EFFECTS OF CHANNEL STABILIZATION IN TUCSON STREAM REACHES ON INFILTRATION AND GROUND-WATER RECHARGE

VOLUME I

TECHNICAL APPENDIX

MODEL STUDIES: HOMOGENEOUS-ISOTROPIC FLOW SYSTEM

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SUBMITTED TO

PIMA COUNTY DEPARTMENT OF TRANSPORTATION AND FLOOD CONTROL DISTRICT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EFFECTS OF CHANNEL STABILIZATION IN TUCSON STREAM REACHES ON INFILTRATION AND GROUNDWATER RECHARGE

MODEL STUDIES: HOMOGENEOUS-ISOTROPIC FLOW SYSTEM

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SECTION 1 - INTRODUCTION

The flow system reported in Volume I of this report is homogeneous and anisotropic. The flow system reported in this technical appendix is homogeneous and isotropic. The finite element grids used to simulate infiltration and recharge with UNSAT2 are identical to those used for the homogeneous and anisotropic system (see Figure 10 in Volume I). In addition, the same physical-hydraulic properties of the vadose zone are used, except that the system is homogeneous and isotropic. Finally, head values for generating flow in the system are derived from the 10-year synthetic hydrograph, shown on Figure 8 in Volume I.

The original results for this system are included in the Draft Final Report submitted to Pima County Department of Transportation and Flood Control District in August 1986. This appendix is the revised draft of the Section 4 of the Draft Report, incorporating reviewers comments.

As reported in Volume I, the effect of bank stabilization and channel modification on infiltration in the Rillito River is simulated for two base cases. For the first case, designated case 1, infiltration is simulated in a channel section with a bottom width of 326 ft, before (case 1a) and after (case 1b) soil cement stabilization of the banks. Similarly, for case 2, infiltration is simulated in a channel section of width 202 ft, before (case 2a) and after (case 2b) soil-cement stabilization of the banks. Results from these two base cases are used to generate four additional cases involving bank protection and/or channel modification. Table 1 summarizes the channel conditions for the six cases produced during this study. Observe that cases 3 and 4 involve both bank stabilization and channel modification, whereas cases 5 and 6 involve only channel modification.

SECTION 2 - EFFECT OF THE "BATHTUB EFFECT" ON MODELLING RESULTS

The rationale for the bathtub effect is as follows: The program UNSAT2 was run on the Cyber 175 computer of the University of Arizona. Due to limitations on the available central memory of this computer, the number of nodes and elements could not exceed a certain limit. This made it necessary to restrict the size of the flow domain to be analyzed by UNSAT 2. The bottom boundary of the domain is placed a few feet below the water table and the lateral boundaries extend only a finite distance from the axis of the channel. Thus, the flow domain is a closed system. If the simulation is sustained long enough, the artificial boundaries will preclude water from leaving the modelled area through the bottom and sides. Accordingly, the UNSAT 2 calculations show a "bathtub" effect and water gradually rises to saturate successively higher regions of the vadose zone as infiltration progresses.

TABLE 1

SUMMARY OF CASES

Case Number	Initial Channel Width (Subcase a) (ft)	Final Channel Width (Subcase b) (ft)	Bank Stabilization (yes or no)	Channel Modification (yes or no)
1	326	326	YES	NO
2	202	202	YES	NO
3	202	326	YES	YES
4	326	202	YES	YES
5	202	326	NO	YES
6	326	202	NO	YES

The bathtub effect also occurs in nature, although probably to a lesser extent, when subsurface flow in channel alluvium is retarded by contiguous basin-fill deposits of lesser permeability. As the water table rises, the rate of infiltration gradually decreases at a rate which is faster than would be observed if channel alluvium contacts basin-fill deposits with transmissive properties similar to the channel deposits.

As a consequence of the bathtub effect, the model results depict the extreme effect of impermeable basin-fill sediments on flow in the stream channel alluvium along the Rillito River.

Examination of the data from the modelling study shows that the bathtub effect seems to have occurred between 25 and 35 hours for each of the four subcases (i.e., case 1a, 1b, 2a and 2b). To remain on the conservative side, our approach will be to place greater confidence in the results obtained at the end of 25 hours, prior to the onset of artificial accumulation in the section. For completeness, cumulative infiltration results at 90 hours are also quoted with the understanding that there is uncertainty in the absolute values.

SECTION 3 - RESULTS

3.1.2 Case 1: Wide Channel With Bank Protection

The final infiltration rate and cumulative infiltration at twenty five hours and 90 hours for this case are presented in Table 2. Percentage changes in cumulative infiltration volume are indicated in Table 3.

3.1.2.1 Infiltration Relationships

The simulated channel before bank stabilization is designated Case 1a. Similarly, the channel after bank stabilization is designated Case 1b. Infiltration rate curves for these two cases are shown on Figure 1, and the cumulative infiltration curves for the two cases are included as Figure 2.

The final infiltration rate for case 1a, at the termination of the simulated flow event, is 0.64 ft/day, in contrast to a rate of 1.05 ft/day for case 1b. The differences among the final infiltration rates (0.64 and 1.05 ft/day), observed during this study, and rates reported in the literature (1.1 to 3.7 ft/day reported by Keith, 1980, and 1.7 ft/day, reported by Cluff, Katz, and Scovill (1987) could be the result of the following variables: The physical condition of the channel, the initial saturation of the soils underlying the channel, the length of the flow event, and the negative influence of the bathtub effect.

The shapes of the two infiltration curves are similar, showing the classical decline in infiltration rate as time progresses during an event. The rapid decline in infiltration rate at about six hours into the event for both cases appears to coincide with the time that the advancing wetting front contacts the water table. This effect will be illustrated in a subsequent paragraph.

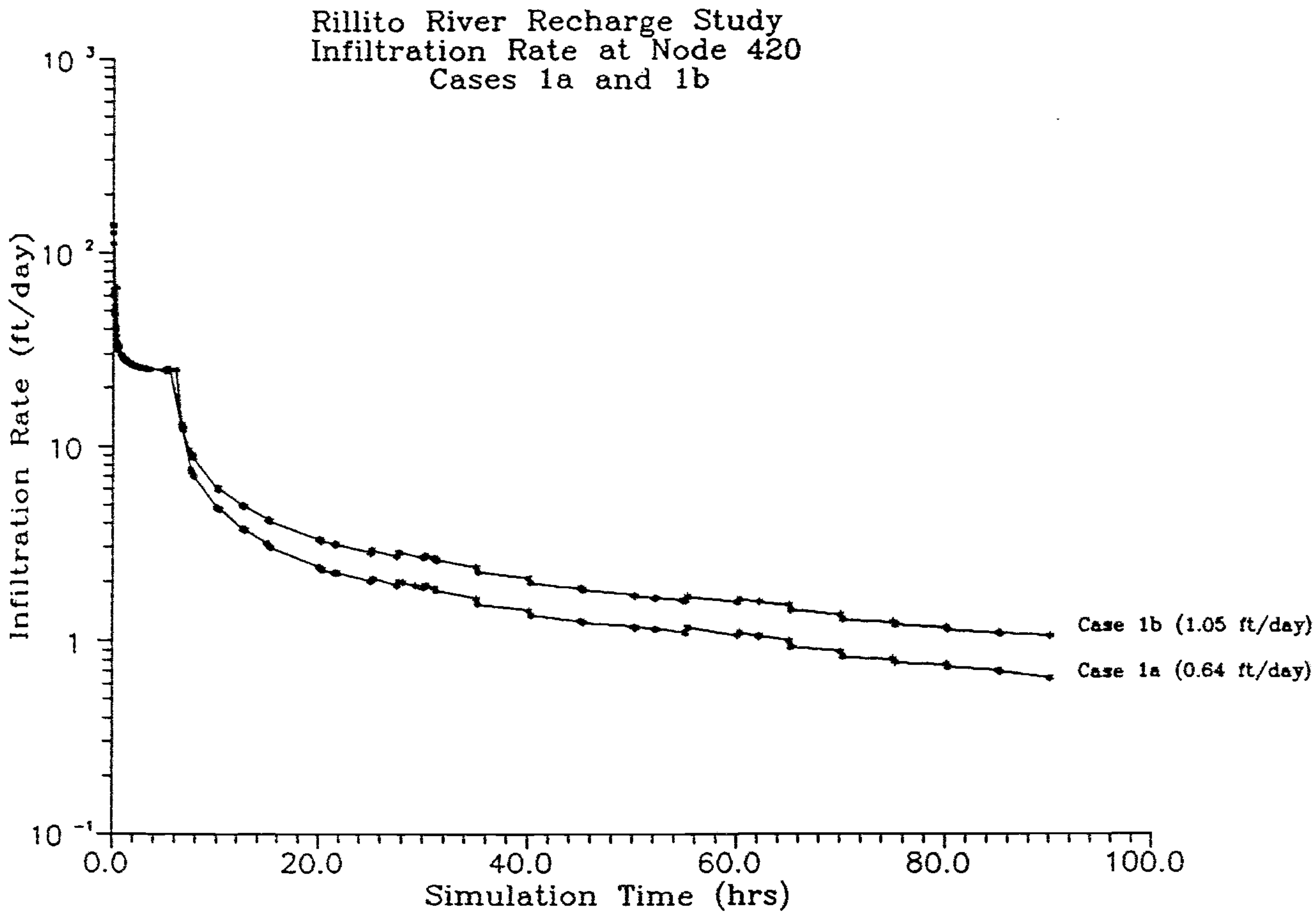


Figure 1. Infiltration rate at node 420 for case 1 (wide channel) before and after bank protection.

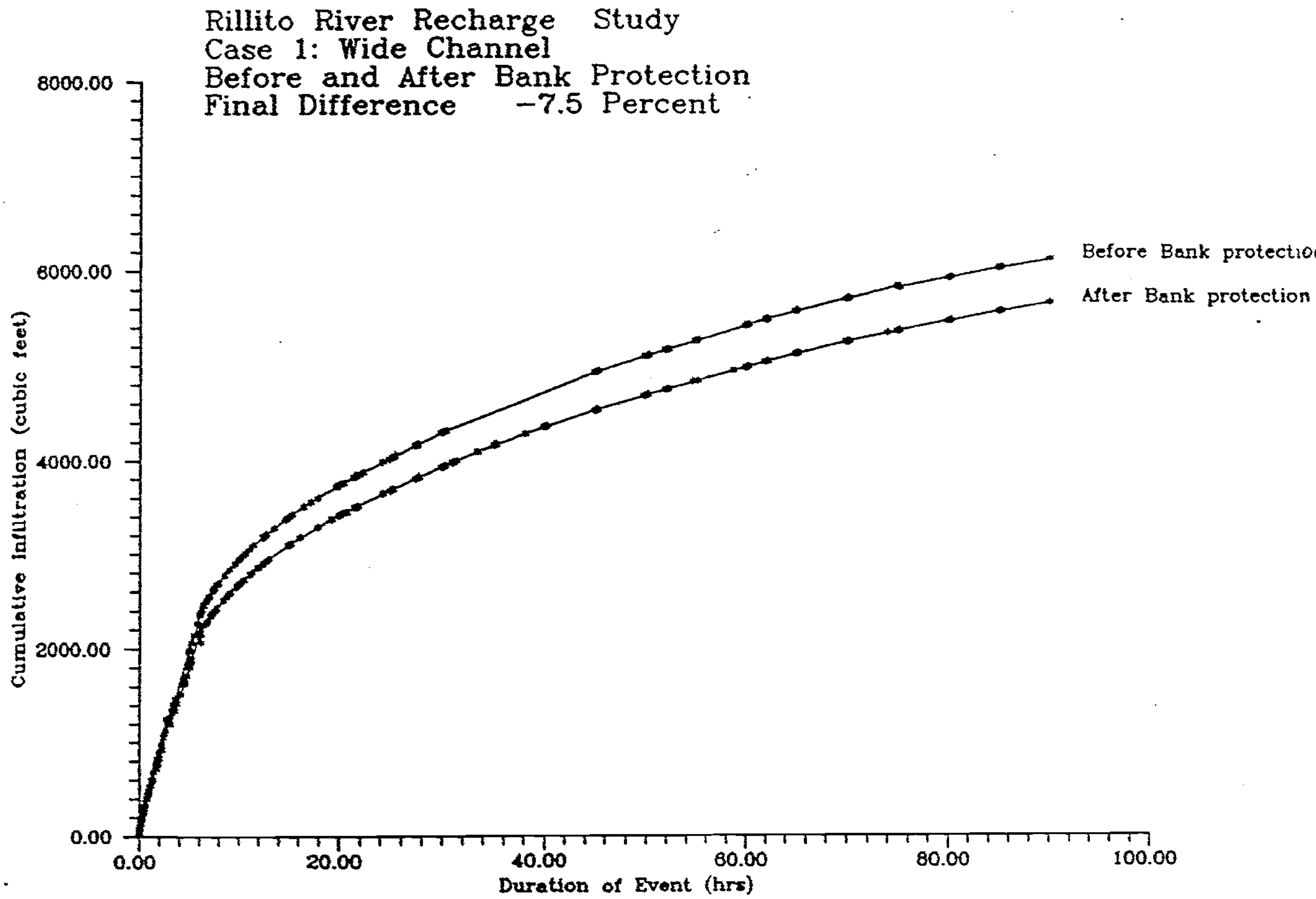


Figure 2. Difference in cumulative infiltration for case 1 (wide channel) before and after bank protection.

Table 2

Final Infiltration Rate and Cumulative Inflow Volume for the Base Cases

Case Number	Description	Final Infiltration Rate (ft/day)	Cumulative Infiltration Volume (cubic feet)	
			25hrs	90hrs
1a	Wide channel before bank stabilization	0.64	4038	6114
1b	Wide channel after bank stabilization	1.05	3698	5657
2a	Narrow channel before bank stabilization	1.24	3057	5121
2a	Narrow channel after bank stabilization	2.22	2651	4595

TABLE 3

Percent Differences in Cumulative Inflow Volumes as a Result of Channel Modifications for Six Cases

Case Number	Description	Gains (+) and Losses (-) in Cumulative Infiltration After Channel Modification (Percent)	
		25 hrs	90 hrs
1	Wide channel before and after bank protection	-8.4	-7.5
2	Narrow channel before and after bank protection	-13.3	-10.3
3	Narrow channel before bank protection; widened after bank protection	+21.0	+10.5
4	Wide channel before bank protection; narrowed after bank protection	-34.4	-25.0
5	Channel widening without bank protection	+32.1	+19.4
6	Channel narrowing without bank protection	-24.3	-16.2

Despite the possible bathtub effect, the cumulative infiltration curves on Figure 2 clearly show the influence of bank stabilization on infiltration: cumulative inflow is greater throughout the runoff event in Case 1a with no bank protection than in Case 1b, with bank protection. The total cumulative infiltration at the end of 25 hours for case 1a is 4038 cubic ft, compared to 3698 cubic ft for case 1b. The percent difference between the two cases is therefore 8.42. The cumulative infiltration at the end of 90 hours were 6114 and 5657 cubic ft for case 1a and 1b, respectively. The percent difference is 7.50.

3.1.2.2 Subsurface Advance of Wetting Front

Plots showing patterns of water movement through the simulated flow region are in terms of relative saturation. For case 1a these are shown for 1, 5, 10, and 25 hours (before the onset of the bathtub effect) on Figure 3. Figure 4 shows the same for case 1b. Due to symmetry the figures depict only one-half of the flow system; the missing part of the flow system on the left is mirror image of the part shown on these figures.

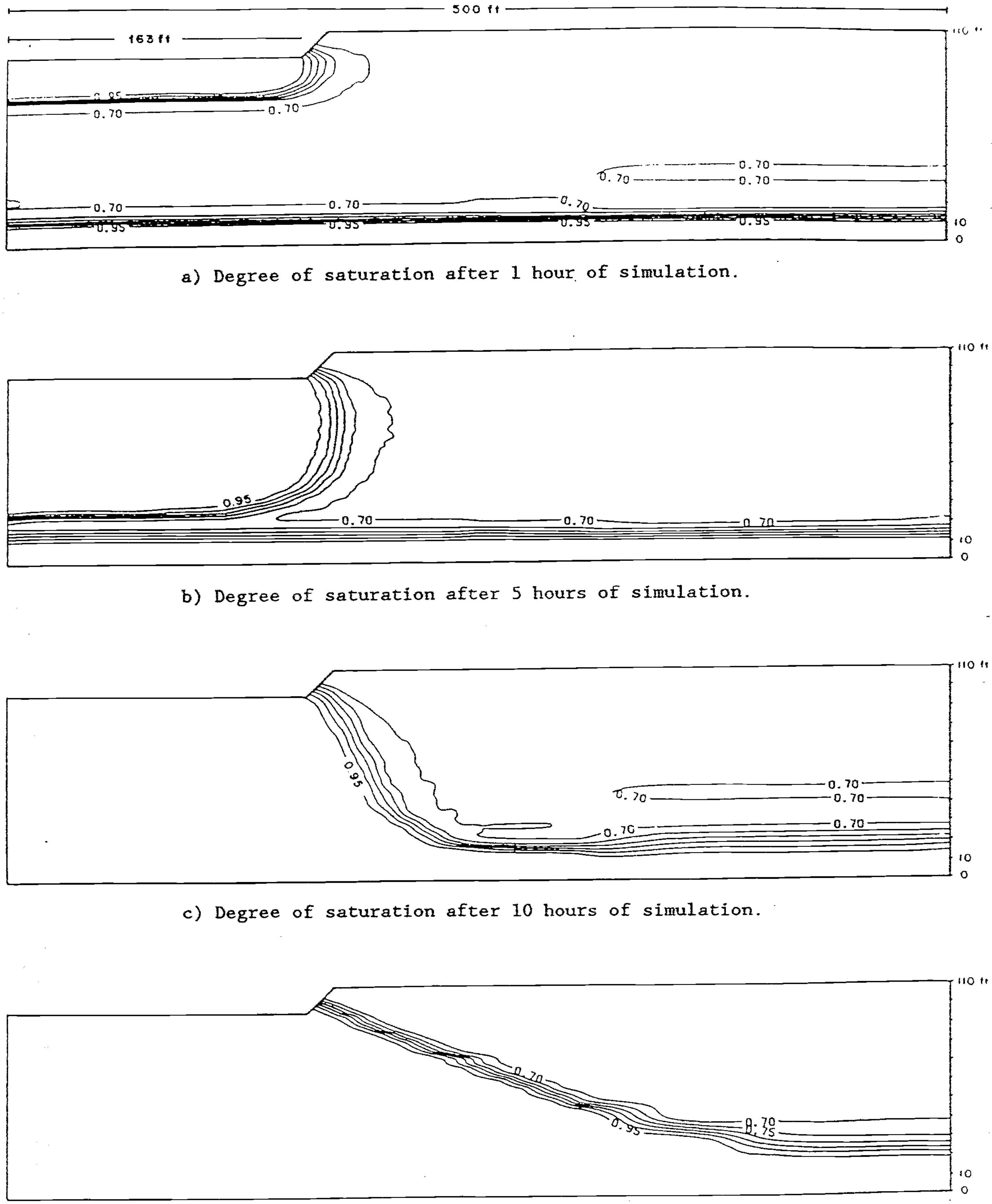
As shown on the plots for case 1a, the wetting front and the region of saturation (the region above the 0.95 contour) moves rapidly down the profile, contacting the water table at the depth of 100 ft between 5 and 7.5 hours into the simulation. Ground-water recharge begins at this time. The region underlying the channel is essentially saturated by 7.5 hours. The wetting front moves vertically into the profile at a rate of approximately 13.9 ft/hr (i.e., 87 ft/6.25 hours).

At first it was suspected that this rapid rate might have been a manifestation of the coarse grid that was used for the flow system, rather than representing realistic field values. (It will be recalled that a coarse grid was necessary because of the extensive flow systen that is being simulated, coupled with limitations on the memory of the computer used during the project.) In order to accept the results with confidence, a test was designed to examine the effects of grid density (element size) on the rate of wetting front propogation. This was undertaken by constructing a small experimental grid with a greatly increased element density and then repeating the same infiltration simulation.

Results from the fine-grid simulation reveal that the element density has a negligible effect on the rate at which the wetting front propagates. A mass balance analyses was also conducted to ensure that the volumetric changes in the profile corresponded with the cumulative inflow across the channel. The two values correspond closely. Accordingly, it appears that water in fact moves very rapidly through the vadose zone during the early stages of a flow event.

The companion set of flow profiles for case 1b, i.e., the system with bank protection, are included as Figure 4. Once again the direction of flow is vertically downward in the profile during the early hours of the simulation, followed by lateral flow above the water table as the profile below the stream channel becomes saturated. The wetting front contacts the water table at about the same time (between 5 and 7 hours) as in Case 1a.

The effect of the 12 ft deep soil-cement embankment on flow is revealed upon comparing the relative water content diagrams before and after



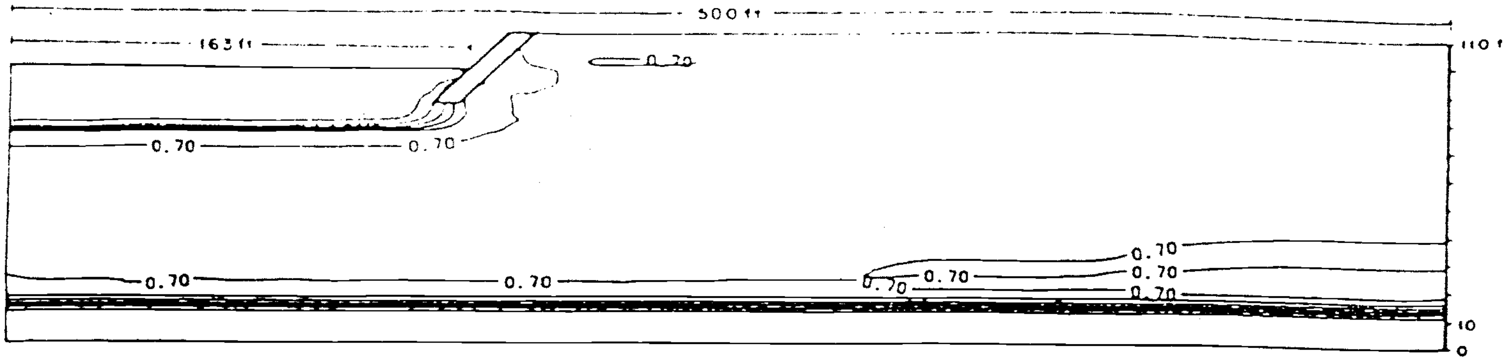
a) Degree of saturation after 1 hour of simulation.

b) Degree of saturation after 5 hours of simulation.

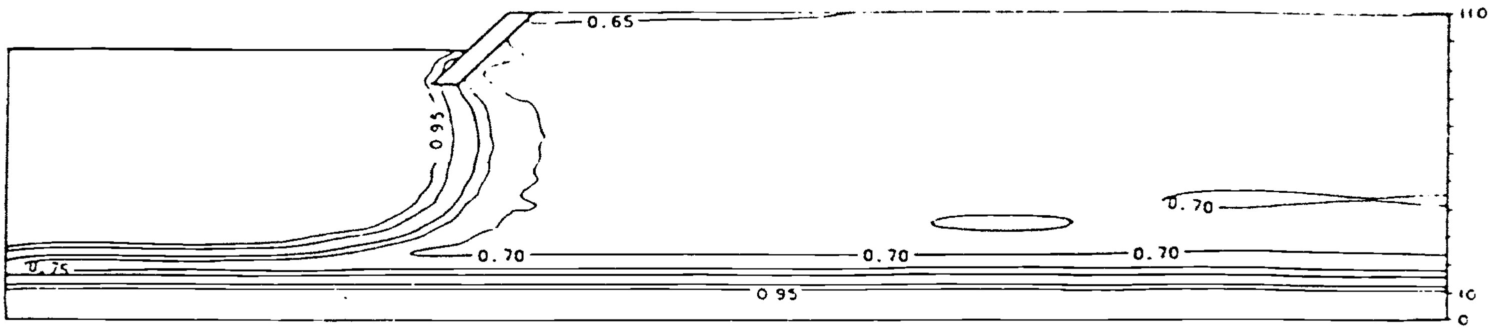
c) Degree of saturation after 10 hours of simulation.

d) Degree of saturation after 25 hours of simulation.

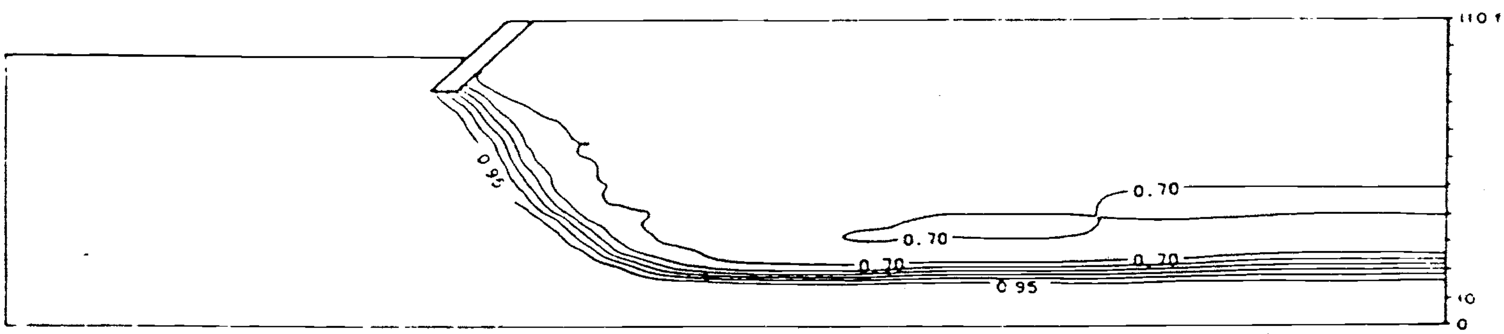
Figure 3. Wetting front patterns for case la.



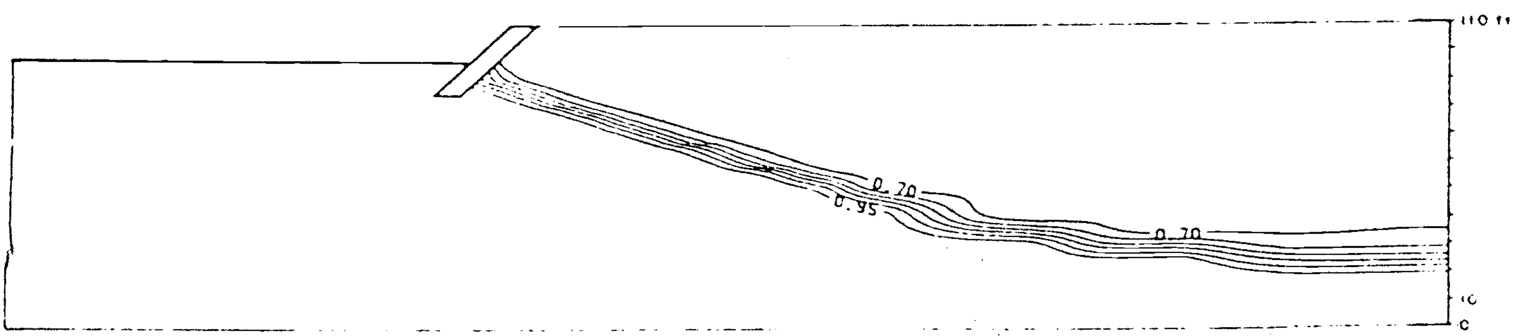
a) Degree of saturation after 1 hour of simulation.



b) Degree of saturation after 5 hours of simulation.



c) Degree of saturation after 10 hours of simulation.



d) Degree of saturation after 25 hours of simulation.

Figure 4. Wetting front patterns for case 1b.

construction. Bank protection prevents lateral infiltration into the banks and thus restricts the flow to a downward direction. This is shown more clearly when one considers hydraulic heads as we proceed to do.

Total hydraulic head reflects the sum of elevation head and water pressure head at given points in the system. Differences in total hydraulic head across a distance provide the force to drive water through a flow system. Lines of equal total head for Case 1a are shown in Figure 5 at 1 hour, 5 hours, 10 hours, and 25 hours. The corresponding set of curves for Case 1b are included as Figure 6. Arrows drawn perpendicular to these equipotential lines, show the direction of subsurface flow at selected points. The plots for Case 1a show that the equipotential lines are nearly horizontal during the early stage of infiltration, except near the banks. Accordingly, flow is vertically downward except for a lateral component near the channel banks. At 10 hours lateral flow becomes evident throughout the simulated section. This, to some extent, is an artifact of the no-flow boundary condition imposed 10 ft below the water table which precludes water from continuing its journey downward beyond this elevation. In reality, lateral flow is expected to be less pronounced than shown in Figure 4c.

In Case 1b flow is seen to be forced around the structure first vertically and later also laterally. By comparing the flow lines for Case 1a and Case 1b, it is evident that the soil-cement structure impedes lateral infiltration into the bank above the channel bottom as well as below it down to a depth 12 ft.

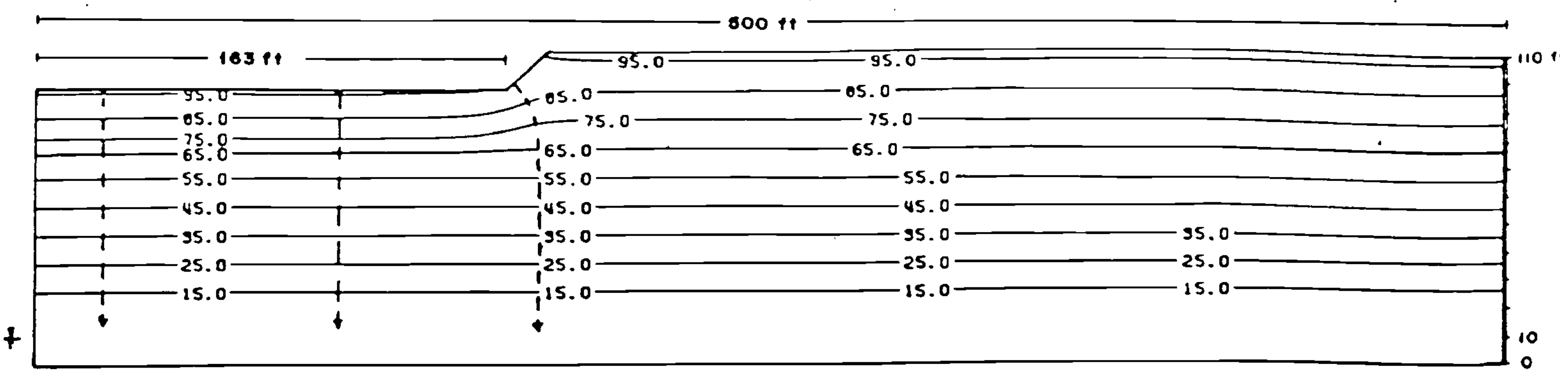
3.1.3 <u>Case 2: Narrow Channel With Bank Protection</u>

3.1.3.1 <u>Infiltration Relationships</u>

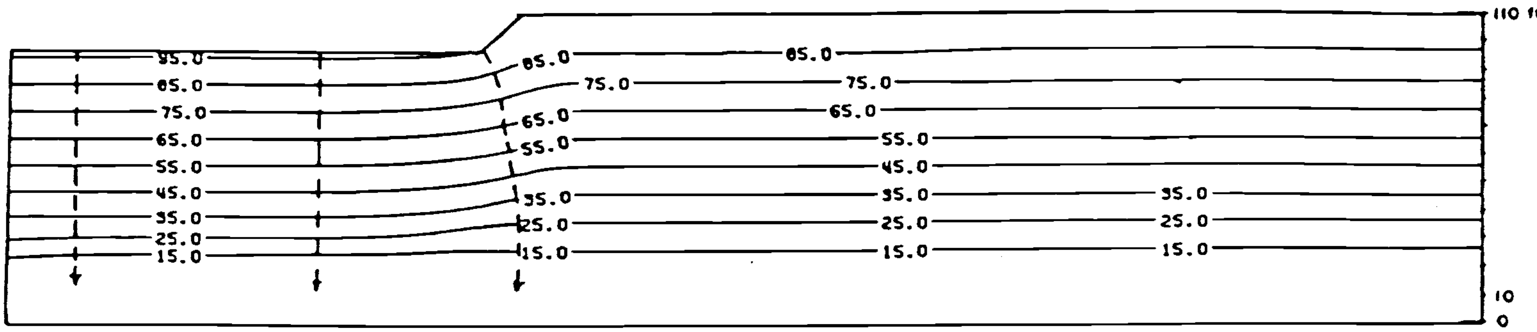
Infiltration curves for Case 2a, the 202 ft channel before bank protection, and for Case 2b, the same channel after bank stabilization, are depicted on Figure 7. As shown, the final, 90 hr, infiltration rate is 1.24 ft/day for the initial channel, compared to 2.22 ft/day for the stabilized channel. The rates are well within the range of 1.1 to 3.7 ft/day cited by Keith (1980) as being representative for the Rillito River, and the rate of 1.7 ft/day found by Cluff,Katz, and Scovill (1987) * for a runoff event in February, 1985.

The infiltration curves show the classical decrease in rate with time. The sudden decrease in rates at about 6 hours into the simulation, after the initial decrease and levelling off, corresponds to the time that the advancing wetting front contacts the water table.

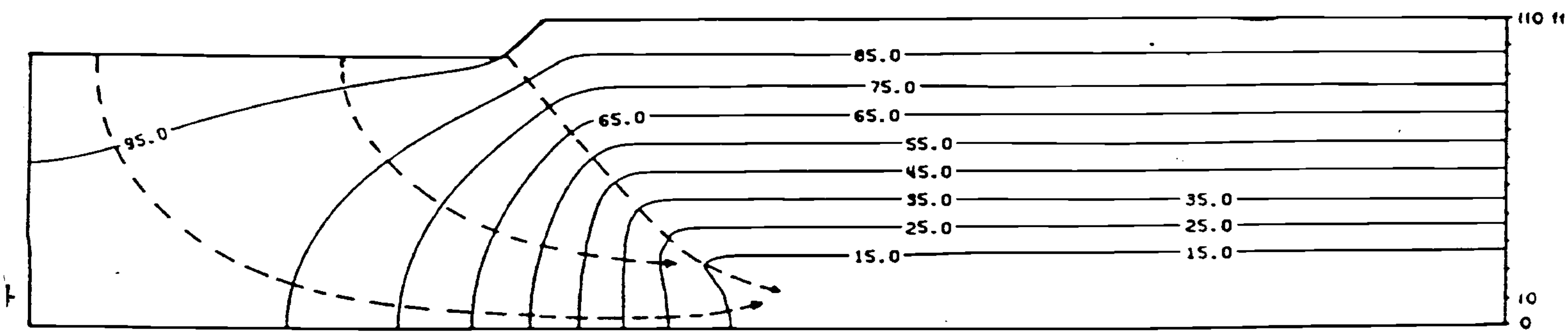
The infiltration rates for the second case (narrow channel) are greater than those for the first case (wide channel) because of the greater stage in the channel throughout the flow event. The cumulative intake curves for Case 2a and 2b are included as Figure 8. As shown, the cumulative infiltration is consistently less for the bank-stabilized channel than for the initial channel. The cumulative inflow 25 hours into the simulation is 3057.0 cubic feet for Case 2a compared with 2651.0 cubic feet for Case 2b. This amounts to a 13.28 percent reduction, caused by the effect of bank protection. The corresponding values at the end of the



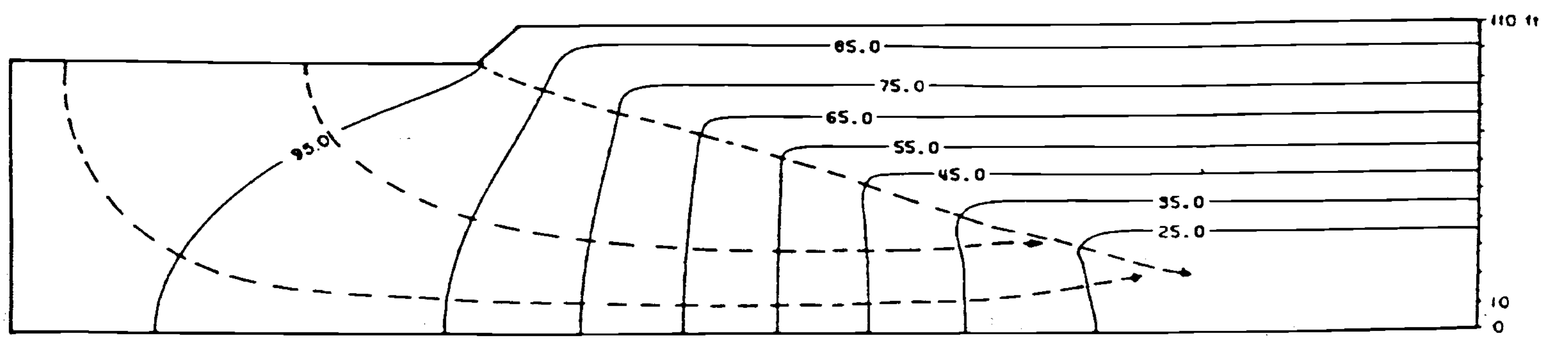
a) Total head distribution after 1 hour of simulation.



b) Total head distribution after 5 hours of simulation.

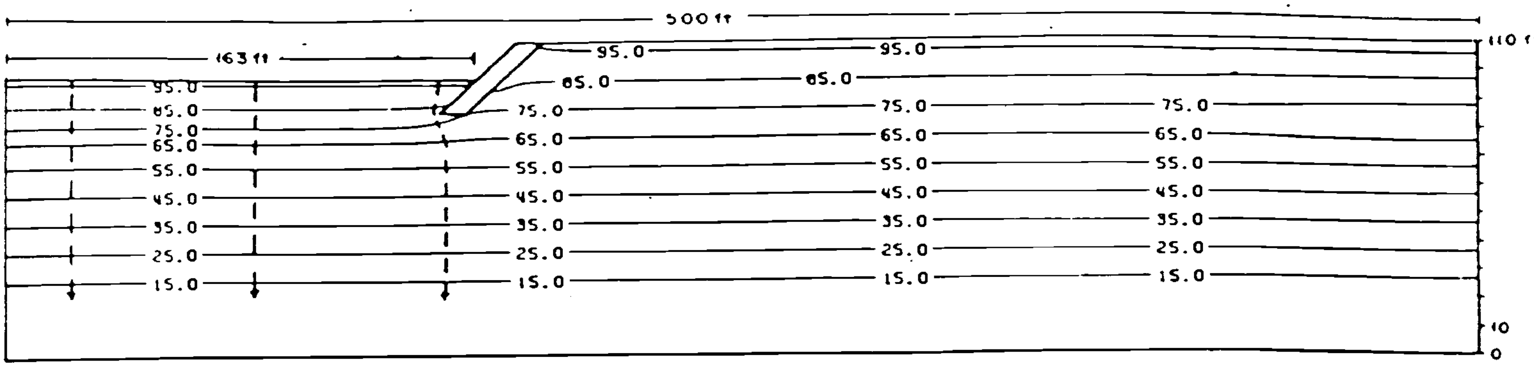


c) Total head distribution after 10 hours of simulation.

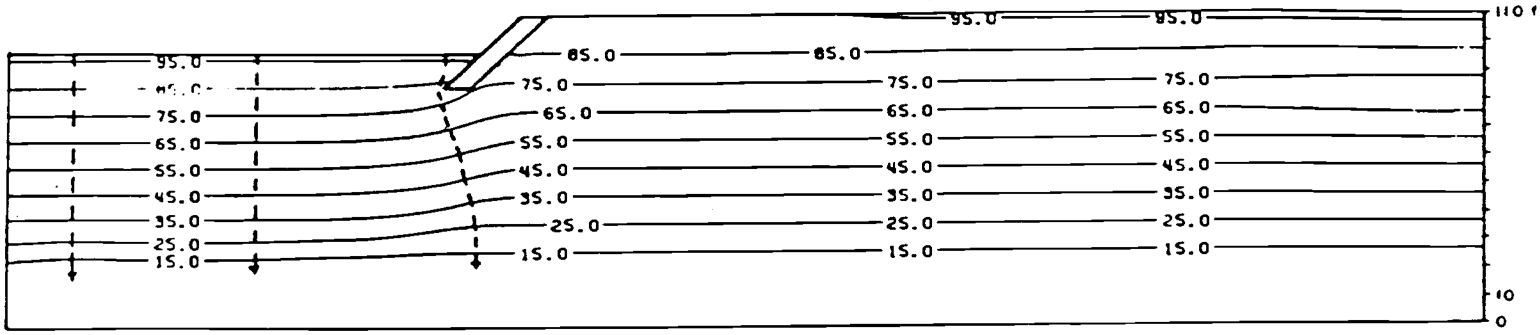


d) Total head distribution after 25 hours of simulation.

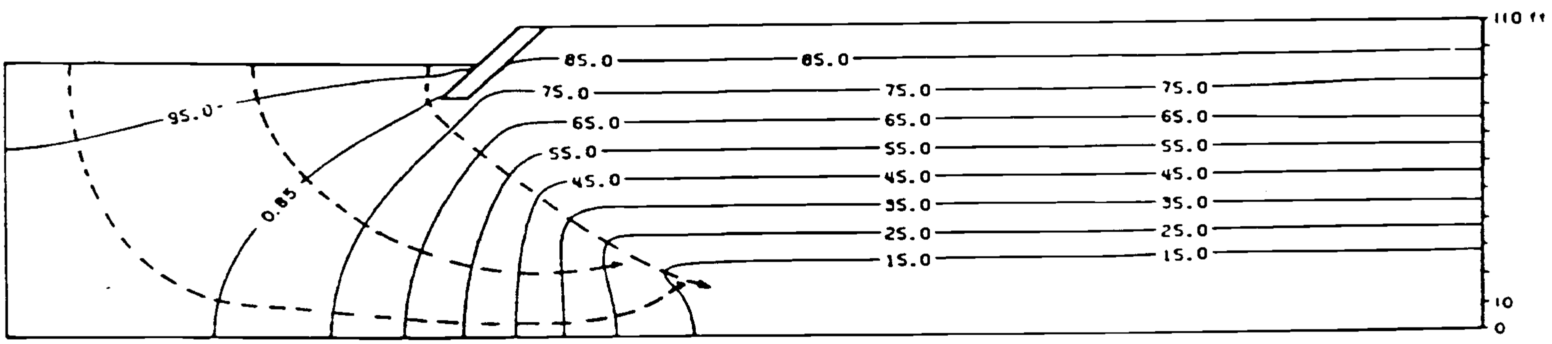
Figure 5. Total head distribution and flow pattern for case 1a.



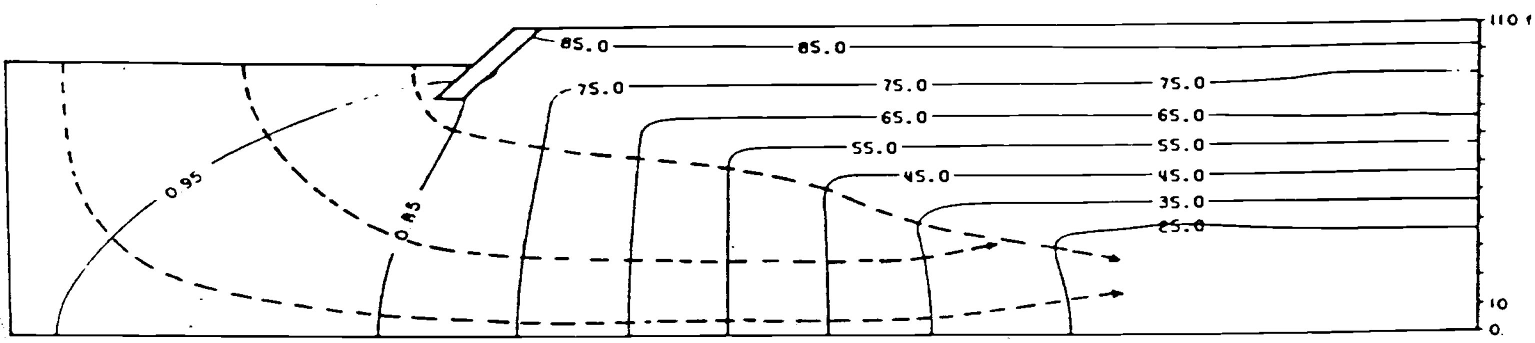
a) Total head distribution after 1 hour of simulation.



b) Total head distribution after 5 hours of simulation.



c) Total head distribution after 10 hours of simulation.



d) Total head distribution after 25 hours of simulation.

Figure 6. Total head distribution and flow pattern for case 1b.

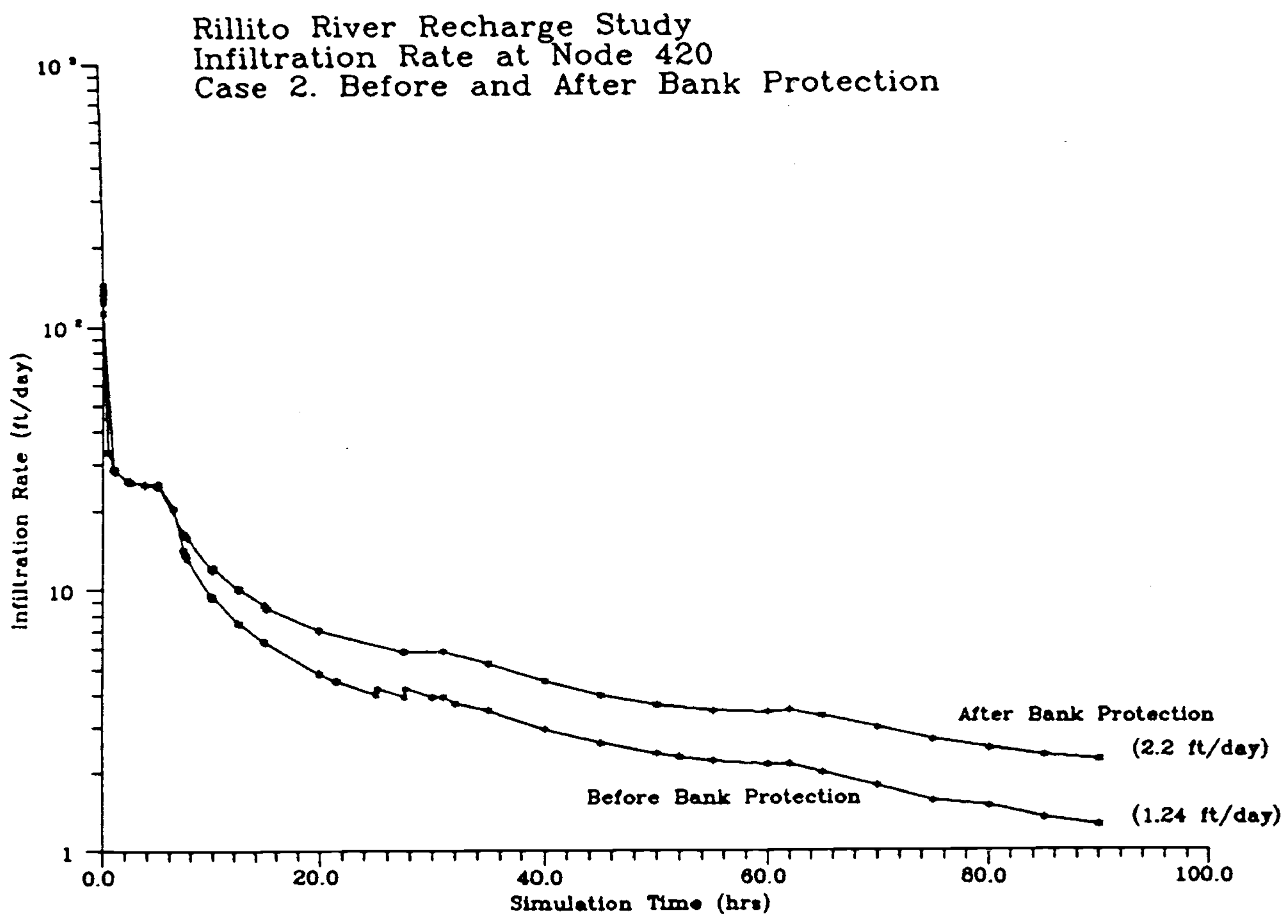


Figure 7. **Infiltration rate at node 420 for case 2 (narrow channel) before and after bank protection.**

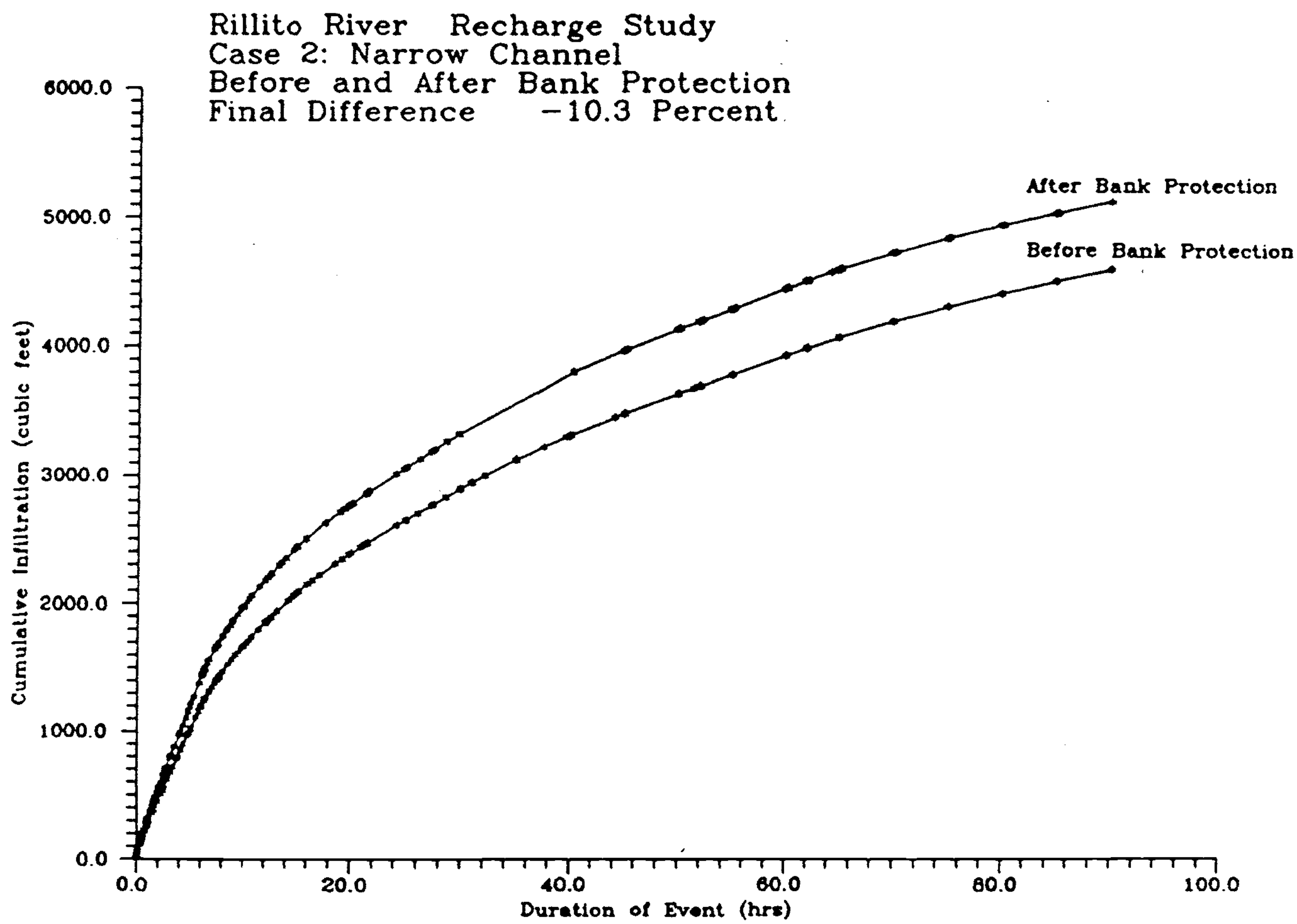


Figure 8. **Difference in cumulative infiltration for case 2 (narrow channel) before and after bank protection.**

flow event are 5121 and 4595 cubic ft for case 2a and 2b, respectively. The percentage difference is 10.3.

Comparing results from Case 2 with those from Case 1, clearly shows that the cumulative inflows for the wider channel are greater, despite the larger infiltration rates for the second case. This result is expected because the larger wetted surface in the first case allows more water to infiltrate despite the reduced head in the river.

3.1.3.2 Subsurface Water Content Profiles

Water content profiles are shown at 1, 5, 10, and 25 hours in Figure 9 for case 2a, and Figure 10 for case 2b. These figures illustrate that flow takes place vertically downward during the early hours of the flow event, spreading laterally inland in the vicinity of the water table as time progresses. As in Case 1, the water table is intercepted by the advancing wetting front between 5 and 7 hours into the simulation. Ground-water recharge commences thereafter. It is evident that the embankment structure impedes the lateral movement of water through the channel sides into the vadose zone. The volume of vadose zone saturated at a given time in Case 2a is greater than in Case 2b due to this effect even though the wetted profile is deeper in Case 2b. After ten hours the wetted profile has advanced further inland in Case 2a than in 2b.

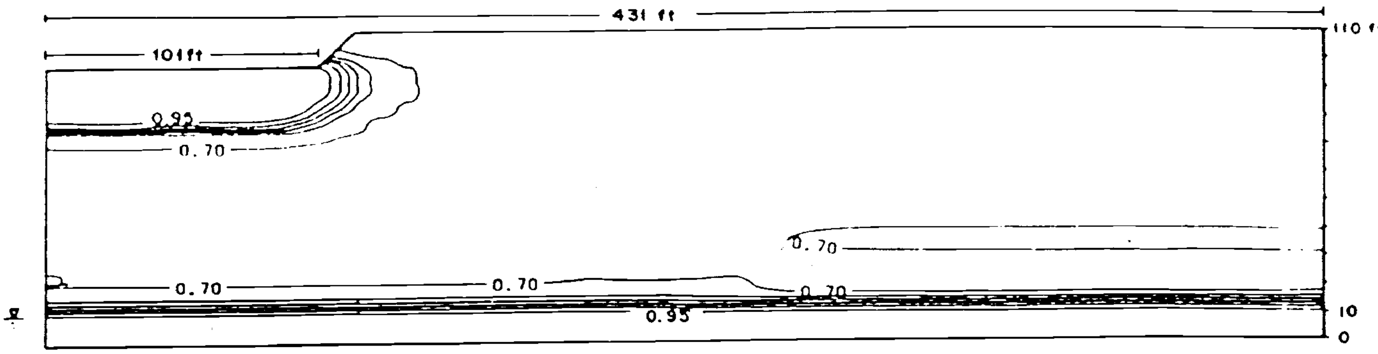
The total head distribution and flow patterns in the modeled profile at 1, 5, 10, and 25 hours into the simulation are depicted in Figure 11 for Case 2a, and on Figure 12 for Case 2b. It is seen that bank protection causes the flow lines to curve around the embankment structure as time progresses. This decreases the volume of infiltration. Lateral flow is more than expected due to imposition of an artificial impermeable horizontal boundary 10 ft below the water table.

3.1.4. Case 3: Channel Widening With Bank Protection

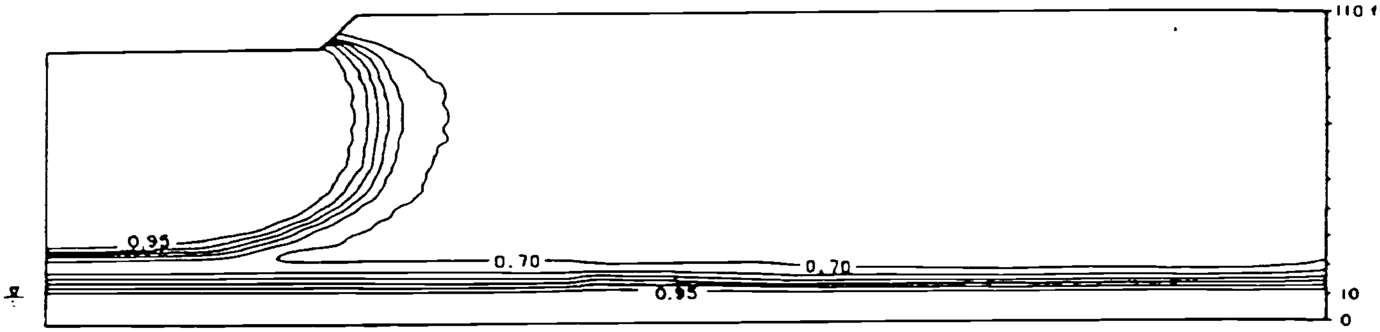
As mentioned in a previous paragraph, the results of the simulations for two base cases are used to generate four additional flow situations. Here we discuss the most realistic situation of channel modification: widening coupled with bank protection.

3.1.4.1 Infiltration Relationships

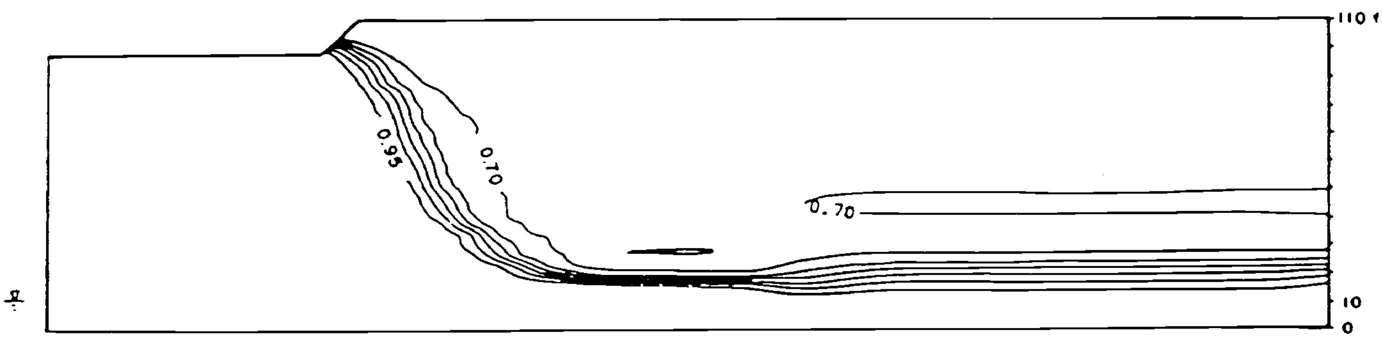
The infiltration rate curve for Case 2a (Figure 7) represents conditions prior to construction and the curve for Case 1b (Figure 1) those after construction. Infiltration rates are seen to decrease due to widening because the hydraulic head in the channel is lower for a given flow rate. However, the cumulative infiltration volume is larger. This is depicted on Figure 13. At 25 hours the cumulative inflow for Case 3b is 3698 cubic feet compared to 3057 cubic feet for the narrow, original section, Case 3a. This amounts to a 21.0 percent increase due to bank protection when accompanied by channel widening. The associated values for case 3a and 3b at 90 hours are 5121 and 5657 cubic ft, respectively. This difference amounts to 10.5 percent.



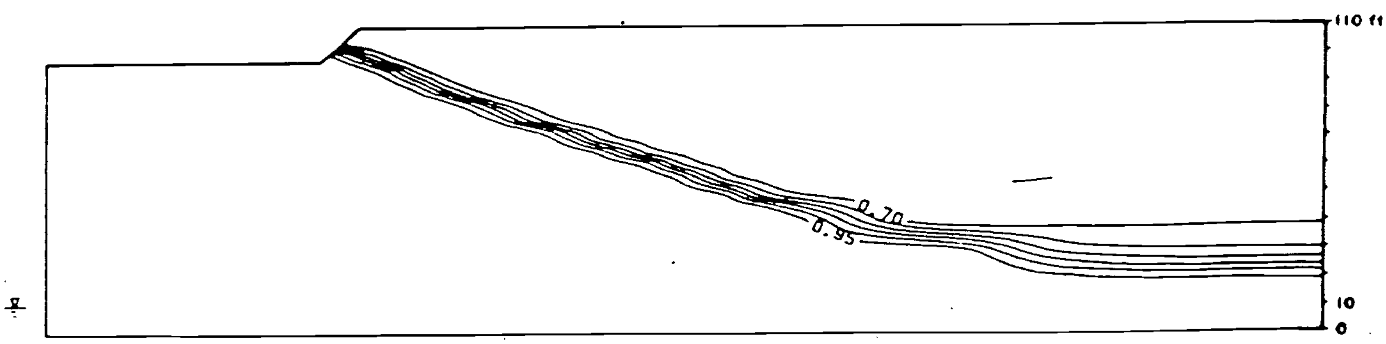
a) Degree of saturation after 1 hour of simulation.



b) Degree of saturation after 5 hours of simulation.

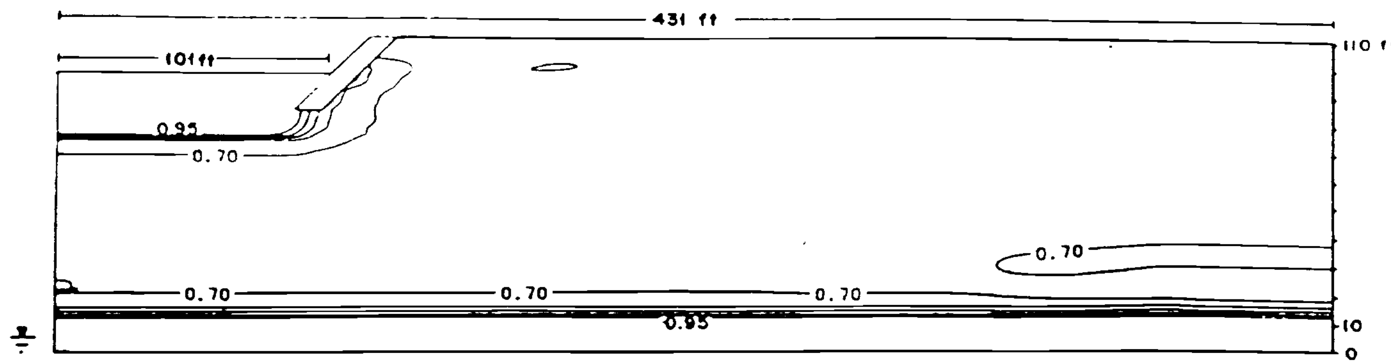


c) Degree of saturation after 10 hours of simulation.

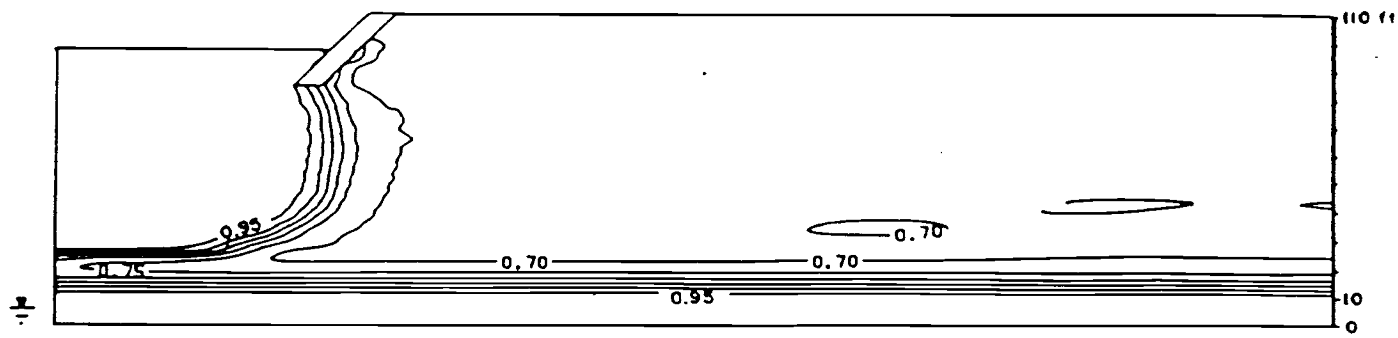


d) Degree of saturation after 25 hours of simulation.

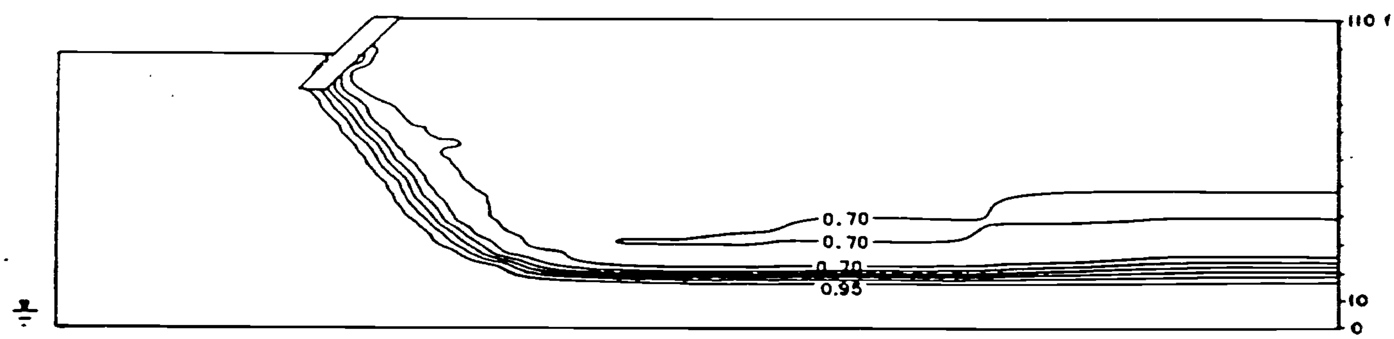
Figure 9. Wetting front patterns for case 2a.



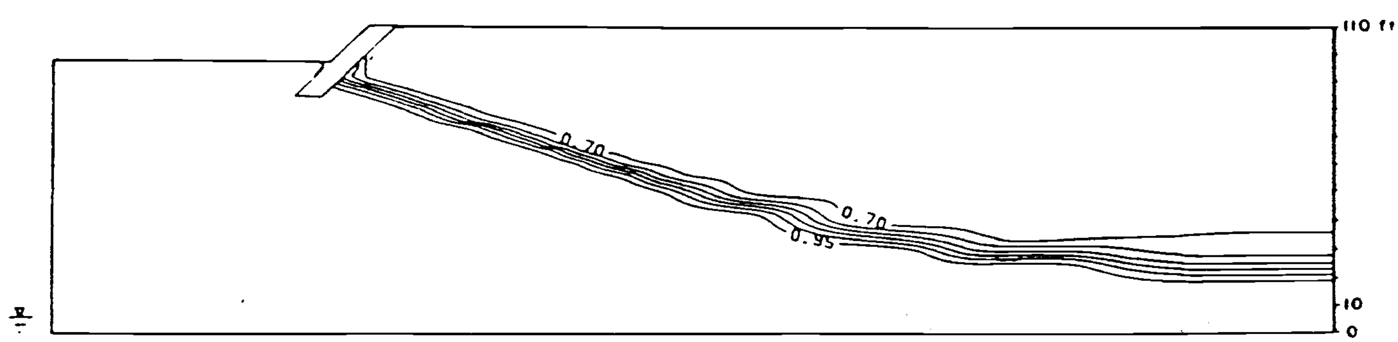
a) Degree of saturation after 1 hour of simulation.



b) Degree of saturation after 5 hours of simulation.

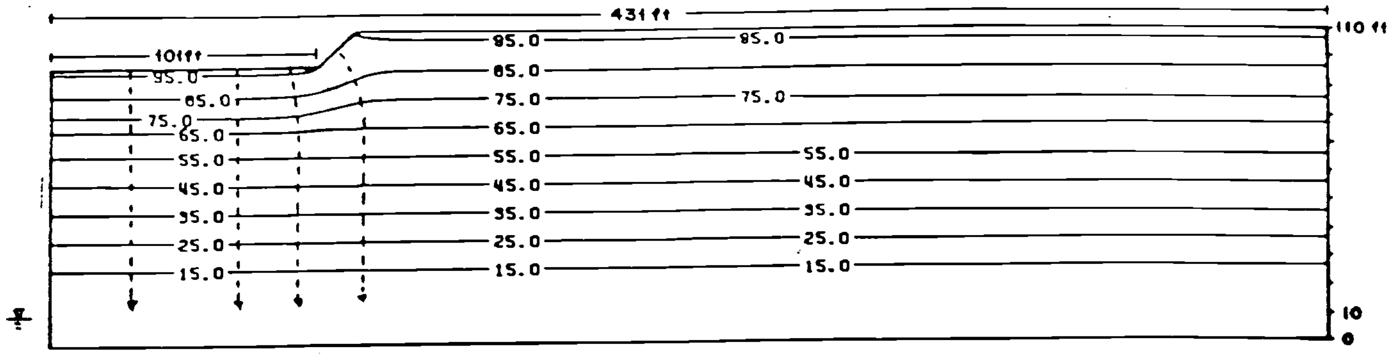


c) Degree of saturation after 10 hours of simulation.

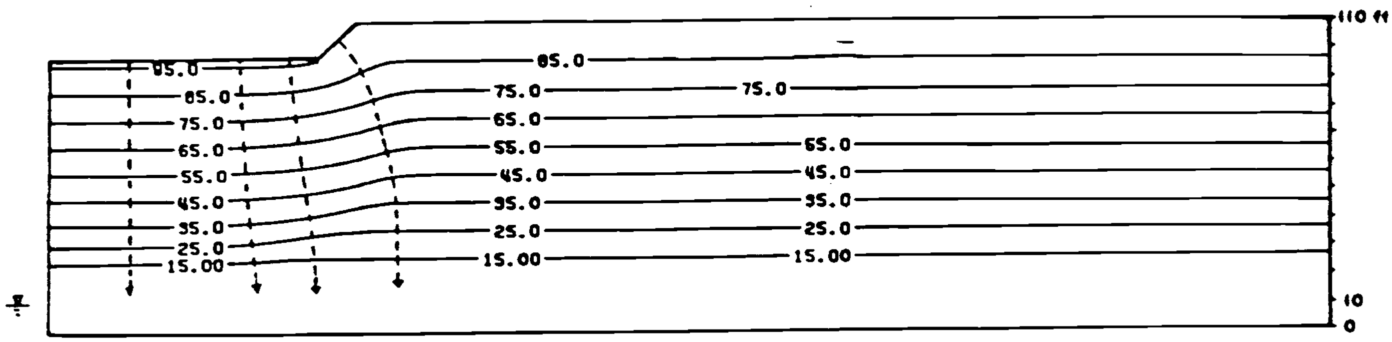


d) Degree of saturation after 25 hours of simulation.

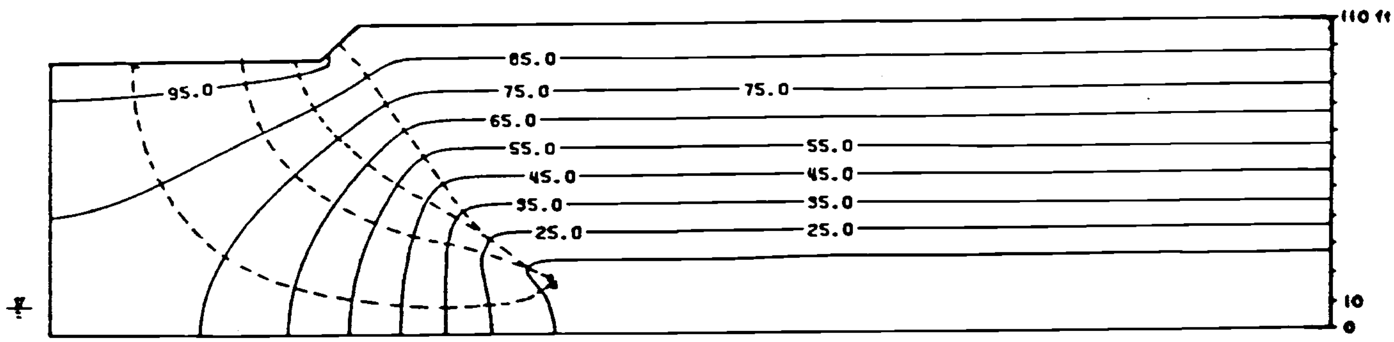
Figure 10. Wetting front patterns for case 2b.



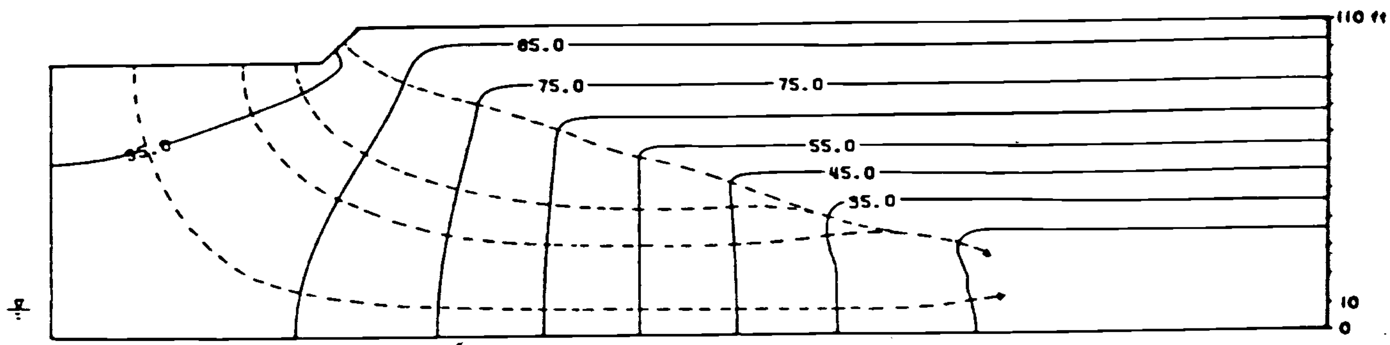
a) Total head distribution after 1 hour of simulation.



b) Total head distribution after 5 hours of simulation.

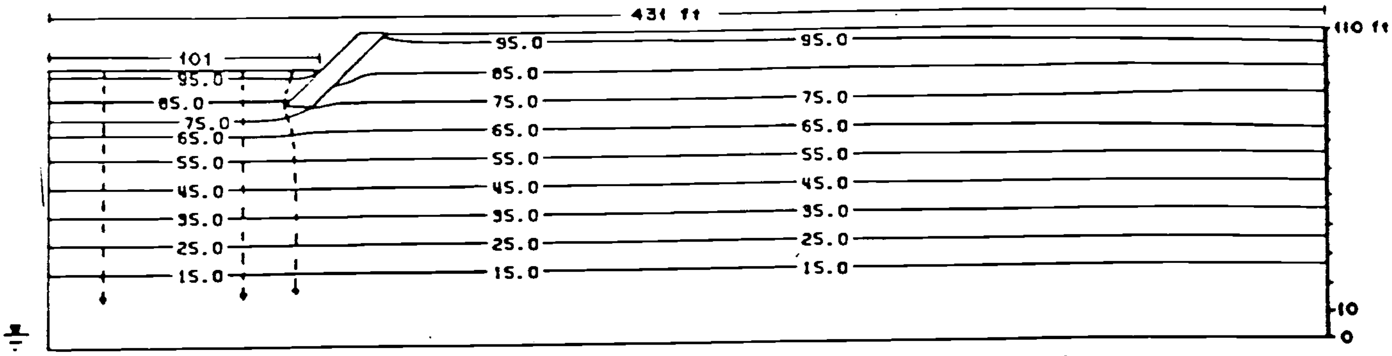


c) Total head distribution after 10 hours of simulation.

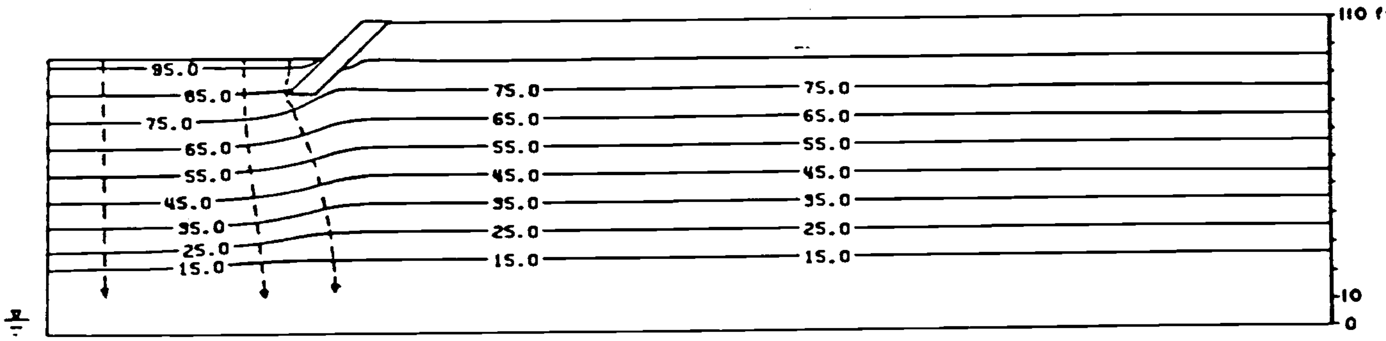


d) Total head distribution after 25 hours of simulation.

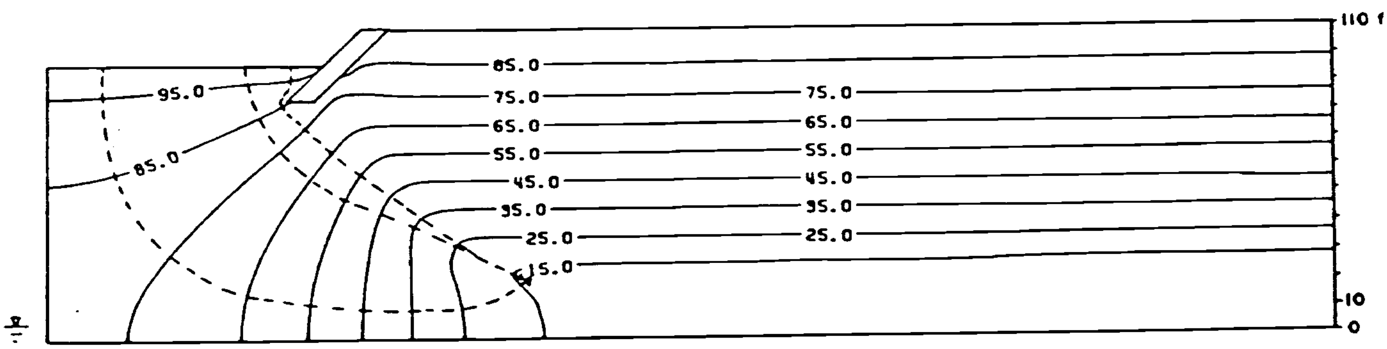
Figure 11. Total head distribution and flow pattern for case 2a.



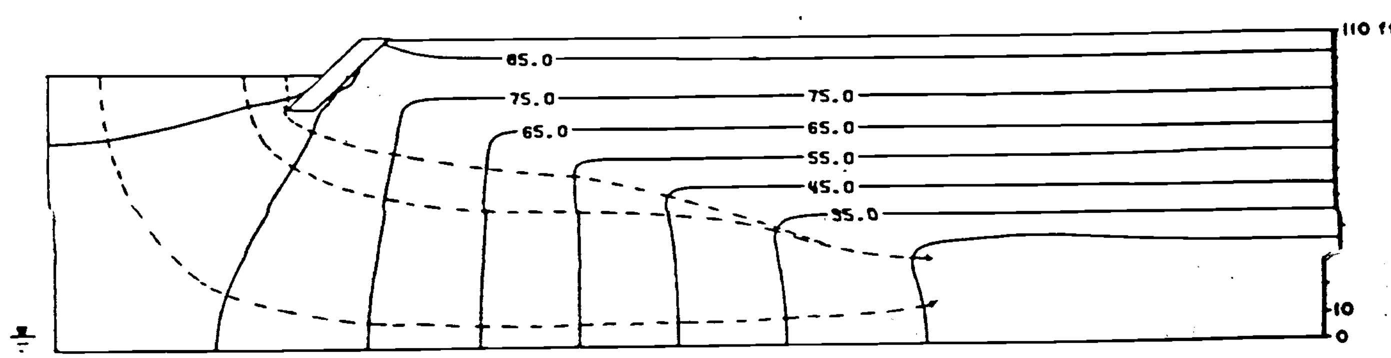
a) Total head distribution after 1 hour of simulation.



b) Total head distribution after 5 hours of simulation.



c) Total head distribution after 10 hours of simulation.



d) Total head distribution after 25 hours of simulation.

Figure 12. **Total head** distribution and flow pattern for case 2b.

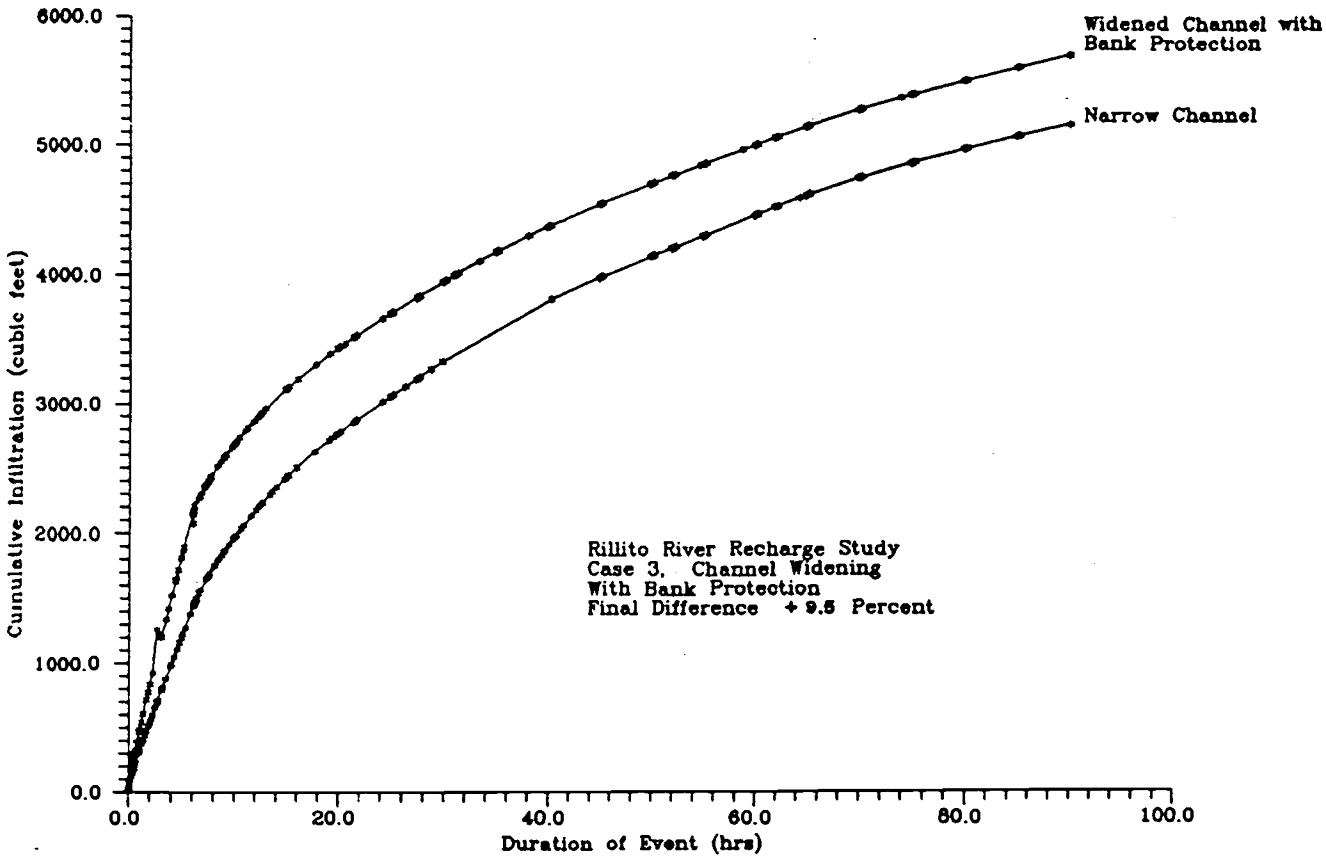


Figure 13. Difference in cumulative infiltration for case 3: channel widening with bank protection.

Widening of a stream channel exposes fresh geologic sediments to infiltration. These deposits may be more or less receptive to infiltration than the original river-bed sediments. In our model, we assumed that these fresh deposits are of the same texture as the original river-bed sediments. The rationale for this assumption is that two off-channel textural logs were used when arriving at the generic texture, sandy loam. These logs are designated 5B and 6B (see Table 1, Volume I). Accordingly, the effect of fresh river-bed sediments on infiltration is not a factor in this study.

3.1.4.2 Subsurface Water Content Profiles

Subsurface water content profiles are depicted on Figure 9 for Case 3a and Figure 4 for Case 3b. The same diagrams also correspond to Case 2a and Case 1b, respectively. As described previously, the wetting front advances rapidly and reaches the water table sometime between 5 and 7.5 hours in both cases. The embankment structure impedes lateral infiltration into the banks and the upper part of the vadose zone. However, this is offset by the larger infiltration surface of the channel bottom resulting from channel widening. Accordingly, the saturated region in the post-construction section is greater than in the original, narrower section.

Contours of total head and arrows showing flow directions for Case 3a and Case 3b are the same as for Case 1b and Case 2a. These are shown on Figures 6 and 11, respectively. Flow is seen to be vertically downward during the first hour with some lateral flow occurring by the fifth hour. Lateral flow is more pronunced than anticipated under realistic conditions due to the artificial no-flow boundary below the water table. The embankment structure impedes bank flow and lateral flow in the near-surface region of the vadose zone. However, the density of flow lines is greater for Case 3b as a consequence of channel widening.

In summary, Case 3 represents the case of channel modification and bank stabilization along the Rillito River. According to the results of the simulation, channel widening more than offsets the adverse effect of reduced infiltration due to bank protection. Consequently, the cummulative infiltration is greater for the post-construction channel.

3.1.5 Case 4: Channel Narrowing With Bank Protection

This case represents an atypical situation in which an originally wide channel (326 ft) is narrowed to 202 ft accompanied by bank protection.

3.1.5.1 Infiltration Relationships

Infiltration relationships for Case 4a and Case 4b correspond to the curves for Case 1a and Case 2b, respectively. The associated curves are on Figures 1 and 7, respectively. As shown, the final infiltration rate for the post-construction channel is greater than for the wider, original channel. The difference is attributable to greater heads in the narrower channel following modification.

The marked effect of channel narrowing coupled with soil-cementing of the banks, is shown by the cumulative infiltration curves on Figure 14. Despite the higher heads in the channel during the Case 4b event, the cumulative inflow is considerably greater throughout the event for the original channel because the surface area available for infiltration was larger. At 25 hours, the cumulative inflow for the original channel is 4038 cubic feet, compared with 2651 cubic feet for the modified channel. The percentage difference between the two cases at 5 hours is approximately -34. At 90 hours the cumulative infiltration are 6114 and 4595 cubic ft for case 4a and 4b respectively, a 25 percent difference.

3.1.5.2 Subsurface Flow Patterns

Subsurface flow patterns for Case 4a and 4b correspond to these depicted earlier for Case 1a and Case 2b in Figures 3 and 10. Subsurface flow for the narrowed and bank stabilized section is constrained primarily to the vertical direction, in contrast to the situation for Case 4a, the preconstruction section, where lateral flow components are more prominent. In addition, the volume of pore space in the vadose zone available for water storage beneath the channel is diminished by constricting the channel. Accordingly, the volume of water in storage at any given time is greater for the original section.

The head contours and flow diagrams for Case 4a and 4b are those of Case 1a and 2b shown in Figures 5 and 12, respectively. The embankment is seen to restrict lateral flow through the sides of the channel and through the near-surface vadose zone.

In summary, the case of a wide channel section that is narrowed and bank protected by soil cement is examined. The effect of channel narrowing reduces the opportunity for recharge. Similarly, the embankment effecively reduces lateral infiltration into the sides of the bank and near-surface vadose zone. The overall effect is to cause a 34 percent reduction in cumulative intake at 25 hours, and a 25 percent reduction at 90 hours. Obviously, this situation should be avoided.

3.1.6 Case 5: Channel Widening Without Bank Protection

Case 5 is included as an example of the effect that channel widening without bank protection would have on overall recharge efficiency.

3.1.6.1 Infiltration Relationships

The infiltration rate curves for cases 5a and 5b are identical to the curves for Case 2a and 1a in Figures 7 and 1, respectively. The influence of channel widening on cumulative infiltration during the 90 hour flow event in the Rillito River is depicted by the curves on Figure 15. As shown, the cumulative infiltration is consistently greater for the widened channel than for the original, narrow section. Accordingly, the increased surface area available for infiltration in the modified channel more than compensates for the loss in head in the channel during the flow event. Total inflow at 25 hours is 3057 cubic feet for the narrow

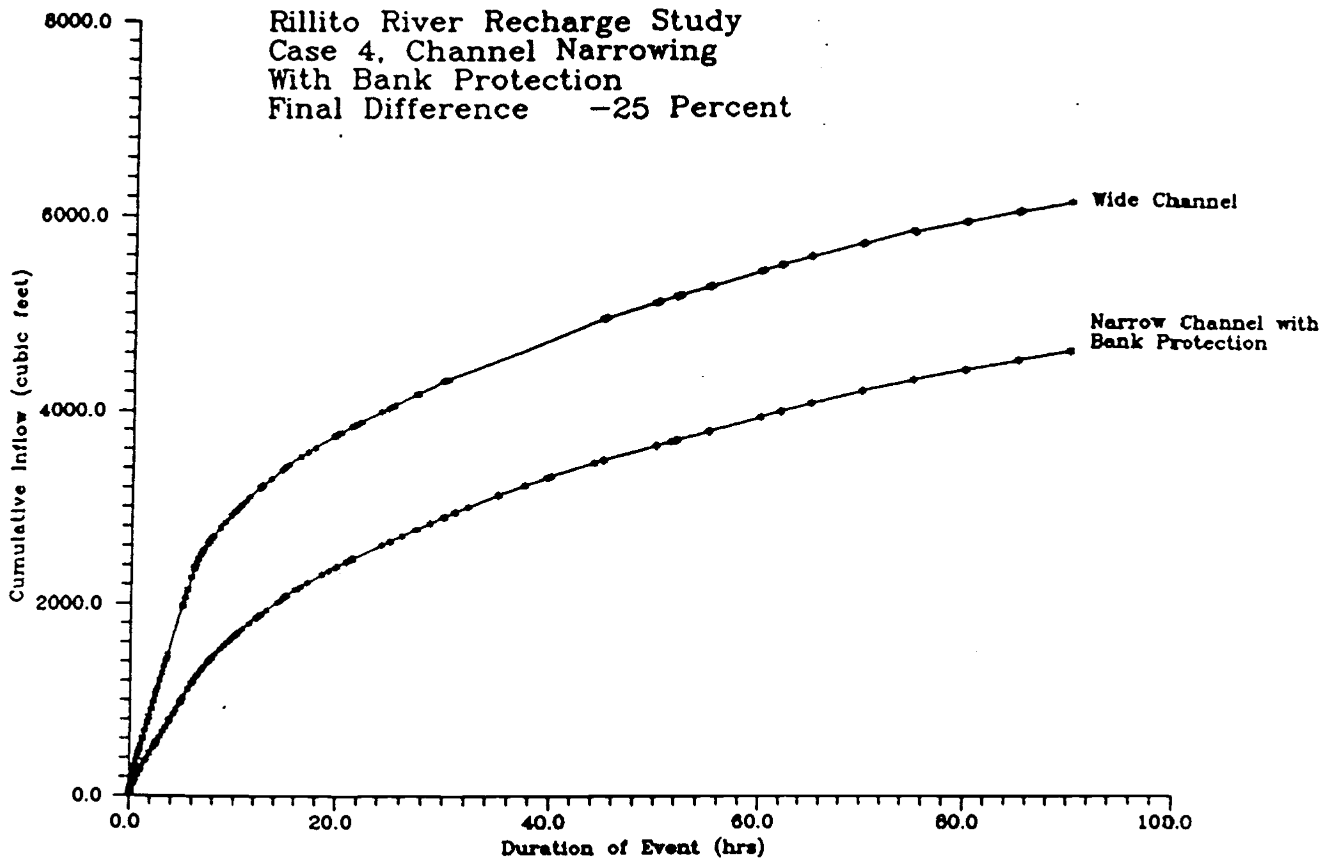


Figure 14. **Difference in cumulative infiltration for case 4: channel narrowing with bank protection.**

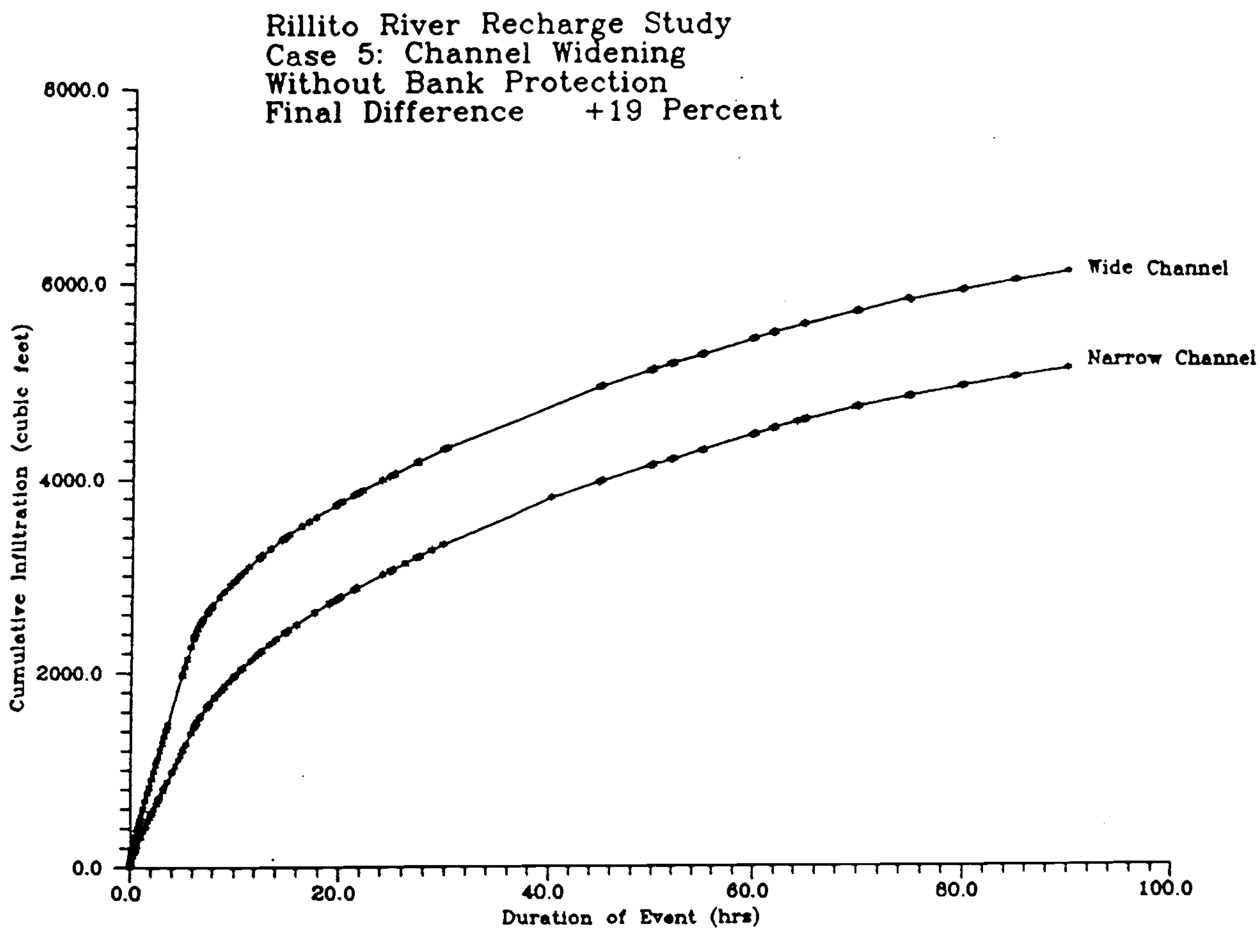


Figure 15. **Difference in cumulative infiltration for case 5: channel widening without bank protection.**

section, compared with 4038 cubic feet for the widened section. The percentage increase in infiltration and recharge is 32. Corresponding values for 90 hours are 5121 and 6114 cubic ft for case 5a and 5b, respectively. The percentage difference is 19.

3.1.6.2 Subsurface Flow Patterns

Wetting front patterns for Case 5a and Case 5b are identical to the patterns for Case 2a and Case 1a, respectively. These flow configurations are depicted on Figures 9 and 3, respectively. For each of the subcases of Case 5, infiltration is not impeded by soil cement on the banks. During both Case 5a and Case 5b, recharge across the water table first occurrs between 5 and 7.5 hours into the simulation. The bulk volume of the vadose zone saturated by infiltration is obviously greater for the enlarged channel than for the original narrow channel. Accordingly, the volume of water crossing the water table to recharge the ground-water system is also greater.

The total head relationships and flow patterns for Case 5a and Case 5b correspond to those for Case 2a and Case 1a, respectively. The associated diagrams for 1, 5, 10, and 25 hours into the simulation are included as Figures 11 and 5, respectively. Perusal of these figures shows that the pressure head distributions and flow patterns are similar for both cases. The major difference between the two systems is the larger area in which flow can occur for the enlarged channel, Case 5b.

In summary, this case is included to provide an indication of the effect of channel widening on infiltration and recharge during a 90 hour hydrograph in the Rillito River. The results of the simululation show that, as expected, infiltration and recharge are increased by widening, For the change depicted by this case, the overall increase in infiltration and recharge is 32 percent at 25 hours and 19 percent at 90 hours.

3.1.7 Case 6: Channel Narrowing Without Bank Protection

Case 6 represents the simulated results of infiltration and recharge during a 90 hour hydrograph in a section of the Rillito River that has been narrowed without being bank protected. Essentially, this case is the converse of Case 5.

3.1.7.1 Infiltration Relationships

The infiltration rate curves for Case 6a and Case 6b are identical to those for Case 1a and 2a as shown in Figures 1 and 7, respectively. The infiltration rate is increased by channel narrowing from 0.64 ft/day to 1.24 ft/day. The increased rate reflects the higher head in the narrowed channel, throughout the flow event and the bathtub effect.

The cumulative infiltration curves for these two subcases are depicted also on Figure 15. The cumulative infiltration is greatly diminished by reducing the channel cross-section. This, however, is not sufficient to compensate for the increased stage in the channel. At 25 hours into the simulated flow event, the total recharge volumes for Case 6a and Case 6b are 4038 cubic feet and 3057 cubic feet, respectively. This amounts to a 24.3 percent reduction in cumulative infiltration. Corresponding values at 90 hours are 6114 and 5121 cubic ft for case 6a and 6b, respectively. This amounts to a 16.2 percent difference.

3.1.7.2 Subsurface Flow Patterns

Wetting front patterns during the simulated flow event for Case 6a and Case 6b are identical to those patterns for Case 1a and Case 2a as shown in Figures 3 and 9, respectively. In both cases, the advancing wetting front merges with the water table and generates recharge sometime between 5 and 7.5 hours into the event. As bank protection is not present in this case to obstruct lateral inflows in the vicinity of the channel banks, the flow patterns for both cases are similar except that the saturated volume of the vadose zone is much greater in the original section than in the modified channel. Consequently, the volume of water crossing the water table to recharge the ground-water system is greatly diminished.

The total head and flow directions for Case 6a and Case 6b are identical to those for Case 1a and Case 2a as depicted in Figures 5 and 11. The general pattern is similar in both subcases except that the flow area is diminished in the second subcase.

In summary, this case is included to illustrate the effect of channel narrowing on infiltration during a flow event in the Rillito River. At the end of 25 hours, recharge is reduced by almost 25 percent. By 90 hours the difference had diminished to 10 percent. This is a substantial difference, showing that channel narrowing should be avoided whenever possible.