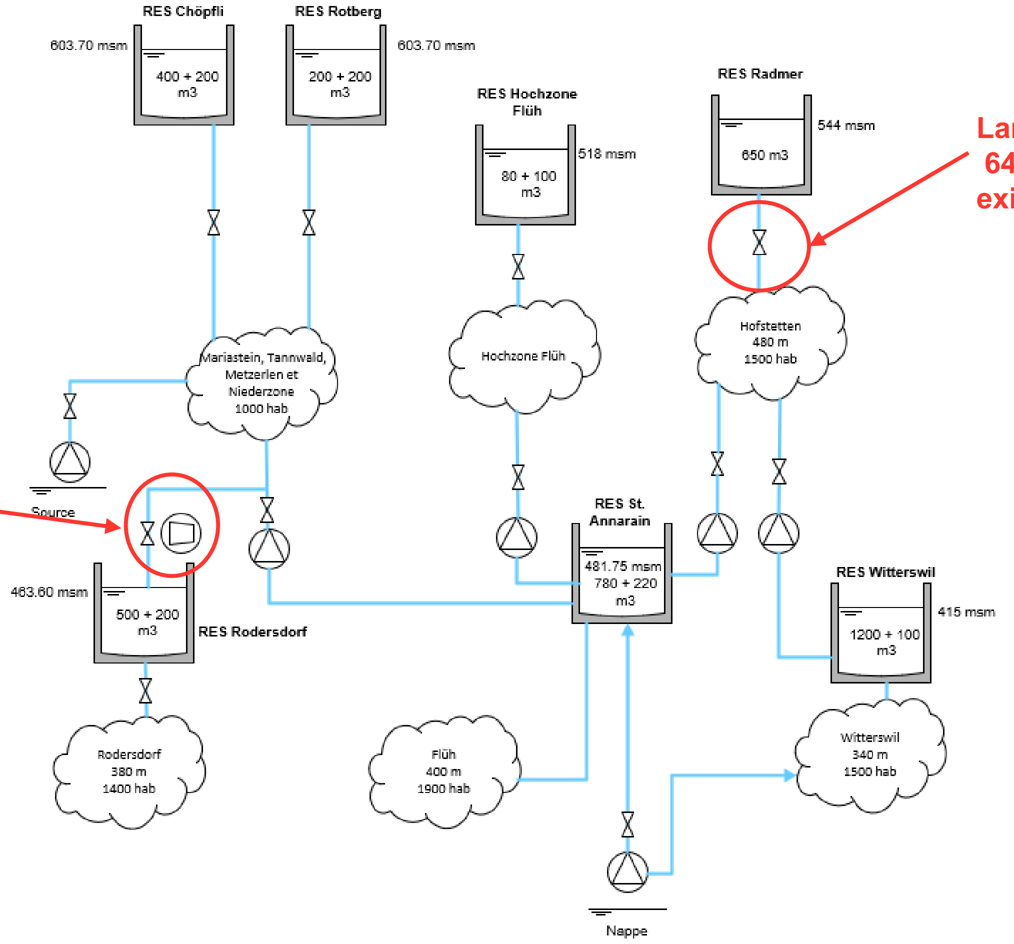


Hydroelectricity - phase 1 : screening example

Simplified synopsis

Identification of potential head drops

Existing pressure reduction



Large reservoir, 64m drop, existing valve

Hydroelectricity - phase 1 : estimation of potential

Estimation of potential :

Available :

- Qj = 250 m^3/day(2.8 l/s)
- H = 140 m

Micro-pelton offer :

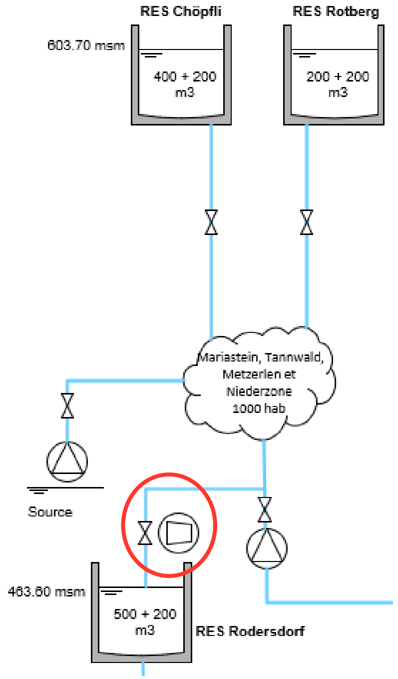
- Qj = 250 m3/day (2.8 l/s)
- Head drop = 130 m
- Efficiency 50%
- P = 2 KW

Producible :

- Constant flow, machine efficiency ~ 70 %
- Production : 17’500 kWh / year

Financial return if valued at 30 ct./KWh

- Income → 5.2 kCHF par year (excluding maintenance)
- Valorised over 20 years, the budget mustn't exceed 72 000 CHF



Hydroelectricity - phase 2 : Feasibility, budget

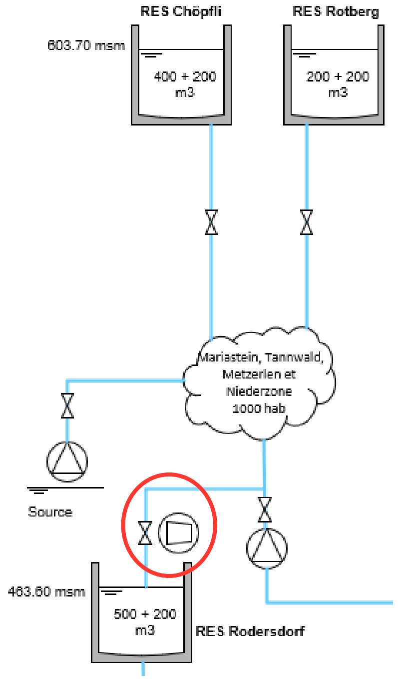
Cost estimation

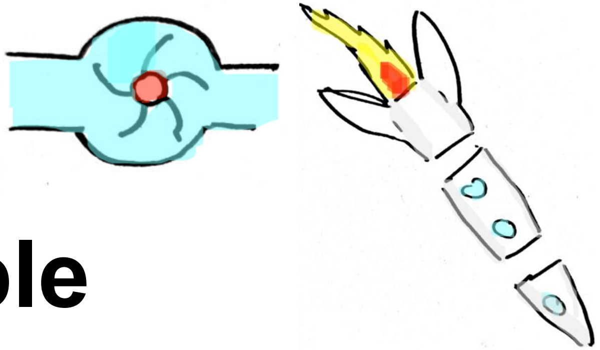
Autonomous :

Description des coûts avec mention du lot de travail	Prix à l'unité* [CHF] / Tarif horaire* [CHF/h]	Nombre [-] / Charge de travail [h]	Coûts [CHF]
Turbine, régulateur	15 188	1	15 188
Vanne d'isolation	1 000	1	1 000
Plue-value tuyauterie + GC Bassin	35 000	1	35 000
Connexion électrique	2 500	1	2 500
Taxe de raccordement réseau électrique	4 000	1	4 000
Honoraires sur équipements	10%	57 688	5 769
			63 457
		Cost/kWh	**0.27**

Connected to network :

Description des coûts avec mention du lot de travail	Prix à l'unité* [CHF] / Tarif horaire* [CHF/h]	Nombre [-] / Charge de travail [h]	Coûts [CHF]
Turbine, régulateur, raccordement	26 160	1	26 160
Vanne d'isolation	1 000	1	1 000
Plue-value tuyauterie + GC Bassin	35 000	1	35 000
Connexion électrique	2 500	1	2 500
Taxe de raccordement réseau électrique	4 000	1	4 000
Honoraires sur équipements	10%	68 660	6 866
			75 526
		Cost/kWh	**0.32**





Hydroelectricity - phase 3 : project example

TUNE
Turbine for Urban NEtwork

Hes·so Valais Wallis
Haute Ecole d'Ingénierie
Hochschule für Ingenieurwissenschaften

BG WSP

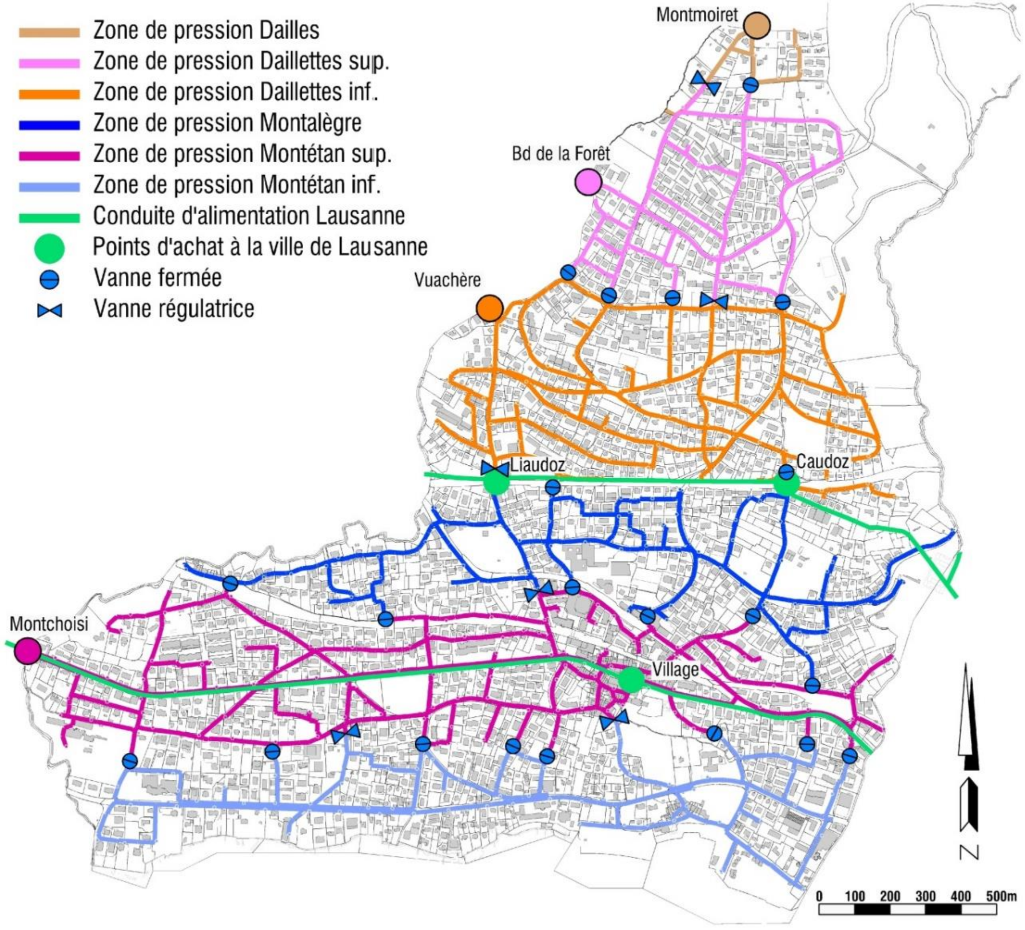
CLA-VAL

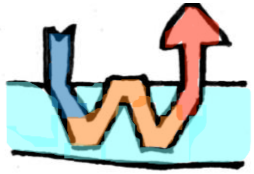
Ville de Pully

FOWA
Forschungsfonds Wasser
Fonds de recherche pour l'eau

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Office fédéral de l'énergie OFEN





Thermal energy

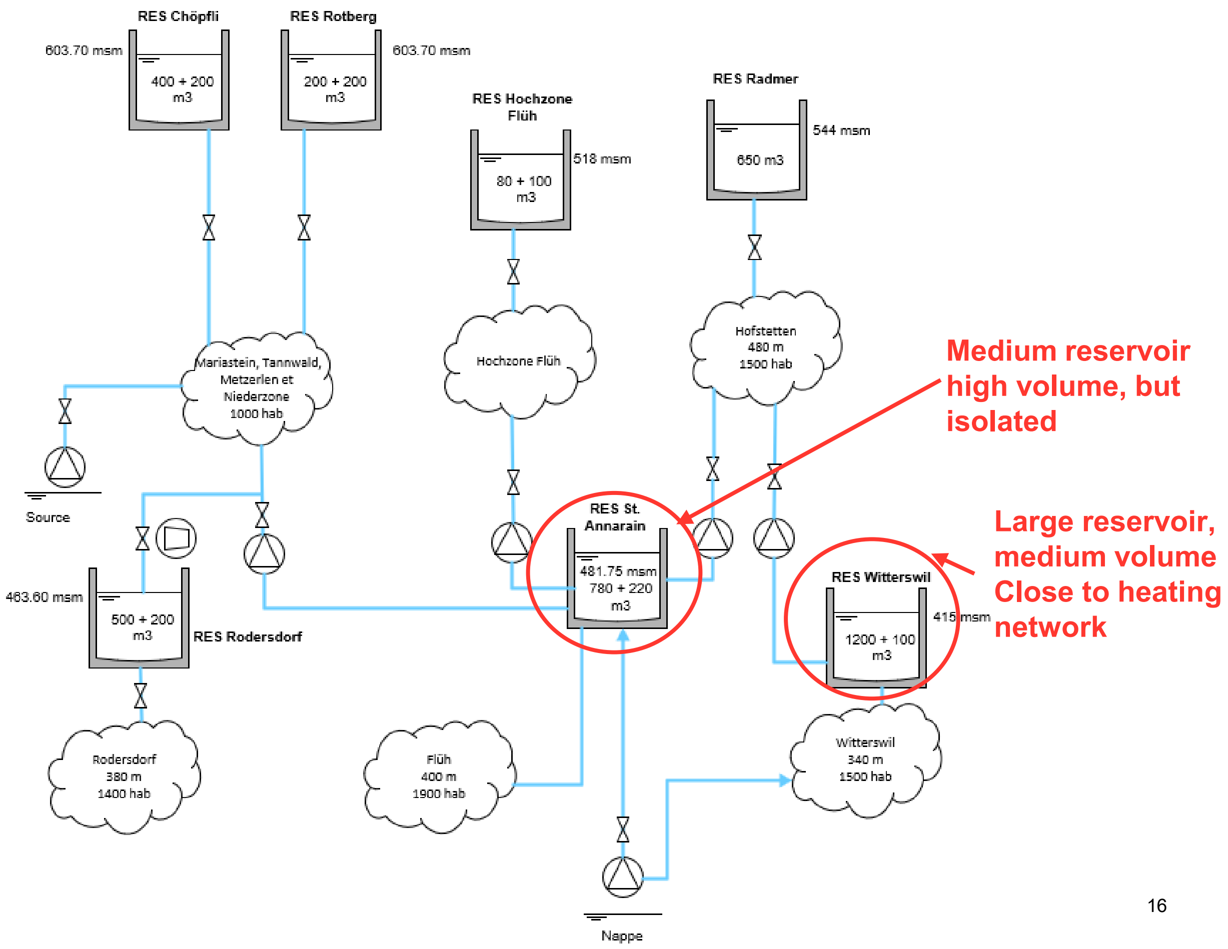
Thermal energy can be used both for cooling and heating

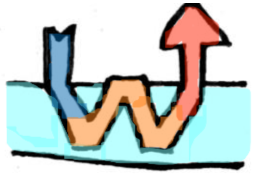
- **Heating :**
  - The cooling must remain reasonable for the final user, usually a few °C
  - A decrease in temperature is generally favourable for water quality
  - Best conditions : moderate temperature water in winter (deep sources…)
- **Cooling :**
  - Increase in temperature must avoid all sanitary risk.
  - Best conditions : cold water in summer (spring, deep in a lake).
- **Thermal exchanges (with the ground) upstream in the network reduce the impact of heat withdrawal → can be modelled if necessary**

Thermal energy– phase 1

Screening process :

- **Identify existing reservoirs and estimate their renewal rate**
  - The higher the transiting volume is, the higher the calorific potential
- **Identify if a thermal energy network exists or is planned nearby and estimate the mean production cost of heat**
  - The higher the costs of heat production on the heating network, the more the water resource can generate savings



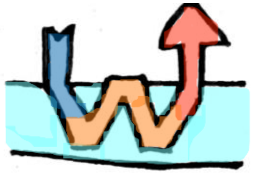


Thermal energy – phase 1, estimation of potential

Recoverable thermal energy with a heat exchanger in a reservoir : Eth (Wh/d)= $V * Cp * \Delta T * \eta = q * X * Cp * \Delta T * \eta$

- **q** = mean provision of water per inhabitant per day = 0.15 *m^3/d/hab* (estimation)
- **Cp** = thermal capacity of water Cp = 1.16 *kWh/m^3/K*
- **ΔT** = temperature difference in reservoir : ΔT ~1 to 3 °
- **η** = efficiency of exchange system~ 0.8
- **X** = number of inhabitants served by the reservoir

Eth(X, ΔT) = $X * \Delta T * (q * Cp * \eta) \sim X * \Delta T * 0.15$ *m^3/d/hab* * 1.16 *kWh/m^3/K* * 0.8 **~ 0.17 * X * ΔT** *kWh / d*

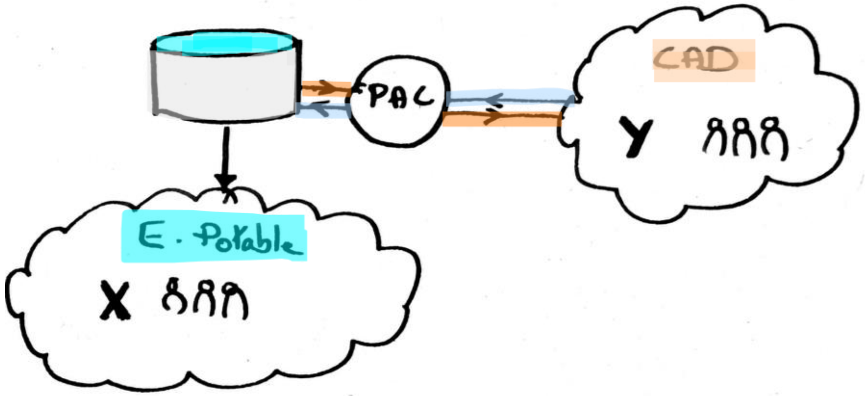


Thermal energy – phase 1, estimation of potential

Recoverable thermal energy with a heat exchanger in a reservoir

- ΔT =temperature difference in reservoir : ΔT ~1 to 3 °
- X = number of inhabitants served by the reservoir

Eth(X, ΔT) ~ 0.17 * X * ΔT *kWh / d*



Energy demand

- **Y :** Number of inhabitants served by the heating network
- d : annual demand in thermal energy per inhabitant : D = 1000 – 3000 *kWh/year/hab*
- Ca : ratio between peak demand (necessary power) and annual consumption : Ca ~3 to 5

Peak demand to provide : **Dth(Y)** = Y * d * Ca ~ Y *hab* * 2000 *kWh/year/hab /365 * 3* ~ **16 * Y** *kWh / d*

- pth: Valorisation of injected thermal energy (mean cost of production avoided) : 0.00 - 0.10 CHF/kWh

Potential max savings in *CHF/year* : **Gth(Y, ΔT, pth)** ~ Dth(Y)*365/Ca*pth ~ **1.3 * X * ΔT**

$$Y \leq \Delta T \frac{X}{100}$$

Thermal energy – phase 1, estimation of potential

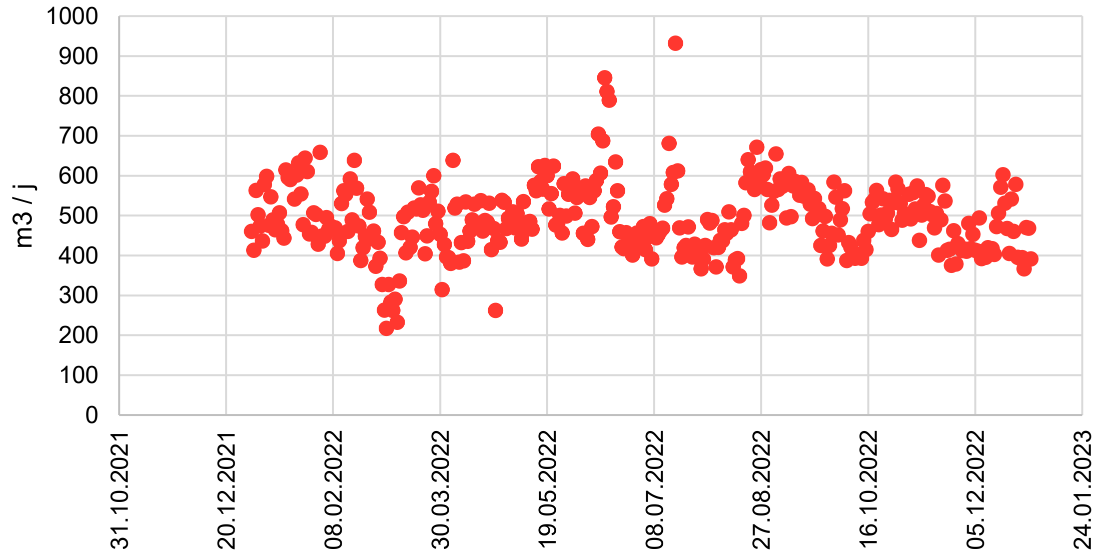
Example Witterswill

Available measurement series → mean daily volume : 490 m^3

- Δ**T** = 2°C
- Ca = 3
- pth = 0.08 CHF/kWh

→ E = 1 100 kWh/d

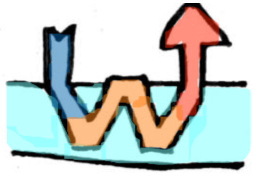
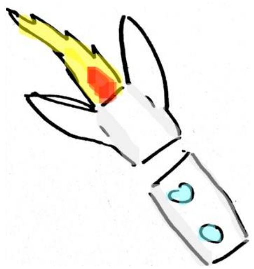
→ Valorisation of injected thermal energy : Gth ~ 8'000 CHF/year



- Δ**T** = 1°C
- Ca = 3
- pth = 0.04 CHF/kWh

→ E = 1 100 kWh/d

→ Valorisation of injected thermal energy: Gth ~ 2'000 CHF/year

Thermal energy – phase 2, feasibility

Example Witterswill

Available measurement series → mean daily volume : 490 m^3

- Δ**T** = 2°C
- Ca = 3
- pth = 0.08 CHF/kWh

→ E = 1 100 kWh/d

→ Valorisation of injected thermal energy : Gth ~ 8'000 CHF/year

Budget estimation

- CAPEX :
  - PAC : 40 kCHF
  - Work in the reservoir: 20 kCHF
  - Conduits and connection to heating network: 60 kCHF
  - Fees, miscellaneous and unexpected events : 30%
  - Budget ~150 kCHF
- OPEX : 2 + 1 k CHF/year
- ROI : ~ 30 years

Regulation → Optimisation of pumping costs

Aim of the reservoir :

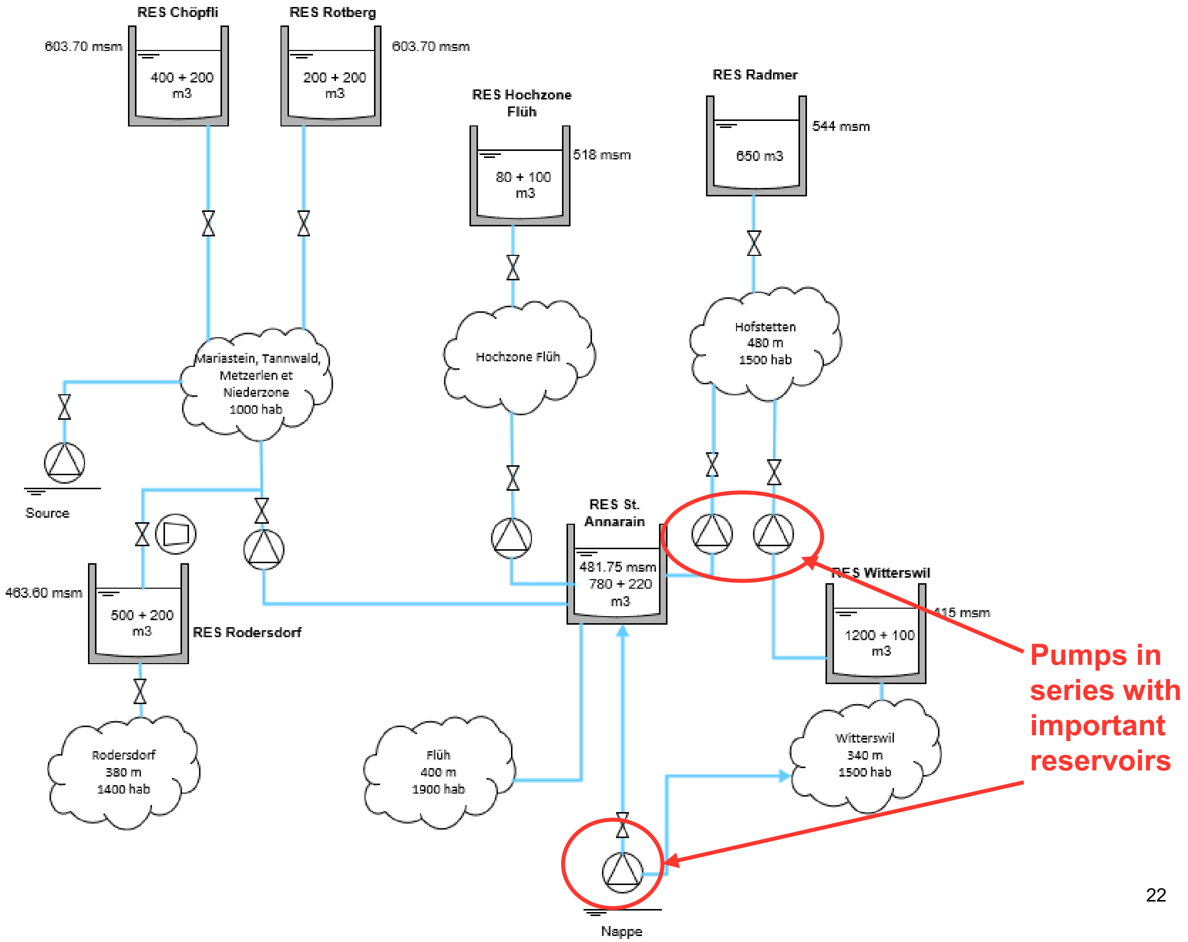
- **Absorb demand variation**
- **Allow a reduction of exploitation costs (minimise pumping when high energy cost)**
- **Insure the robustness of the distribution (storage)**
- **Insure the fire reserve**

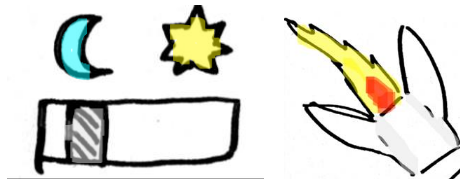
The allocation of volumes (portions) is a compromise between:

- **Storage : to cover a fault in the supply system**
- **Modulation : volume to distribute when the supply is reduced (pumps are stopped)**

Regulation– phase 1, estimation of potential

- Identify the (chains of) pumping stations between reservoirs or sources
- Of significant volume / capacity with regard to the daily provision
- Without (optimisation of the) modulation

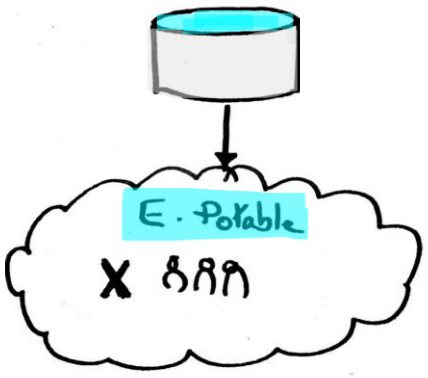




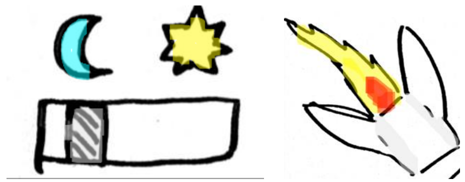
Regulation– phase 1, estimation of potential

Energy to pump a volume V m³ to a height H : E: $E\ (kWh/d) = \rho * g * V * H / \eta = \rho * g * q * X * H / \eta / 3.6*10^6$

- **ρ** = water density = 1000 *kg/m³*
- **g** = gravity = 9.81 *m/s²*
- **q** = mean provision of water per inhabitant per day = 0.15 *m³/d/hab* (estimation)
- **H** = head (in *m*)
- **η** = efficiency of pumping system = 0.6 - 0.8
- **X** = number of inhabitants
- **ΔC** = difference in electricity cost between day and night (*CHF/kWh*)
- **Cj** = ratio of daytime consumption over total consumption=0.7
- **Ca** = Yearly coefficient (periods of sub-optimisation, for example high consumption) = 0.9



Potential savings in *CHF/day* : **Gr(X, ΔC,H)** = ΔC * E * Cj * Ca **~ 0.0004** * **ΔC** * **X** * **H** *CHF/day*



Regulation– phase 1, estimation of potential

Example with :

- **H** = 100 *m*
- **X** = 5’000 *hab*
- **ΔC** = 0.10 *CHF/kWh*

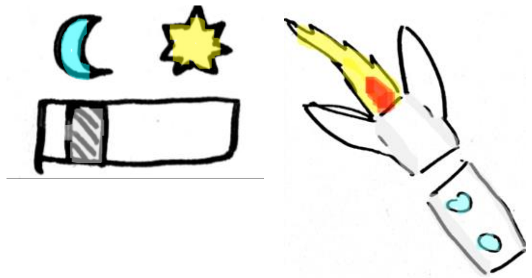
Financial gain in *CHF/year* : $Gr(X, \Delta C, H) = \Delta C * X * H * \alpha = 0.10 * 5000 * 100 * 0.0004 * 365$ = 7300 CHF/year

With :

- **H** = 50 *m*
- **X** = 1’000 *hab*
- **ΔC** = 0.10 *CHF/kWh*

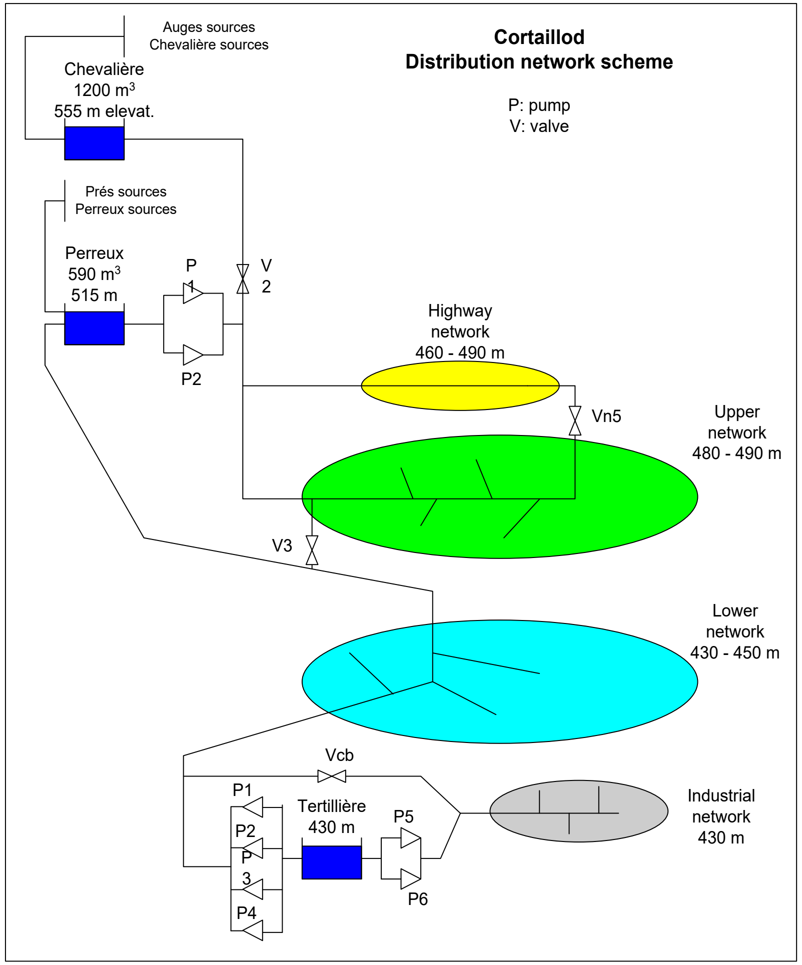
Financial gain in *CHF/year* : $Gr(X, \Delta C, H) = \Delta C * X * H * \alpha = 0.10 * 1000 * 50 * 0.0004 * 365$ = 2 CHF/j = 730 CHF/year

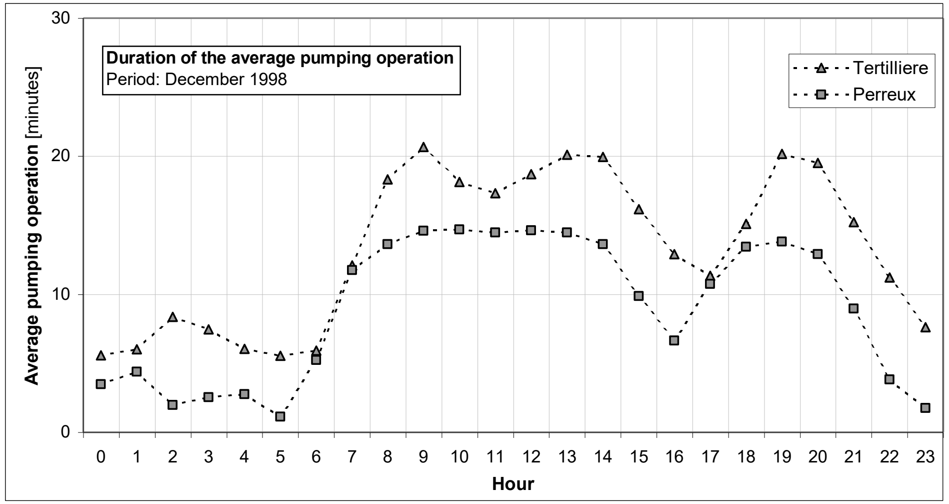
Regulation– phase 2, Real conditions



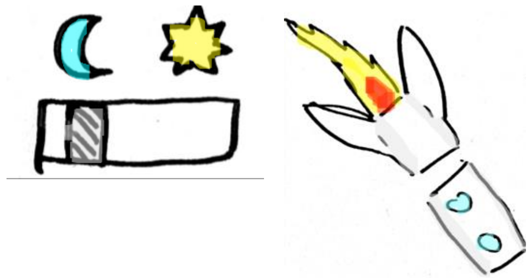
Example 2 :

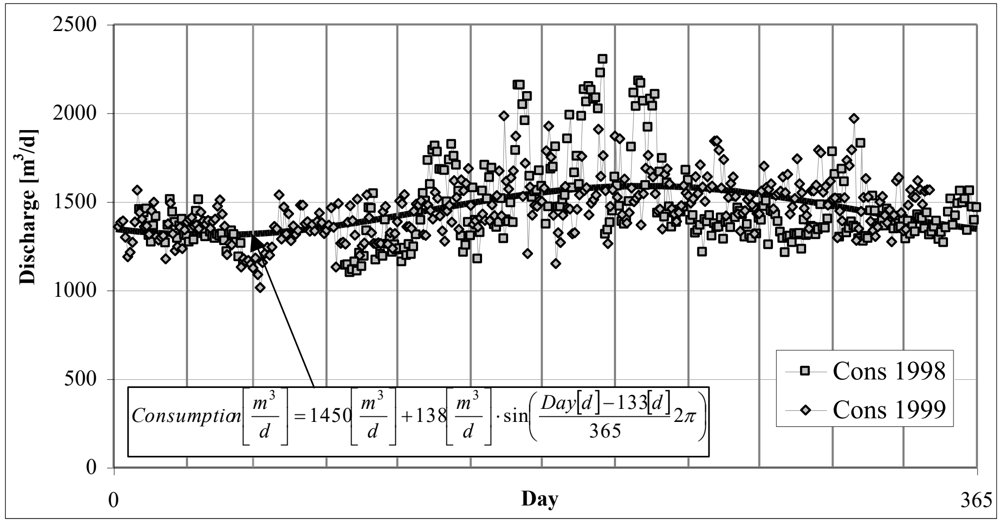
- **Network with supply above and below**
- **Pumping not optimised**
- **Volume of reservoirs… medium (in the order of magnitude of the daily consumption volume)**





Regulation– phase 2, Real conditions

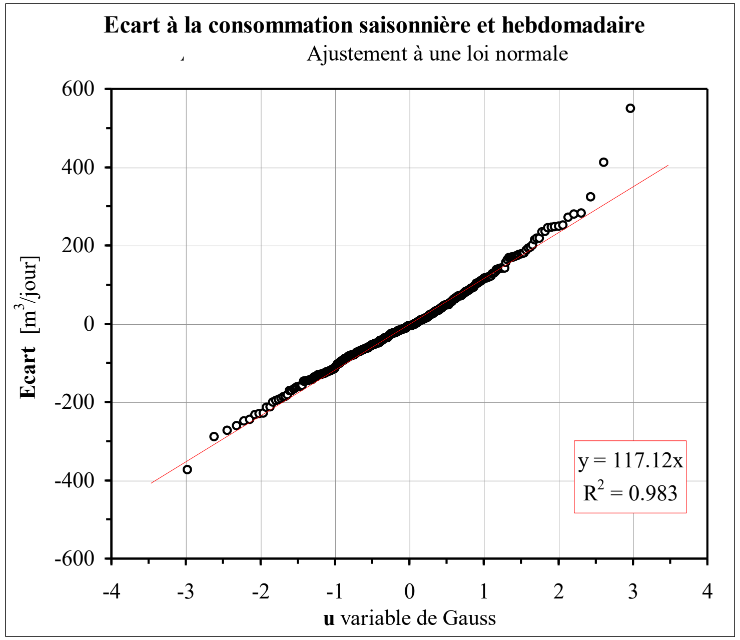




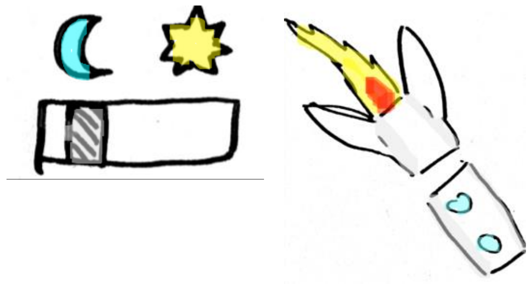
Example 2 :

- **Analysis of the consumption**

→ simple statistical model

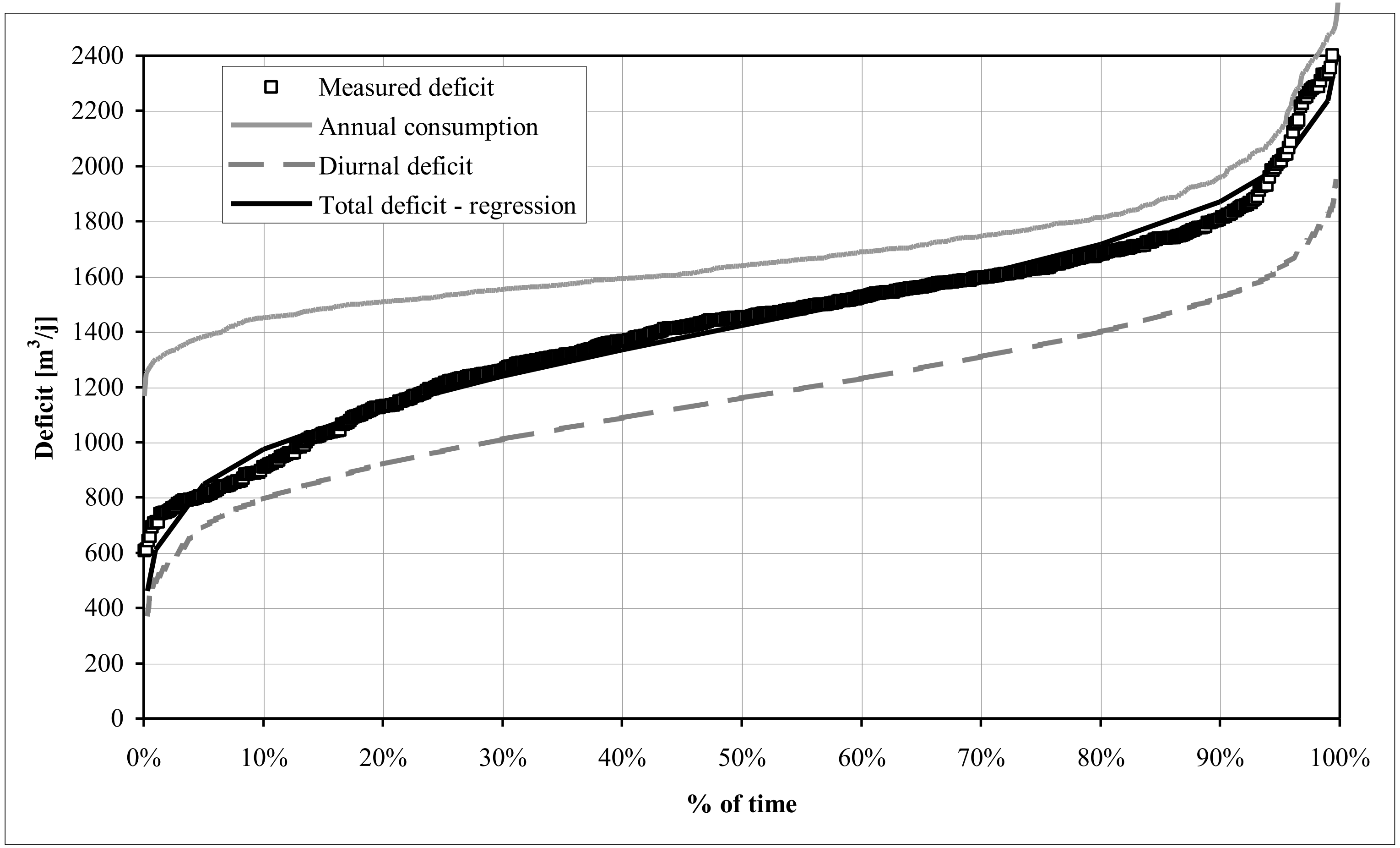


Regulation– phase 2, Real conditions



Example 2 :

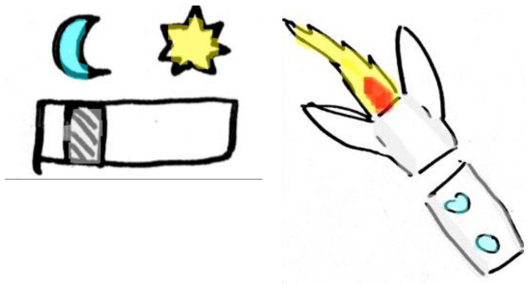
- **Analysis of daily deficit (to be provided by the pumping system)**

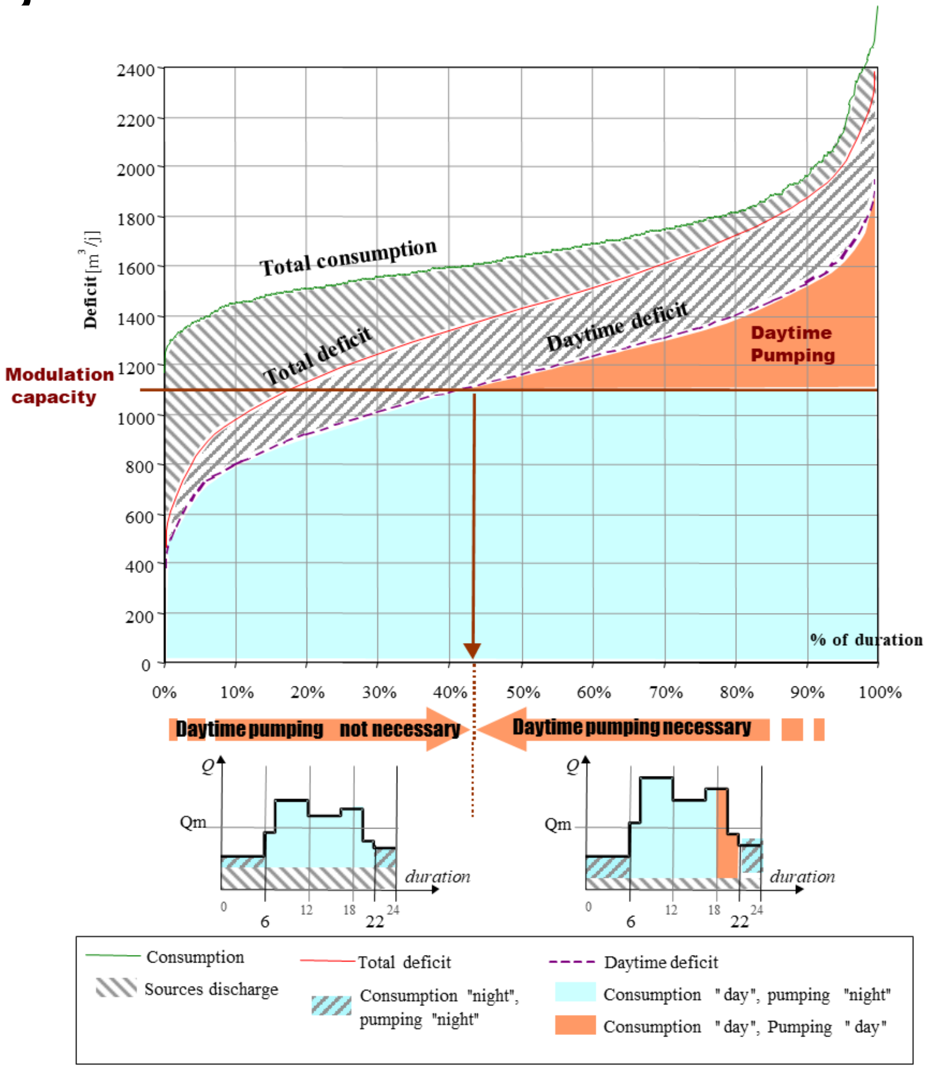


Regulation– phase 2, Real conditions

Example 2 :

- **Analysis of modulation : general principle**

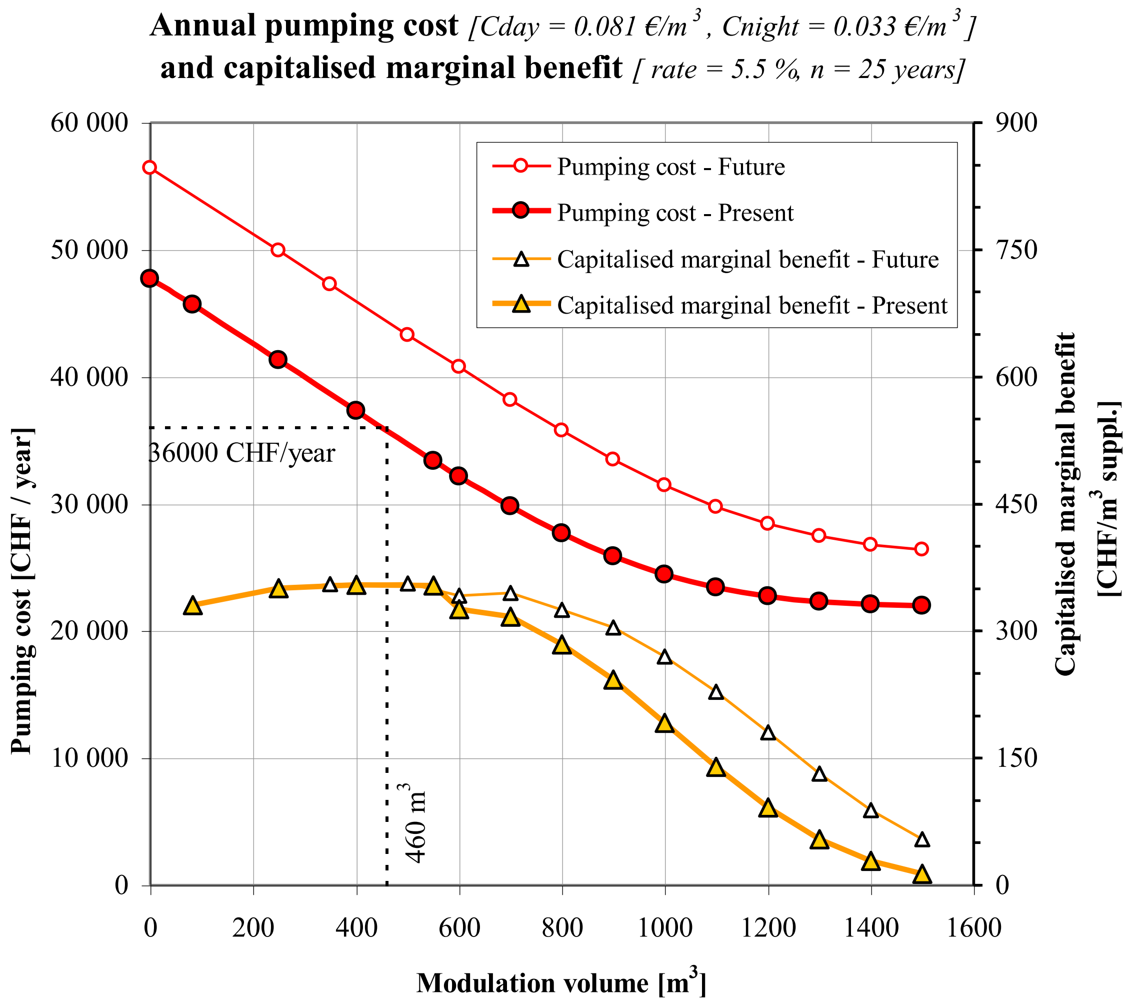


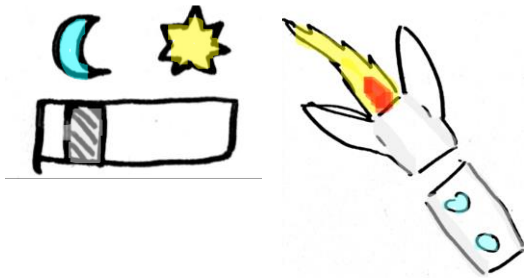


Regulation– phase 2, Real conditions

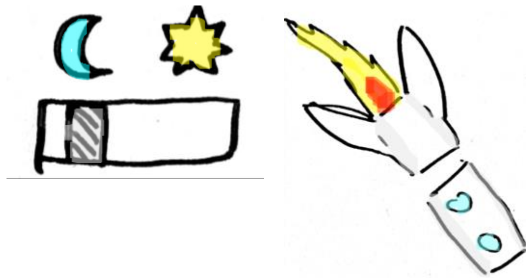
Example 2 :

- **Analysis of modulation : Results**
- **Savings in function of the modulation volume**



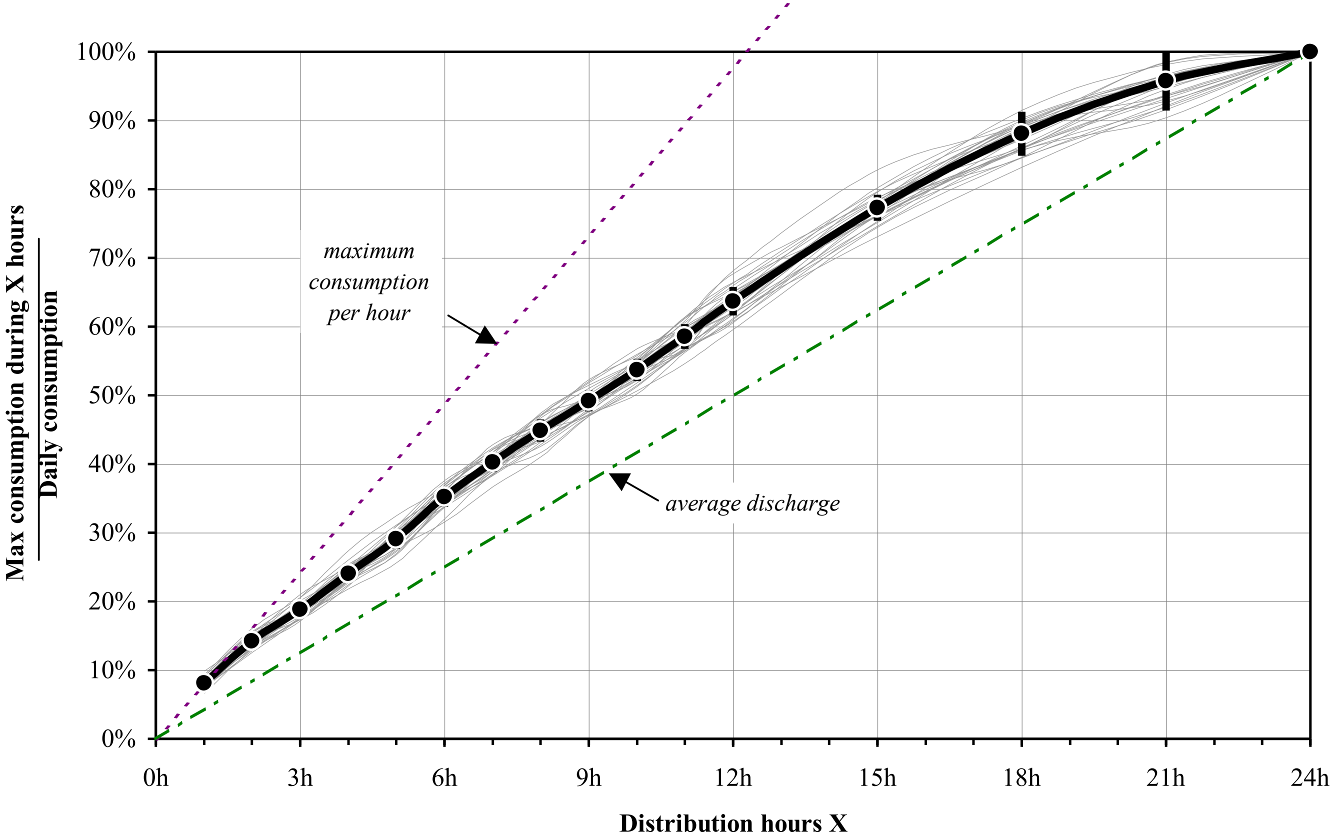


Regulation– phase 2, Real conditions

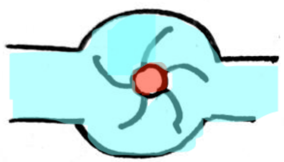
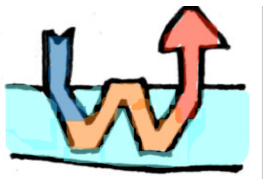


Example 2 :

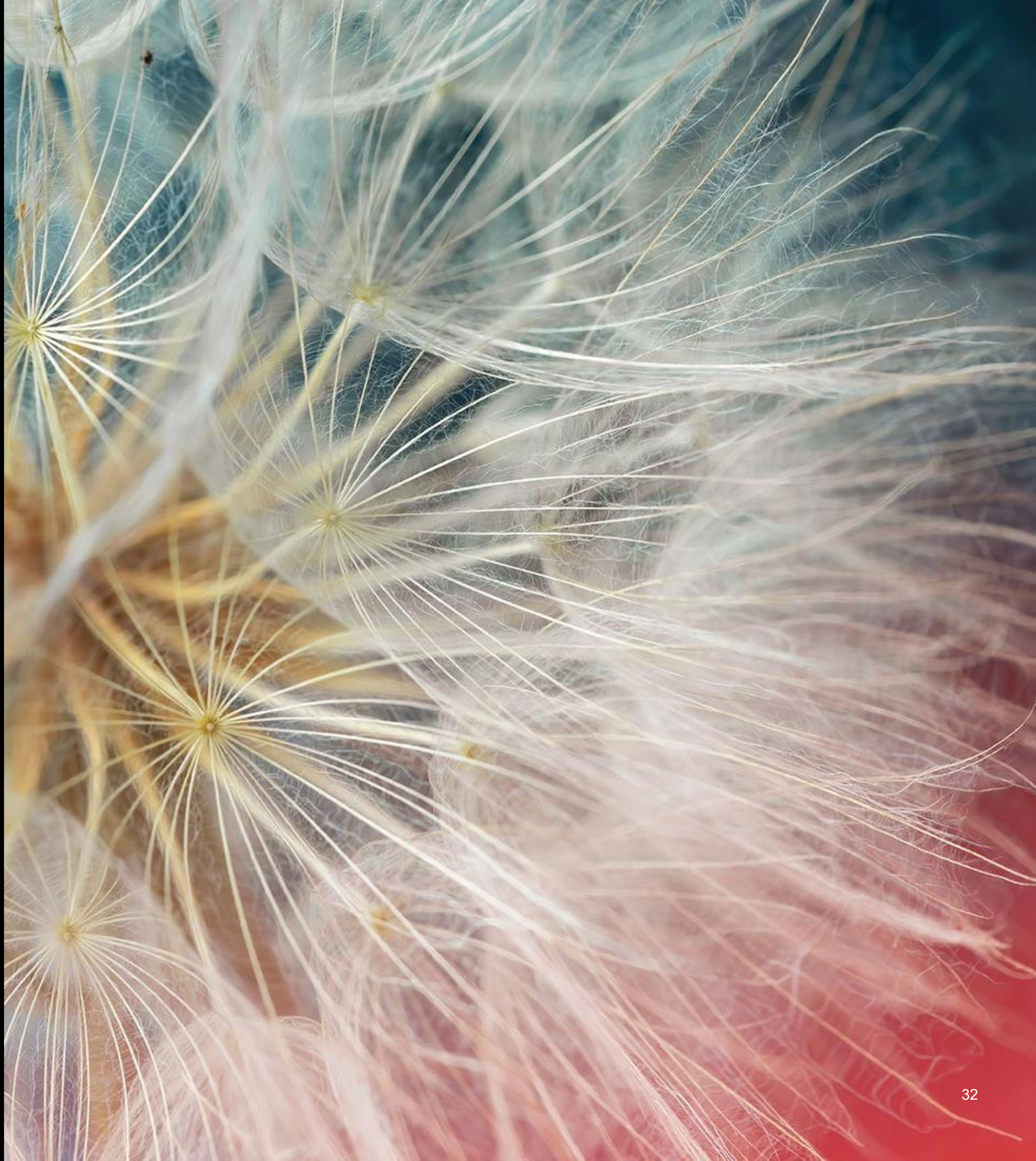
- **Analysis of storage and duration of guaranteed provision**
- **Allow decision making for allocated volumes between:**
  - Reserve portion
  - Modulation portion



Synthesis

	 Hydroelectricity	 Thermal energy	 Regulation
Network conditions	Existence of pressure reduction valves (between pressure districts or at reservoir entrance)	Reservoir (or master conduit with continuous flow)	Modulated energy prices Pumping level with storage capacities available upstream and downstream
Interesting if ..	More than a few thousand inhabitants (3'000 to 5'000) served downstream AND Headrop as big as possible (suggested min 3 bar)	Consequent necessary volumes Close heating network and "small" compared to AEP system	Sufficient storage capacities to allow modulation Sufficient pumping capacity to concentrate pumping in off-peak hours
Magnitude of the cost of a small installation	100 kCHF	100 kCHF	10 kCHF
Typical ROI	20 years	?	1 year

THANK YOU



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