EXAMPLES OF WATER BALNCES IN AGRICULTURAL LAND DRAINAGE TO DETERMINR THE DISCHARGE

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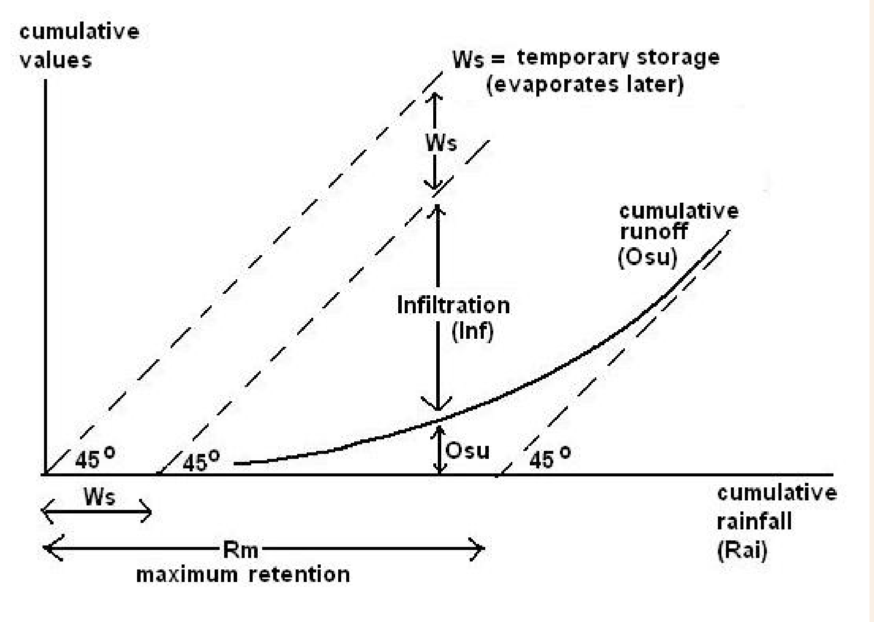
Example of a surface water balance



Principles of the Curve Number (CN) method

An example is given of surface runoff according to the Curve number method. The applicable equation is:

- Osu = $(Rai – Ws)^2$ / (Pp – Ws + Rm)

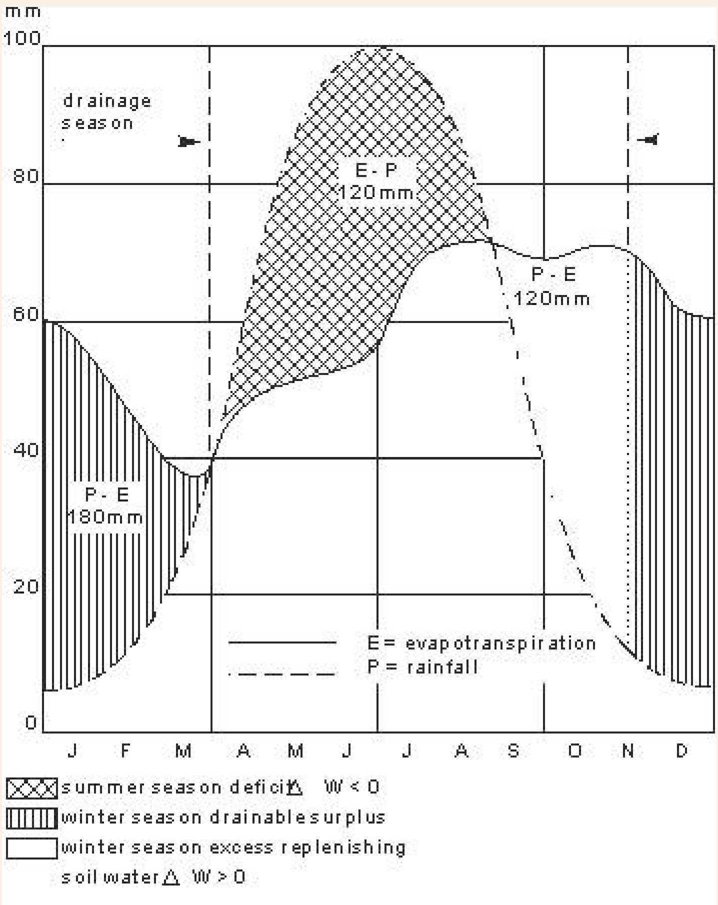
where Rm is the *maximum retention* of the area for which the method is used

Normally one finds that Ws = 0.2 Rm and the value of Rm depends on the soil characteristics. The Curve Number method provides tables for these relations.

The method yields cumulative runoff values. To obtain runoff intensity values or runoff velocity (volume per unit of time) the cumulative duration is to be divided into sequential time steps (for example in hours).

Example of drainage and irrigation requirements

The drainage and irrigation requirements in The Netherlands are derived from the climatic characteristics (see figure).



Climatic data in the figure (mm)	Summer Apr-Aug	Winter Sep-Mar	Annual
Precipitation Rai	360	360	720
Evaporation Eva	480	60	540
Change of storage Ws	–120	+120	0
Drainage requirement Dr	0	180	180
Irrigation requirement	variable	0	variable

The quantity of water to be drained in a normal winter is:

- Dr = Rai – Eva – Ws

According to the figure, the drainage period is from November to March (120 days) and the discharge of the drainage system is
Dr = 180 / 120 = 1.5 mm/day corresponding to 15 m^3/day per ha.

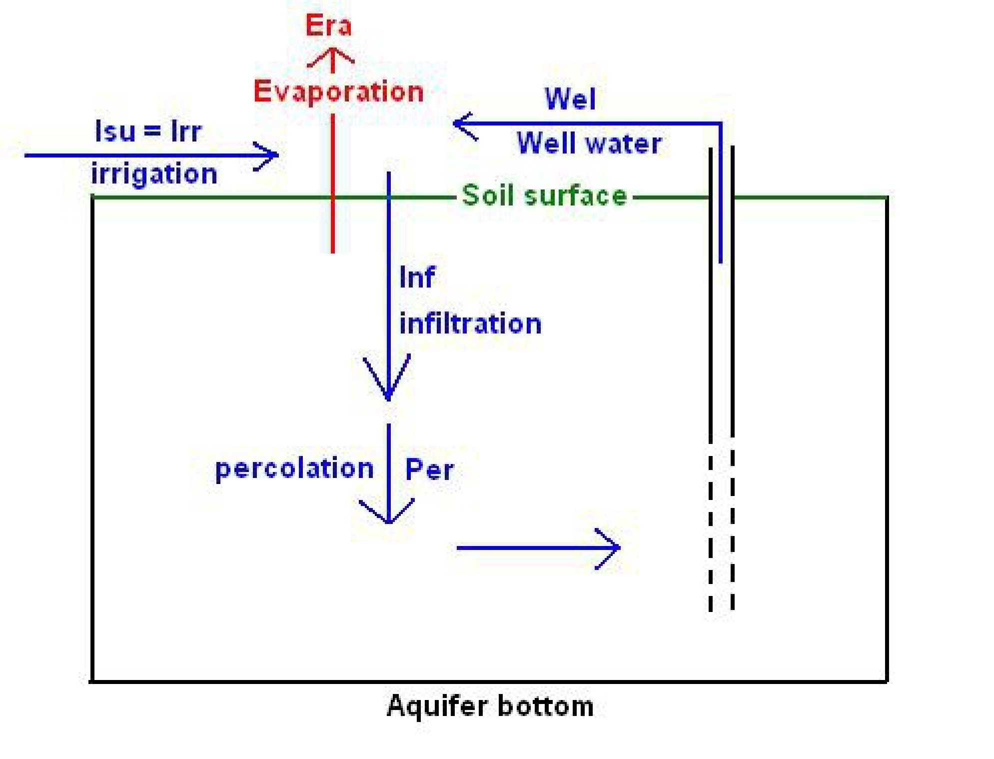
During winters with more precipitation than normal, the drainage requirement increase accordingly.

The irrigation requirement depends on the rooting depth of the crops, which determines their capacity to make use of the water stored in the soil after winter. Having a shallow rooting system, pastures need irrigation to an amount of about half of the storage depletion in summer. Practically, wheat does not require irrigation because it develops deeper roots while during the maturing period a dry soil is favorable.

The analysis of cumulative frequency of climatic data plays an important role in the determination of the irrigation and drainage needs in the long run.

Example of an overall water balance

An example is given of the reuse of groundwater for irrigation by pumped wells.



Reuse of percolation to the aquifer for irrigation (Groundwater reuse)

The total irrigation and the infiltration are:

- Inf = Irr + Wel,

  where *Irr* = surface irrigation from the canal system, and *Wel* = the irrigation from wells

The field irrigation efficiency (*Ff* < 1) is:

- Ff = Era / Inf,

  where *Era* = the evapotranspiration of the crop (consumptive use)

The value of *Era* is less than *Inf*, there is an excess of irrigation that percolates down to the subsoil (*Per*):

- Per = Irr + Wel – Era, or:
- Per = (1 - Ff) (Irr + Wel)

The percolation *Per* is pumped up again by wells for irrigation (*Wel*), hence:

- Wel = Per, or:
- Wel = (1 - Ff) (Irr + Wel), and therefore:
- Wel / Irr = (1 - Ff) / Ff

With this equation the following table can be prepared:

Ff	0.20	0.25	0.33	0.50	0.75
Well / Irr	4	3	2	1	0.33

It can be seen that with low irrigation efficiency the amount of water pumped by the wells (*Wel*) is several time greater than the amount of irrigation water brought in by the canal system (*Irr*). This is due to the fact that a drop of water must be recirculated on the average several times before it is used by the plants.

Example 4

An example of the influence of the length of the critical duration on the average design discharge is presented in Table 4.1.

It shows that the design discharge for drainage by pumped wells, with a critical duration of 6 to 12 months, can be taken as 1.1 to 1.6 mm/d, whereas drainage by pipes or ditches, with a critical period of 1 month to a growing season, requires a design discharge of 2.6 to 2.8 mm/d.

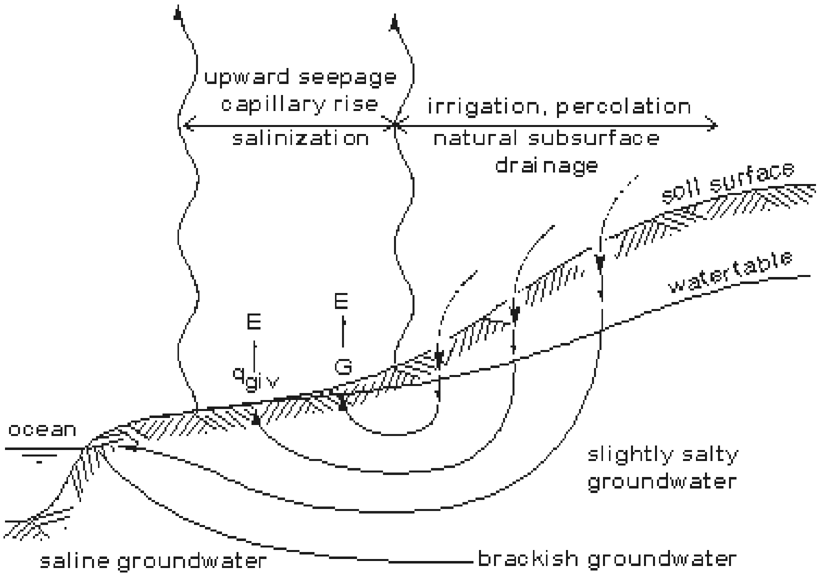
Table 4.1 Average drainage rate (mm/d) as a function of length of the critical period in an irrigated area of Iraq (Euroconsult 1976)

Crop	Peak month	Growing season	Peak half year	Whole year
Wheat	2.0	1.6	-	-
Maize	3.0	2.3	-	-
Potatoes	4.5	2.6	-	-
Combination*	2.8	-	1.6	1.1

*A cropping pattern of 2/3 winter wheat, 1/3 spring potatoes and 1/3 summer maize

Example 5. Coastal Peru

The first Peruvian example concerns an area in the coastal delta of a river that originates in the Andean mountain range. The coastal area is arid, and agriculture is totally dependent on irrigation from rivers descending from the Andes, where rainfall does occur. The irrigation in the river valleys is accompanied by considerable percolation losses. In the underlying deep and permeable aquifers, the percolation losses are transported towards the coast. A salt water wedge intruding from the ocean and a decreasing land slope towards the coast forces the aquifer water to flow upwards, and the water table becomes shallow (see figure below). The continuous upward seepage of groundwater feeds capillary rise into the unsaturated zone. The subsequent evaporation causes salts to accumulate in the topsoil. For these two reasons, irrigation and agriculture can only be practised in seepage zones when a subsurface drainage system is installed.



Cross-sectional sketch of the geohydrological situation in Coastal Peru

The area in the delta has light-textured soils and it had to be prepared for irrigated sugarcane (Suclla Flora 1972). This cane has a growing season of 14 to 16 months, with irrigation for a period of 10 to 12 months (the vegetative period), followed by an un-irrigated period of 4 to 6 months (the ripening or drying period), during which the cane augments its sugar content. The average depth of the water table in the irrigation season is permitted to be 0.8 m (such a value is also found from Figure 17.7, which refers to sugarcane in Australia), but during the ripening period the average depth should be more than 1.3 m; otherwise the crop uses too much of the capillary rise and the ripening does not proceed well. There are therefore two agricultural criteria for the subsurface drainage system, and the system has to satisfy both. The slight resalinization of the soil during the ripening period is not a problem, because, with the first consecutive irrigations, the accumulated salts will be removed again quickly.

The rate of upward seepage from the deep aquifer (called q_{giv}) can be estimated from the equilibrium depth of the water table before irrigation and drainage systems were introduced. In that situation, the topsoil was dry (pF = 4.0) and the seepage rate equalled the rate of capillary rise from the saturated zone (G), which also equalled the rate of evapotranspiration (q_{giv} = G = E). Under such conditions, the rate of capillary rise can be found from the steady-state relationship between depth of water table, hydraulic properties of the soil, and soil-water content. An example is shown in Figure 17.35. If the average depth of the water table before drainage was 0.8 m, the estimated rate of capillary rise from the saturated zone was 2.0 mm/d, which gives us the value of the average seepage rate q_{giv}.

In the water balance of the soil profile, we may ignore the storage term, and we get

$$q_d = R - G + q_{giv}$$

where

q_d = drainage rate (mm/d)

R = percolation rate (mm/d)

G = capillary rise (mm/d)

q_{giv} = upward seepage (mm/d)

The irrigation system is designed to apply 2400 mm/yr (i.e. during the vegetative period), of which 800 mm/yr is assumed to be lost as deep percolation. The average percolation rate thus equals R = 800 / 365 = 2.2 mm/d, and the capillary rise G is nil. Hence, the average drain discharge during the irrigation season can be estimated from Equation 17.4 as $q_d = 2.2 + 2.0 = 4.2$ mm/d (see Table below).

During the ripening period, there is no percolation (R = 0), but some capillary rise will take place as the soil becomes dry; it is estimated at G = 0.5 mm/d. The drain discharge q_d is now estimated from the above equation: 2.0 - 0.5 = 1.5 mm/d.

Table. Estimate of the drain discharge from the components of the water balance for irrigated sugarcane in Coastal Peru

Area	Seepage rate q_{giv} (mm/d)	Percolation rate R (mm/d)	Capillary rise G (mm/d)	Drain discharge $q_d = q_{giv} + R - G$ (mm/d)
		Irrigation season		
A	2.0	2.2	0	4.2
B	3.0	2.2	0	5.2
C	1.0	2.2	0	3.2
		Ripening season		
A	2.0	0	0.5	1.5
B	3.0	0	0.5	2.5
C	1.0	0	0.5	0.5

Notes

During the ripening season, without irrigation, the water table should be deeper because the sugarcane does not ripen properly with too much soil moisture.

During the ripening season, without irrigation, the soil becomes more saline due to capillary rise. However, the percolation from irrigation in the vegatative will leach the soil sufficiently.

Example 6. Guyana

This example concerns the collectors for surface drainage systems in sugarcane plantations in the coastal region of Guyana (Naraine 1990).

The surface water balance, for a period of one day, reads

$$Osu = Rai - Inf - Eva + Irr - Ws$$

where

Osu	=	runoff depth (mm)
Rai	=	precipitation (mm)
Inf	=	infiltration (mm)
Eva	=	evaporation from the surface (mm)
Irr	=	surface inflow depth (mm)
Ws	=	change in storage of surface water (mm)

In this example, the term Irr can be set equal to zero. Because we consider a short period with intensive rainfall, the term Eva can also be neglected. Thus the above equation can be reduced to

$$Osu = Rai - Inf - Ws$$

The Curve Number Method uses this balance to calculate the runoff. This will also be done here.

The following table shows data on the cumulative 5-day rainfall with a 10-year return period and the resulting cumulative surface runoff Osu_c calculated with the Curve Number method, using a Curve Number value of 40. This empirical method takes into account the storage Ws and infiltration Inf in the sugarcane fields, but not the dynamic storage in the fields that is needed to induce the discharge, as will be explained below. The table also shows the daily surface runoff Osu_d and the surface runoff rate Osu_a as a time average of the cumulative surface runoff: $Osu_a = Osu_c/t$,

where t is the time (days).

Table 6.1 Example of a rainfall-runoff relationship with a return period of 10 years in the case study of Guyana, using the Curve Number method with a Curve Number value CN = 40

Duration t	Cumulative rainfall	Surface runoff		Average surface runoff rate
		Cumulative Osu_c	Daily Osu_d	
(d)	(Rai)			$Osu_a = Osu_c/t$
	(mm)	(mm)	(mm)	(mm/d)
	2	3	4	5
1	150	14	14	14
2	250	59	45	29
3	325	104	45	35
4	360	128	24	32
5	375	138	10	28

The design discharge of the main drainage system can be chosen as the maximum value of the average surface runoff rate: q_{design} = Osu_a = 35 mm/d. It occurs after 3 days, which is the critical period because, with shorter or longer durations, the Osu_a values are less than 35 mm/d.

The cumulative surface runoff (Osu_c, Column 3 in the table) is plotted in the next figure against the time. It shows a curve with an S-shape. The slope of the tangent line from the origin to this curve indicates the required discharge capacity of the collectors, with a return period of 10 years (q_{design} = 35 mm/d).