22 Tubewell Drainage Systems

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22.1 Introduction

Tubewell drainage is a technique of controlling the watertable and salinity in agricultural areas. It consists of pumping, from a series of wells, an amount of groundwater equal to the drainable surplus.

Tubewell drainage is not new, but it has not been widely used. Early attempts to use series of pumped wells for land drainage and salinity control were made in the U.S.A. and the former U.S.S.R. more than half a century ago.

The Indus Plain in Pakistan is a notable example of using tubewells for land drainage, salinity control, and the supply of irrigation water. There, over the last 25 years, thousands of public tubewells have been constructed as part of Salinity Control and Reclamation Projects (SCARPs; The White house 1964; Demster and Stoner 1969; Calvert and Stoner 1975; and Nespak-ILACO 1983, 1985).

A review of studies and experiences with tubewell drainage in various countries shows that this technique cannot simply be regarded as a substitute for the conventional technique of subsurface drainage. The success of tubewell drainage depends on many factors, including the hydrogeological conditions of the area, the physical properties of the aquifer to be pumped, and those of the overlying fine-textured layers.

Enough water has to be removed from the aquifer to produce the required drop in hydraulic head, and, for vertical downward flow, the hydraulic conductivity of the overlying layers must be such that the watertable in these layers responds sufficiently quickly to the reduced head in the pumped aquifer.

Another important factor, of course, is that skilled personnel are needed to operate and maintain the tubewells, and to monitor watertables and the quality of the pumped water.

This chapter will discuss the principal aspects of tubewell drainage. First, we explain its various advantages and disadvantages over other subsurface drainage systems. We then go on to examine the factors determining the feasibility of a tubewell drainage system. Before presenting a design procedure for tubewell drainage, we include a section on basic equations pertaining to the subject. The reason for this is that Chapter 10 only presented equations that dealt with the flow to single wells pumping extensive aquifers without recharge. The next section of this chapter is devoted to the actual design procedures, including various design considerations and design optimization. Finally, we discuss maintenance of the system.

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22.2 Tubewell Drainage Versus Other Subsurface Drainage Systems

The difference between tubewell drainage and other subsurface drainage systems is primarily the way excess water is removed from the underground.

Tubewell drainage removes excess water by pumping from a series of wells drilled into the aquifer to a depth of several tens of metres. The pumped water is then discharged into open surface drains.

Subsurface drainage removes excess water entirely by gravity through open ditches or pipes installed underground at depths varying from 1 to 3 m. With pipes, the water flows either into collector drains with a free outfall into surface drains, or into collector drains that end in sumps. The water is then pumped from these sumps into open surface drains.

A comparison between tubewell drainage and other subsurface drainage systems reveals that both systems have certain advantages and disadvantages. The advantages of tubewell drainage are:

- The total length of open surface drains is considerably less with tubewell drainage than with the other subsurface drainage systems;
- On undulating land with local depressions that have no natural outlets, the pumped water is generally disposed of through pipelines connecting the various wells. Excessive earth-moving is thus avoided, because no deep canals or ditches need to be dug through topographic ridges. Moreover, the absence of such canals and ditches allows more efficient farming operations;
- Such a pipeline system may cost considerably less to maintain than open drains and transport canals;
- Tubewell drainage enables the watertable to be lowered to a much greater depth than do the other subsurface drainage systems. This means that a greater portion of excess water can be stored before it has to be removed, whilst in arid and semi-arid regions a deeper watertable reduces salinization of the soil;
- The deeper layers, or substrata, may be much more pervious than the layers near the surface. Pumping from these layers may reduce the artesian pressure that is often present, creating instead a vertical downward flow through the upper layers. If the pervious substrata are found at a depth of 5 m or more, it is only with tubewell drainage that full benefit can be derived from these favourable hydrogeological conditions;
- If the water in the pumped aquifer is of good quality, it can be used for irrigation. The drainage water then has an economic value, which may contribute considerably to the economic feasibility of the venture.

Tubewell drainage also has certain disadvantages. To mention a few:

- A pumped well is more difficult and costly to maintain and operate than a pipe drain;
- The energy required to operate a multiple-well system has to be purchased as electricity or fuel;
- Legal regulations sometimes forbid the use of pumped wells for land drainage; pumping from wells can reduce the pressure in aquifers to such an extent that existing domestic wells cease to flow;

- Unlike the other subsurface drainage systems, tubewell drainage is not economically feasible in small areas because too much of the water drained out of the area then consists of 'foreign' water (i.e. groundwater flowing in from surrounding areas);
- If, during the growing season, the watertable rises to the land surface (because, for instance, of a heavy rainstorm after irrigation), it has to be lowered rapidly because most crops have only a limited tolerance to waterlogging. This implies a high drainage rate (i.e. a dense network of wells). Of course, the high investment costs of installing a dense network of wells can be reduced by spacing the wells farther apart and pumping them continuously, but this in turn will raise the cost of operating and maintaining the wells;
- Tubewell drainage can only be successfully applied if the hydraulic characteristics are favourable (i.e. if the transmissivity of the aquifer is fairly high); only then can the wells be widely spaced. If the aquifer is semi-confined (Chapter 2), an additional criterion is the value of the hydraulic resistance of the upper clay layer (the aquitard). This value must be low enough to ensure an adequate percolation rate. Hence, a decision in favour of tubewell drainage should only be taken after a careful hydrogeological investigation has proved that its application is practicable;
- Tubewell drainage may not be technically and economically feasible in areas where the artesian pressure in the aquifer is too high or where seepage is excessive;
- The salt content of the drainage water can be considerably higher with tubewell drainage because the streamlines towards the well occur deeper in the aquifer than those towards pipe drains or ditches.

The decision to use one drainage system or the other has to be based on a comparison of their respective advantages and disadvantages, and of their costs and benefits. If the systems are designed and operated properly (i.e. if they meet the agricultural criteria), the tangible benefits of either system ought to be more or less equal. The choice then depends mainly on their costs, leaving aside the imponderabilia.

22.3 Physical and Economic Feasibility

Whether tubewell drainage is physically and economically justified depends primarily on the hydrogeological conditions of the area. For tubewells to be effective in draining agricultural land, a continuous aquifer capable of transmitting water towards the pumped wells needs to underlie the whole area. For unconfined aquifers, this means that both the hydraulic conductivity and the thickness of the aquifer (whose product is the aquifer's transmissivity, KH) must be high enough to ensure an economic spacing and yield of the wells.

For semi-confined aquifers, a further condition is that the hydraulic resistance of the overlying aquitard should not be too high. Finally, the quality of the groundwater can play an important role in the economics of tubewell drainage.

The drainage effluent of a tubewell drainage system in areas with saline groundwater is more saline, and more saline over a longer period, than the drainage effluent of other subsurface drainage systems. With the other subsurface systems, the upper layer of saline water is skimmed off, after which the groundwater is replaced by fresher groundwater. After a few years of drainage, this results in a better quality effluent. This replacement period is much longer in tubewell drainage, where pumping affects a much deeper layer of groundwater.

The above three factors will be discussed below in more detail. Other factors to be considered in the selection procedure are the availability and cost of energy and the timely replacement of pumps and engines after their economic lifetime.

22.3.1 Hydraulic Conductivity and Thickness of the Aquifer

Hydraulic conductivity varies from one aquifer to another, and even within a single aquifer, appreciable variations can occur, both horizontally and vertically. Also the thickness of an aquifer can vary. The economics of tubewell drainage becomes questionable for poorly transmissive aquifers (i.e. aquifers whose transmissivity is less than approximately 600 m^2/d). For a given mean hydraulic conductivity, a minimum thickness of the aquifer is therefore required (Table 22.1).

A comprehensive program of exploratory work and aquifer testing needs to be executed to determine these aquifer properties.

22.3.2 Hydraulic Resistance of the Aquitard

If a low-permeable layer, or a system of such layers, overlies the aquifer, the hydraulic resistance, $c = D'/K'$, plays a crucial role in determining the physical feasibility of tubewell drainage. Even though the aquifer's transmissivity may be very high, thereby allowing widely-spaced, high-capacity wells to be installed, this resistance can be so high that the shallow watertable in the aquitard does not respond, or responds too slowly, to the drawdown in the aquifer. The question thus arises whether the hydraulic resistance has a maximum value that makes tubewell drainage questionable or not feasible at all.

Consider the situation shown in Figure 22.1. It is assumed that there is a steady recharge from excess rain or irrigation water. This implies that the recharge rate towards the aquifer, R, equals the rate of downward flow through the aquitard. This

Table 22.1 Minimum required aquifer thickness (after McCready 1978)

Mean hydraulic conductivity (m/d)	Minimum required aquifer thickness (m)	Transmissivity (m^2/d)
43	14	602
26	25	650
17	40	680
13	60	780

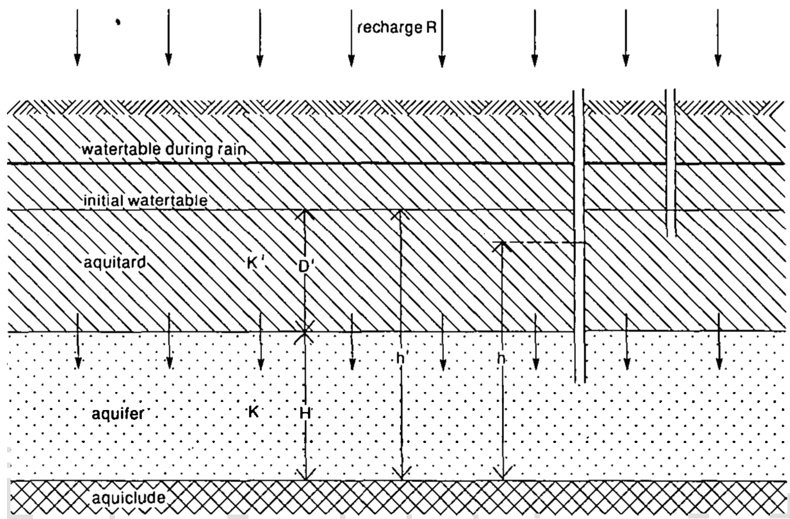

Figure 22.1 Semi-confined aquifer uniformly recharged by infiltrating rain or irrigation water

rate towards the aquifer is governed by Darcy's equation (Chapter 7), which is written as

$$v_z = \frac{K'(h' - h)}{D'} = \frac{h' - h}{c} \tag{22.1}$$

where

v_z = rate of downward flow through the aquitard (m/d)
h' = watertable elevation in the aquitard (m)
h = hydraulic head in the aquifer (m)
c = hydraulic resistance of the aquitard (d)
K' = hydraulic conductivity of the aquitard for vertical flow (m/d)
D' = saturated thickness of the aquitard (m)

The rate of downward flow through the aquitard is proportional to the head difference and inversely proportional to the hydraulic resistance. The watertable in the aquitard is usually shallow, say between 0.5 m and 2 or 3 m below the surface. The piezometric surface of the aquifer may lie above or below the watertable, depending on the local hydrogeological conditions. Head differences ($h' - h$) of the order of a few centimetres to 1 or 2 m are fairly common, and differences of many metres are unrealistic, except in areas with high artesian pressure. Head differences of a few centimetres to, say, 0.1 m are so small that they can be neglected.

Assuming therefore an average head difference, $h' - h = 1$ m, and taking two extreme values for the recharge, say R = 1 mm/d and R = 10 mm/d, we then find from Equation 22.1 that the hydraulic resistance, c, varies between 100 and 1000 days. Note that, during peak-irrigation periods, the average drainage rate in a peak month may vary from 2 to 5 mm/d, depending on the type of crop.

A value of the hydraulic resistance twice as high (i.e. c = 2000 days) would require a head difference twice as high than was assumed, so as to maintain the same downward flow rate. For a downward flow of 10 mm/d, this would result in a head difference of 20 m, which is impossible.

These tentative calculations clearly show that, when tubewell drainage in semi-confined aquifers is under consideration as an alternative to other subsurface drainage systems, particular attention has to be given to the upper limit of the hydraulic resistance of the aquitard. For values of c much larger than 1000 days, tubewell drainage will not be feasible.

22.3.3 Groundwater Quality

A third factor to be considered with tubewell drainage is the quality of the groundwater. If the pumped groundwater is fresh, it can serve a dual purpose: it can control the watertable and salinity, and can supply water for irrigation. The pumped water then has an economic value, which may largely offset the pumping costs. In semi-arid regions, where surface water is usually scarce, the availability of tubewell water of good to fair quality makes it possible to irrigate more land. This alone makes the technique promising for such regions.

When water is pumped from the aquifer and used for irrigation over a long period of time, a crucial question arises: How will the salt concentration of the tubewell water applied to the crops change with time, or, if well water is mixed with fresh river water, how will the salt concentration of the tubewell water vary with time? When the salt build-up in the aquifer is being calculated, all flow components of the system (Figure 22.2) and their salt concentrations must be considered and evaluated. The salt balance of an area was discussed in Chapter 16.

There are a number of factors to be considered when the salt build-up in this type of combined tubewell drainage and irrigation projects is being investigated:

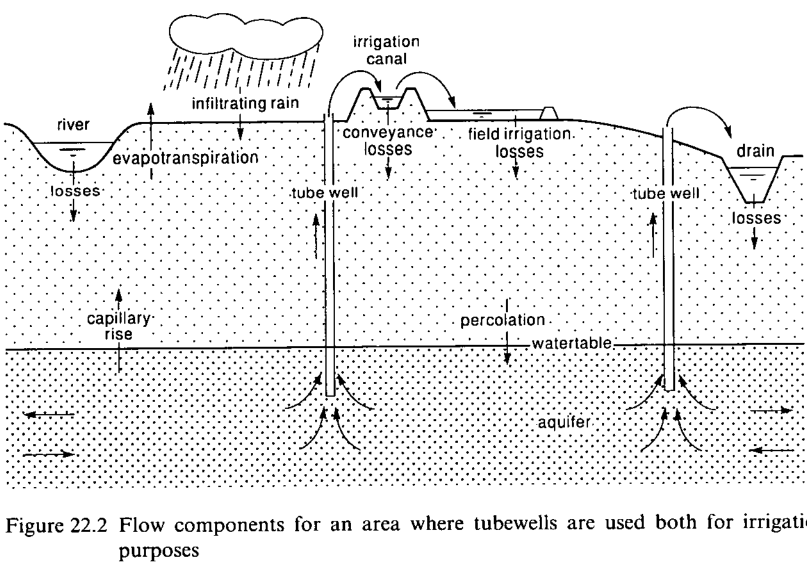

Figure 22.2 Flow components for an area where tubewells are used both for irrigation and drainage purposes