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1. Irrigation Systems and Drought Management

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

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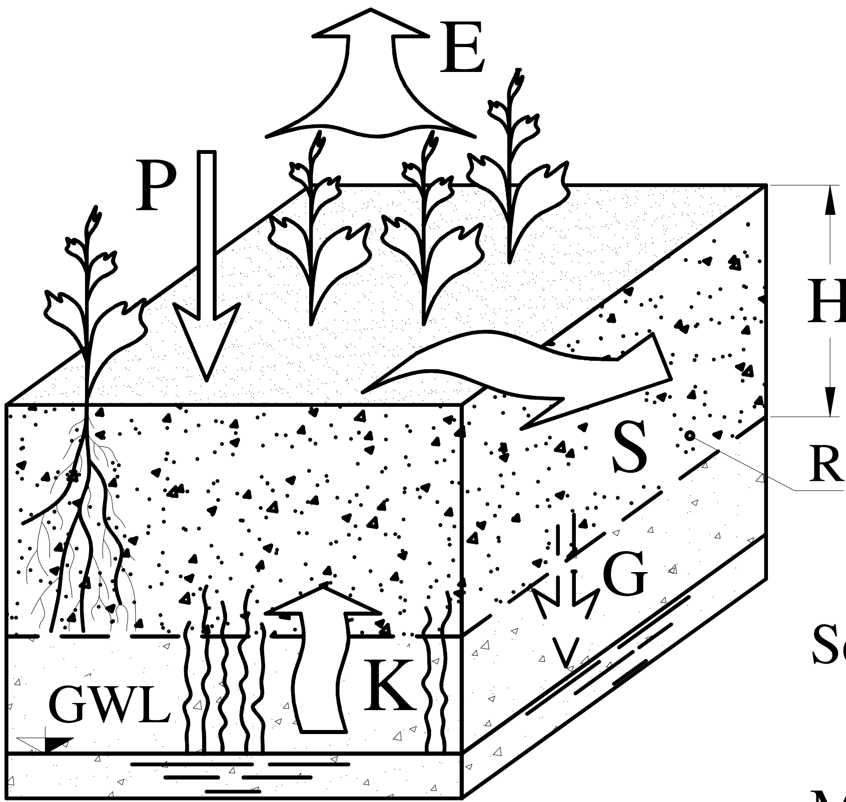
1. General Information

- ***Irrigation*** – artificial application of water to soil according to crop requirements during the vegetation (crop) period.
- **Crops** use water from the soil, so the soil can be regarded as a reservoir.
  - ➢ the soil reservoir should be filled up in a regular basis
  - ➢ there are 2 major ways to fill in the soil reservoir:
    - ✓ by rainfall
    - ✓ by irrigation

1. General Information

- **Necessity of Irrigation**
  - Based on *Inflow to Outflow* Ratio
    - ✓ Soil volume – e.g. 1 ha area, 1 m depth



P – Precipitation;

S – Surface Runoff;

E – Evapotranspiration;

K – Capillary Rise

G – Gravitational water

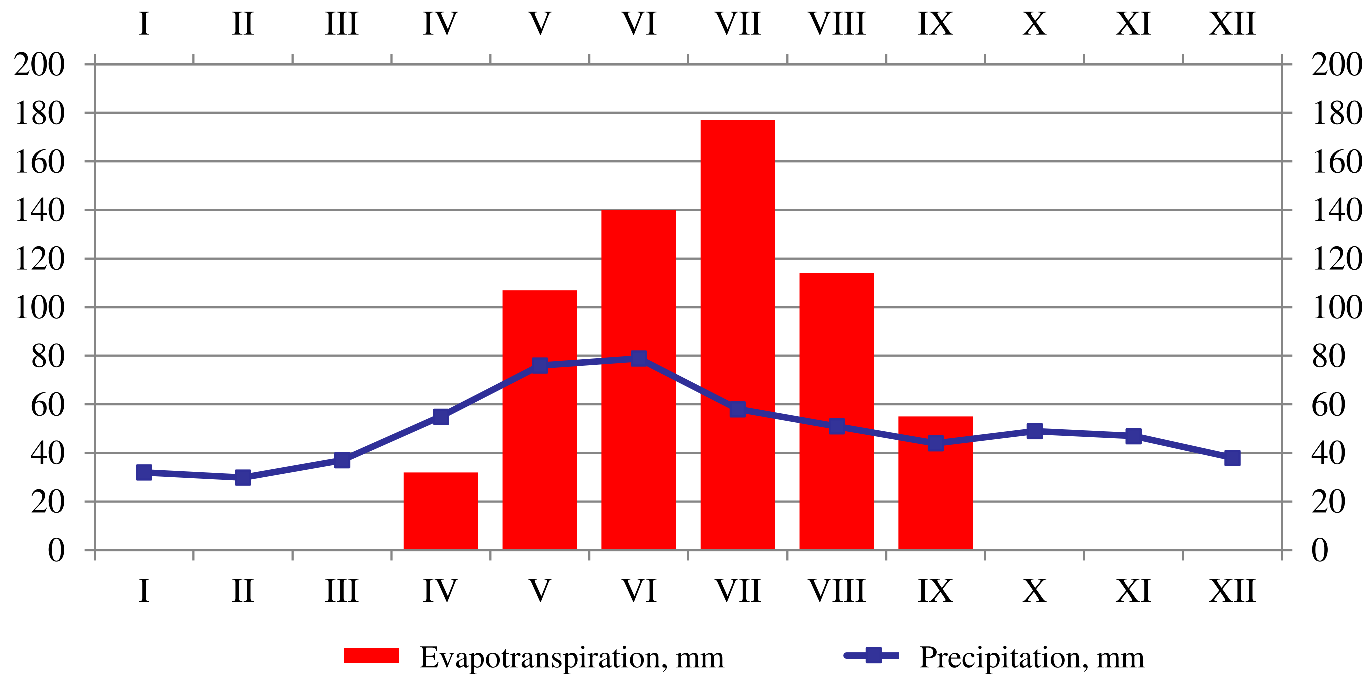
$$Inflow = P + K$$

$$Outflow = E + S + G$$

Seasonal or annual ratio: $\eta_i = \frac{Inflow}{Outflow}$

Multiannual mean value: $\eta = \frac{\Sigma \eta_i}{n}$

1. General Information



N.B. Average data for Bulgaria.
ET is estimated only for the crop period.

- If η **> 1** – superfluous water; necessity of ***drainage***
  - ✓ Excess rainfalls and/or bad natural drainage (e.g. impervious soil);
- η **< 1** – insufficient water; necessity of ***irrigation***
  - ✓ Lack of or insufficient rainfalls; due to high soil permeability;
- η_i **> 1 and** also η_i **< 1** for different years – ***transitional case*** – *sometimes irrigation, sometimes drainage is needed.*

1. General Information

- It is possible to have η ≈ 1 on annual basis, but to have the rainfall only outside the crop period (η < 1 for crop period).

- **Semi-arid areas** – areas, where the rainfall is almost sufficient or it makes possible growing of (some) crops without irrigation.
  - the irrigation is known as ***supplementary irrigation***
  - *in Bulgaria* **wheat** can be grown without irrigation
    - nowadays **sunflower** is grown as a "**rainfed**" crop
    - in some years and in some regions **maize** is also **rainfed** crop

- **Arid areas** – where the rainfall is insufficient and the irrigation is a must for agriculture.
  - in these areas all the yield is a result of irrigation

1. General Information

- **Effect of Irrigation on Yield of Major Crops in Bulgaria**

Crop	Yield (rainfed) t/ha	Yield (irrigated) t/ha	Additional Yield t/ha	Average Irrigation Requirement M_{avrg} m3/ha
Wheat	3,0 - 3,5	4,0 - 5,0	1,0 - 1,5	600
Corn (Maize)	4,0 - 5,5	9,0 - 11,0	5,0 - 5,5	2000
Sunflower	1,5 - 2,8	3,0 - 4,0	1,2 - 1,5	1200
Sugar beet	35,0 - 55,0	50,0 - 75,0	15,0 - 20,0	2400
Alfalfa	5,0 - 8,0	9,0 - 16,0	4,0 - 8,0	2400
Soy bean	1,0 - 2,0	2,5 - 4,0	1,5 - 2,0	2400
Gherkins	2,5 - 3,0	25,0 - 30,0	23 - 27	3000
Tomatoes	3,0 - 4,5	35,0 - 45,0	32 - 40	3600
Pepper	2,5 - 3,5	25,0 - 35,0	23 - 32	4200
Cabbage	5	40	35	3200
Potatoes	6,0 - 11,0	15,0 - 21,0	9,0 - 10,0	1800
Apple	5,0 - 7,0	15,0 - 20,0	10,0 - 13,0	3000
Peach	7,5 - 10,0	17,5 - 18,0	8,0 - 10,0	2400
Wine Grape	5,5 - 6,0	9,0 - 9,5	3,5 - 4,5	1800
Strawberries	3,0 - 5,0	9,0 - 15,0	6,0 - 10,0	3600
Forages	15 - 25	40 - 55	25 - 30	2300

1. General Information

- Irrigation is regarded as an activity of *general public benefit (interest)*
  - ➢ Irrigation water delivery is not profitable in lots of places in the world
- **Benefits and ill effects of irrigation**
  - ➢ **Benefits**
    - ✓ A tool for Draught Management
    - ✓ Increase of crop yields (in some instances – assures all yields)
      - – National economy development and general prosperity
      - – Sustainable economy
    - ✓ Possible multipurpose use of water
      - – e.g. Hydro-power generation + Irrigation

1. General Information

- **Benefits (not typical for Bulgaria)**
  - ✓ Domestic Water Supply + Irrigation
  - ✓ Inland navigation (need of huge canals)
  - ✓ Afforestation
- **Ill effects**
  - ✓ Water pollution with nitrates, phosphates, etc. from fertilizers
    - polluted water goes to groundwater and to surface water (rivers, lakes, etc.)
  - ✓ Salinization of soil – in hot climates
  - ✓ Water-logging due to over-irrigation (yields decrease)

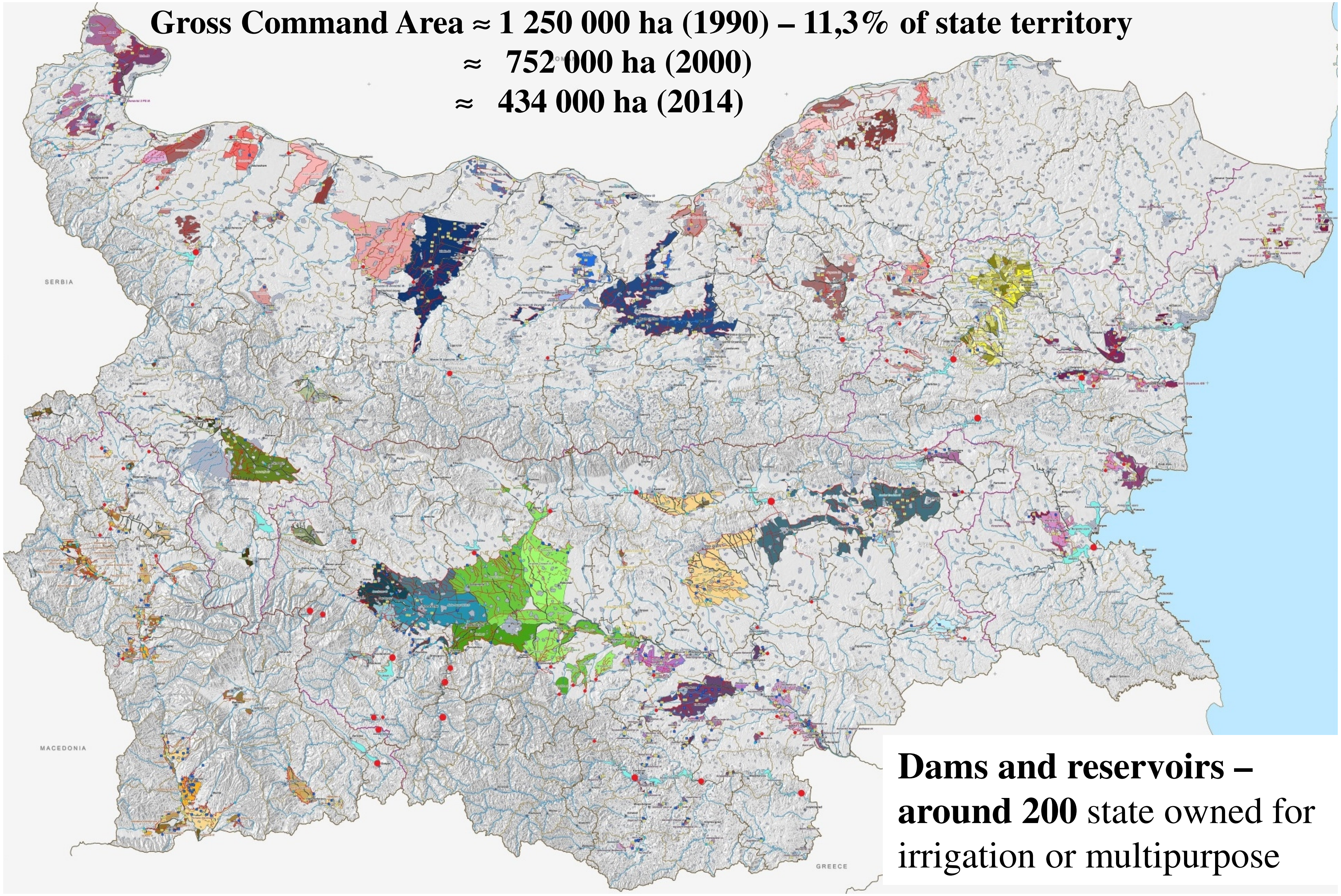
2. Irrigation Systems

- Irrigation System (IS)
  - a complex of hydraulic structures and networks designed to operate together as a system for abstraction and delivery (conveyance and distribution) of water for irrigation
- Irrigation Systems (in BG) or Irrigation Schemes (US English)
  - *Large scale* systems for abstraction and delivery of water to smaller units (farms or small scale irrigation systems)
- Irrigation Fields (in BG) or Irrigations Systems (US English)
  - *Small scale* irrigation systems for distribution of water between farms.
  - Each IS includes in its area many Irrigation Fields (in special case – one Irrigation Field).

2. Irrigation Systems

- **Irrigation Systems (IS) in Bulgaria**

Gross Command Area ≈ 1 250 000 ha (1990) – 11,3% of state territory
≈ 752 000 ha (2000)
≈ 434 000 ha (2014)



Dams and reservoirs – around 200 state owned for irrigation or multipurpose

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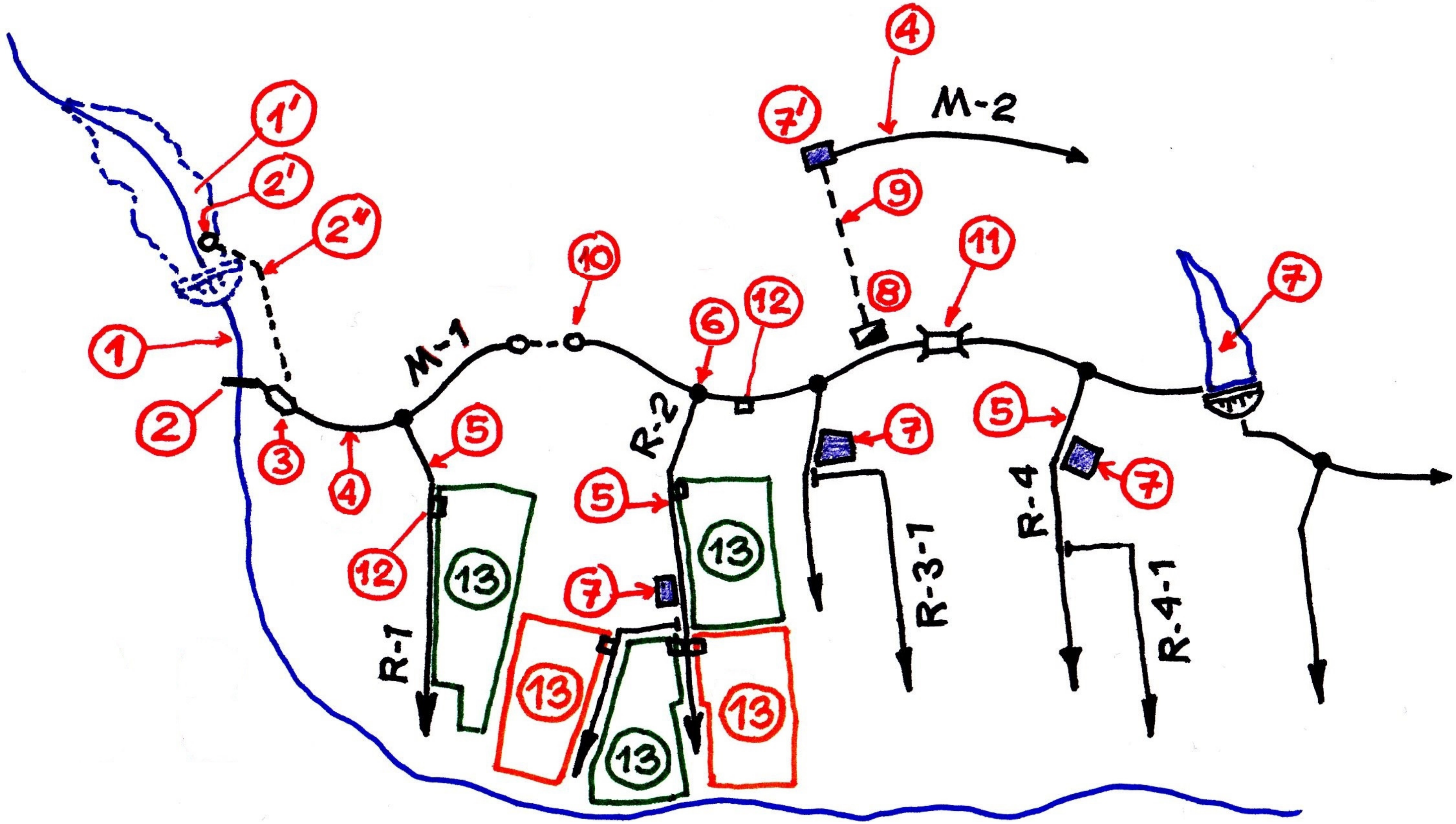
2. Irrigation Systems

- **Irrigation Systems in Bulgaria**
  - Number of ***Irrigation Systems*** – 232;
  - Total gross command (constructed) area **434 000 ha** (year 2014)
    - ✓ around **4%** of the state territory
  - Water Intake Structures (Headworks) – 420;
  - Derivation supply canals – 530 km;
  - Conveyance and distribution open canals – 5 441 km (75% of them lined);
  - Irrigation Pumping Stations (PS) – 188;
  - Pressure pipelines (of PS and others) – 2 238 km;
  - Regulating Reservoirs – 612;
  - Buried pipe network – 9 269 km.

3. Structure and Elements of IS



1- River; 1'-Reservoir
2- Headworks; 2' – Intake tower
2" – Conveyance tunnel
3-Settling basin

4- Main Canal
5- Secondary Canals
6-Turnouts (Division Boxes)
7-Regulating Reservoirs

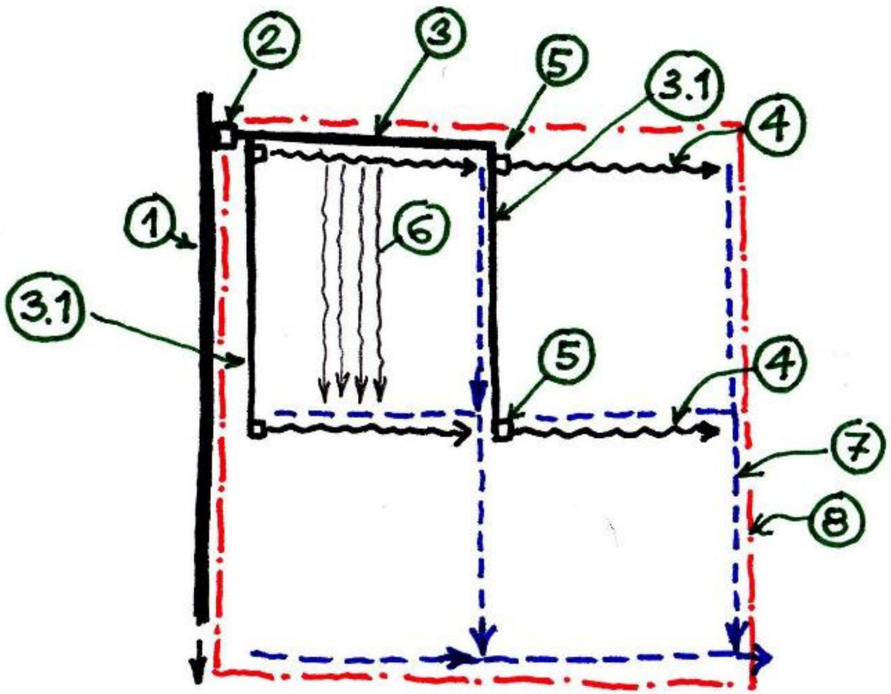
7'-Regulating reservoir of a Pumping Station
8-Pumping Station (Lift Type)
9 – Pressure pipeline; 10 – Inverted Siphon
11 – Aqueduct; 12 – Intakes for Irrigation Fields (13)

3. Structure and Elements of IS

- Irrigation Fields (BG) or Irrigation System (US) – (13)
  - Irrigation Field (IF) - technologically separated unit of the IS.
    - ✓ It has only one intake structure from main canal network
    - ✓ It has its own distribution network – **tertiary (canal) network**
  - Each IS comprises of many irrigation fields (IFs)
  - In Bulgaria, in the past, each IF was designed for one irrigation method
    - ✓ IF for surface irrigation
    - ✓ IF for sprinkler irrigation
    - ✓ IF for drip/micro irrigation

4. Irrigation Fields

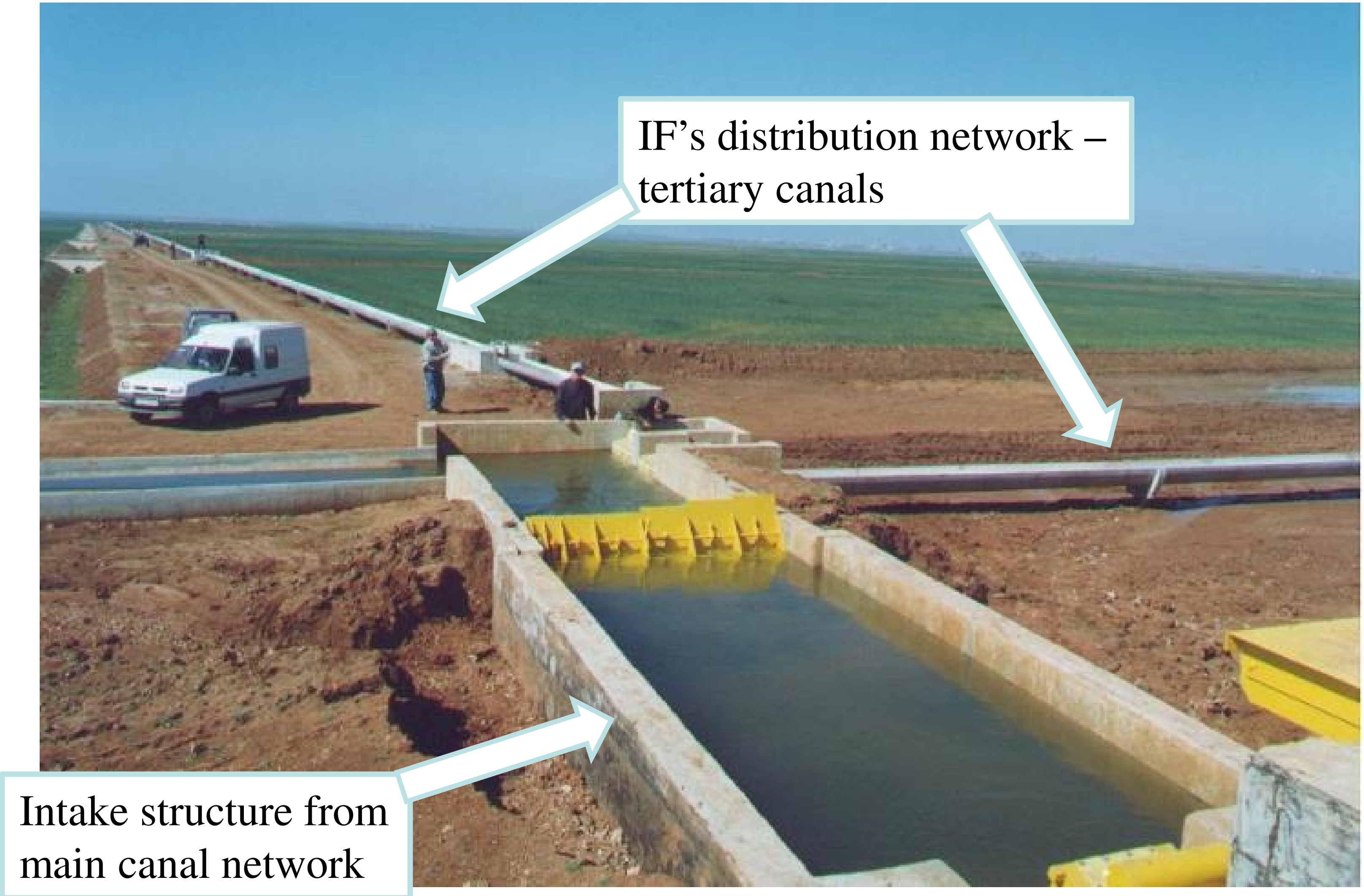
- **IF for surface irrigation**



- ➢ Main or Secondary canal ①
- ➢ Turnout for IF ②
- ➢ Tertiary network - ③ and (3.1)
  - ✓ Internal Canal Network *or*
  - ✓ Distribution Network of IF
    - ✓ usually consists of open canals;
    - ✓ usually canals are lined.
- ➢ Watercourses ④
  - ✓ earthen/unlined canals
- ➢ Turnouts ⑤ of tertiary network
- ➢ Furrows ⑥
- ➢ Drains ⑦ and boundary ⑧

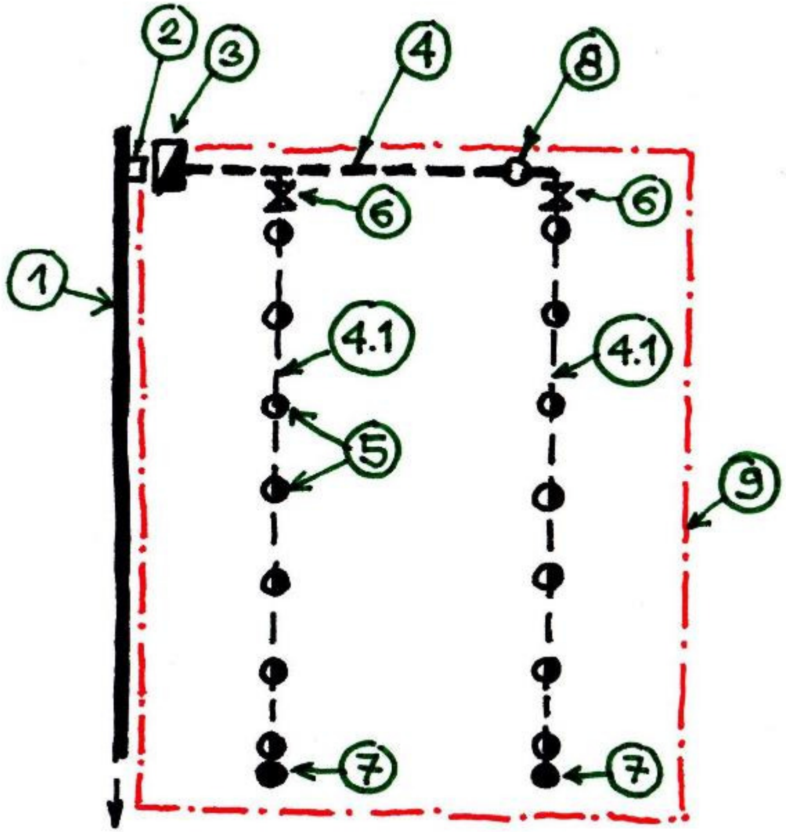
4. Irrigation Fields

- **IF for surface irrigation**



4. Irrigation Fields

- **IF for sprinkler irrigation**

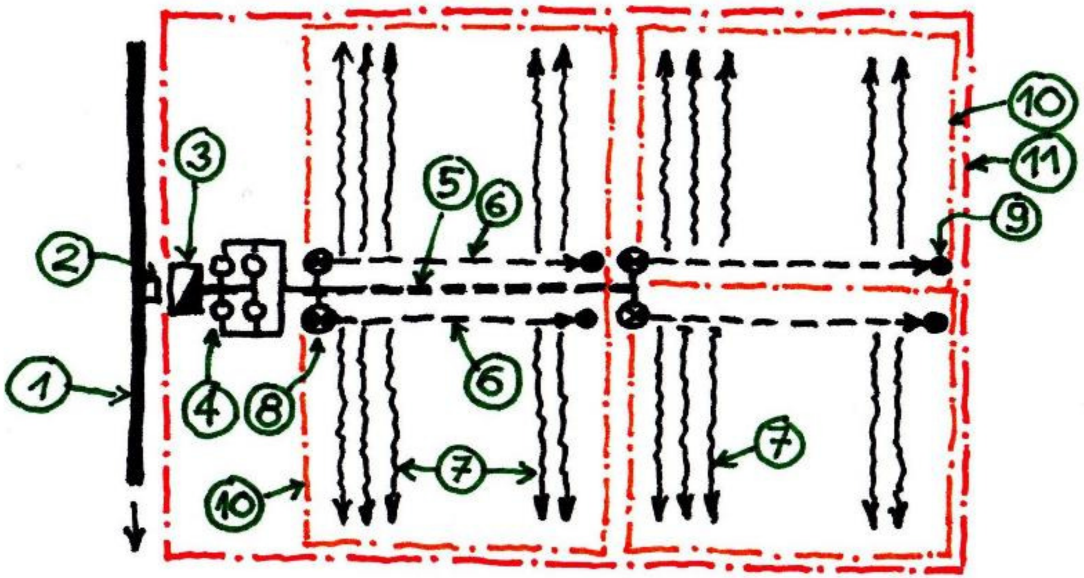


⑤

- ➢ Main or Secondary canal ①
- ➢ Turnout for IF ②
- ➢ Sprinkler (Booster) Pumping Station - ③
- ➢ Tertiary network - ④ and (4.1)
  - ✓ Distribution Network of IF
  - ✓ usually consists of buried pipelines
- ➢ Irrigation hydrants ⑤
  - ✓ for sprinkler equipment / machines
- ➢ Gate Valves (stopcocks) ⑥
- ➢ Drains ⑦
- ➢ Air vents ⑧ and boundary ⑨

4. Irrigation Fields

- **IF for drip/micro irrigation**



- Mainline ⑤
- Manifolds ⑥
  - ✓ usually are buried pipelines
- Hose lateral ⑦
  - ✓ with drip emitters or microsprayers
  - ✓ usually above ground
- Block valve ⑧
- Drains ⑨
- Block boundary (10)
- IF boundary (11)

- Main or Secondary canal ①
- Turnout for IF ②
- Booster Pumping Station ③
- Filters ④

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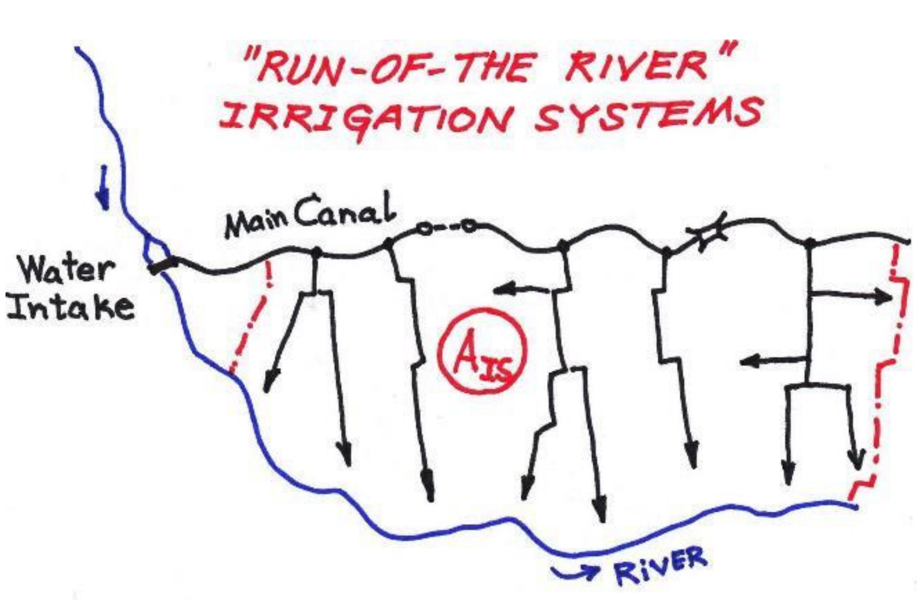
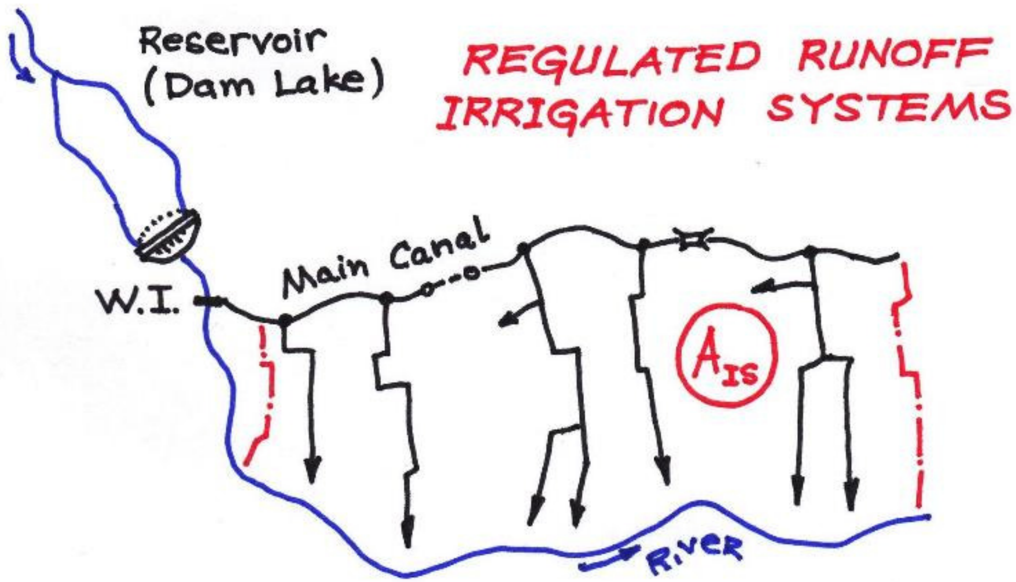
5. Types of Irrigation Systems

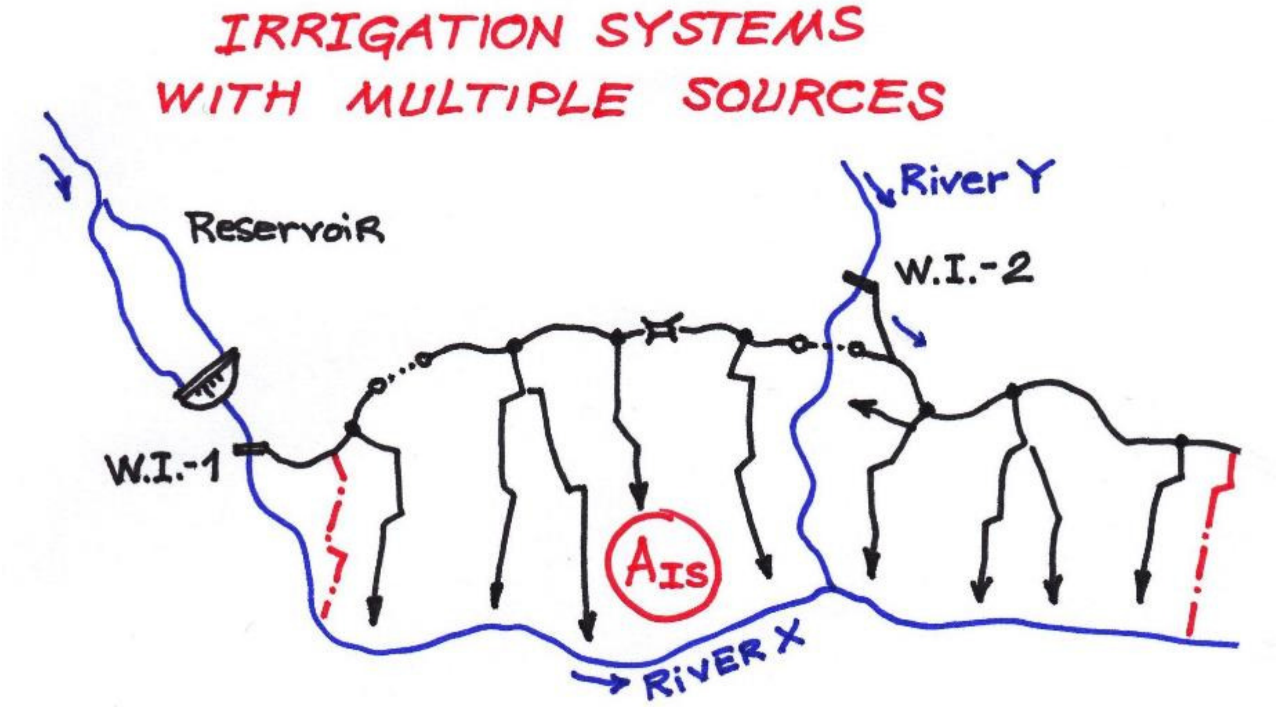
- **According to water source**
  - “***Run-of-the-river***” **IS** – water is diverted directly from the river
  - ***Regulated runoff*** **IS** – water is supplied from a reservoir
    - ✓ Directly from the reservoir or
    - ✓ By releasing water and diverting it downstream by means of Headworks (water intake structure)





5. Types of Irrigation Systems

- **According to water source**
  - ➢ ***Multiple Source IS*** – more than one water source is used

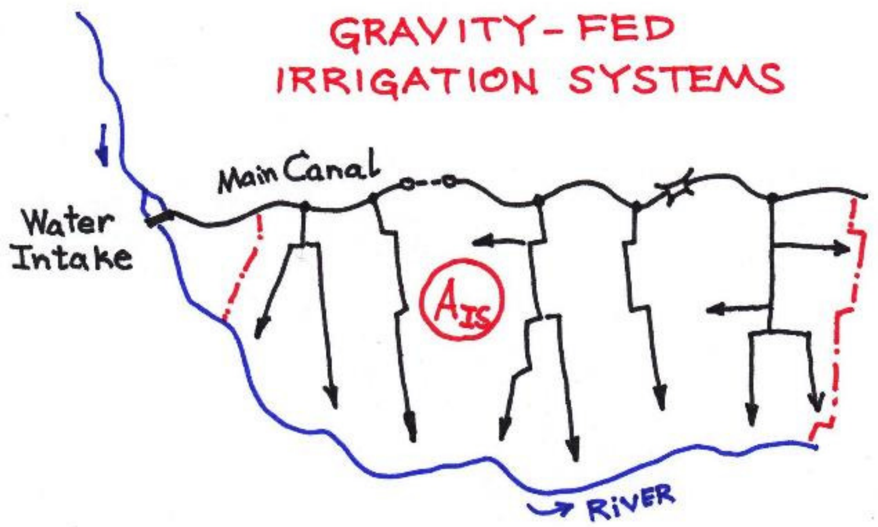


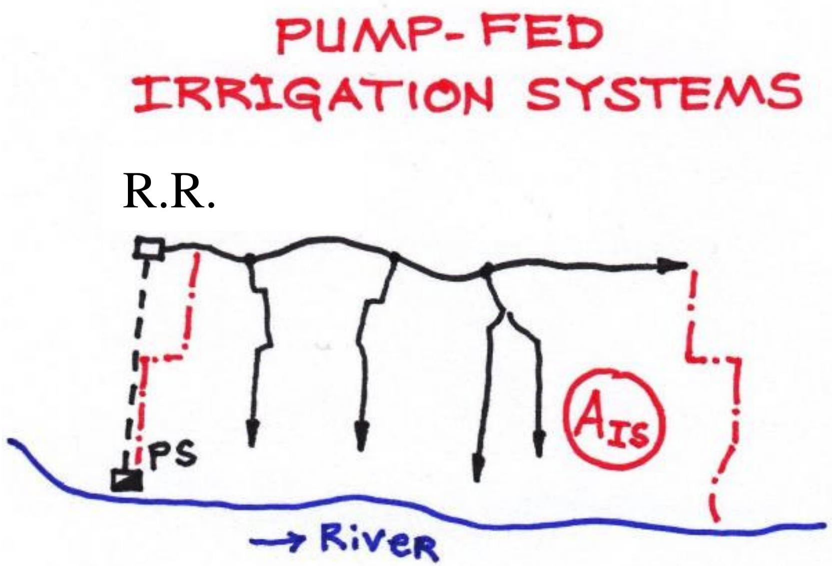
5. Types of Irrigation Systems

- **According to way of water delivery**

  - **Gravity-fed IS –** all the Command Area can be supplied by irrigation canals
    - ✓ they can be either Run-of-the-river, or Regulated runoff IS

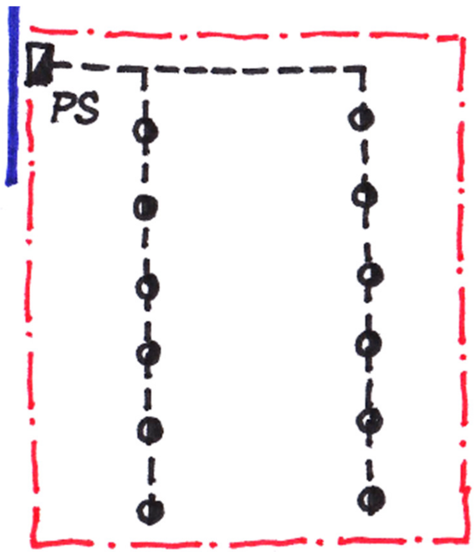
  - **Pump-fed IS –** all the Command Area can be supplied by irrigation canals
    - ✓ Abstraction from rivers
      - – they can be either *Run-of-the-river*, or *Regulated runoff* IS
    - ✓ Abstraction of groundwater

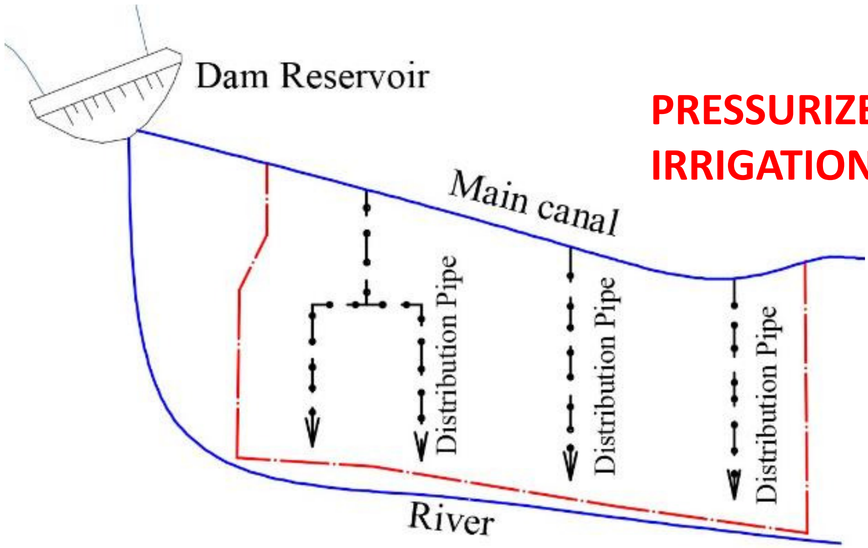




5. Types of Irrigation Systems

- **According to way of water delivery**
  - **Pressurized IS –** all the network is made of pipes; flow is pressurized by Booster Pumping Station
    - ✓ small scale IS, consisting of one Irrigation Field
  - **Pressurized by gravity IS -** mixture of above mentioned 3 types of IS
    - ✓ Regulating reservoir or Dam Reservoir can pressurize the whole IS.
    - ✓ In some instances a Main Canal can be present – either gravity-fed, or pump-fed
    - ✓ Distributaries – pipes with pressurized flow



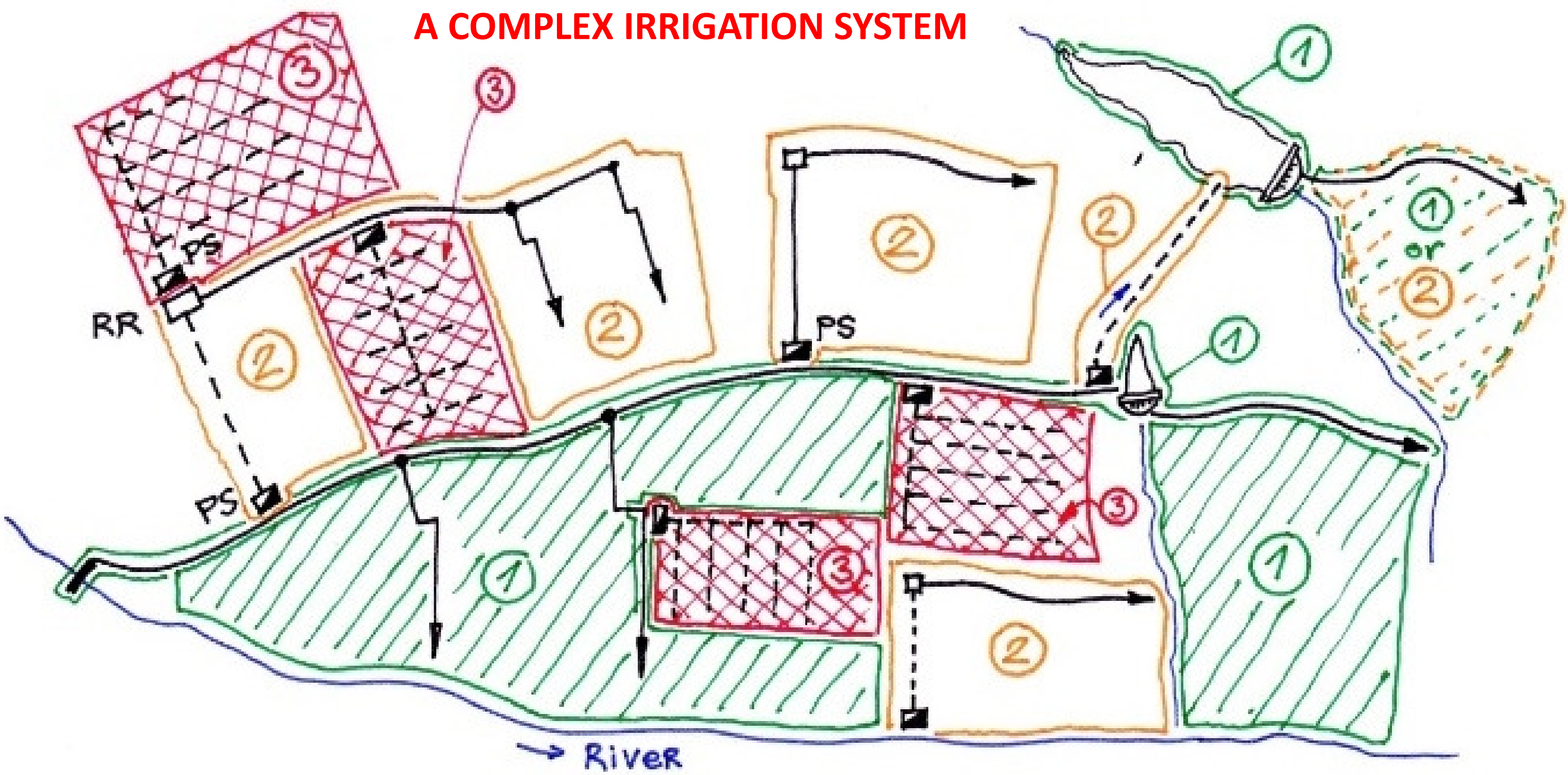


PRESSURIZED BY GRAVITY IRRIGATION SYSTEM

5. Types of Irrigation Systems

- **According to way of water delivery**
  - ➢ **Complex IS –** when different parts of the system are supplied in different ways
    - ✓ these IS consist of different ***subsystems***

A COMPLEX IRRIGATION SYSTEM

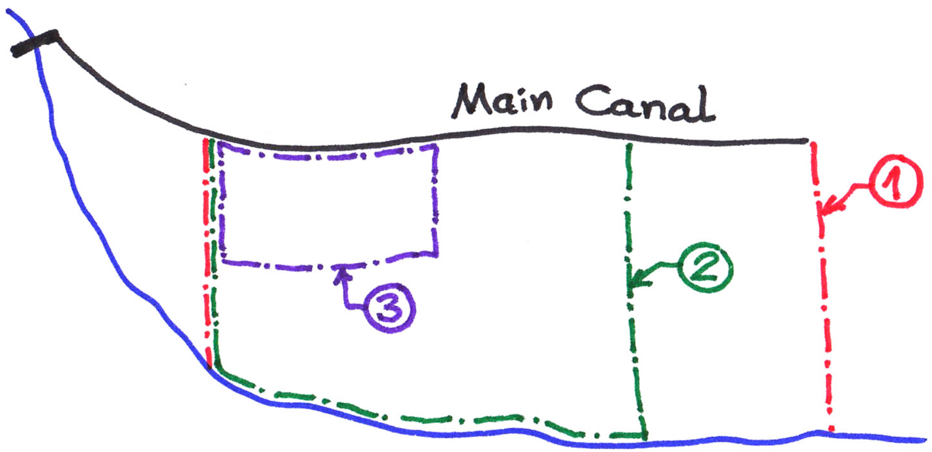


5. Types of Irrigation Systems

- **Subsurface irrigation**
  - ➢ **Natural subsurface irrigation**
    - ✓ leakages from irrigation canals, rivers, lakes, etc.
      - – in plain areas
      - – limited spatial effect
  - ➢ **Artificial subsurface irrigation**
    - ✓ Individual irrigation systems or schemes
    - ✓ Specially designed drainage systems
      - – In Bulgaria called ***Double-acting drainage systems***
      - – Need special soil and terrain conditions
      - – Very expensive

6. Irrigation System Parameters and Indicators

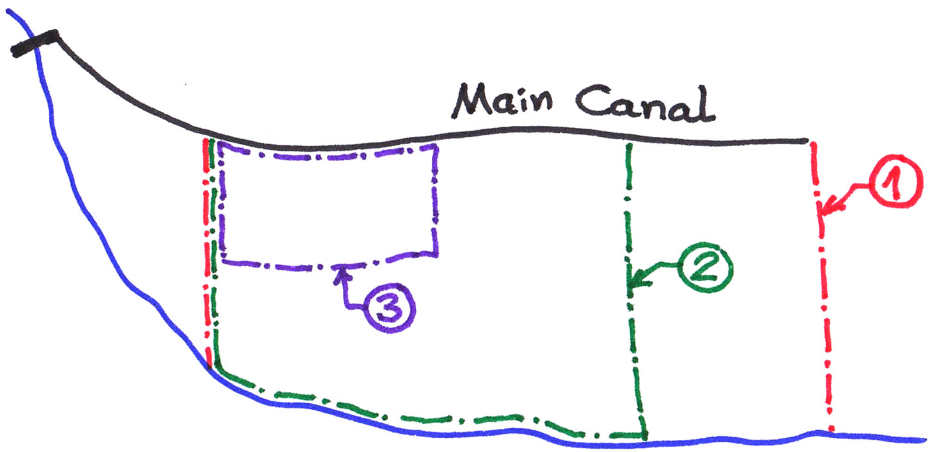
- **Irrigation System Areas**
  - **Command area** ① (also **Constructed area**) – the area that can be irrigated by IS network *according to original design* of the system/scheme
  - ***Gross Command Area*** – total area within the boundary of IS, incl. canals, roads, reservoirs, forests/green areas along canals and roads, etc.
  - ***Net Command Area*** ① – includes only area which is *cultivable* within the boundaries of IS.
    - ✓ When speaking of IS area, we mean *Net Command Area*



6. Irrigation System Parameters and Indicators

- **Irrigation System Areas**

  - **Suitable area** ② (also named **Equipped area**) – area fit for irrigation, i.e. area to which water can be delivered at present
    - ✓ usually smaller than constructed area, because of the damage of some structures and networks
    - ✓ there is ***Gross*** and ***Net Suitable area*** ②;
  - **N.B.** Not all ***Net Suitable Area*** is actually cultivated/planted every year
  - **N.B.** Not all ***Net Suitable Area*** is irrigated every year
  - **Irrigated area** ③ – area actually irrigated in a given year
    - ✓ usually smaller than **command** and **suitable** area, because of the crops actually grown within the IS boundary.



7. Crop Water Requirements

- Crop Water Requirements are essential for:
  - Design of the Irrigation System
    - ✓ design flow rates of canals, total water abstraction, etc.
  - Operation of the Irrigation System
    - ✓ irrigation frequency, flow rates, duration, water use, efficiency, etc.
- Crop Water requirements are presented by 3 parameters:
  - Irrigation requirement – $\boldsymbol{M}$ (net M_{net} or gross M_{gr});
  - Irrigation dose (also called *application*) – $\boldsymbol{m}$ (net or gross)
    - ✓ number of doses
    - ✓ frequency of delivery (period between two applications);
  - Water Duty (hydraulic module, or hydromodule) – $\boldsymbol{q}$ (net or gross).

7. Crop Water Requirements

- **Irrigation requirement *M*** is used to determine the annual demand *U* of the IS:

$$U = \frac{F_{IS} M_{net}}{\eta_{IS}}, \text{ m}^3.$$

- **Irrigation Requirement** (*M*) is defined as the sum of irrigation doses *m* for the crop period [m^3/ha]

$$M = \Sigma m, \text{ m}^3/\text{ha}$$

- **Irrigation dose *m*** (also called *application*) is the amount of water delivered to plants during one watering (for one water application)

7. Crop Water Requirements

- **Irrigation dose *m*** is used to determine:
  - the design and operational parameters of the irrigation equipment;
  - the specific water flow rate (so called *water duty* or *hydromodule*).
- **Water duty (hydromodule) *q*** is the flow rate in ℓ/s needed for irrigation of 1 ha.
  - It is used to determine the design flow rate Q_0 of irrigation canals:

$$Q_0 = \frac{q_{net} F_{IS}}{\eta_{IS}}, \quad \frac{l}{s}$$

where F_{IS} is the irrigation system net command (or suitable) area, ha;
η_{IS} – the efficiency of the irrigation system.

7. Crop Water Requirements

- ***Irrigation Schedule*** contains and provides data for ***M*** and ***m***
  - ➢ It contains data for:
    - ✓ the number and size of irrigation doses ***m*** and
    - ✓ the moments for their delivery.
    - ✓ the irrigation requirement M ($M = \Sigma m$)
  - ➢ Irrigation Schedule is done for one (a single) crop
- ***Irrigation Regime*** contains and provides data for ***q***
  - ➢ Irrigation regime is presented by *water duty diagram*
  - ➢ Irrigation regime can be done for:
    - ✓ One crop;
    - ✓ Multiple crops (more than one crop);
    - ✓ Crop rotation(s).

7. Crop Water Requirements

- **Crop Water Requirements** depend on climatic factors (air temperature, vapor pressure deficit, precipitations, etc.)
  - the climatic factors are stochastic variables.
  - thus, the Crop Water Requirements have probability of occurrence
- Crop Water Requirements for **design purposes**
  - They are determined only once – when the IS is designed
  - They are determined on the basis of ***past period*** of time
  - A representative year is chosen to obtain data for climatic factors
  - **In Bulgaria**, this representative year is a ***moderately dry year***
    - ✓ ***A moderately dry year*** is a year in which the value of the irrigation requirement M has a cumulative probability of $p = 75\%$.
      - In other words, the Irrigation requirement will be equal or less than this value of M in 75 out of 100 years.

7. Crop Water Requirements

- Crop Water Requirements **for operational purposes**
  - They are determined each year
  - They are determined on the basis of **a forecast** for climatic factors for the upcoming irrigation season
  - They are done in the beginning of the irrigation season year (end of March or beginning of April)
- For both design and operational purposes **3 basic irrigation factors** should be determined :
  - **Frequency** (or **Rotation Period**);
    - ✓ in Bulgaria *Irrigation Interval T* – minimum period between two applications is used instead of frequency
  - **Flow Rate** ***Q*** of delivered water
  - **Duration** ***t*** of the flow rate *Q*

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8. Determining Crop Water Requirements

- Crop Water Requirements are established by means of a water balance of a given soil volume
  - ➢ This water balance is known as water budget
  - ➢ The water balance is done by means of a balance equation
- The water balance equation (WBE) of a soil volume can be solved for:
  - ➢ design purposes – using data for representative year
  - ➢ operational purposes – using data from forecasts
- Determining of the Crop Water Requirements for the design purpose, i.e. for representative (moderately dry) year is further described

8. Determining Crop Water Requirements

8.1. Kostyakov's Method (USSR) for Irrigation Schedule

- The general view of the water balance equation is as follows:

$$W_{end,i} = W_{beg,i} + Inflow_i - Outflow_i + m_i - G, \text{ m}^3/\text{ha},$$

while $W_{end,i} \leq W_{max,i}$, m³/ha (shows presence of G_i)

and $W_{end,i} \geq W_{min,i}$, m³/ha (show presence of m_i)

Notation:

$W_{end,i}$ is the water content of the soil in the end of calculation interval i;

$W_{beg,i}$ is the water content of the soil at the beginning of the interval i;

$Inflow_i$ is the amount of water infiltrated in the soil during the interval i;

$Outflow_i$ is the amount of water left the soil during the interval i;

m_i is the irrigation dose for the calculation interval i,

G_i is the deep percolation from soil volume for the interval i;

8. Determining Crop Water Requirements

8.1. Kostyakov's Method (USSR) for Irrigation Schedule

- Notation:

  $W_{max,i}$ is the maximum water content in the soil (at its field capacity);

  $W_{min,i}$ is the amount of water at minimum allowable capacity of the soil

- Continuity of the equation

$$W_{beg,i} = W_{end,i\text{-}1}$$

  - The water content at the beginning of the interval *i* is equal to water content at the end previous interval (*i*-1).

- Calculation interval and period
  - Calculation interval (step) = Irrigation interval T = 10 days
  - Calculation period – vegetation period of the crop

8. Determining Crop Water Requirements

8.1. Kostyakov's Method (USSR) for Irrigation Schedule

- **Constituents of the water balance**

$$Inflow_i = P_e + \Delta W + K$$

$$Outflow_i = E$$

where P_e is the income from effective precipitation

$$P_e = P - S,$$

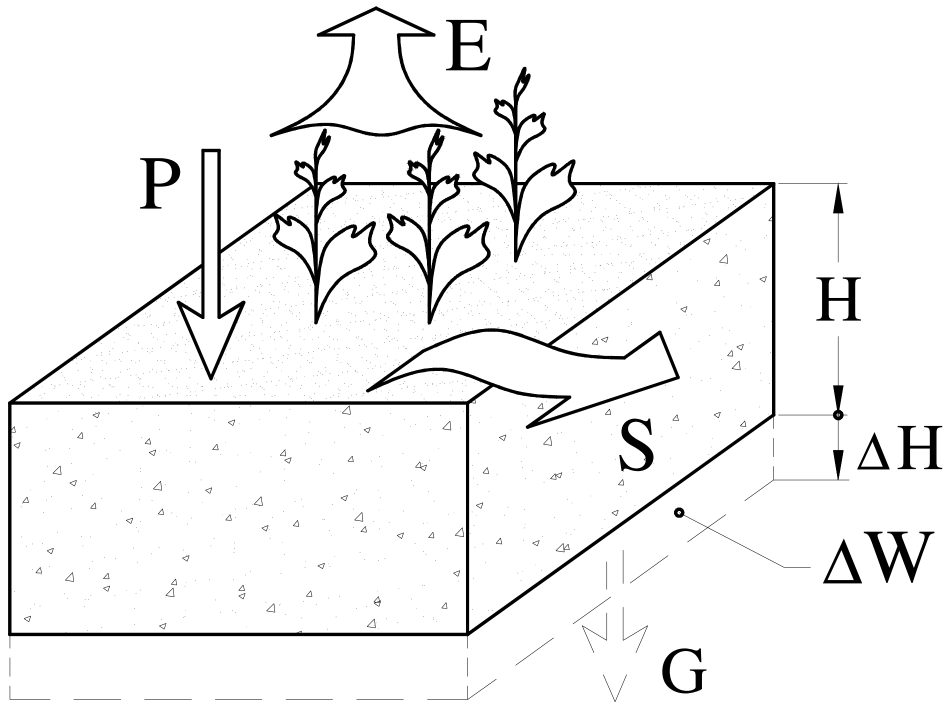
P – precipitations

S – surface runoff;

ΔW – income from available water into increased soil volume;

K – income from capillary rise

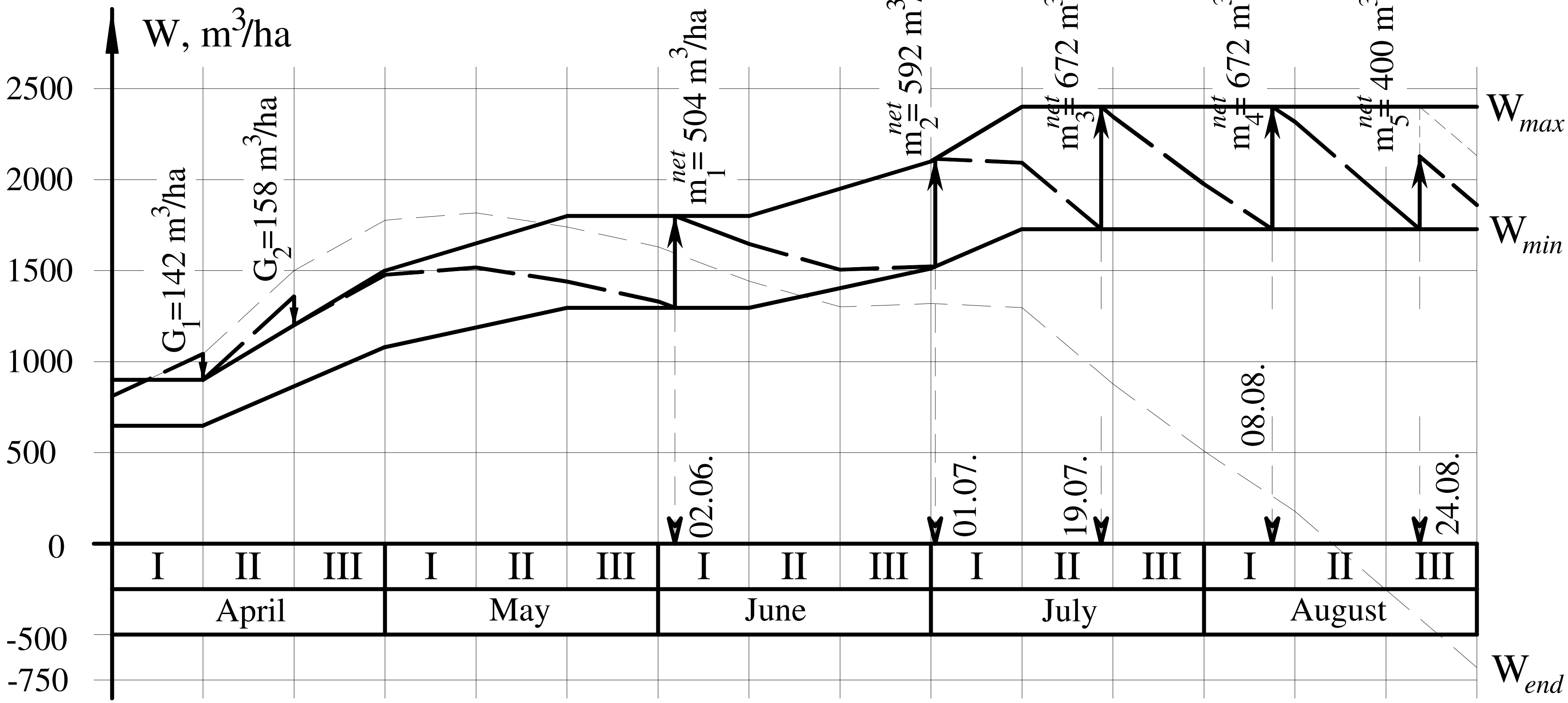
E – Evapotranspiration.



8. Determining Crop Water Requirements

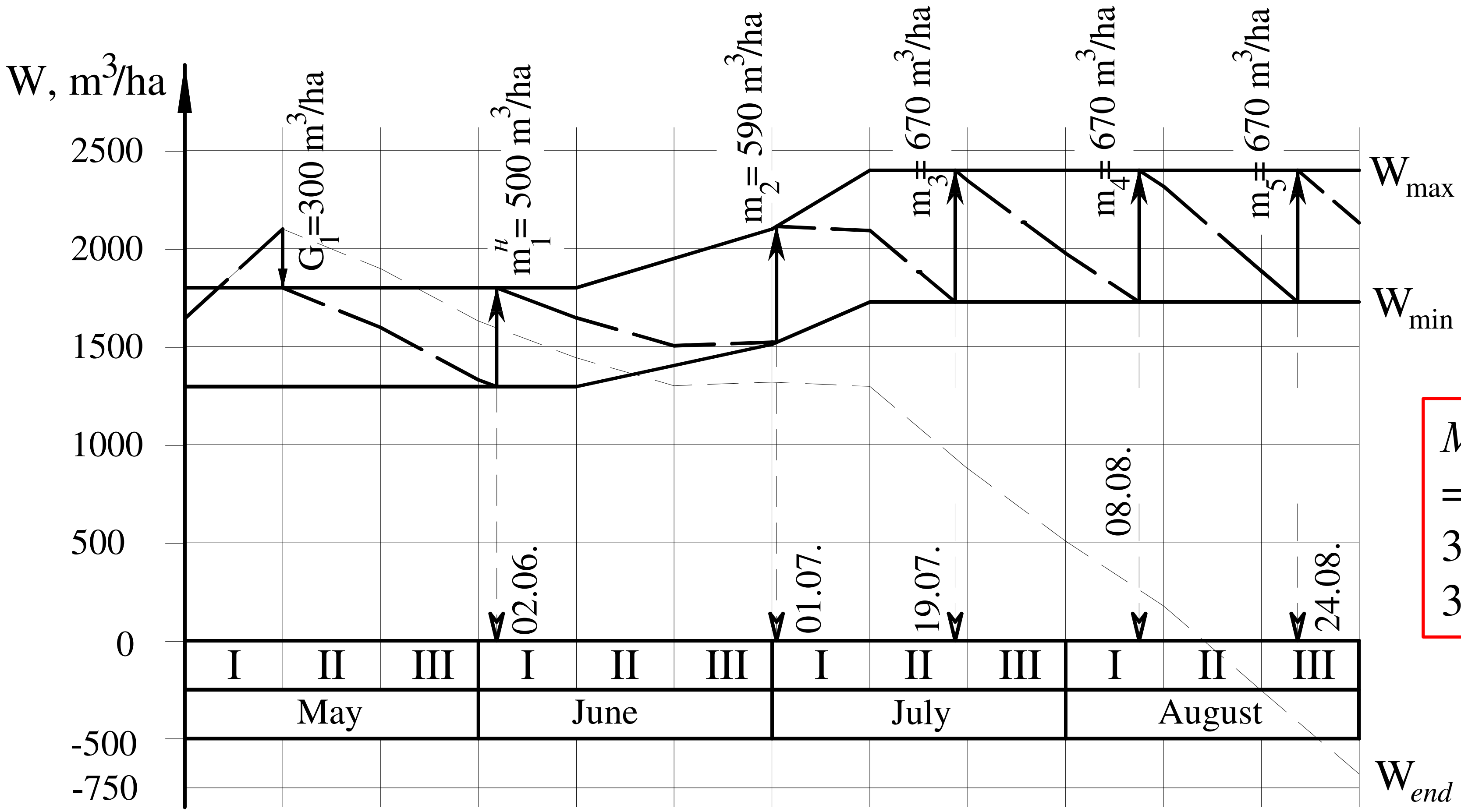
8.1. Kostyakov's Method (USSR) for Irrigation Schedule

Graphical solution



8. Determining Crop Water Requirements

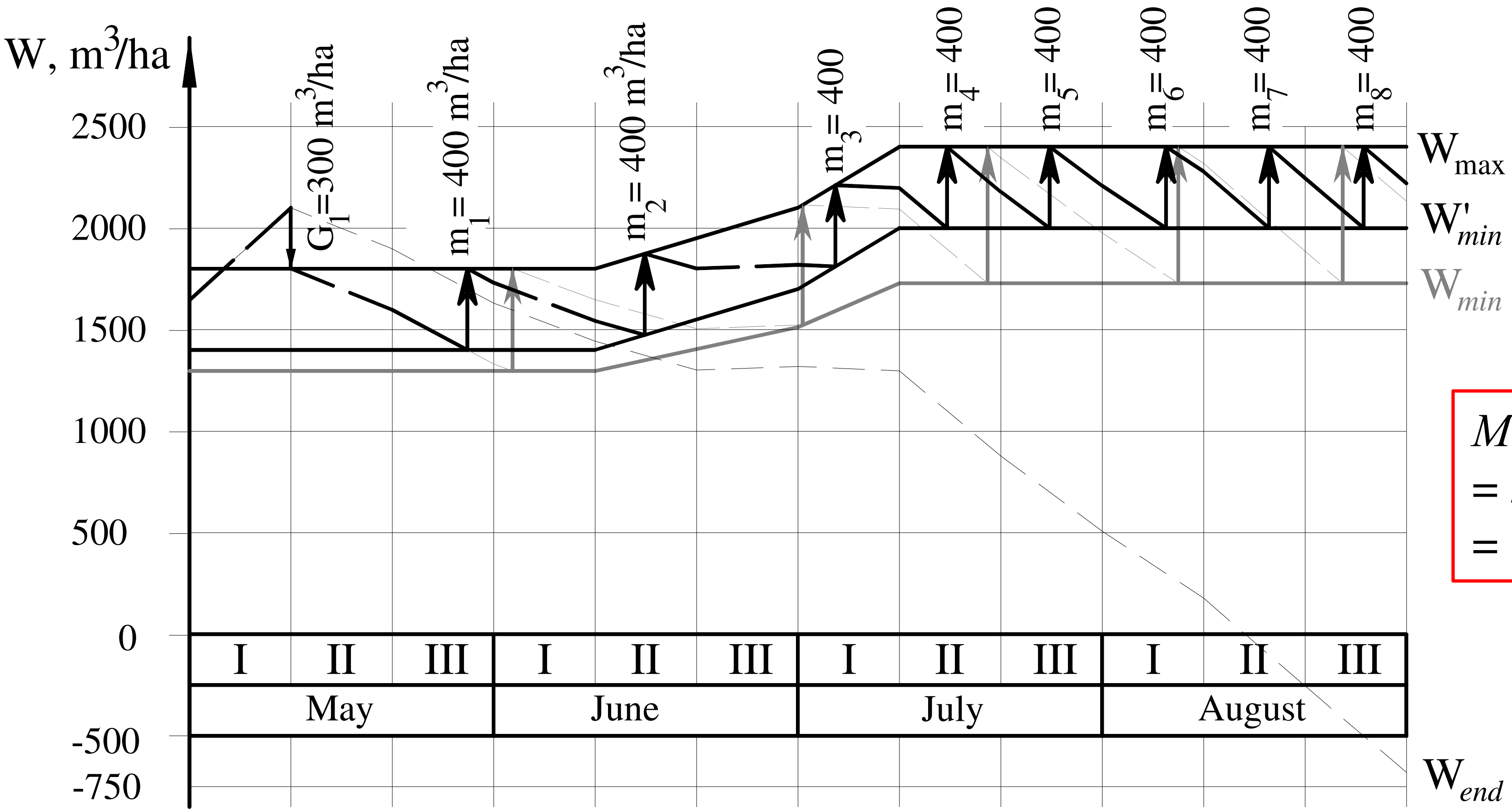
- Constraints influence on *m* and *T*.
  - Classic lower constraint: $W_{end,\,i} \geq \boldsymbol{W}_{\mathbf{min}}$
  - ***Result:*** Irrigation interval (July - August) T = 18-20 days.



$M = \Sigma m =$
$=500+590+$
$3.670 =$
3100 m³/ha

8. Determining Crop Water Requirements

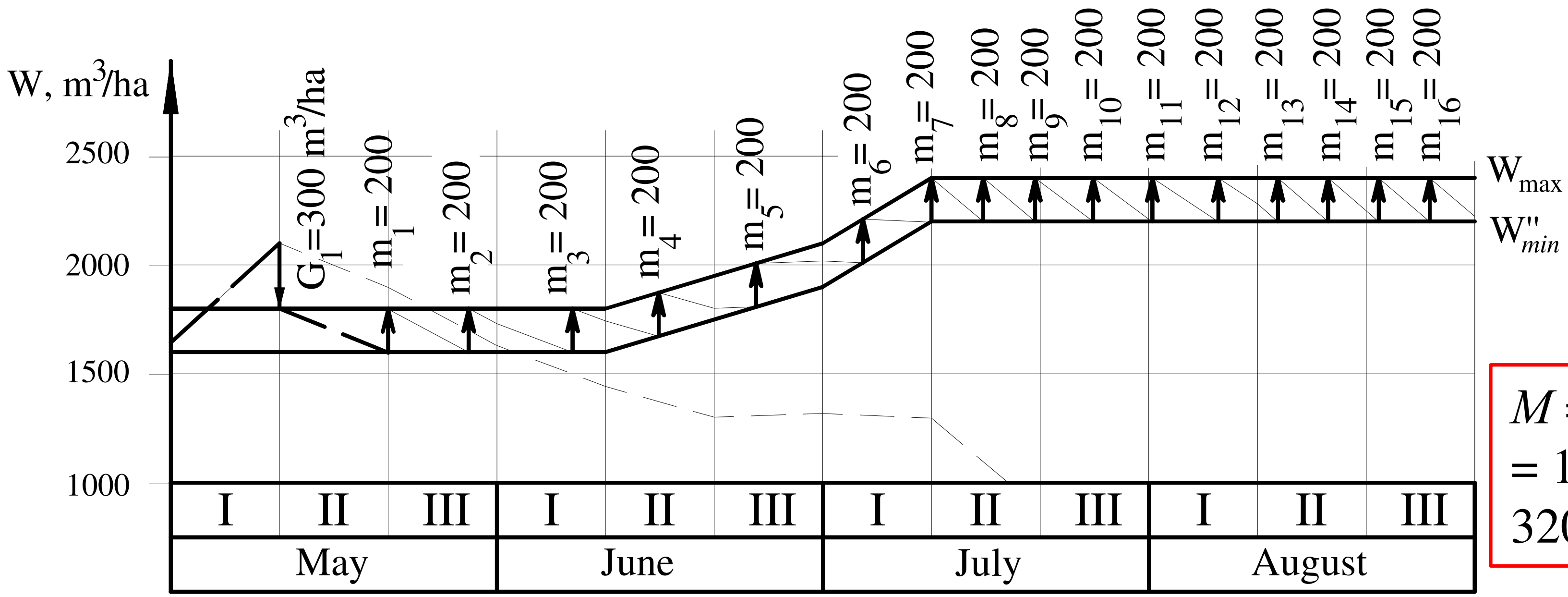
- Constraints influence on *m* and *T*.
  - ➢ Modified lowed constraint: $W_{end,\,i} \geq \boldsymbol{W'_{min}} > \boldsymbol{W_{min,\,i}}$
  - ➢ ***Result:*** Irrigation interval (July - August) T = 10-12 days.



$M = \Sigma m =$
$= n.m = 8.400$
$= 3200$ m³/ha

8. Determining Crop Water Requirements

- Constraints influence on *m* and *T*.
  - Modified lowed constraint: $W_{end,\,i} \geq \boldsymbol{W''_{min}} > \boldsymbol{W'_{min,\,i}} > \boldsymbol{W_{min,\,i}}$
  - ***Result:*** Irrigation interval (July - August) T = 4 - 6 days.

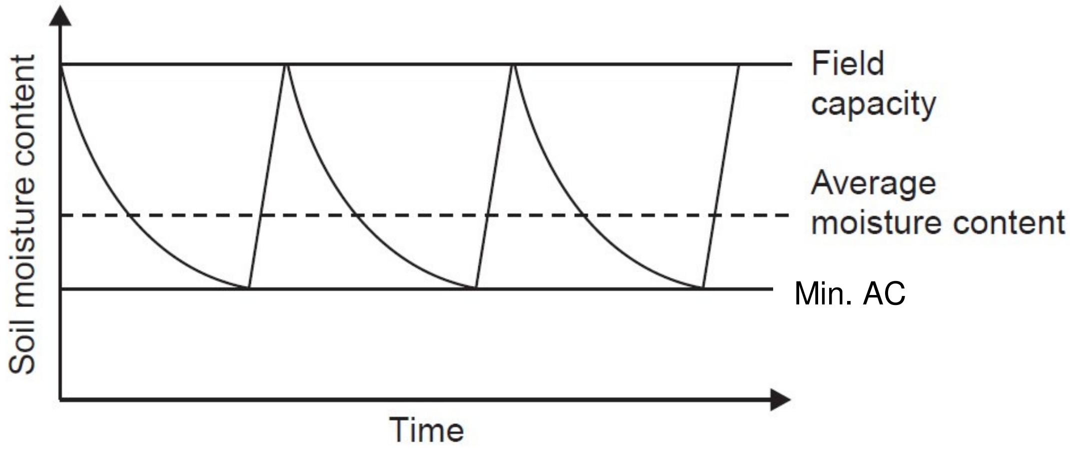


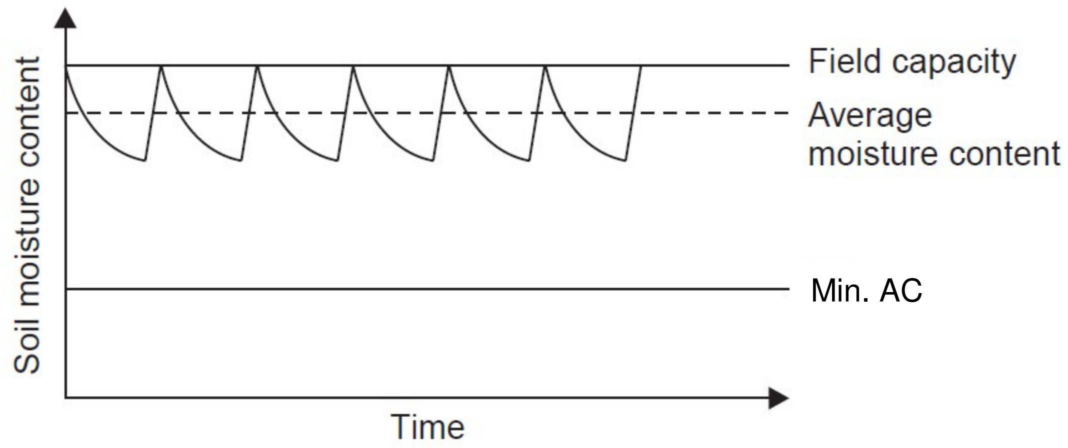
$M = \Sigma m = n.m$
$= 16.200 =$
$3200\ m^3/ha$

- The same approach can be applied for the upper constraint – W_{max} to be decreased

8. Determining Crop Water Requirements

- Constraints influence on *m* and *T*.
  - ➢ If the application is made before the water content drops to Min. Allowable Capacity, then:
    - ✓ the applications will be more frequent, i.e. the ***frequency will increase***
    - ✓ ***Irrigation doses m will be smaller***
    - ✓ ***Irrigation requirement M will stay the same***
    - ✓ Average moisture content will increase



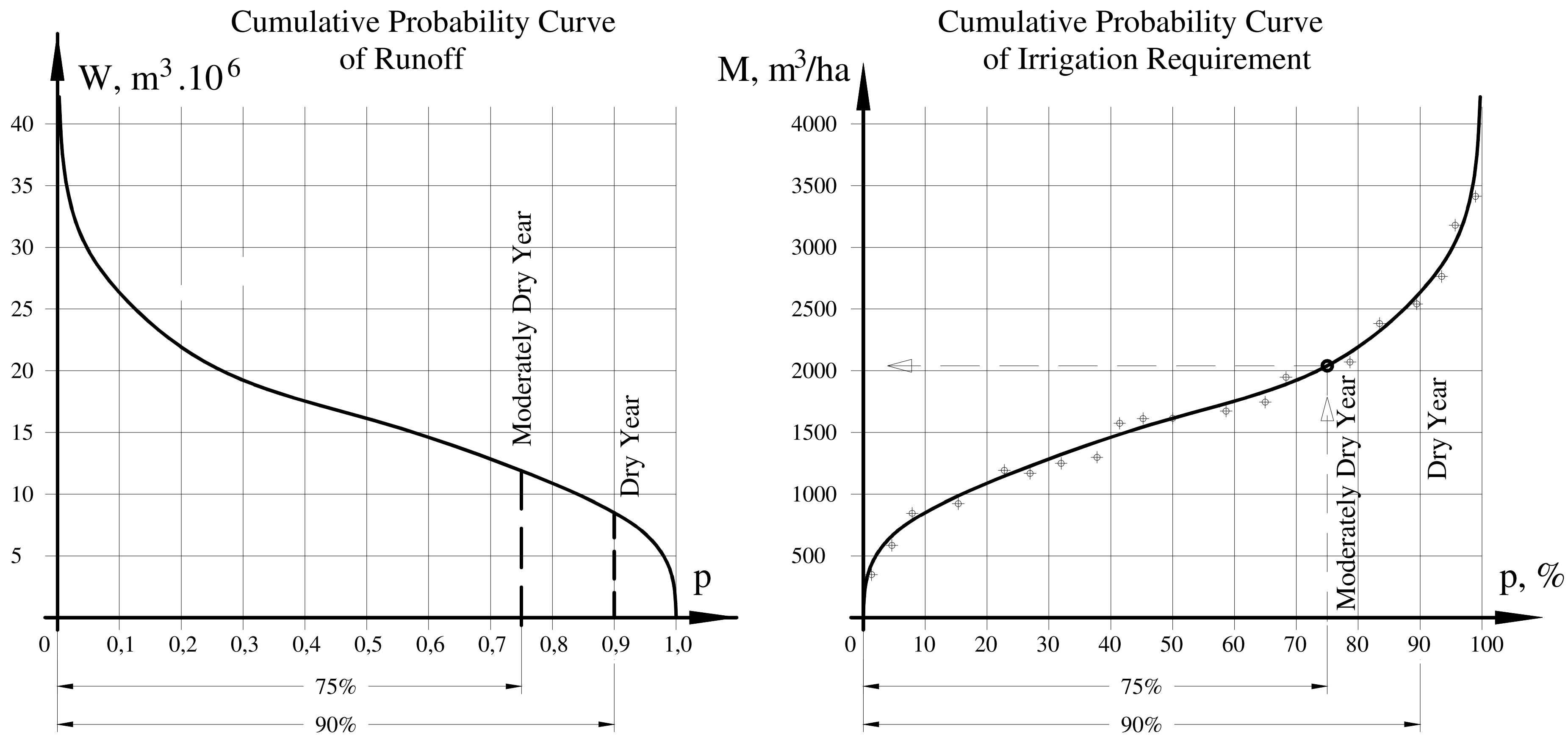


➢ This is what is happening in drip irrigation.

8. Determining Crop Water Requirements

8.2. Variation of Crop Water Requirements in Time

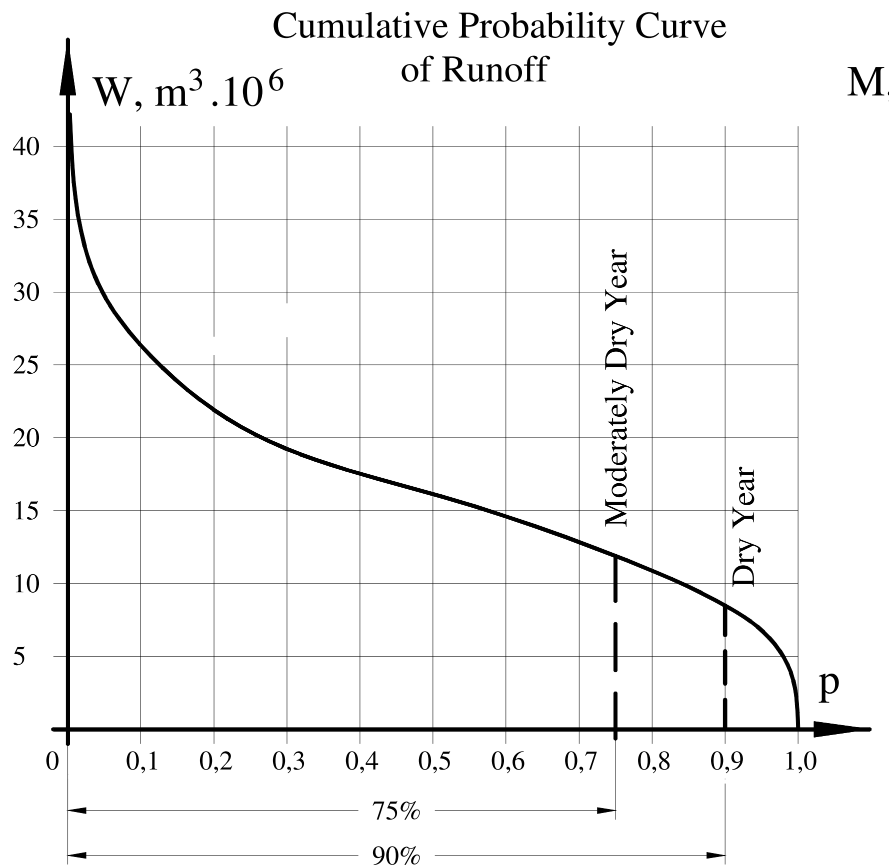
- The data for the Irrigation Requirement for series of years is processed and drawn as Cumulative Probability Curve.

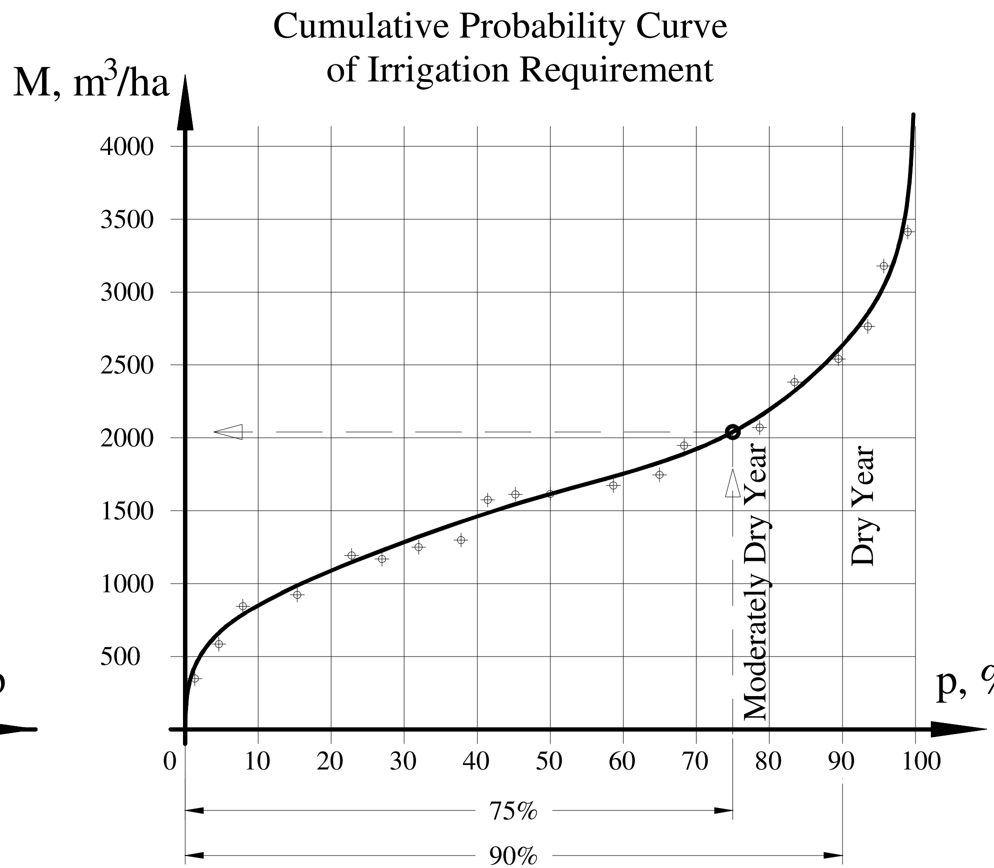


8. Determining Crop Water Requirements

8.2. Variation of Crop Water Requirements in Time

- Cumulative probability for Irrigation Requirement – probability not to surpass a given value.





9. Deficit Irrigation Scheduling

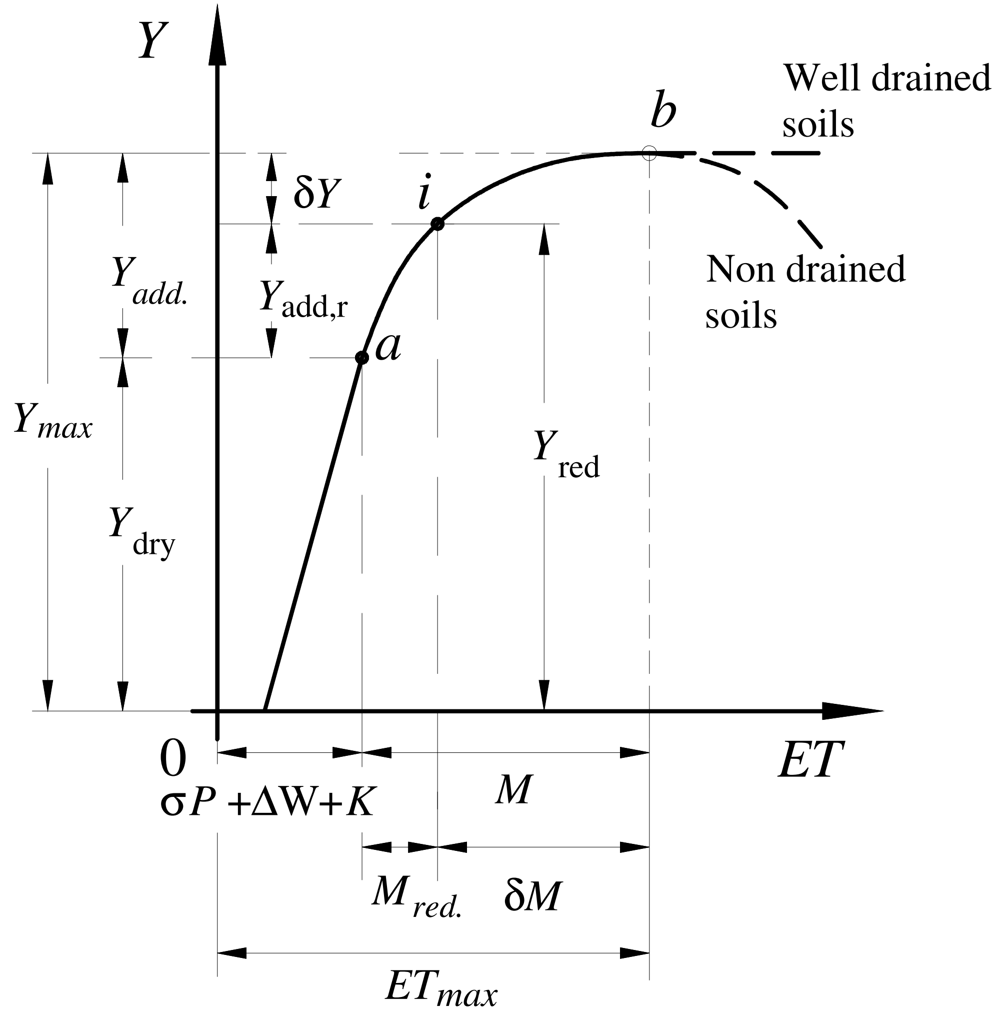
- **Deficit Irrigation Scheduling** – when there is not enough water to meet the crop requirements during the crop period
  - ➢ recently called ***water stress***
- Reasons:
  - ➢ Not well secured water source
    - ✓ insufficient volume (runoff) *W* - in Regulated Runoff IS;
    - ✓ insufficient flow rate *Q* - in Run-of-the-River IS.
  - ➢ Extremely hot year – low capacity of delivery network of IS or distribution network of IF.
  - ➢ Bad flow regulation in IS delivery network
  - ➢ Breakdowns or malfunctions of IS delivery network

9. Deficit Irrigation Scheduling

- The IS operates in water shortage conditions during some years of its exploitation
  - ➢ Acc. to Bulgarian Standards IS is designed for moderately dry year, i.e. security of irrigation requirement $p = 75\%$;
    - ✓ On average - in 1 out of 4 years IS will operate in water shortage conditions.
    - ✓ On average - in 3 out of 4 years IS will be capable to deliver requested irrigation requirements.
- For the farmers it is essential to know how the crops respond to water and what is the effect on yield in case of water deficit
  - ✓ The "Yield – Water" relationship provides needed information

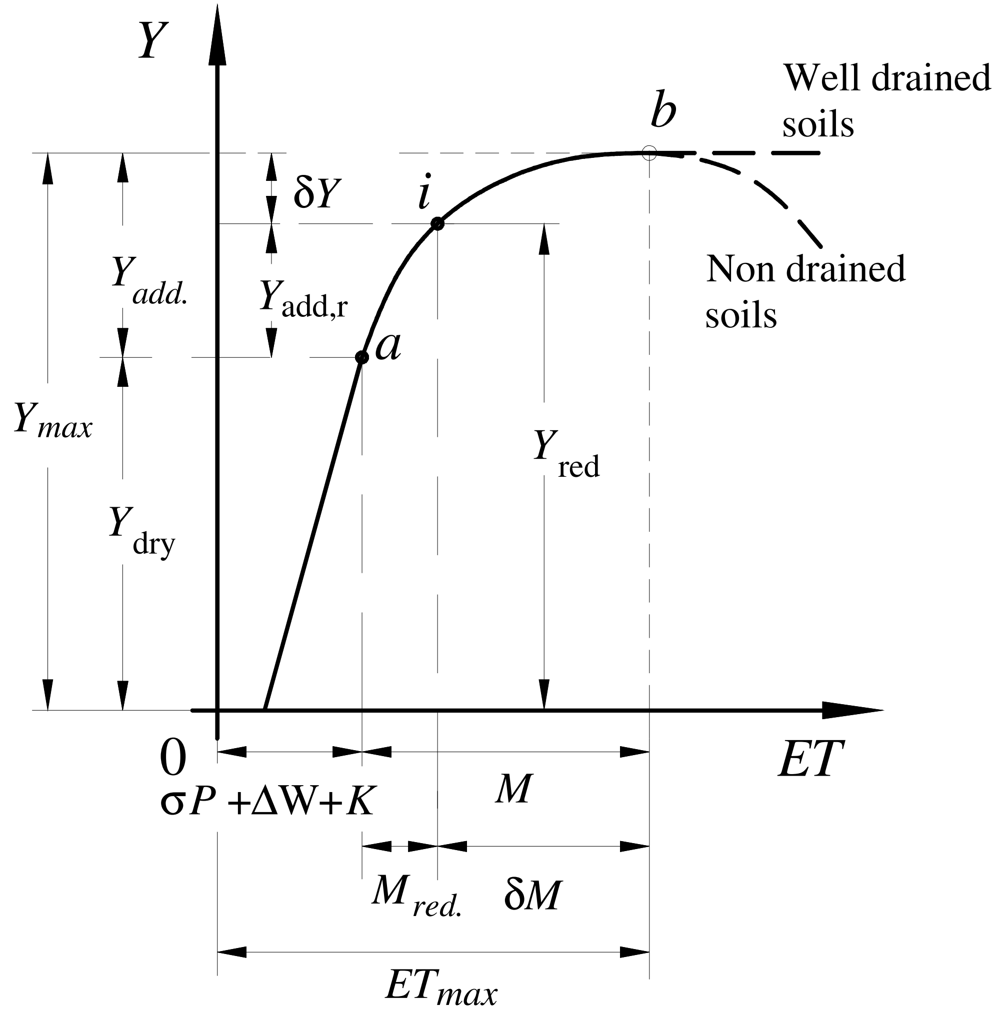
10. Yield – Water Relationship

- **Yield – Evapotranspiration in absolute terms**
  - ➢ Usefull for a good uderstanding of the idea,
  - ➢ Not exact and commonly used.
  - ➢ On x axis - ET includes the natural water sources $\sigma P + \Delta W + K$ and irrigation requirement M.
  - ➢ On y axis - the maximum value of the yield Y_{max} corresponds to $ET_{\max} = \sigma P + \Delta W + K + M$. (***point b***)
  - ➢ ***Point a*** – represents the max. yield in dry (rainfed) conditions.



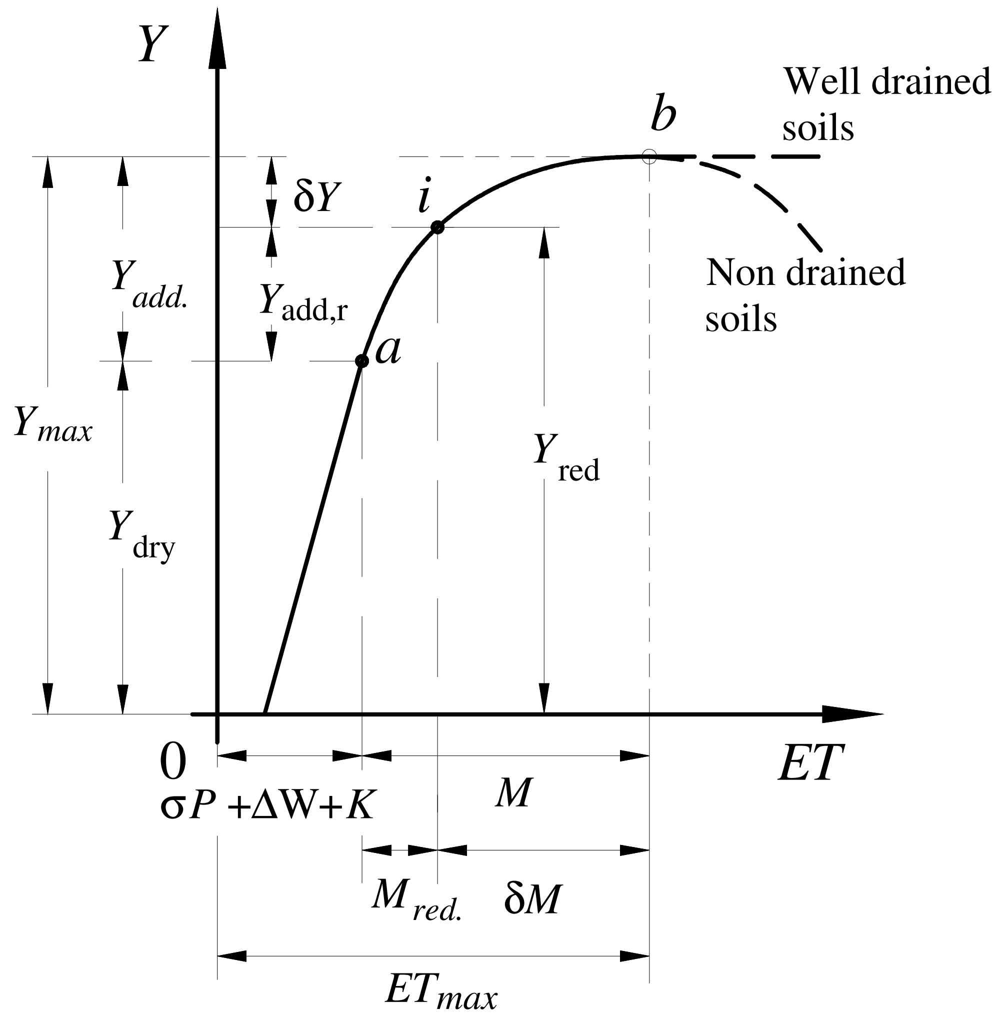
10. Yield – Water Relationship

- **Yield – Evapotranspiration in absolute terms**
  - Below ***point a*** the line is straight one (linear function).
  - Above the ***point a*** is the additional yield Y_{add} due to irrigation (due to M).
  - Some scientist claim that after ***point b*** the *Yield –ET* relationship declines, if the soils are not well drained and remains horizontal line if they are well drained.
  - Other scientist claim that in any case the excess (surplus) water leads to yield decrease.



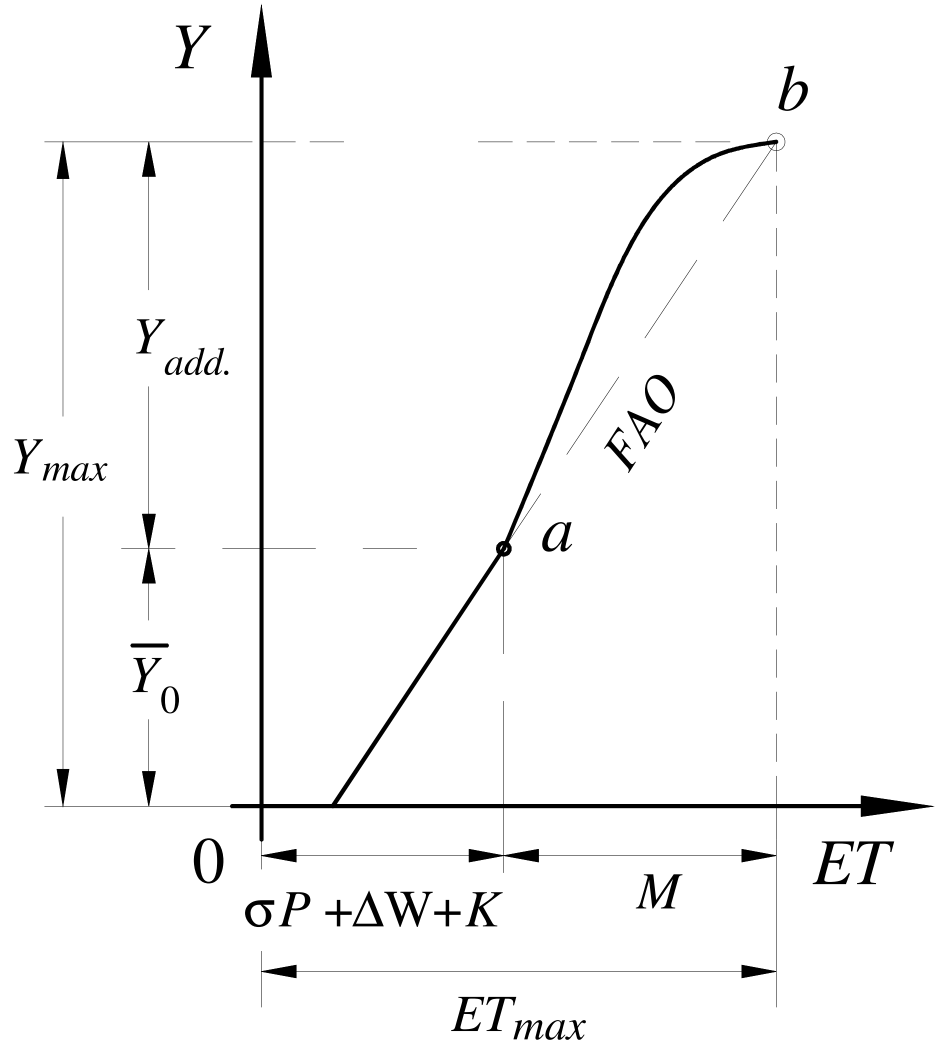
10. Yield – Water Relationship

- **Yield – Evapotranspiration in absolute terms**
  - ***Point i*** represents an example case of water shortage. If the decrease of irrig. requirement is δM, then it is read from the curve the yield decrease δM.
  - $Y_{add,r}$ is will be reduced additional yield in that case.
  - Y_{red} is the reduced absolute yield in the same case.
  - The effect of irrigation decreases near ***point b*** – the yield increment is almost zero!
  - Vice-versa – near ***point b*** water reduction is almost without effect.



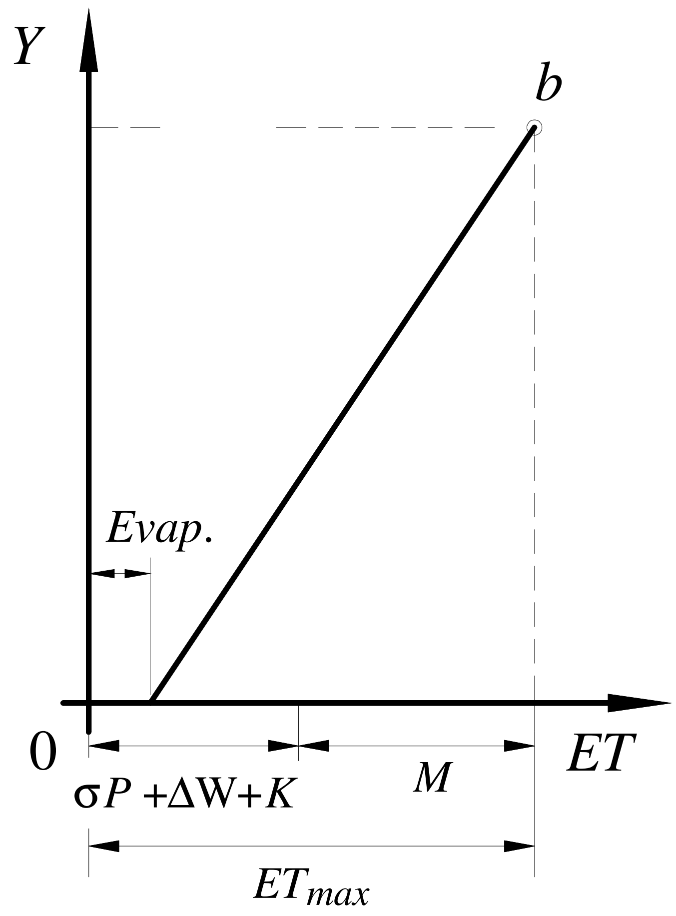
10. Yield – Water Relationship

- **Yield – Evapotranspiration in absolute terms**
  - Some scientist claim that at ***Point a*** there is a bend
  - This is effect from irrigation – the yield increases more rapidly when irrigation appear.
  - Others (like FAO) claim that *Y- ET* relationship is not a curved line, but a **straight line** (see the dashed line right).
  - In any case the *Y-ET* relationship does not pass through the origin of the coordinate system – ***point*** **0**.



10. Yield – Water Relationship

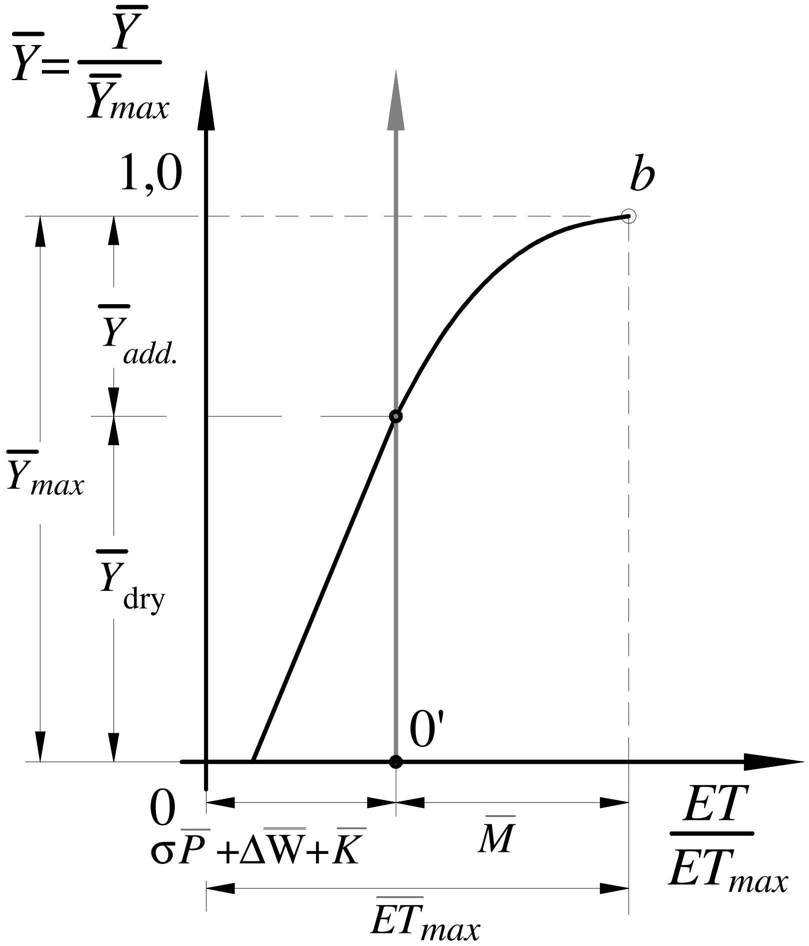
- **Yield – Evapotranspiration in absolute terms**
  - The *Y*- *ET* relationship does not pass through the origin 0, because there is evaporation from the soil surface even without a crop.
  - Thus, the section marked with *Evap*. (see right) is the evaporation.
  - The *Y* – *ET* relationship in absolute terms is not usable, because in different years, different part of natural inflow ($\sigma P + \Delta W + K$) will occur .



10. Yield – Water Relationship

- **Yield – Evapotranspiration in relative terms**
  - When plotted on *x* axis relative ET and on *y* axis relative yield, then the relationship becomes “more stable”.
  - ET_{max} and Y_{max} are maximum observed (on a long term basis) ET an Yield.
  - Even in that case, FAO claims that the relationship is a straight line, but in Bulgaria it is established via experiments that after the ***point a*** there is a curve or the whole relationship is a curved line.

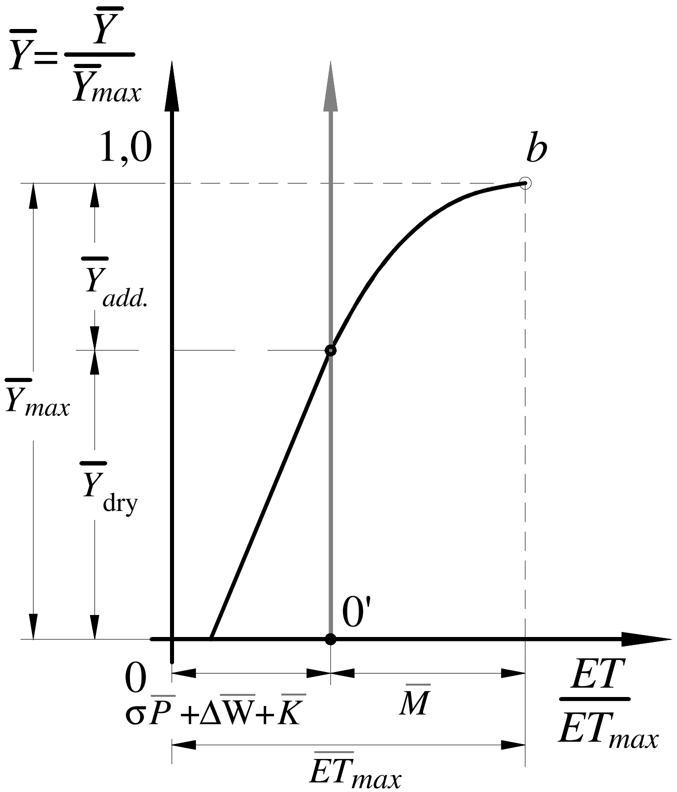
Yield - ET Relationship



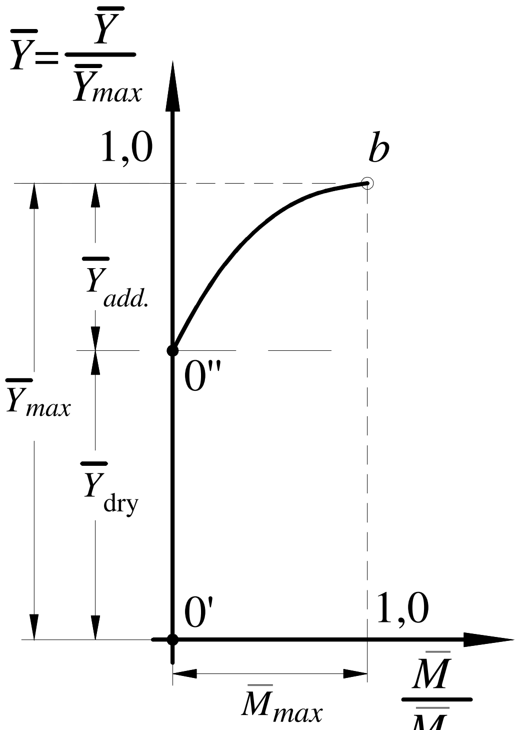
10. Yield – Water Relationship

- **Other expressions**
  - ➢ If the origin of the coordinate system is moved in such a way that *y* axis crosses ***point a***, then the relationship Yield-Irrigation Requirement is established.
  - ➢ If the origin of the coordinate system is moved to point a, then the relationship Additional Yield-Irrigation Requirement is established.

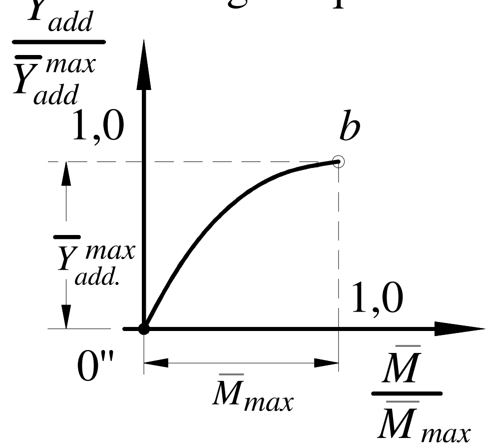
Yield - ET Relationship



Yield - Irrig. Requirement



Additional Yield vs. Irrig. Requirement



10. Yield – Water Relationship

- **Some formulae**
  - **Yield – Evapotranspiration in relative terms**
  - FAO

$$\frac{Y}{Y_{max}} = 1 - k_Y\left(1 - \frac{ET}{ET_{max}}\right)$$

where Y is estimated yield in a year in which a value of ET is observed;

k_Y – is the yield response factor.

If $k_Y > 1$, then the crop is sensitive to water stress (deficit)

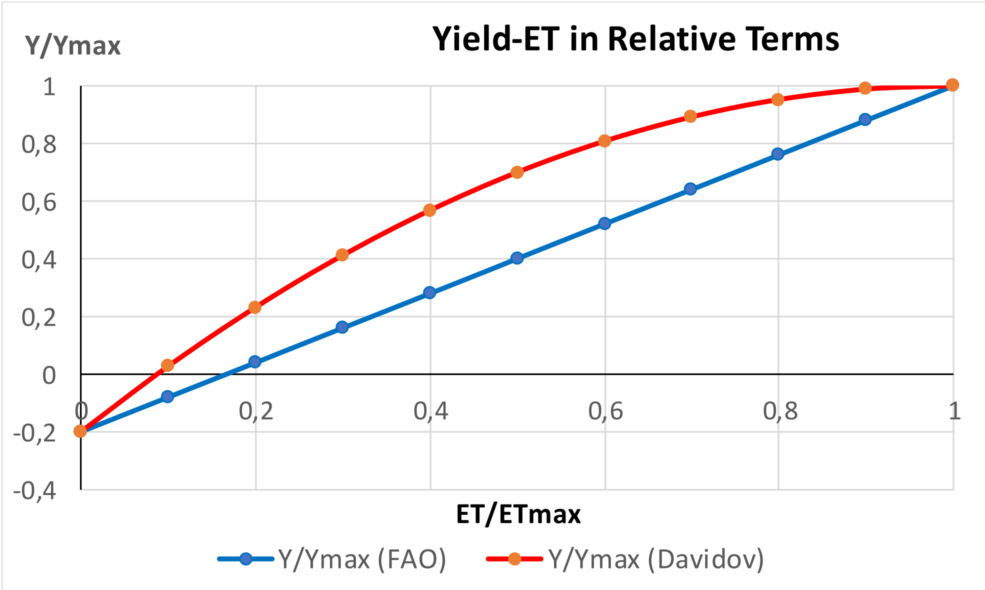
If $k_Y < 1$, then the crop is more tolerant to water shortage

- Davidov (Bulgaria)

$$\frac{Y}{Y_{\max}} = 1 - k_Y\left(1 - \frac{ET}{ET_{\max}}\right)^n$$

all notation is as in FAO formula;

the power factor n is a subject of adjustment depending on the observed data. It can very between 1 and 2, so *this is non-linear function!*



10. Yield – Water Relationship

- **Some formulae**
  - **Yield – Irrigation requirement in relative terms**
  - Vurlev (Bulgaria)

$$y = 1 - (1 - y_{dry})(1 - x)^2$$

where y = Y/Y_{max}, $y_{dry} = Y_{dry}/Y_{max}$,
$x = M/M_{max}$;

  - Davidov (Bulgaria)

$$y = 1 - (1 - y_{dry})(1 - x)^n$$

where y = Y/Y_{max}, $y_{dry} = Y_{dry}/Y_{max}$,
$x = M/M_{max}$;

n = 1.2 – 2.0 is subject to adjustment

  - **Additional Yield vs. Irrigation requirement in relative terms**
  - Davidov (Bulgaria)

$$\Delta y = 1 - (1 - x)^n$$

$\Delta y = \mathrm{Y_{add}/Y_{add}^{max}}$;

$x = M/M_{max}$;

n = 1.0 – 2.0 is subject to adjustment

10. Yield – Water Relationship

- The Yield-Water relationship is not an universal tool
- The Yield-Water relationship is relative (dependable):
  - ➢ When fertilizer application is increased, the Yield increases for the same amount of water applied
  - ➢ Not always the maximum quantity (yield) matches the maximum quality
    - ✓ Examples – Grape, Sugar beet.
- The Yield-Water relationship does not take into account the crop specifics in different growth stages
  - ➢ In different growth stages the crops react to deficit differently
    - ✓ usually in the first and last stage crops are more tolerant to water stress (deficit).