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HOOGHOUDT, SYMEN BAREND

P A C Raats, Wageningen University, Wageningen, The Netherlands
R R van der Ploeg, University of Hannover, Hannover, Germany

Introduction

In the absence of dikes against sea and river water, more than half of The Netherlands would be flooded. Moreover, The Netherlands has a humid climate with, on average, precipitation exceeding evapotranspiration during autumn, winter, and early spring. Historically, crop yield records show a strong correlation between wet autumn and winter seasons and later low crop yields. However, from about 1850, the ability to get rid of excess water was the determining factor in crop yield. In the first half of the nineteenth century, much effort was put into modernizing the design, maintenance, and management of waterways. Replacement of windmills by steam-driven pumping stations started in 1845 and made removal of water independent of the whims of the weather. At the field scale, originally the removal of water was by a ridge-and-furrow system or a dense network of trenches. Already early in the nineteenth century, trenches filled with brushwood covered with soil were used incidentally, but such drains were found to decay rapidly. Earthenware tiles were introduced in England around 1845, and the first experiments in The Netherlands with these 'drying pipes' were done in 1851. Gradually, ditches were replaced by tiles of 0.05 m inside diameter, with a slope of 0.01–0.02 m m^{-1}, and draining into the remaining main ditches spaced 100–300 m apart, the larger spacings always being used in new polders. The choice of drain depth and distance depended on the nature of the soil and the drainage requirement. Leading the introduction of tile drainage, especially on arable land, was the province of Groningen, in the northeast, followed by the province of Zeeland, in the southwest, and the polders being reclaimed from the IJsselmeer. When, around 1960, tube drains succeeded tile drains, the practice also spread to other parts of the country. The drains not only serve to remove water, but in late spring and summer may also supply water from the main ditches to the fields by subirrigation.

In the 1850s, drainage experiments were conducted by the French engineer S.C. Delacroix. In the 1860s this work was noted by the Danish engineer D. Hannemann, who in turn inspired Ludvig August Colding (1815–88) to derive the ellipse equation. This Dupuit-type equation describes the shape of the water table for steady flow Q, resulting from uniform input s at the water table, to tile drains spaced l apart and resting on an impermeable base (**Figure 1**):

$$Q = ls = \frac{4kH_0^2}{l} \qquad [1]$$

with k representing the hydraulic conductivity of the soil and H_0 the height of the water table above the impermeable base at the midpoint between the drains. The ellipse equation was widely used in Denmark and also became known in other European countries. In The Netherlands it was used only sporadically, but nevertheless became the point of departure for S.B. Hooghoudt's drainage research in the early 1930s.

From Physical Chemistry to First Contacts with Drainage Theory and Practice

Symen Barend Hooghoudt (**Figure 2**) was born on August 31, 1901 at Slochteren, in the province of Groningen, in the Netherlands. He studied physical chemistry at the State University of Groningen, receiving a BSc degree in 1922, an MSc degree in 1926, and a doctoral degree in 1928. His doctoral thesis, supervised by Frans Maurits Jaeger (1877–1945), dealt with a method for the accurate measurement of the Becquerel effect. This photovoltaic effect is the basic physical process through which a solar cell converts sunlight into electricity.

Hooghoudt joined the Soil Science Institute at Groningen on March 16, 1929 and remained with it till his death on August 30, 1953. In the late 1920s, the Institute's Director, David Jacobus Hissink

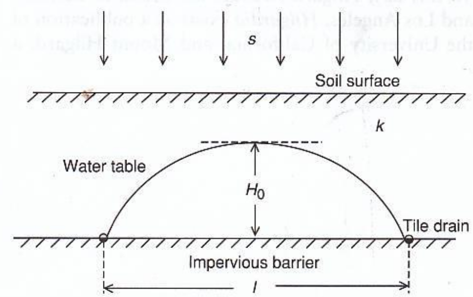

Figure 1 Flow to tile drains, as considered by L.A. Colding in 1872.

Figure 2 Symen Barend Hooghoudt (1901–53). (Reproduced with permission from Bruin P and Visser WC (1953) Het werk van Dr S.B. Hooghoudt in dienst van het landbouwkundig onderzoek. *Landbouwkundig Tijdschrift* 65: 650–657, © KLV Royal Netherlands Society for Agricultural Sciences.)

(1874–1956), was heavily involved in discussions within the International Society of Soil Science (ISSS) on the measurement of soil pH and its use as a diagnostic tool. The chinhydron electrode was the best method available, but unfortunately it could not be used in soils high in manganese and pH >8.5. Hooghoudt's first assignment was to study the antimony electrode as an alternative for soils with pH >8.5. Soon after this study was completed successfully, the glass electrode was introduced, allowing simple and rapid measurement up to pH 12–13, and as a result the antimony electrode was widely considered obsolete almost immediately.

In 1930–31 Hooghoudt was involved with Hissink in a first study of some physical properties in a wide range of Dutch soils, namely the permeability for water, the dry bulk density, and the air capacity, using methods devised by J. Kopecky early in the twentieth century. The prime motivation was the need for guidance in developing drainage systems for the planned IJsselmeerpolders, in particular the pilot polder Andijk and the first full-scale polder Wieringermeer. For reference, subsidence and prognosis of temporal changes in soil properties were studied in a series of polders reclaimed in 1550, 1844, 1924, and 1925. Several fields devoted to studies of drainage or subirrigation and an area intended to be used for a complex of sports and playing fields were also included in the study. The practical context exemplified by these field sites remained a hallmark of Hooghoudt's research.

The soil permeability was expressed in terms of the *D*-value, defined as the amount of water in meters per day flowing under a ponding depth of 0.04 m vertically through a sample of 0.07 m freely into the air. Despite its operational nature, the *D*-values enabled Hissink and Hooghoudt to delineate important aspects of the flow of water in Dutch soils. It was shown that for sandy soils without structure the particle-size distribution can be used to estimate the *D*-value, but that large structural pores dominate the conduction of water in all other soils. In soils with such structural pores, the *D*-values measured with ring samples of 3850 mm^2 cross section were found to be extremely variable, even at very small distances.

In December 1931, Hooghoudt went on a study tour to Breslau, Prague, and Zurich. At Breslau, F. Zunker studied the dependence of various physical properties upon the specific surface derived from the particle-size distribution. In his trip report, Hooghoudt emphasized that Zunker's methods could only be used for sandy and very light loamy soils. At Prague, Hooghoudt learned about many practical aspects of soil and water management. But he found little of direct use, mainly because the structure of the soils differed too much from the generally rather young Dutch soils with comparable distributions of particle sizes, and also because some of the concepts being used were somewhat esoteric. The visit strengthened his belief that Dutch soils reclaimed from the sea have unique properties and that field methods were needed to determine soil properties relevant to the drainage process. The visit to E. Diserens at Zurich was by far the most fruitful. It brought Hooghoudt in contact with an analysis of drainage problems based on what he called the law of Dupuit–Darcy, and the associated laboratory and field methods for determining the required soil physical properties.

In July 1932, the 6th Commission of the ISSS held a meeting at Groningen on water management, with emphasis on drainage and reclamation of land from the sea. Together, the ISSS contacts, the impressions from the European study tour, the first study of soil physical properties with Hissink, and the practical needs of water management in The Netherlands shaped Hooghoudt's research plans for the next 10 years.

Physical Characterization of Soils in the Laboratory

From the very beginning, attempts were made to relate the physical properties of soils to the composition of the solid phase and the volume fractions of the solid, aqueous, and gaseous phases. The composition of the solid phase was given in terms of the contents of humus and calcium carbonate, and the content and size distribution of particles other than humus and calcium carbonate. At Groningen, the size distribution of particles was originally determined using either the Atterberg sedimentation cylinder method for the range 2–30 μm or the Kopecky multiple-tube elutriation method for the range 16–100 μm, complemented with sieving of the coarse fraction to 2000 μm. Hooghoudt made very detailed evaluations of these and other methods. The 323-page report of this methodological study includes a 59-page review of validity, limitations, and extensions of the Stokes law for the rate of fall of solid particles in a fluid. This report was submitted in August 1944. As for many scientists, for Hooghoudt scholarly work of this kind was a way to cope with the stagnation caused by the war-time conditions. In 1946 this study resulted in a switch to the combined sieve–pipette method for routine determinations, the pipette method being used for the fraction less than 35 μm and the sieve method for the fraction greater than 35 μm.

Following F. Zunker, Hooghoudt introduced the specific surface, U, which is defined as the ratio of the surface area of a given mass of soil divided by the surface area of this same mass of soil in the form of spheres having a reference diameter $\sigma_r = 1$ cm. He showed that if $w = f(\sigma)$, where w is the weight fraction of the total amount of particles smaller than a specific particle diameter σ, then the specific surface U is given by:

$$U = \sigma_r \int_{w=0}^{w=1} \sigma^{-1} \mathrm{d}f = \sigma_r \int_{\sigma=\sigma_1}^{\sigma=\sigma_2} \sigma^{-1} (\mathrm{d}f/\mathrm{d}\sigma) \mathrm{d}\sigma \qquad [2]$$

A hypothetical soil with uniform particle diameter $\sigma_{\mathrm{eff}} = \sigma_r/U$ has the same specific surface U as the actual soil. Hooghoudt refers to σ_{eff} as the effective particle diameter of the actual soil. The specific surface area U and effective particle size σ_{eff} derived from it are particularly relevant in the range 16–2000 μm. Clearly, U and σ_{eff} are proper measures of the coarseness or fineness of a soil and σ_{eff} can be regarded as a characteristic microscopic length scale of a soil, comparable with that used in the Miller–Miller scaling theory of modern soil physics. Consistent with this, in expressions used by Hooghoudt, the hydraulic conductivity is inversely proportional to U^2 and the height of capillary rise is proportional to U.

From the very beginning, Hooghoudt distinguished two broad classes of soils: a class of soils without structure, and a class of soils with structure arising from aggregation, cracking, and perforation. For the class of soils without structure, the physical properties can be determined in the laboratory on disturbed samples and the results can be extrapolated to the field situation, using formulas involving the porosity, volume of entrapped air, and temperature. For the class of soils with structure in their natural condition, meaningful measurements of the hydraulic conductivity cannot be made in the laboratory, but must necessarily be made in the field. In fields without drainage systems, this can be done by the auger-hole method. In fields with drainage systems, the hydraulic conductivity can also be inferred from the relationship between the groundwater level and the flux into or out of drains and ditches.

The phase distribution of soils was characterized by the total porosity, considered as the sum of the drainable porosity and the water-filled porosity after drainage, and the air-filled porosity below the water table. Related to the dynamics of the water, Hooghoudt determined two physical parameters in the laboratory: the height of capillary rise and the hydraulic conductivity below the water table. To interpret data on height of capillary rise and hydraulic conductivity, he made use of rational formulas, showing the dependence upon the specific surface U and the porosity. By modern standards, the concepts used by Hooghoudt may seem simplistic, but they were perfectly suited for his goals.

Hooghoudt also paid some attention to rheological properties of soils, resulting in a 200-page publication on hardness and on rupture by various means of soils in the dried state. The aim was to get a basic understanding of the mechanical properties of dry clods and crusts. He used methods suitable for dried pastes borrowed from research related to the pottery and porcelain industry. He focused on the influence of particle-size distribution and the composition of the adsorption complex on the mechanical properties.

In the context of a large-scale study of irreversible drying of peat soils, Hooghoudt studied the causes of the phenomenon and developed a method to express the degree of irreversible drying by a single number.

Auger-Hole Method for Determining Hydraulic Conductivity in the Field

Observations of the rate of rise of the water level in an auger-hole following lowering of the water table by pumping can be used to calculate the hydraulic conductivity. E. Diserens and J. Donat pioneered this method. Following his discussions with Diserens in December 1931, Hooghoudt greatly improved the underlying theory, arriving for homogeneous soils at a formula expressing the rate of rise of the water level as the sum of a term due to horizontal flow through the wall of the hole and a term due to vertical flow through the bottom of the hole. He also derived corresponding formulas allowing for soil heterogeneity, either in the form of layering or continuous variation with depth. The formulas were verified by laboratory tests in a 62.5-cm-diameter drum with a perforated copper tube placed at the center. In the experiments the diameter of the tube, the depth of the bottom of the tube below the undisturbed water table, the initial lowering of the water in the tube, and the location of the impermeable layer were varied. Both homogeneous and layered soils were used in the tests. To study the possible influence of the small diameter of the drum, tests were also performed in a soil bin 10 m long, 2 m wide, and 2 m deep.

By necessity the tests of the theory in the small soil drum and large soil bin were done with sandy soils. However, Hooghoudt also developed the equipment needed for measurements in the field, allowing measurements to be made not only in sandy soils, but also in structured soils. With this equipment, measurements were made in the Wieringermeerpolder in a drained field, allowing comparison with hydraulic conductivity inferred from the relationship between groundwater levels and drain fluxes. The agreement between the hydraulic conductivities determined with the two methods was quite satisfactory, and Hooghoudt proceeded to use the auger-hole method widely and used the results to give advice with regard to design of drainage systems. In his extensive 1936 report on the auger-hole method, he gave as examples data for a proposed airfield near Leeuwarden and for the Rietwijkeroorderpolder near Amsterdam, intended to be developed as a recreational park.

The theory underlying the auger-hole method was developed further after World War II. At Groningen, L.F. Ernst in 1950 used J.J. van Deemter's numerical relaxation method to obtain a new formula to calculate the hydraulic conductivity from auger-hole measurements. In the USA, Don Kirkham and his associates made important contributions from 1948 onward. Based on their very general analytical theory for auger-hole seepage, C. Boast and D. Kirkham in 1971 concluded:

> Hooghoudt's formula should be used only for a restricted range of geometries. Ernst's formula or graph, or table we give should be used otherwise.

Flow of Water in Shallow Soils Without or With Structure in Their Natural Condition

In a 1937 publication, Hooghoudt developed a theory for flow to ditches and drains in shallow soils. Building upon the hydraulic approach of Colding and his followers, he assumed that the vertical distribution of the pressure is hydrostatic at any point in the field, and that as a consequence the slope of the water table can be regarded as the driving force for the flow in the horizontal direction. For structured soils, he ignored the contribution from horizontal flow in a capillary fringe. For a steady flow Q resulting from uniform input s at the water table, to ditches spaced l apart and reaching to the impermeable base, and with a water table everywhere below the soil surface, Hooghoudt derived the following expression for the flux Q (**Figure 3**):

$$Q = ls = \frac{4k(H_0^2 - h_0^2)}{l} = k\frac{8h_0 + 4m_0}{l}m_0 \qquad [3]$$

where H_0 is the height of the water table above the impermeable base at the midpoint between the drains, h_0 is water level in the ditch, and $m_0 = H_0 h_0$. If the hydraulic conductivity k is known, say from measurements with the auger-hole method, then Eqn [3] can be used to calculate the desired drainage spacing l for given s, H_0, and h_0. Alternatively, if the hydraulic conductivity k is not known, it can be calculated if l, s, H_0, and h_0 for a drainage system are known.

To verify Eqn [3], Hooghoudt used a soil bin 10 m long, 2 m wide, and 2 m deep, filled with river sand. He found that the estimates of hydraulic conductivity on the basis of Eqn [3] agreed very well with laboratory data, provided the effect of flow in the capillary fringe of thickness h_c was included by replacing H_0, and h_0 by $H_0 + h_c$ and $h_0 + h_c$.

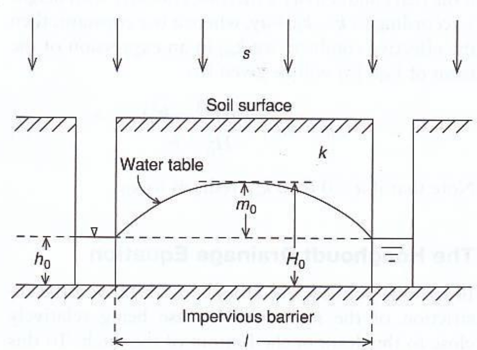

Figure 3 Flow to ditches, as considered by Hooghoudt in 1937.

Still for homogeneous soils, Hooghoudt considered various complicating factors:

- Situations with the input s exceeding the value for which the water table at the midpoint between the ditches or drains reaches the soil surface;
- Situations with the drain or the bottom of the ditch being some distance above the impermeable base. Tentatively these were handled by increasing l in the denominator of Eqn [3] by $r(r+b)/(2h_0)$ where b is the width of the bottom of the ditch ($b=0$ for a drain) and r is the depth of the impermeable layer below the bottom of the ditch or drain;
- Situations with flow not only to parallel drains and small ditches but also toward a larger ditch that intercepts the flow from the parallel drains or small ditches; for this case he also used the large soil bin to test the results.

Hooghoudt also extended the hydraulic approach to heterogeneous soils, considering in detail cases with jump discontinuities of the hydraulic conductivity at interfaces between horizontal, homogeneous layers, and cases with gradual changes of the hydraulic conductivity with vertical position. In effect he replaced, at any point between the drains, the hydraulic conductivity k by an apparent hydraulic conductivity k_{av}, being defined as the vertically averaged conductivity between the impermeable base and the location of the water table. Clearly, even with the heterogeneity being restricted to the vertical direction, k_{av} is inherently dependent on the location of the water table. Nevertheless, the results of the analysis can still be written in the form of Eqn [3], provided k is replaced by an effective conductivity k_{eff}, which is a function not only of the vertical distribution of the real conductivity, but also of H_0 and h_0. For example if the real conductivity k increases linearly with height y according to $k=k_0+ay$, where a is a constant, then the effective conductivity k_{eff} in an expression of the form of Eqn [3] will be given by:

$$k_{eff}=k_0+\frac{\frac{1}{3}a(H_0^3-h_0^3)}{H_0^2-h_0^2}. \qquad [4]$$

Note that if $a=0$ then k_{eff} reduces to k_0.

The Hooghoudt Drainage Equation

In a 1940 publication, Hooghoudt removed the restriction of the impermeable base being relatively close to the drain or the bottom of the ditch. To this end he introduced the device of partitioning the flow region in two parts, one part away from the drain or ditch in which the flow is approximately horizontal and another part close to the drain or the ditch in which the flow is radial. The result was cast in a form similar to Eqn [3], with the radial resistance being accounted for by replacing h_0 by an equivalent thickness h_{eq} of the water-conducting layer below the drain, and allowing for the hydraulic conductivity in the layers above and below the drain having different values of, respectively, k_1 and k_2 (**Figure 4**):

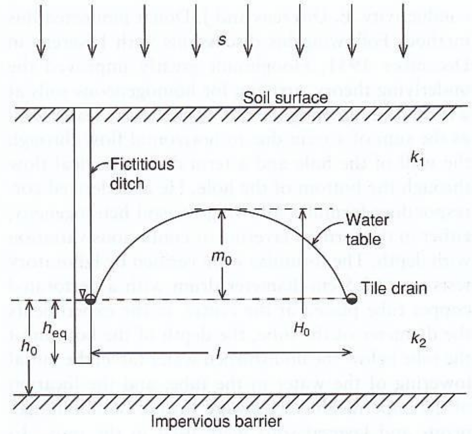

Figure 4 Flow to tile drains, as considered in the Hooghoudt drainage equation of 1940.

$$Q=ls=\frac{8k_2h_{eq}+4k_1m_0}{l}m_0 \qquad [5]$$

with the equivalent thickness h_{eq} being a known function of drain spacing l, the real thickness of the water-conducting layer below the drain h_0, and the diameter of the drain. Eqn [5] is usually referred to as the Hooghoudt drainage equation.

Applications of Drainage Theory

The planning of reclamation of the IJsselmeerpolders stimulated a rapid development of the study of drainage of soils for agricultural purposes, with theory and practice going hand in hand. D.J. Hissink and his staff started activities in the pilot polder Andijk in the late 1920s and made extensive studies in the Wieringermeerpolder in the early 1930s. Hooghoudt was responsible for the scientific basis of the design of the drainage systems. In the same period, smaller polders were also studied. For example, for the Linthorst Homanpolder in the north of the province of Groningen a drainage plan was developed, and for the Nijkspolder in the southeast of the province of Friesland a study was made of the expected increase in seepage into the polder as a result of an increase in the size of this polder and a lowering of the water levels in the open water within the polder. On an even smaller scale, numerous drainage recommendations were given for individual farmers' fields.

Three reports concerning sports fields were submitted in 1938. In the post World War II period 1947–51, 15 more reports followed. Recommendations included design of drainage systems and alterations of the soil profile to improve playability by changes in layering and by supplementing clay soils with sand. A comparison of the 1939 and 1953 guidelines for the design of soccer fields illustrates the progress.

Hooghoudt and his colleagues J.D. de Jong and A.J. Wiggers assisted the Laboratory of Soil Mechanics at Delft in a government assignment to make recommendations regarding suitability and possible improvements of sites for civilian and military airfields. Two reports concerning the military airfield Valkenburg in the province of South Holland were presented in 1939. In the post World War II period 1945–48, about 20 more reports were presented, concerning nearly as many locations.

The Committee Forestry Plan Amsterdam prepared an ambitious plan for a recreational park at the southwestern edge of the city of Amsterdam. Hooghoudt was asked to design a drainage plan. In the period 1936–39, Hooghoudt submitted eight reports concerning the soils in the area, including measurements of the hydraulic conductivity by the auger-hole method, and recommendations for spacing and depth of drains. Based on these, 300 km of tiles were laid.

Hooghoudt was also responsible for the first regional hydrologic study. In the Veenkoloniën, the thickness and the hydraulic conductivity of the water-conducting layer were studied to a depth of 20 m. On the basis of these data, the functioning of canals and ditches was analyzed. It was the first study at this scale, allowing a prognosis of the consequences of a variety of measures such as eliminating or reducing the size of canals originally dug for the purpose of transport of peat being mined for fuel, eliminating superfluous ditches, and the breaking of poorly conducting layers inside and underneath remaining peat layers.

Water Management of the Plant Root Zone

All along, it was of course realized that generally the purpose of drainage and subirrigation is to promote a favorable environment for the growth and functioning of plant roots. In February 1936, Otto de Vries (1881–1948), son of the botanist Hugo de Vries (1848–1935), gave a lecture on 'Soil, water, and plant' at the first meeting of the Dutch section of the ISSS. Following his 22 years in agricultural chemistry in the Dutch Indies, in 1930 Otto de Vries became director of the Agricultural Experiment Station and Soil Testing Laboratory at Groningen and, in 1939, following the retirement of Hissink, director of the Soil Science Institute. In 1943 the Departments for Agricultural Research and for Agricultural Industries of the Central National Council for Applied Scientific Research in the Netherlands (TNO) were founded and Otto de Vries was appointed chairman of both. He left Groningen in 1944 and lived in The Hague until his death in 1948.

In 1942 a field experiment for studying the influence of controlled water table depth upon the growth and yield of crops was realized at Nieuw Beerta in the eastern part of the province of Groningen. The experiment was continued till autumn 1955. The detailed description and interpretation of the results in eight publications illustrate Hooghoudt's evolving interest in the agronomical effects of drainage. Of particular interest is the early demonstration that crop response to drainage is complicated, being mediated by the influence of the water table depth on soil structure, plant root development, and the fate of soil nitrogen.

In 1943 a national Working Committee for Evaporation Research was formed, and in 1946 the more broadly based Committee for Hydrological Research TNO. Under the leadership of Hooghoudt, plans were made for a study of the evaporation from a polder, comparing three methods: (1) determining the water budget of the entire polder, (2) direct measurement of evaporation on the basis of a calculation of vertical vapor transport from measured vertical humidity and wind velocity profiles by the Royal Dutch Meteorological Institute, and (3) determining the soil-profile water balance using a lysimeter and soil-moisture sampling. For the latter purpose, the use of tensiometers and thermal conductivity probes was initially considered, but later abandoned for various reasons. The spatial variability of the soil moisture was recognized as a major obstacle. Hooghoudt played a leading role in the choice of the location and the detailed planning of this experiment. Perhaps not surprising, from a large number of possibilities the Rottegatspolder near Groningen was selected. Data collection started August 1, 1947 and terminated February 1, 1971, thus long after the agrohydrologic research had moved in 1956 from Groningen to Wageningen.

Mentor of Young Talents: The Theorists Van Deemter and Ernst

After World War II, Hooghoudt concentrated on the application of drainage theory and the exploration of its agronomical implications. Eventually he coached a large team working throughout the country. Further development and experimental verification of the theory were the responsibility of, respectively, J.J. van Deemter and L.F. Ernst.

Jan Josef van Deemter, after earning in 1945 an MSc degree in physics from the University of Groningen, was employed in the Agrohydrology group from June 1946 till some time in 1947, when he joined the Royal/Dutch Shell Laboratory at Amsterdam. On the basis of the results of his research started in the brief period at Groningen, in 1950 he was awarded a doctoral degree in applied mathematics at the University of Amsterdam. In his thesis, he adapted the hodograph method to give exact solutions of the problems of drainage and infiltration for systems of parallel, equidistant drains or ditches in soils with homogeneous hydraulic conductivity to infinite depth, including the effects of rainfall, evaporation, and upward or downward flow. He also used the so-called relaxation method of Southwell, which can be applied to all two-dimensional steady-state problems, as well as for soils with heterogeneous hydraulic conductivity.

After van Deemter left Groningen, he was succeeded by Lodewijk Ferdinand Ernst, who improved the auger-hole method and generalized the drainage formulas. Ernst became involved in several large-scale field studies and continued research in the style of Hooghoudt after he moved to Wageningen in 1956. In 1962, Ernst was awarded a doctoral degree in applied mathematics at the University of Utrecht on the basis of a thesis about groundwater flow in the saturated zone in the presence of parallel open conduits.

Hooghoudt's Legacy

In the autumn of 1952, there was a proposal to move the Agricultural Experiment Station and Institute for Soil Research TNO partly or entirely to a more central location at Wageningen. Hooghoudt was strongly opposed to such a move and pointed out that in his experience it was quite possible to lead joint research projects throughout the country from Groningen. At a staff meeting on December 9, 1952, he illustrated this with a description of recent and current agrohydrologic research by him and his team, emphasizing the great advantage of having agronomic and hydrologic expertise under one roof. Theory, experiment, and practical application were perfectly balanced in the research program of Hooghoudt.

Hooghoudt died at Groningen on August 30, 1953. At a memorial meeting on October 1, 1953, the director, P. Bruin, gave a detailed survey of his work. Three years later the agrohydrogic program was moved to Wageningen to become the core of the newly formed Institute for Land and Water Management Research (ICW). At the ICW, Wageningen University, and the International Institute for Land Reclamation and Improvement (ILRI; founded in 1955), Hooghoudt's ideas flourished and were promoted worldwide. The ILRI International Course on Land Drainage has, since its first session in 1962, drawn more than 1000 drainage professionals from all over the world. Dutch-born PhD students at Iowa State University and Cornell University have facilitated the export of some of Hooghoudt's ideas published mainly in Dutch to the USA and the English-speaking world in general. This was consolidated by the 1957 monograph *Drainage of Agricultural Lands*, published by the American Society of Agronomy, as well as in the later, updated editions of 1974 and 1999.

See also: **Drainage, Surface and Subsurface**

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