Co-funded by the Erasmus+ Programme of the European Union

Management Issues of Irrigation Systems

Losses of Water in ISs.

Efficiency of an IS

Assoc. Prof. Petar Filkov
University of Architecture, Civil Engineering and Geodesy - Sofia

Sofia winter School 29 November – 10 December 2021
Date: 30 November – Lecture 4.

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

University of Nis

www.swarm.ni.ac.rs

Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders
Project number: 597888-EPP-1-2018-1-RS-EPPKA2-CBHE-JP

1. Losses of Water

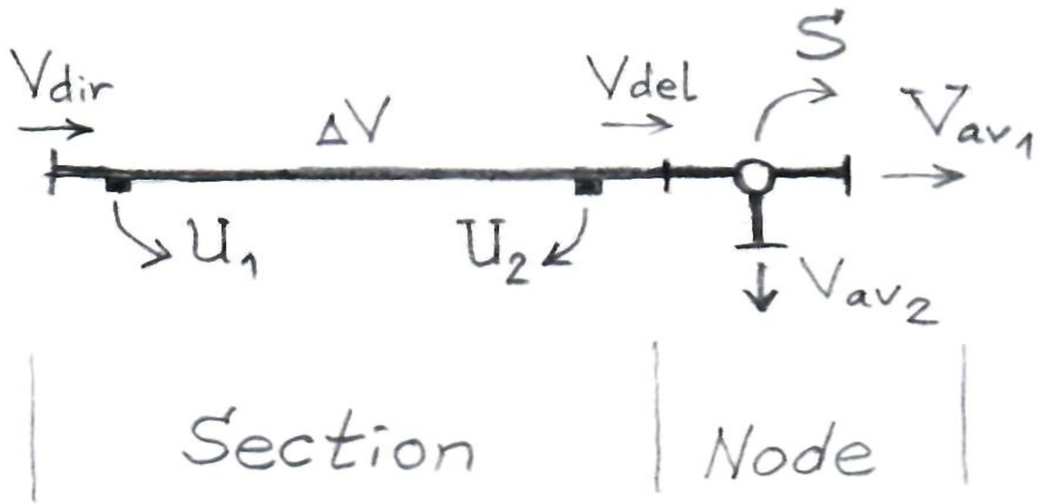
- One of the most important issue related to operation of Irrigation Systems is the problem of water losses
- There are two sides interested in decrease of water losses
  - ➢ The Irrigation System Operator
    - ✓ the abstracted water is paid to the State
    - ✓ loss of water means loss of resource, 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*

1. 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

1. 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



1. 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

1. 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)

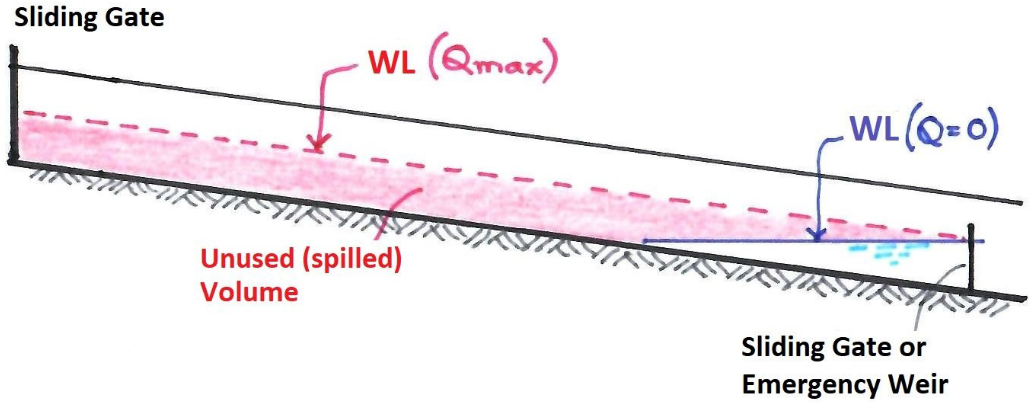
where ΣU is the sum of all volumes delivered to clients

- ✓ 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

Co-funded by the Erasmus+ Programme of the European Union

1. Losses of Water

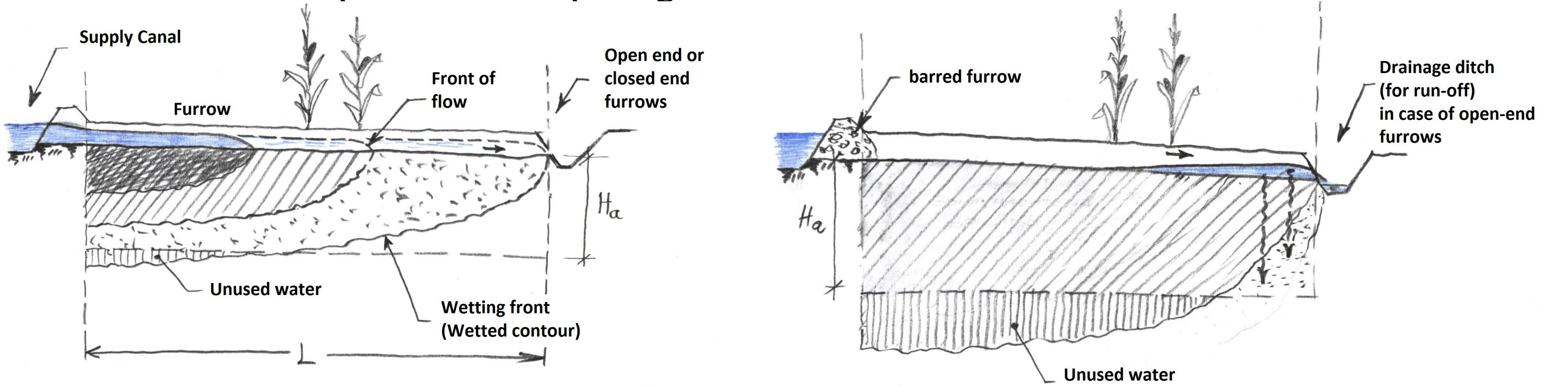
- ***Operational (Technological) losses*** - ΔOp
  - ✓ $\Delta Op = V_{delivered} - V_{available}$ (2)
  - ✓ Operational losses depend on:
    - – Water distribution type used in the IS
      - » the selected type and the structures/facilities used for its implementation predetermines the level of unused 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.

1. 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



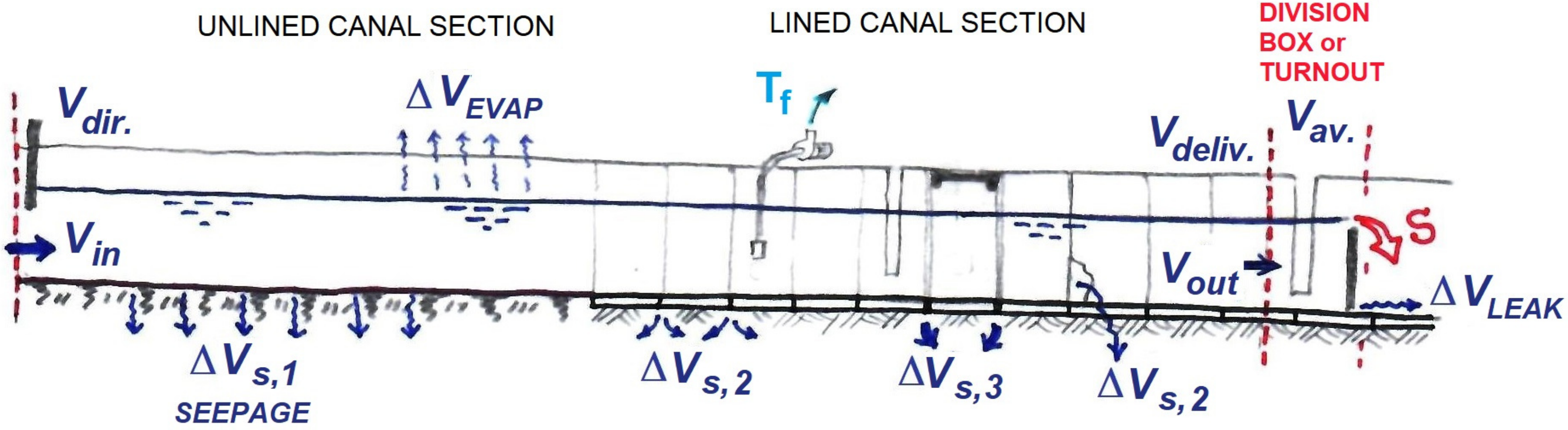
- ✓ Part of operational losses are avoidable and manageable.
- ✓ Usually, ΔOp are equal to spilled water S at the end of canal section

1. 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).

1. Losses of Water

- Losses in Delivery Network of IS



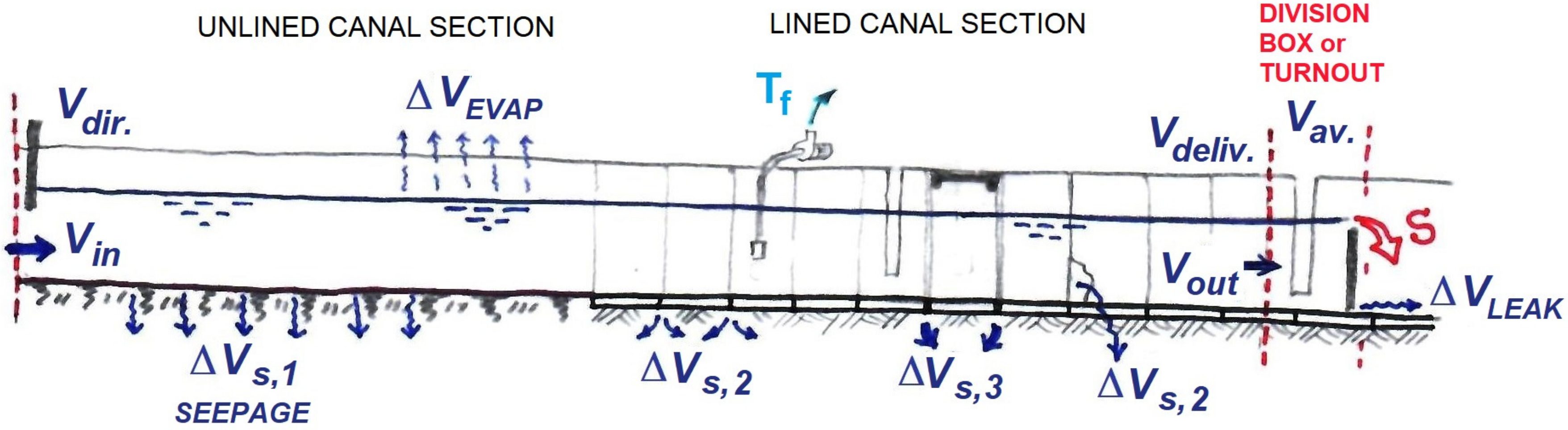
➢ **Evaporation losses** – ΔV_{EVAP} – from water surface of canals and regulating reservoirs;

➢ **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};

1. Losses of Water

- Losses in Conveyance and Distribution Network of IS

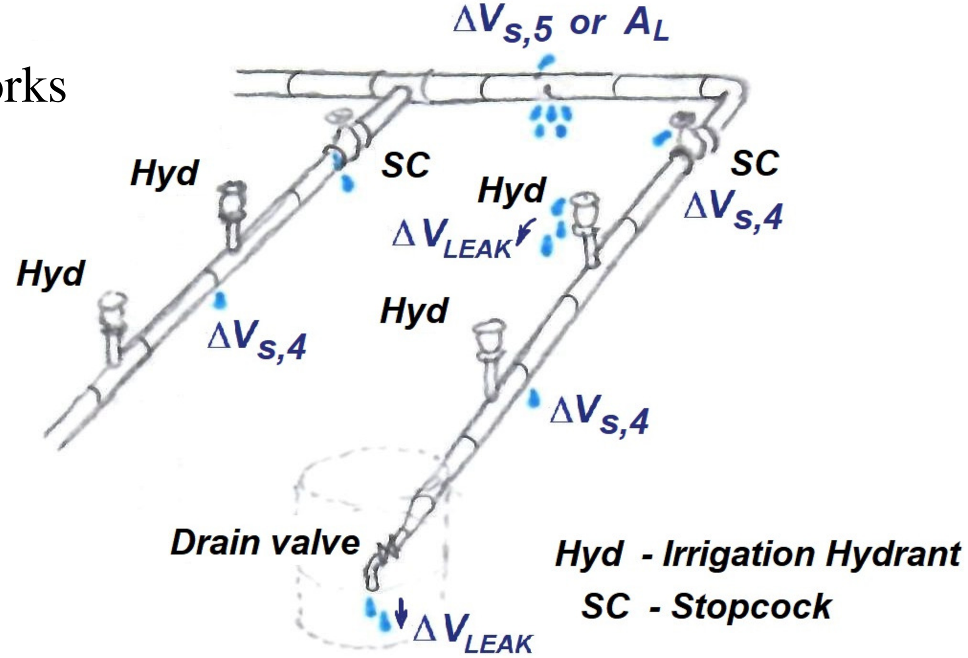


- **Leakage losses** – ΔV_{LEAK} – through gates and other regulating devices not tightly closed, slightly damaged or worn out;
- **Spills –** S – due to mismatch between delivery and consumption, i.e. technological looses due to type of water distribution;
- **Accident losses** – A_L – losses due to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

1. Losses of Water

- Losses in Distribution Network of IF

Pressurized Pipe Networks



➢ **Seepage losses**

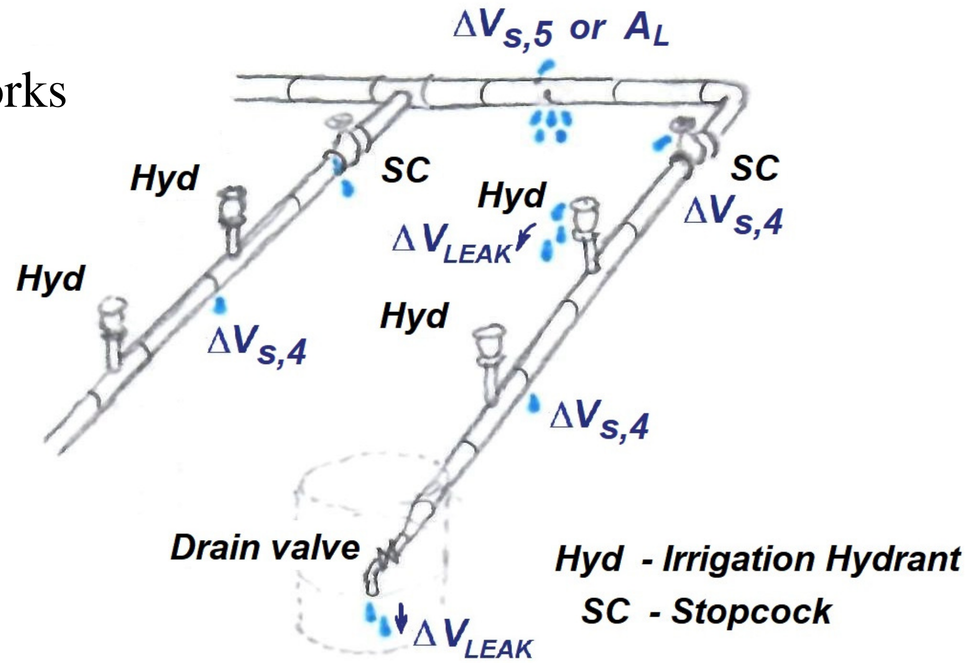
✓ seepage caused by leaks through pipe joints, through joints between pipes and valves - ΔV_{S4} ;

✓ seepage caused by cracked pipes - ΔV_{S5}

1. Losses of Water

- Losses in Distribution Network of IF

Pressurized Pipe Networks

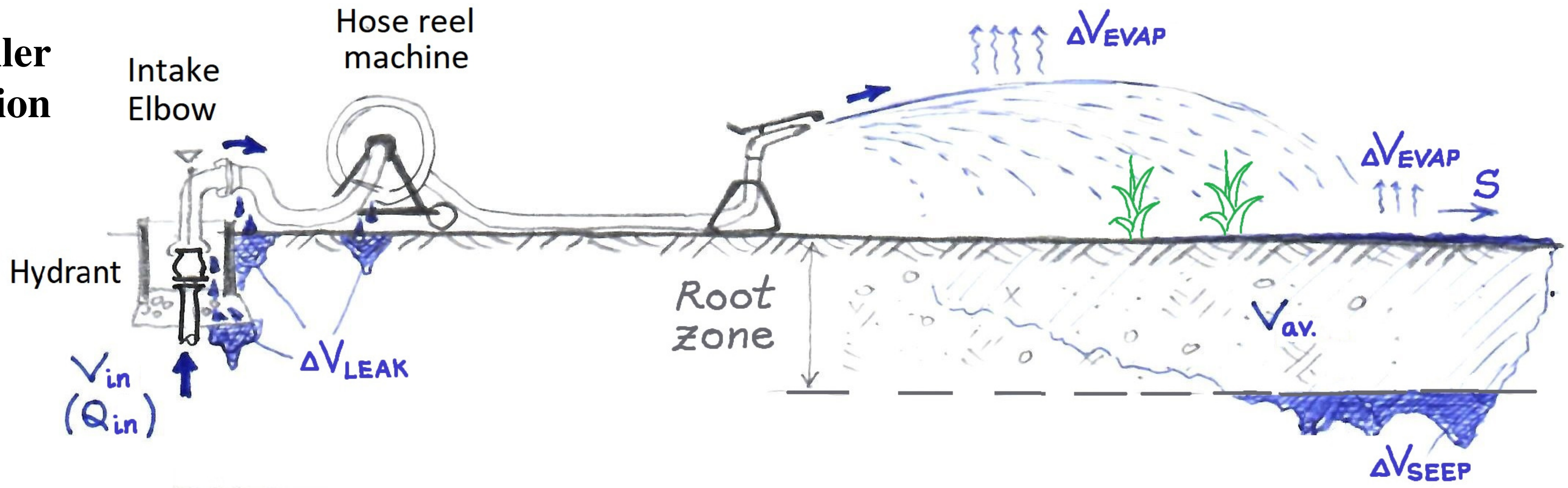


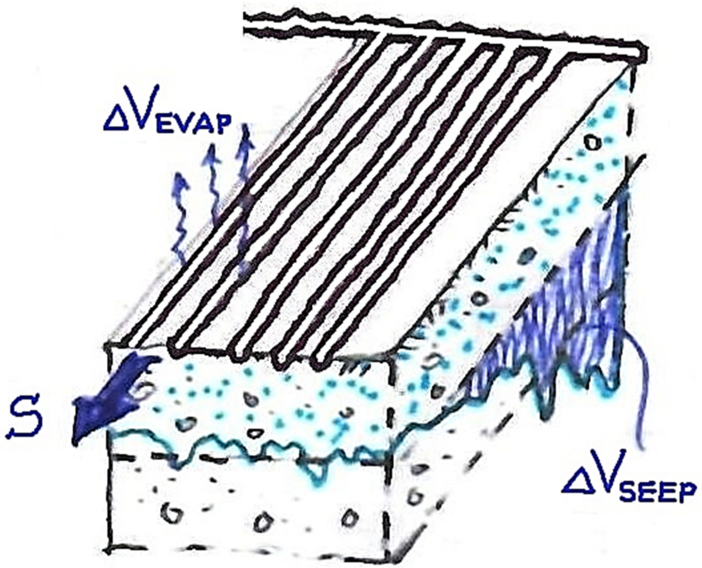
- **Leakage losses** – ΔV_{LEAK} – leaks from valves which are not tightly closed, slightly damaged or worn out – e.g. hydrants, drains, worn out air valves, etc.
- **Accident losses** – A_L – losses due to breakdowns in pipe system
- **Thefts –** T_f – all water used without it has been paid.

1. Losses of Water

- Losses in farms (in irrigation plots)

Sprinkler irrigation





Surface irrigation

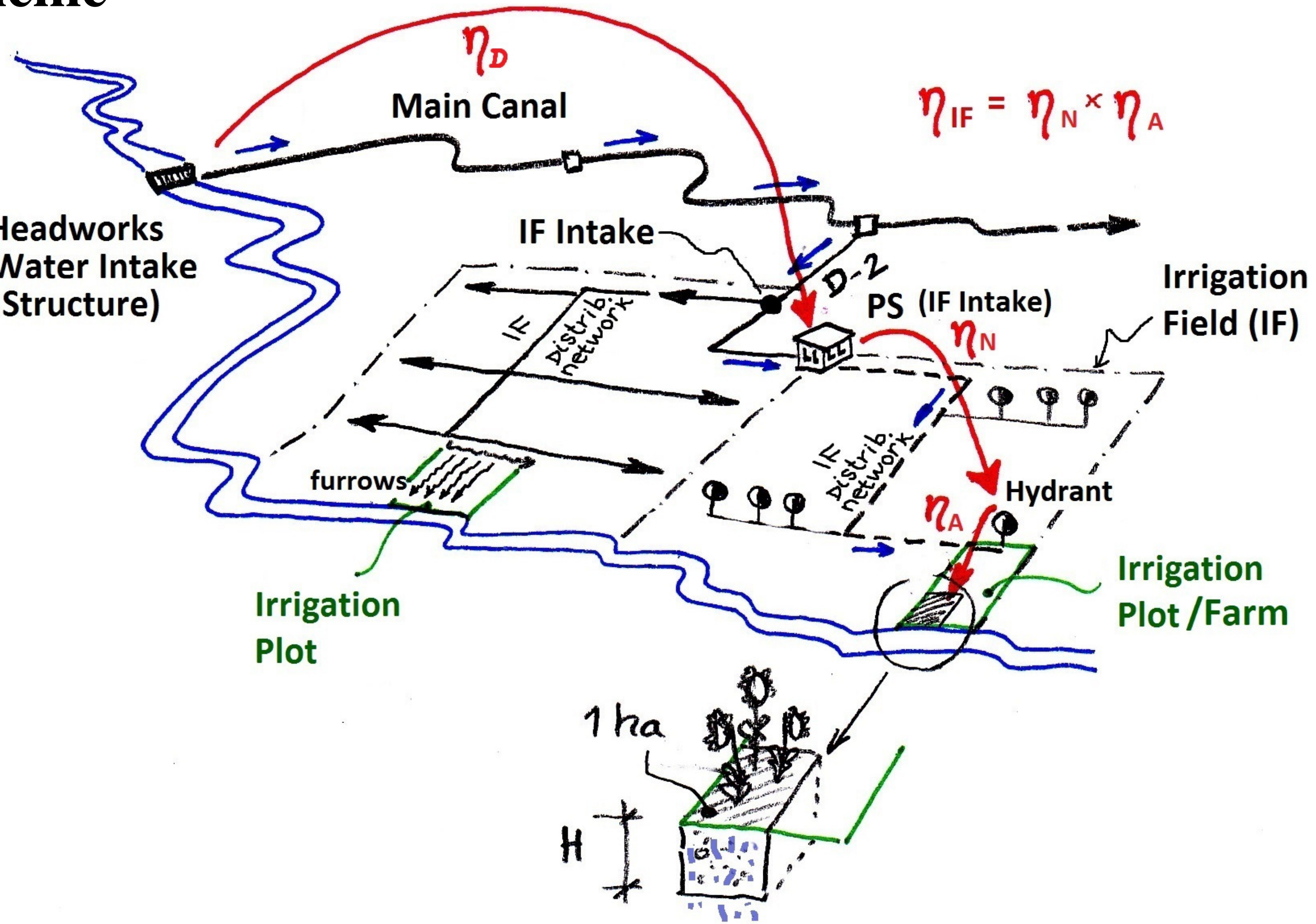
1. Losses of Water

- 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.

2. Efficiency of Irrigation Systems

- **Scheme**



2. 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: $\eta = \dfrac{V_{available}}{V_{directed}} = \dfrac{V_{net}}{V_{gross}} = \dfrac{V_{in} - \Delta V - \Delta Op}{V_{in}} = 1 - \dfrac{\Delta V + \Delta Op}{V_{in}}$

2. 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*)
    - ✓ $$\eta_T = \frac{V_{delivered}}{V_{directed}} = \frac{V_{out}}{V_{in}} = \frac{V_{in} - \Delta V}{V_{in}} \quad (1)$$
    - ✓ 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:
    - ✓ $$\eta_{op} = \frac{V_{available}}{V_{delivered}} = \frac{V_{in} - \Delta V - S}{V_{in} - \Delta V} \quad (3)$$

2. Efficiency of Irrigation Systems

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

  - ✓ $\eta_0 = \dfrac{V_{available}}{V_{directed}} = \dfrac{V_{in} - \Delta V - S}{V_{in}}$, 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.

2. 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

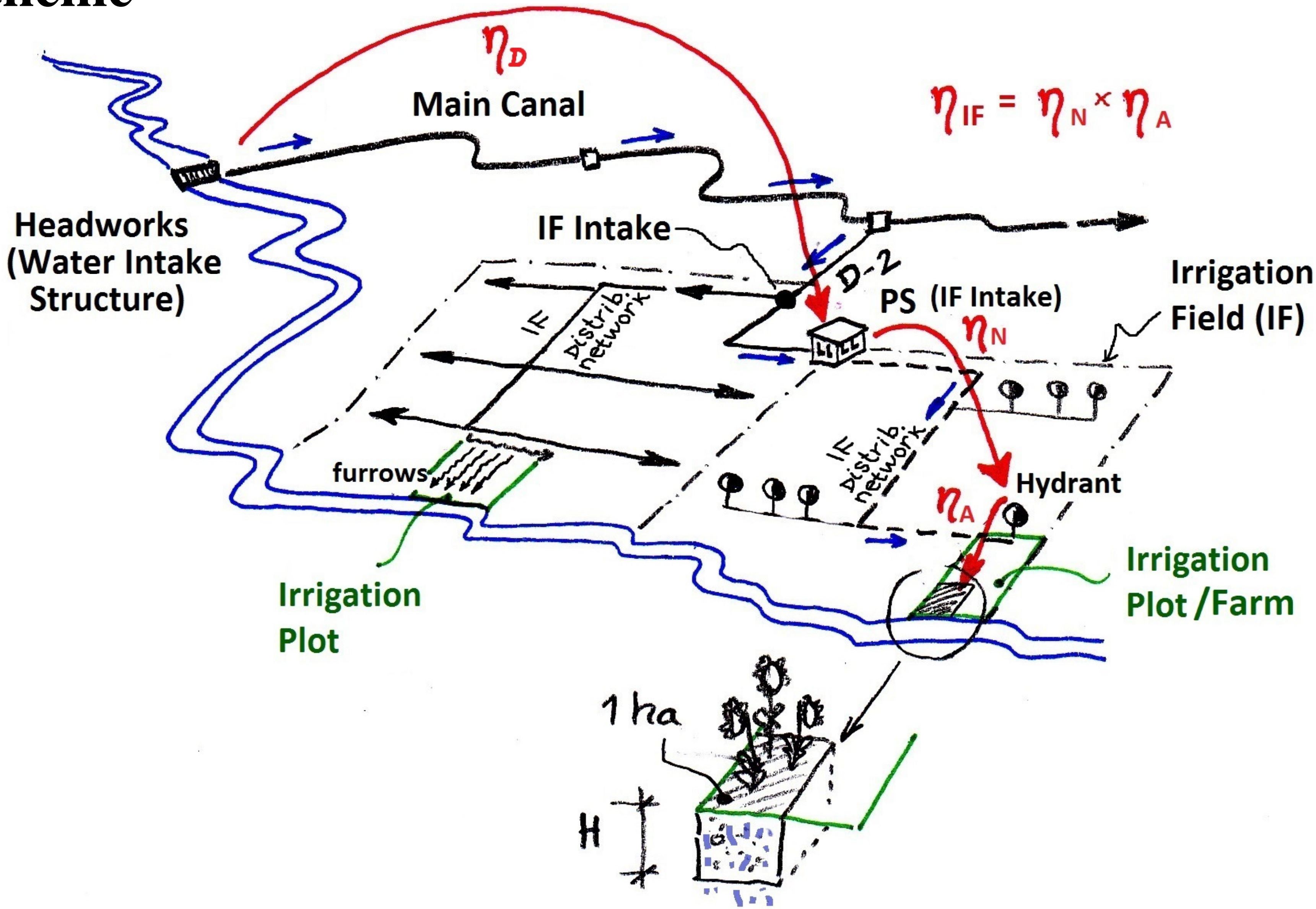
  - **Technical efficiency is used for estimation of the design discharges of the canal and pipe network**
    - ✓ Operational losses represent the lost *volumes*, due to insufficiency of the distribution method
    - ✓ In that respect, the operational losses should not be taken into account when design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

2. 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.**

2. Efficiency of Irrigation Systems

- **Scheme**



Co-funded by the Erasmus+ Programme of the European Union

2. 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.

2. 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:**

$\eta_T = 0,85 \div 0,90$ in case of lined canal;

$\eta_T = 0,95 \div 0,98$ in case of pipeline.

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

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

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

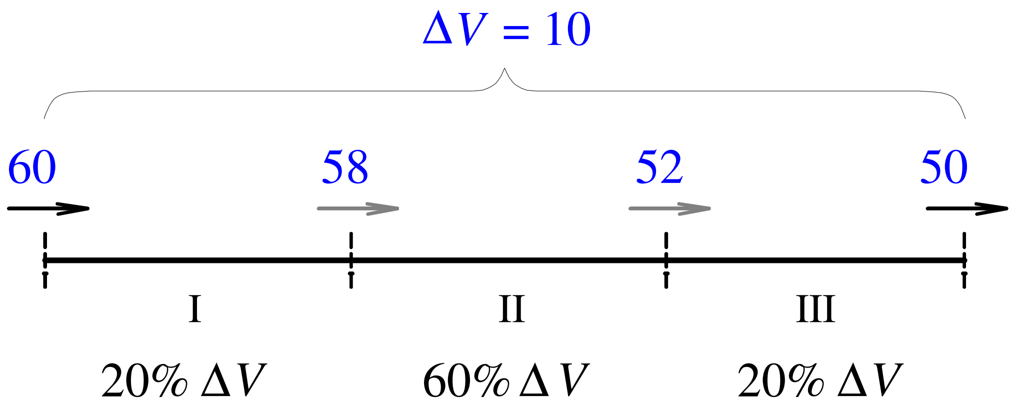
2. Efficiency of Irrigation Systems

➢ 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)



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

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

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

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

2. 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

2. 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;

2. 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:**

η_A = 0,80 ÷ 0,82 – for furrow or border strip irrigation;

η_A = 0,85 ÷ 0,87 – for sprinkler irrigation;

η_A = 0,95 ÷ 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)