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3. Determining Potential Water Savings due to investments

Water Losses, Efficiencies and Potential Water Savings

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Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

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1. Potential Water Savings

- Potential Water Savings (*PWS*), according to Article 46:

$$PWS = U_{old} - U_{new}$$

  - The difference between the water use before the investment is made – U_{old} and the water use after the investment – U_{new}.
  - U_{old} is the average current water use, in case of bad or not satisfactory technical status of the IS or the irrigation equipment
  - U_{new} is the anticipated (or expected) average water use in the future, decreased, due to investments and improved technical status of the IS or the irrigation equipment
- Relative Potential Water Savings (*RPWS*) can be defined as:

$$RPWS = \frac{U_{old} - U_{new}}{U_{old}}$$

1. Potential Water Savings

- PWS have to be estimated on the same basis, i.e. at *the same net water use* before and after the investments are made.
  - The net water use is: $U_{net} = F.M_{net}$, m^3,

where F is the irrigation system area, ha

M_{net} is the net irrigation requirement, estimated on the basis of the entire IS area, m^3/ha.

- The gross water use before the investment is made is:

$$U_{gross}^{old} = \frac{FM_{net}}{\eta_{IS}^{old}}$$

  - where η_{IS}^{old} is the overall IS efficiency before the investment.
- The gross water use after the investment will be:

$$U_{gross}^{new} = \frac{FM_{net}}{\eta_{IS}^{new}}$$

1. Potential Water Savings

- If it is assumed:
  - The net irrigation requirement M_{net} will be the same before and after the investment, and
  - The IS area F will be the same,
- The following short formula for estimation of PWS is present:

$$PWS = U_{gross}^{old} - U_{gross}^{new} = \frac{FM_{net}}{\eta_{IS}^{old}} - \frac{FM_{net}}{\eta_{IS}^{new}} = FM_{net}\left(\frac{\eta_{IS}^{new} - \eta_{IS}^{old}}{\eta_{IS}^{old}\eta_{IS}^{new}}\right)$$

- The formula for direct estimation of the $RPWS$ is:

$$RPWS = \frac{U_{gross}^{old} - U_{gross}^{new}}{U_{gross}^{old}} = \frac{FM_{net}\left(\frac{\eta_{IS}^{new} - \eta_{IS}^{old}}{\eta_{IS}^{old}\eta_{IS}^{new}}\right)}{\frac{FM_{net}}{\eta_{IS}^{old}}} = \frac{\eta_{IS}^{new} - \eta_{IS}^{old}}{\eta_{IS}^{new}}$$

1. Potential Water Savings

- Considering the short formula for *RPWS*, if the old and new efficiencies of the IS are known, on can quickly estimate expected *RPWS* and can see if the eligibility requirement is met.
- To estimate *RPWS*:
  - ➢ The current efficiency of the IS η_{IS}^{old} has to be determined
  - ➢ The new efficiency of the IS η_{IS}^{new} has to be obtained
    - ✓ The value of the new efficiency η_{IS}^{new} depends on the measures taken during the process of improvement of the IS infrastructure
  - ➢ The investments may be used for improvement of:
    - ✓ the **technical status** of the IS (i.e. to decrease the technical losses)
    - ✓ the **operational capabilities** of the IS (i.e. to decrease the operational losses)
    - ✓ both **technical status** <u>and</u> **operational capabilities**

1. Potential Water Savings

- The *PWS* are estimated *before the investments* are made
  - ➢ Thus, *PWS* show *anticipated*, or *planned*, or *theoretical* water savings due to investments
- The actual water savings (*AWS*) are determined *after the investments* are made
  - ➢ *AWS* have to be determined on the *basis of actual measurements* done by means of the water measurement structures and devices – existing or installed as part of the investment
    - ✓ Obviously, the *AWS* have to be determined as average value for several years of operation of IS after the investments
      - – This is due to the fact that years differ – some are wet, with small irrigation requirements, some are dry, with high irrigation requirements
    - ✓ The <u>comparison</u> between *PWS* and *AWS* has to be on the same basis, i.e. it has to be *based on the same average net irrigation requirement*

1. Potential Water Savings

- The ***effective reduction of water use***, mentioned in Article 46, is the same as the actual water savings (AWS) :

$$AWS = U_{gross}^{old} - U_{gross}^{new,actual}$$

where $U_{gross}^{new,actual}$ is the actual gross water use after the investments.

- It is possible and it is natural to have AWS less than PWS.
  - ➢ Possible reasons:
    - ✓ Overestimation of the effect of the rehabilitation works
    - ✓ Overestimation of the effect of the implemented new automation or new method for water distribution
- That is why the requirement is to have at least AWS =50%PWS
  - ➢ In case of water body with status less than good, related to quantity
  - ➢ In case of increase of the irrigated area.

1. Potential Water Savings

- The ***level of the investment***
  - When PWS or efficiencies are estimated it is essential to specify *at which point* of the IS this is done
  - The main idea behind the requirements of Article 46 is to assure that EU funded investments lead to water savings, i.e. lead to decrease of the abstraction from water bodies.
- The ***level of the investment*** should mean that part of the IS which benefits from the investments
  - ***Benefit*** means that the water losses are decreased in that part of the IS (thus, the water use is decreased in that part of IS)

Example: One cannot expect that the decrease of the water use in a single farm will have an effect of reduction between 5% and 25% of the water use in entire IS.

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1. Potential Water Savings

- The ***level of the investment*** may be:
  - ➢ **a farm** – when investment is for new, water saving irrigation equipment
    - ✓ *example*: switching from surface or sprinkler irrigation to drip
  - ➢ **a Water User Association** or **Irrigation Field** – when the investment is for improvement of:
    - ✓ (part of) distribution network and/or
    - ✓ water distribution method and/or
    - ✓ automation of water delivery.
  - ➢ **part of IS** – when investments are used for improvement of technical or operational status of part of the delivery network
  - ➢ **IS as a whole** – when head reach of the main canal is included in rehabilitation (improvement) together with other parts of the delivery network

2. Losses of Water

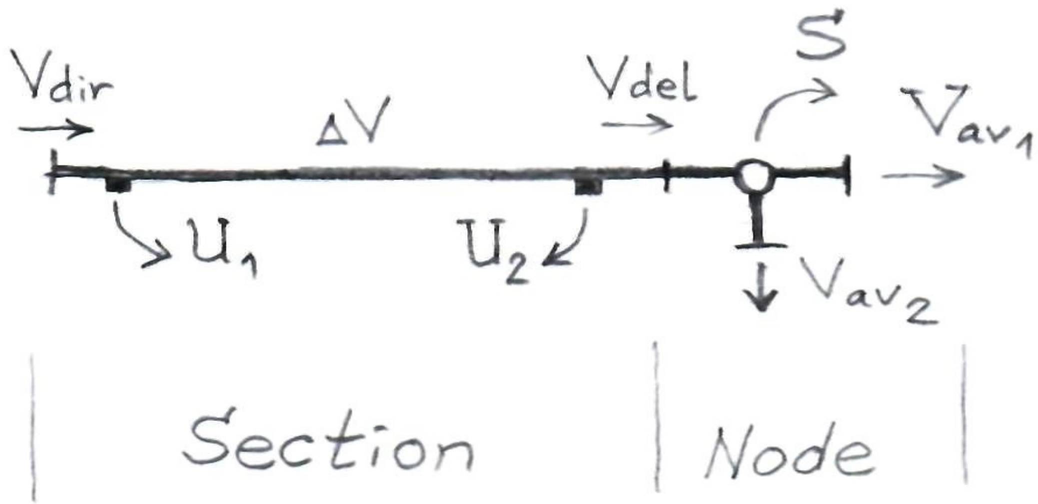
- One of the most important issue related to operation of Irrigation Systems is the problem of water losses
- There are two sides interested in decrease of water losses
  - ➢ The Irrigation System Operator
    - ✓ the abstracted water is paid to the State
    - ✓ loss of water means loss of resource, which can be sold
    - ✓ there are expenses for water delivery, but only part of them are returned back when small amount of water is sold.
    - ✓ the price of water is higher than it can be
  - ➢ The farmers
    - ✓ usually farmers pay the losses – the expenses for water delivery are included in price of water
    - ✓ *in dry years the water is not enough for all farmers*

2. Losses of Water

- The irrigation water “travels” down the following way:
  - ➢ it is abstracted from the water source
  - ➢ it is transported through delivery network of IS
  - ➢ it is transported through the distribution network of IF to farms
  - ➢ it is applied on soil.
- There are losses of water in each element of the IS during transport, distribution and application, due to imperfection of the structures, equipment and operation of the system
- The losses of water in IS are significant problem
  - ➢ They lead to unjustified abstraction from water sources
  - ➢ They increase the price of water
  - ➢ They may cause waterlogging
  - ➢ They may cause damage to infrastructure

2. Losses of Water

- The following **volumes of water** V can be defined for the needs of losses estimation:
  - **Directed – $V_{directed}$**
  - **Delivered – $V_{delivered}$**
  - **Available – $V_{available}$**
- The discharges Q can be defined in the same way



2. Losses of Water

- The following **volumes of water** V can be defined for the needs of losses estimation:
  - ➢ **Directed –** $V_{directed}$ – the volume which passed through the inlet of the element (e.g. a canal).
    - ✓Sometimes it can be called volume at the inlet V_{in}
  - ➢ **Delivered –** $V_{delivered}$ – the volume at the outlet of the element
    - ✓Sometimes it can be called volume at the outlet V_{out}.
    - ✓Not all water directed at the inlet comes to outlet, due to losses (and water delivered to clients along the canal section).
  - ➢ **Available –** $V_{available}$ – the volume which is available for use by the next element of the IS (e.g. canal, pumping station, etc.)
    - ✓Not all water delivered at the canal section end can be available for use – e.g. part of water can be spilled, thus it is unused.
- The discharges Q can be defined in the same way

2. Losses of Water

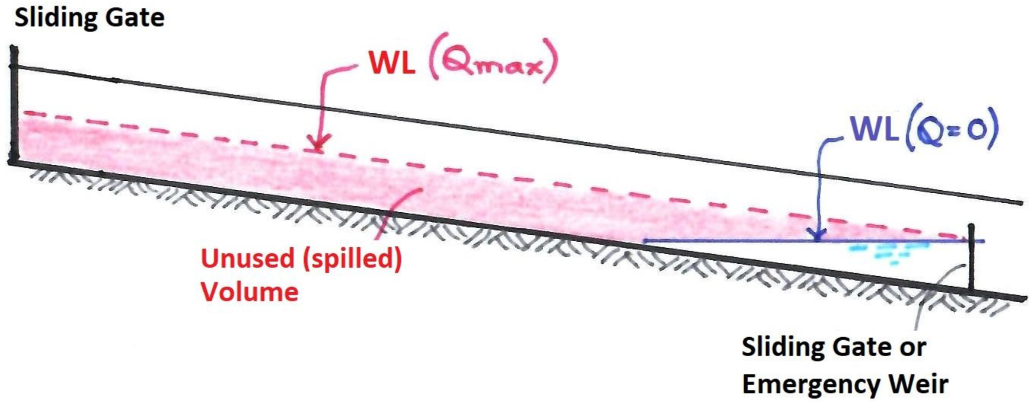
- The losses can be divided in 2 groups from point of view of management
  - ***Technical losses*** - ΔV
    - ✓ $\Delta V = V_{directed} - V_{delivered} - \Sigma U$ (1)

where ΣU is the sum of all volumes delivered to clients

- ✓ Technical losses depend on the technical status of the canals, pipelines, structures, valves and irrigation equipment.
- ✓ Part of the technical losses are inevitable due to construction and the technical features of different elements of the IS
  - Even if the elements are in perfect technical status there are some losses
- ✓ Part of the technical losses can be avoided, by improving the technical status of different elements.
  - These are manageable losses

2. Losses of Water

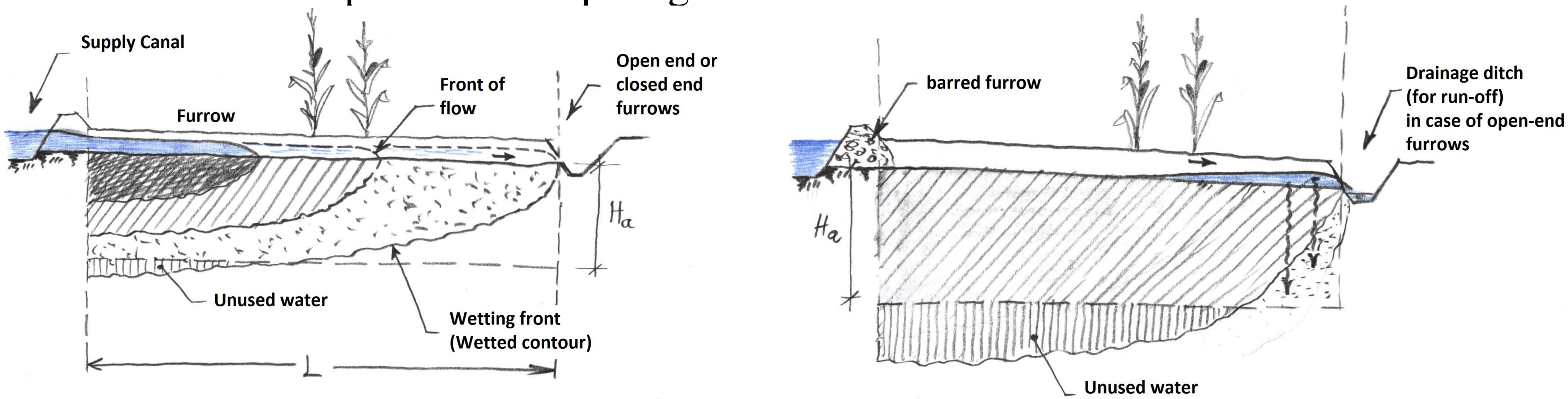
- ***Operational (Technological) losses* - ΔOp**
  - ✓ $\Delta Op = V_{delivered} - V_{available}$ (2)
  - ✓ Operational losses depend on:
    - – Water distribution type used in the IS
      - » the selected type and the structures/facilities used for its implementation predetermines the level of unused water (losses)
      - » for example – if a canal operates periodically (say 10 days in a month), it should be filled with water before put in operation – this leads to serious waste of water – spilled water from the canal after each irrigation cycle.



      - » it is possible to have zero technological looses in some instances.

2. Losses of Water

- ***Operational (Technological) losses*** - ΔOp
  - ✓ $\Delta Op = V_{delivered} - V_{available}$ (2)
  - ✓ Operational losses depend on:
    - – Type of irrigation equipment in the farm
      - » for example – surface irrigation lead to much more unused water in comparison to drip irrigation



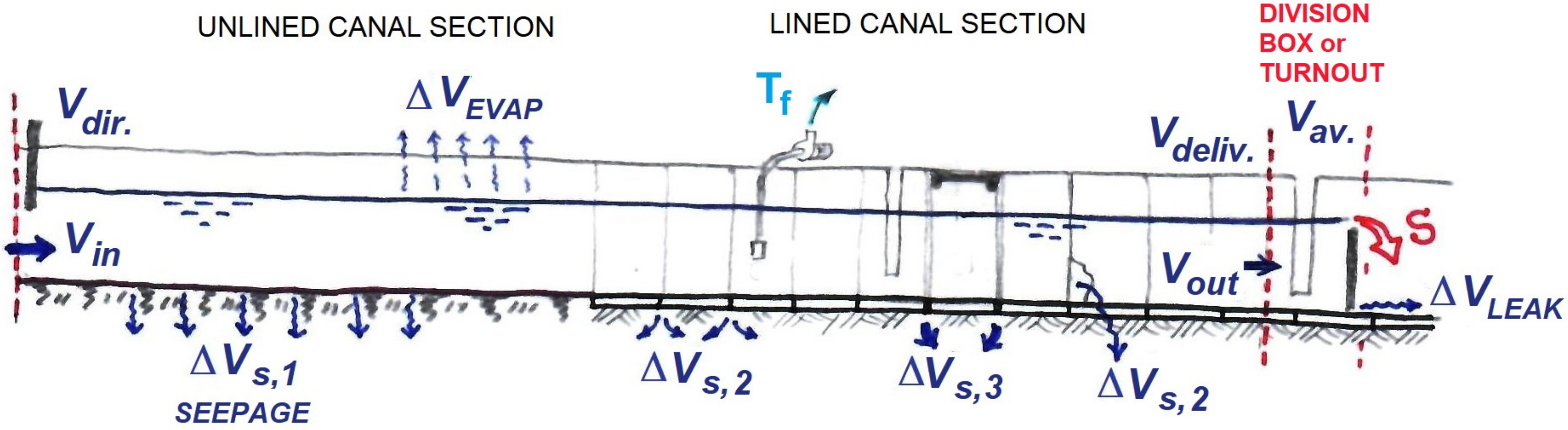
- ✓Part of operational losses are avoidable and manageable.
- ✓ Usually, ΔOp are equal to spilled water S at the end of canal section

2. Losses of Water

- Types of losses according to the structural level of the IS:
  - Losses in Delivery Network of IS
  - Losses in Distribution Network of the Irrigation Fields (IF)
  - Losses in farms
- Types of Losses according to the reasons:
  - Evaporation losses – ΔV_{EVAP}
  - Seepage losses – ΔV_{SEEP}
  - Leakage losses – ΔV_{LEAK}
  - Spilled (unused) water or surface runoff losses – S
  - Accident losses – A_L (due to breakdowns and accidents)
  - Thefts – T_f (all water used, but not paid).

2. Losses of Water

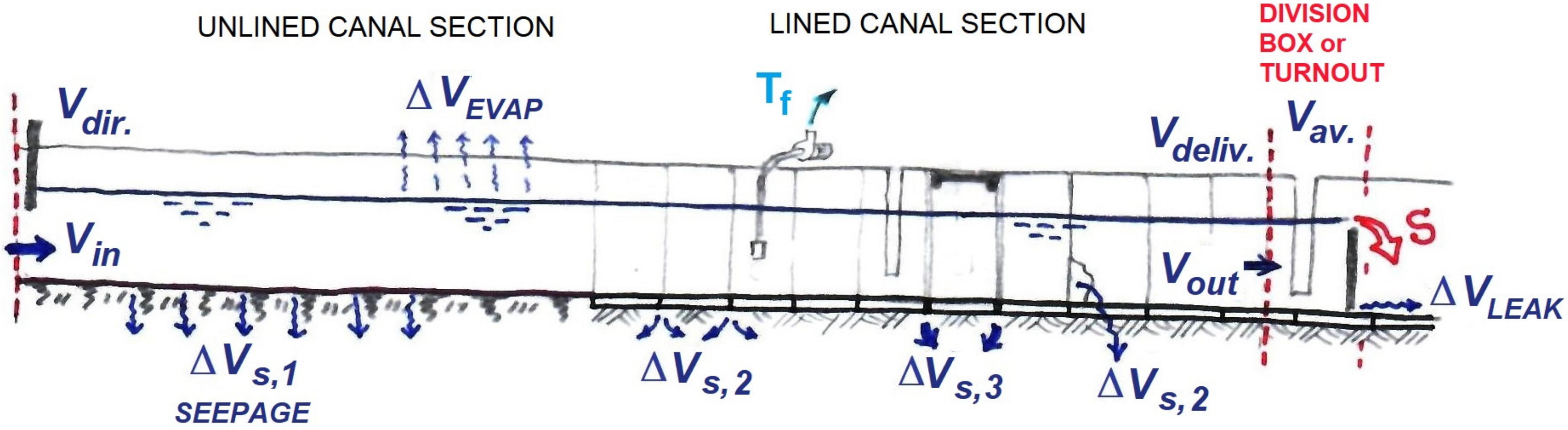
- Losses in Delivery Network of IS



- **Evaporation losses** – ΔV_{EVAP} – from water surface of canals and regulating reservoirs;
- **Seepage losses**
  - ✓ unlined canals – from bed and slopes– ΔV_{S1};
  - ✓ lined canals – leaks through joints and damaged lining – ΔV_{S2};
  - ✓ control structures – seepage around the structure – ΔV_{S3};

2. Losses of Water

- Losses in Conveyance and Distribution Network of IS

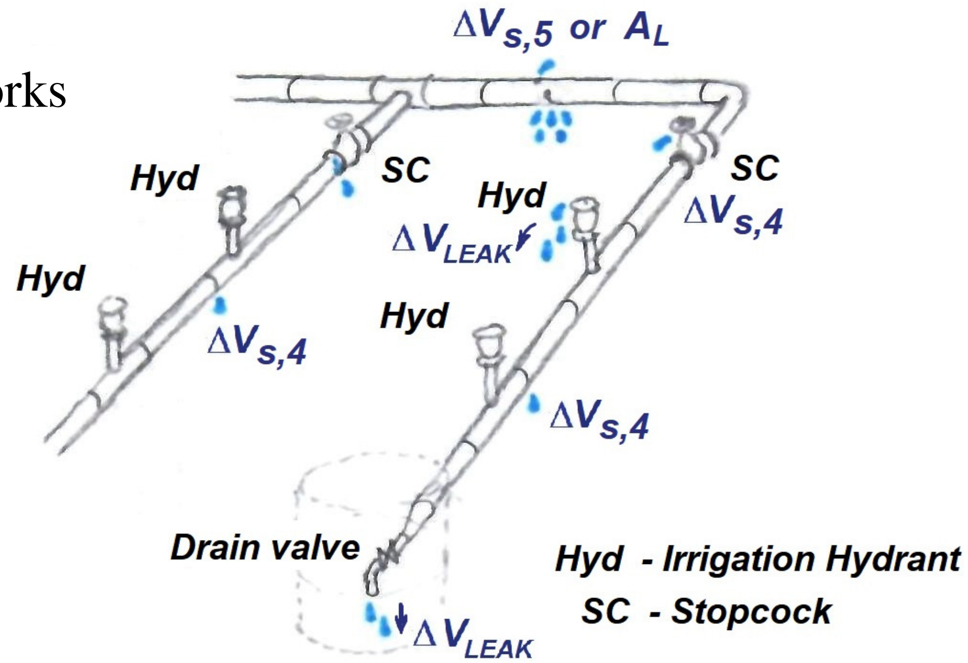


- **Leakage losses** – ΔV_{LEAK} – through gates and other regulating devices not tightly closed, slightly damaged or worn out;
- **Spills –** S – due to mismatch between delivery and consumption, i.e. technological looses due to type of water distribution;
- **Accident losses** – A_L – losses due to canal breakdowns;
- **Thefts –** T_f – all water used without it has been paid.

2. Losses of Water

- Losses in Distribution Network of IF

Pressurized Pipe Networks



➢ **Seepage losses**

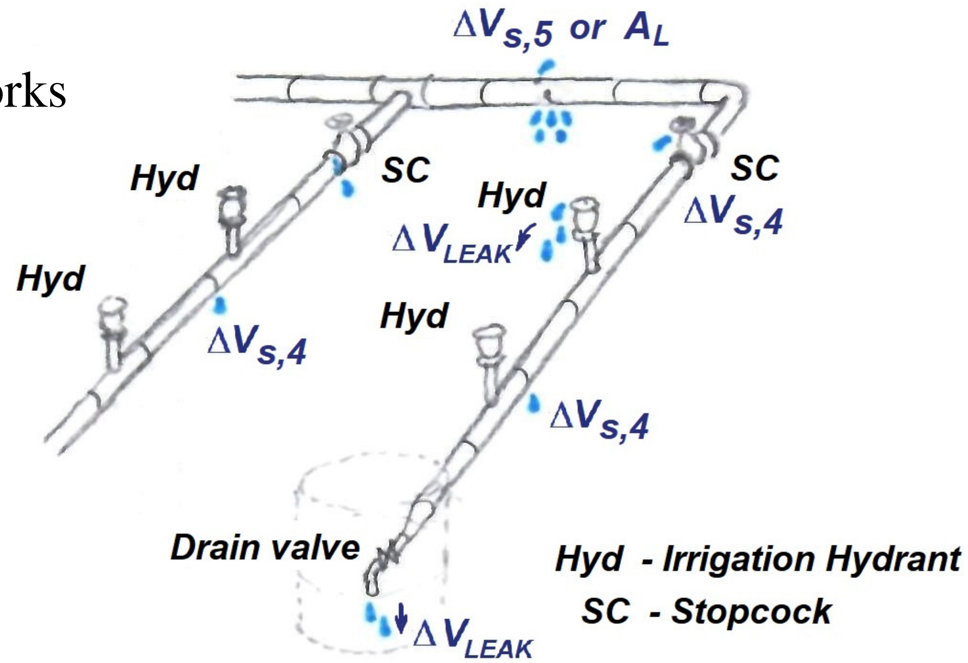
✓ seepage caused by leaks through pipe joints, through joints between pipes and valves - ΔV_{S4} ;

✓ seepage caused by cracked pipes - ΔV_{S5}

2. Losses of Water

- Losses in Distribution Network of IF

Pressurized Pipe Networks



- ➢ **Leakage losses** – ΔV_{LEAK} – leaks from valves which are not tightly closed, slightly damaged or worn out – e.g. hydrants, drains, worn out air valves, etc.
- ➢ **Accident losses** – A_L – losses due to breakdowns in pipe system
- ➢ **Thefts –** T_f – all water used without it has been paid.

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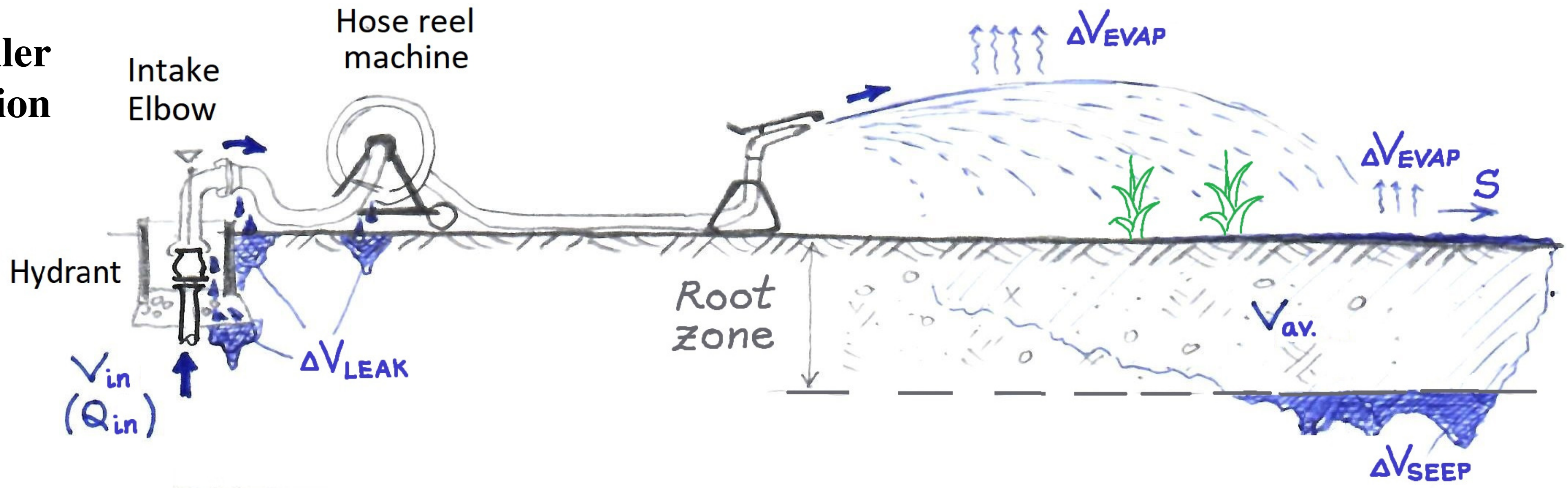
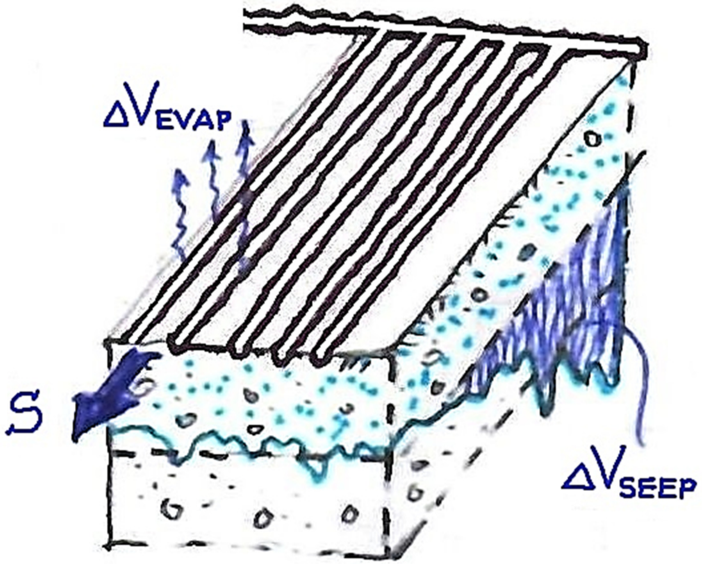
2. Losses of Water

- Losses in farms (in irrigation plots)

Sprinkler irrigation





Surface irrigation

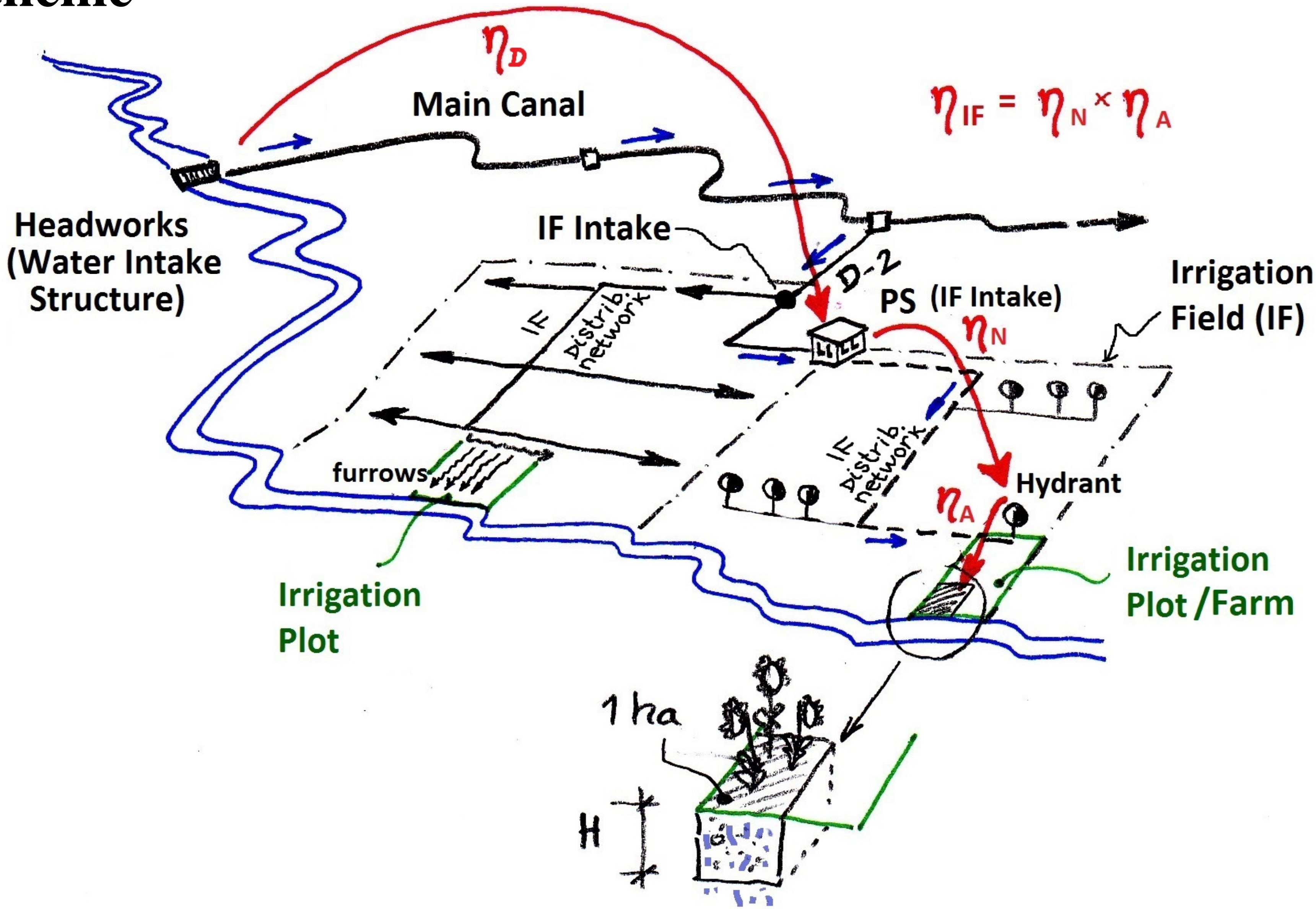
2. Losses of Water

- Losses in farms (in irrigation plots)
  - These are losses due to selected irrigation method and its equipment
    - ✓ **Evaporation losses** – ΔV_{EVAP} – observed during application; these are amounts of water spread by irrigation equipment, but not entered the soil
    - ✓ **Seepage losses** – ΔV_{SEEP} – water infiltrated below the root zone (below the soil layer of interest H)
    - ✓ **Leakage losses** – ΔV_{LEAK} – water lost at the irrigation equipment
    - ✓ **Surface runoff losses** – S – due to very high application rate or bad timing of the application.
    - ✓ **Accident losses** – A_L – losses due to equipment breakdowns

N.B: The losses ΔV_{SEEP} and S can be classified as *operational losses*, because they can be controlled and minimized during application. However, the losses in farms can hardly be separated to pure technical and pure operational losses.

3. Efficiency of Irrigation Systems

- **Scheme**



3. Efficiency of Irrigation Systems

- The *efficiency* of IS is related with the losses of water in the IS
- **The efficiency** (η) can be defined as:

  the ratio between volumes available for use $V_{available}$ and the volumes directed for use $V_{directed}$.
- The efficiency can be estimated for the entire IS, for a part of the IS or for any element of the system
- Sometimes, the efficiency is defined as the ratio between the net V_{net} and the gross V_{gross} volumes of water
  - The net volume equals to gross volume minus losses.
  - The problem is which losses are taken into account and which is V_{gross}
- The efficiency is: $\eta = \dfrac{V_{available}}{V_{directed}} = \dfrac{V_{net}}{V_{gross}} = \dfrac{V_{in} - \Delta V - \Delta Op}{V_{in}} = 1 - \dfrac{\Delta V + \Delta Op}{V_{in}}$

3. Efficiency of Irrigation Systems

- The following types of efficiencies can be defined:
  - **Technical efficiency** – η_T – it takes into account the technical losses (and also accident losses A_L and thefts T_f – *see the note*)
    - $$\eta_T = \frac{V_{delivered}}{V_{directed}} = \frac{V_{out}}{V_{in}} = \frac{V_{in} - \Delta V}{V_{in}} \qquad (1)$$
    - In this case: $\Delta V = \Delta V_{EVAP} + \Delta V_{SEEP} + \Delta V_{LEAK}$ (+ T_f).
  - **Operational efficiency** – η_{op} – it takes into account only the operational losses – usually only spills – S
    - It is estimated as:
    - $$\eta_{op} = \frac{V_{available}}{V_{delivered}} = \frac{V_{in} - \Delta V - S}{V_{in} - \Delta V} \qquad (3)$$

3. Efficiency of Irrigation Systems

- **Overall Efficiency** – η_0 – it takes into account both technical and operational losses

  - ✓ $$\eta_0 = \frac{V_{available}}{V_{directed}} = \frac{V_{in} - \Delta V - S}{V_{in}}$$, thus
  - ✓ $\eta_0 = \eta_T . \eta_{op}$.

N.B. The losses from thefts T_f are neither technical, nor operational. However, they can be classified as technical losses, due to the fact that they cannot be exactly measured and part of them can be described as inevitable.

3. Efficiency of Irrigation Systems

- **Application of different types of efficiencies**
  - **Technical efficiency** can be used both for the *volumes V* and for the *discharges Q*

$$\eta_T = \frac{V_{in} - \Delta V}{V_{in}} \qquad \text{или} \qquad \eta_T = \frac{Q_{in} - \Delta Q}{Q_{in}}$$

where ΔQ are the discharge losses due to technical reasons

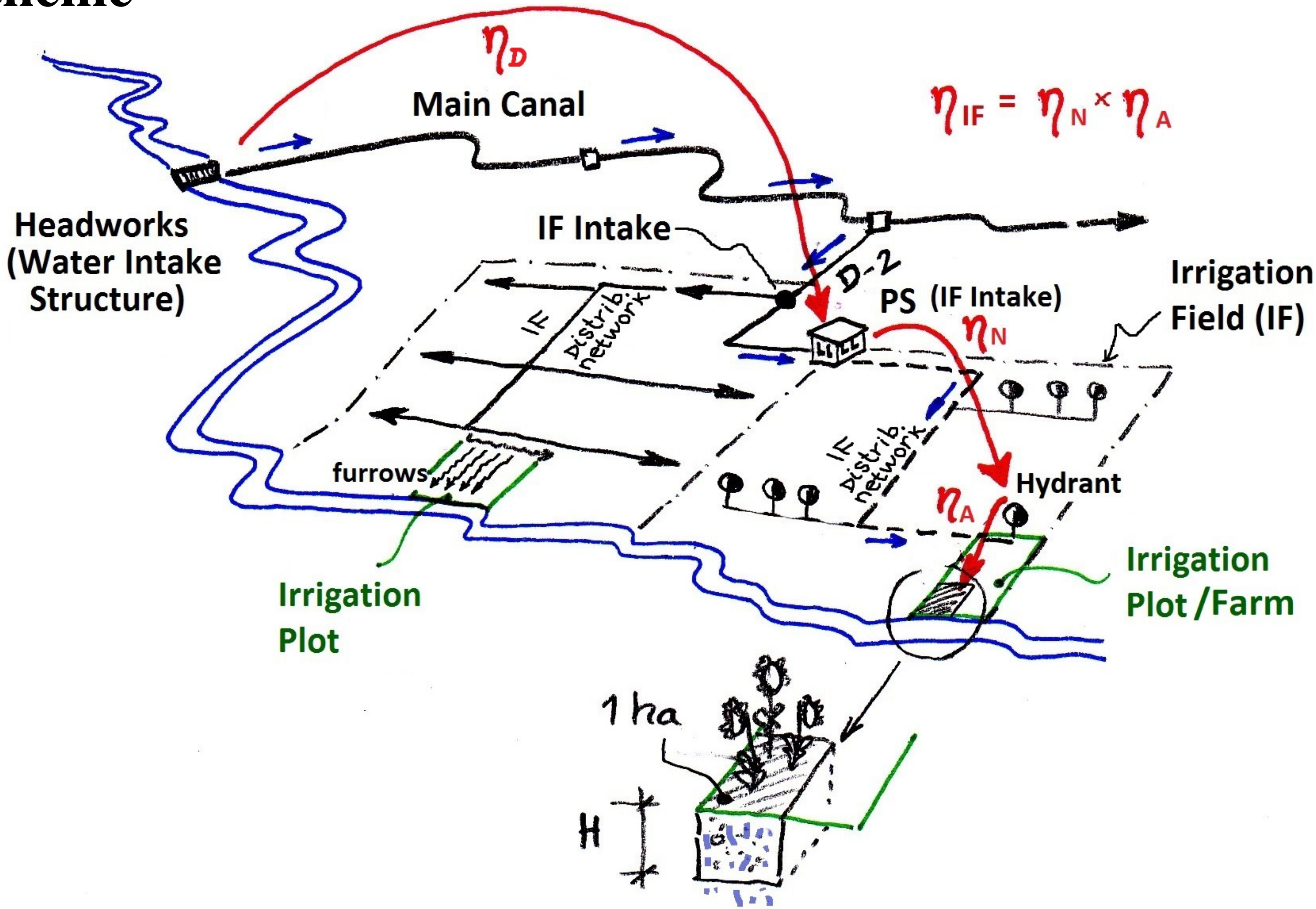
  - **Technical efficiency is used for estimation of the design discharges of the canal and pipe network**
    - ✓ Operational losses represent the lost *volumes*, due to insufficiency of the distribution method
    - ✓ In that respect, the operational losses should not be taken into account when design *discharges* are estimated, since the discharges are increased unreasonable.

3. Efficiency of Irrigation Systems

- **Application of different types of efficiencies**
  - **Overall efficiency** *should* be used in all cases of estimation of the water consumption (***water use***) as *volumes*:
    - ✓ when water resources planning are performed
    - ✓ when water budget of a reservoir is done
    - ✓ when the water abstraction from a water source is estimated
  - It is hard to distinguish technical and operational losses in real (exploitation) conditions, **thus regular measurements have to performed.**

3. Efficiency of Irrigation Systems

- **Scheme**



3. Efficiency of Irrigation Systems

- **Delivery network efficiency η_D –** the ratio between the volume delivered to field outlet(s), i.e. intake(s) of Irrigation Field(s) and the volume of water discharged at the head of the Main canal.
  - ✓ $\eta_D = \eta_{MC} \cdot \eta_{DC}$,

where η_{MC} is the efficiency of the Main canal

η_{DC} is the efficiency of the Distributary canals

- ✓ In Bulgaria, these are overall efficiencies, which take into account both technical losses and operational losses
- ✓ It is possible to use the above formula for calculation of technical or the operational efficiencies, according to the definitions and principles, presented in previous slides.

3. Efficiency of Irrigation Systems

- **Efficiency η of a single canal –** takes into account both technical and operational losses.
  - *For example*, for Main canal

$$\eta_{MC} = \eta_T \eta_{op},$$

where η_T is the technical efficiency of the Main canal

η_{op} is the operational efficiency of the Main canal

- **According to Bulgarian Standards:**

η_T = 0,85 ÷ 0,90 in case of lined canal;

η_T = 0,95 ÷ 0,98 in case of pipeline.

η_{Op} = 0,75 – for non-automated IS, operated under scheduled delivery;

η_{Op} = 0,90 – for automated IS, which uses scheduled delivery principle;

η_{Op} = 1,00 – for automated IS, which uses "on-demand" delivery principle

3. Efficiency of Irrigation Systems

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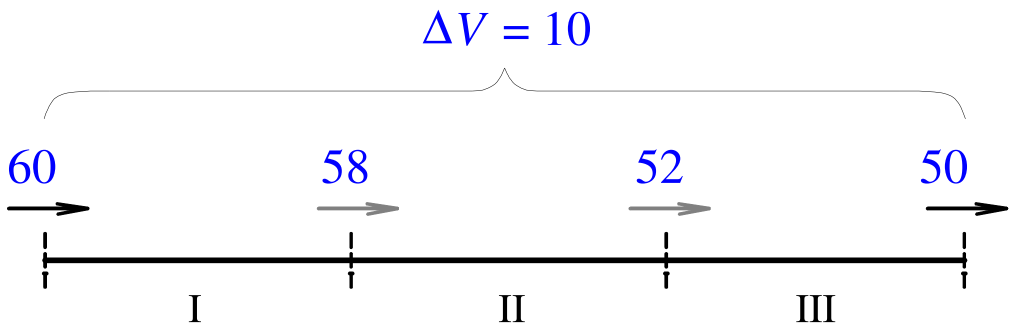
➢ Efficiency η of multiple canals

✓ if the canals are connected in series – the *aggregate efficiency* η_Σ is a *product* of the efficiencies of different canals.

$$\eta_\Sigma = \eta_I \, \eta_{II} \, \eta_{III} \,,$$

where η_I, η_{II} and η_{III} are the efficiencies of 1st, 2nd and 3rd canal (or canal sections of a single canal)



20% ΔV 60% ΔV 20% ΔV

$\Delta V_I = 2{,}0$ $\Delta V_{II} = 6{,}0$ $\Delta V_{III} = 2{,}0$

$$\eta_I = \frac{58}{60} = 0{,}967 \qquad \eta_{II} = \frac{52}{58} = 0{,}897 \qquad \eta_{III} = \frac{50}{52} = 0{,}962$$

$$\eta_{T,\Sigma} = \frac{50}{60} = 0{,}833$$

N.B. The above formula is valid only in case if there are no turnouts in the canal sections or at the nodes between canals

3. Efficiency of Irrigation Systems

- **Efficiency η of multiple canals**
  - ✓ if the canals are connected in parallel – the *aggregate efficiency* η_Σ is *an average* value of the efficiencies of different canals.

$$\eta_\Sigma = \frac{\sum_j \eta_j}{n}$$

where η_j is the efficiency of the j-th canal in parallel;

n – number of canals in parallel.

- Overall efficiency of multiple canals
  - ✓ The canals of IS delivery network is divided in several groups
  - ✓ In each group the canals are either in series, or in parallel
  - ✓ The efficiency of each group is estimated as described above
  - ✓ The overall efficiency is a product of the efficiency of the groups

3. Efficiency of Irrigation Systems

- **Irrigation Field Efficiency η_{IF} –** the ratio between the volume delivered ***into soil*** (root zone) and the volume of water run through the intake of the Irrigation Field.

$$\eta_{IF} = \eta_N \, \eta_A,$$

where η_N is the efficiency of the distribution network of a IF;

η_A is the **application efficiency**

- **The efficiency of the distribution network** of the IF η_N depends on the type of the network – canals (lined or unlined) or pipelines.

✓ **According to Bulgarian Standards:**

η_N = 0,80 – for unlined canal network;

η_N = 0,85 ÷ 0,87 – for lined canal network (watercourses);

η_N = 0,95 ÷ 0,98 – for pipe network;

3. Efficiency of Irrigation Systems

- **Application efficiency** η_A – the ratio between the amount of water delivered to ***into soil*** (root zone) and the amount of water taken from the farm outlet or hydrant.
  - **According to Bulgarian Standards:**

    $\eta_A = 0{,}80 \div 0{,}82$ – for furrow or border strip irrigation;

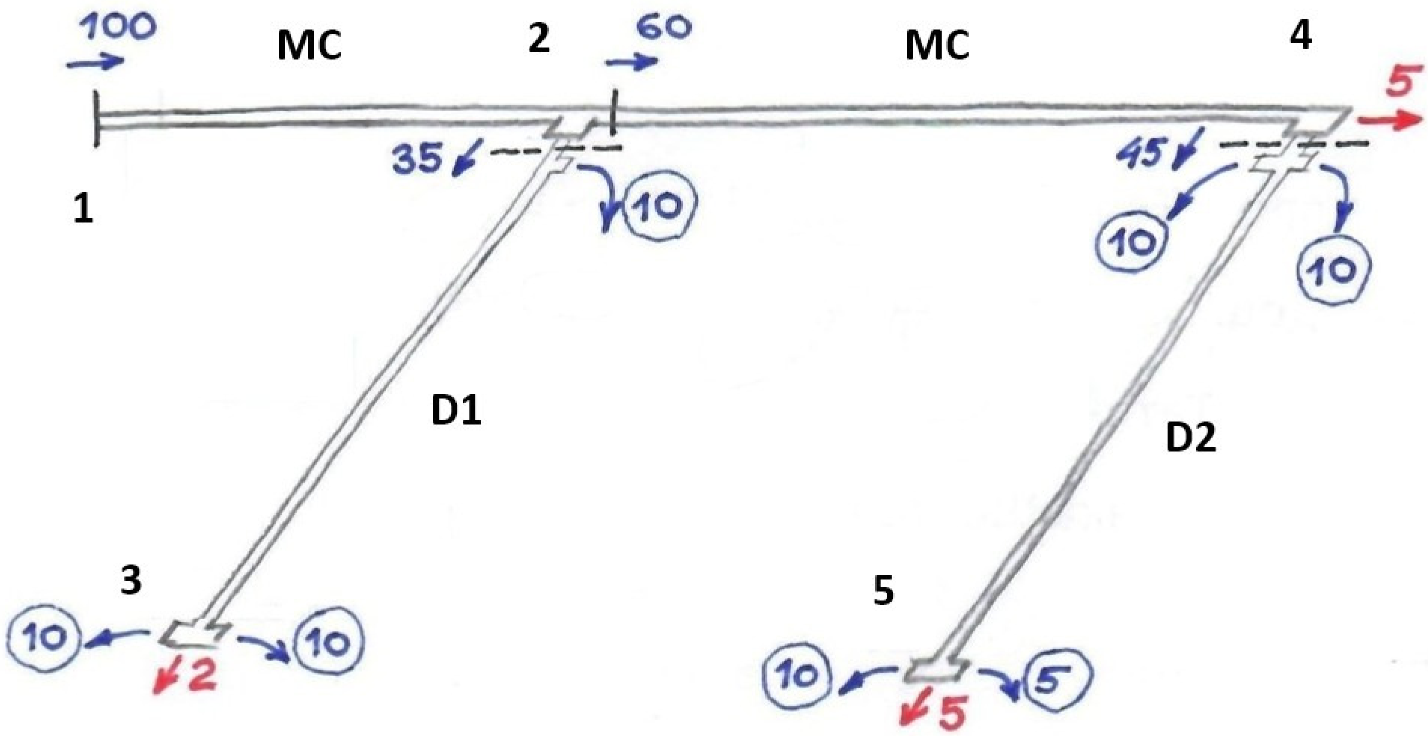
    $\eta_A = 0{,}85 \div 0{,}87$ – for sprinkler irrigation;

    $\eta_A = 0{,}95 \div 0{,}97$ – for drip irrigation.

- It should be noted that the actual (real) efficiencies are lower than those specified in the Standards.
  - For example:
    - the actual η_A for furrow irrigation can vary, according to the farmer's skills and experience between 0,67 and 0,75;
    - the actual η_A for sprinkler can be between 0,75 and 0,9 (0,9 is in case of Center Pivot Machine)

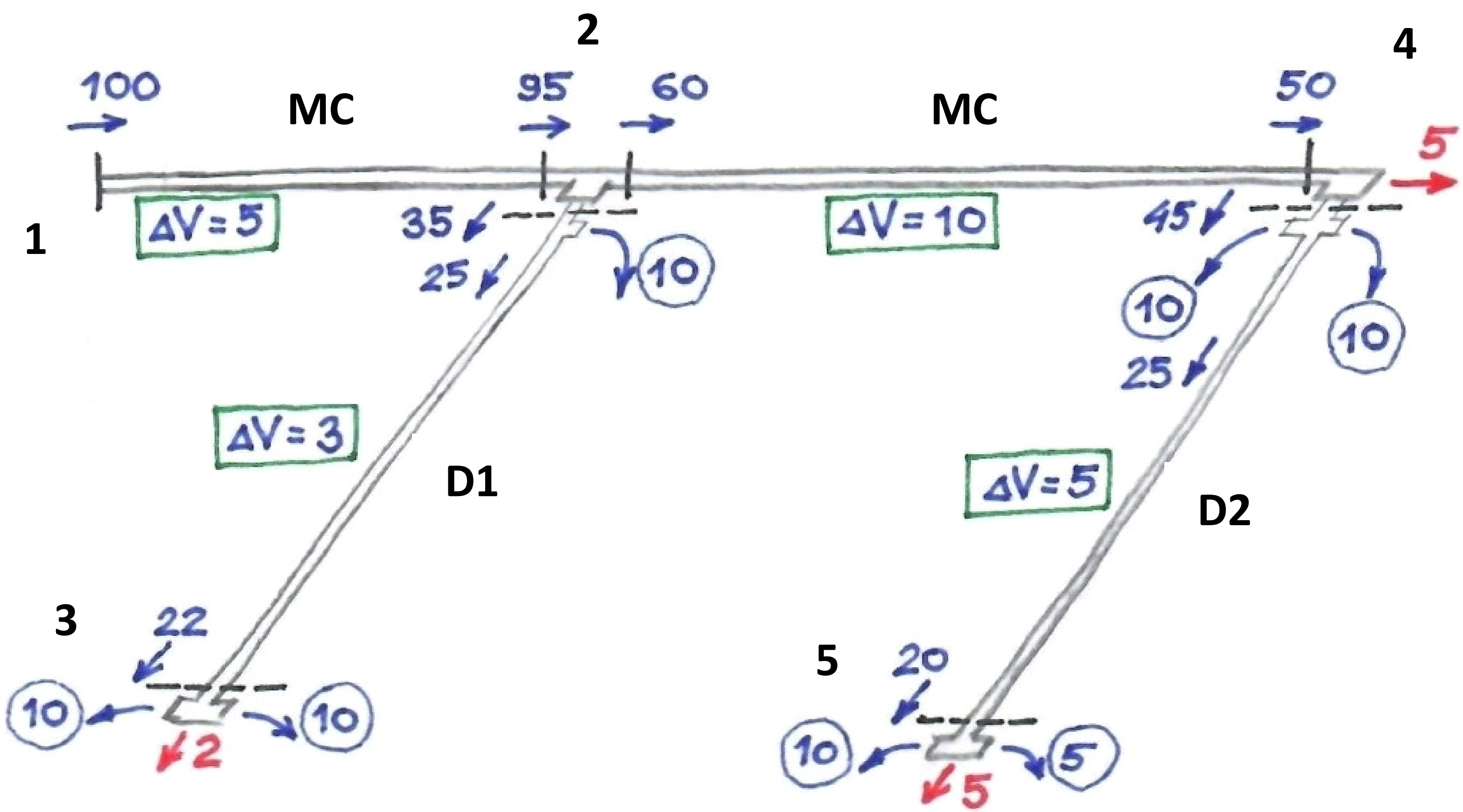
4. Potential Water Savings Example

- Student's task:
  - ➢ The terms of reference (TOR) include a schematic view of the IS and the volumes of water measured at different canal cross sections.



4. Potential Water Savings Example

- Student’s task:
  - ➢ The students have to determine the losses.



4. Potential Water Savings Example

- Student's task:
  - ➢ The students have to determine the efficiencies.

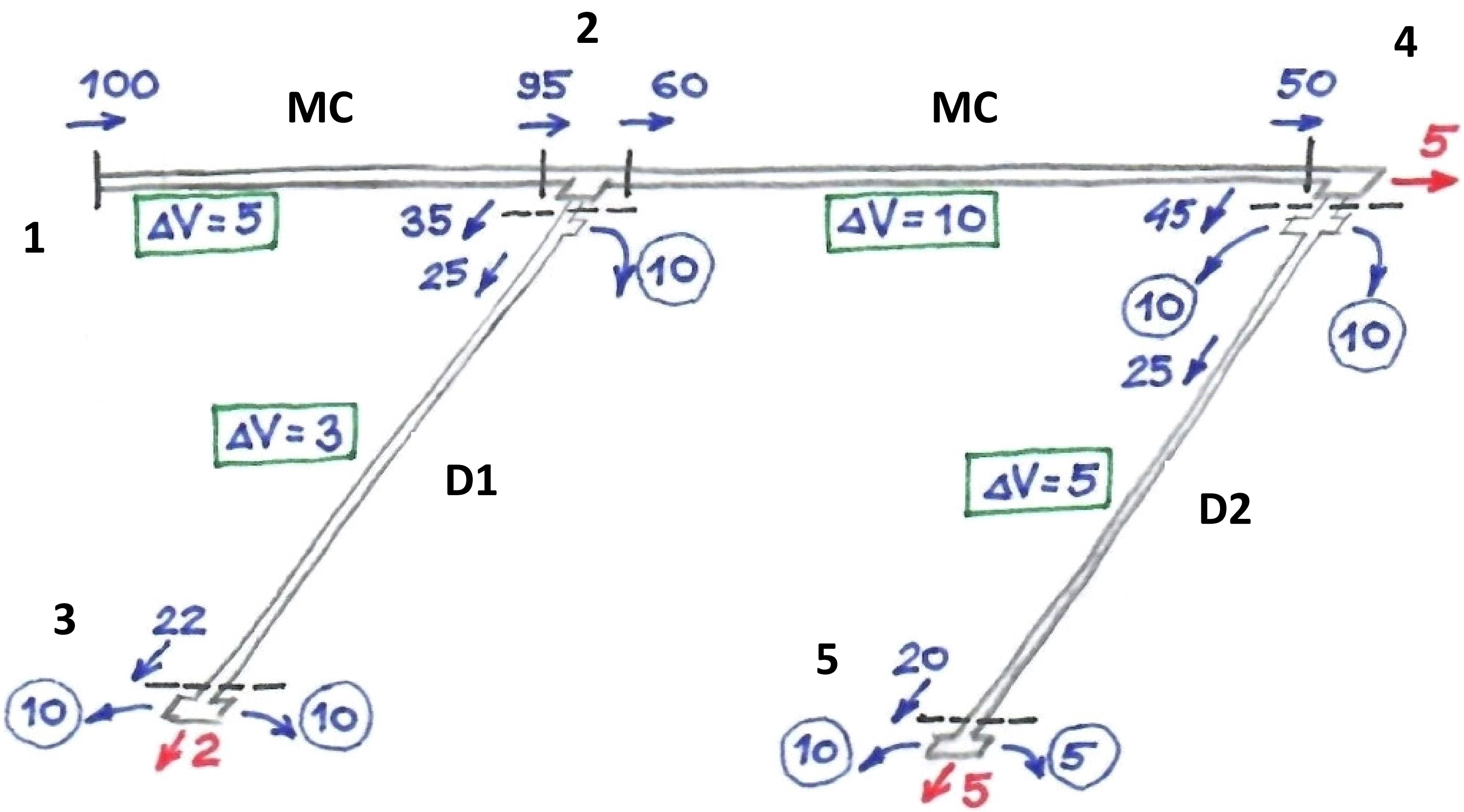
Table 1. Estimation of Water Losses and Efficiencies of the Delivery Network (Volumes in million m^3)

Canal	Section from node to node	Measured values				Estimated			
		V_{dir}	ΣV_{av}	ΣU	S	ΔV	η_T	η_{op}	η_0
1	2	3	4	5	6	7	8	9	10
M	1 – 2	100	95	0	0	5	0,95	1,0	0,95
M	2 – 4	60	45	0	5	10	0,833	0,9	0,75
	Sum/Average*	100**	-	-	5	15	**0,850**	**0,941**	**0,800**
D1	2 – 3	35	0	30	2	3	0,914	0,938	0,857
D2	4 – 5	45	0	35	5	5	0,889	0,875	0,778
	Sum/Average*	80	-	65	7	8	**0,900**	**0,903**	**0,813**
	IS Sum/Average*	100**	-	65	12	23	**0,770**	**0,844**	**0,65**

*Notes: * When considering volumes – it is a sum of the values above, when considering efficiencies – it is an average.*
*** For Main Canal and for IS, the total directed volume V_{dir} is the one, measured at the head of the first section, not sum of all directed volumes in different sections. This is due to the fact that the different sections of Main Canal are linked in series, not in parallel.*

4. Potential Water Savings Example

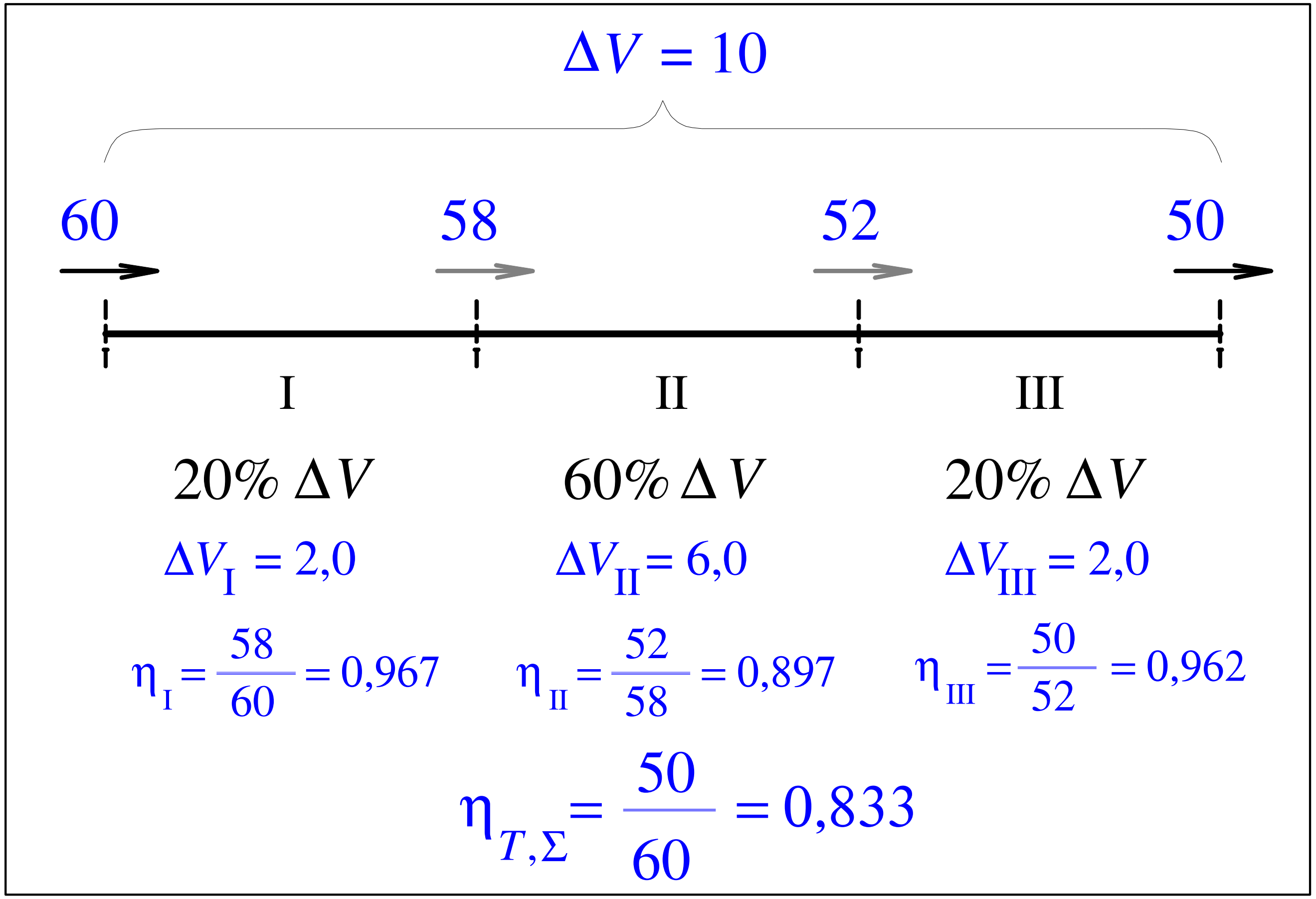
- Student's task:
  - The students have to determine the potential water savings when only one section of Main canal is rehabilitated – e.g. between nodes 2 and 4.



4. Potential Water Savings Example

- Example:
  - For that canal section the losses are decreased from 10 to 5,5 units.

The **picture** shows the water losses and delivered volumes before the investments



4. Potential Water Savings Example

- Example:
  - For that canal section the losses are decreased from 10 to 5,5 units.

The **picture** shows the water losses and delivered volumes after the investments

$$\underbrace{\Delta V_{I} = 2{,}0 \qquad \Delta V_{II}^{new} = 25\%.\Delta V_{II}^{old} = 0{,}25.6{,}0 = 1{,}5 \qquad \Delta V_{III} = 2{,}0}_{\Delta V^{new} = 5{,}5}$$

55,5 → 53,5 → 52 → 50

I II III

$$\eta_{I} = \frac{53{,}5}{55{,}5} = 0{,}964 \qquad \eta_{II}^{new} = \frac{52}{53{,}5} = 0{,}972 \qquad \eta_{III} = \frac{50}{52} = 0{,}962$$

$$\eta_{T,\Sigma} = \frac{50}{55{,}5} = 0{,}900$$

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4. Potential Water Savings Example

- Example:
  a) If **the level of investment is the canal subsection II**, i.e. the delivery network downstream of the section I, then the *RPWS* will be:

$$RPWS = \frac{58-53,5}{58} = 7,76\%$$

  b) If **the level of investment is the canal section** (between nodes 2 and 4), i.e. the delivery network downstream of the node 2, then the *RPWS* will be

$$RPWS = \frac{60-55,5}{60} = 7,5\%$$

  c) If **the level of investment is the entire IS**, then the *RPWS* will be:

$$RPWS = \frac{100-95,5}{60} = 4,5\%$$