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QUANTITATIVE ANALYSIS OF DEEP GROUNDWATER USE FOR IRRIGATION

The balance method of the resources of deep groundwater used for irrigation is presented. In the method described the following factors are taken into account: annual distribution of the changes in groundwater resources, annual distribution of water requirement for irrigations as well as annual distribution of atmospheric precipitations. The aim of the paper is to establish the fact whether the static resources of water used for irrigation will be made up during the standstill of the irrigation system operation under climatic conditions of Iraq.

1. CONCEPT OF TECHNICAL PROJECT

When the strength of surface water sources is insufficient and deep groundwater occurs in abundance, it is possible to make use of the latter for the irrigation of crops provided that its chemical composition raises no objections.

The concept involves construction of deep bored wells in appropriate arrangement. Water may be supplied either from all the wells into a common pipe system or from each well separately to irrigate the respective area via its own distribution system [1].

High building costs (along with the considerable operating costs associated with the pumping of water which is drawn from deep wells) as well as the limited availability of deep groundwater resources call for an optimum solution of the water distribution system (optimum with respect to building and operating costs) and for a rational use of the available quantities.

2. WATER DEMAND FOR VEGETABLE CULTURE

Water demand depends primarily on the vegetation process – from the moment of implantation to the moment of harvesting. Thus, water demand varies with time and is determined by the type of the culture involved. Figure 1 gives the diagram of water demand in a characteristic

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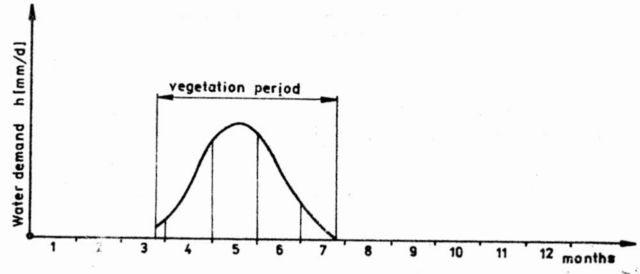

Fig. 1. Annual diagram of water demand for vegetable culture

year (in mm/day) for a certain type of crops. Prior to, and after completion of, the vegetation period, water demand equals zero.

Taking into account the random nature of some factors affecting the process of water uptake by the crop, many years' observations are required to determine the water demand distribution curve.

3. BALANCE OF AVAILABLE WATER RESOURCES

Plants cover their water demand from precipitation water (rainfall, snowfall, dew), from artificial irrigation involving external water supply or from both sources. Influenced by the climatic conditions and some meteorological factors, the quantity of precipitation water is a random variable which may be established by statistical methods. In the climate of Iraq, rainfall occurs primarily in the winter season (from November till February), appears occasionally in the remaining months to disappear completely between June and September. In the absence of rainfall, dew is the only natural water source available to plant growth. Needless to say that the amounts at which dew occurs are insufficient to support crop growth, especially in the summer months with very low air humidity. Combining the heights of precipitation and dew, and using the data sets of many years' observations, we can determine the diagram of the two parameters for a year with anticipated probability that the assumed sum of precipitation and dew will be exceeded. Figure 2 shows an example of such a diagram.

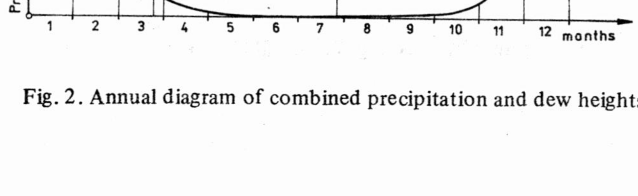

Fig. 2. Annual diagram of combined precipitation and dew heights

Another source is deep groundwater. The static and dynamic resources of deep groundwater vary with time – both in many years' and yearly periods. Precipitation water penetrating the ground by infiltration increases the groundwater level. But during a long-term drought, there is an escape of groundwater to the recipient streams, and evaporation through soil, thus abating both static and dynamic deep groundwater resources. Summing up, the level of groundwater resources increases during wet years and after long-lasting rainfall to decrease during dry years and after long-lasting drought (figs. 3 and 4).

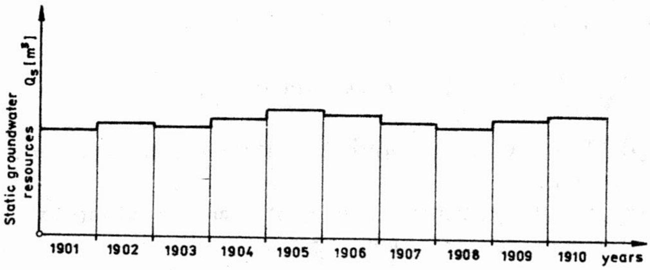

Fig. 3. Diagram of static groundwater resources (for many years' period)

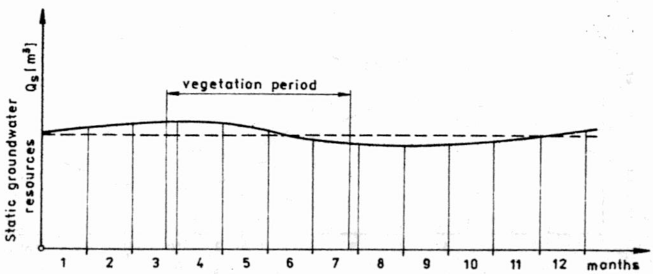

Fig. 4. Annual diagram of static groundwater resources

The term "static resources of groundwater", Q_s, is used here to denote the quantity of water which is found in the pores of the soil and can be filtered off by gravitation. Hence,

$$Q_s = A\,H\,\mu \quad [\mathrm{m}^3] \tag{1}$$

where A denotes the surface area of the investigated region $[\mathrm{m}^2]$, H indicates the average thickness (depth) of the saturated soil layer (saturation zone) [m], and μ is the coefficient of volume dewaterability.

When water is drawn from the wells, the static resources of groundwater decrease by the quantity of water filtrated off from the volume of the depression funnel. When the quantity of water drawn from the wells exceeds the quantity of dynamic resources, either throughout the irrigation period or during some part of it, the depression funnel will continue to increase, and the water level in the wells will continue to decrease. It is therefore necessary to determine the admissible drawability value for the static resources which will be made up during break in irrigation (winter season) and in the period of increased infiltration of precipitation water. If the admissible value is neglected, water withdrawal from the aquiferous layer becomes complete and irreversible.

To determine the quantity of available groundwater resources it is necessary to consider the annual distribution of dynamic resources. The term "dynamic resources of groundwater", Q_d, is used to denote the rate of groundwater flow through a given cross-section of the aquiferous-layer perpendicular to the flow direction. Thus, we have

$$Q_d = BHkI \; [\mathrm{m^3/d}] \tag{2}$$

where B is the length of the cross-section [m], k is filtration coefficient [m/d], and I is hydraulic gradient of groundwater table.

Like static resources, the dynamic resources of deep groundwater vary with time. They rise during periods of increased infiltration of precipitation water to decrease during drought periods (fig. 5).

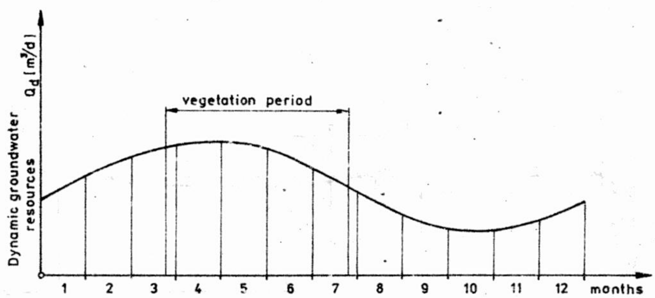

Fig. 5. Annual diagram of dynamic groundwater resources

4. DIAGRAM OF ANNUAL WATER DEMAND FOR IRRIGATION

Most of the precipitation and dew water flows in the form of surface runoff and evaporates. Only some part of it penetrates the soil and becomes available to plant growth. To balance the overall water demand for vegetable cultures with the water quantity made available to them through atmospheric precipitation and dew, it is necessary to determine (on the basis of investigations) the percentage of atmospheric water available to the crops and the remaining (non-available) portion. This remaining atmospheric water portion may evaporate, may flow in the form of surface runoff, or may penetrate the soil. The percentage of water available to plant growth varies throughout the vegetation period. For simplification, let us assume an analogous diagram in each year. Figure 6 gives the annual diagram of precipitation and dew height available to vegetable cultures and the remaining portion.

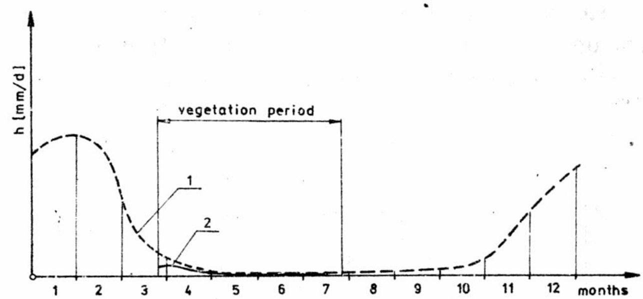

Fig. 6. Annual diagrams of precipitation and dew heights available and not available to vegetable growth
1 – annual diagram of water demand for vegetable cultures, *2* – diagram of precipitation water available to vegetable growth

Having at hand the overall water demand during vegetation (fig. 1) and the diagram of precipitation water available to vegetable growth (fig. 6, curve 2), we can determine the diagram of the demand for additional water which is to be supplied through irrigation systems. Figure 7 shows a graphical method of constructing such a diagram. The same diagram, related to the coordinate axis, is given in fig. 8. If the water demand of the initial vegetation period (following implantation) does not exceed the quantity of precipitation water available to plant growth, artificial irrigation may begin at a later date with regard to the moment of implantation. If the precipitation water quantity of the ripening period is sufficient for this stage of vegetation, artificial irrigation may be discontinued at an earlier date. As shown by the plots of fig. 8, the required irrigation doses vary considerably with time. Thus, if we match the efficiency of the wells accordingly, we shall achieve a rational utilization of the groundwater resources and a compatible energy demand for pumping. The efficiency of the wells, as well as the efficiency of the entire water distribution system, should be increased by the quantity of evaporation losses (fig. 8, curve 2). A combination of rational irrigation doses and expected crop growth parameters might be of great help when formulating a stochastic model of the artificial irri-

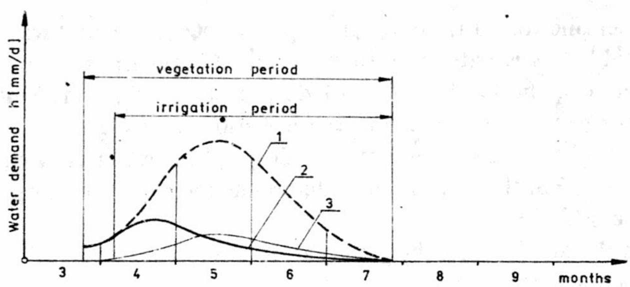

Fig. 7. Graphical method of determining the annual diagram of water demand for irrigation:
1 – water demand curve, *2* – curve for precipitation water utilized by vegetable cultures, *3* – evaporation losses of irrigation water, *4* – diagram of irrigation water demand

gation process. The stochastic model would make it possible to forecast and verify the irrigation water demand one week (or even one day) in advance. Using the stochastic model should also enable a computer-aided control of the irrigation equipment.

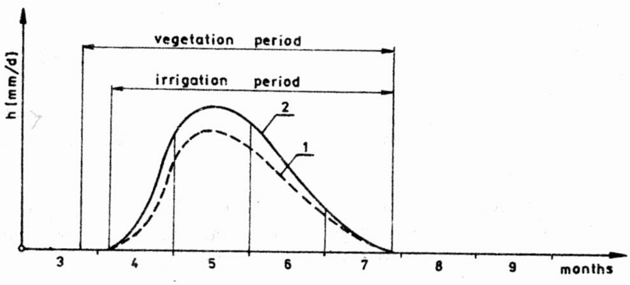

Fig. 8. Diagram of water demand for irrigation in a characteristic year:
1 – curve of additional water demand for vegetable cultures, *2* – curve of irrigation water demand, including evaporation losses

5. THE EFFECT OF IRRIGATION WATER WITHDRAWAL ON THE STATE OF DEEP GROUNDWATER RESOURCES

To assess the effect of irrigation water withdrawal on the deep groundwater regime, it is necessary to transform the diagram of fig. 8. Thus, the abscissa should include the volumetric water demand related either to the total (Q_t) (fig. 8) or to the unit (Q_u) surface area of irrigation. Hence, we have

$$Q_t = 0.001\, hA \quad [\mathrm{m^3/d}] \tag{3}$$

or

$$Q_u = 10\, h \quad [\mathrm{m^3/d\ ha}] \tag{4}$$

where Q_t is water demand for artificial irrigation [m^3/d], Q_u is the unit water demand for artificial irrigation [m^3/d ha], h is water dose [mm/d], and A is the irrigated surface area [m^2].

It is convenient to quantify the effect of deep groundwater consumption for irrigation purposes by comparing the integral curve of the irrigation water demand for a given area with the integral curve for the dynamic resources of deep groundwater flowing through the area influenced by the wells. But there is a need to determine the breadth of the groundwater stream which feeds these wells (fig. 9).

Figure 10 gives the graphical method of quantifying the degree of utilization of static and dynamic deep groundwater resources.

If the integral curve of water demand runs below the integral curve of dynamic resources, we have an indication that the static resources are not utilized, whereas the dynamic resources cover the water demand in excess. But if the integral curve of water demand (1) intersects the

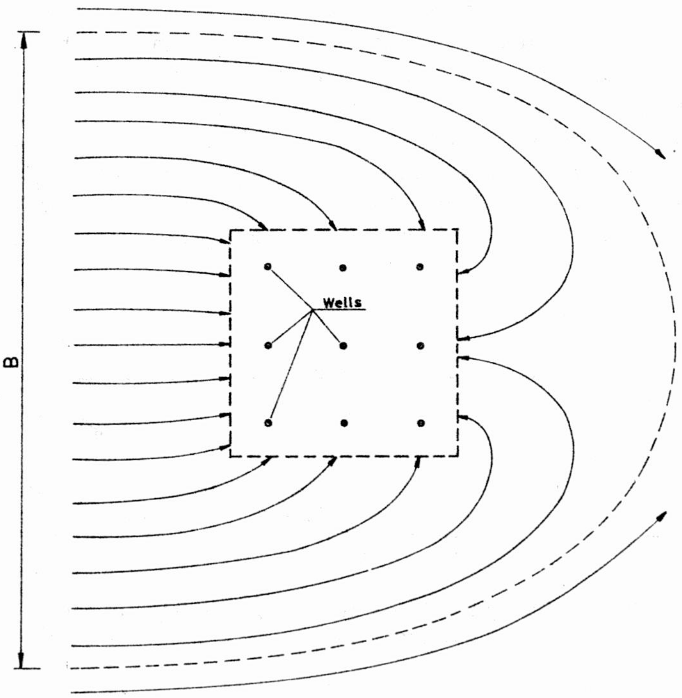

Fig. 9. Determination of groundwater stream breadth (*B*)

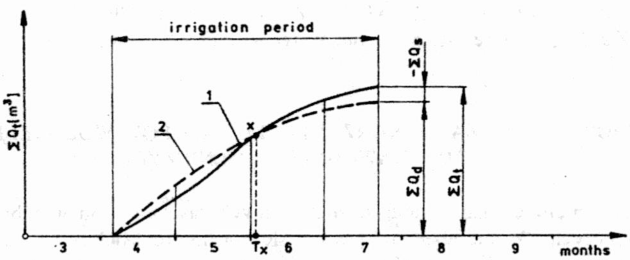

Fig. 10. Graphical method of quantifying the degree of utilization of static and dynamic deep groundwater resources for irrigation
1 -- integral curve of irrigation water demand in the irrigation period
2 -- integral curve of available dynamic deep groundwater resources in the irrigation period

integral curve of dynamic resources (2) (point x in fig. 10) to run above it, this means that, with the moment T_x, the intake will draw the entire dynamic resources and partially, the static resources. The problem itself is sophisticated, because the withdrawal of static resources increases the breadth of the feeding stream (as a result of the decreasing of drawdown of the intake and the widening of the radius of influence), thus increasing the dynamic resources which reach the intake. If the comparison of the integral curves shows that the static resources will be utilized, it is necessary to assess whether or not the decrement of the static resources can be made up by the dynamic resources during standstill of the irrigating system.

Valuable information may be obtained when analysing the integral curve of dynamic resources for the standstill period (fig. 11). Thus, if the sum of dynamic resources (ΣQ_d) markedly exceeds the withdrawal of static resources ($-\Sigma Q_s$), there is a high probability that this decrement will be made up. To make our analysis more accurate, we have to determine the time required for the filling of the depression funnel. And this depends on the water-permeability of the soil.

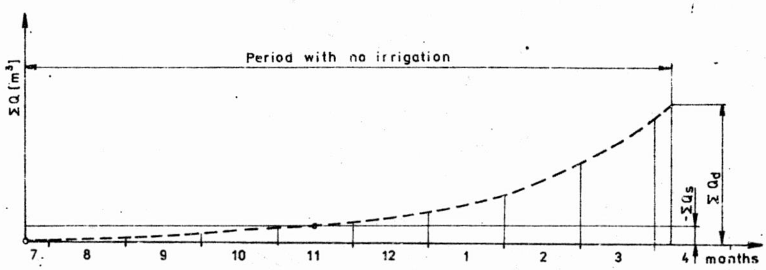

Fig. 11. Graphical method of quantifying the make-up of static deep groundwater resources

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ILOŚCIOWA ANALIZA WYKORZYSTANIA ZASOBÓW WÓD GŁĘBINOWYCH DO NAWODNIEŃ ROLNICZYCH

Zaproponowano metodę bilansowania dyspozycyjnych zasobów wód wgłębnych wykorzystywanych do nawodnień rolniczych. W metodzie uwzględnia się roczny rozkład zmian zasobów wód wgłębnych, roczny rozkład zapotrzebowania na wodę do nawodnień oraz roczny rozkład opadów atmosferycznych. Zbadano, czy wykorzystane do nawodnień wody statyczne będą odnowione w okresie przerwy w działaniu sztucznego nawadniania w warunkach klimatycznych Iraku.

КОЛИЧЕСТВЕННЫЙ АНАЛИЗ ИСПОЛЬЗОВАНИЯ РЕСУРСОВ ГЛУБИННЫХ ВОД ДЛЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ОРОШЕНИЙ

Предложен метод балансирования имеющихся в распоряжении ресурсов глубинных вод, используемых для сельскохозяйственных орошений. В методе учитываются годичные распределения изменений ресурсов глубинных вод, потребности в воде для орошений, а также атмосферичных осадков. Было исследовано, будут ли используемые для орошений статические воды восстановлены во время перерыва в работе искусственного орошения в климатических условиях Ирака.