Principles of Siphons With Respect to the Artificial-Recharge Studies in the Grand Prairie Region Arkansas

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ARTIFICIAL RECHARGE OF GROUND WATER—GRAND PRAIRIE REGION, ARKANSAS

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PRINCIPLES OF SIPHONS WITH RESPECT TO THE ARTIFICIAL-RECHARGE STUDIES IN THE GRAND PRAIRIE REGION, ARKANSAS

By R. T. Sniegocki and J. E. Reed

ABSTRACT

In artificial-recharge experiments in the Grand Prairie region, siphoning has caused both favorable and adverse effects. This report discusses these effects and methods of utilizing or minimizing them. For any recharge rate, negative pressure exists in the injection line when water is siphoned into the recharge well. The length of the injection line in which the vapor-pressure limit prevails is principally controlled by the depth to water in the recharge well. Filtering through a closed system into the recharge well allows the negative head to increase normal filter-head loss and destroys filter effectiveness. A valve at the discharge end of the injection line provides a means of eliminating negative pressure in the line.

INTRODUCTION

In 1953 the Grand Prairie region of Arkansas was selected for an investigation of the principles or artificially recharging ground-water reservoirs in alluvial deposits through wells. This area (fig. 1) in the Coastal Plain of east-central Arkansas provided a large natural laboratory in which studies of general interest could be made. The U.S. Army, Corps of Engineers, and the University of Arkansas have actively participated with the U.S. Geological Survey in these studies. State and local agencies, companies, and individuals have given invaluable advice and assistance.

The general plan of study has involved controlled experiments to determine the feasibility of artificial recharge using various types of wells and water. Two experimental recharge wells were constructed, and 22 recharge tests were completed; in the first test ground water was used and in the others surface water treated in several ways was used. In many of the tests, there have been favorable and adverse effects because of siphoning. The purpose of this report is to discuss these effects and methods for utilizing or minimizing them.

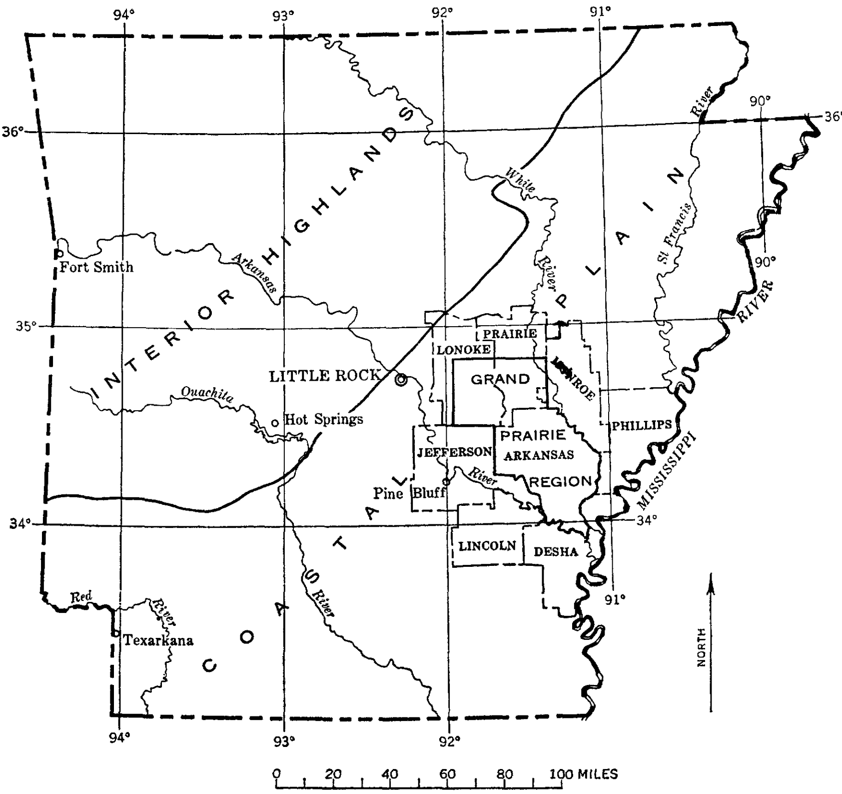

FIGURE 1.—Map of Arkansas showing the location of the Grand Prairie region.

PRINCIPLES OF SIPHONS

THEORETICAL CONCEPTS

Physics textbooks commonly refer to a siphon as a conduit that conveys liquid from one point to another of lower elevation after raising the liquid to a higher elevation at an intermediate point. Negative pressures exist in siphons and are greatest at the summit of the conduit; if the negative pressure approaches the vapor pressure of the liquid conveyed, the siphon will not flow full. The limiting height of the apex of the siphon is the barometric height of a column of the liquid conveyed.

These and other siphon characteristics may be comprehended more easily by examining the siphon shown in figure 2 and by considering the following mathematical relationships. Vessels A and B are subject to virtually the same atmospheric pressure, p_a.

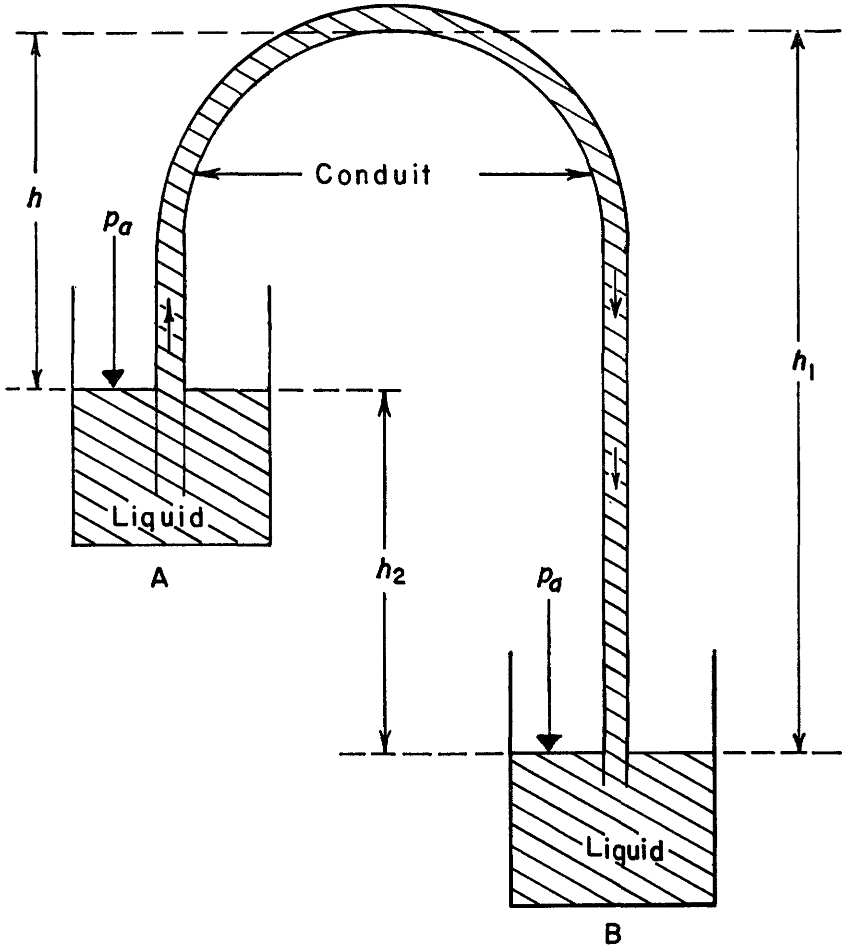

FIGURE 2.—Simplified sketch of a siphon. Modified from Weber, White, and Manning (1952, p. 218).

The atmospheric pressure forcing liquid from A to B is diminished in the conduit by the pressure, ρgh, of the column of liquid in the conduit, where h is the height of the conduit apex above the liquid level in A (the maximum value of h in an operative siphon transferring water is approximately 34 feet) ρ is the density of the liquid, and g is the acceleration due to gravity. The atmospheric pressure forcing liquid from B to A is diminished by the pressure, σgh_1, of the column of liquid in the conduit, where h_1 is the height of the conduit apex above the liquid level in B. The net pressure effect operating between vessels A and B then becomes

$$h_1\rho g - h\rho g.$$

If h becomes greater than the height of a column of liquid that the atmosphere can support ($h = p_a / \rho g$), the siphon will not operate.

The velocity of flow in a full siphon may be expressed as follows (Engineering Hydraulics, 1949, p. 429):

$$V = \sqrt{\frac{2gh_2}{1+K}},$$

where h_2 is the difference in inflow and outflow elevation and K represents the sum of the loss coefficients in terms of velocity head.

The quantity, Q, flowing through a siphon is expressed as

$$Q = A\sqrt{\frac{2gh_2}{1+K}},$$

in which A is the cross-sectional area of the conduit.

The pressure at the summit of a siphon cannot approach absolute zero without the formation of discontinuities, and because p_a is the atmospheric pressure, the maximum value of h for water is about 34 feet. Dissolved gases always present in natural water, however, come out of solution at pressures well above the vapor pressure and collect at the apex of the conduit. Thus, h must be appreciably less than 34 feet or the siphon will not flow full.

A siphon not flowing full may still discharge at a useful rate. Surges, however, will occur as intermittent discontinuities develop at the summit. This important aspect of siphon operation is discussed in a later section of this report.

THE ARTIFICIAL-RECHARGE SYSTEM

GENERAL DESCRIPTION

It is not the purpose of this report to describe in detail the physical layout of the equipment used in this study of artificial recharge through wells. Under certain conditions, however, the recharge system is analogous to a siphon, and a brief description of the equipment layout is necessary to show this analogy. A diagrammatic sketch of the recharge well and attendant water facilities is shown in figures 3 and 4.

During the recharge tests at least two siphon conditions existed in the recharge system. Consider first a test in which water is taken from the canal through a pipeline and injected directly into the recharge well through the pump column (fig. 3). The canal corresponds to A in figure 2, the pipeline corresponds to the conduit, and the recharge well represents B. Thus, the field layout is the equivalent of a siphon.

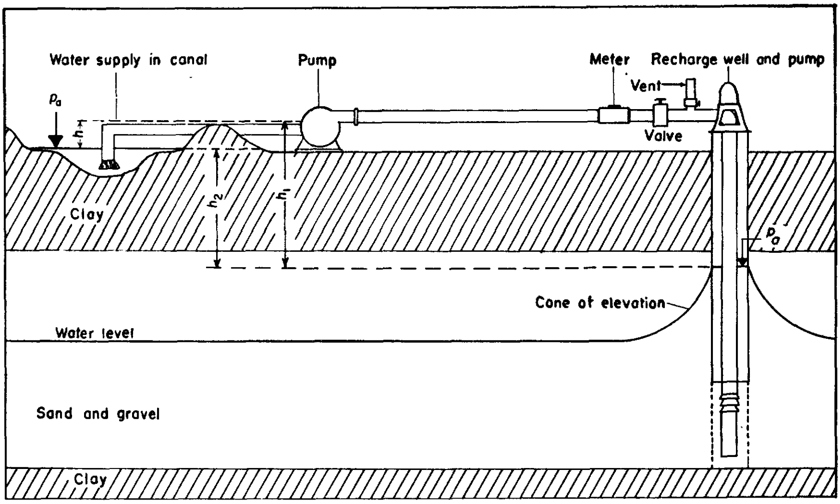

FIGURE 3.—Diagrammatic sketch showing injection of water from the canal into the recharge well.

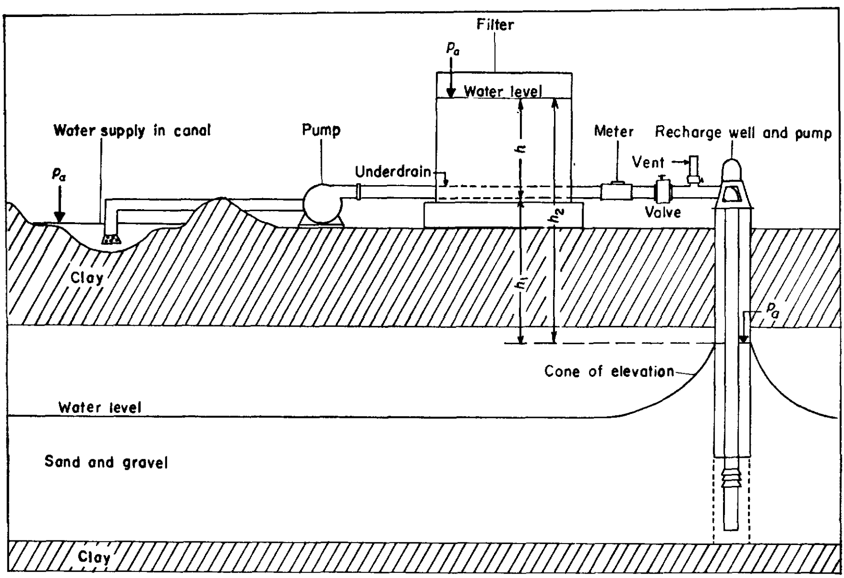

FIGURE 4.—Diagrammatic sketch of the recharge well when a filter is used to treat the injected water.

The following approximate relationships apply to the recharge system shown in figure 3: h=4 feet, h_1=100 feet, and h_2=96 feet. Although the water level in the canal declines slightly as water is withdrawn, h is considered to be constant for all practical purposes, because the canal conveying water to the project site is in direct connection with a large surface-water reservoir.

The dimensions given for h_1 and h_2 apply for one period of time at a given recharge rate. Buildup of water level in the recharge well changes with time because of hydraulic conditions imposed on the aquifer by injection. Additional changes in h_1 and h_2 may be caused by plugging of the well screen and aquifer.

A siphon condition also exists when a filter is used (fig. 4). Water is pumped from the canal to the top of the filter tank. The water passes through the filter medium into an underdrain and then through the pump column into the recharge well. Under these conditions of injection, the filter corresponds to A in figure 2, the underdrain and pump column correspond to the conduit, and the recharge well represents B.

The following approximate relationships apply to the recharge system shown in figure 4 for one period of time at a fixed recharge rate: h=8 feet, h_1=100 feet, h_2=108 feet.

When water is transmitted from the filter into the recharge well under gravity head, the usual definition of a siphon does not apply, because the liquid has not been raised to a higher elevation at an intermediate point. The pressure in the injection line, however, becomes negative at some point in the system when flow from the filter is restricted, and this negative pressure has the same effect as negative pressure created by a siphon. Therefore, in this report, siphon effect and siphon conditions refer to negative pressure created in the pipes by pipe geometry and head conditions, although the system may not meet the usual definition of a siphon. The definition of a siphon may be applied algebraically to the foregoing relationships if h is considered to be negative.

HYDRAULIC-GRADELINE ANALYSIS

It is generally advantageous to plot hydraulic gradelines to scale to aid in visualizing and solving complex problems of pipe flow. A hydraulic gradeline is the line of piezometric head and is the plot of the resulting sum of pressure head and position for each point along the pipe. The method by which siphon-effect gradelines may be applied to the recharge system is shown schematically in figure 5. It is inconvenient to superimpose scaled gradelines on a scaled drawing of the recharge system; hence, in subsequent representations of

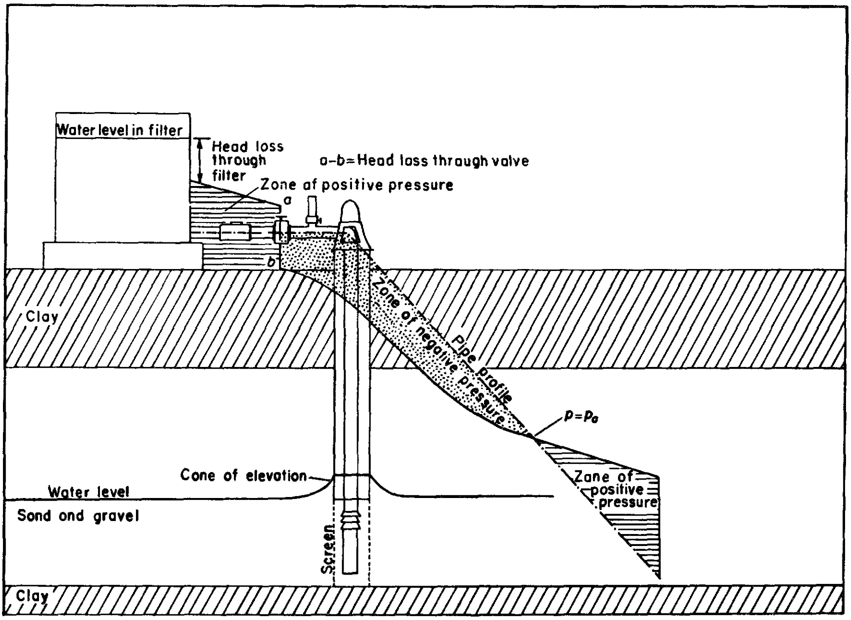

FIGURE 5.—Schematic representation of hypothetical gradelines as applied to the recharge system.

siphon effects only the scaled hydraulic situation is plotted. Further simplification is achieved by assuming that the injection line has uniform friction loss throughout, no friction loss at elbows and connections, and no entrance and exit losses. Although these assumptions are not valid during recharge, their use does not significantly alter the interpretation.

The hydraulic gradelines in the recharge system when water is siphoned from the canal into the recharge well are shown in figure 6 for two different water levels in the well. Construction of the plots was based on the following approximate dimensions of the recharge system. (See fig. 3.)

	Feet
Lift from water level in canal to summit of injection line (h)	4
Distance from water level in recharge well to summit of injection line at beginning of injection period (h_1)	100
Difference between the water level in canal and water level in the recharge well at beginning of injection period (h_2)	96
Distance from water level in recharge well to summit of injection line (h_1), after 50 feet of buildup of water level in recharge well	50
Difference between water level in canal and water level in the recharge well (h_2), after 50 feet of buildup of water level in the recharge well	46
Length of pipe from canal to valve	70
Length of pipe from valve to top of well	5
Length of pipe from top of well to end of tailpipe	125

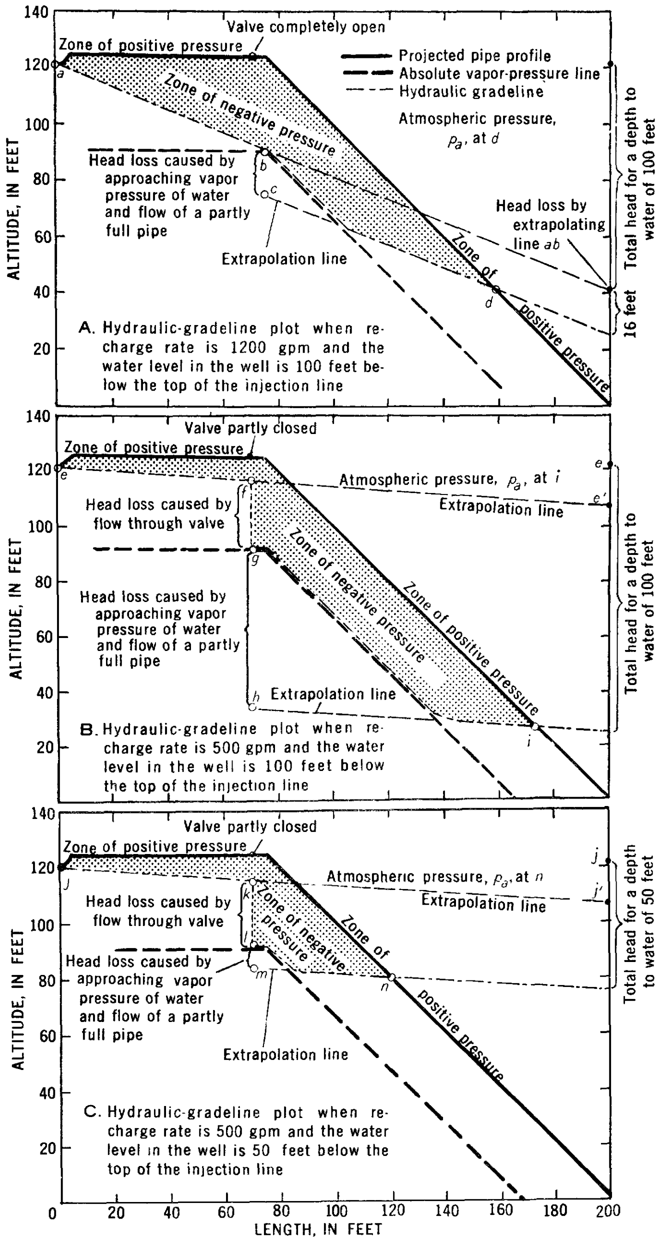

FIGURE 6.—Scaled plots of hydraulic gradelines when recharging is done with water siphoned from the canal. *A*, Hydraulic-gradeline plot when recharge rate is 1,200 gpm and the water level in the well is 100 feet below the top of the injection line; *B*, Hydraulic-gradeline plot when recharge rate is 500 gpm and the water level in the well is 100 feet below the top of the injection line; *C*, Hydraulic-gradeline plot when recharge rate is 500 gpm and the water level in the well is 50 feet below the top of the injection line.

The smoothness and continuity of the lines on the plots (figs. 6*A*, 6*B*, and 6*C*) are the result of the assumptions regarding head losses in the recharge system. The slopes of the lines were determined by use of three factors—the physical dimensions of the recharge system, a maximum observed rate of flow of the siphon of about 1,200 gpm (valve completely open), and a negative head in the pipe of 34 feet or less.

In figure 6*A* the difference in head (elevation) between *a* and *b* represents the head loss between the two points in the pipe when the flow is 1,200 gpm. The head loss throughout the length of the pipe would be 80 feet. Differences in the water level in the canal and in the well (h_2) show an available head of 96 feet. The difference of 16 feet between the available head and the head loss was caused by pressure in parts of the injection line approaching the vapor pressure of water when the siphon was operated at 1,200 gpm. The valve controlling flow into the recharge well was completely open at this flow rate.

The hydraulic-gradeline plot (fig. 6*A*) was constructed to determine the amount of head loss caused by pressure approaching the vapor pressure of water when the pipe is flowing partly full. Because recharge tests generally were made at 500 gpm or less, no further consideration will be given figure 6*A* in interpretation of the siphon effects.

The rate of flow through a pipe is approximately proportional to the square root of head. A flow of 500 gpm through the recharge system would require a head loss of 14 feet, which is represented by *ee′* in figure 6*B* and *jj′* in figure 6*C*. Because 96 feet of head is available, the valve must be closed if flow is to be reduced. Closing the valve so that the siphon discharges at 500 gpm causes a head loss through the valve of about 24 feet (*fg* and *kl*, figs. 6*B* and 6*C*, respectively). The resultant additional head loss (loss in excess of that in a full pipe) must be accounted for, but, as shown in figures 6*B* and 6*C*, it is dependent upon the water level in the recharge well. Accordingly, the head loss at a recharge rate of 500 gpm is 58 feet when the water level is 100 feet (*gh*, fig. 6*B*). When the water level is 50 feet, the head loss is 8 feet (*lm*, fig. 6*C*). These losses are caused by negative pressure in the line approaching the vapor pressure of water when the pipe is flowing partly full, as when water is siphoned at 1,200 gpm.

The plots show that for any recharge rate, negative pressure will exist in the injection line when water is siphoned into the recharge well, and the water level in the recharge well controls the length of pipe in which negative pressure prevails. Furthermore, the valve must be opened as the depth to water in the well decreases, if a constant recharge rate is to be maintained. The following table shows the decline in injection rate recorded when water was siphoned into the well without changing the valve setting.

Injection rates and depths to water, recharge test 20, March 10, 1959

Time (minutes)	Injection rate (gpm)	Depth to water in recharge well (feet below measuring point)	Time (minutes)	Injection rate (gpm)	Depth to water in recharge well (feet below measuring point)
0	[1]	97.8	90	311	78.5
6		83.1	120		77.6
7	320		180	302	
10	316		305	305	
15	315	80.8	318		74.9
30	313	80.3	1,355	238	
45		79.9	1,360		51.7

[1] Begin recharge.

The hydraulic gradelines in the recharge system when recharging is done with water from the filter at two different water levels in the recharge well are shown in figure 7. Construction of the plots was based on the following approximate dimensions of the recharge system (fig. 4) and the simplifying assumptions used in constructing the gradeline analyses in figure 6.

	Feet
Height of water level in filter above injection line (h)	8
Distance from water level in the recharge well to summit of injection line at beginning of injection period (h_1)	100
Difference between water level in filter and water level in the recharge well at beginning of injection period (h_2)	108
Distance from water level in the recharge well to summit of injection line (h_1), after 50 feet of buildup of water level in the recharge well	50
Difference between water level in filter and water level in the recharge well (h_2), after 50 feet of buildup of water level in the recharge well	58
Length of pipe from filter to valve	20
Length of pipe from valve to top of well	5
Length of pipe from top of well to end of tailpipe	125

When recharging under closed-system conditions between the filter and the recharge well, the length of pipe over which negative pressures occur becomes less with a buildup of water level in the well. The injection rate decreases unless the valve controlling the flow is opened. This is demonstrated by the data shown in the following table.

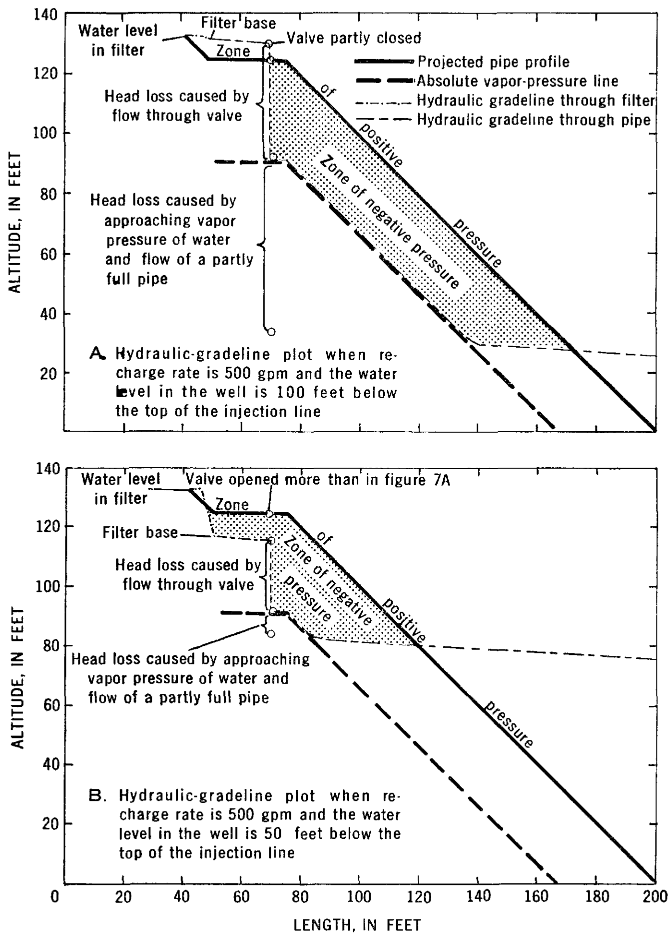

FIGURE 7.—Scaled plots of hydraulic gradelines when recharging is done with water from the filter. *A*, Hydraulic-gradeline plot when recharge rate is 500 gpm and the water level in the well is 100 feet below the top of the injection line; *B* Hydraulic-gradeline plot when recharge rate is 500 gpm and the water level in the well is 50 feet below the top of the injection line.

Injection rates and depths to water, recharge test 2, March 28, 1956

Time (minutes)	Injection rate (gpm)	Depth to water in recharge well (feet below measuring point)	Time (minutes)	Injection rate (gpm)	Depth to water in recharge well (feet below measuring point)
0	(1)	2 90	79	500	
3	600		119	495	
28		71.9	131	495	
31	520		163	495	
66	500		203		67.2

1 Begin recharge.
2 Estimated.

A similar condition of flow decline can be observed when filtering to waste. If interstices of the filter bed become clogged, the filter output decreases. If the effluent valve is opened, the head loss through the filter is increased and the flow is maintained; however, if the valve is opened to maintain flow when filtering through a closed system into the recharge well, the negative head caused by the siphon effect increases the normal filter head loss and the total head loss through the filter soon exceeds the physical limitations of filter depth. (Compare the length of filter gradelines in figs. 7*A* and 7*B*.)

SIPHON EFFECTS ON RECHARGE

AIR ENTRAINMENT

When the pressure inside the injection line is less than the atmospheric pressure, air enters the line if there are any leaks, however small. Pinhole leaks in welded joints, loose valve shafts, worn grease seals, and improperly connected couplings provide entrances for air that are difficult to eliminate. Ordinarily, such leaks cannot be detected when the pipeline is under positive pressure, but they will allow air to enter when the pressure is less than the atmospheric pressure.

The arrangement of the injection line, controlled injection rates, and the resultant siphon condition make air entrainment a major cause of clogging in the recharge well and aquifer. Air entrainment as a clogging factor was discussed in another report (Sniegocki, 1959).

CAVITATION AND RELEASE OF DISSOLVED GASES

Pressure reduction in the injection line due to the siphon effect causes the release of dissolved gases and cavitation of the recharge water. This is another possible cause of air binding and may be more difficult to control. Water vapor formed in the area of negative pressure condenses to water when positive pressure is restored. The released gases, however, do not go back into solution instantaneously and could reduce aquifer permeability, as when air is introduced from an outside source. No data have been collected to support the possibility of clogging of the recharge well by air released from solution in the injected water.

CHEMICAL CHANGES

Pressure effects also alter the chemical balance of dissolved solids in the recharge water. Chemical precipitates are formed by reduction in solubility caused by reduced pressure and by increased dissolved-solids contents when part of the water is vaporized. The iron content of the water is especially affected by the reduction of pressure to less than atmospheric pressure and by subsequent cavitation of the water, which causes iron to precipitate. Such changes have been observed in laboratory tests and, consequently, must be considered possible in the recharge studies, even though no supporting data have been collected.

FILTER OPERATION

When the increased head loss allowed by the siphon effect exceeds the height of the filter (figs. 7*A* and 7*B*), flow lines through the filter medium are altered and the throughput of water per square foot over part of the filter-bed surface is increased. During a test in which a closed-system injection line was used between the filter and the recharge well, a negative pressure of 7.5 inches of mercury was measured at the bottom of the filter tank. As the negative pressure caused part of the filter mat (floc mat) to be pulled through the filter medium, water of inferior physical quality resulted. The filter medium also may have been downwarped; this condition would have decreased the thickness of the filter medium and allowed water to move down the sides of the filter tank. An increase in turbidity of as much as 30 ppm was noted in the filter effluent when the head loss through the filter was allowed to exceed the filter height.

WATER TRANSFERENCE

The siphon effect (negative pressure) created by recharge under closed-system conditions was used to advantage in several recharge tests. When transferring water from the canal directly into the recharge well, the siphon was primed by filling the injection line with water pumped from the recharge well. When the pump was stopped, the direction of water movement reversed and water flowed from the canal to the well.

A clear well was constructed to receive the filter effluent. The siphon was primed as above and used to move water from the clear well into the recharge well. The length of pipe from the clear well to the top of the recharge well was only about 8 feet, resulting in fewer joints and fewer chances for pinhole leaks, whereas there was more than 100 feet of pipeline from the canal to the recharge well. Although the siphon effect was of some use in recharge operations, the benefits derived may have been seriously offset by problems created when operating with negative pressure in the injection line.

INJECTION RATES

Water was transferred from the canal to the recharge well by siphoning during one of the recharge tests (test 20). Daily observations were made on all equipment and control points as the test progressed. The injected water ranged in turbidity from 40 to more than 150 ppm. The water temperature ranged from 48° to 66° F and averaged 54.1° F. The water was injected at a rate ranging from 47 to 367 gpm and averaged about 240 gpm. Chlorination, at a rate ranging from 0 to 20 pounds of chlorine per day, was the only water treatment used. The specific capacity of the recharge well was 20 gpm per ft of drawdown at the beginning of the test and 2 gpm per ft at the end; these data indicate severe plugging of the well and aquifer. Apparently, suspended solids were the principal cause of clogging, but there was a possibility of air entrainment.

An automatic water-level recording gage was maintained in an observation well 20 feet from the recharge well througout the test period (March 10–29, 1959). A typical part of the hydrograph for the period of recharge from March 24 through March 28, 1959, is shown in figure 8.

Injection of water was stopped periodically, and the deep-well turbine pump was used to redevelop the recharge well by surging and pumping. The redevelopment periods are conspicuous in the hydrograph (fig. 8). Upon completion of the surging and pumping, recharge was resumed. If the recharge rate was too low, the valve in the injection line at the recharge well was opened slightly. The change in injection rate caused by valve adjustment is indicated by a characteristic "pip," or an abrupt change in the water level shown in the hydrograph. These pips are indicated in figure 8 as rate increases caused by opening the valve.

As the water level in the recharge well rose during each cycle of injection, the negative head in the injection line decreased. The resulting gradual decline in injection rate (recorded to be as much as 150 gpm) is apparent in the hydrograph as an increase in depth to water between the beginning and end of a recharge cycle. For example, on March 24, 1959, the depth to water in the observation well was about 92.4 feet at 1200 when the injection rate was about 300 gpm. Near the end of the same cycle of recharge at 0800 on March 25, 1959, the depth to water in the observation well was 93.0 feet and the injection rate was about 190 gpm. The overall decline in water level in the observation well during the next three cycles of recharge (fig. 8) is not as great as it would have been if the recharge rate had not been increased by opening the valve after 4 or 5 hours of injection.

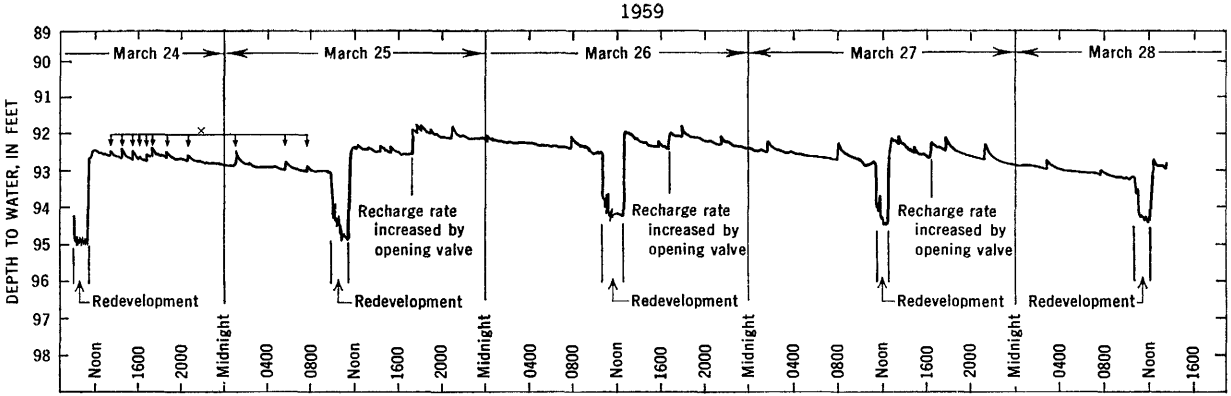

FIGURE 8.—Hydrograph of the water level in an observation well 20 feet from the recharge well.

The changes in water level recorded in the observation well (see examples designated "X" during first cycle of recharge in fig. 8) are not as readily explained as the changes caused by opening the valve and increasing the rate of recharge. The recording gage was checked and was operating satisfactorily, and none of the water-level changes could be attributed to malfunctioning of the observation well. No correlation existed between changes in atmospheric pressure and changes in water level. Once, however, a temporary increase in the injection rate was observed, and the water level in the recharge and observation well rose in response. Furthermore, the shape of each pip suggests a sudden but temporary rate change which quickly reverts to the previous rate. It was assumed, therefore, that each pip was caused by rate changes within the injection line, causing more water to enter the recharge well.

The anomalous change in water level in the observation well originally was throught to be related to plugging of the recharge well and the aquifer by air entrainment and suspended solids. As plugging occurred in and near the recharge well, the head in the well rose and may have caused the plugging material to break and let a sudden surge of water into the aquifer. The depth to water in the recharge well, however, did not become greater as the water level in the observation well rose. It was concluded tentatively that a breaking up of clogging material was not related to the pips in the hydrograph shown in figure 8.

Dissolved gases in natural water come out of solution at pressures greater than the vapor pressure of water. These gases collect at high points in a conduit and cause discontinuities and surges in flow. It was concluded that cavitation resulting from the siphoning of water from the canal into the recharge well caused temporary changes in the injection rate, these changes in rate affecting the water level in the observation well.

Another recharge test (test 21) was set up to collect additional data on the anomalous changes in water level in the observation well. An electric pump with a valve on its discharge side was installed in the injection line to permit water transference from the canal into the recharge well without using a siphon. The pump was placed near the water supply to make the suction side of the line as short as possible and to thereby reduce the possibility of air entrainment. By operating the pump, pressure would be increased in the injection line. During test 20 (before the electric pump was installed), water did not flow from a sample valve in the injection line located about 18 feet from the recharge well; instead, the valve allowed air to enter the line. This behavior indicated that pressure in the system was less than atmospheric pressure at that point. When the electric pump was operated during test 21, water flowed from the sample valve when opened; this behavior indicated that pressure was positive at that point. Although all possible causes of the anomalous water-level changes in the observation well were though to have been eliminated, they were still in evidence during test 21. Test 22 was made in the same manner as test 21 but at an average recharge rate of 37 gpm. Similar pips were observed on the hydrograph but at a much reduced amplitude.

Hydraulic-gradeline analysis showed that even though the pump was used in water transference during tests 21 and 22, negative pressure could exist in the system at some point between the pump and the the end of injection line. The point of negative pressure must have been located in the injection line near the top or inside of the recharge well or water would not have flowed through the sample valve when it was opened.

It was concluded that discontinuities of flow in the system would be virtually impossible to eliminate as long as the layout of the injection line was not changed.

Hydraulic-gradeline analysis showed that the pump used to transfer recharge water should be near the recharge well and that the valve on the discharge side of the pump should not be used to control injection rates if negative pressure on the discharge side of the pump is to be eliminated.

MINIMIZING SIPHON EFFECT ON THE RECHARGE SYSTEM

Several methods may be used to minimize or eliminate siphon effects when recharging under the conditions mentioned in this study.

The simplest method is to place a large opening or vent in the injection line between the source of water and the recharge well. This provides for entrance of air so that the line pressure is in equilibrium with atmospheric pressure. Air-entrainment problems, however, may be intensified greatly unless care is taken to select a pipe whose diameter is large enough to deliver the flow required but is small enough to create enough friction to cause positive pressure in the line.

If a clear well is used to receive the filter effluent, the siphon effect will be prevented from operating on the filter by providing an interruption in the hydraulic continuity of the pipeline between the filter and the recharge well. Siphoning of water from the clear well into the recharge well would permit more efficient filter operation. Cavitation effects, possible air leaks, and consequent air entrainment would not be eliminated, however.

By recharging under constant-head conditions with the water level in the well at the land surface and allowing the injection rate to change, the siphon effect and possible air entrainment can be eliminated. In the High Plains near Lubbock, Tex., water was injected into wells at a rate sufficient to raise the water level in the recharge well to the elevation of the source of water. This method of introduction of water into a recharge well was considered in this study; however, less experimental variation is possible and treatment of water in various ways becomes more difficult by this method. Furthermore, because water velocity through the screen is undesirably high and injection heads are greatest, redevelopment of the recharge well is made more difficult.

The most satisfactory method for eliminating the siphon effect used in this study was the installation of a butterfly valve at the bottom of the injection line inside the recharge well. The valve was rigged for manual operation at the surface by means of a long shaft. The hydraulic-gradeline plot shown in figure 9 demonstrates the effectiveness of the valve in creating positive pressure throughout the injection line.

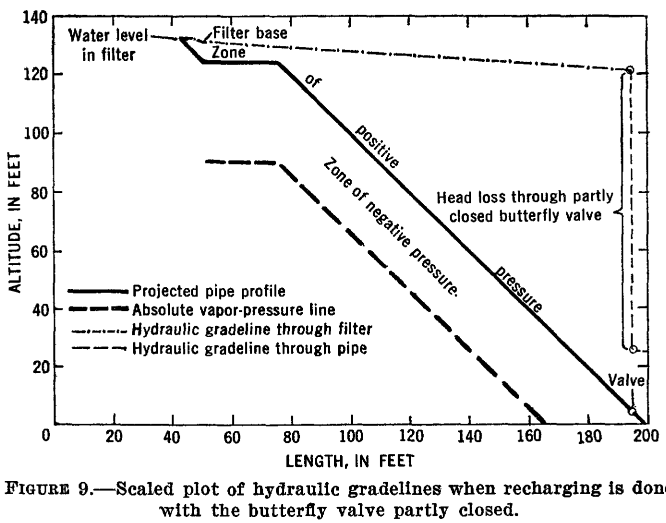

FIGURE 9.—Scaled plot of hydraulic gradelines when recharging is done with the butterfly valve partly closed.

SUMMARY AND CONCLUSIONS

Siphon conditions may cause difficulty in artificial-recharge operations by creating negative pressure in the injection line. Air entrainment, caused by the entrance of air through pinhole leaks due to negative pressure in the pipeline is a major cause of clogging in the recharge well and the aquifer. Another source of air binding is the release of dissolved gases and cavitation of the recharge water. Pressure effect may cause the formation of chemical precipitates by the reduction in solubility and increased dissolved-solids content. Also, the effectiveness of the filter operation is reduced by the increased head loss allowed by the siphon effect.

REFERENCES CITED

Rouse, Hunter, ed., Engineering hydraulics, Proceedings of the Fourth Hydraulics Conference, Iowa Institute of Hydraulic Research, June 12–15, 1949, Engineering hydraulics: New York, John Wiley and Sons, Inc., 1,039 p.

Sniegocki, R. T., 1959, Plugging by air entrainment in artificial-recharge tests: Water Well Jour., v. 13, no. 6, p. 17–18, 43.

Weber, R. L., White, M. W., and Manning, K. V., 1952, College physics: New York, McGraw-Hill Book Co., Inc., 820 p.

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