Faculty of World Economy and
International Affairs

Master's Programme
Environmental Economics and
Sustainable Development

Moscow, Nov. 17, 2023

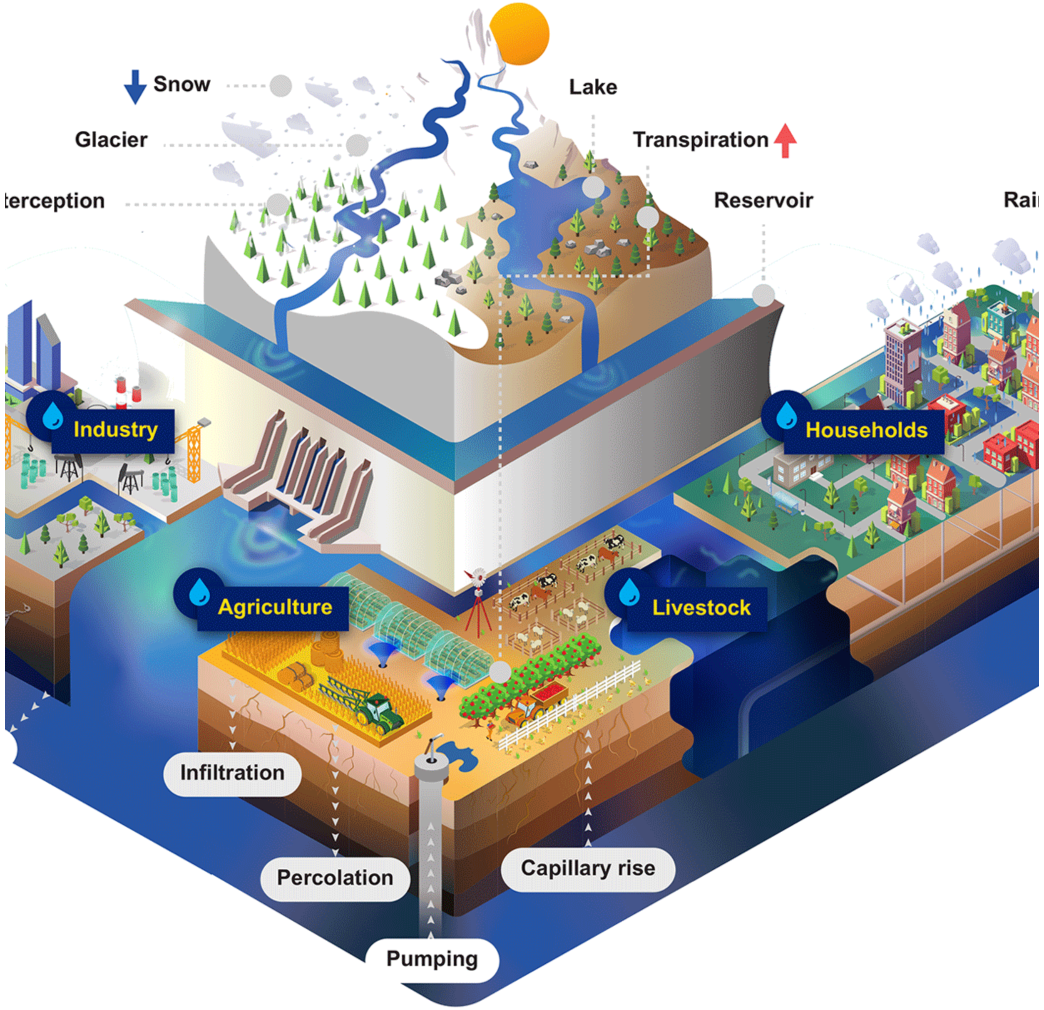
Introduction to Environmental Economics
Part 8: Water Resources & Systems
Lecture 2: Water Infrastructure Systems & Services

Alexandre MARTUSEVICH, Guest Senior Research Scholar, IIASA

CONTENT

- **Water Infrastructure Systems & Services**, the case of:

  - municipal water supply and sanitation (WSS) / water utilities;
  - industrial water supply systems;
  - irrigation systems; and
  - multi-purpose water infrastructure (MPWI)



Municipal WSS

Municipal water utilities (WUs) provide essential, vital water supply and sanitation (WSS) services, largely determining the quality of life and having great impact on public health and life expectancy (+ some 10 years, e.g. in Marseille)

Out of all infrastructure systems (telecom, highways, railways, electricity grid), municipal WSS is **the most capital intensive system in terms of upfront capital costs per person served/connected** - several times more expensive than any other infrastructure system listed above.

WSS uses advanced treatment techniques invented only in the 2nd half of the 19th century, and advanced equipment (e.g. ultra-sonic flow-meters, UV disinfection) and methodologies (e.g. for hydraulic modelling, pressure mgt etc.)

Development stages over the last 25 centuries:

- centralised water supply (*aqueducs*, by gravity, fm Ancient Ages) with raw fresh water treatment added much later on, incl. filtering (e.g. Hamburg), coagulation, UV disinfection

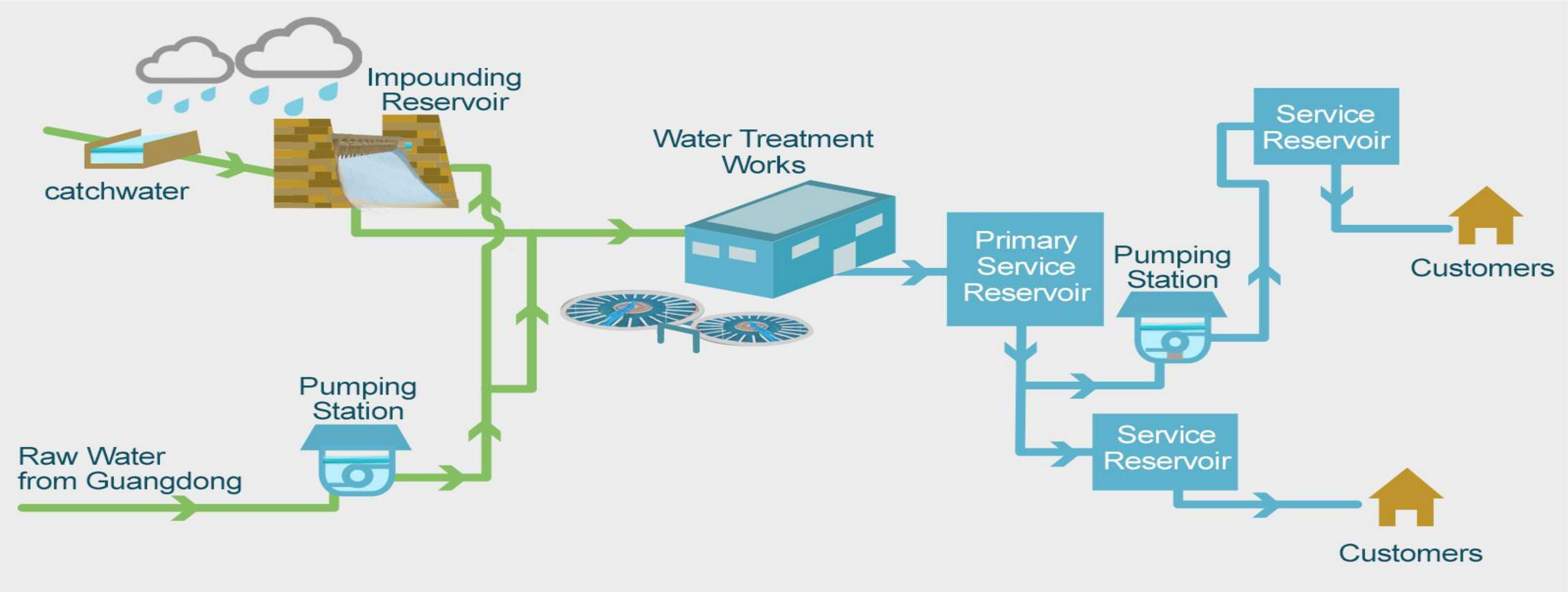
- centralised wastewater (WW) collection and disposal, adding WW treatment & disinfection later on

- sludge treatment and safe disposal or use (as fertiliser, or soil filler, or in *waste-to-energy* schemas - links to climate change and green transition agenda

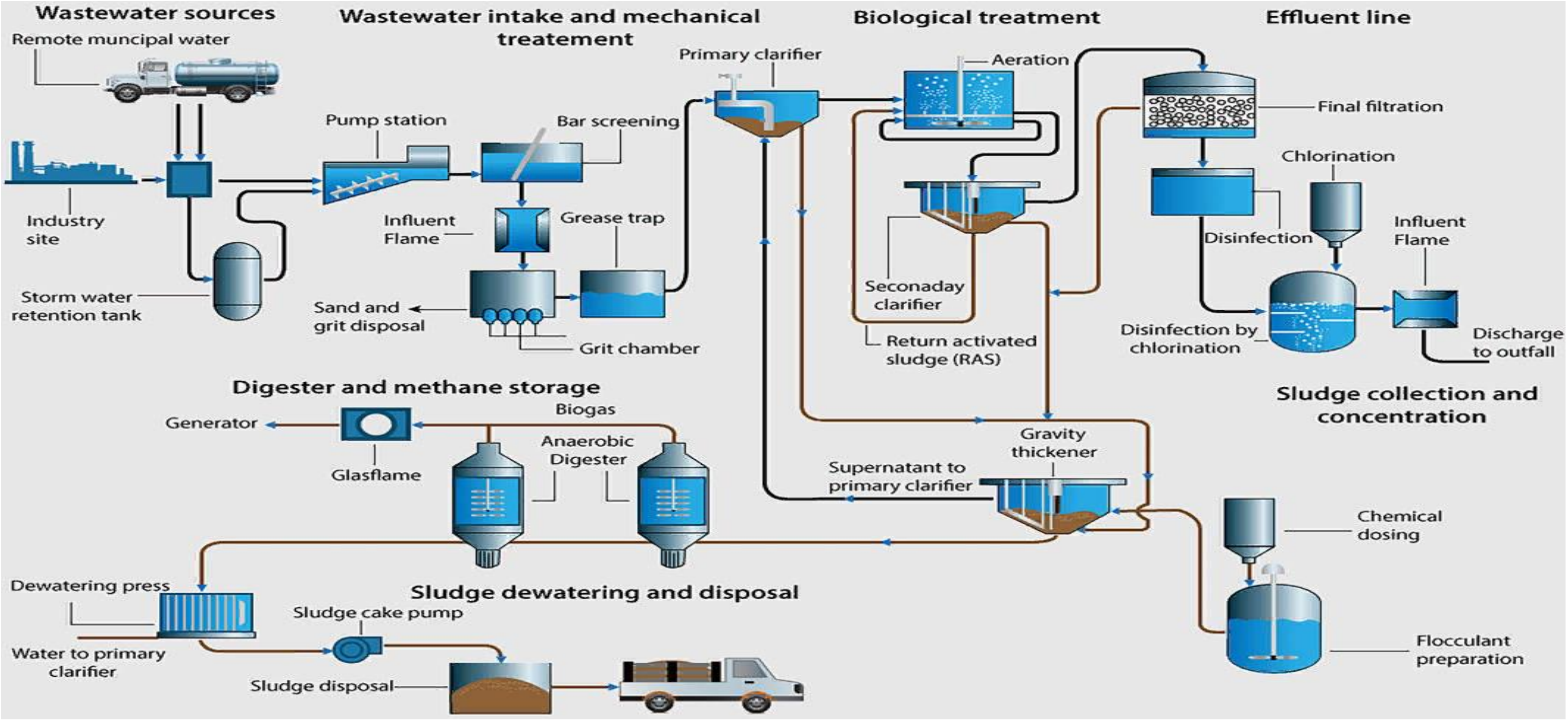
Municipal Water supply – schematic

Typical elements: water source(s): SW (water intake) or GW (boreholes, up to 1000 meters deep, e.g. in Jordan); 1st lift pumping station; water treatment plant; 2nd, 3rd etc. lift pumping stations (up to 400 m, e.g. in East Kazakhstan); clear water reservoirs; water main & distribution network, flow & water meters; taps / stand pipes

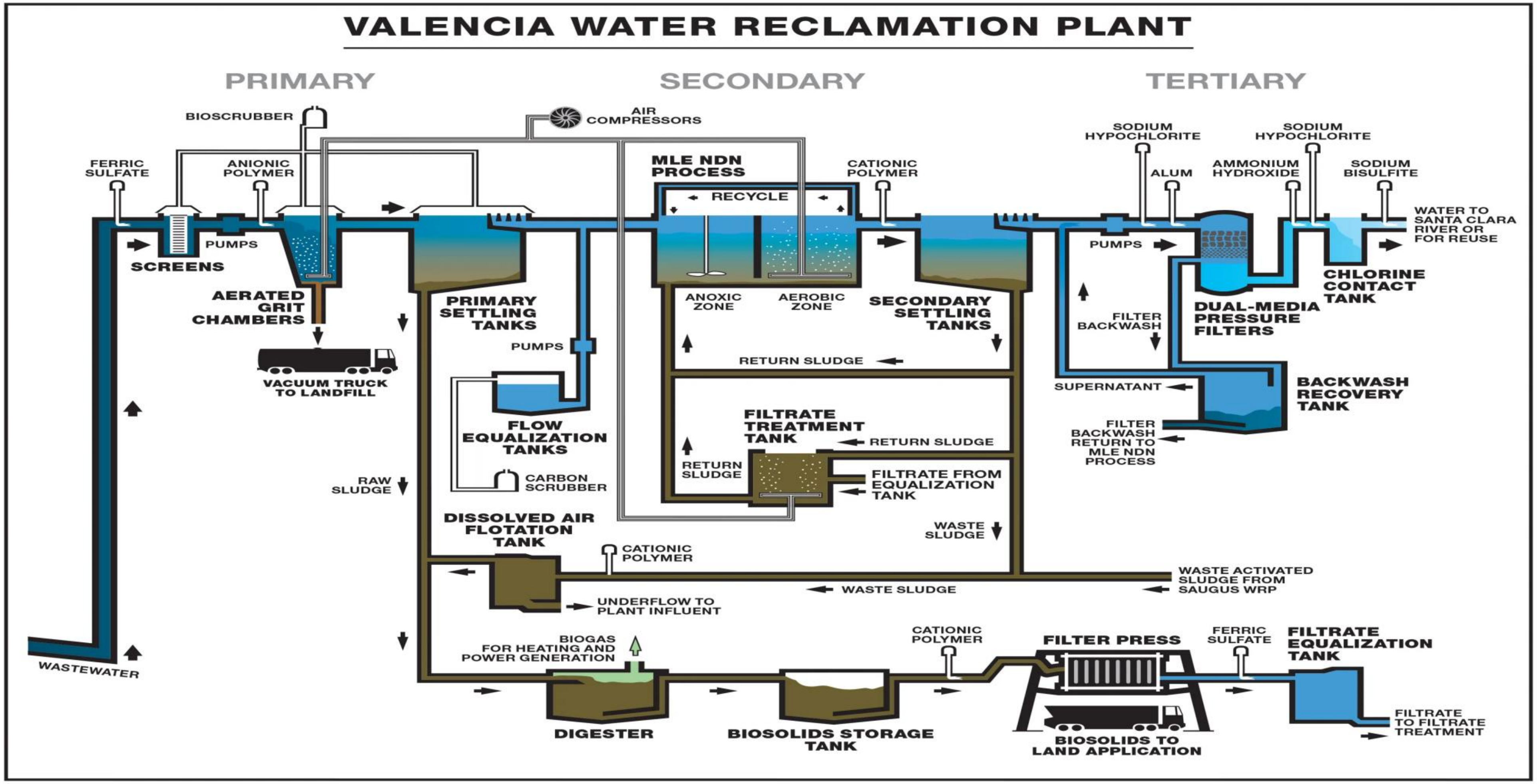
Data source: https://www.wsd.gov.hk/en/core-businesses/operation-and-maintenance-of-waterworks/water-supply-and-distribution/index.html



Municipal wastewater collection and treatment – schematic



Municipal wastewater collection and treatment: primary, secondary & tertiary (EU Urban WWT Directive)



Specificity of municipal WSS impacting its costs & economics: Demand side

- **Water is an essential good, having no good substitutes**

Essential good (жизненно-необходимый продукт) ==>

- **human right** to water and sanitation recognised by the UN GA; and

- the need to guarantee to each citizen access to water irrespectively of the behaviour of other consumers (==> specific technical requirements to WSS systems), and irrespectively of his/her expenses for other Goods & Services (**G&S**).

Absence of any good substitute (not to speak about a perfect one) ==> very limited room for indirect competition on the food&drinks market (e.g. from producers of milk, beer or Pepsi) ==> special measures to address water affordability constraints (see below)

- **the Demand for WSS services has low income and price elasticities (typical for essential G&S); and is not procyclical** (unlike the demand for real estate or luxury goods)

  Over 1990ies, in many cities in EECCA the water utility (*vodokanal, in Russia*) was top 5-10 employer, and in some towns (e.g. in depressive *marzes* in Armenia) - **the only** employer.

  On the negative side, it implies that affordability constraints become more tough when either income falls or WSS tariff increases faster than income grows.

- Further more, the demand for water in each specific settlement very much depends on:

- demography and migration, incl labour migration (typical for many post-Soviet republics); and

-structural reforms in the economy (e.g. water intensive enterprises & sectors) ==> **high uncertainty over crisis or reform periods**

Specificity of municipal WSS impacting its costs & economics: Supply side

- **Water supply and sanitation (WSS) represent a combination of a public and private good & service (G&S)**

  Good - the amount of water a user gets from the tap

  Service - ability to get water in/near his/her dwelling at any time

  Public G&S are typically provided by the State to everybody for free. While consumers pay price for private G&S they consume

- **WSS - is one of the most capital intensive infrastructure sectors** ==>

  - large upfront investments; and

  - high O&M costs and capital replacement costs (replacing deteriorated fixed assets).

- Moreover, **fixed assets in the water sector have significant lifetime** (50-100+ years)

==> a long payback period for investment;

- **High sunk cost & transaction specificity of fixed assets** (the value of assets out of operation is much lower than their historical value on the accounting books)

==> the price of eventual mistakes in making investment decisions could be very high and paid over decades.

Examples of costly investment mistakes

- construction of highly oversized water systems (or of insufficient capacity); or

- building a poorly designed system (e.g. highly vulnerable to floods and droughts)

- WSS cost structure: over 50% of costs are the costs related to water abstraction and transportation, wastewater transportation and treatment (even in the case of transportation by gravity, without much pumping)
- Much of fixed assets in the water sector are placed underground ==> difficult to monitor, lack of info about their real status, need for special (costly) control measures (the lack or asymmetry of information is the reason of some market failures)
- Overall, there are several **high risks and uncertainty impacting water sector development,** including:

  - risks of sudden changes in the demand for water (ex. of rural Moldova)

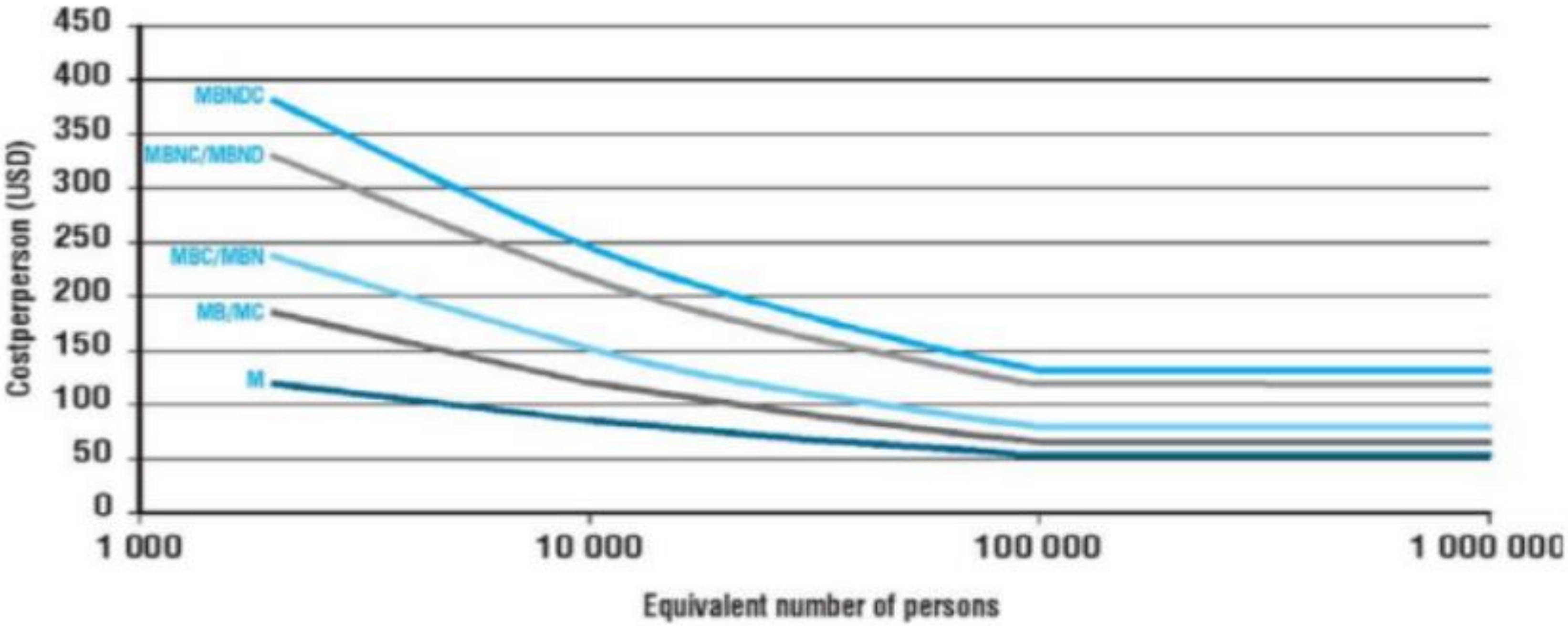
  - tariff & other regulatory & institutional risks (e.g. unfavorable changes in the Technical or ENV regulation); and

  - risk of natural hazards (those impacting water quantity or quality - floods & droughts, or safety& integrity of water infrastructure - e.g. earthquakes, or *tsunami* - e.g. Fukushima)

Specificity of centralized/piped WSS ... - 4

- **key elements of water infrastructure systems (e.g. pipeline and pumping stations & treatment plants) has the feature of** natural monopoly **with a high economy of scale** ==> an obstacle for developing competition on the market

Fig. 1. Unit capital cost function for main wastewater treatment technologies, in USD per person served (in 2000 West EU prices)



Source: FEASIBLE model User guide

Specificity of centralized/piped WSS ... - 5

The dark side of the (dis-)economy of scale in WSS can be seen in small human settlements (see Figure 2 below, with data fm Moldova)

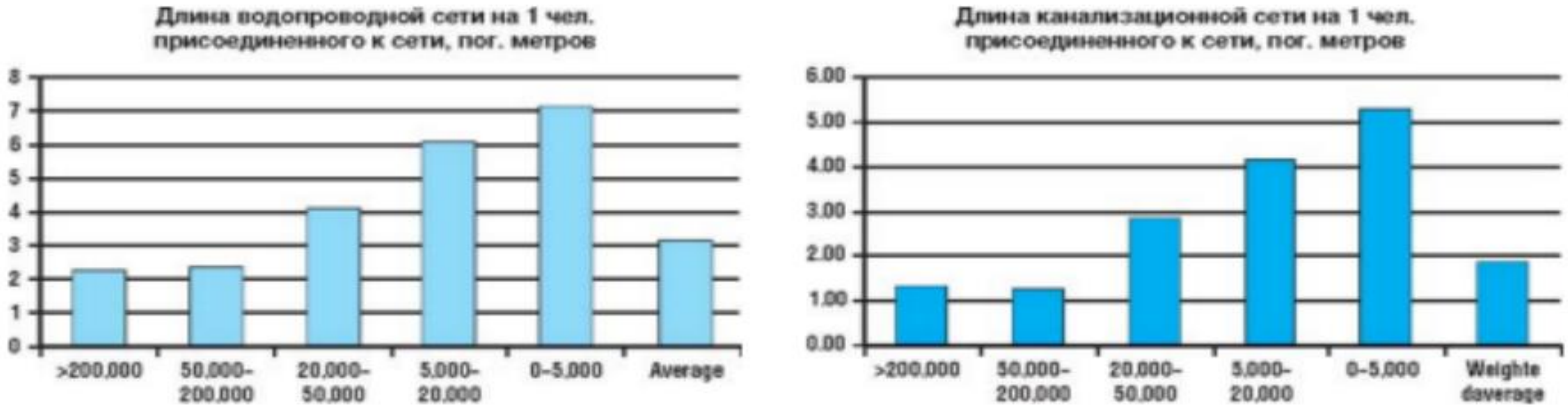


Рис. 2. Средняя длина уличной водопроводной и канализационной сети на 1 обслуживаемого жителя в населенных пунктах с разной численностью населения, погонных метров

Источник: *OECD/EAP Task Force (2008).*

Specificity of centralized/piped WSS ... - 6

Significant variation of specific consumption of some main inputs, not least electricity: unlike processing industries, where the difference in specific electricity consumption (per unit of output) between best & worst performing enterprises might be +/- 20%, in the water sector it could be up to 10-15 times! - see Fig 3 with data fm Moldova again

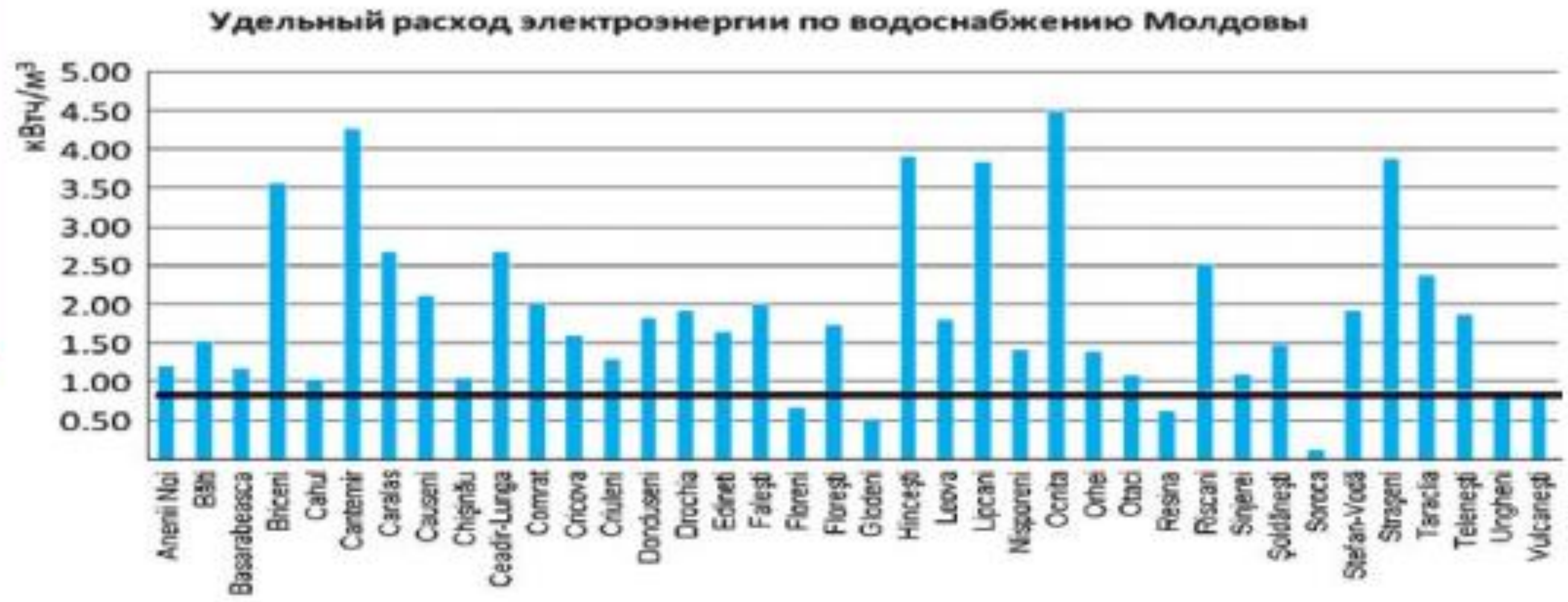


Рис. 3. Удельный расход электроэнергии по водоснабжению в населенных пунктах Молдовы, кВтч на 1 м³

Specificity of centralized/piped WSS ... - 7

High **non-revenue water (NRW):** up to 70-85% of water pumped into the transportation (water main) and distribution networks. Example fm Yerevan: in early 2000ies, NRW over 80%

Many positive and negative externalities, including:

- positive impact on the quality of life and labour productivity;

- **negative health impact**, if tap water does not meet drinking water standards, and ENV impact if wastewater is not treated to the standard, or sludge is not properly treated.

Specificity of competition in the sector:

- no competition **on** the market; but

- the possibility to compete **for** the market (for the right to serve the whole market in certain settlement(s) or area, during an agreed period of time) - if to properly address challenges associated with PSP/PPP: from selecting concessionaire through properly organised tender to preparing a balanced contract with the winner.

Complexity to attract bank loans due to: (i) transaction specific assets; (ii) the issue of proper collateral.

The Water sector is often **very fragile for corruption** (increasing costs by up to 30%)

Industrial water supply systems

(i) Direct flow water supply system

Translation:

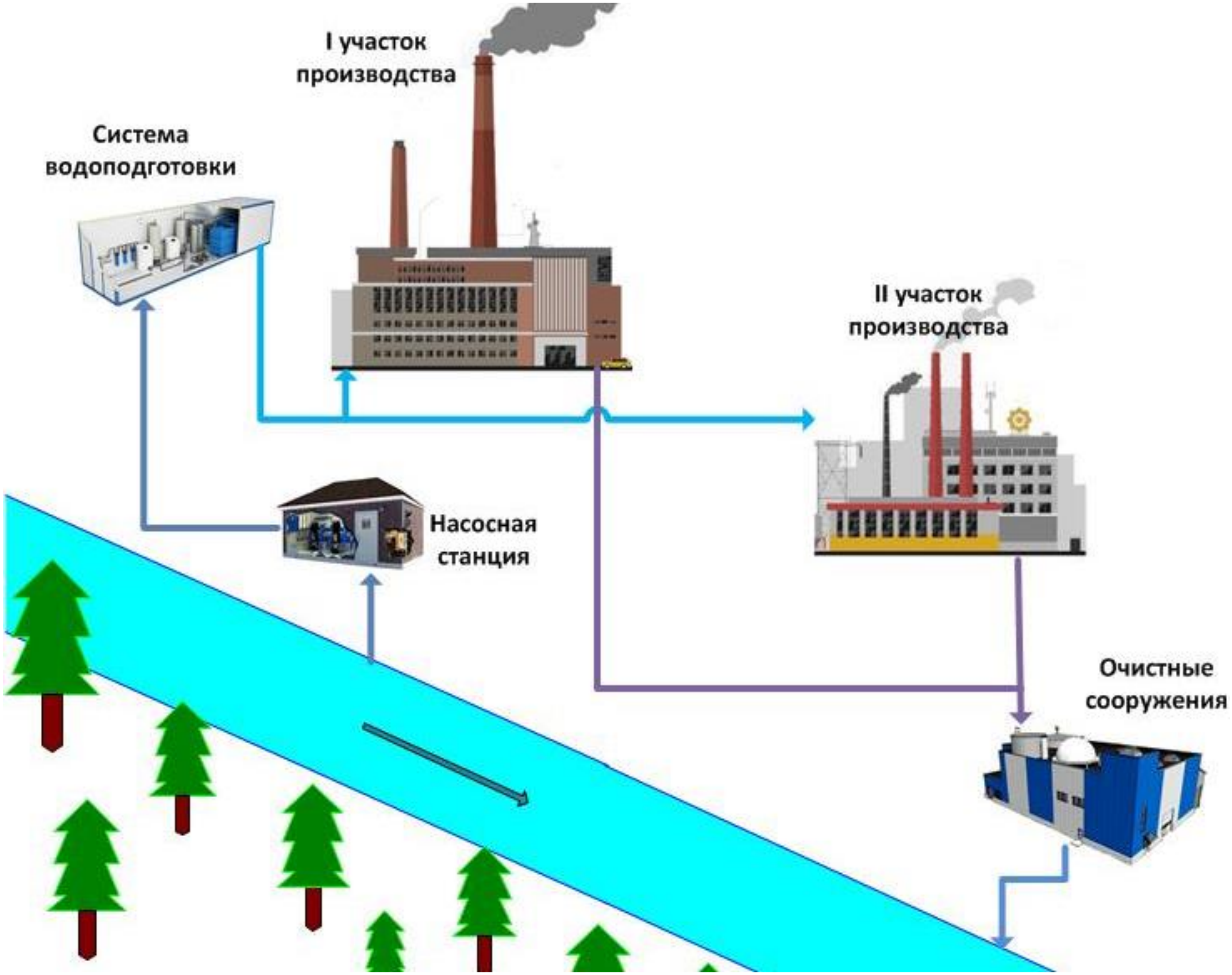
Насосная станция - Pumping station

Система водоподготовки - Water treatment facility

Участок производства – shop, factory

(локальные) Очистные сооружения - local (wastewater) treatment facility

Source: КЭУ (2023)



Industrial water supply systems

(ii) Sequential water supply system

Translation:

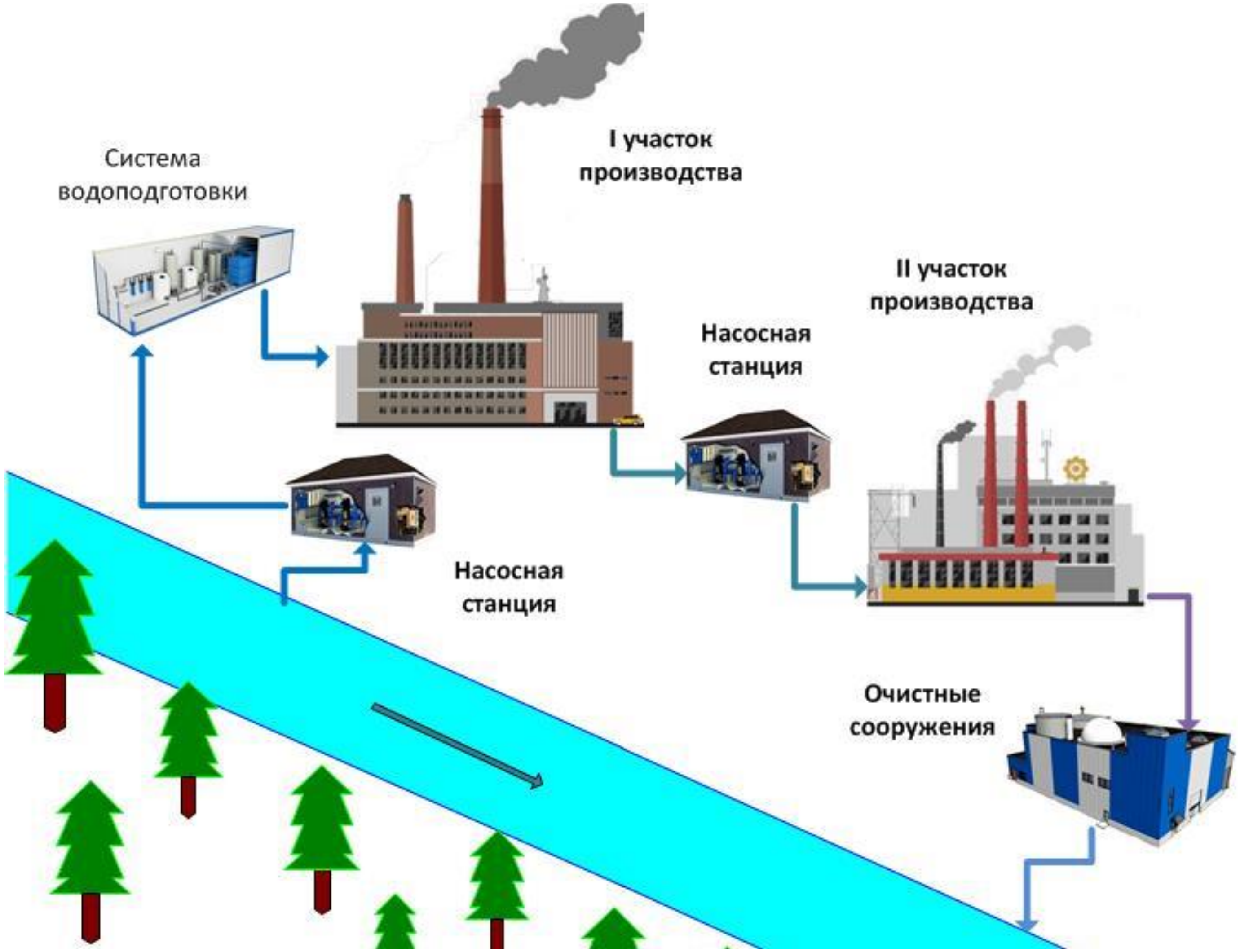
Насосная станция - Pumping station

Система водоподготовки - Water treatment facility

Участок производства – shop, factory

(локальные) Очистные сооружения - local (wastewater) treatment facility

Source: КЭУ (2023)



Industrial water supply systems

(iii) Recycling water supply system/schema

Translation:

Насосная станция - Pumping station

Система водоподготовки - Water treatment facility

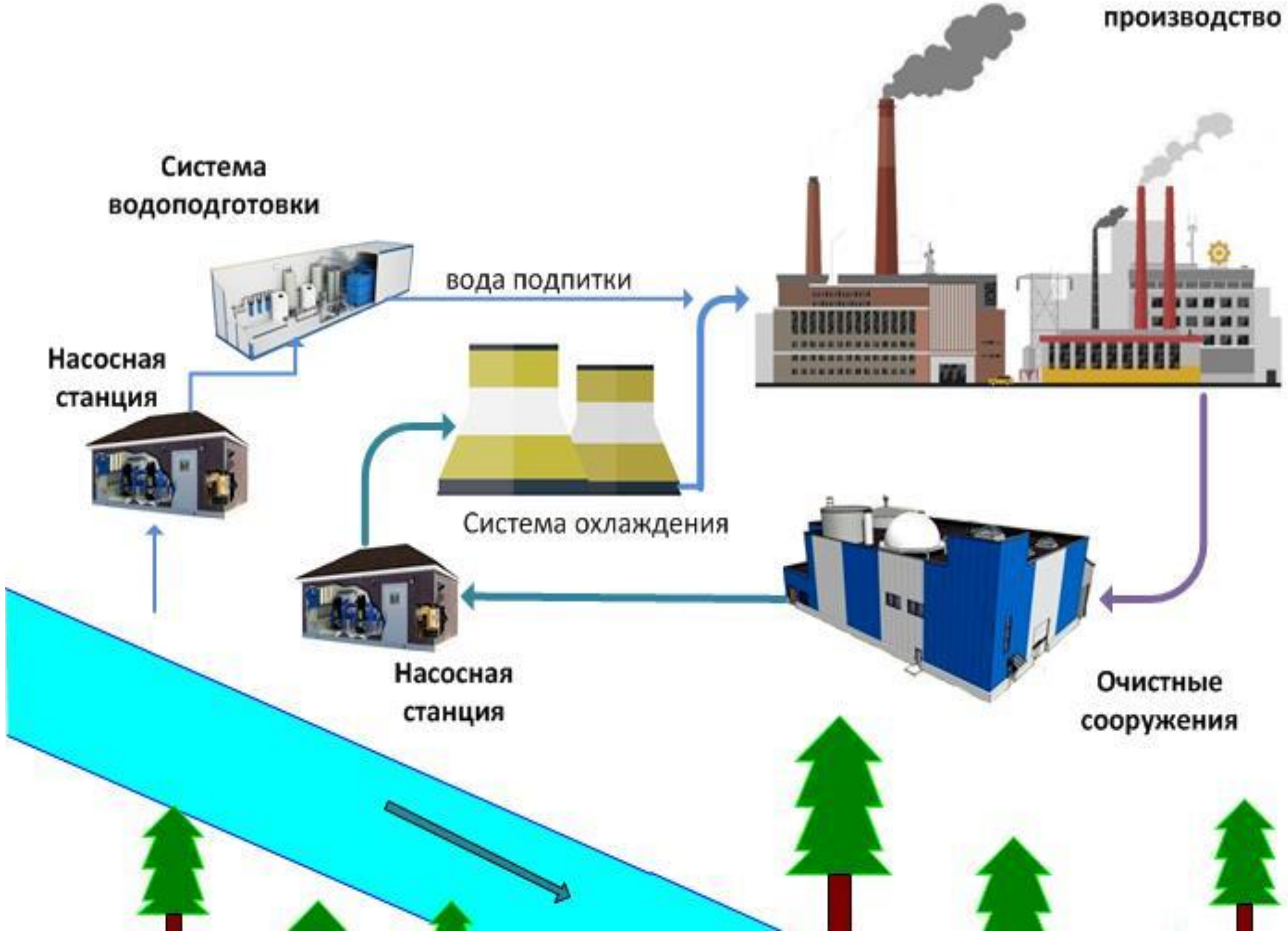
Вода подпитки – make-up water

Система охлаждения – cooling system

Производство – shop, factory

(локальные) Очистные сооружения - local (wastewater) treatment facility

Source: КЭУ (2023)



Water saving potential in water intensive industries: the case of tanneries

Ultimate objective: to drastically increase resource use efficiency (reduce specific consumption of resources per unit of produce) and in this way improve the economic and financial performance of the enterprise in question

Tool : analysis of the mass & energy balance prepared as part of ENV & water audit

The factual indicators should be compared with those corresponding to BAT - *best available technique* (per ton of raw hides):

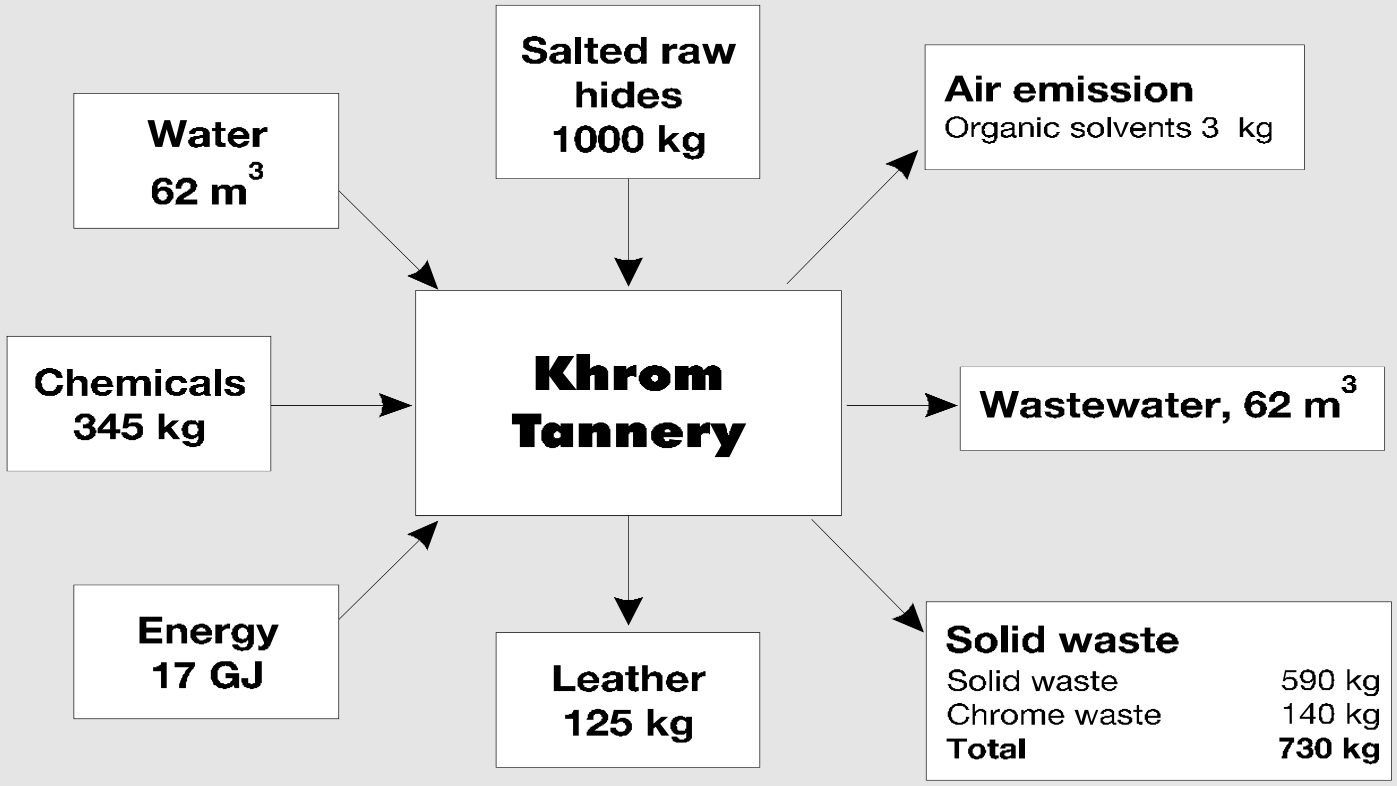
Water – 15 m3 per (4 times (!) lower)

Chemicals (less hazardous) – 250 kg

Energy – 10 GJ

Leather – 200-240 kg (market product priced per sq. decimeter = 100 cm2)

Lower emissions & pollution charges



Irrigation systems

High impact on food security (hence, on social stability):
globally, agriculture (water for irrigated crop, livestock and watering pastures) consumes some **70%** of fresh water abstracted

Irrigated crop production:

- on positive side: much (2-5 times) higher land productivity
- on the negative side: the risk of increased soil salinity. Hence, importance of **collector-drainage systems**

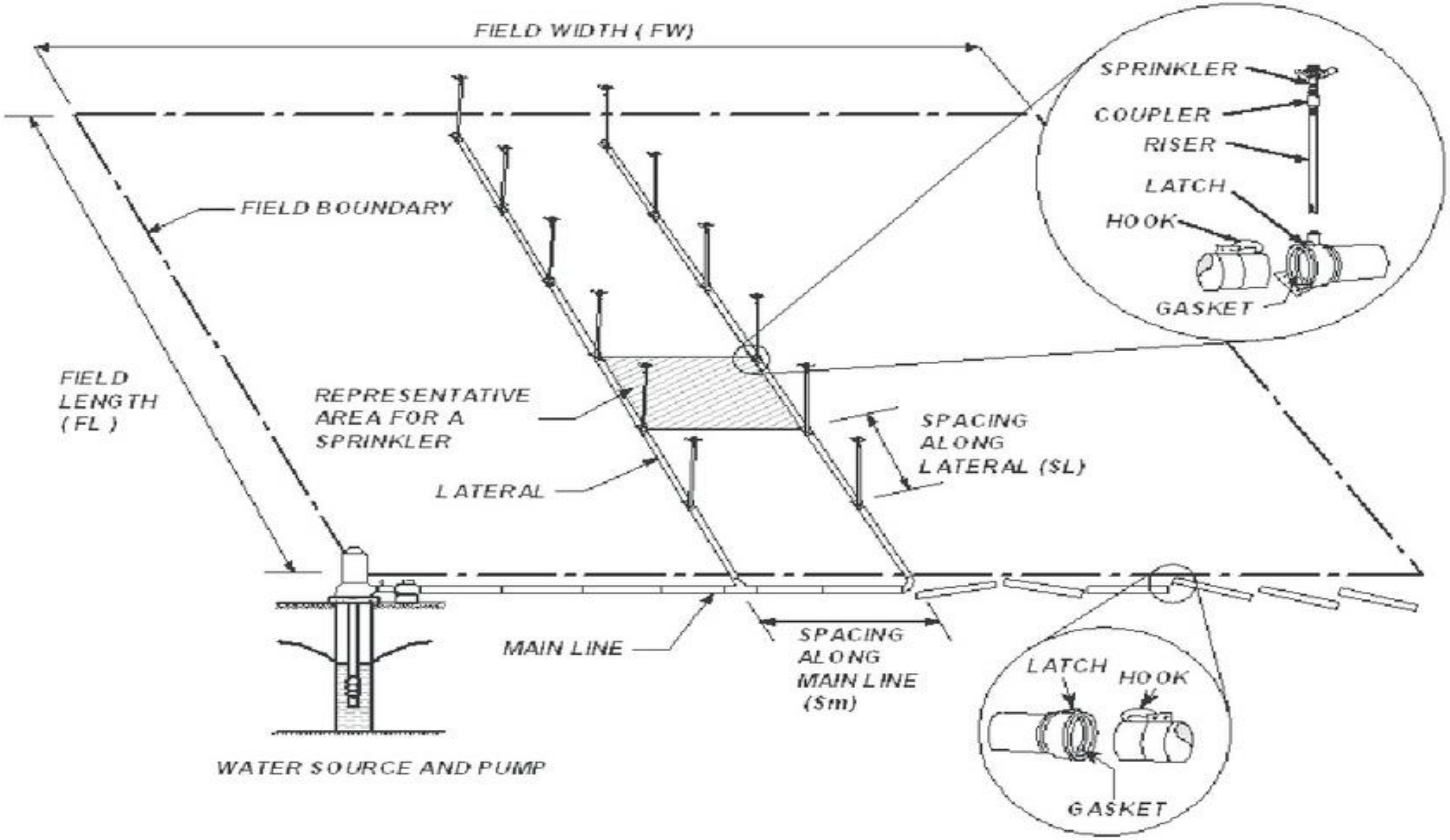
Effectiveness of irrigation highly depends on the irrigation technique:

irrigation by flooding, or using sprinklers, drip irrigation etc.

Irrigation system should be complemented by collector-drainage system, resulting in:
(i) higher land productivity (yields); (ii) much lower risk of salinity

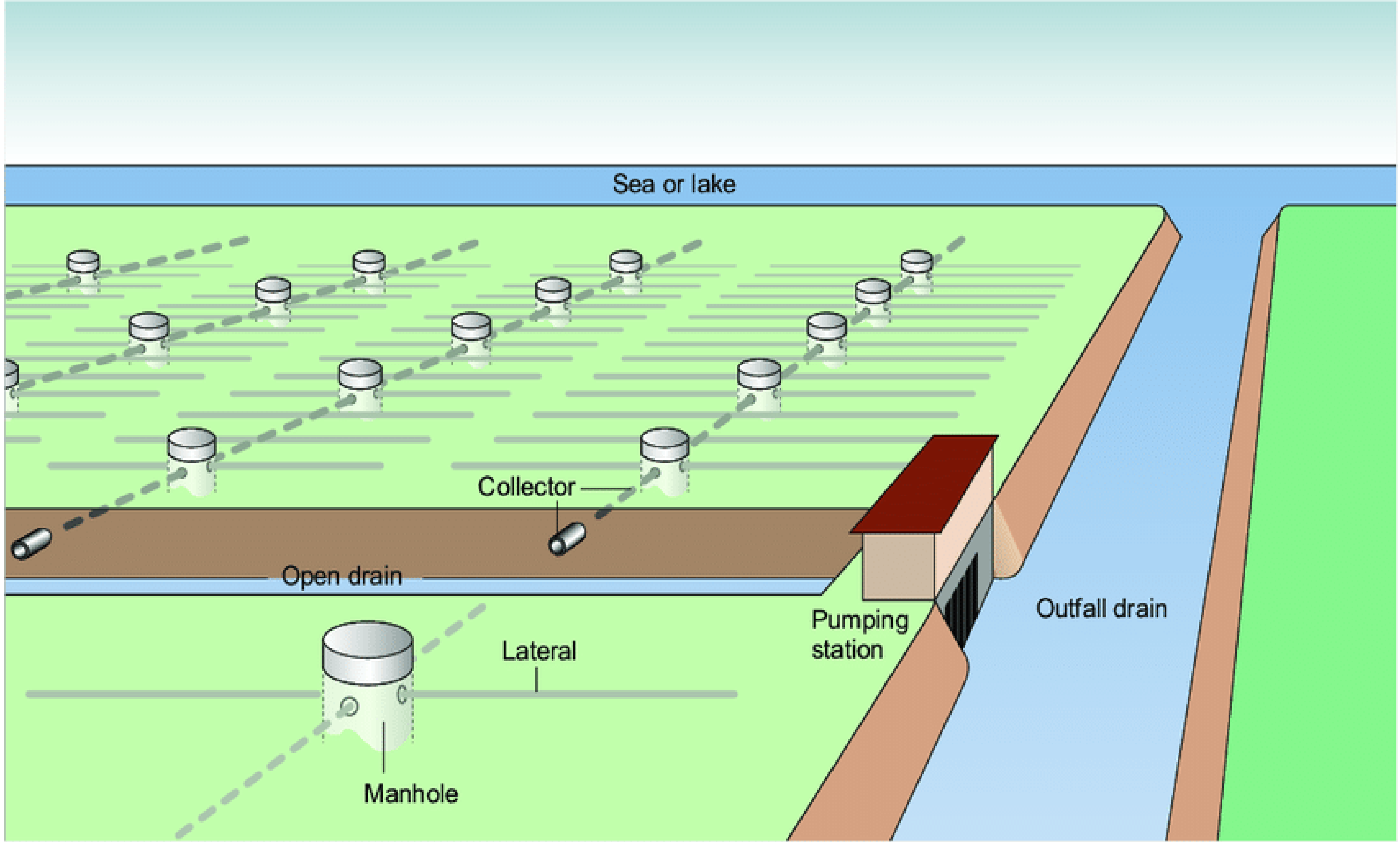
Role of complementary measures to reduce demand for irrigation water as well as water and wind erosion of soil:
little tillage, protective forest belts (windbreakers)

Sprinkler irrigation system - schematic



Source:
https://www.researchgate.net/figure/Components-and-general-layout-of-sprinkler-irrigation-systems_fig1_43265028

Subsurface drainage system used in Egypt - schematic



Source:
https://www.researchgate.net/figure/Schematic-representation-of-the-subsurface-drainage-system-used-in-Egypt_fig5_37791839

Multi-Purpose Water Infrastructure (MPWI)

Definition (OECD, 2017): *MPWI "encompasses all man-made water infrastructure, including dams, dykes, reservoirs and water distribution networks, which are used or may be used for more than one purpose"*.

While **irrigation or hydropower generation** constitutes the most important purpose(s) and accompanying service of most MPWIs, other services prevail. Among these are **flood control, drought mitigation, drinking water supply, water supply for industrial needs, commercial fisheries, recreational activities, and transport and navigation**. Each service has its stakeholders and economic impacts.

Actions can enhance economic and financial returns from the existing MPWI in question, increase water, food and energy security through greater water use efficiency and improved flood management. Examples of possible actions are:

› Investments in improved conveyance systems (e.g. lining) to reduce water losses;

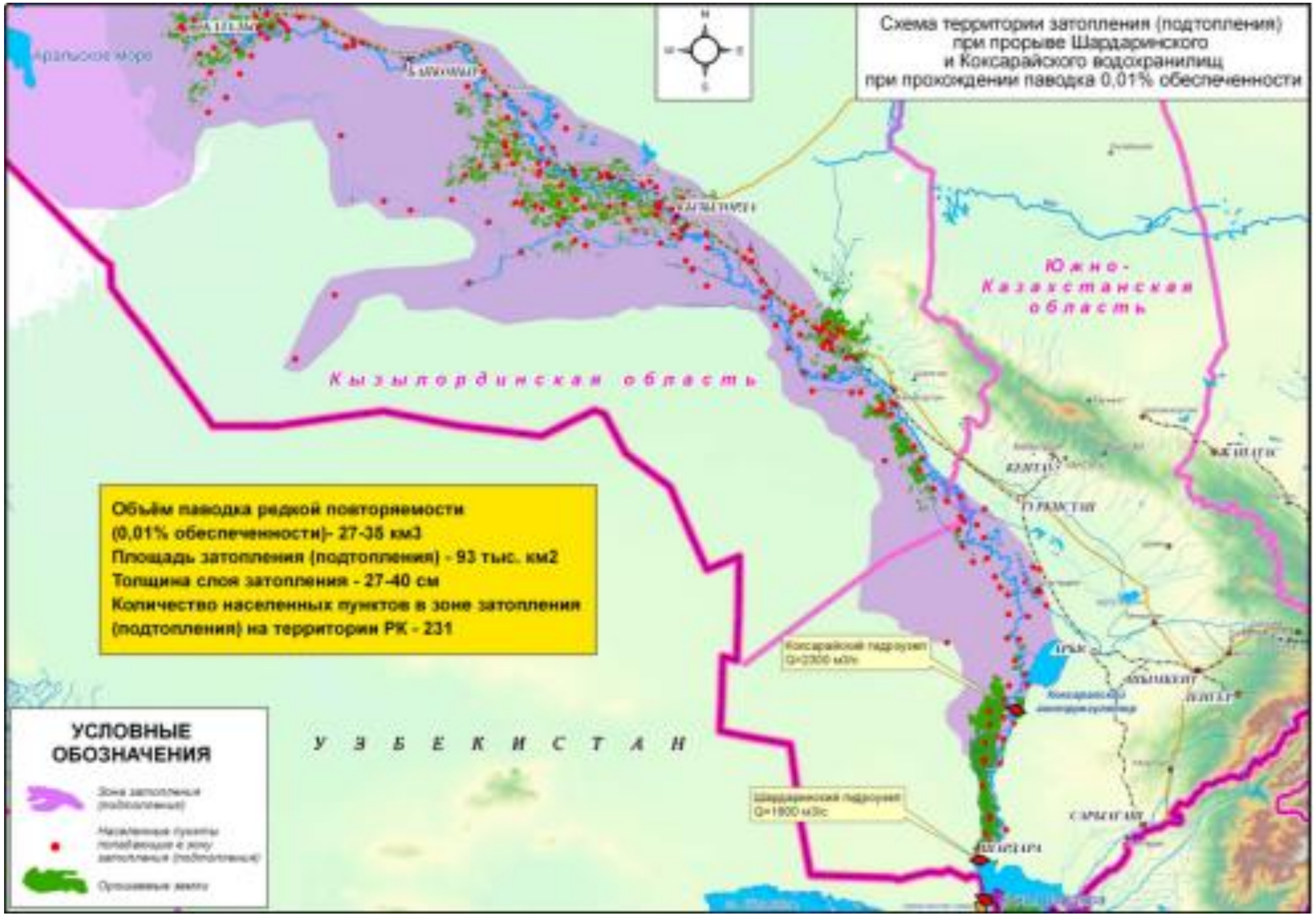
› Investments in improved on-farm water application systems;

› Investments in reservoirs and hydro power;

› Management of reservoirs for alleviating flood and drought risks;

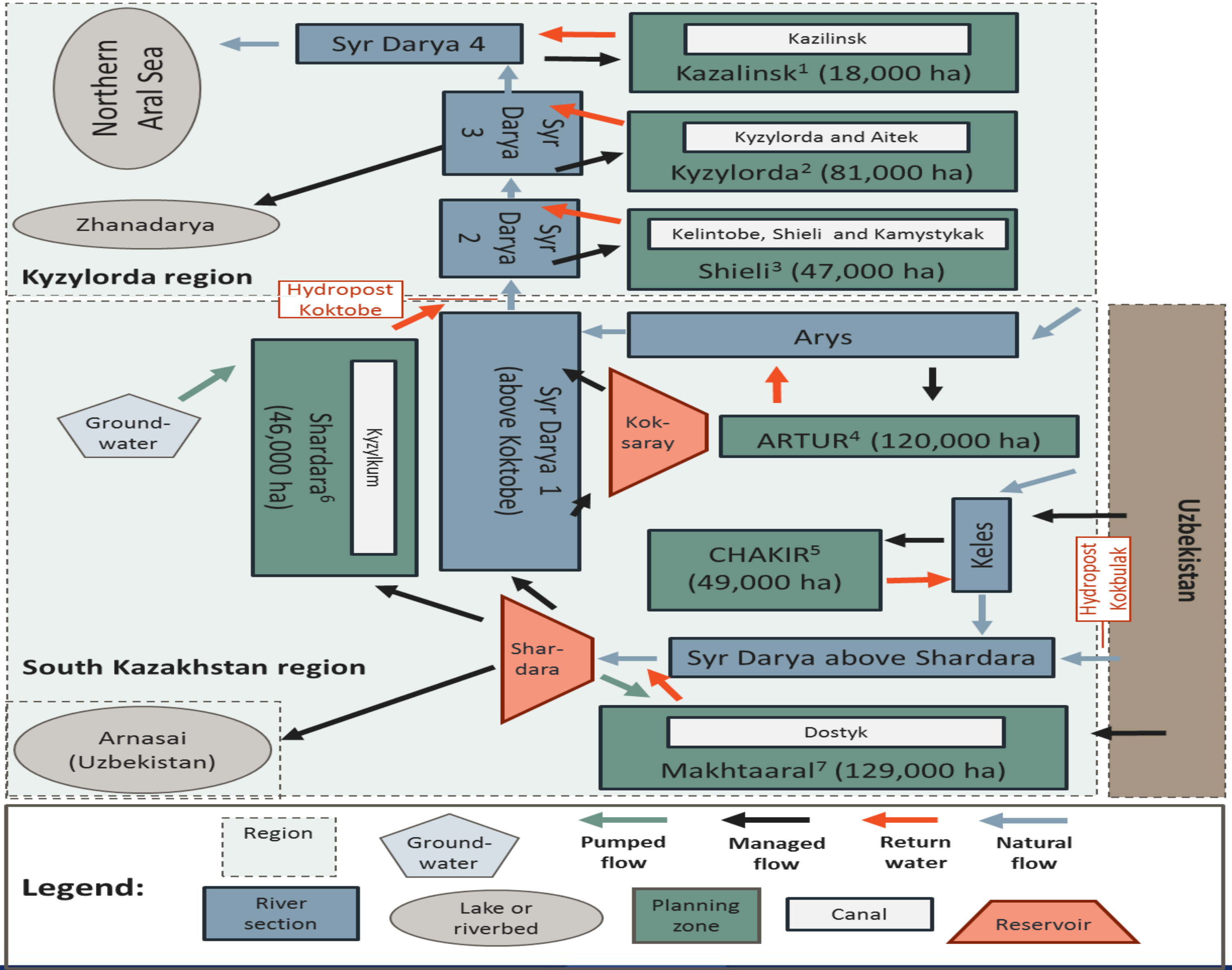
› Irrigation water tariffs reform; or Changes in taxes or government subsidies related to MPWI.

The case of Shardara MPWI - Low Syr Darya - Northern Aral Sea Basin



The case of Shardara MPWI – schematic

Source: https://www.oecd.org/countries/kazakhstan/strengthening-multi-purpose-water-infrastructure-in-shardara-mpwi-kazakhstan-9789264289628-en.htm)



Specificity of MPWI, irrigation & flood protection systems

General observation: High (& growing, due to climate) variability of seasonal precipitation and annual run-off ==> high risks and uncertainty for water users; and Costly mistakes of wrong forecasting of (spring/autumn or flash) floods - examples

Irrigation: in many regions (e.g. arid areas in Central Asia, or *Volgodrad oblast & Kalmykiya in Russia*) the value of land spots very much depends on the access to irrigation water

- **large upfront investment**, ideally building irrigation systems jointly with collector-drainage systems, to increase yields and prevent the land salinity problem), but **relatively low O&M** costs (e.g. in Kyrgyzstan, at some 40 USD per hectar) compared to additional agri-food produce on irrigated land vs non-irrigated land (e.g. USD 5000 versus USD 2000 per hectar)

- **significant water losses** (evaporation fm open canals - the case of AUS, infiltration, non-accounted for water \ non-revenue water)

- challenge of **ensuring equity** in access to irrigation water (upstream vs downstream users)

- **the need for co-operative management of large systems** (sometimes 100s km) ==> the challenge related to selecting a sustainable business model (BM): e.g. state irrigation system + water-users associations + individual agri-food producers

Multi-Purpose Water Infrastructure (MPWI): the need to manage trade-offs impacting major water uses, incl. (i) saving water for irrigation during vegetation period (late spring - summer) *versus* using water for electricity generation at winter times; or (i) water for environment *versus* (ii) water for irrigation & electricity.

Flood & mud-flow protection systems: often generate no revenues but prevents fm huge losses ==> should be funded fm the public budget; the benefits = prevented losses of life & economic assets.

THANK YOU FOR YOUR ATTENTION!

Literature

OECD (2017): Environment Working papers No. 115: *Managing Multi-Purpose Water Infrastructure*

OECD (2018): *Strengthening Shardara Multi-Purpose Water Infrastructure in Kazakhstan* https://www.oecd.org/countries/kazakhstan/strengthening-multi-purpose-water-infrastructure-in-shardara-mpwi-kazakhstan-9789264289628-en.htm)

TACIS (2000), *Working paper # 49,* produced under the project titled "*Institutional support to Goscomecologia of Russia*"

Гальперин В.М., Игнатьев С.М., Моргунов В.И., *Микроэкономика* (тома 1-2, раздел 10.9 Естественная монополия) - СПб: Экономическая школа ГУ ВШЭ, 2008

Мартусевич А.П., Мартусевич Р.А. (2010), *«Особенности ВКХ, определяющие сложности регулирования и создания рынка в отрасли»*, Вестник РАВВ. № 6'2010, Москва

Региональный проект USAID по водным ресурсам и окружающей среде (в Центральной Азии), Турсуналиева Д.М., Мартусевич А.П., Сиваев С.Б., *Учебный модуль 2: «Особенности рынка воды и регулирования водохозяйственных услуг»*

КЭУ (2023), *Экономические инструменты управления для устойчивого развития водного хозяйства и повышения уровня водной безопасности* (есть в библиотеке НИУ-ВШЭ)

HSE UNIVERSITY • EST 1992 •