Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

5 ETCS, Master course

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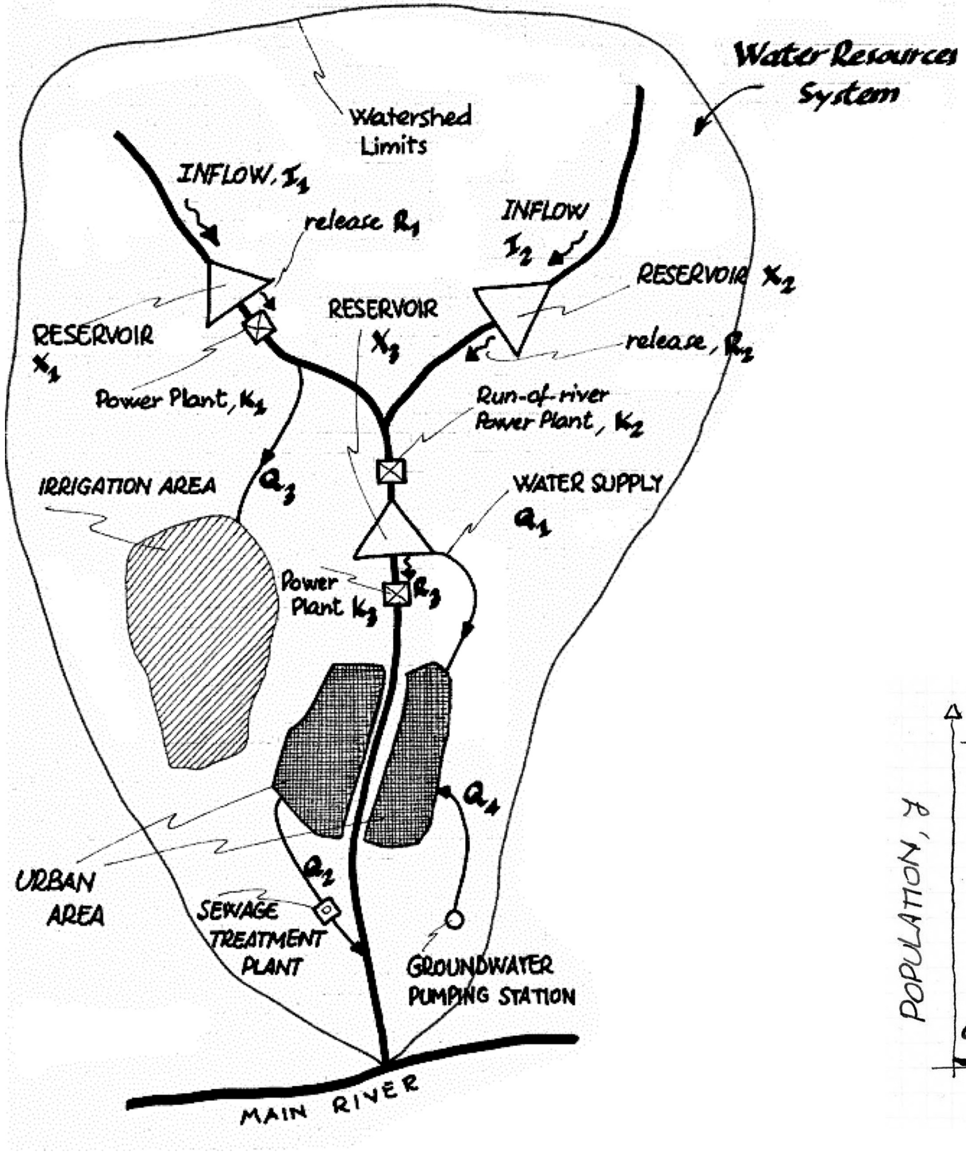
Platform of hydraulic constructions

Lecture 4-2 Water uses: domestic and industrial uses, population dynamics and emergency supply

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

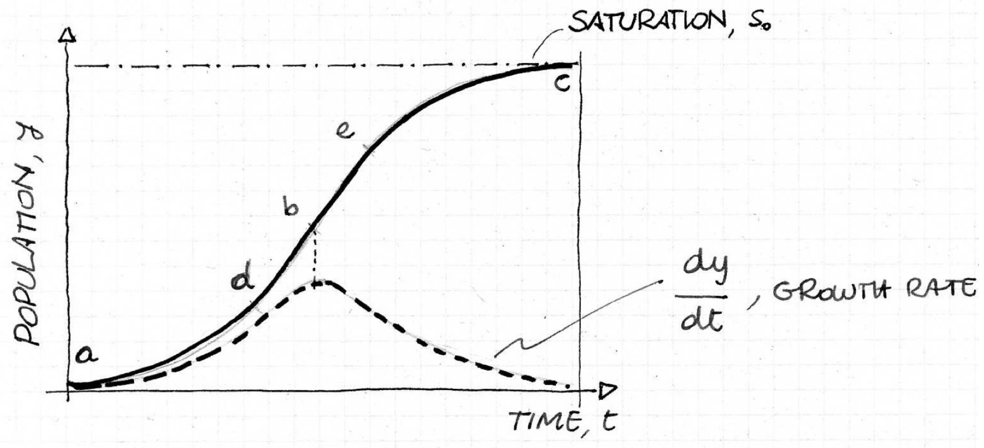
Traditional water uses: water demand for domestic and industrial uses

Some typical questions: drinking water supply



What is the amount of water required to satisfy the drinking water needs of an urban area?

How can this be projected into the future?



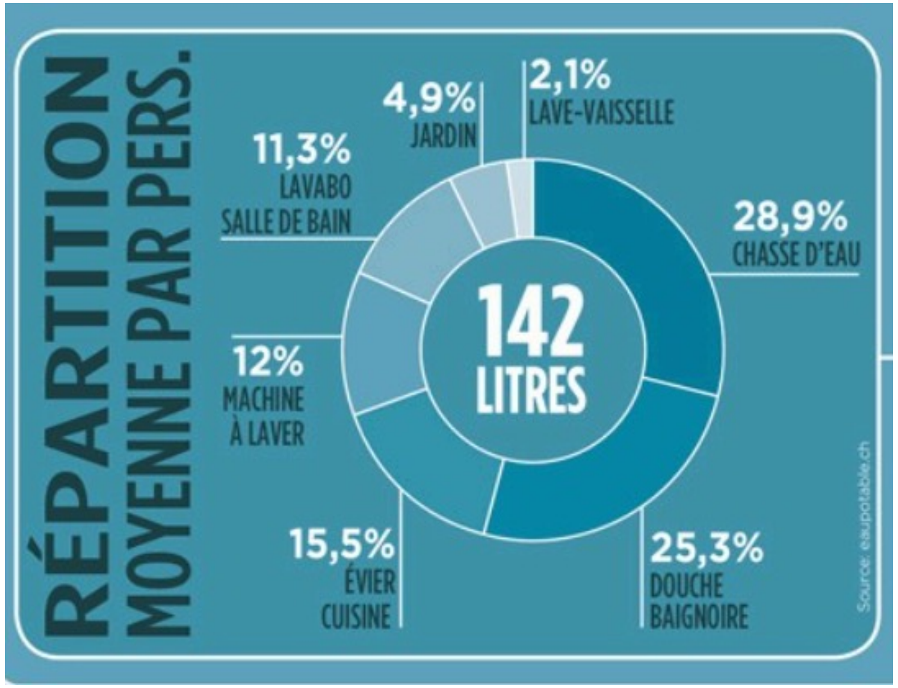
Public and domestic use in Switzerland

In the greater Lausanne area, daily per capita consumption varies between 210 and 400 liters of water per day and per inhabitant.

These are "rough estimates" that take into account the different types of consumption such as

- household consumption
- industrial consumption
- consumption of market gardeners
- consumption of hospitals
- etc.

In Switzerland, household water consumption amounts to 52000 liters per person each year (or 142 liters per day).



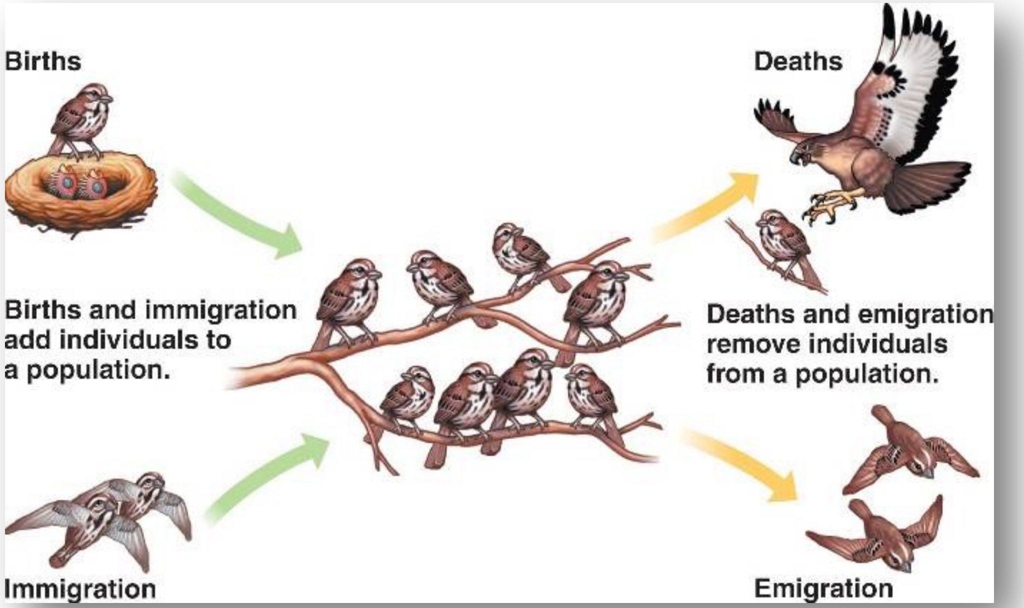
Domestic and industrial uses

Demand for water supply is (in theory) based on the analysis of population growth and the expected daily consumption per-capita

Q_t [l/day] = q·X

Where X is population size [No of persons] and q [l/day person] is the per-capita consumption, which depends on regions and country habits

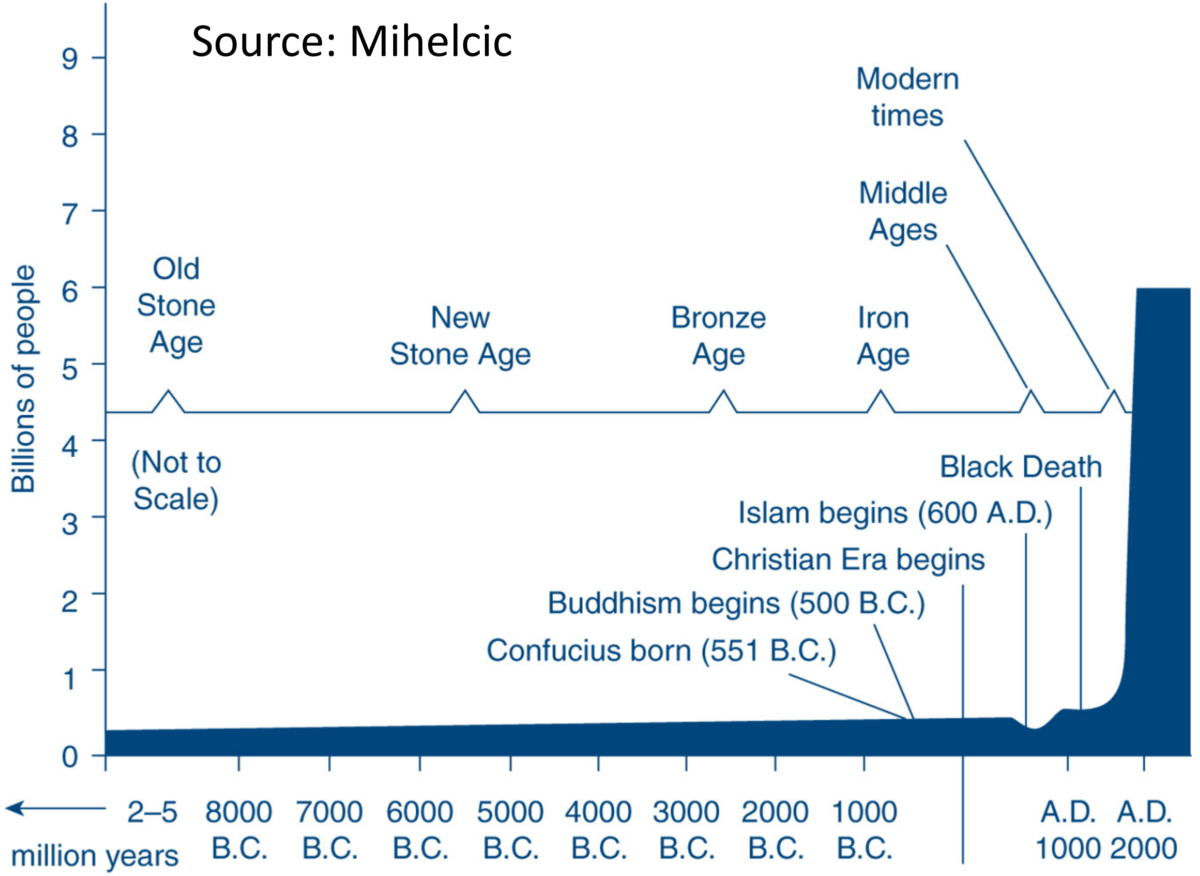
Population dynamics models have the form of balance equations



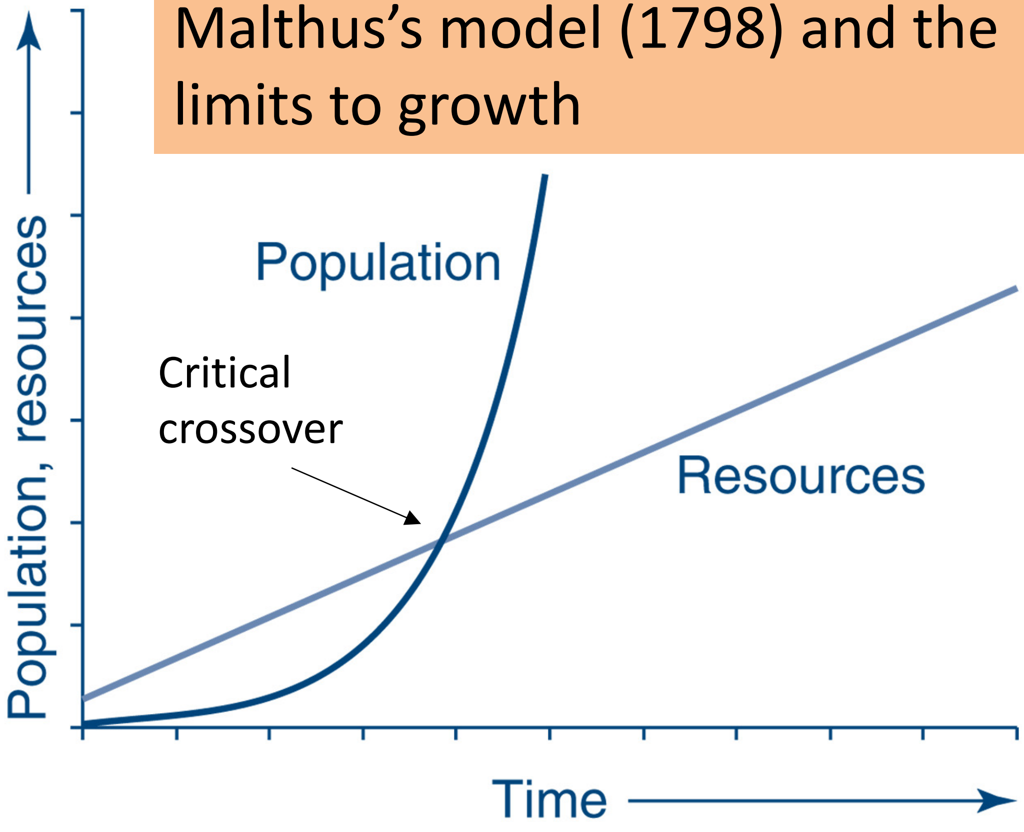
Mass balance equation for population dynamics

$$\frac{dX}{dt} = f_{births}(X) - f_{deaths}(X) \pm reaction$$

Human population growth over time



Malthus's model (1798) and the limits to growth



18th Century prediction:
"If resources grow less than exponentially, then it would only be matter of time until demand outstripped supply with catastrophic consequences"

However, this did not happen so far. So, what's was wrong with Malthus' idea?

Exponential or unlimited growth model

$$\frac{dX}{dt} = \mu_{\max} X$$

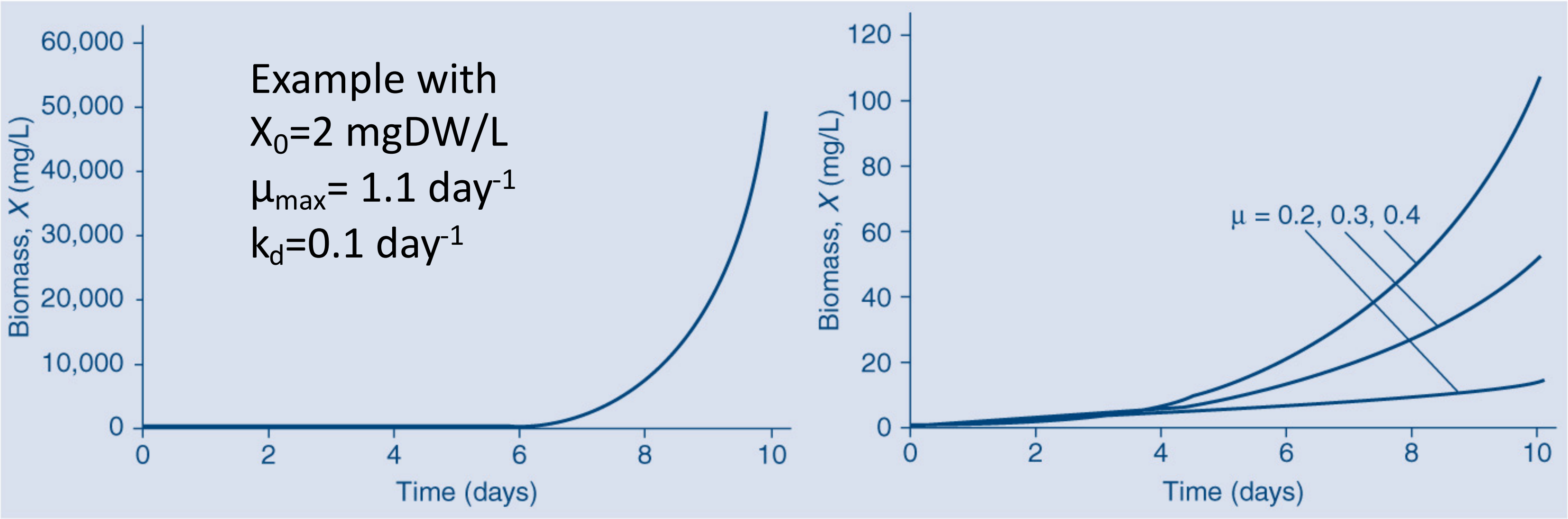
$$\frac{dX}{dt} = -k_d X$$

e.g., energy cost for respiration

$$\frac{dX}{dt} = (\mu_{\max} - k_d) X$$

Useful for many organisms, from bacteria to humans, with unlimited energy resources

This model is useful for short-terms prediction horizon T (e.g., for human population growth is usually accurate for T <10 years



Example with
X_0=2 mgDW/L
μ_{max}= 1.1 day^{-1}
k_d=0.1 day^{-1}

(a) (b)

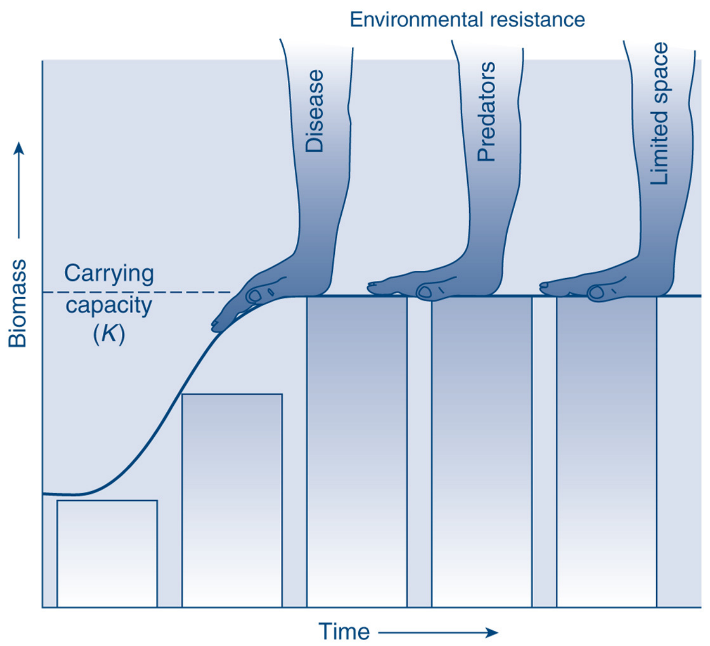
Logistic growth model: the effect of carrying capacity

$$\frac{dX}{dt} = (\mu_{max} - k_d)\left(1 - \frac{X}{K}\right)X$$

Useful to describe environmental resistance to grow (Verhulst model)

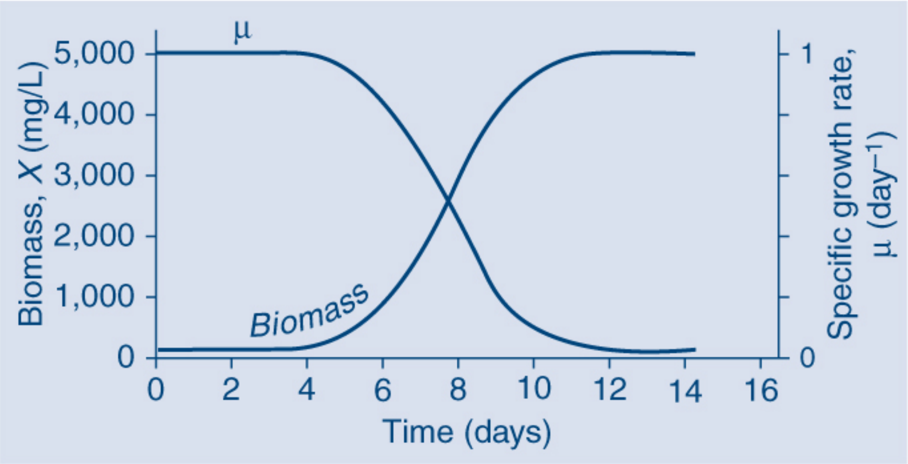
K is called the carrying capacity

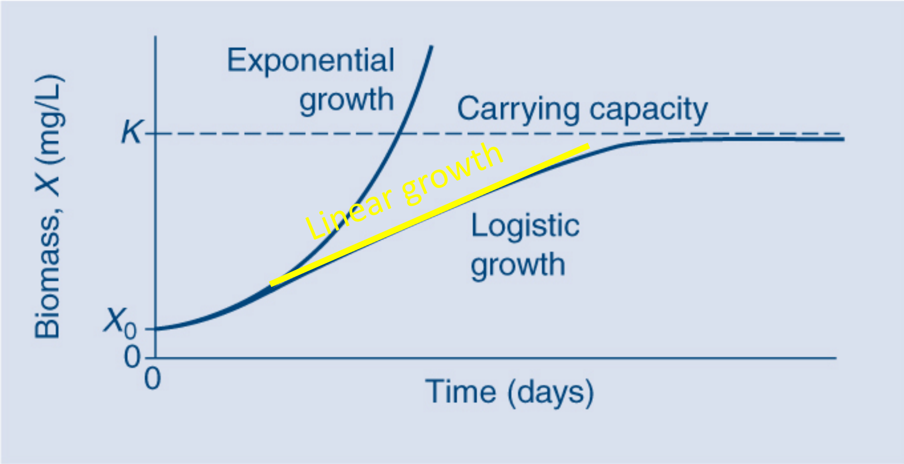
NOTE: there is a similarity with the logistic map, but this is a continuous model -> no CHAOS!



$$X(t) = \frac{K}{1 + \left[\left(\frac{K - X_0}{X_0}\right)e^{-(\mu_{max} - k_d)t}\right]}$$

Analytical solution





Public and domestic water needs

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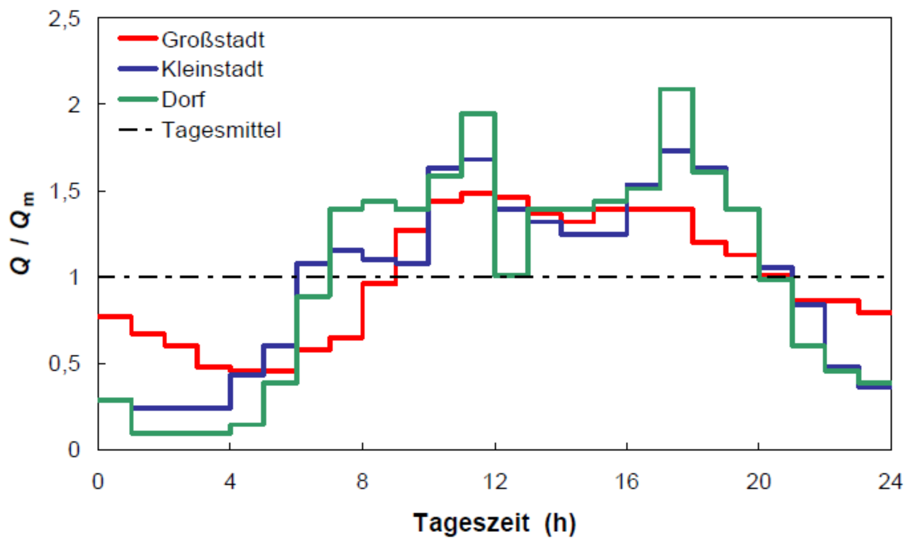
Water demand typically changes along the day and along the year.
The range of fluctuations depends on the number of persons served (high number implies smaller fluctuations and vice-versa)

Hourly domestic water consumption



Source: TU Dresden, Prof. Krebs

$$Q_t\ [l/day] = q \cdot X$$

In practice, we need to account for a number of factors and extra uses, so that the formula becomes

$$Q_P = K_s \,.\, K_t \,.\, K_p \,.\, (K_{day} \,.\, q \,.\, X + Q_i)$$

Q_p : required flowrate
K_s : losses between source and treatment (1.04 to 1.05)
K_t : losses at the treatment (1.06 to 1.10)
K_p : losses in the network (1.10 to 1.60)
K_{day}: variation of the average daily demand (1.3 to 1.8) (average flow of the peak day/average annual flow)
q : specific demand (25 to 400 l/d/capita)
X : number of inhabitants in the future
Q_i: fire reserve

Emergency water demand for fire fighting (can be estimated based on the type of buildings, the material and the distance among them).

Industrial use

For the industrial use, in general one can consider

$$Q_p = (Q_n - Q_r) + Q_{te} + Q_c$$

Q_p : flow taken or to be provided
Q_n : characteristic water requirement, which depends on
- number of inhabitants and expected consumption per inhabitant
- volume of industrial production and type of production

Q_r: recycled flow inside the industrial plant
Q_{te}: flow for own needs for treatment and washing of the networks
Q_c: losses (infiltration, leakage, evaporation)

Water demand must be estimated not only for present conditions but accounting also for the future development of the served area.

Typical Distribution of Water Demand

Category	Average use (liters/day)/person	Percent of total
Residential	380	56
Commercial	115	17
Industrial	85	12
Public	65	9
Loss	40	6
Total	685	100

Design periods and capacities in water-supply systems

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Component	Design period (years)	Design capacity
1. Source of supply:		
River	indefinite	maximum daily demand
Wellfield	10–25	maximum daily demand
Reservoir	25–50	average annual demand
2. Conveyance:		
Intake conduit	25–50	maximum daily demand
Conduit to treatment plant	25–50	maximum daily demand
3. Pumps:		
Low-lift	10	maximum daily demand, one reserve unit
High-lift	10	maximum hourly demand, one reserve unit
4. Treatment plant	10–15	maximum daily demand
5. Service reservoir	20–25	working storage plus fire demand plus emergency storage
6. Distribution system:		
Supply pipe or conduit	25–50	greater of (1) maximum daily demand plus fire demand, or (2) maximum hourly demand
Distribution grid	full development	same as for supply pipes

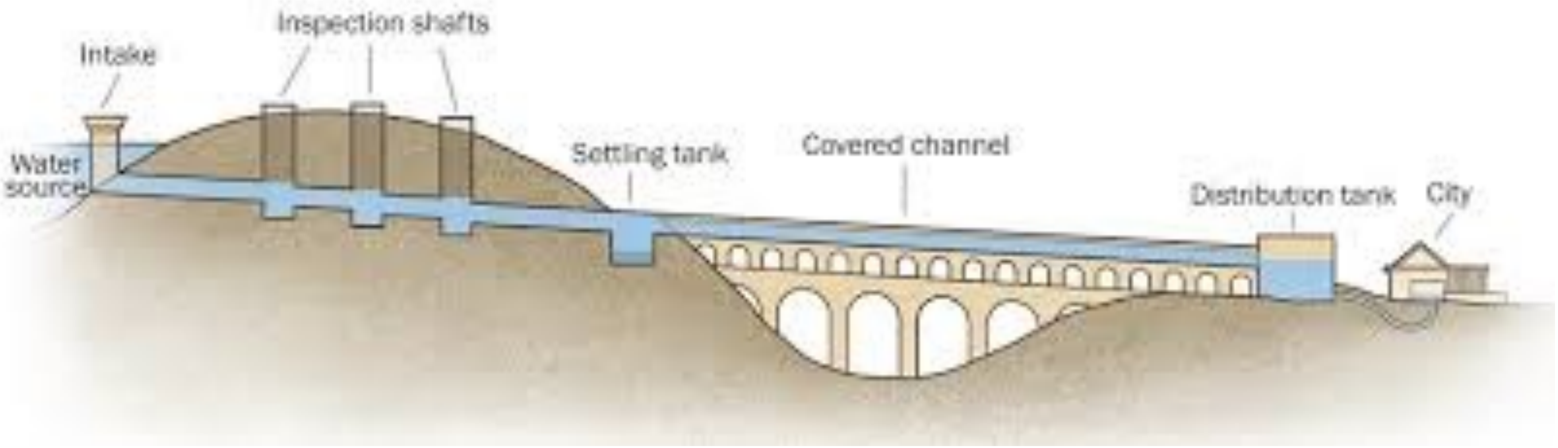
Low-lift pumps: form source to service reservoir

High-lift pumps: pressure boosters in the distribution network

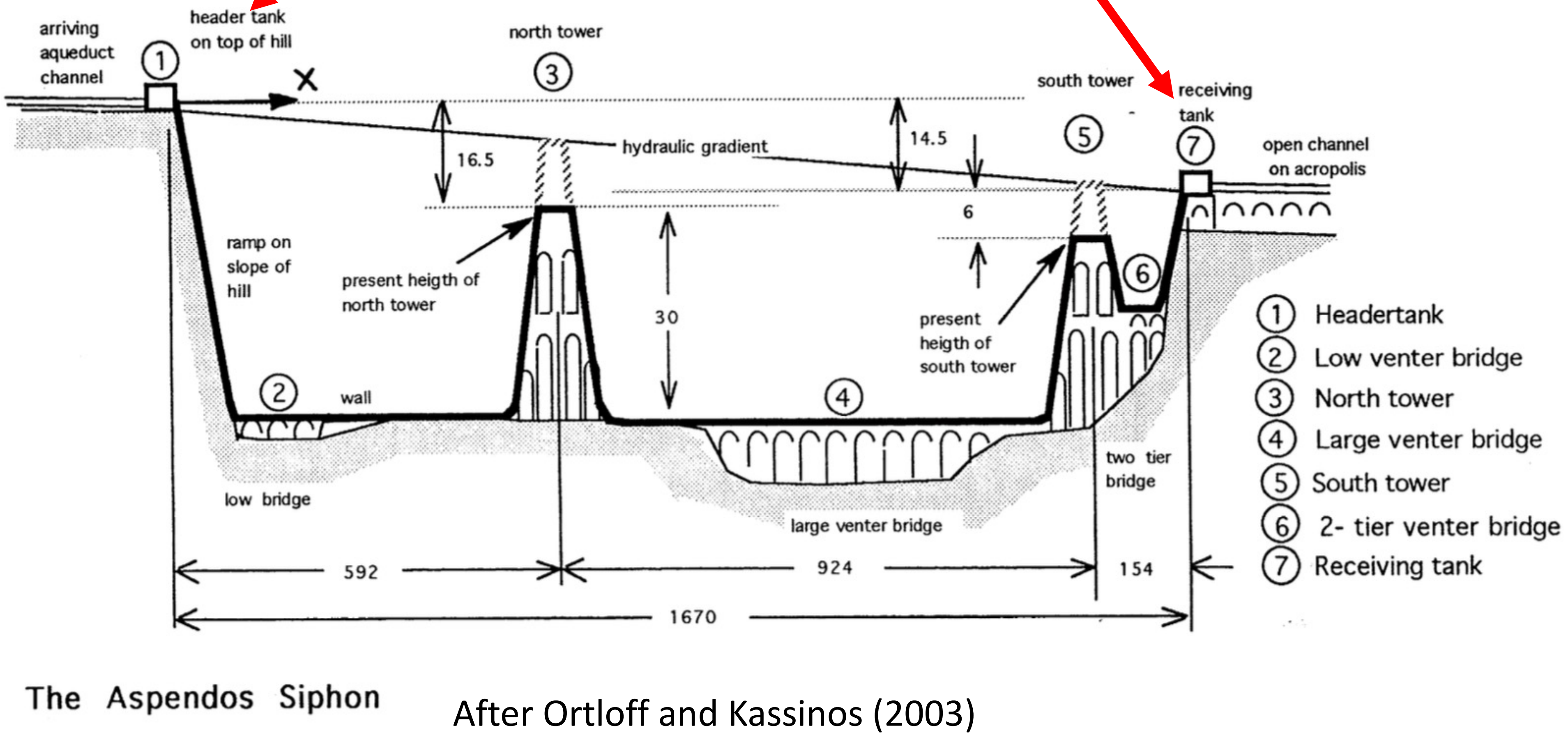
Water distribution network

Aqueduct systems

Pipe networks are part of aqueduct systems



- Height difference between 1 and 7 must provide enough energy to overcome friction in all the pipes and fittings
- Provided it does so, the water will flow, including on the up hill sections



After Ortloff and Kassinos (2003)

Conveyance through pipe networks

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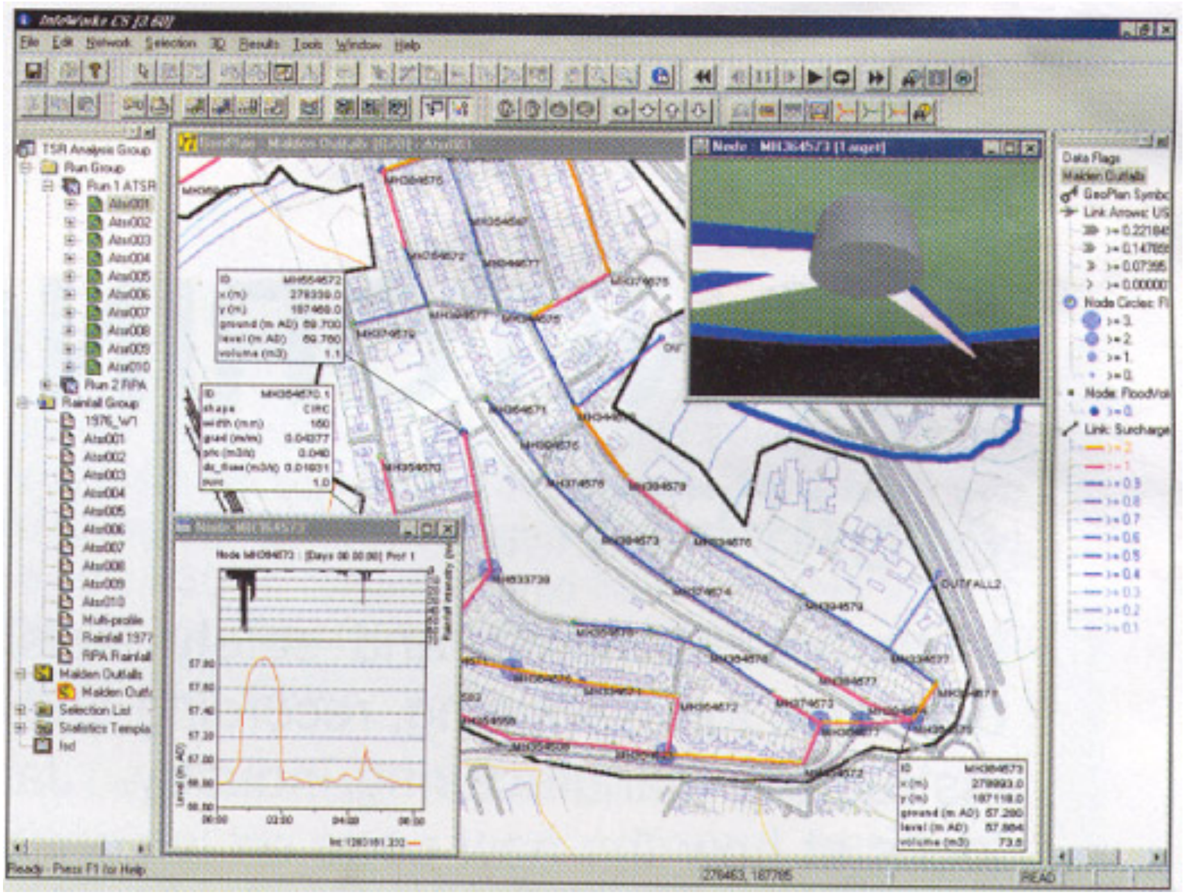
- In civil engineering applications pipes generally exist not singly but in systems of increasing complexity:
  - Pipes in series with other pipes of different properties such as diameter
  - Pipes in parallel with other pipes
  - Branched pipe systems
  - More complex networks
  - Pump-pipe systems

- The figure aside shows an example of water distribution networks in a model giving an idea of the complexity involved.



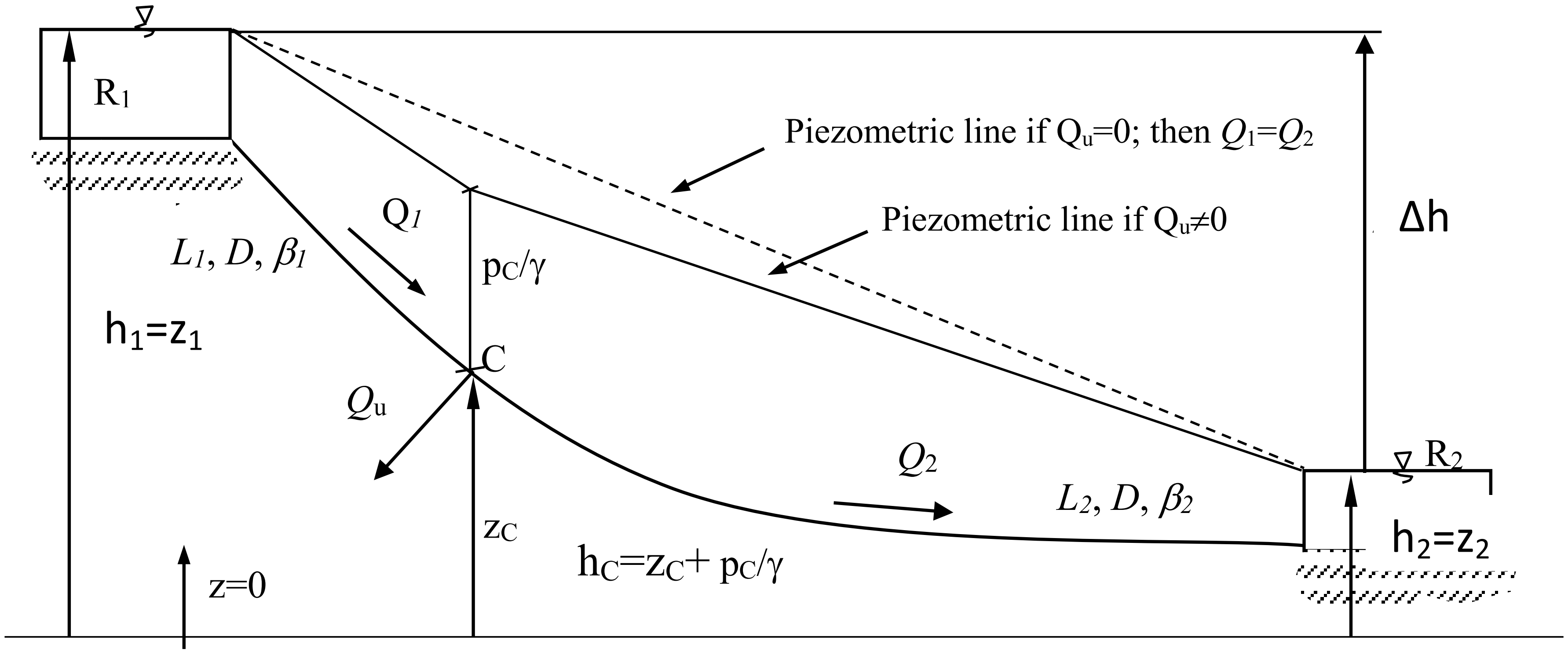
Working conditions

Required pressure to serve a 3-story building: 290 kPa; 10-story: 410 kPa; 20-story: 830 kPa. Very tall buildings are usually served with their own pumping equipment.
Mains with pressure higher that 650 kPa require pressure reducing valves to serve water for domestic purposes.

TABLE 3.8: Minimum Acceptable Pressures in Distribution Systems

Demand condition	Minimum acceptable pressure (kPa)	Minimum acceptable pressure (psi)
Average daily demand	240–410	35–60
Maximum daily demand	240–410	35–60
Maximum hourly demand	240–410	35–60
Fire situation	>140	>20
Emergency conditions	>140	>20

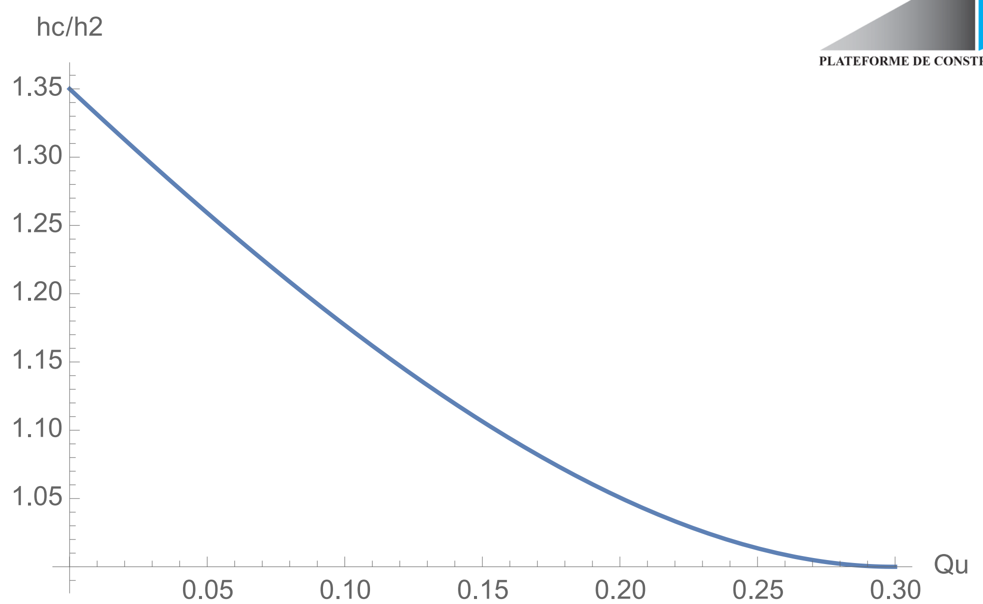
Pipeline management: emergency supply to ext. user 1



At node C, an external user muct be supplied a flowrate Q_u. What does happen to the HGL and what is the maximum flow that can be withdrawn?

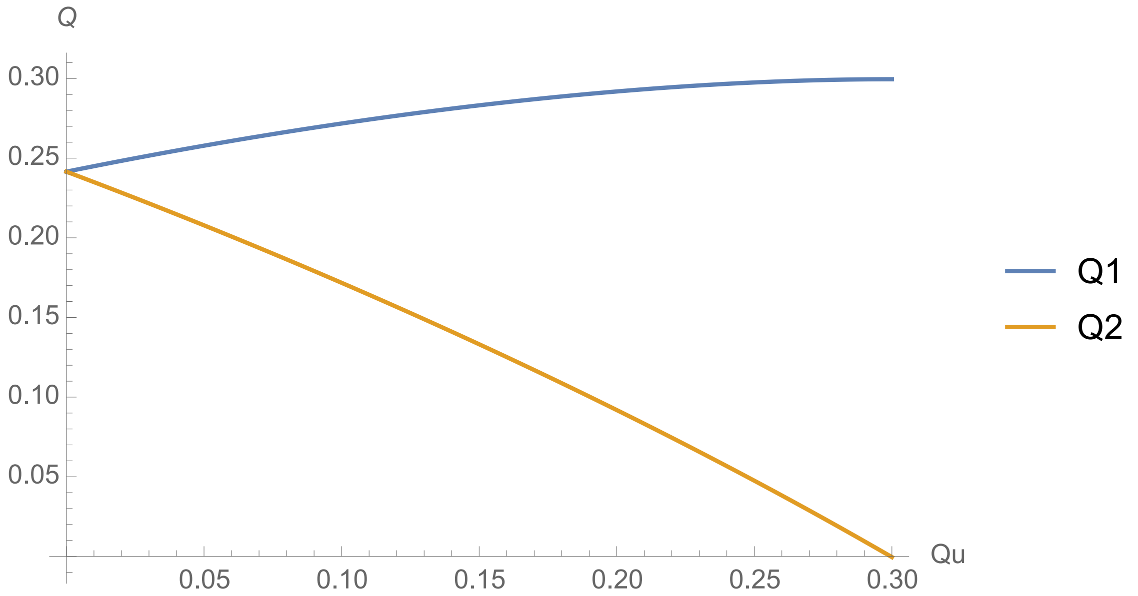
Knowns: Q_u, h_1, h_2, L_1, L_2, pipes characteristics
Unknowns: Q_1, Q_2, h_c

$$\begin{cases} h_1 - h_c = \beta_1 \dfrac{Q_1^2}{D^5} L_1 \\ h_c - h_2 = \beta_2 \dfrac{Q_2^2}{D^5} L_2 \\ Q_2 = Q_1 - Q_u \end{cases}$$

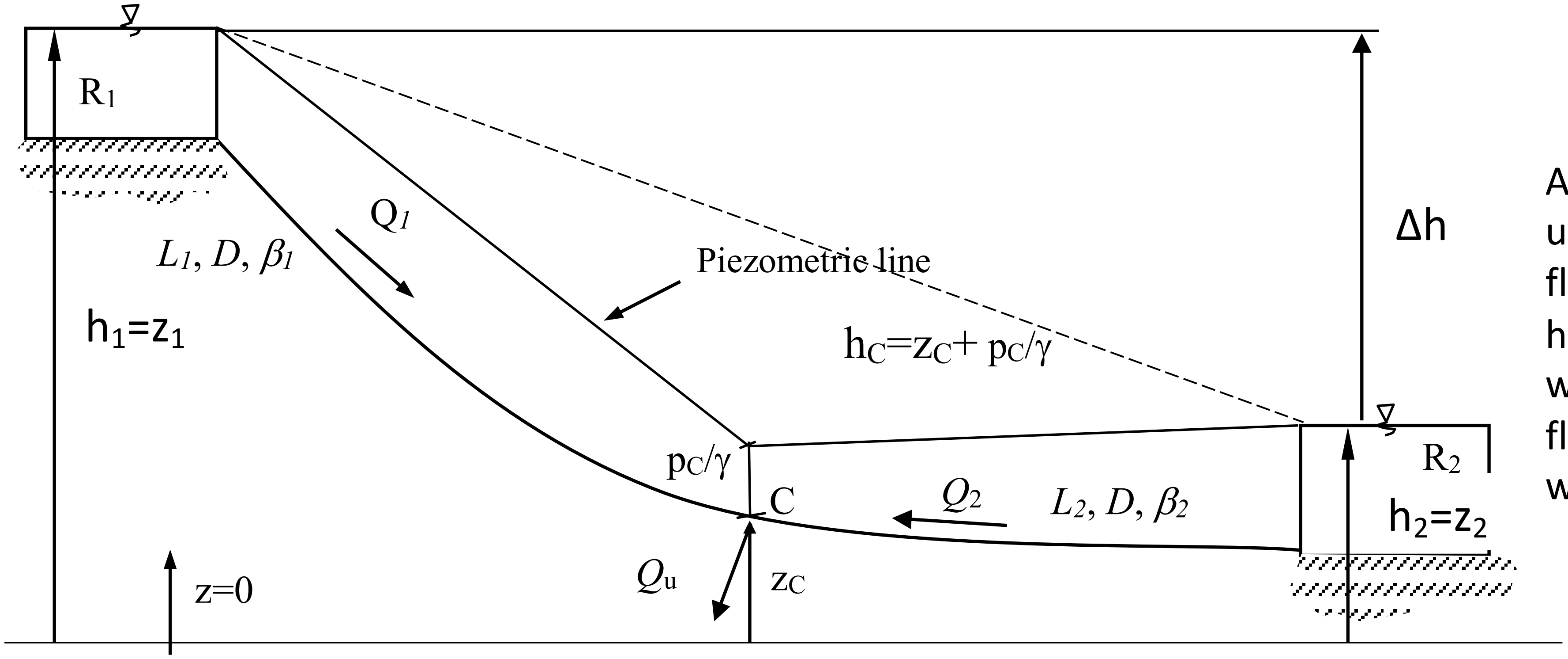


$$Q_u = \sqrt{\frac{(h_1 - h_c)D^5}{\beta_1 L_1}} - \sqrt{\frac{(h_c - h_2)D^5}{\beta_2 L_2}}$$

$$Q_u^{MAX} = \sqrt{\frac{(h_1 - z_c)D^5}{\beta_1 L_1}} - \sqrt{\frac{(z_c - h_2)D^5}{\beta_2 L_2}}$$



Pipeline management: emergency supply to ext. user 2



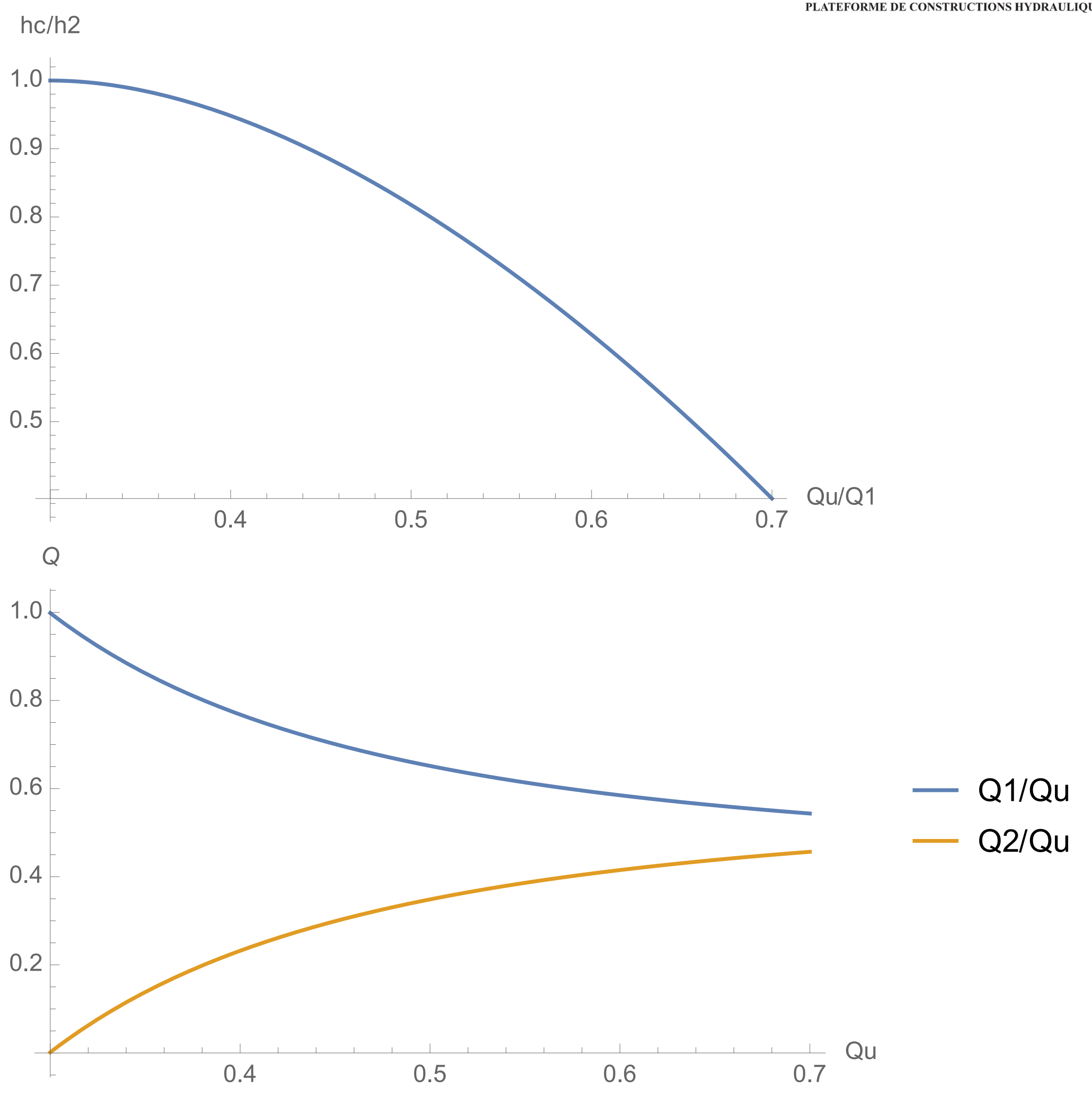
At node C, an external user must be supplied a flowrate Q_u. What does happen to the HGL and what is the maximum flow that can be withdrawn?

Both reservoirs supply water to the external user

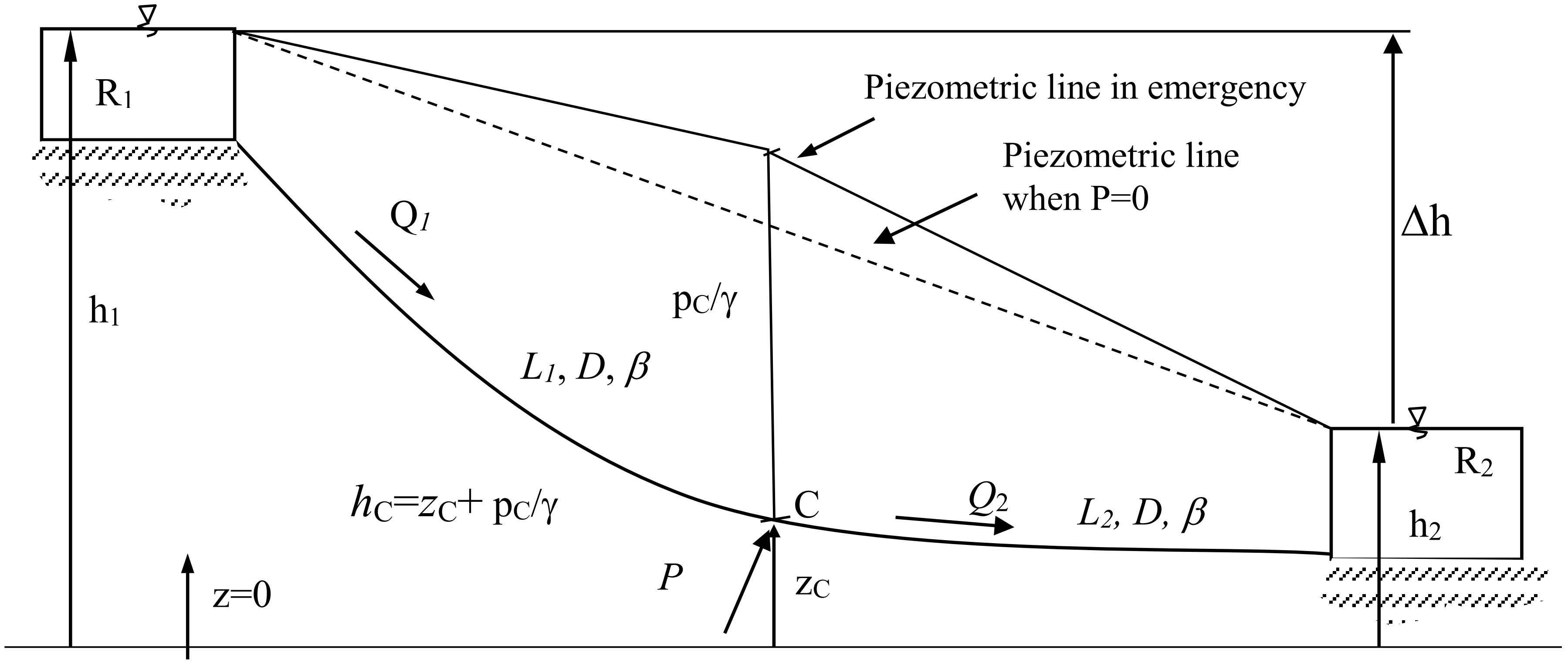
Knowns: Q_u, h_1, h_2, L_1, L_2, pipes characteristics
Unknowns: Q_1, Q_2, h_c

$$\begin{cases} h_1 - h_c = \beta_1 \dfrac{Q_1^2}{D^5} L_1 \\ h_2 - h_c = \beta_2 \dfrac{Q_2^2}{D^5} L_2 \\ Q_u = Q_1 + Q_2 \end{cases}$$

$$Q_u = \sqrt{\frac{(h_1 - h_c)D^5}{\beta_1 L_1}} + \sqrt{\frac{(h_2 - h_c)D^5}{\beta_2 L_2}}$$



Pipeline management: emergency supply to storage reservoir

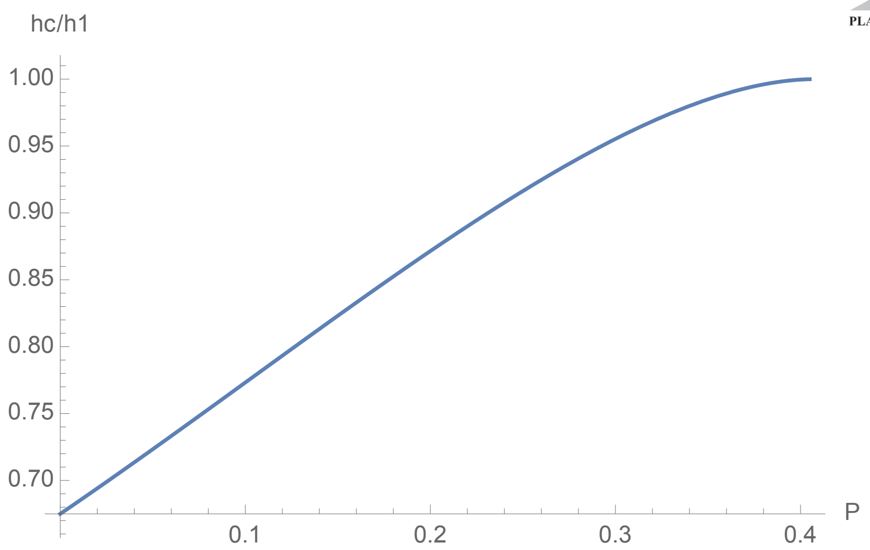


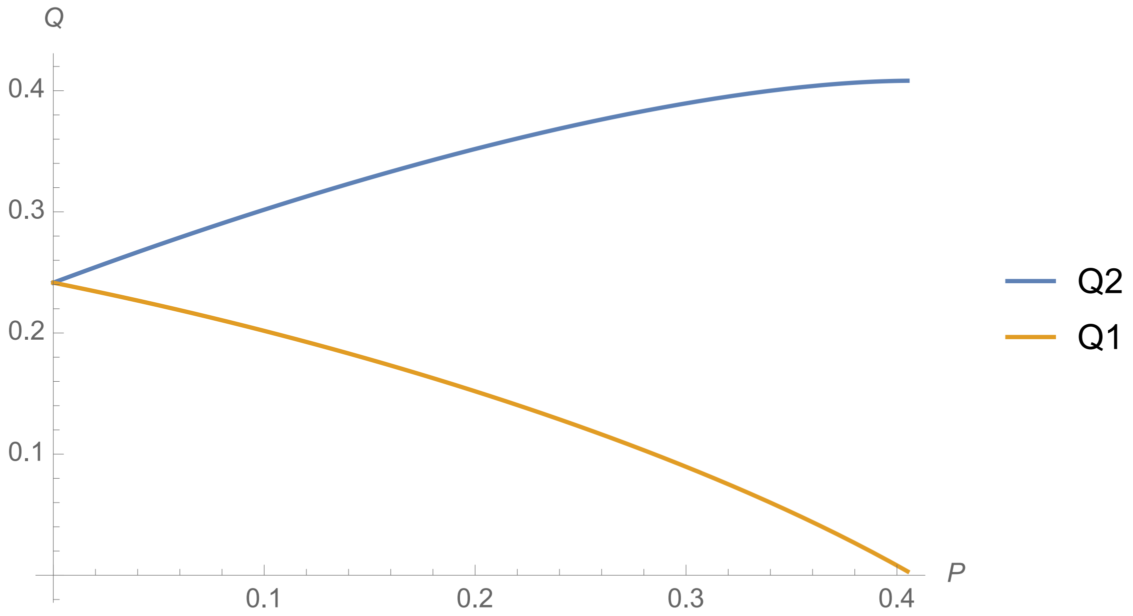
The flowrate P is pumped inside the conduit and this produces an increase of the piezometric line in C and so an increase of Q2 and a decrease of Q1

$$\Delta h_1 = h_1 - h_C = \beta \frac{(Q_2 - P)^2}{D^n} L_1$$

$$\Delta h_2 = h_C - h_2 = \beta \frac{(Q_2)^2}{D^n} L_2$$

$$Q_2 = Q_1 + P.$$

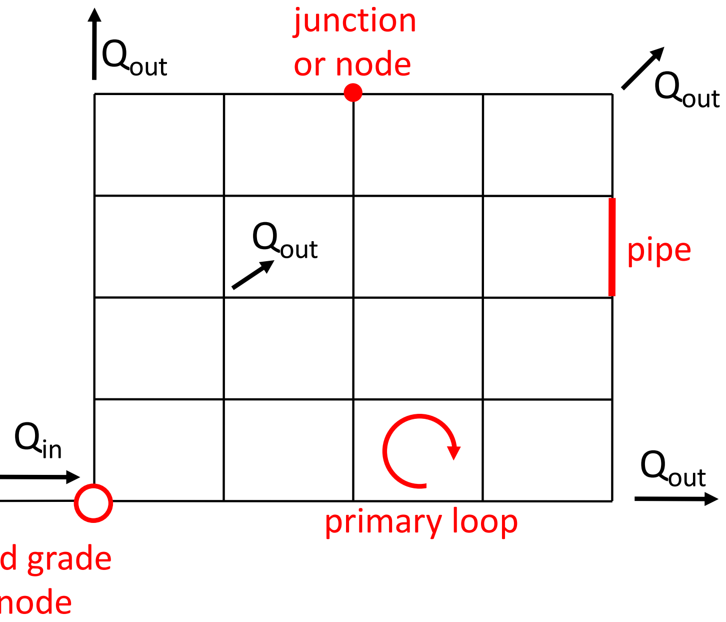


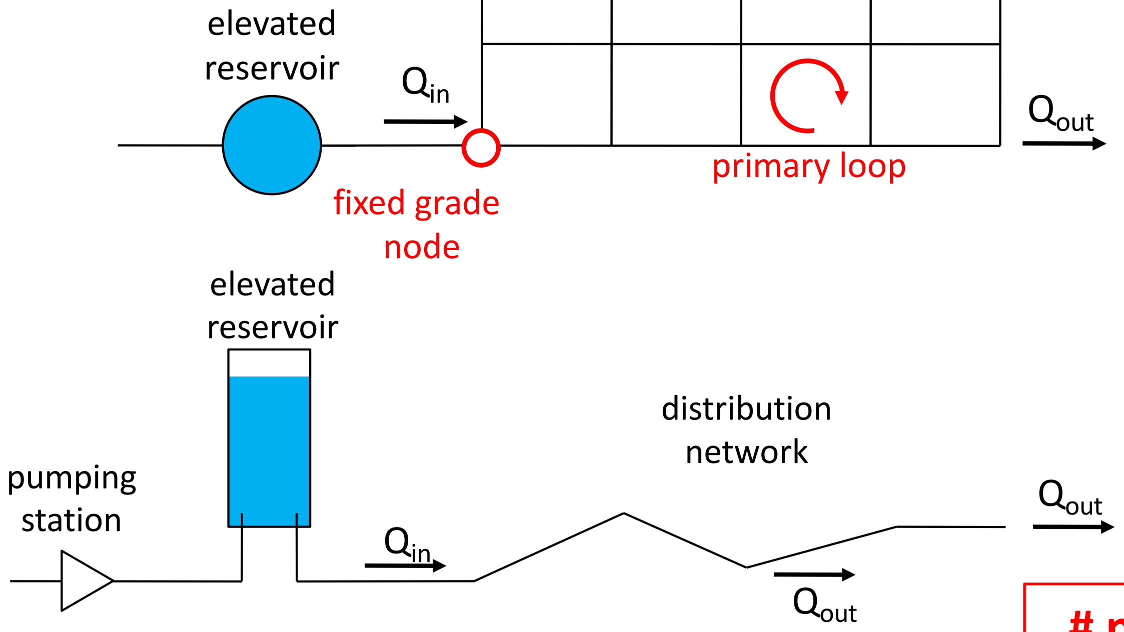


Distribution networks containing loops

The goal of a water distribution system is to supply the system's users with the amount of water demanded at the adequate pressure under various patterns of demand.

- Estimate water demand patterns
- Estimate pressure at different points of the network under different demand patterns





Network elements

Junction or node: a node where two or more pipes meet or where flow is put into or removed from the system.

Fixed grade nodes: a node in the system where both the pressure head and elevation (HGL) are known. This is usually a connection to a storage tank or reservoir or a source or discharge point operating at a specified pressure.

Primary loop: a closed pipe circuit with no other closed pipe circuits contained within it.

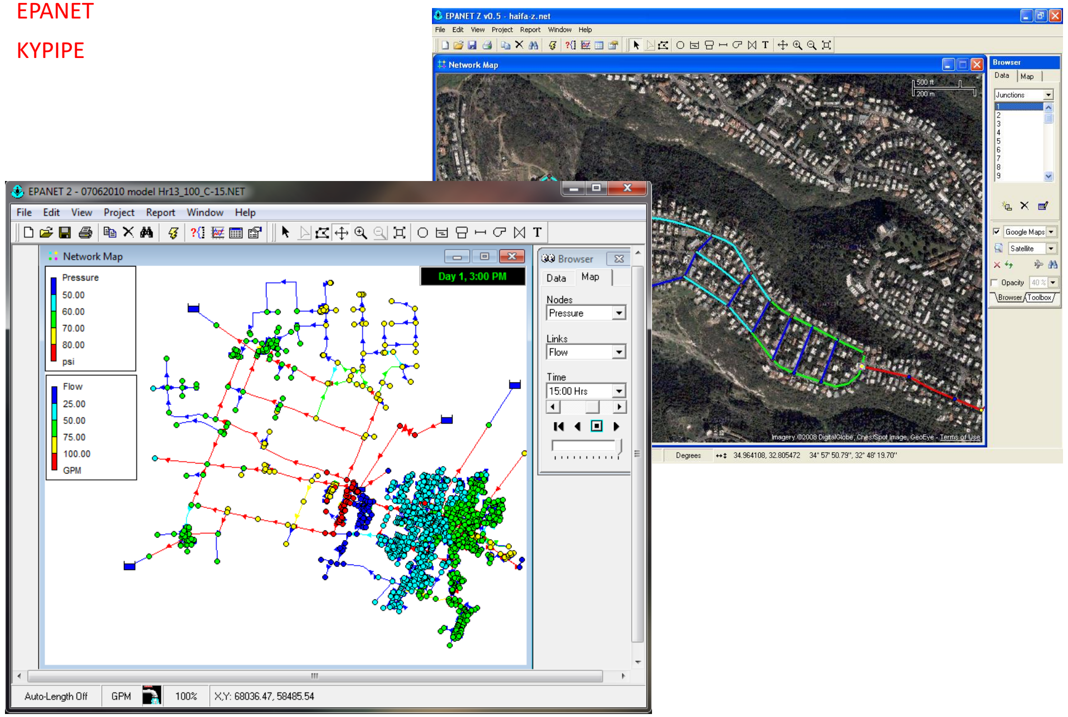
 # pipes = # nodes + # fixed grade nodes + # primary loops -1

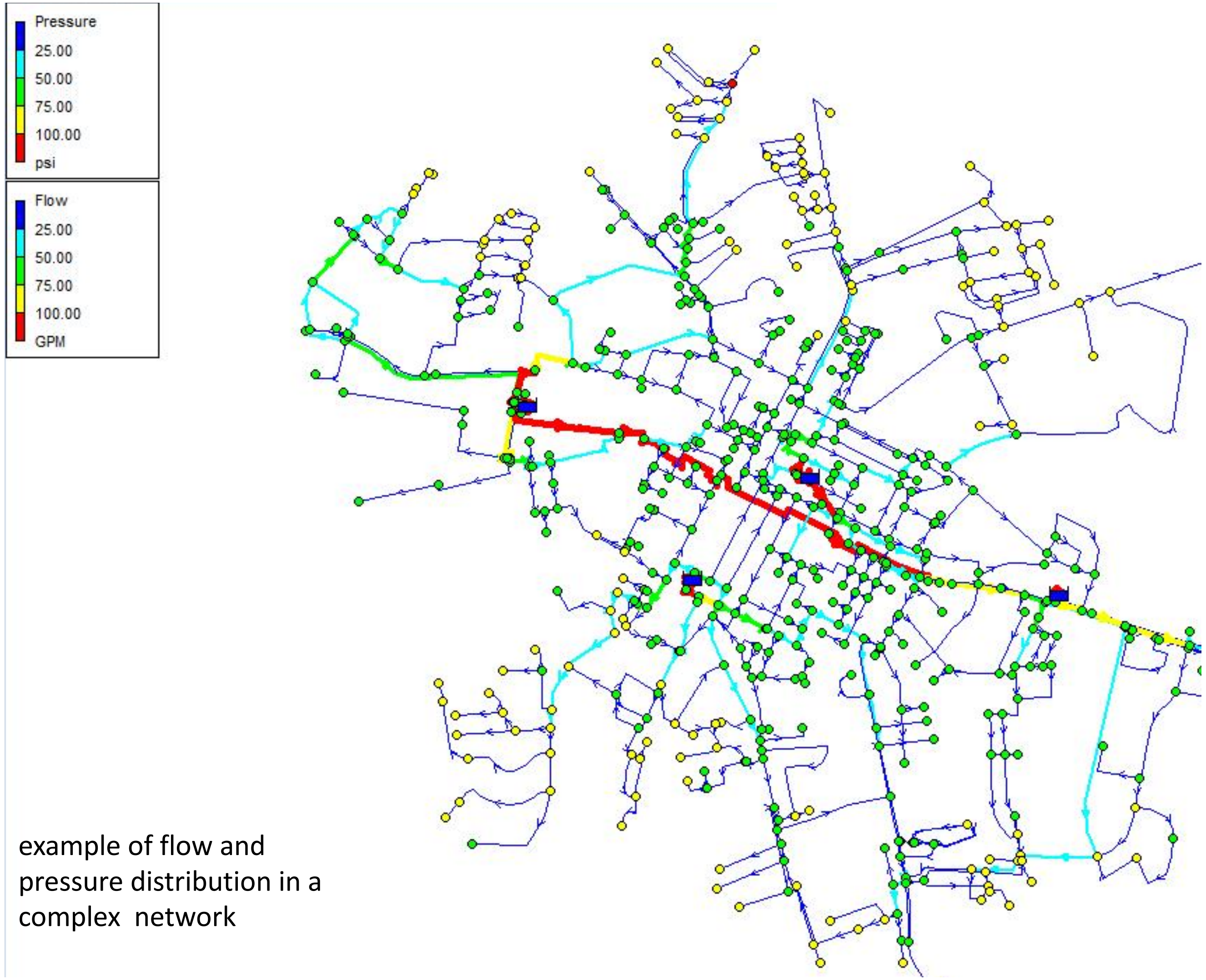
$$N_P = N_J + N_{FG} + N_L - 1$$

Free software for network simulation:

EPANET

KYPIPE





example of flow and pressure distribution in a complex network