ABSTRACT

Analytical expressions are derived for predicting flow into an auger hole in an unconfined aquifer of finite horizontal and vertical extents and underlain by an impervious substratum. Solutions are provided for two cases, namely, (i) when the auger hole fully penetrates the aquifer up to the impervious base and (ii) when the hole suspends above the base layer. The validity of the developed analytical solutions are checked by drawing parallel numerical models for a few flow situations and then comparing the analytical predictions with the corresponding numerical ones. A further check on the developed equations is performed by first reducing these solutions (by letting the finite horizontal extent of the aquifer to become large) to account for a phreatic aquifer of large (theoretically infinite) horizontal extent and then comparing the analytical results obtained from them with corresponding results obtained from the analytical works of others for a few flow situations. From the study, it is seen that the zone of influence of an auger hole test in a water table aquifer underlain by an impervious layer may be considerable, particularly if the test is being carried out in an aquifer having a high anisotropy ratio (ratio of horizontal to vertical hydraulic conductivity of soil). Further, the study also reveals that the thickness of an unconfined aquifer, extent of penetration and level of water in an auger hole, play an important role in determining flow into the hole and hence due care must be taken to include these parameters in the mathematical analysis of the problem. The developed equations can be used to determine the directional conductivities of a phreatic aquifer by making use of results obtained from a typical auger hole test and can also be utilized to estimate the horizontal domain of influence associated with the test. This is important because the soil volume over which the directional conductivities of an aquifer is being sensed in a standard auger hole test is generally believed to be confined close to the centre of the hole and the existing auger hole seepage theories are not able to estimate this capture zone as these theories have been developed with the assumption of an aquifer of infinite horizontal extent. For ease of computation, shape factors (a shape factor is a coefficient which when multiplied with the rate of rise of water in a pumped auger hole, gives the hydraulic conductivity of the surrounding soil) for a wide range of auger hole flow geometries are being provided in the text so that a field practitioner can take advantage of these values in the design of an auger hole experiment. That way, a field practitioner can make a direct use of these factors for converting a set of auger hole test data obtained from a phreatic aquifer into the directional conductivities of the aquifer as well as for estimating the horizontal extent of the disturbed zone arising due to the test, without the necessity of going through the intricate details of the developed solutions.

Analytical solutions are also provided for predicting time dependent seepage into an array of equally spaced parallel ditch drains in a homogeneous and anisotropic soil medium underlain by an impervious layer and receiving water from a ponded horizontal field of infinite extent when (i) the levels of water in the ditches are equal and the depth of ponding is uniform, (ii) the levels of water in the adjacent ditches are unequal ditches and the depth of ponding is uniform and (iii) levels of water in the adjacent ditches are unequal and the depth of ponding is non-uniform. Even though independent solution for each of these three cases are being provided in the text, the solutions of the first two cases can also be reached from the general solution obtained for the third case, a fact which is being demonstrated in the text with the help of a few examples. The validity of the developed solutions are tested by first reducing them to corresponding steady state solutions and then comparing predictions obtained from them for a few flow situations with identical predictions obtained from the analytical works of others. Further, a MODFLOW check on the general solution [case (iii)] is also being carried out. From the study, it is seen that the specific storage of soil influences the time required for a transient ditch drainage system to move to the steady state situation; a relatively longer time is required for a soil with a high specific storage coefficient than that for a soil with a low specific storage coefficient. The discharge from the top of the field as well as through the sides of the drains are found to be influenced by the directional conductivities and specific storage of soil, spacing, depth and levels of water in the ditches and depth of ponded water over the surface of the soil. The surface discharge distribution is found to show relatively greater uniformity at the early stages of simulation but with the progress of time, the extent of uniformity is found to reduce particularly for cases where the soil is subjected to a uniform depth of ponding. However, even when a soil surface is subjected to a constant depth of ponding, a high anisotropy ratio of the soil alone may lead to a marked improvement on the uniformity of the surface discharge distribution at all times in comparison to a soil having a low anisotropy ratio. A better uniformity of surface discharge may also be achieved by suitably adjusting the depths of ponding over the soil surface – regions close to the ditches be provided with zero or negligible depths of ponding and the ponding depths may be made to progressively increase with the increase in distance from the ditch faces. It is hoped that the solutions provided herein will lead to a better and realistic design of ditch drainage networks for controlling waterlogged areas, providing a balanced subsurface water environment for the wildlife habitats and in reclaiming salt affected soils.

Keywords: Analytical models; Unconfined aquifer; Horizontal and vertical extents of aquifer; Auger hole test; Fully and partially penetrating auger hole; Hydraulic conductivity; Anisotropy; Shape factor; Ditch drains; Transient seepage; Non-uniform ponding depth; Specific storage.