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# PERFORMANCE EVALUATION OF PERCOLATION PONDS FOR ARTIFICIAL RECHARGE - A CASE STUDY

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# ABSTRACT

A percolation pond is a small water storage structure constructed across a natural stream or water course to harvest the runoff from the catchment and impound for longer time to facilitate percolation of impounded water into the soil substrata both vertically and laterally, thereby recharging ground water storage in the zone of influence of the pond. With a view to assess the benefits of these ponds in terms of the artificial recharge to the aquifers, two percolation ponds are studied in the state of Tamilnadu. The study broadly aims at : assessing the quantum of seepage to the aquifers through the ponds; assessing the zone of influence of the ponds, and; correlating the quantum of seepage to the total storage loss in the pond.

The seepage losses from percolation ponds have been assessed by computing the water balance of the ponds. As far as the percolation ponds are concerned the loss in storage is entirely due to percolation and evaporation. Therefore using the available data, the inflows, the evaporation losses and the change in storage are calculated and the seepage losses are assessed for each of study pond for various observation periods. The study shows that the seepage rates in Uralipatti percolation pond vary from 34.7 to 16.3 cum per day for storages between 1500 to 300 cum during 1991 and from 180.1 to 19.7 cum per day for storages between 2700 to 260 cum during 1993. In the case of Viralipatti pond, these rates are found to vary from 137 to 20.40 cum per day for the storage amount between 10905 to 2830 cum. The average rates of seepage computed over the entire periods of study are obtained as 41.06 and 45.84 cum per day for Uralipatti and Viralipatti pond respectively. Since these seepage rates calculated on volume basis may not be representative in view of the high variability in the storage capacities due to siltation, the column of water recharging the aquifers is also calculated. It is found that these rates, expressed in terms of column of water in the pond, vary from 55.7 to 5.4 mm per day in Uralipatti pond and from 23.3 to 5 mm per day in Viralipatti pond. Over a total observation period of 123 days in Uralipatti pond, the total storage loss is observed to be about 5734 cum, of which 5051 cum percolated down and the rest 683 cum was lost through evaporation. In Viralipatti pond, the seepage and evaporation losses are computed as 5455 and 2860 cum respectively against a total storage loss of 8315 cum over 119 days. These seepage and evaporation losses account for 88% and

12% of the total storage loss in Uralipatti pond and 65.60% and 34.40% in Viralipatti pond. The zone of influence of the ponds is assessed by analysing the response of the water table in the selected wells with the start of recharge. For this purpose, the hydrographs of ponds and observation wells and the ground water table contour maps are drawn for all the recharge periods. In the case of Uralipatti pond, it is observed that the wells located within a radius of 340 m downstream of the pond get adequate recharge from the pond. While the wells located upto 840 m also show moderate recharge effect, the wells at 950 m and beyond have negligible effect of the pond storage. In the Viralipatti pond, the wells located downstream of the pond show a significant recharge upto a distance of 200 m but only a marginal recharge at 305 m.

It is concluded from the study that such percolation ponds are very useful in recharging the shallow ground water aquifers. During the field visits, the farmers in the command areas of such ponds also expressed the increased availability of water in their wells, which they utilize for irrigating the wet crops.

# 1.0 INTRODUCTION

The economy of India is essentially dependent on agriculture. Water being the most vital input for agriculture, assured availability of adequate water throughout the crop period is essential for successful crops production. Since a major part of the country is subject to erratic rainfall distribution both in time and space, harnessing of water resources for irrigation has been intensified since independence. However, there are still vast zones in arid and semi-arid regions which suffer from paucity of surface water resources and as such ground water continues to be major source from which the various requirements are to be met. Owing to the intensive development of ground water resource in excess of its replenishment has resulted in continuous decline of ground water levels rendering a huge number of open wells in these areas dry. The farmers are thus compelled to deepen the wells and drill deep bore wells and in-well bores but this can only offer a temporary relief as the recharge to ground water basins remains constant. Therefore, some methods of water harvesting and ground water recharge are warranted to save the well command areas in the dry tracts of the country. The National Water Policy, which was adopted by Govt. of India during 1987, also lays emphasis on the artificial ground water recharge programme by stating that "Ground Water recharge projects should be developed and implemented for augmenting the available supplies."

Artificial recharge is the process by which the ground water reservoir is augmented at a rate exceeding that under natural conditions of replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system. A variety of techniques of artificial recharge which are mainly based on three methods, namely, spreading, induced recharge and injection have been developed and are in use in different parts of the world. The choice of a particular technique is governed by local topography, geological and soil conditions, the quantity of water to be recharged, the quantity and quality of water available for the purpose of recharge and the techno-economic viability of such schemes.

In India, the commonly adopted method for artificial recharge is construction of percolation ponds/tanks. These tanks have been constructed extensively in the states of

Tamilnadu, Andhra Pradesh, Karnataka, Maharashtra, Gujarat and also in other parts of the country by State Govt agencies under various Soil and Water Conservation Schemes, Drought Relief Programme and Rural Landless Employment Guarantee Programme. Percolation ponds are usually constructed on government lands and get water either from a catchment or from a natural drain across which they are constructed. Since these tanks are constructed to recharge nearby ground without any direct surface irrigation, it is desirable to assess their utility in providing invisible support to the wells around. Also, a continuous appraisal of the quantitative aspects of the induced recharge through these tanks needs to be carried out as considerable money has been invested in this endeavour. The present case study is, therefore, taken up to assess the benefits of percolation tanks in terms of artificial recharge to the aquifers with the specific objectives as given below :

## 1.1 Objectives of the Study

The main objectives of the study are,

(i) to assess the quantum of seepage to the aquifer through the percolation ponds;

(ii) to assess the zone of influence of the percolation ponds; and,

(iii) to correlate the quantum of seepage to the total storage loss in the percolation pond.

Since quite a large number of percolation ponds have been constructed by the Department of Agricultural Engineering and Public Works Department in Tamilnadu state, two percolation ponds are selected in the state of Tamilnadu to study and analyse the above set objectives. The general guidelines on the practice of percolation pond for artificial recharge, the description of the selected ponds for the study, the methodology adopted and the results of the study are presented in the following chapters.

# 2.0 PERCOLATION PONDS AS A PRACTICE FOR ARTIFICIAL RECHARGE

## 2.1 General

A percolation pond is a small water storage structure constructed across a natural stream or water course to harvest the runoff from the catchment and impound for longer time to facilitate percolation of impounded water into the soil substrata both vertically and laterally, thereby recharging ground water storage in the zone of influence of pond. It is formed by the construction of an earthen bund with a surplus weir across a stream at a suitable location upstream of the zone which needs to be recharged. Such ponds have been reported to be very useful in harvesting the unutilized balance of the surface flow during periods of availability and conserving it in the underground reservoirs and thereby ensuring sustained agricultural production under many well commands in the vicinity of the ponds.

Construction of percolation ponds have been carried out extensively by the State Govt agencies in various states, viz., Tamilandu, Andhra Pradesh, Maharashtra, Gujarat, Karnataka etc under various Soil & Water Conservation Schemes, Drought Relief Programme and Rural Landless Employment Guarantee Programme at suitable locations selected based on scientific hydrological and geohydrological investigations. In fact these ponds have gained such a popularity that the public in drought prone areas demand for conversion of many of the existing minor irrigation tanks into percolation ponds/tanks. Percolation ponds are usually constructed on Government lands and do not provide any direct surface irrigation. In other words, the loss from the percolation ponds is entirely due to percolation and evaporation.

## 2.2 Considerations in Planning and Construction of Percolation Ponds

Formulation of percolation pond scheme is preceded by extensive hydrological, hydrogeological, geohydrological and engineering investigations. Besides these technical aspects, practical aspects also play important role while planing for construction of percolation pond. Some broad guidelines regarding selection of sites and investigations for taking up the percolation ponds are given below :

(i) There should be adequate scope to accommodate, in the aquifer, the augmented recharge from the proposed percolation pond. This implies that the ground water levels in the influence zone are deep enough and should not be less than 3 metres below ground level during post-monsoon season.

(ii) There should be substantial number of working wells in the influence zone with adequate extent of cultivable land to reap the benefits of the pond.

(iii) There should be no springs and seepage zones in the influence zone of the pond.

(iv) The percolation pond should not be located in heavy soils or in impervious strata. The soils in the water spread area should have good structure to permit reasonable percolation rates and the soil substrata should have a weathered mantle thickness of more than 3 m.

(v) There should not be extensive outcrops of hard massive rock, intrusive bodies like dykes across the general direction of seepage immediately downstream of the bund.

(vi) The topography at the proposed site of the pond should be such that a deep pond is formed. This results in reduced loss of water by evaporation and lesser extent of land under submergence per unit capacity.

(vii) The pond site should avoid runoff from easily erodible catchment areas.

(viii) The site should be such that the construction materials are available as near as possible and the labour potential is adequate in the vicinity of the proposed site.

(i) Percolation ponds should be located in such areas that they do not interfere with the existing minor irrigation tanks or other water storage system.

(x) The site should be located in Govt land and the private land to be kept to the minimum if not completely avoidable.

(xi) Proper study of catchment area and rainfall pattern should be made to ensure that the percolation tank get filled every year.

(xii) As the yield of catchments in low rainfall areas generally varies between 0.44 to 0.55 MCM/sq.km, the catchment areas for small tanks may be between 2.5 to 4 sq.km and for larger tanks between 5 to 8 sq.km.

(xiii) Depending on occurrence of good precipitation storms during the rainy season the percolation tank get fully filled up two to three times during the rainy season. The enhanced percolation caused due to repeated filling may lead to the total percolation getting enhanced upto one and half times of percolation expected through a single filling.

(xiv) The size of the percolation pond should be governed by the percolating capacity of the strata in the tank bed rather than yield of the catchment. For, in case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses thus depriving the downstream area of a valuable resource. Therefore, larger capacity tanks should be constructed only if percolation capacity is established to be good. Otherwise under moderate percolation rates, tanks of smaller capacity may be constructed.

(xv) As a part of geohydrological and hydrogeological investigations, complete inventory of the existing wells is made and the geological and geomorphological mapping of the area is carried out. Infiltration tests at representative locations in the water spread area of the proposed tank are carried out to assess the infiltration capacity of the soils. Soil samples at these test sites should be collected for laboratory analysis and pumping tests on some representative wells in the influence zone should be conducted to estimate the aquifer characteristics, specific capacity and recuperation rates of the wells.



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# 3.0 SELECTION OF PERCOLATION PONDS FOR THE STUDY AND DATA AVAILABILITY

## 3.1 The State of Tamilnadu and Percolation Ponds

The State of Tamilnadu is not endowed with perennial rivers. Its rivers are seasonal and mostly originate in the neighbouring states. The per capita water resources of Tamilnadu of 4224.5 $m^3$ steeply falls short of the all India figure of 24645 $m^3$. The surface water resources in the state are almost fully harnessed by impounding the available water in 61 major reservoirs and also in about 39000 small and big tanks. Therefore, the groundwater resource alone could be developed in the formulation of any new schemes. But even in utilisation, as per recent estimates, 60% of the available ground water resources are now used, and the remaining resources are available in selected pockets and in coastal sedimentary tracts in the eastern part.

The population increase in the state is forcing the people to convert dryland into irrigable garden land under well irrigation to ensure assured crop harvest. Recent advancement in ground water technology, development of sophisticated deep-well construction machineries, pumping machineries, improved water conveyance system, novel water application methods, rural electrification and the technical and financial assistance rendered to the farmers by the Government and other agencies have brought a revolution in increased use of ground water for irrigated agriculture in the last decade. In Tamil nadu, there are more than 18 lakhs irrigation wells (tubewells and open wells), out of which 14.48 lakhs of wells are energised. Apart from this, there are many number of bore holes drilled for the purpose of drinking water supply. On the other hand, replenishment of ground water storage is not in tune with the rate of ground water exploitation. Natural recharging of ground water reservoir during rainfall and post rainfall periods has come down due to various factors. The indiscriminate removal of forest cover to meet the increased need of fuel, fodder and food has led to poor infiltration capacity of soils, quick drainage of rainfall from the watershed and probably the reduction in rainfall amount also. During the drought years of 1983 and 87, the ground water levels in several districts of Tamilnadu were observed to deplete by 3 to 3.5 m over the normal years. Modernisation of major irrigation systems aimed at arresting the percolation losses by lining the canal system, optimum use of water for crops thereby avoiding deep percolation losses are some of the other major factors which have contributed to the reduction in ground water storage.

The combined effect of increased exploitation and deficit recharge of ground water storage has caused faster depletion of ground water levels in the state. As a result, many of the wells have gone completely dry and have to be deepened to get the required supply to raise the crops. Realising this alarming situation the Government of Tamilnadu, from the year 1984 onwards, took up the construction of percolation ponds on a massive scale for augmenting the groundwater recharge. The Department of Agricultural Engineering and the Public Works Department of the state are constructing a large number of percolation ponds every year under various programmes. So far, about 10,000 percolation ponds have been constructed by both the Departments in the state.

## 3.2 Selection of Percolation Ponds

A detailed discussion was held with the concerned officials of the Department of Agricultural Engineering and the Ground Water Wing of Public Work Department of Tamilnadu state before selection of the percolation ponds for the study. A few percolation ponds were also visited in Tiruvallur district alongwith the officials of the Deptt. of Agricultural Engineering. While studying the schemes of percolation ponds constructed by the Deptt. of Agricultural Engineering, it was observed that the water level data of the ponds and ground water levels of the wells located in the zone of influence of the ponds are not available. It was informed by the Department that nowehere in the state these ponds are being monitored for the storage and the ground water level fluctuations. As such, the desired data for quantitative assessment of recharge may not be available unless some ponds are exclusively taken up for monitoring for this purpose. Same was the case found with the Public Works Department. However, during discussion with the officials of the ground water wing in PWD, it was learnt that the department had monitored about 10-12 percolation ponds for 2-3 years in the state a few years back. The data of four such percolation ponds as could be available with them were provided for the present study. On studying the details of these schemes it was observed that in one of the schemes the ground water levels of the wells located in the zone of influence were higher for most of the time than the pond water levels and the pond retained water almost throughout the year. The pond storage was probably influenced by the subsurface flow and therefore this pond was excluded from the study. Another pond having full pond capacity of 13568 cum could receive a maximum of only 397 cum storage during the observation period of two years. Since the pond did not get adequate water it was discontinued for monitoring purpose in the third year. Therefore, this pond is also not considered in the present study. The remaining two ponds located in the villages (i) Uralipatti, and (ii) Viralipatti are thus taken up for the present study.

## 3.3 Details of the Study Ponds and Data Availability

As described above, two percolation ponds are selected for the study of recharge. The details of each of these ponds alongwith the status of data availability are given below.

### 3.3.1 Uralipatti Percolation Pond

The pond was constructed in 1989-90 in S.F.No.331 of Uralipatti Village, Vedasandur Taluk Dindigul Anna District, Tamilnadu. The length of the pond bund is 150 m with a maximum height of 1.85 m. The storage in the pond is provided between the contours of 267.45 and 268.50 m above msl. The capacity and the water spread area of the pond at full pond level i.e. at 268.50 m are 2900 cum and 3700 sq.m respectively. The pond mainly receives water from a small channel which collects water for about a km on the road side on the upstream of the pond. Besides, it also receives surface water from a catchment area of about 2 ha. These two sources with a combined catchment of about 0.12 sq.km. provide required storage in the pond. Topographically, it has a flat terrain sloping towards West and South-west. The topographical map of the area showing location of pond is given in Fig.3.1.

The area consists of red gravelly soils varying from 1 to 1.5 m in depth. The climate of the area is generally sub-tropical having three distinct rainy seasons viz. South-west monsoon (June to September), North-east monsoon (October to December) and transitional season (January to May). The normal rainfall of the district is 834 mm with a major portion occurring in North-east monsoon. The depth of nine dug wells located in the vicinity of the percolation pond varies from 8.55 to 16.40 m below ground level. These wells are operated mostly by a 5 H.P. electric motor or a diesel engine irrigating a total area of about 8 ha.

The pond and nine dug wells located in the vicinity of the percolation pond were monitored concurrently twice a month for water level fluctuations for recharge periods between Nov.1991 to Dec.1994 and these data are available. The data of daily pan evaporation, daily rainfall and the pond stages vs capacity are also available for the above observation period. The pumping test was conducted in well No.3 during the above observation period which provided the value of coefficient of transmissivity and hydraulic conductivity as 178.5 $m^2$/day and 37 m/day respectively. The steady rate of infiltration as obtained through the infiltration test conducted inside the pond was 0.352 cm/hr.

### 3.3.2 Viralipatti Percolation Pond

The percolation pond is located in S.F. No.34 of Viralipatti village, Dindigul Taluk, Dindigul Anna district, Tamilnadu. The pond has a semi circular shape with a total bund length of 360 m. The maximum depth of storage from the deepest bed level of 337.184 m to full pond level of 340.634 m above msl works out to 3.45 m. The capacity and the water spread area at full pond level are calculated as 12275 cum and 7082 sq.m respectively. The area in the vicinity of the pond has a flat terrain sloping towards North East. The pond is fed by a stream originating from a hill. Geologically, the area has archean metamorphic rocks which are mainly comprised of granite, gneiss and charnockite. Recent valley filled sediments with Kankar are also found in some wells. The top soil which consists of valley fill sediments with kankar ranges between 1 to 2.5 m below ground level. This is followed by kankars upto 4.5 m, weathered gneiss upto 18 m and jointed gneiss upto a depth of 24 m below ground level. The topographical map of the Viralipatti pond area is given in Fig.3.2.

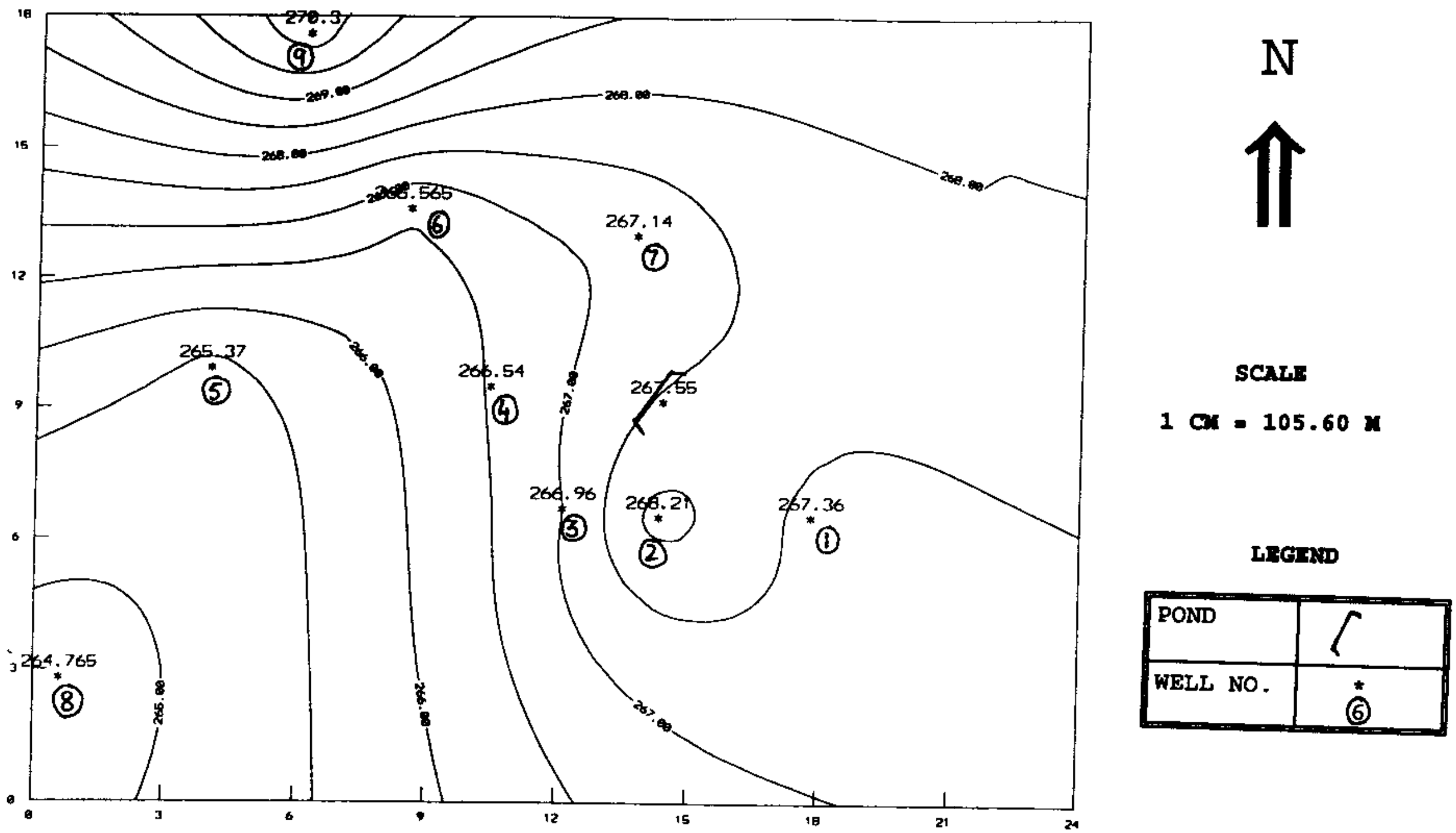
The rainfall and climatic conditions as described in the case of Uralipatti pond apply here also as both the ponds are located in the same district. A study of 12 dug wells located around the pond indicated that the depth of these wells varies between 6.20 to 21.5 m below ground level. The total ayacut area of these wells is estimated to about 6 ha.

The water level data of percolation pond and 12 dug wells located around the pond, with observations made twice a month during the period from Jan.1990 to May 1990, are available. The data of daily pan evaporation and daily rainfall as applicable to the pond are also collected for the study purpose. The value of coefficient of transmissivity and hydraulic conductivity for the observation well No.5 and the steady infiltration rate inside the pond are given as 94.77 sq.m per day, 16.63 m per day and 0.53 cm per hour respectively.

The above information and data as collected from the Ground Water wing of Public Works Department, Tamilnadu are used to study the seepage from the selected percolation ponds.

FIG. 3.1

GROUND LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND




SCALE

1 CM = 105.60 M

GROUND LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND

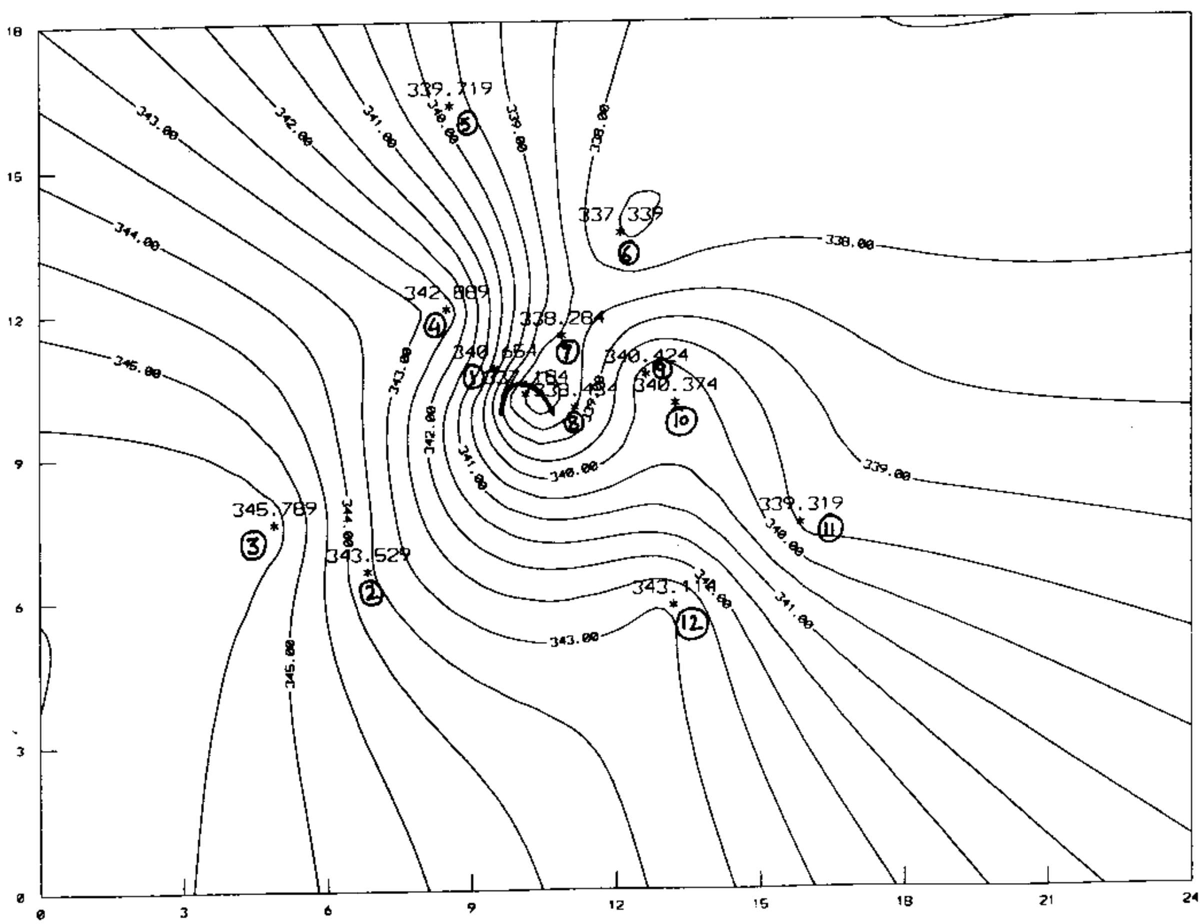



**FIG. 3.2**

N

**SCALE**

**1 CM = 66 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

# 4.0 METHODOLOGY

## 4.1 General

The construction of percolation pond allows infiltration of the storage through the top soil to percolate deep to join the ground water storage. The quantity of water reaching the ground water storage is known as the recharge. The quantity of recharge mainly depends on the infiltration capacity of the soil, water holding capacity of the underground formation and the consequent formation of the hydraulic gradient line at the water table. The quantification of recharge through a percolation pond and identification of its influence zone is a very complex problem due to a number of varying parameters with reference to time and space. First of all the quantity of water recharged to the underground reservoir is very small as compared to the total ground water storage underneath the pond. The insufficient information on the rate at which the pond is filled up, the soil moisture conditions when the pond received water, the reduction in infiltration capacity due to silting up of pond, recharge due to rainfall and return flow of applied irrigation water in adjoining fields, pumping of ground water from the wells simultaneously when percolation through the pond is also taking place are some of the factors which make it very difficult to correctly assess the quantity of recharge from a percolation pond. The seepage losses from a percolation pond can, however, be quantified more realistically. Since a major part of the seepage losses ultimately joins the water table, they can be treated as an index of recharge to the aquifer.

## 4.2 Methodology Adopted

The following methodology is adopted for analysing the various objectives as set out in the study.

### 4.2.1. Assessment of Quantum of Seepage to the Aquifers

Storage changes in surface storage structures are effected by many factors. The storage is increased by surface runoff from catchment area, by direct addition from rainfall and by ground water appearing as effluent seepage. The depletion is caused by recharge to the ground water reservoir, by evaporation and by other usage through distribution works. In so far as the percolation ponds are concerned the loss in storage is entirely due to percolation and evaporation. Since the quantum of seepage from a pond can not be measured directly by a gauge, it can be computed theoretically by accomplishing the water balance of the pond by using the following equation.

Inflow - Outflow = Change in pond storage

Or

$$(I_s + I_r) - (E + L_s) = \Delta S$$

where,

$I_s$ = inflow to the pond due to surface flow

$I_r$ = direct addition to pond storage from rainfall

$E$ = evaporation

$L_s$ = losses due to seepage

$\Delta S$ = change in pond storage

The above terms represent the volume of water in cum over a specified period of time.

In the present study, the seepage or percolation losses are computed from both the study ponds using the above water balance approach. The water stages in the pond are recorded twice in a month. The available storage in the pond and its water spread area is computed for each stage using the stage-capacity table and the contour-capacity survey. The inflow terms of $I_s$ and $I_r$ are computed for the catchment area and the average water spread area of the pond respectively using the daily rainfall data of a nearby raingauge station. Evaporation from pond surface is the other factor to be determined. Daily pan evaporation data from a nearest observatory are taken as representative and the pond evaporation rate is taken as 0.7 times of the observed pan evaporation rate observed.

### 4.2.2 Assessment of the Zone of Influence of the Percolation Ponds

Increase in ground water storage is reflected in the fluctuations in water table in respective command areas of the ponds. The areal extent and magnitude of such fluctuations to be observed are dependent upon, among others, the volume of seepage water, hydraulic conductivity, extent, inter-relation of various aquifers concerned, irrigation practices and topographic factors like slope and occurrence of water courses. In order to assess the area influenced by the recharge from the ponds, the hydrographs of observation wells and ponds and also the contour maps of ground water table are drawn for the recharge periods for both the study ponds. The influence zone is then assessed by analysing the response of the water table to the pond storage.

### 4.2.3 Correlation Between the Quantum of Seepage and the Storage Loss

The quantum of seepage and the total loss of storage in the ponds during the periods of study are computed. The percentage seepage with respect to the total storage loss is then worked out in respect of each of the study pond.

# 5.0 RESULTS AND ANALYSIS

The results of the study are presented and analysed as per the objectives set out in the first chapter of the report.

## 5.1 Assessment of Quantum of Seepage to the Aquifers

The seepage to the aquifers from the percolation ponds is assessed by computing the water balance of the ponds. The water balance as computed for the two study ponds namely Uralipatti and Viralipatti are given in Tables 5.1 and 5.2 respectively. These tables present, among others, the estimates of the total losses, the evaporation losses and the seepage losses from the ponds.

In the case of Uralipatti percolation pond (Table 5.1), the study is carried out for two storage periods i.e. (i) from November 1991 to January 1992 and (ii) from Nov.1993 to January 1994. It is observed from the table that in the year 1991 the quantity of seepage, for various periods of observations, varied from 521 to 262 cum giving a rate of seepage of 34.7 to 16.3 cum per day for storage ranging between 1500 to 300 cum. In the year 1993, the rate of seepage is obtained almost in the same order except for the observation period of 10-23 Nov.1993 where it is observed as high as 180 cum per day. The higher rate of seepage during this period can probably be attributed to two simple reasons. Firstly, the pond achieved its almost full level on 10th November 1993 with a storage of 2700 cum and the water spread area of 3625 sq.m. Secondly, as the pond received water after a long dry spell, the soils below the pond were initially unsaturated and the rate of infiltration from the pond was very high during this period. Over the observation period of 123 days during 1991 and 1993, the total loss from the pond storage is computed to be about 5734 cum, of which 683 cum is the evaporation loss and the remaining 5051 cum forms the seepage losses. The average rate of seepage over a period of 123 days is computed as 41.06 cum per day.

The analysis of seepage for Viralipatti percolation pond is carried out for the recharge period from January to May 1990. Table 5.2 shows that the storage in the pond during the study period varies from 10905 to 2830 cum. The rate of seepage is found to vary between 137 to 20.40 cum per day for different periods of observations. The average rate of seepage over a total observation period of 119 days works out to 45.84 cum per day. Out of the total storage loss of 8315 cum, the evaporation and the seepage losses account for 2860 and 5455 cum respectively.

The above analysis of seepage carried out on volume basis may not be representative in view of the high variability in the storage capacities due to siltation. An equally valuable alternative is, therefore, to find out the column of water recharging the aquifers. In Tables 5.1 and 5.2 the seepage losses as expressed in terms of the column of water in the ponds are also therefore presented. These seepage losses in Uralipatti and Viralipatti percolation ponds are found to vary from 55.7 to 5.4 mm/day and 23.3 to 5.0 mm per day respectively.

As is evident from the above analysis the percolation rates are seldom uniform even in the same pond. The infiltration generally takes place at a higher rate at the start of the recharge but the rate gradually decreases due to saturation of the top soil. After some time, the infiltration rate tends to increase due to displacement of the entrapped air under the recharge basin. This rise of the infiltration rate may take as long as several days to several weeks. After this period, the rate decreases again due to sediment and biological clogging or excessive mounding under the basin. Normally after a long period, the infiltration rate reaches a low but fairly constant rate called the basic infiltration rate. This phenomena is clearly observed in the case of Uralipatti pond for both the recharge periods. The recharge from the pond starts on Nov.22, 1991 and lasts till January 9, 1992. It again starts on Nov.10, 1993 and takes place till January 24, 1994. The initial rates of seepage of 11.5 mm and 55.7 mm per day for these two recharge periods respectively are observed to decrease to 5.4 mm and 6.3 mm per day which again increase to 10.1 mm and 22.8 mm per day over a period of 48 and 75 days respectively. In the case of Viralipatti percolation pond, the recharge starts from Oct.1988 and continues even beyond May 1990 without any dry period in between. The infiltration rates for the study period of January 24 to May 23, 1990 are, thus, the basic infiltration rates in saturated condition and therefore do not show the above trend. Clogging of pores in the pond bed by silt and clay over a period of time tends to reduce the infiltration rate from the pond.

## 5.2 Assessment of the Zone of Influence of the Ponds

Increase in ground water storage due to recharge from percolation ponds is reflected in the water table fluctuations in respective command areas of the ponds. So, with a view to assess the extent of zone of recharge of the study ponds, the hydrographs of the pond storage and of the selected observation wells in the vicinity of the ponds are drawn. Such hydrographs for Uralipatti and Viralipatti percolation ponds are given in Figs.5.1(a) to 5.1(d) and 5.2(a) to 5.2(c) respectively. The topographical maps (Figs.3.1 and 3.2) and the ground water level contour maps (Appendices 1 to 18) are also prepared to study the ground water flow pattern in the zone of influence of these ponds.

It may be observed from the topographical map of the Uralipatti percolation pond (Fig.3.1) that the ground is sloping downwards in the downstream side of the pond in the west and south-west direction. The well Nos.3 and 4 are located in the south-west and west direction of the pond in downstream level. While the well No.2 is located very near the pond in the south direction, the well No.7 is located in North direction. The well No.1 is located in the upstream side of the pond. The other wells are located more distantly from the pond. The distances of these observation wells from the pond are given in Table 5.3.

A study of hydrographs of these wells and pond (Figs.5.1a to 5.1d) indicates that all wells have got significant rise in all the recharge periods. This rise in all the wells is probably due to the rainfall which causes storages in the pond as the recharge from rainfall will also have its own influence to rise in the water table. Since the quantity of recharge from percolation pond is much less than that from the rainfall, the assessment of the extent of the influence zone becomes a complex problem. However, a critical examination of these hydrographs shows that with the availability of storage in the pond the Well Nos.2, 3, 4 and 7 rise more and faster than other wells. This may be due to the influence of the pond. Although the well Nos.2 and 4 become dry during non recharge periods but they get water with the start of recharge from the pond. While the rise in water tables in well Nos. 1, 5 and 6 is observed to be moderate, the well Nos. 8 and 9 are noticed to have minimum influence. The water table contour maps of the study area (Appendices 1 to 9) also indicate that flow is taking place towards well Nos.2, 3, 4 and 7. Hence, it is concluded that while the well No.2,3,4 and 7 lie in the influence zone of the pond, the well Nos.1,5 and 6 also have moderate influence of recharge from the pond.

In the case of Viralipatti percolation pond, the topographical map (Fig.3.2) shows that the terrain in general is sloping towards the North-East direction. While the well Nos.1,4, 5,6,7,8,9 and 10 are located in the downstream side and near the pond, the other wells namely 2,3,11 and 12 fall away and on the upstream side of the pond. The distance of the wells from percolation pond is given Table 5.3. It is observed from the hydrographs of wells that the well Nos.1,4,6,7,8,9 and 10 show almost a steady trend in water table and get appreciable recharge from the pond. Although, the well Nos.6 and 10 lie within the area of influence of the pond but become dry owing to their shallow depth. So, these wells need to be deepened in order to get the recharge benefit from the pond. The well Nos 2 and 3 also show significant rise in the water tables but they are mostly influenced owing to the terrain rather than the pond. The well Nos.5,11 and 12 show large variation in the water table regime despite the continuance of recharge from the pond. The well Nos.5, 11 and 12, therefore, seem to have only marginal recharge from the pond. The flow pattern as observed from the water table contour maps (Appendices 10 to 18) also indicate that the well No.1,4,6,7,8,9and 10 are influenced maximum while well Nos.5,11 and 12 get only a marginal recharge owing to their distances from the pond.

## 5.3 Correlation between the Quantum of Seepage and the Loss in Pond Storage.

The percentage of seepage with respect to the total loss of storage in the pond is worked out for the study periods for Uralipatti and Viralipatti percolation ponds and are given in Tables 5.4 and 5.5 respectively. From these tables, it is observed that the seepage varies from 62.98 to 97.38 % from Uralipatti pond and 51.0 to 84.0 % from Viralipatti pond for different pond storages during various periods of observation. Further, it can be seen that over the entire study periods an average of 88% and 65.60 % of the storage loss percolated down and the remaining 12% and 34.40% formed evaporation losses from Uralipatti and Viralipatti percolation ponds respectively.

# TABLE 5.1 : WATER BALANCE OF URALIPATTI PERCOLATION POND

| Sl No | Period | No. of Days | Pond stage (m) | Pond Storage (cum) | Water spread due to pond (sq.m) | Avg. Water spread area of pond (sq.m) | Change in pond stage (m) | Change in Pond Storage (Cum) | Rain-fall (m) | In-flow to the pond due to Rain-fall (Cum) | Direct addi-tion to pond sto-rage due to rain-fall (cum) | Total addi-tion to pond sto-rage due to rain-fall (cum) | Total loss from pond sto-rage (cum) | Pan eva-pora-tion (m) | Actual evaporation | | Seepage | | Seepage per day | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | (m) | (cum) | (Cum) | (m) | (cum) | m/day |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) = (7) x (10) | (13)= (11 + (12) | (14)= (13)- (9) | (15) | (16)= (15)x 0.7 | (17)= [(14)x (16)/ (8) | (18) = (14)- (17) | (19)= [(8)x (18)]/ (9) | (20) = (18)/ (3) | (21)= (19)/ (3) |
| 1 | 22-11-91 to 7-12-91 | 15 | 268.10<br>267.91 | 1500<br>928 | 3000<br>2525 | 2762.50 | -0.19 | -572 | 0.016 | 0 | 44 | 44 | 616 | 0.0421 | 0.0294 | 95 | 521 | 0.1730 | 34.7 | 0.0115 |
| 2 | 7-12-91 to 23-12-91 | 16 | 267.91<br>267.82 | 928<br>658 | 2525<br>2260 | 2392.50 | -0.09 | -270 | 0.027 | 81 | 65 | 146 | 416 | 0.0478 | 0.0334 | 154 | 262 | 0.0873 | 16.3 | 0.0054 |
| 3 | 23-12-91 to 9-1-92 | 17 | 267.82<br>267.60 | 658<br>300 | 2260<br>1400 | 1830.0 | -0.22 | -358 | 0 | 0 | 0 | 0 | 358 | 0.0675 | 0.0473 | 77 | 281 | 0.1726 | 16.5 | 0.0101 |
| 4 | 10-11-93 to 23-11-93 | 13 | 268.45<br>267.88 | 2700<br>680 | 3625<br>2200 | 2912.50 | -0.65 | -2100 | 0.088 | 210* | 95 | 305 | 2405 | 0.0244 | 0.0171 | 63 | 2342 | 0.7248 | 180.1 | 0.0557 |
| 5 | 23-11-93 to 23-12-93 | 30 | 267.88<br>268.05 | 680<br>1385 | 2200<br>2875 | 2537.50 | +0.25 | +785 | 0.188 | 1011 | 477 | 1488 | 703 | 0.0569 | 0.0398 | 112 | 591 | 0.1881 | 19.7 | 0.0062 |
| 6 | 23-12-93 to 10-1-94 | 18 | 268.05<br>267.90 | 1385<br>890 | 2875<br>2500 | 2687.50 | -0.15 | -495 | 0.011 | 80 | 31 | 111 | 606 | 0.045 | 0.0315 | 127 | 479 | 0.1451 | 26.61 | 0.0080 |
| 7 | 10-1-94 to 24-1-94 | 14 | 267.90<br>267.55 | 890<br>260 | 2500<br>1000 | 1750.0 | -0.35 | -630 | 0 | 0 | 0 | 0 | 630 | 0.044 | 0.0308 | 55 | 575 | 0.3194 | 41.0 | 0.0228 |
| | Total | 123 | | | | | | -3640 | 0.33 | 1382 | 712 | 2094 | 3734 | 0.3277 | 0.2291 | 683 | 5051 | | | |

Note: Since the pond became full, only this quantity could be stored and the rest became overflow.

## TABLE 5.2 : WATER BALANCE OF VIRALIPATTI PERCOLATION POND

| Sl No | Period | No. of Days | Pond stage (m) | Pond Storage (cum) | Water spread due to pond (sq.m) | Avg. Water spread area of pond (sq.m) | Change in pond stage (m) | Change in Pond Storage (Cum) | Rain-fall (m) | In-flow to the pond due to Rain-fall | Direct addition to pond storage due to rain-fall | Total addition to pond storage due to rain-fall | Total loss from pond storage | Pan evaporation | Actual evaporation | | Seepage | | Seepage per day | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | (Cum) | (Cum) | (cum) | (cum) | (m) | (m) | (cum) | (Cum) | (m) | (cum) | m/day |
| | | | | | | | | | | | (12) = (7) x (10) | (13)= (11 + (12) | (14)= (13)- (9) | | (16)= (15)x 0.7 | (17)= [(16)x (18)]/ (8) | (18) = (14) - (17) | (19)= [(8)x (18)] /(9) | (20)= (18)/ (3) | (21)= (19)/ (3) |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | | | | (15) | | | | | | |
| 1 | 24-1-90 to 6-2-90 | 13 | 340.434<br>340.284 | 10904.85<br>9916.30 | 6700<br>6468 | 6584 | -0.15 | -988.55 | 0.0 | 0.0 | 0.0 | 0.0 | 988.55 | 0.059 | 0.0413 | 272.18 | 716.37 | 0.108 | 55.10 | 0.0083 |
| 2 | 6-2-90 to 26-2-90 | 20 | 340.284<br>340.084 | 9916.30<br>8662.70 | 6468<br>6068 | 6268 | -0.20 | -1252.60 | 0.0 | 0.0 | 0.0 | 0.0 | 1253.60 | 0.108 | 0.0756 | 473.86 | 779.74 | 0.124 | 38.98 | 0.0062 |
| 3 | 26-2-90 to 7-3-90 | 9 | 340.084<br>339.834 | 8662.70<br>7195.85 | 6068<br>5700 | 5884 | -0.25 | -1466.85 | 0.0 | 0.0 | 0.0 | 0.0 | 1466.85 | 0.057 | 0.0399 | 234.10 | 1232.75 | 0.210 | 136.97 | 0.0233 |
| 4 | 7-3-90 to 21-3-90 | 14 | 339.834<br>339.684 | 7195.85<br>6360.20 | 5700<br>5426 | 5563 | -0.15 | -835.65 | 0.017 | 0.0 | 94.50 | 94.50 | 930.15 | 0.089 | 0.0623 | 386.32 | 543.83 | 0.097 | 38.84 | 0.0069 |
| 5 | 21-3-90 to 6--4-90 | 16 | 339.684<br>339.484 | 6360.20<br>5308.30 | 5426<br>5076 | 5251 | -0.20 | -1051.90 | 0.0 | 0.0 | 0.0 | 0.0 | 1051.90 | 0.122 | 0.0854 | 449.16 | 602.74 | 0.114 | 37.67 | 0.0071 |
| 6 | 6-4-90 to 24-4-90 | 18 | 339.484<br>339.234 | 5308.30<br>4094.30 | 5076<br>4620 | 4848 | -0.25 | -1214.00 | 0.0 | 0.0 | 0.0 | 0.0 | 1214.00 | 0.124 | 0.0868 | 421.50 | 792.50 | 0.163 | 44.02 | 0.009 |
| 7 | 24-4-90 to 8-5-90 | 14 | 339.234<br>339.084 | 4094.30<br>3430.20 | 4620<br>4210 | 4415 | -0.15 | -664.10 | 0.033 | 0.0 | 145.70 | 145.7 | 809.80 | 0.087 | 0.0609 | 328.77 | 481.03 | 0.108 | 34.36 | 0.0077 |
| 8 | 8-5-90 to 23-5-90 | 15 | 339.084<br>338.934 | 3430.20<br>2829.60 | 4210<br>3800 | 4025 | -0.15 | -600.60 | 0.0 | 0.0 | 0.0 | 0.0 | 600.60 | 0.105 | 0.0735 | 294.29 | 306.31 | 0.076 | 20.42 | 0.0050 |
| | Total | 119 | | | | | | -8075.25 | 0.05 | 0.0 | 240.20 | 240.20 | 8315.45 | 0.751 | 0.5257 | 2860.18 | 5455.27 | | | |

**TABLE 5.3: Distances between the deepest bed level of the Uralipatti and Viralipatti Percolation Ponds to the Observation wells**

| Uralipatti Percolation Pond | | Viralipatti Percolation Pond | |
|---|---|---|---|
| Well No. | Distance (m) | Well No. | Distance (m) |
| 1 | 325 | 1 | 43 |
| 2 | 190 | 2 | 244 |
| 3 | 260 | 3 | 293 |
| 4 | 335 | 4 | 124 |
| 5 | 840 | 5 | 305 |
| 6 | 600 | 6 | 190 |
| 7 | 340 | 7 | 70 |
| 8 | 1210 | 8 | 53 |
| 9 | 950 | 9 | 124 |
| | | 10 | 152 |
| | | 11 | 311 |
| | | 12 | 265 |

**TABLE 5.4 : Total Storage, Seepage and Evaporation Losses from Uralipatti Percolation Pond.**

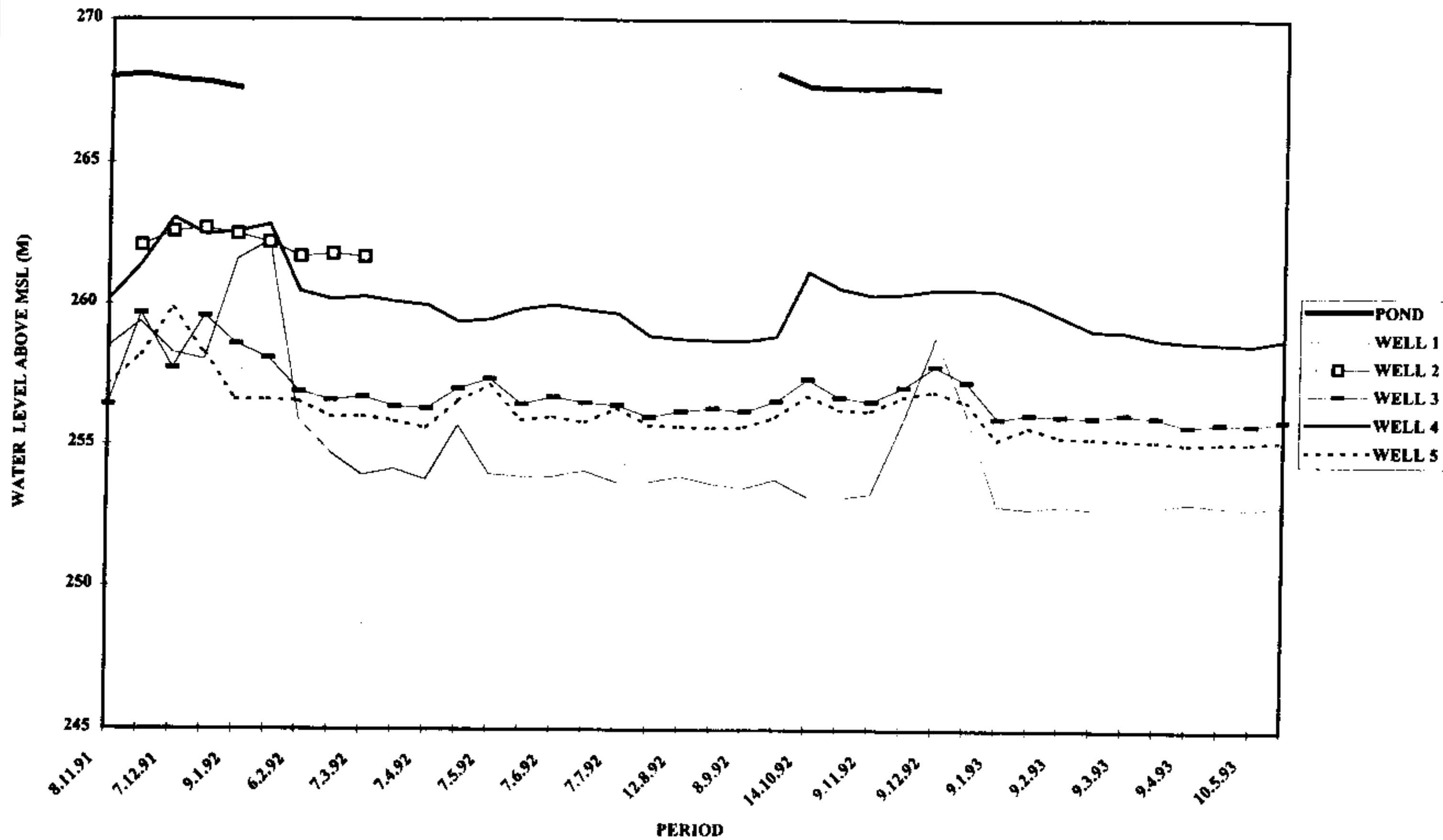
| Sl.No. | Period | Total loss from the pond storage (cum) | Seepage (cum) | Evaporation (cum) | Percentage of evaporation to total storage loss | Percentage of Seepage to total storage loss |
|---|---|---|---|---|---|---|
| 1 | 22-11-91 to 7-12-91 | 616 | 521 | 95 | 15.42 | 84.58 |
| 2 | 7-12-91 to 23-12-91 | 416 | 262 | 154 | 37.02 | 62.98 |
| 3 | 23-12-91 to 9-1-92 | 358 | 281 | 77 | 21.50 | 78.50 |
| 4 | 10-11-93 to 23-11-93 | 2405 | 2342 | 63 | 2.62 | 97.38 |
| 5 | 23-11-93 to 23-12-93 | 703 | 591 | 112 | 15.93 | 84.07 |
| 6 | 23-12-93 to 10-1-94 | 606 | 479 | 127 | 20.95 | 79.05 |
| 7 | 10-1-94 to 24-1-94 | 630 | 575 | 55 | 8.73 | 91.27 |
| | Total | 5734 | 5051 | 683 | 11.92 | 88.08 |

**TABLE 5.5 : Total Storage, Seepage and Evaporation Losses from Viralipatti Percolation Pond.**

| Sl.No. | Period | Total loss from the pond storage (cum) | Seepage (cum) | Evaporation (cum) | Percentage of evaporation to total storage loss | Percentage of Seepage to total storage loss |
|---|---|---|---|---|---|---|
| 1 | 24-1-90 to 6-2-90 | 988.55 | 716.37 | 272.18 | 27.53 | 72.47 |
| 2 | 6-2-90 to 26-2-90 | 1253.60 | 779.74 | 473.86 | 37.80 | 62.20 |
| 3 | 26-2-90 to 7-3-90 | 1466.85 | 1232.75 | 234.10 | 15.96 | 84.04 |
| 4 | 7-3-90 to 21-3-90 | 930.15 | 543.83 | 386.32 | 41.53 | 58.47 |
| 5 | 21-3-90 to 6-4-90 | 1051.90 | 602.74 | 449.16 | 42.70 | 57.30 |
| 6 | 6-4-90 to 24-4-90 | 1214.00 | 792.50 | 421.50 | 34.72 | 65.28 |
| 7 | 24-4-90 to 8-5-90 | 809.80 | 481.03 | 328.77 | 40.60 | 59.40 |
| 8 | 8-5-90 to 23-5-90 | 600.60 | 306.31 | 294.29 | 49.00 | 51.00 |
| Total | | 8315.45 | 5455.27 | 2860.18 | 34.40 | 65.60 |

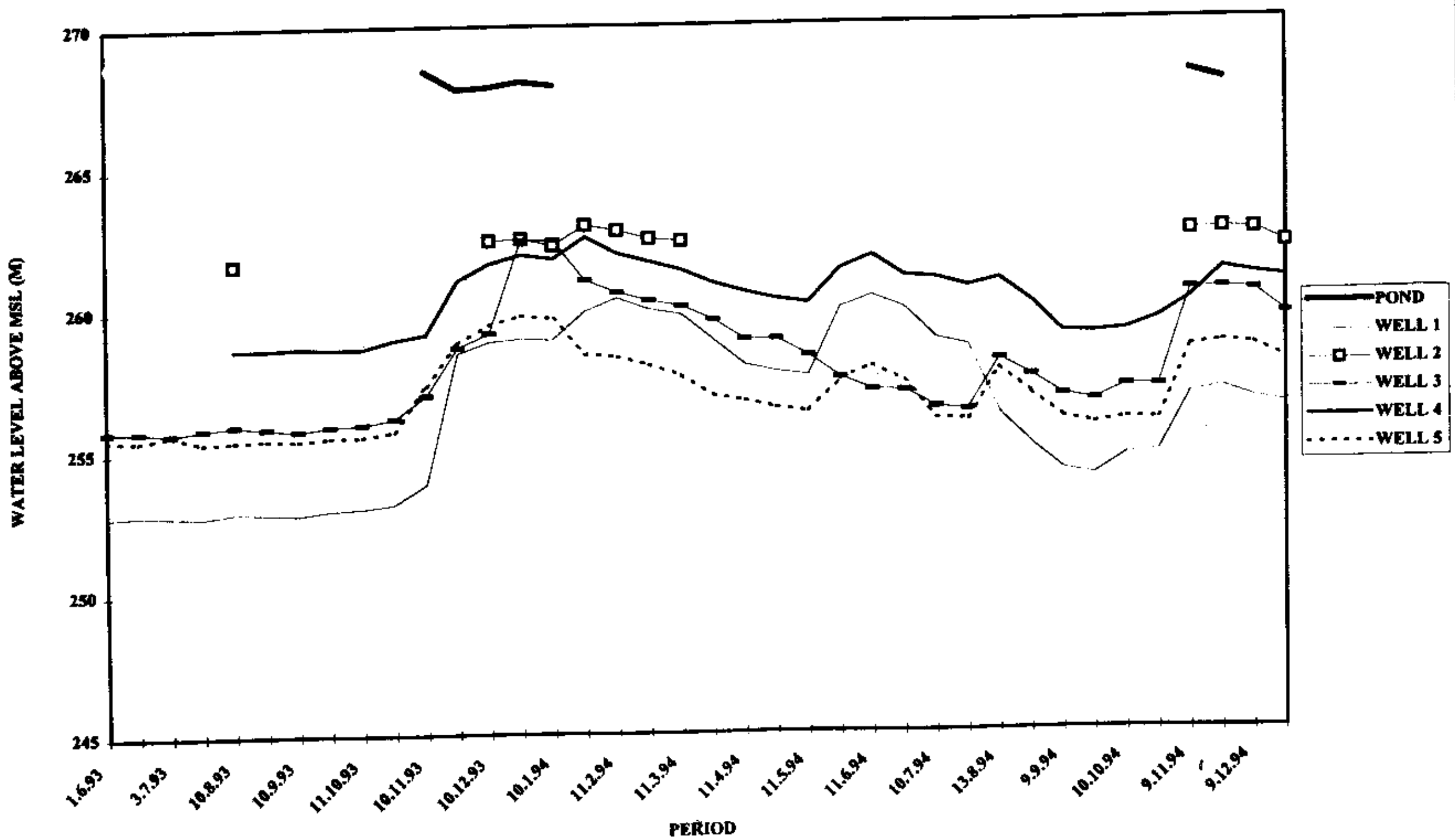
HYDROGRAPHS FOR URALIPATTI PERCOLATION POND AND ITS WELL NO. 1, 2, 3, 4, 5

FIG. 5.1(a)



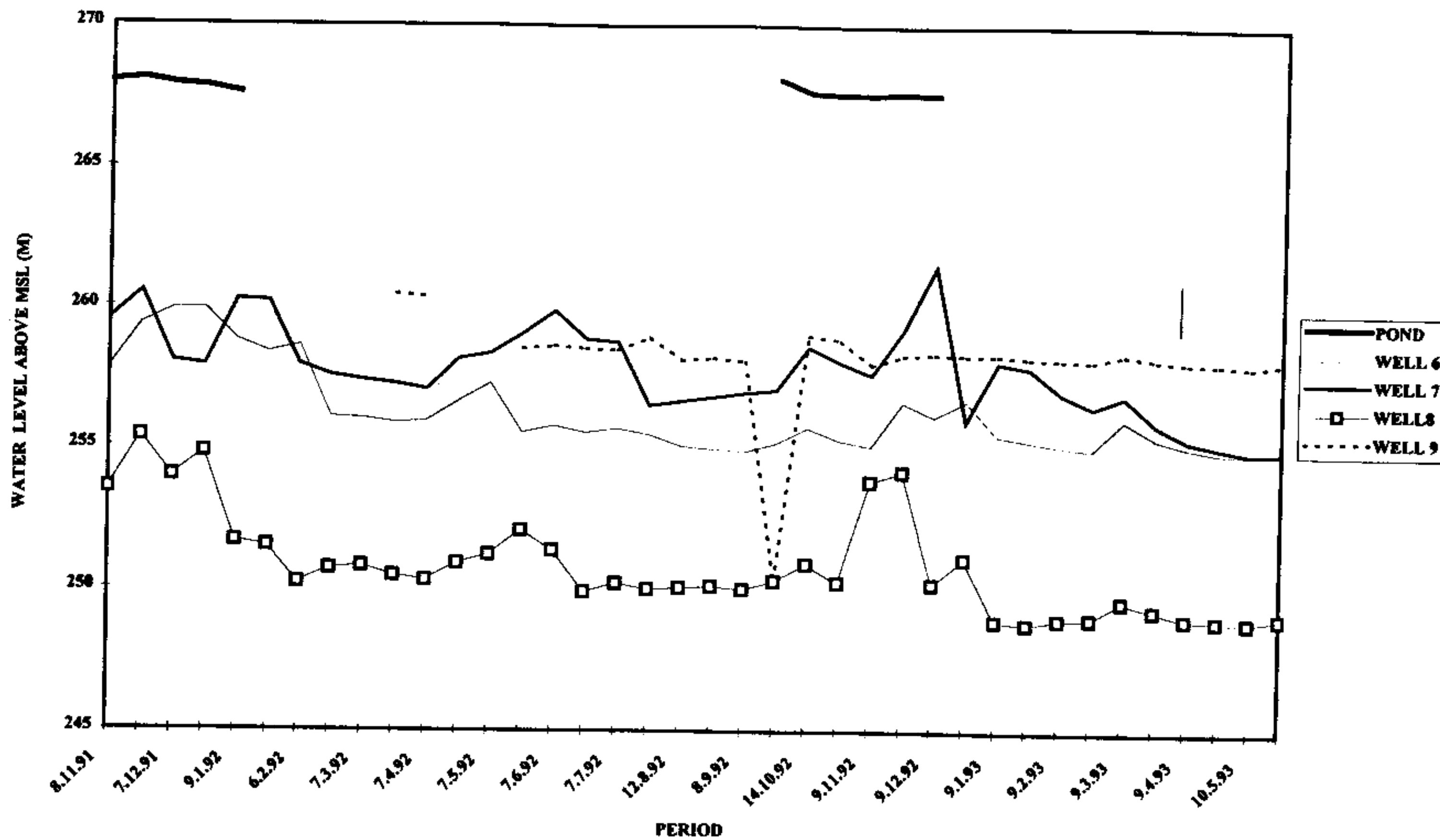
## HYDROGRAPHS FOR URALIPATTI PERCOLATION POND AND ITS WELL NO. 1, 2, 3, 4, 5

FIG. 5.1(b)



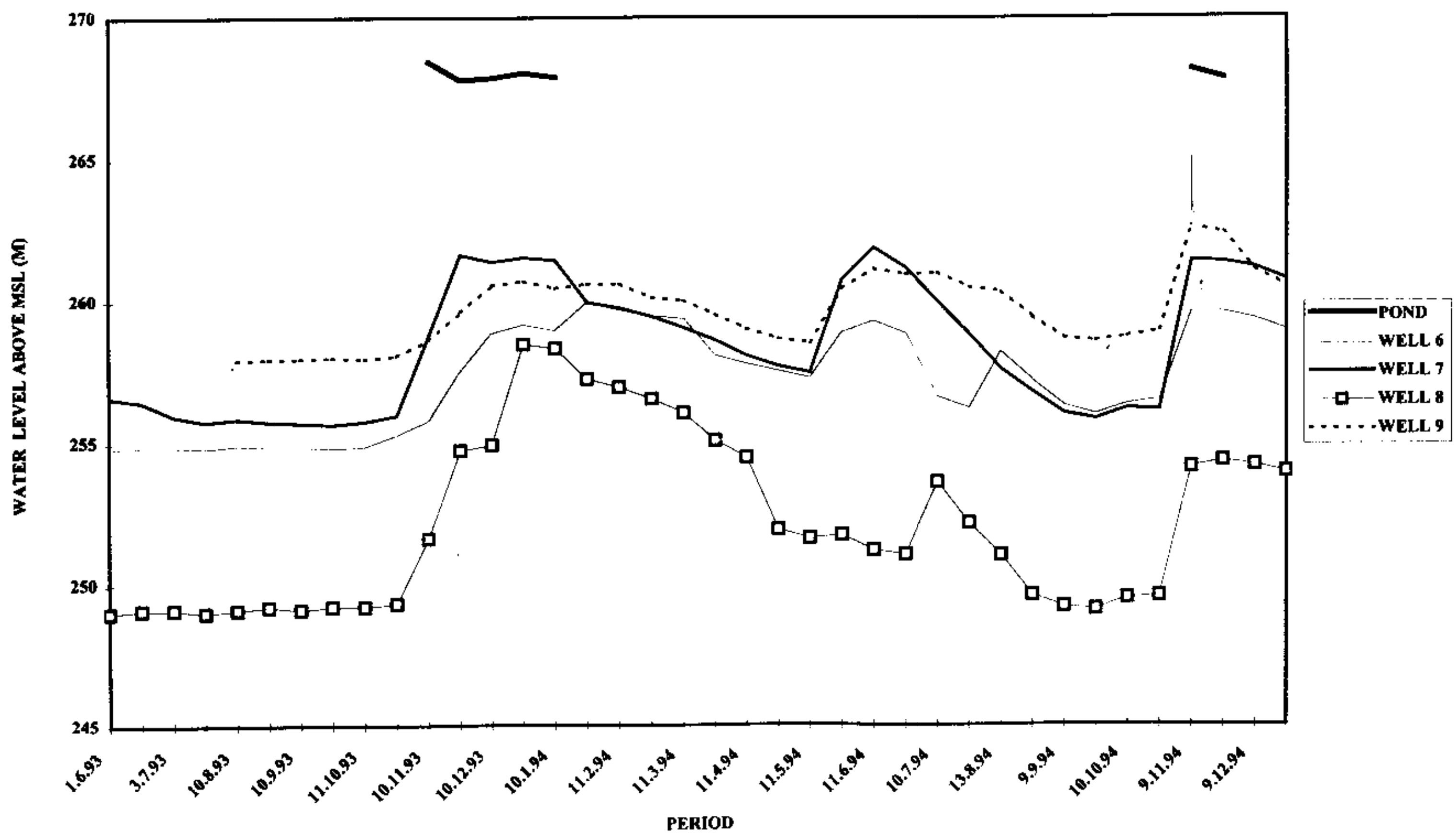
## HYDROGRAPHS FOR URALIPATTI PERCOLATION POND AND ITS WELL NO. 6, 7, 8, 9

FIG. 5.1(c)



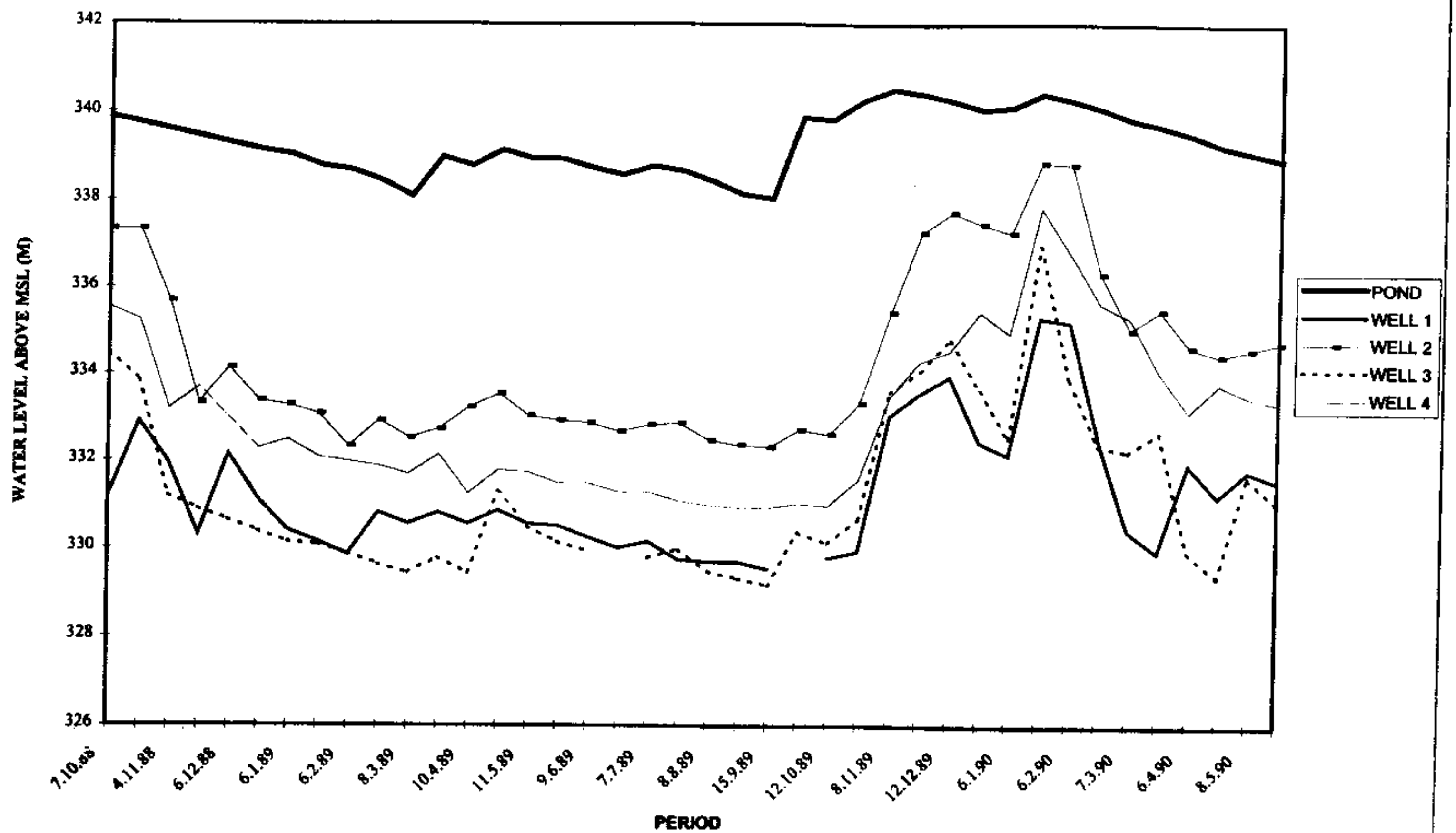
## HYDROGRAPHS FOR URALIPATTI PERCOLATION POND AND ITS WELL NO. 6, 7, 8, 9

FIG. 5.1(d)



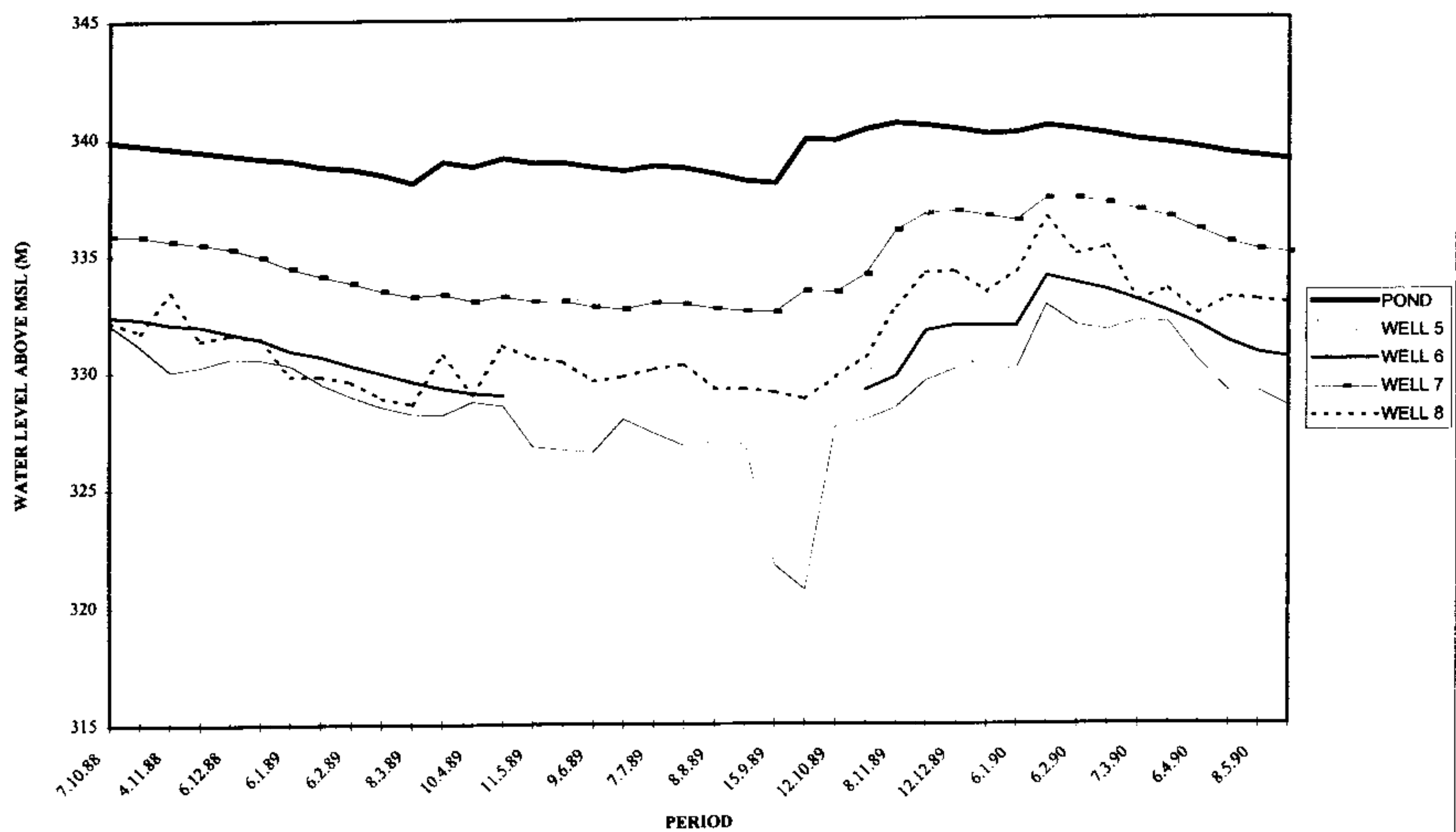
## HYDROGRAPHS FOR VIRALIPATTI PERCOLATION POND AND ITS WELL NO. 1, 2, 3, 4

FIG. 5.2(a)



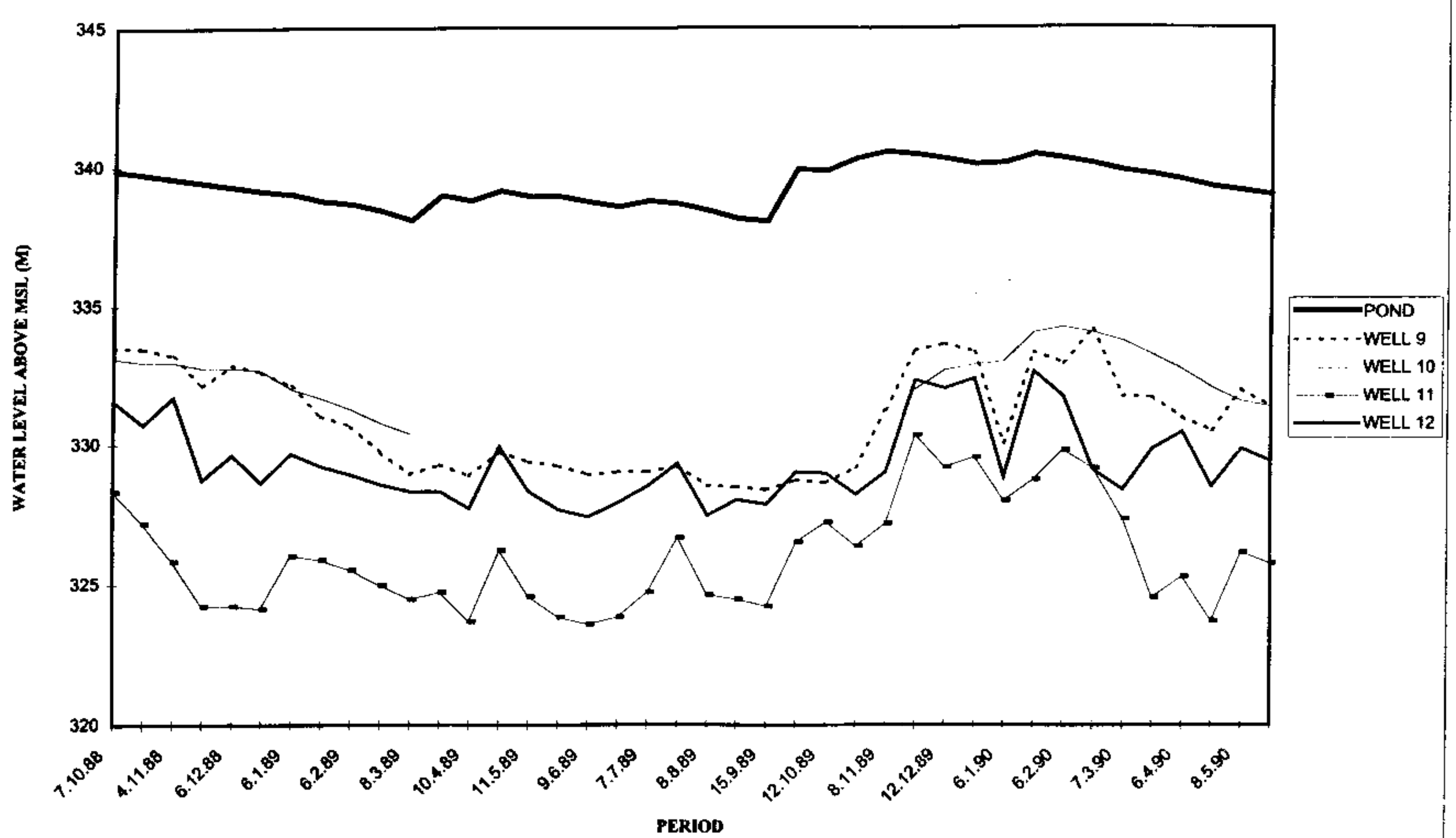
## HYDROGRAPHS FOR VIRALIPATTI PERCOLATION POND AND ITS WELL NO. 5, 6, 7, 8

FIG. 5.2 (b)



**HYDROGRAPHS FOR VIRALIPATTI PERCOLATION POND AND ITS WELL NO. 9, 10, 11, 12**

**FIG. 5.2(c)**



# 6.0 CONCLUSIONS

Two percolation ponds namely, Uralipatti and Viralipatti are studied for selected recharge periods to assess the benefits of percolation ponds in terms of artificial recharge to the aquifers. The following conclusions are drawn from the study.

## 6.1 Uralipatti Percolation Pond

(i) The rate of seepage is found to vary between 34.7 to 16.3 cum/day for pond storages between 1500 to 300 cum during the year 1991 and between 180.1 to 19.7 cum/day for the pond storages between 2700 to 260 cum during 1993.

(ii) The average rate of seepage computed over a total observation period of 123 days during the years 1991 and 93 is obtained as 41.06 cum per day.

(iii) The seepage losses as expressed in terms of column of water in the pond vary from 55.7 to 5.4 mm/day for various storage amounts during different observation periods.

(iv) A total of 5734 cum of storage loss is observed from the pond over 123 days. Out of this, about 5051 cum of water percolates down and the rest 683 cum is lost through evaporation. In other words, about 88% of the total storage loss becomes seepage and the remaining 12% is lost through evaporation.

(v) The well Nos.2, 3, 4 and 7 which are located within a radius of 340 m show a faster rise in their water tables with the start of recharge and are therefore influenced by the recharge from the pond.

(vi) Although the well No.1 is located at a distance of 325 m but it being located on the upstream side of the pond gets moderate recharge effect.

(vii) While the well Nos. 5 and 6 located at a distance of 840 and 600 m respectively also show moderate recharge effect, the well Nos.8 and 9 which are located at 950 m and beyond have negligible effect of the pond storage.

(viii) The well Nos. 2 and 4 though lie within the influence zone but get dry soon due to their shallow depths. These wells, therefore, need deepening to reap the benefits of the pond.

## 6.2 Viralipatti Percolation Pond

(i) The storage in the pond during the study period varied from 10905 to 2830 cum and the rate of seepage is found to vary from 137 to 20.40 cum per day for various storage amounts. These seepage rates, if expressed in terms of column of water in the pond, represent a loss of 23.3 to 5 mm/day.

(ii) The average seepage rate over the entire study period of 119 days is computed as 45.84 cum per day.

(iii) Out of the total storage loss of 8315 cum, the seepage and evaporation losses account for 5455 cum and 2860 cum respectively or 65.6% and 34.40% of the total storage loss respectively.

(iv) The well Nos. 1,4,6,7,8,9 and 10 which are all located within a radius of about 200 m downstream of the pond get significant recharge from the pond.

(v) The well Nos. 11 and 12 which are located upstream of the pond at a distance of 311 and 265 m respectively get only a marginal recharge. The well No.5 at a distance of 305 m but in the downstream of the pond is also influenced only marginally.

(vi) Though the well Nos.2 and 3 also show significant rise in the water table but they are mostly influenced owing to the terrain rather than the pond.

(vii) As the well Nos.6 and 10 are shallow and become dry they need to be deepened to get the benefit of recharge from the pond.

In general, it is concluded from the study that these percolation ponds are very effective in recharging the shallow ground water aquifers. In the discussion during field visits the farmers in the command areas of such ponds also expressed that the water levels in their wells have increased after construction of the ponds. Because of the increased availability of water, the area under wet crops is also increased in the vicinity of ponds.

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(iv) Shri I.I.J.Arputharaj, Executive Engineer, G.W.Div., Chennai

(v) Shri K.S. Nagrajan, Asstt. Director (G), O/O C.E.Chennai

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(vi) Shri C.Selvaraj, Junior Engineer (A.E.), Tiruvallur.

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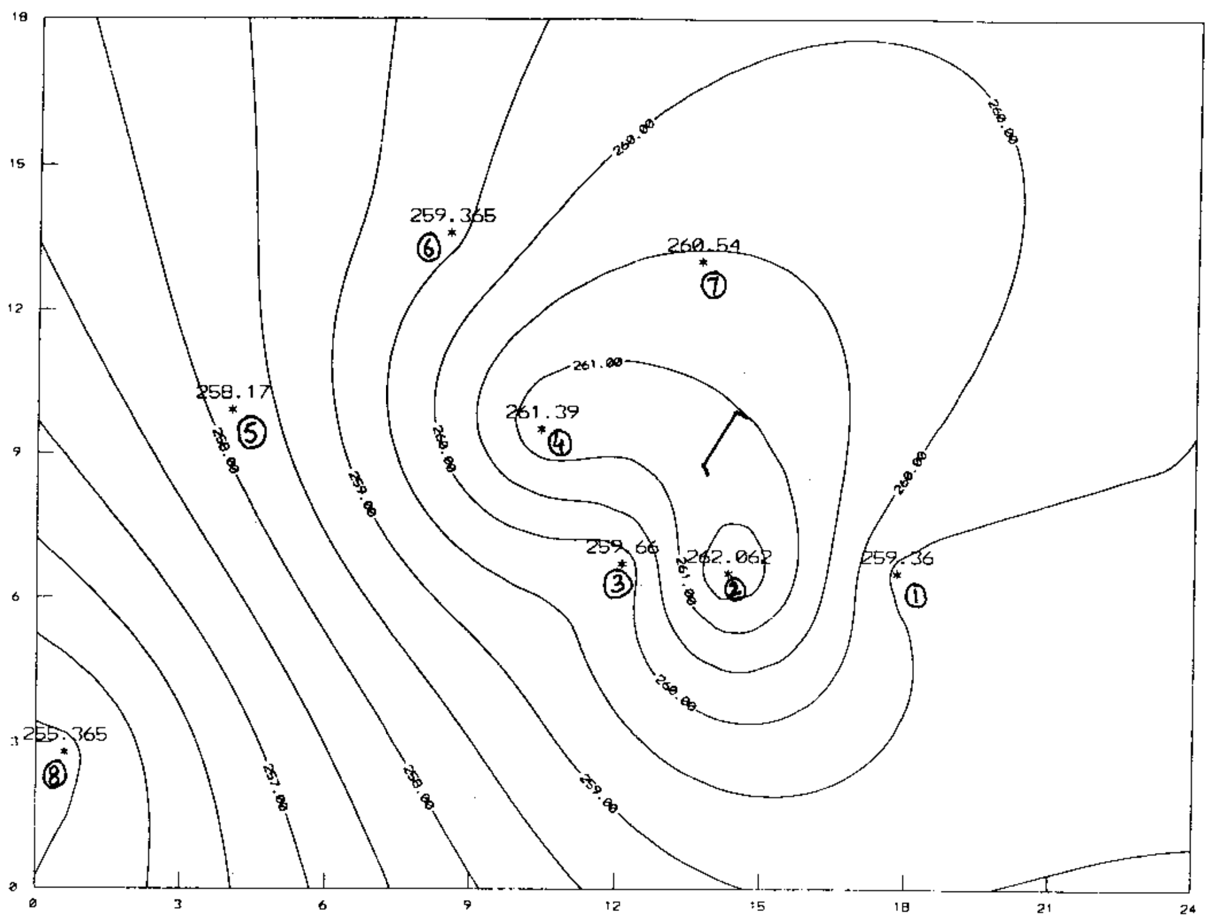
# LIST OF APPENDICES

| APPENDIX NO. | TITLE | PAGE NO. |
|---|---|---|

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 22.11.91




**APPENDIX 1**

N

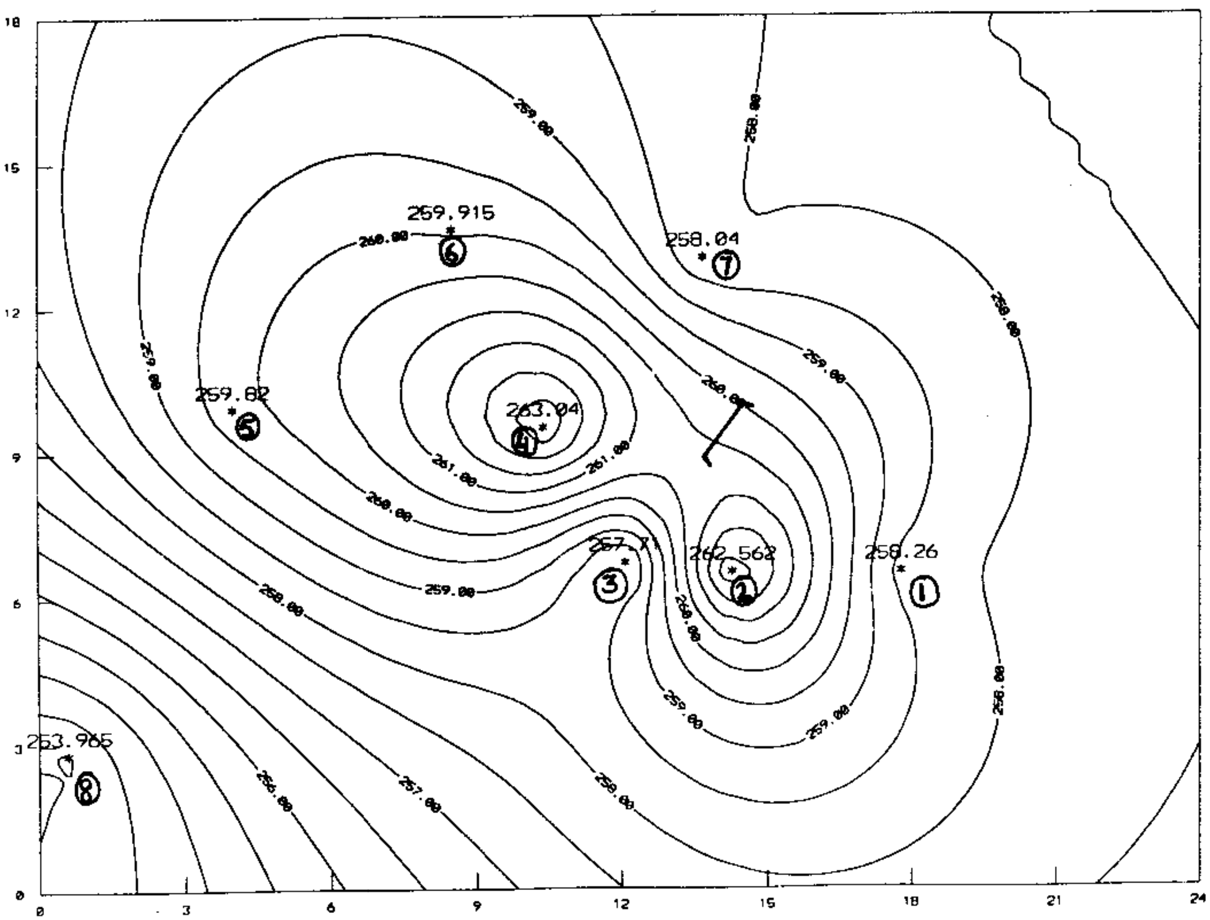
**SCALE**

**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND |  |
| WELL NO. |  |

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 7.12.91




**APPENDIX 2**

**N**

**SCALE**

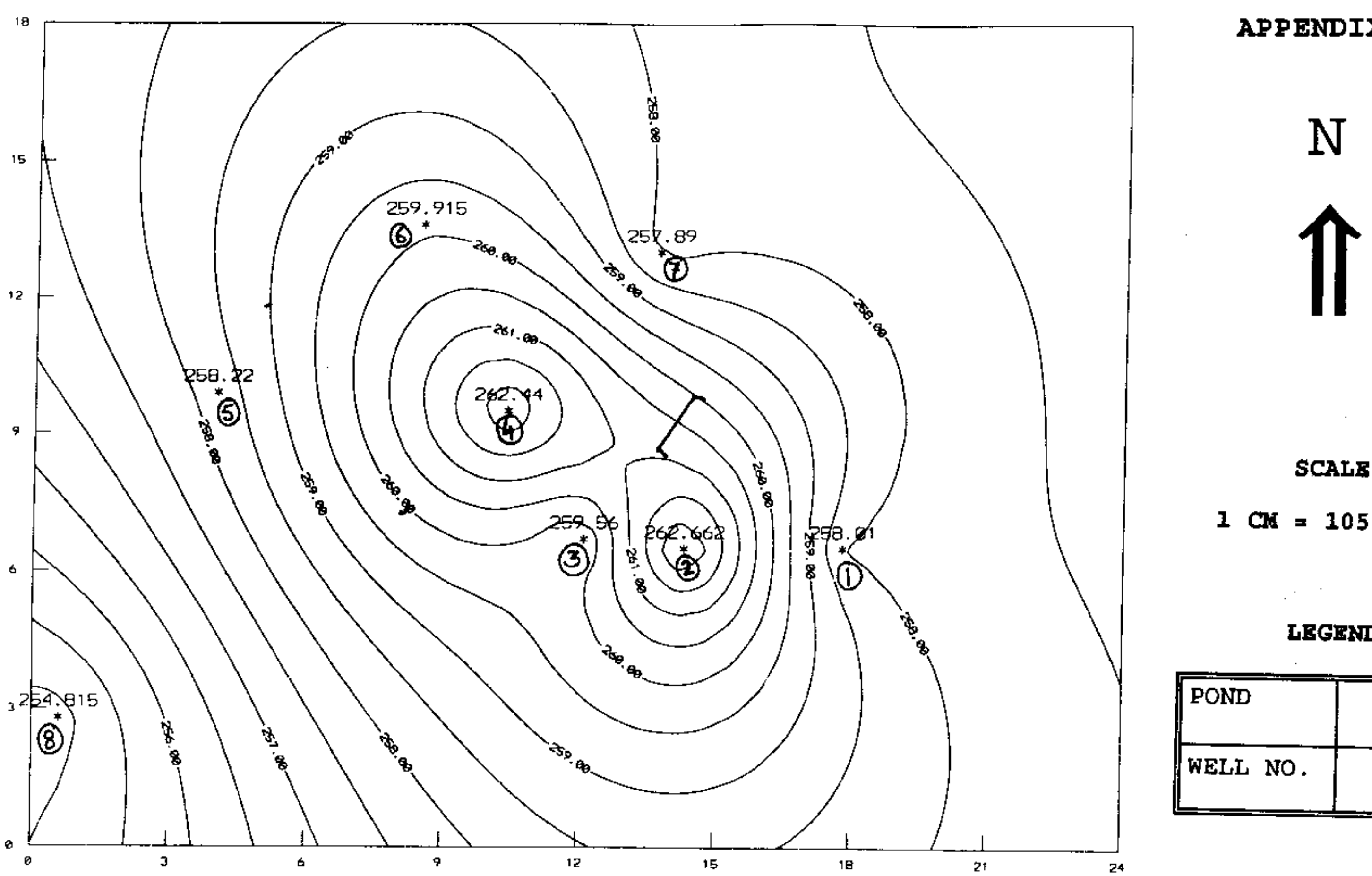
**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

## APPENDIX 3

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 23.12.91




**SCALE**

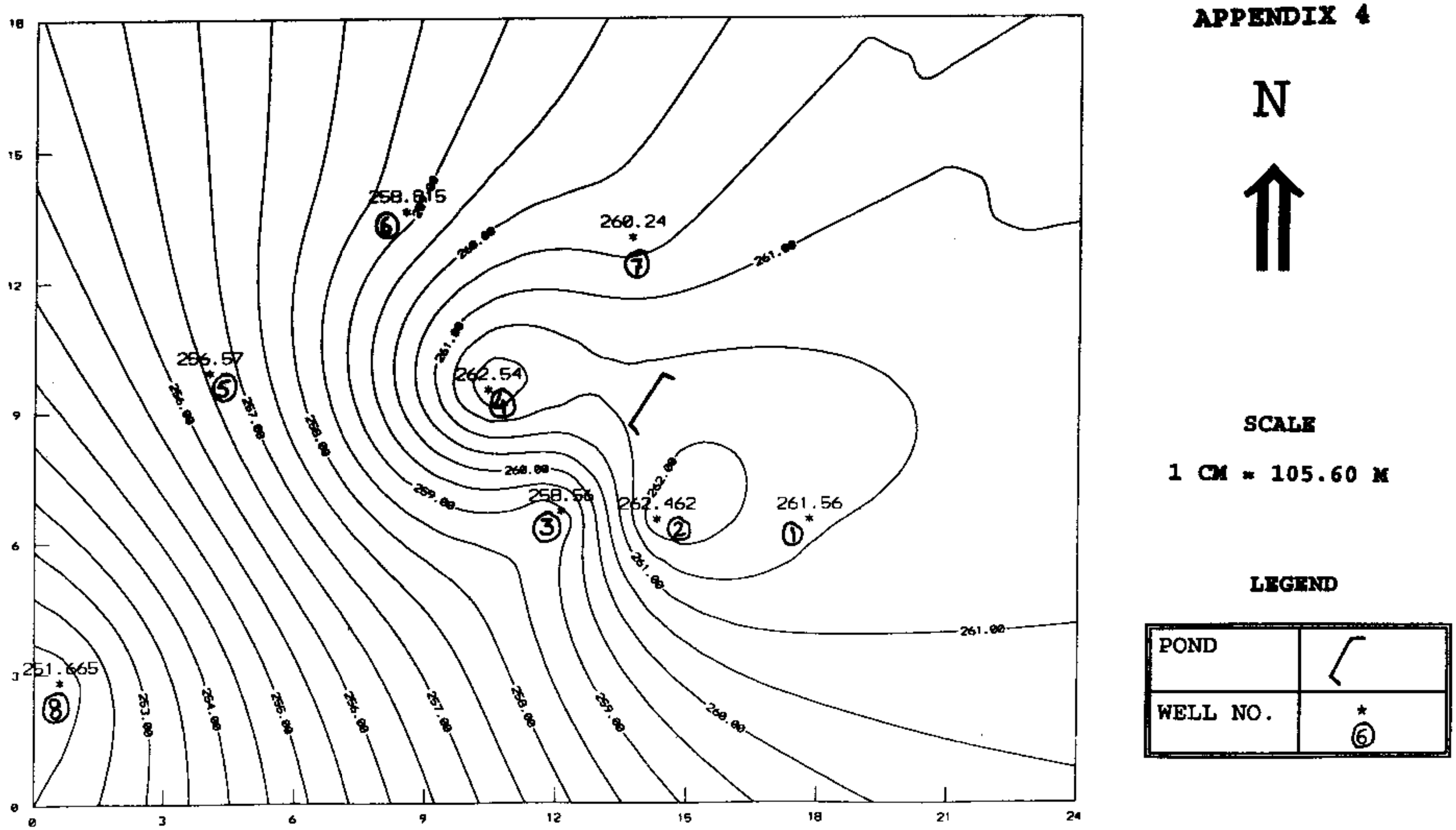
**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND | ⌐ |
| WELL NO. | * ⑥ |

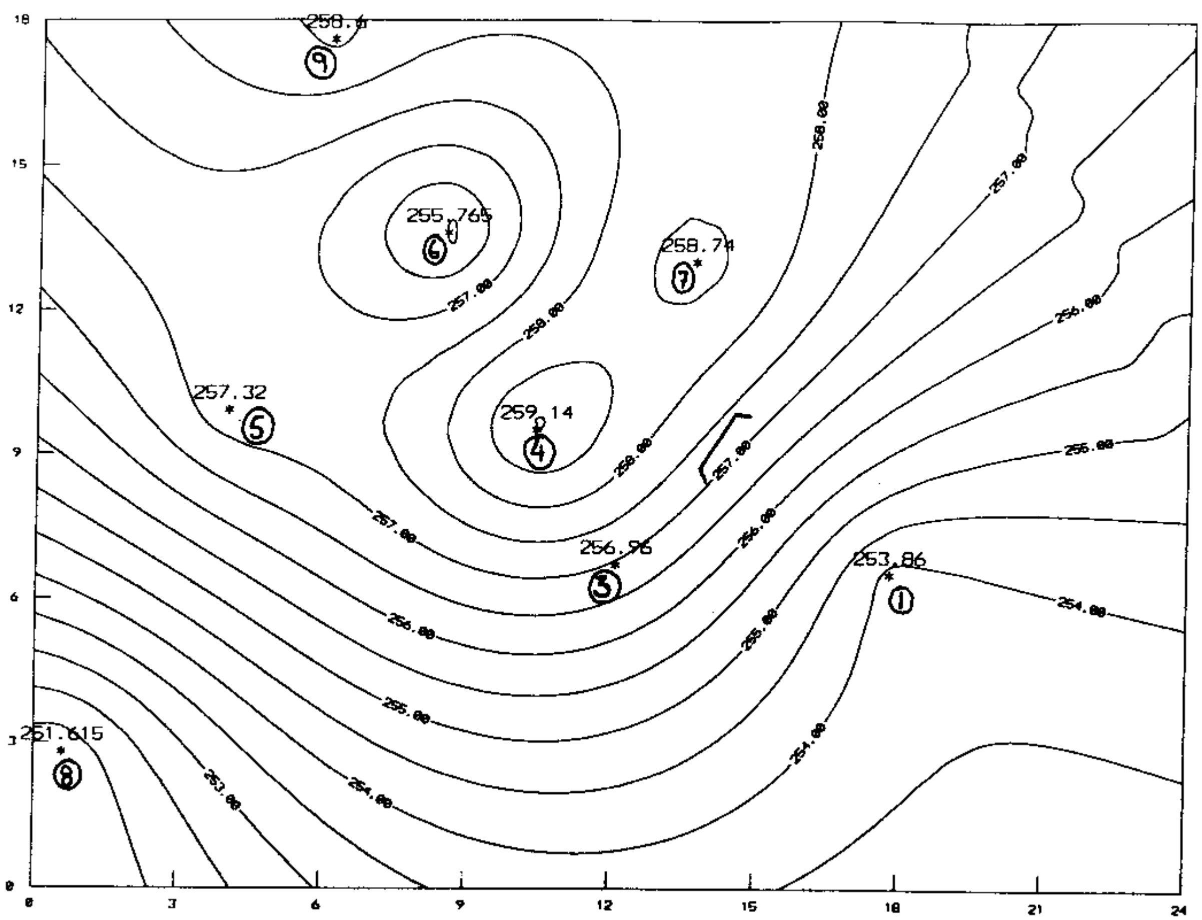
## APPENDIX 4

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 9.1.92



# APPENDIX 5

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 10.11.93




N

**SCALE**

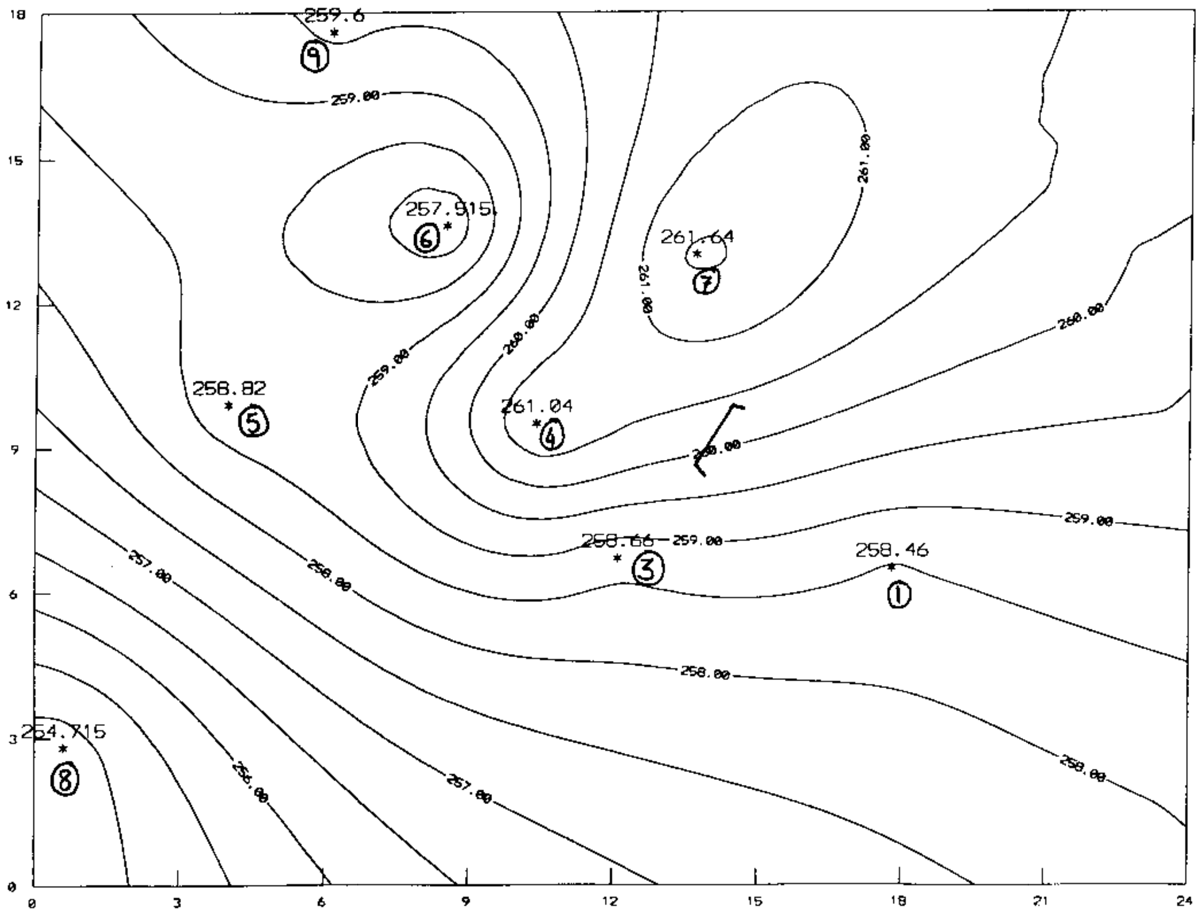
**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

# APPENDIX 6

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 23.11.93




N

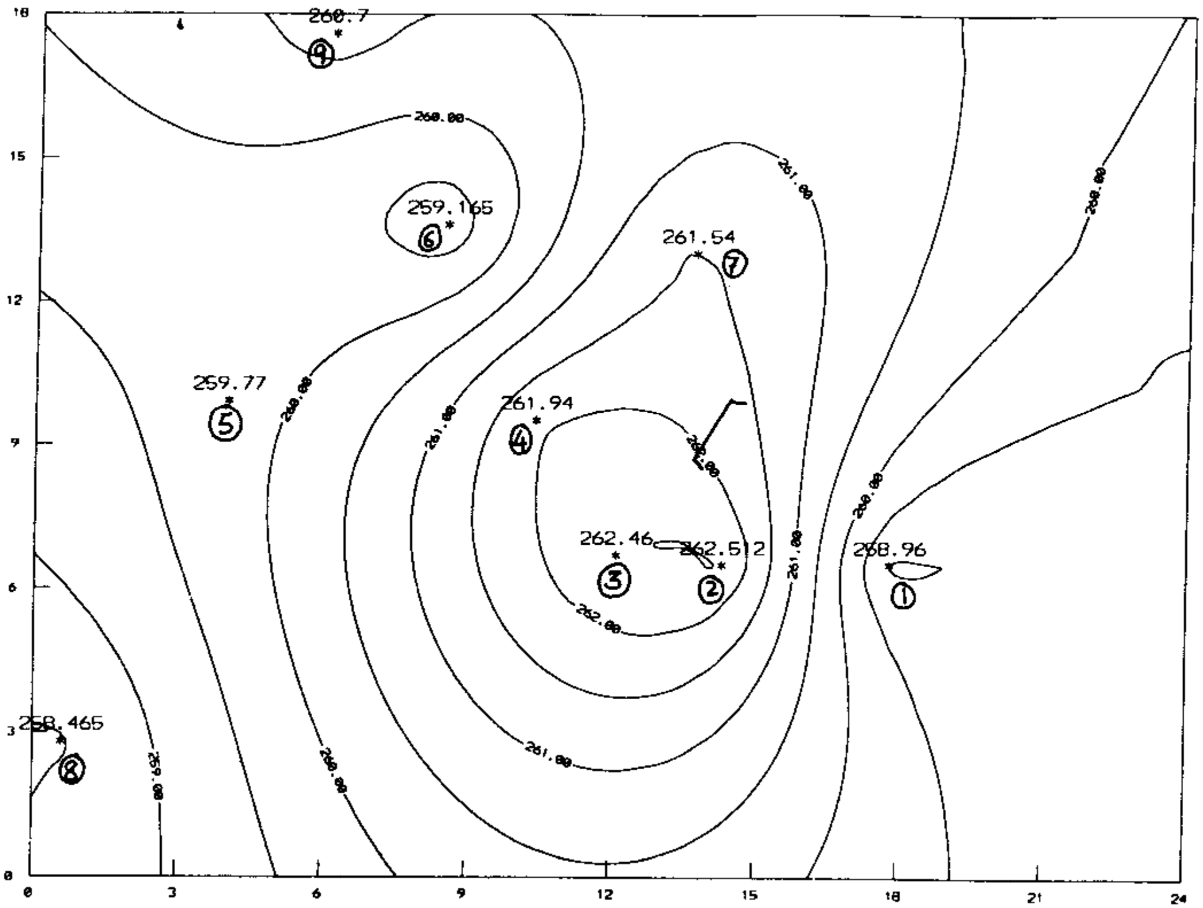
SCALE

1 CM = 105.60 M

LEGEND

| | |
|---|---|
| POND | |
| WELL NO. | * 6 |

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 23.12.93




**APPENDIX 7**

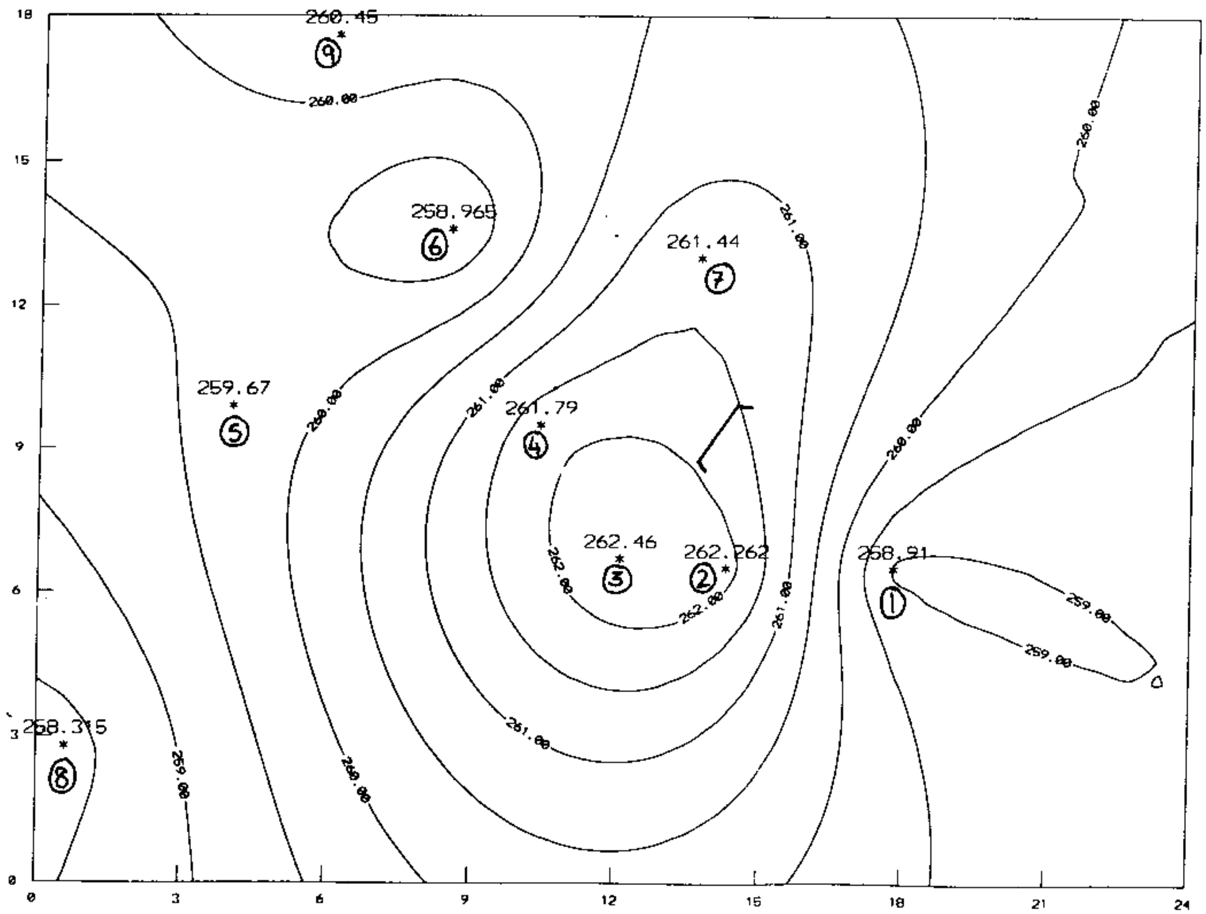

**SCALE**

**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND |  |
| WELL NO. | * ⑥ |

GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 10.1.94



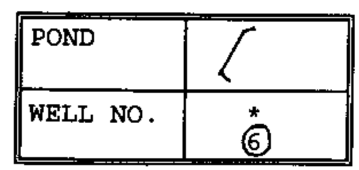

**APPENDIX 8**

N

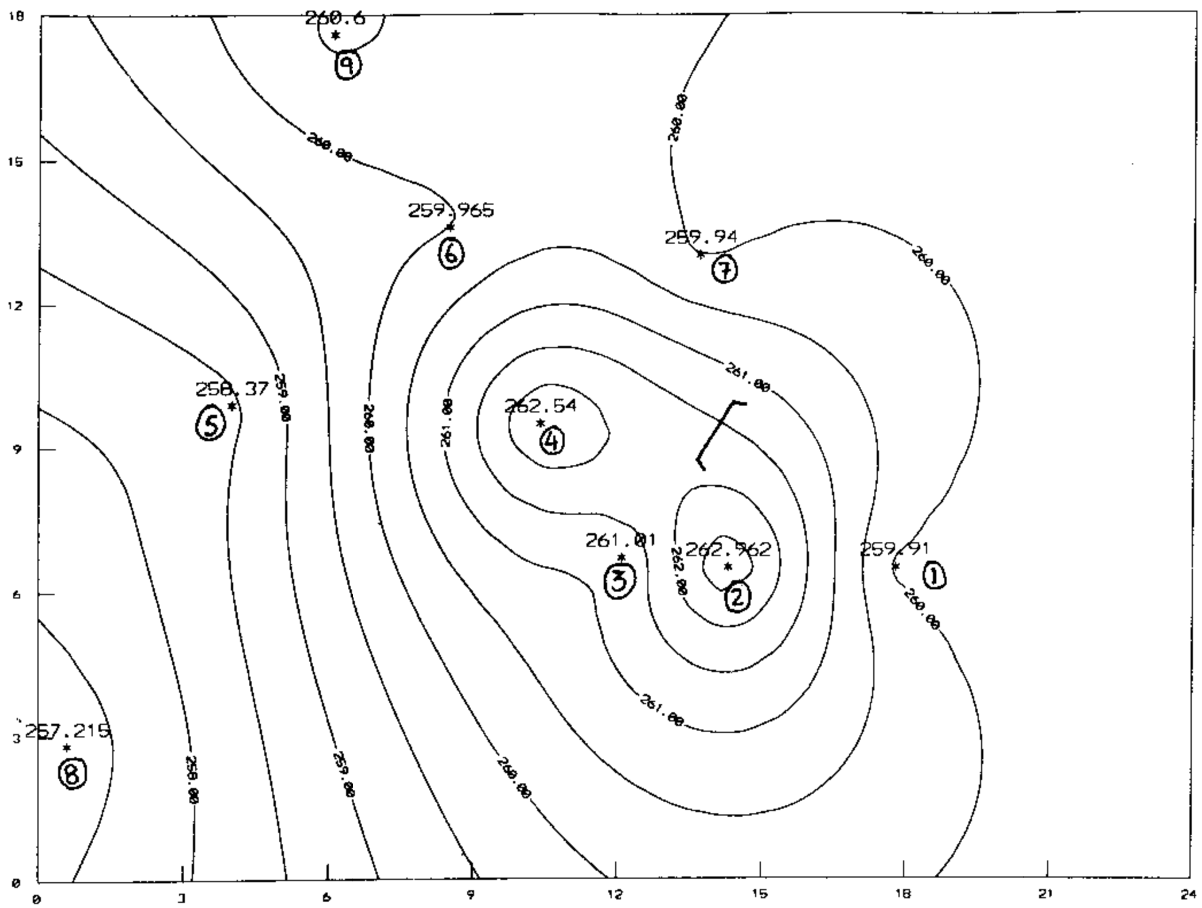
**SCALE**

**1 CM = 105.60 M**

**LEGEND**



GROUND WATER LEVEL CONTOURS FOR URALIPATTI PERCOLATION POND ON 24.1.94




**APPENDIX 9**

N

**SCALE**

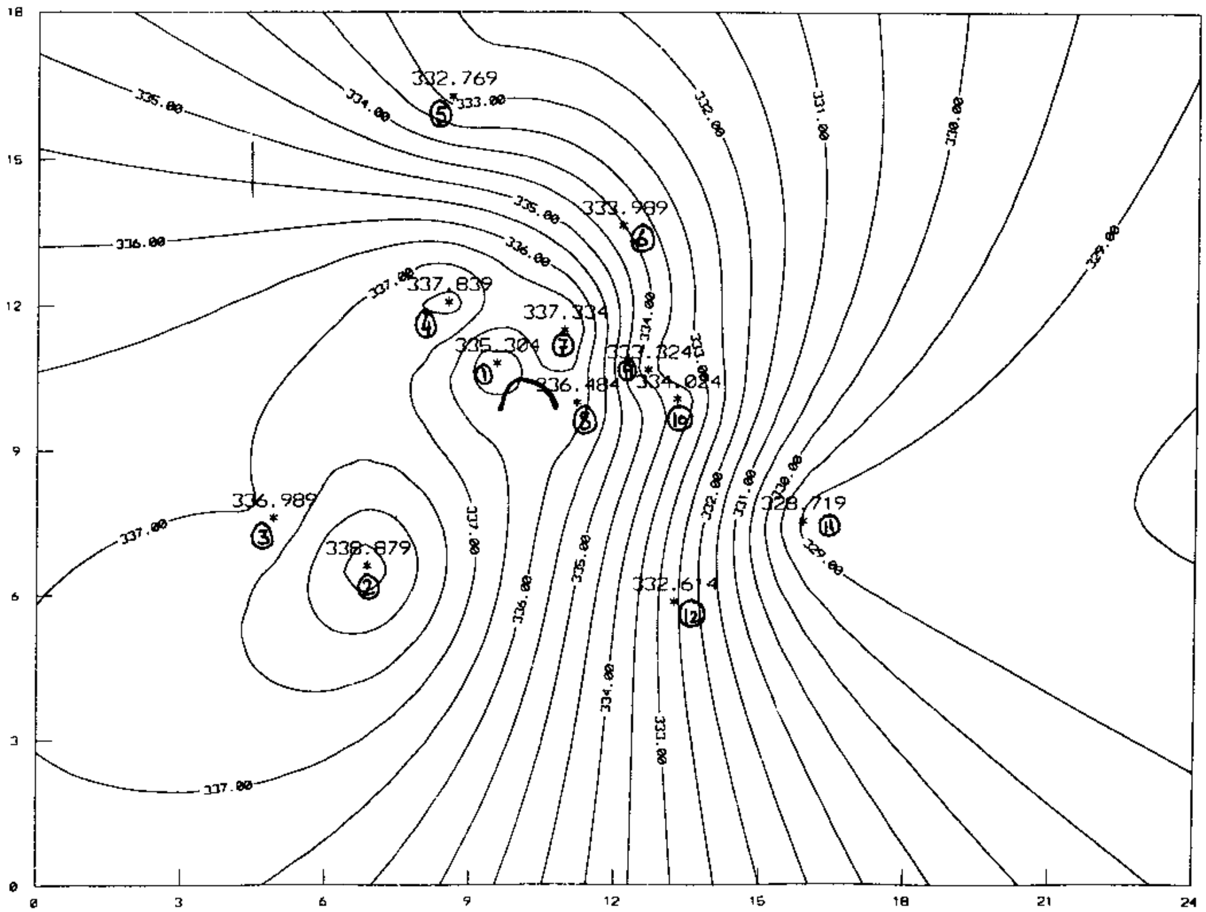
**1 CM = 105.60 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

# APPENDIX 10

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 24.1.90




N

SCALE

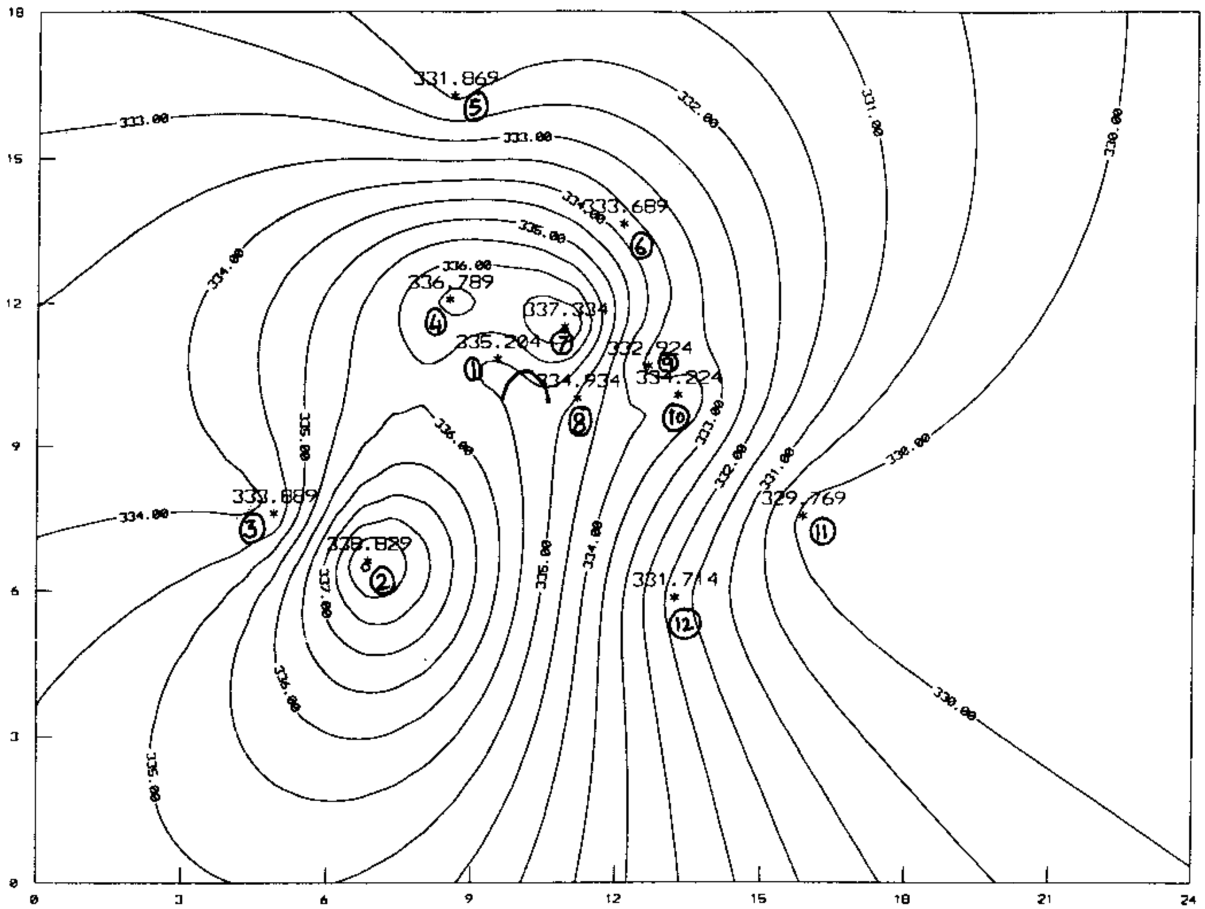
1 CM = 66 M

LEGEND

| | |
|---|---|
| POND | ∩ |
| WELL NO. | * ⑥ |

## APPENDIX 11

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 6.2.90




N

SCALE

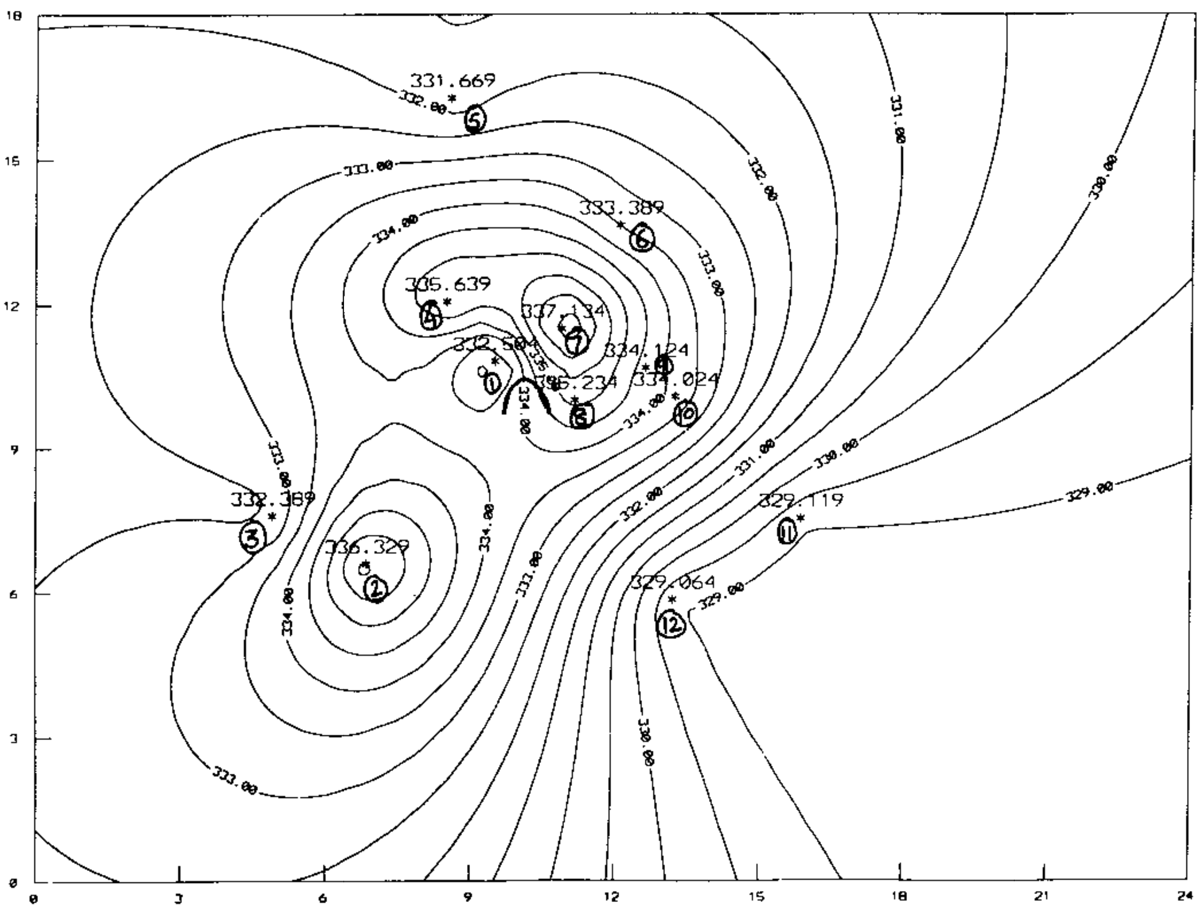
1 CM = 66 M

LEGEND

| | |
|---|---|
| POND | ∩ |
| WELL NO. | * ⑥ |

## APPENDIX 12

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 26.2.90





SCALE

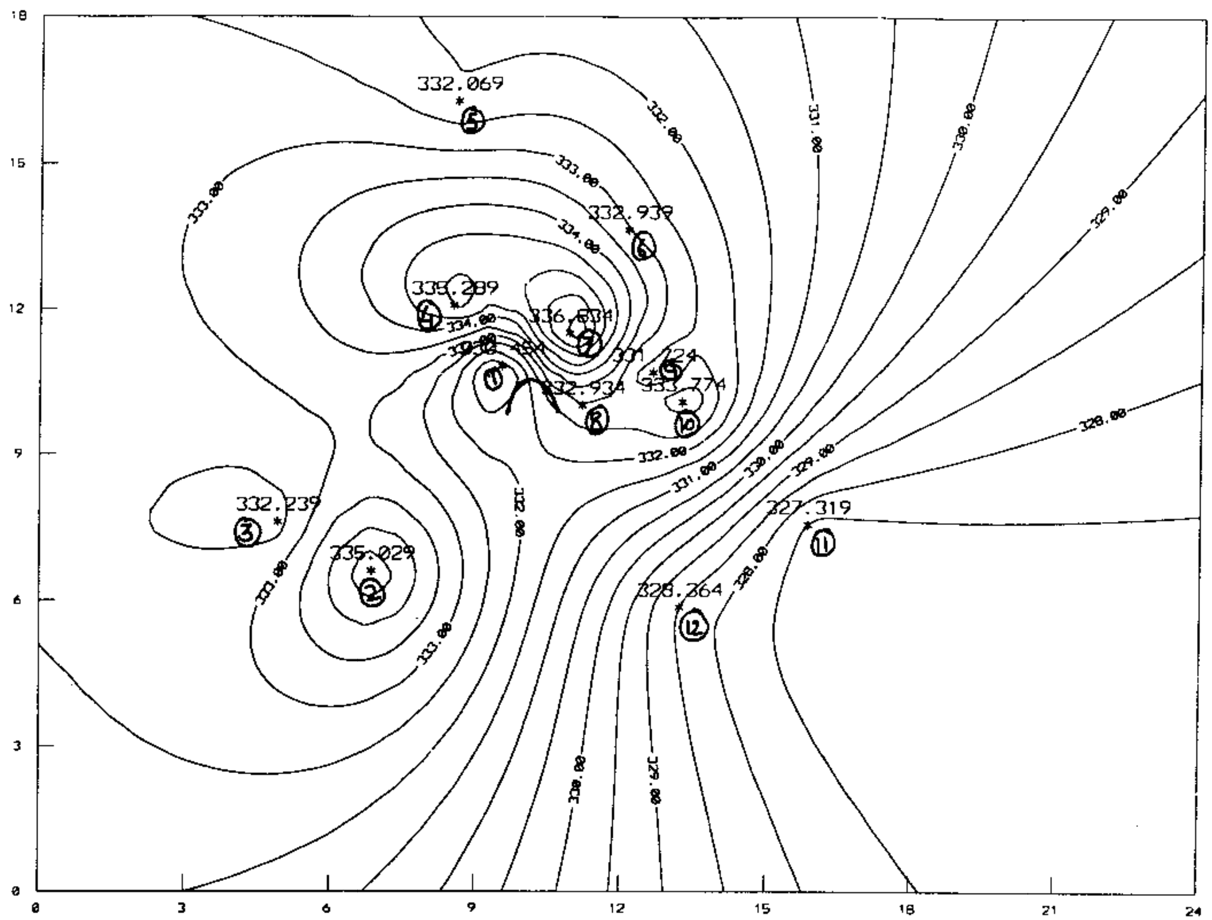
1 CM = 66 M

LEGEND

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

## APPENDIX 13

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 7.3.90




N

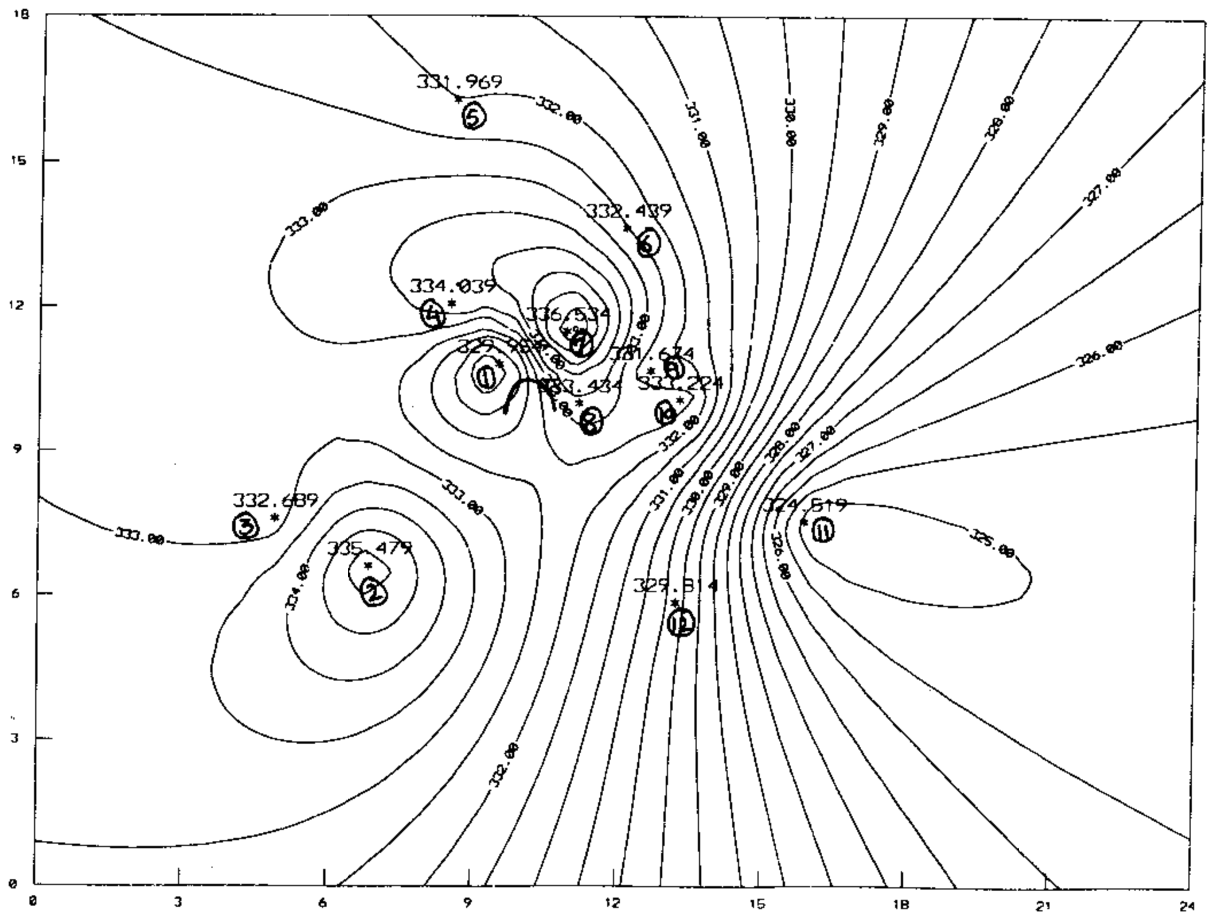
SCALE

1 CM = 66 M

LEGEND

| | |
|---|---|
| POND | ∩ |
| WELL NO. | * ⑥ |

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 21.3.90




**APPENDIX 14**

N

**SCALE**

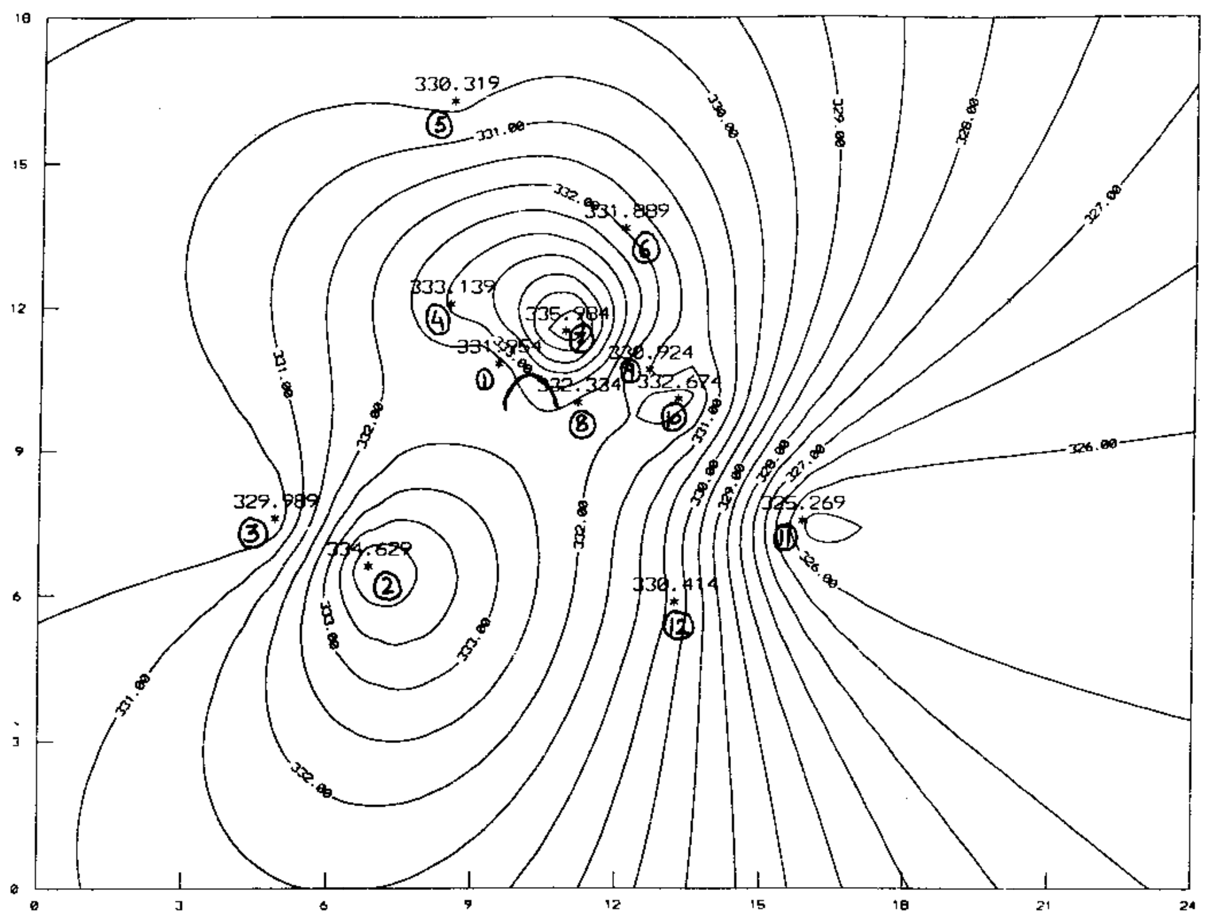
**1 CM = 66 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | * ⑥ |

APPENDIX 15

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 6.4.90




N

SCALE

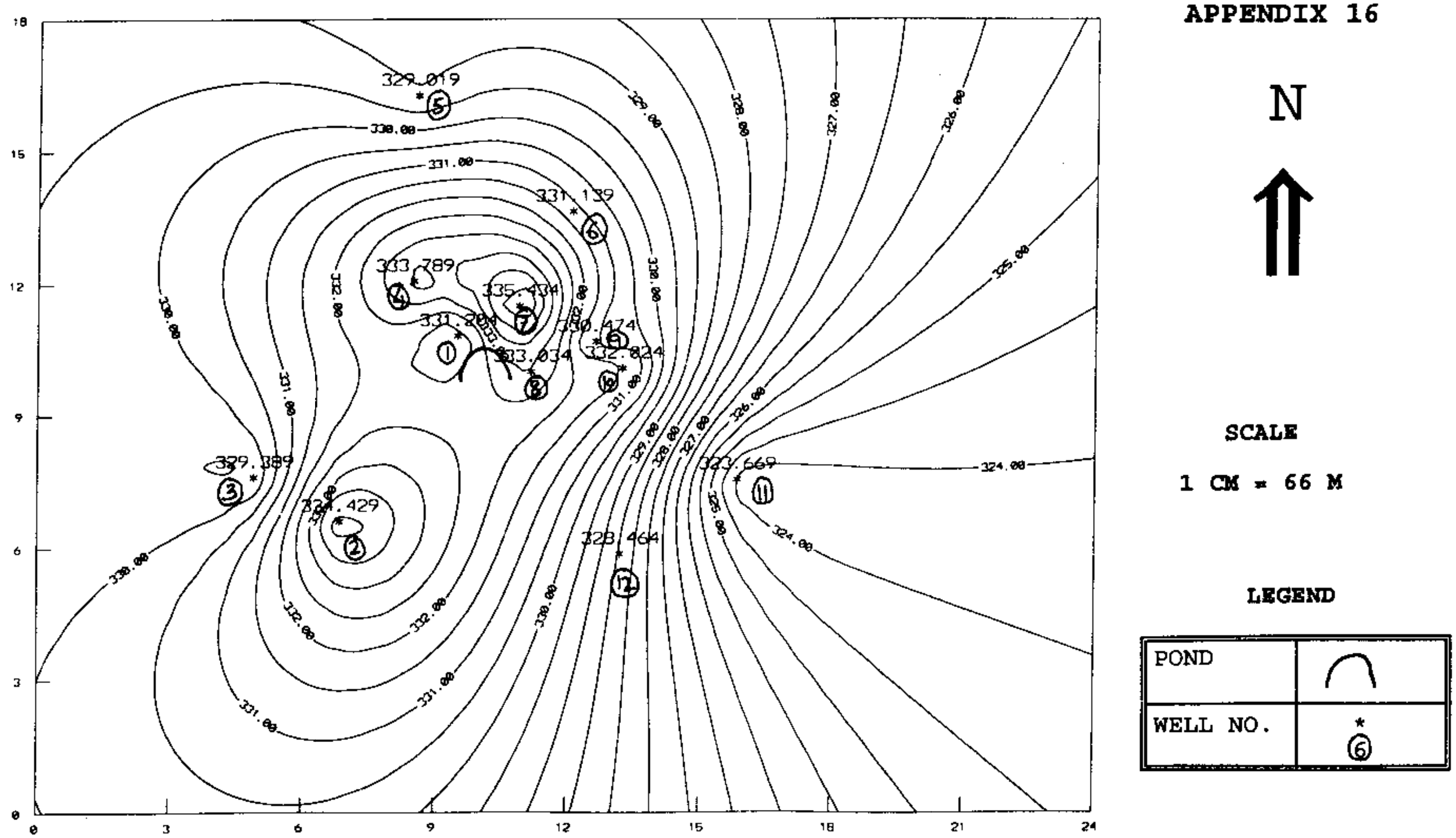
1 CM = 66 M

LEGEND

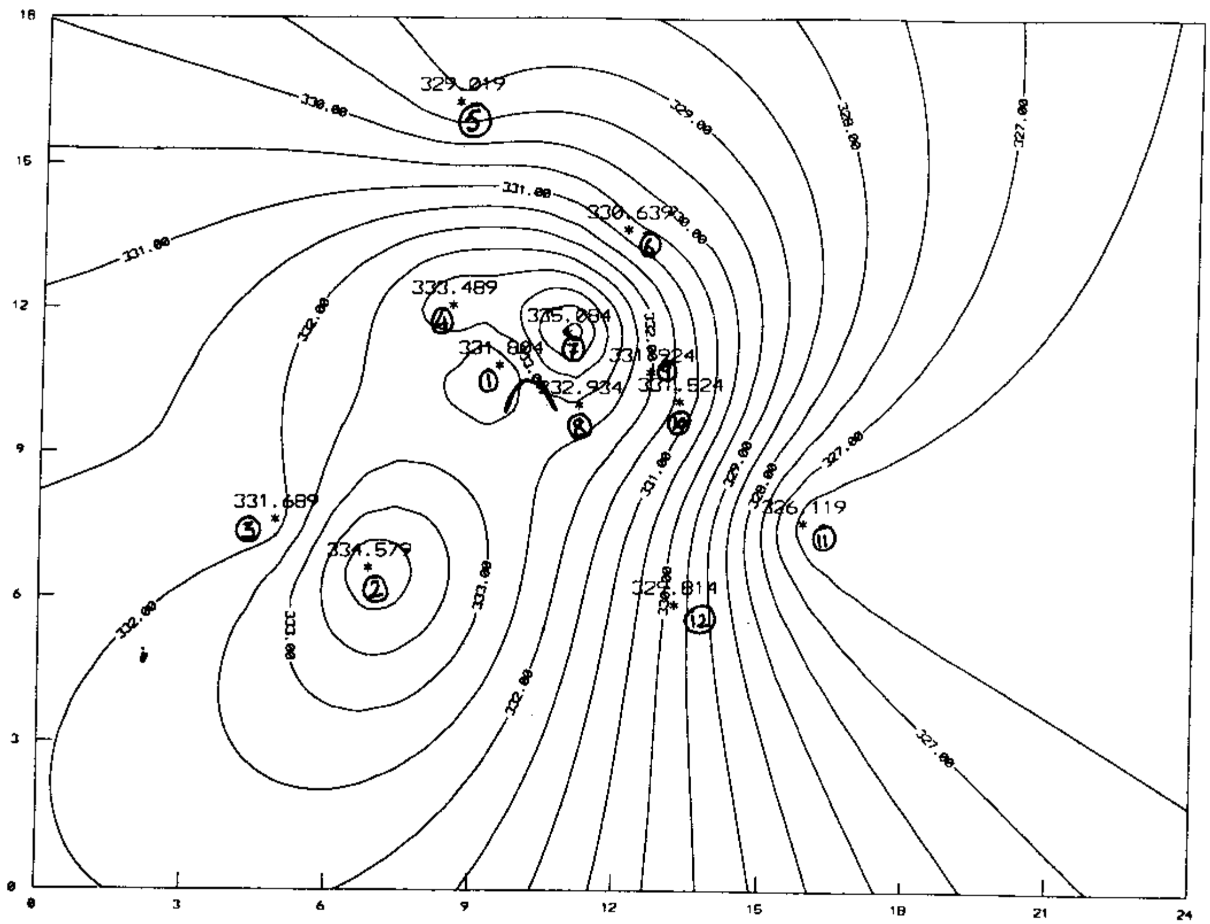
| | |
|---|---|
| POND | ⌒ |
| WELL NO. | * ⑥ |

## APPENDIX 16

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 24.4.90



GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 8.5.90




## APPENDIX 17

N

**SCALE**

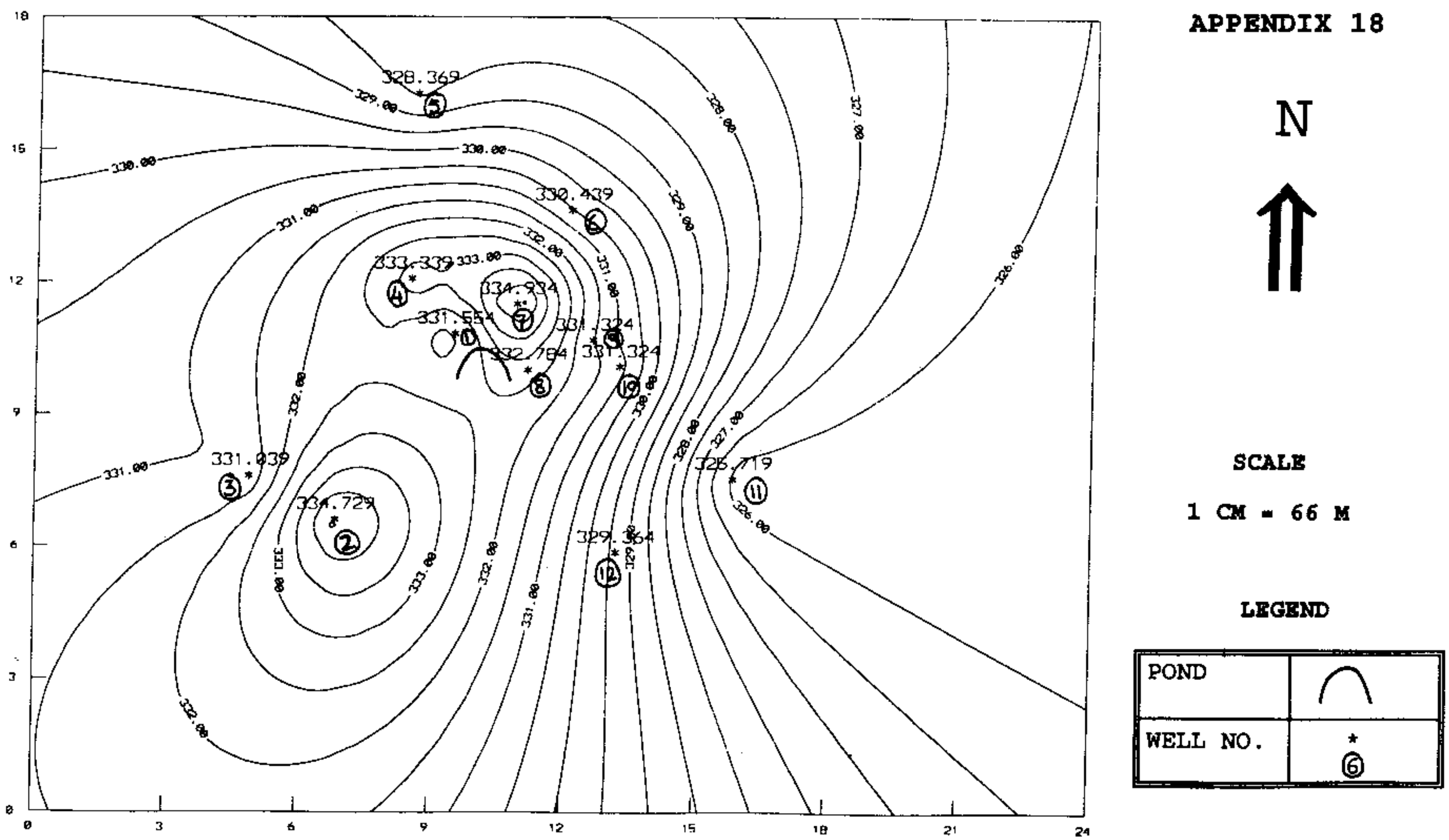
**1 CM = 66 M**

**LEGEND**

| | |
|---|---|
| POND | |
| WELL NO. | |

APPENDIX 18

GROUND WATER LEVEL CONTOURS FOR VIRALIPATTI PERCOLATION POND ON 23.5.90



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