PROJECT NUMBER A701101

EVALUATION OF SHALLOW GROUNDWATER REGIME AT ANMORE ESTATES

Prepared for

ANMORE DEVELOPMENT CORPORATION
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Project No. A701101

November 30, 1994

Anmore Development Corporation
840 Sperling Avenue
BURNABY, B.C. V5B 4H8

Attention: Mr. Brian Kask
President

Subject: **Evaluation of Shallow Groundwater Regime at Anmore Estates**

Dear Sirs:

Enclosed herewith is our report "Evaluation of Shallow Groundwater Regime at Anmore Estates".

We trust that the report is adequate for your present requirements; however, please do not hesitate to call for further discussion or clarification.

Yours truly,
PACIFIC HYDROLOGY CONSULTANTS LTD.

Ed Livingston

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EVALUATION OF SHALLOW GROUNDWATER REGIME AT ANMORE ESTATES

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1.0 INTRODUCTION

The receiving environment for domestic wastewater at Anmore Estates, as elsewhere, is the local groundwater regime. Thus, it is important to first outline the character of this regime before evaluating the impacts of adding water to the regime through ground disposal of wastewater. With respect to wastewater disposal, the issue is whether the zone of unsaturated flow is sufficient at the time of maximum groundwater recharge to provide the desired treatment of the wastewater before it reaches the water table and enters the active groundwater flow system with which it then travels. In the situation at Anmore Estates, where the water table is known to be shallow, of specific concern is how the shallow groundwater regime responds to intense winter storms.

The relationship between precipitation events and groundwater recharge is not straightforward because of a number of factors. In general, the rate of groundwater recharge decreases with the duration of the precipitation event. According to most published literature, there is a large decrease from the initial rate of recharge to an eventual constant rate. Many variables affect the infiltration or recharge to groundwater from precipitation events; the more important ones are:

1. topography - specifically, the slope of the ground surface and the presence or absence of depressions which can store water on surface;

2. surficial geology and, in particular, the character of the upper soil zone and vegetation that has developed on the soil;

3. groundwater hydrology;

4. climate - season of the year and, in particular, the timing and amount of precipitation preceding a precipitation event.

2.0 VARIABLES AFFECTING INFILTRATION AND GROUNDWATER RECHARGE

2.1 Topography and Surface Drainage

Lots 28, 29 and 30 of Anmore Estates are located on the north side of Hemlock Drive in an area with a gentle (about 7%) southeast-facing slope, at elevation about 180 metres above mean sea level (amsl), close to the height of land between the Anmore Valley and a creek which runs southward through the west end of Anmore Estates Subdivision. The actual height of land is located about 200 m northwest of Lot 28. There is an old open drainage ditch along the south side of the Hydro right-of-way that flows southward through Lot 30 and other Anmore Estates lots further east.

2.2 Surficial Geology, Soils and Vegetation

The surficial geology of the southern part of the Anmore Estates Property is straightforward: the area is underlain by glacial till on which a soil has formed over about 10,000 years since the till was deposited by the last glacial event. Since the elevation of the subject Property is about 180 metres amsl, the Property was not submerged at the end of the last major glaciation when sea level was over 100 metres above its present level. Thus, there is none of the glaciomarine silt which is widespread in the Lower Fraser Valley.

The till in the subject area is a typical grey, gravelly mountain till, with a matrix composed mostly of sand, with lesser amounts of silt and clay. The till includes stones ranging in size from small pebbles to very large boulders. Recent excavation for an house foundation on Lot 25(?) and digging of a drain on the west boundary of Lot 28, have provided more widespread exposures of the till. These show that the till is not as uniform as it appears in the scattered test pits and, in general, it appears to be more gravelly and more permeable than had been thought previously.

The brown sandy soil which has developed on the till underlying the Anmore Estates Property and surrounding area, seems to be quite uniform, with an average thickness of less than one metre. The contact between the brown granular subsoil and the unweathered till is very sharp in most places. In least disturbed places, the old dark organic forest soil can be seen overlying the brown subsoil. The origin of the very sharp contact is not known. An excavator operator reports that the top of the till below the contact is more compact than the two metres below the compact zone which is about 20 cm thick.

Until the Anmore Estates Property was logged for the first time, it was covered with a forest of very large fir and cedar trees and probably also some hemlock and spruce. Over much of the Property, the soil has been disturbed during logging and land-clearing operations. Some of the test holes show old disturbance, probably dating from the early land clearing. Further local disturbance occurred during the recent logging and also as a result of land clearing and road building which followed.

The north end of the lots is on a major B.C. Hydro power line right-of-way which was cleared at least ten years ago. The power line is now largely covered with a very dense growth of thimbleberry and salmonberry. There has been recent dumping of unwanted soil - probably from excavations on the right-of-way - particularly north and northeast of Lot 28.

2.3 Groundwater Hydrology

2.3.1 Natural Conditions

Shallow groundwater in or on top of the glacial till comes from precipitation on or immediately up-slope of the subject Lots 28, 29 and 30. There is very little chance of upward movement of groundwater from the underlying sandy till because the subject Property and surrounding area is in a groundwater recharge zone where the gradient is downward away from the land surface. In fact, as mentioned previously, the subject Lots are located very close to the height of land, which is under the power line a short distance to the northwest. The movement of shallow groundwater is downward through the soil, down through the till and eventually probably into fractures in the bedrock. During and following periods of heavy precipitation, particularly during the non-growing season, a saturated zone (water table) forms at the top of the till where there is a change in permeability from the permeable weathered soil zone to less permeable fresh till. This water continues to move down through the till but part of it is driven by gravity laterally down slope through the weathered zone. During a recent visit immediately following a period of very heavy precipitation, a large flow of groundwater was observed to be entering the recently excavated drain from a small patch of gravel located about 1½ m below surface at the northwest corner of Lot 28. This flow, which probably occurs only after intense precipitation events, is intercepted by the lot-boundary drains.

In some detailed studies of unsaturated groundwater flow, the hydraulic conductivity for unsaturated flow is determined for individual soils from data on soil suction determined in the field or, in some cases, in the laboratory. Depending on soil moisture, on the amount of clay in the soil, on compaction and on other factors, there are large differences in the unsaturated hydraulic conductivity of a particular soil. In any case, the hydraulic conductivity of the soil for unsaturated flow is much lower than that for the saturated condition. The large difference between saturated and unsaturated hydraulic conductivity is due to "matric forces" - the physical conditions at the contact between soil water and the grains of the soil. Matric forces vary with grain size and the mineral composition of the soil - in particular, the identity of the fine particles and the proportion of particles of the various clay minerals. Other factors, such as soil structure and water chemistry, may also be important in influencing the rate of infiltration of precipitation. Matric forces are responsible for the capillary fringe of saturation which exists above the water table.

The permeability of the undisturbed till is an important factor in determining the groundwater hydrology of the site. The hydraulic conductivity of the till is estimated to be in the range of 10^{-4} to 10^{-6} cm/sec. It is difficult to measure the hydraulic conductivity of an heterogeneous material such as till, so common practise is to estimate hydraulic conductivity from inspection of the till. The very sandy tills, such as are present on the Anmore Estates Property, are obviously much more permeable than the more common clay tills. The movement of water downward through the till is significant. For example, an house disposing of 1.3 m^3/day (250 ig/day) of effluent into a field with an area of 300 m^2 would represent a downward velocity of 4.3×10^{-6} cm/sec. Such a velocity is in the range of the hydraulic conductivity of 10^{-4} to 10^{-6} cm/sec of the sandy till present in the Anmore area, indicating that a disposal field can work without significant lateral flow. Such an hydraulic conductivity, estimated from inspection, is confirmed by sieve analyses carried out on samples of the weathered till and also the soil. It is important to note that the permeability of the sandy till characteristic of the Anmore area is much higher than that of more silty till present elsewhere in the Lower Fraser Valley.

In winter months, there is, of course, precipitation, which may average 1 cm/day for several days at a time. However, if water from an house and paved driveway is discharged to storm drainage, the water contributed by precipitation to groundwater on each developed Lot will be less than on the undeveloped lot. Precipitation of one centimetre per day on a 3,000 m^2 lot is about 30 m^2 (6,600 igal). Thus, the effluent flow is about 3.8% of the precipitation on the lot and about 38% of the precipitation on the disposal field.

One of the important characteristics of unsaturated flow, particularly in sandy loam soils, is the advance of a "saturation front" when the ground surface is saturated. The front advances downward at a sufficient rate to maintain saturation behind the front but it stops almost advancing when the surface is no longer saturated. We suggest that this phenomenon results in a sudden rise in the water table when the saturation front reaches the water table. The groundwater then moves downward at the rate determined by the saturated hydraulic conductivity, causing a rapid rise in the water table. The duration of the higher water table depends on the lateral hydraulic conductivity of the lower part of the soil and on the vertical hydraulic conductivity of the underlying sandy till.

The hydraulic conductivity of the underlying till is important in the behaviour of the water table. Its conductivity - probably in the range of 10^{-4} to 10^{-5} cm/sec (0.36 to 0.036 cm/hr) - is not high enough to have much effect on the short peak rises but it is important, however, in maintaining a low water table between rises when lateral flow is small due to the low groundwater gradient.

2.3.2 Altered Conditions

The hydrology of the subject Lots has been modified by the installation of the drains and more have been added recently, particularly a long deep drain along the north and west sides of Lot 28.

Water level data which were collected between November 1993 and April 1994 show that the groundwater level fluctuates as expected, with a rapid rise during and following intense precipitation followed by a rapid decline. These fluctuations can be considered the maximum that is likely to occur on the subject lots since:

1. There is no vegetation on the site; vegetation - in particular, lawns, would slow the rate of recharge and increase runoff.
2. If the Lots are developed, groundwater recharge will be significantly reduced because stormwater from building roofs and paved areas will be piped to the lot boundary drains.

A till with an hydraulic conductivity of 10^{-5} cm/sec can accept 8.64 mm of water per day. This is more than average winter rainfall if the precipitation (5 mm/day) is assumed to be 750 mm over 150 days during the season of groundwater recharge. In our opinion, downward movement of water into the till is the most important element in considering the groundwater hydrology at Anmore. An assumption of an impermeable till leads to far different conclusions. In fact, it suggests that an area with a gentle slope would become waterlogged in winter months; this is not the case. The extent of temporary saturation is indicated by colour mottling. In some of the test holes, as shown by the lithologs, there is well-developed mottling in the top few centimetres of the till and in the bottom few centimetres of the overlying subsoil. This mottling indicates that there are periods following precipitation in winter months when temporary conditions of saturation exist locally at the top of the unaltered till. In other places, there is no mottling at the contact, indicating the local nature of temporary saturation.

In view of the estimates of conditions when drains are present, it must be kept in mind that in winter months, before the original logging and after logging and eventual land clearing, the area was not waterlogged (water table approximately at surface). Further, there is no evidence of streams, either permanent or ephemeral in the immediate area, showing that downward movement of water into the till was able to deal with precipitation in the winter months with only minimum removal of water by evapotranspiration. This is not to say that the water table in winter months did not rise temporarily closer to surface than ½ m in parts of the area but it did not remain high for long periods or the natural vegetation would have been more characteristic of wetlands. The construction of storm drainage and other modifications decrease groundwater recharge and remove water from the saturated zone, more than making up for decreased evapotranspiration in winter months.

Based on knowledge of site conditions and expected behaviour of wastewater after it enters the disposal fields, there is no chance that water from the disposal fields on the subject Lots will reach ground surface before reaching the subsurface drains at the lot boundaries. In other words, there will be no "breakout".

Certain measures can be carried out in conjunction with the construction of a disposal field to further improve the situation. One of these is to decrease groundwater recharge from precipitation by increasing runoff. This can be done by installation of a low permeability (or impermeable) cover near surface on part of the lot, preferably on the area downslope from the disposal field. This would increase the groundwater gradient under the field, thus reducing and shortening the periods of groundwater water rise caused by precipitation events.

2.4 Climate and Precipitation Events

Much of the literature dealing with groundwater recharge is concerned with surface runoff and not with the position of the water table. Another area of the literature is concerned with subsurface drainage for maintaining a water level favourable for crops under conditions of either natural precipitation or irrigation. In such studies, the concern is longer term average high water tables and not the maximum peaks in water levels over one or two days, as is the case with wastewater disposal on the subject Anmore Estates Lots.

The water level hydrograph, in which distance to water below ground is plotted versus time, is a standard visual method used to show the relation between precipitation and the response of the water table to precipitation. Water level hydrographs from monitoring wells installed on Lots 28, 29 and 30, along with plots of daily precipitation, show how complex and how variable conditions can be, even within a very small area. Figures 2, 3 and 4 in Appendix B (Pages B - 1, B - 2 and B - 3) are hydrographs of water levels in monitoring wells on respective Lots 28, 29 and 30 for the period November 11, 1993 to March 15, 1994. Figures 5 and 6 (Page B - 4) are three-day and five-day total precipitation distribution for the nearby Ioco Refinery Meteorological Station, with Figure 7 (Page B - 5) a plot of total precipitation. Figure 8 (Page B - 6) is an expanded plot of total precipitation at Ioco Refinery from March to May 1993; Figure 9, a plot of the water level in the monitoring well on Lot 28, is contained directly below the expanded plot of total precipitation for the same period; note that these water level data were collected in a former monitoring well on Lot 28.

3.0 ANALYSIS OF THE BEHAVIOUR OF SHALLOW GROUNDWATER IN RESPONSE TO PRECIPITATION EVENTS AT ANMORE ESTATES

The complex situation described above is not well adapted to modelling. It is possible, however, by using equations which have been developed to deal with certain land drainage problems, to estimate the lateral hydraulic conductivity of the lower soil zone. Since reliable data are available from several episodes of rises and rapid declines of the water level in monitoring wells installed on Anmore Estates Lots 28, 29 and 30, and, since the rapid decline is due mostly to lateral flow to drains, it is possible to determine a range of lateral hydraulic conductivity by using one of the dynamic drain spacing equations. The most workable equation seems to be the one used by the U.S. Bureau of Reclamation for drains resting on an impermeable barrier. In using this method, the permeability of the underlying till is ignored as is the 7% slope of the land since the published literature is all in agreement that a slope less than 10% can be ignored for most calculations.

The U.S. Bureau of Reclamation Method for analysis of drain spacing is described in **Seepage and Groundwater** (Miguel A. Marino and James N. Luthin, 1982, published by Elsevier); the graphical solution of this method is attached to this memorandum as Figure 1 in Appendix A. As shown, the method is based on a simple situation:

- two parallel drains are located on an impermeable base;
- the distance between drains as **L**;
- the initial water table midway between the drains is at height **H** and it declines to height **Z** in time **t**.

As shown on Figure 1, the method uses a plot of Z/H vs HKt/SL^2 where Z, H, t and L are as above and

K = hydraulic conductivity in the flow zone;

S = specific yield in the water table zone.

Table 1 below was prepared for Anmore Estates Lot 28 to show a range of values for **K**, which is the unknown and is critical in the operation of the actual situation.

Table 1. U.S. Bureau of Reclamation Dynamic Drainage Method for Lot 28 of Anmore Estates

L (m)	S	t (days)	H (m)	Z (m)	L^2 (m^2)	Z/H	KHt/SL^2	K (Hydraulic Conductivity) (m/day)	(cm/sec)	(m/hr)
100	0.2	2	0.8	0.3	10^4	0.38	0.32	400	0.460	17.0
100	0.2	3	0.8	0.3	10^4	0.38	0.32	267	0.310	11.0
50	0.2	2	0.8	0.3	2500	0.38	0.32	100	0.120	4.3
50	0.2	3	0.8	0.3	2500	0.38	0.32	67	0.077	2.8
100	0.1	2	0.8	0.3	10^4	0.38	0.32	200	0.230	8.3
50	0.1	2	0.8	0.3	2500	0.38	0.32	50	0.060	2.2
50	0.1	3	0.8	0.3	2500	0.38	0.32	33	0.038	1.4
100	0.2	4	0.8	0.3	10^4	0.38	0.32	200	0.230	8.3
50	0.2	4	0.8	0.3	2500	0.38	0.32	50	0.060	2.2
50	0.1	4	0.8	0.3	2500	0.38	0.32	100	0.120	4.3

Obviously, because of the irregular shape of the lots, the drains in the situation under consideration are not parallel; however, this is not a significant parameter with respect to analyzing the relationship between precipitation and groundwater table rise, as shown by the observed behaviour of the water table in the monitoring wells on the subject Anmore Estates lots. The data collected for the monitoring wells on Anmore Estates Lots 28, 29 and 30 are the decline of the water table **H-Z** in time **t**.

The values for the parameters in the table include values estimated from actual data namely, H, Z and T. **S**, the specific yield of the soil above the water table probably lies in the range 0.1 to 0.2 although for many sediments the value may be above 0.2, as shown by pump testing of wells. The table shows, as expected, that for given soil conditions, the distance to a drain is very important in shortening the length of periods of groundwater rise.

4.0 CONCLUSIONS

The range of hydraulic conductivities obtained by application of the U.S. Bureau of Reclamation Dynamic Drainage Method, and which are contained in Table 1 on the previous Page 7, is realistic but seems to be a little larger than expected. Infiltration into the underlying till, along with the 7% slope would tend to make the estimate too high; however, the important point is that the values are in the right order of magnitude and show that the drainage system is able to deal with the maximum rainfall events of the 1993-1994 winter season.

Obviously, maximum precipitation events with a five-year return period at Anmore are larger than those of the current season. This raises the question of what is likely to happen when larger storms occur. We believe that larger storms, under conditions of residential development, are not likely to cause water table rises significantly higher than those already recorded because proper landscaping and a grass cover on most of the lot area will result in increased surface runoff - especially for long events of, say, three (3) days or longer. The following are reasons for drawing this conclusion:

1. Precipitation falling on roofs and paved areas will not be available for recharge.

2. Proper landscaping and a grass cover on most of the lot area will result in increased surface runoff - especially for long events of, say, three (3) days or longer.

3. Grass cover will decrease the very rapid initial recharge, thus lowering the high peaks in the water level hydrograph.

As pointed out previously, groundwater recharge even under the favourable conditions on the undeveloped lots is not 100% of the precipitation during a storm event because of runoff and other factors. Further, all of the literature on the subject states that the proportion of precipitation recharging groundwater decreases with the length of the event. With this in mind, we suggest that the an assumed worst case could be to assume that 100 mm of precipitation is recharged instantly to the water table to cause a sudden rise in the water table followed by lateral groundwater flow along the top of the less permeable underlying till.

These assumptions are quite beyond what is likely to occur. This is shown by the precipitation intensity data from the Ioco meteorological station, based on 65 years of records; these data are summarized in Table 2 below.

Table 2. Precipitation Intensity at Ioco Meterological Station

Period of storm event	1 day	2 days	3 days
5-year return period	99.2 mm	148 mm	180.5 mm
10-year return period	111.4 mm	169.5 mm	207.3 mm

Recharge is never 100% of precipitation and the proportion of precipitation recharging groundwater decreases with the length of the event. Thus, the proportion of recharge on the second day is less than the first, the third day less than the second, etc.

Previous calculations based on observation data using the US Bureau of Reclamation transient drainage method gave values of lateral hydraulic conductivity in the range 100 to 300 m/day. This is quite a narrow range considering that hydraulic conductivity of granular sediments can vary by several orders of magnitude. The coefficient of storage is assumed to be 0.20 which is the value for permeable sediments. Thus, the rise in the water table from the instant infiltration of 100 mm of precipitation would be 0.5 m. Assuming that the water table before the event was 0.15 m above the till, the starting position of the water table would be 0.65 m above the till. The assumption of an initial zone of saturation of 0.15 m is not unreasonable. Assuming an hydraulic conductivity of 200 m/day and the slope of 0.06, the saturated zone could conduct a flow of 1.8 m^3/day/m width which is equivalent to 30 mm of recharge over a strip 60 m in length.

The decline of the water table has then been calculated over one and two day periods as presented in Table 3 below.

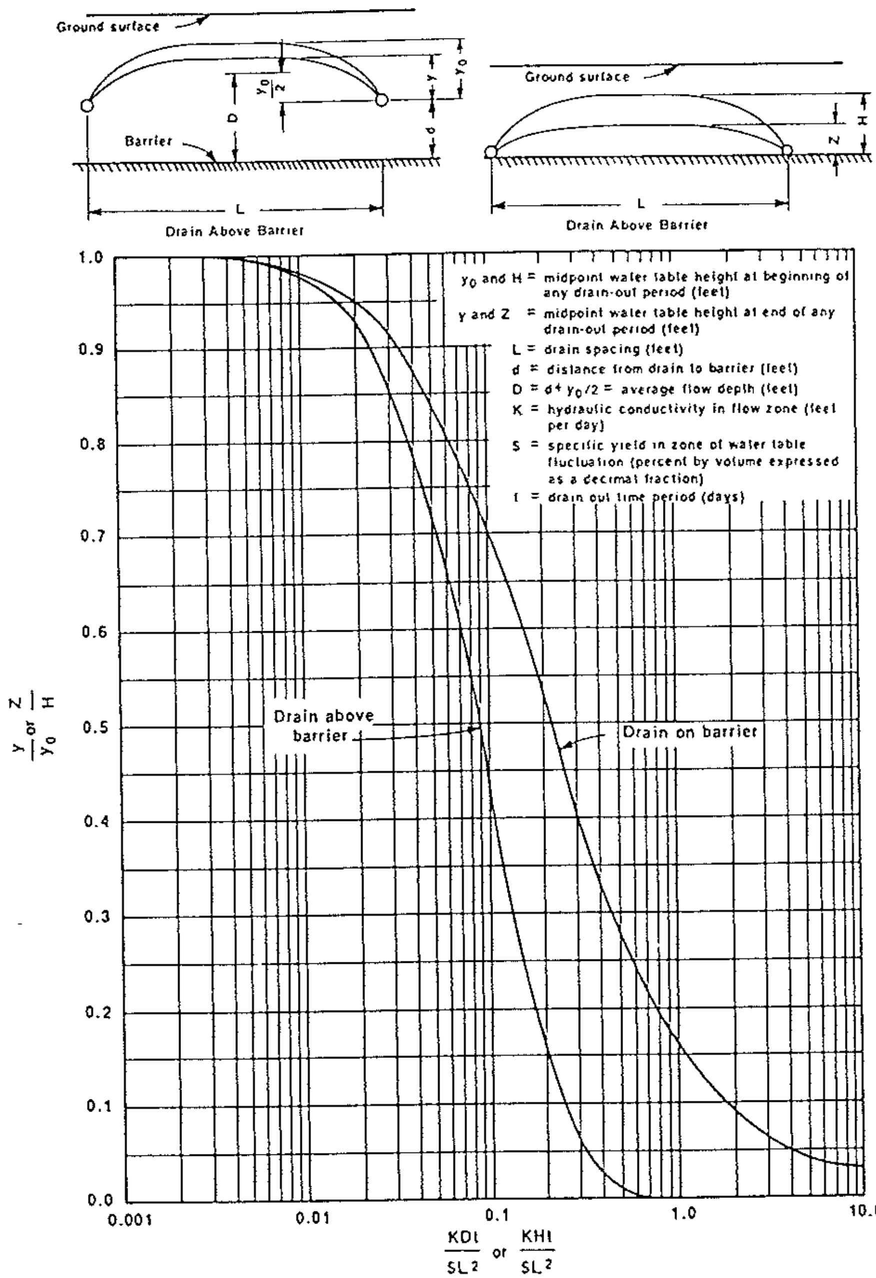
Table 3. Water Level Decline Following Instant Recharge of 100 mm of Precipitation

t (days)	k (m/day)	$\frac{KHt}{SL^2}$	$\frac{Z}{H}$	Z (m)	Decline water level (m)	Equivalent Recharge (mm)
1	100	0.09	0.73	0.47	0.18	36
2	100	0.18	0.57	0.35	0.30	60
1	200	0.18	0.57	0.35	0.30	60
2	200	0.36	0.36	0.23	0.42	81
1	300	0.27	0.44	0.29	0.36	72
2	300	0.54	0.26	0.17	0.48	96

The table shows that the water table declines quite rapidly the first day and less so the second day as expected. The last column shows the amount of recharge from precipitation which is equivalent to the decline. For instance, the decline during the first day, assuming an hydraulic conductivity of 200 m/day, would be equivalent to 60 mm, indicating that a two day event producing 160 mm of recharge precipitation would not result in a very shallow water table.

APPENDIX A

DETAILS ABOUT U.S. BUREAU OF RECLAMATION DRAIN SPACING ANALYSIS



Notes:

1. The United States Bureau of Reclamation Method for drain spacing is described on Pages 126, 127 and 128 of **Seepage and Groundwater** by Miguel A. Marino and James N. Luthin, 1982, published by Elsevier; the graphical solution above is Figure 6.6 on Page 127.
2. As noted by Marino and Luthin, the Bureau of Reclamation Procedure is based upon "the dynamic equilibrium concept" in which similar annual recharge and discharge result in a range of cyclic fluctuations which is "reasonably constant".

PROJECT NO.: A701101	**PACIFIC HYDROLOGY CONSULTANTS LTD.** CONSULTING HYDROGEOLOGISTS
PROJECT: **ANMORE ESTATES**	**UNITED STATES BUREAU OF RECLAMATION METHOD FOR DESIGNING DRAIN SPACING**

DATE:	DRAWN BY:	FIGURE:
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APPENDIX B

WATER LEVEL HYDROGRAPHS AND PRECIPITATION DATA

Figure 2. Hydrograph of Water Levels in Monitoring Wells on Lot 28 of Anmore Estates

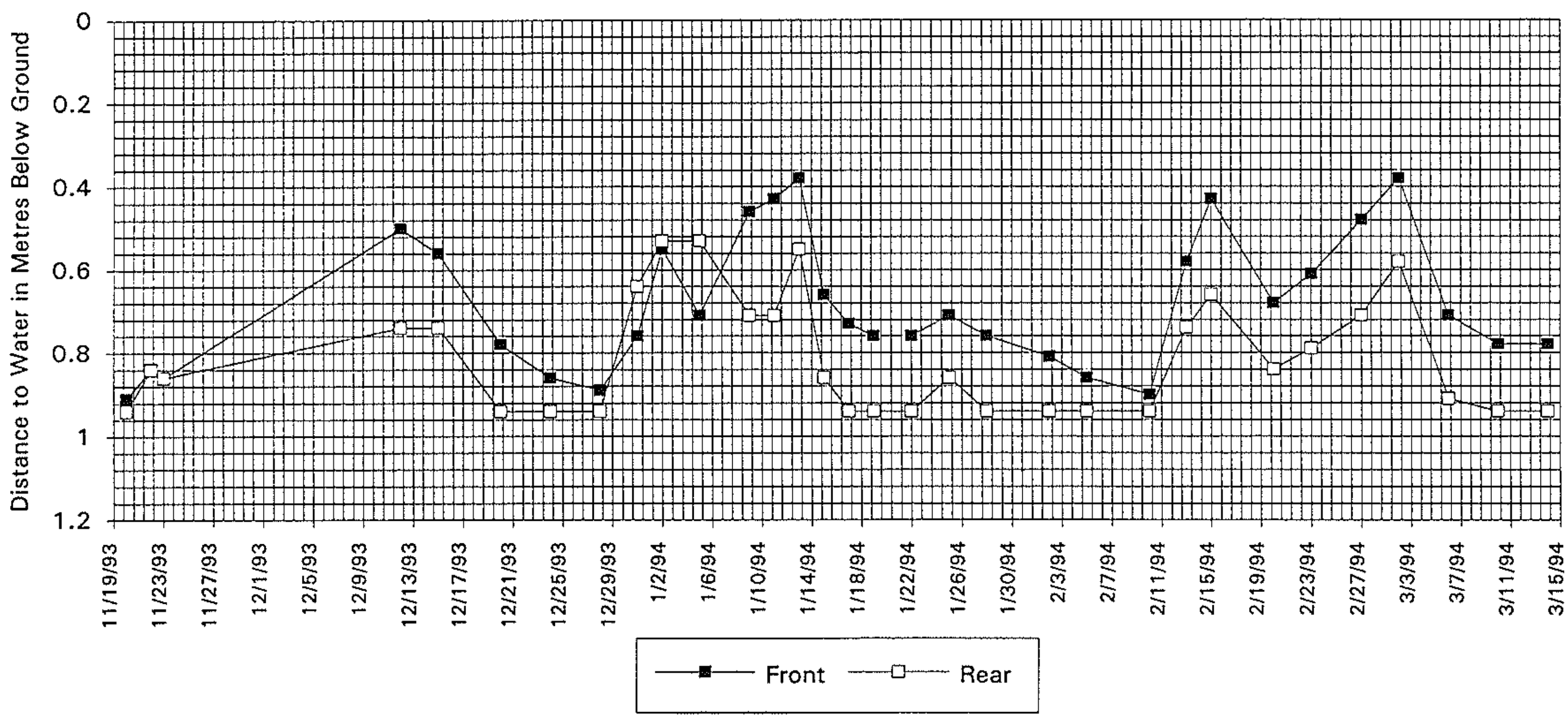

Figure 3. Hydrograph of Water Levels in Monitoring Wells on Lot 29 of Anmore Estates

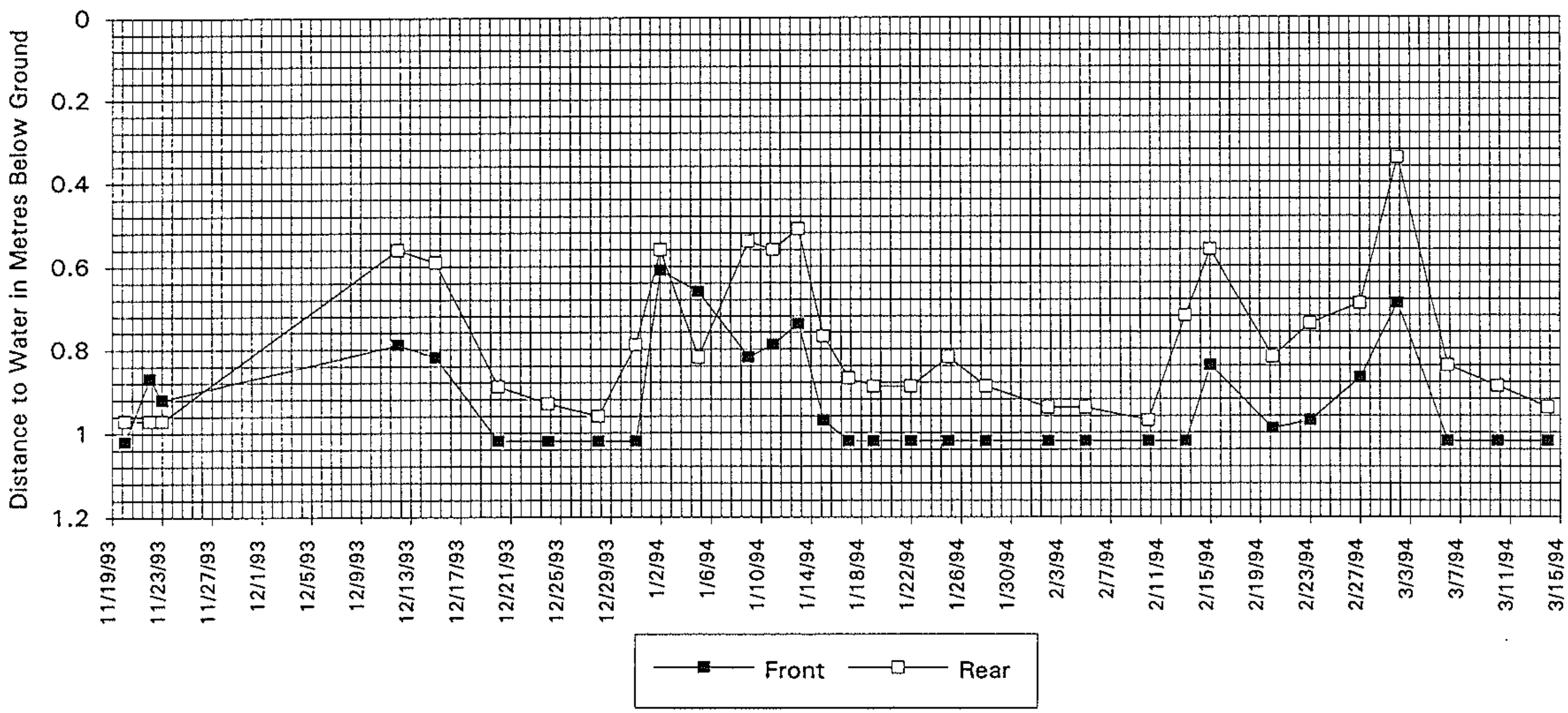

Figure 4. Hydrograph of Water Levels in Monitoring Wells on Lot 30 of Anmore Estates

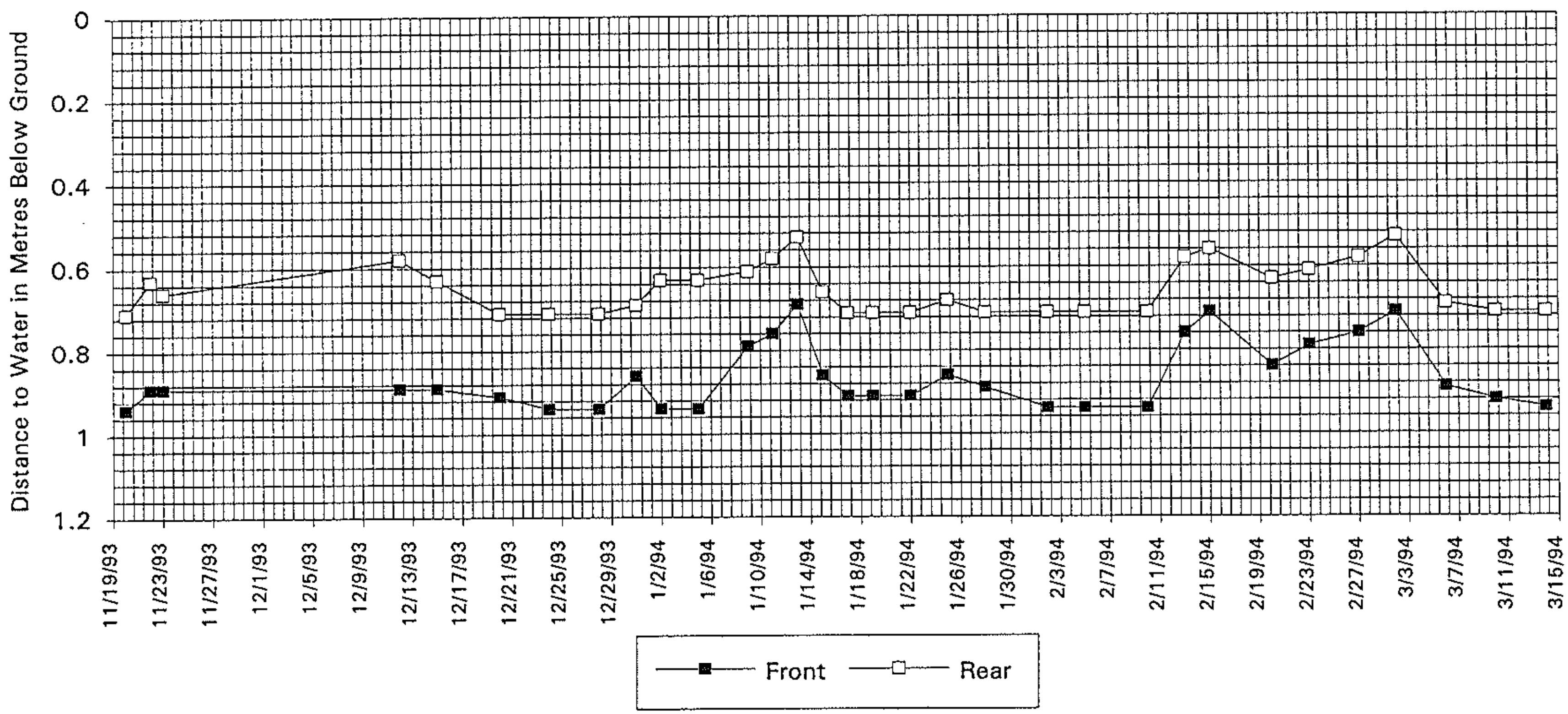

Figure 5. Three-Day Total Precipitation at Ioco Refinery

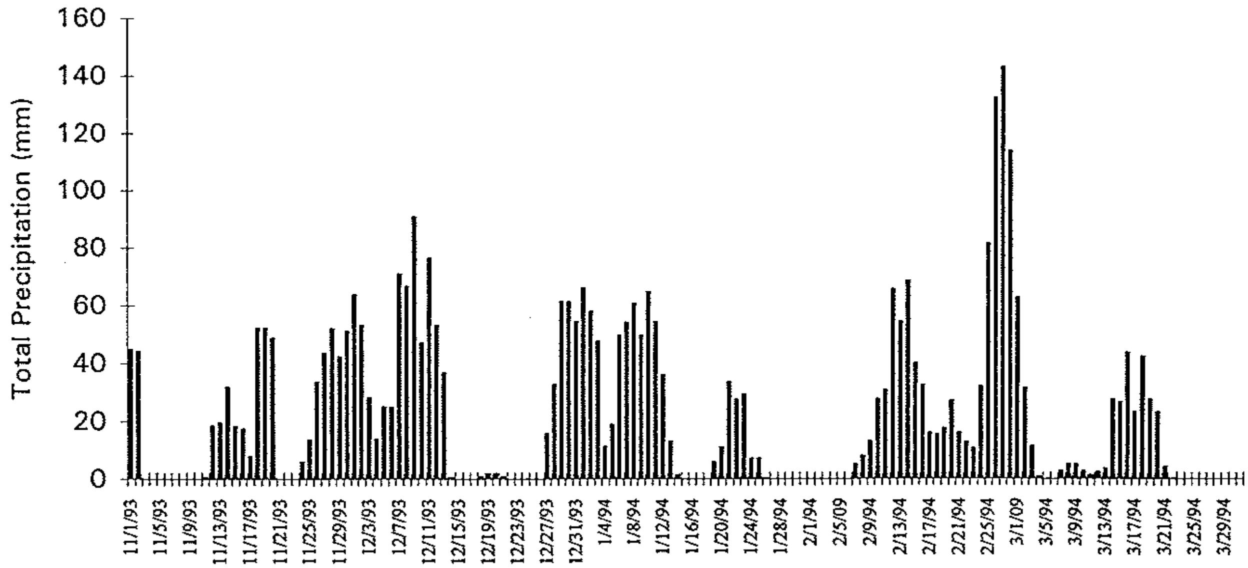

Figure 6. Five-Day Total Precipitation at Ioco Refinery

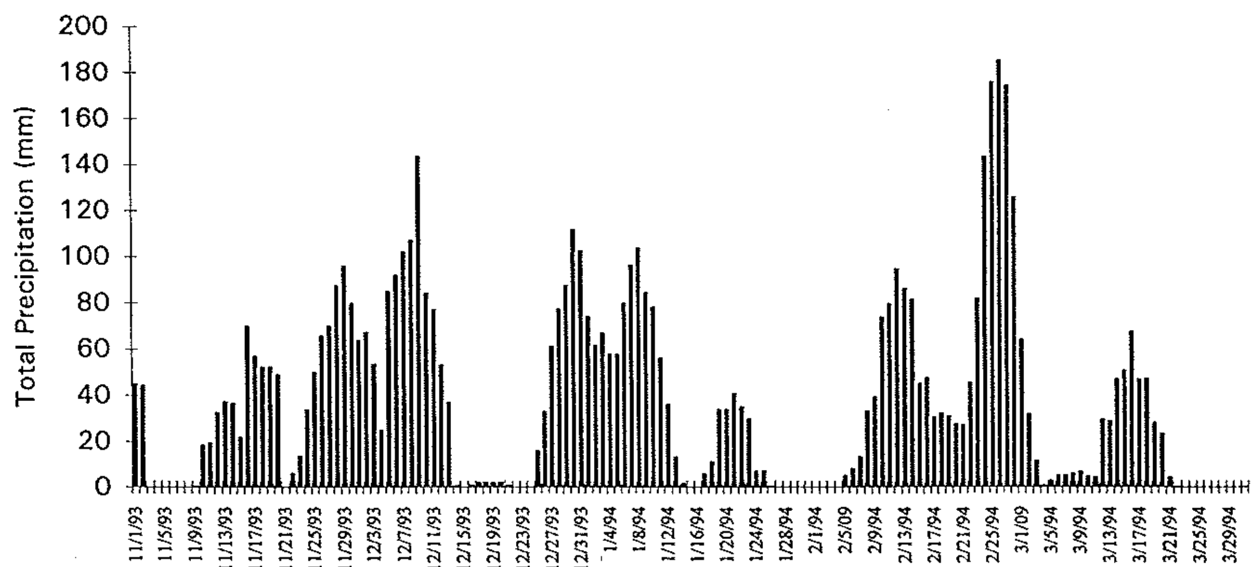

Figure 7. Total Precipitation at Ioco Refinery from November 1993 to April 1994

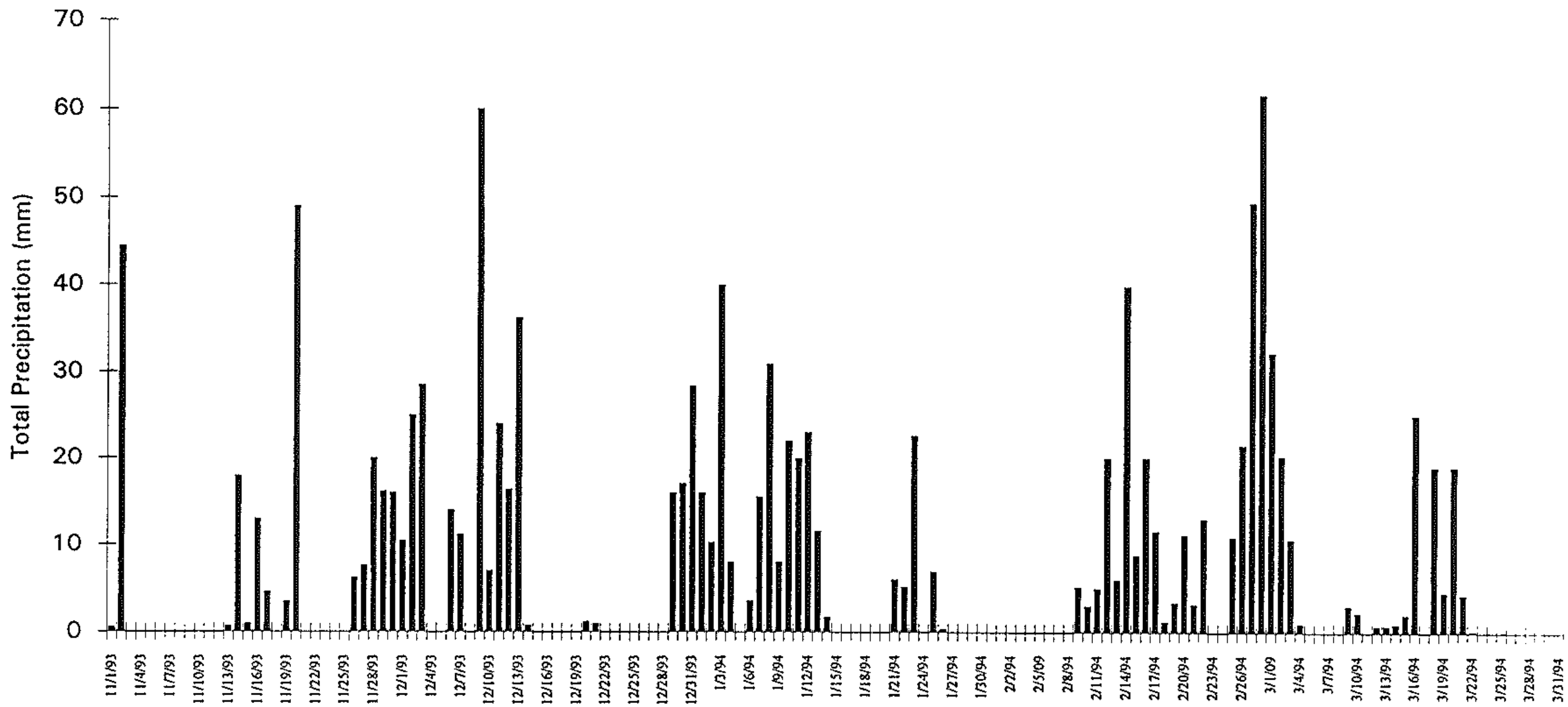

Figure 8. Total Precipitation at Ioco Refinery from March to May 1993

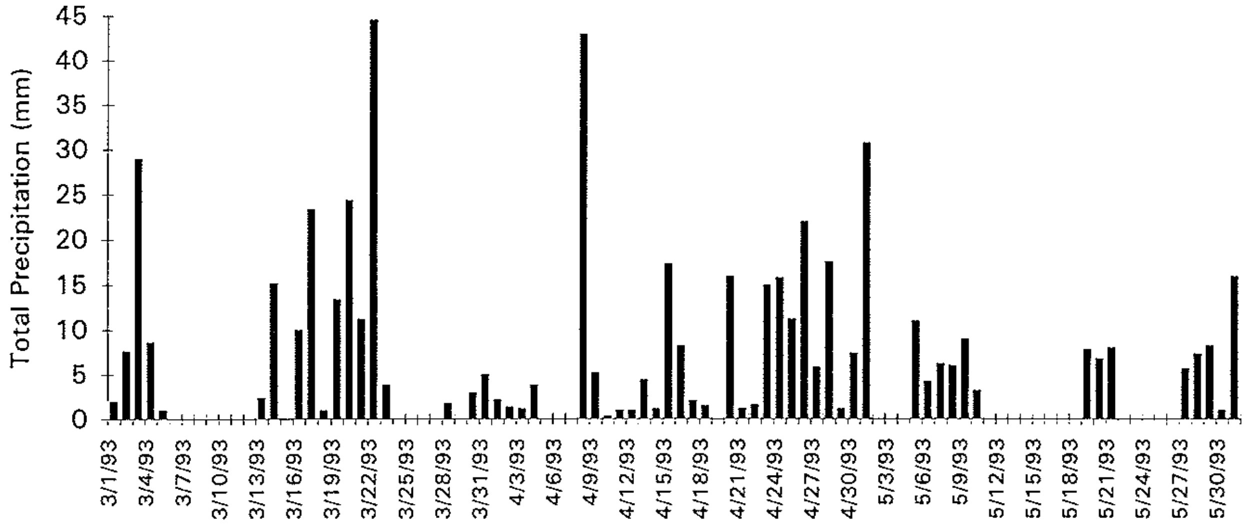

Figure 9. Water Level Data for Monitoring Well on Anmore Estates Lot 28 for Spring 1993