Technical Report No. 91

CENTRAL BASIN HYDROLOGIC PROCESS STUDIES

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GRASSLAND BIOME
U. S. International Biological Program

April 1971

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ABSTRACT

This report summarizes the objective and approach to the Central Basin Studies and reports the progress to date. In general, the objective of the Central Basin Study is to model the hydrologic behavior of the basin as a complement to the microwatershed studies. For modelling purposes the basin represents a much more complex system than the microwatersheds.

Progress during 1970 includes the preparation of a set of topographic maps of the basin, the tabulation of 30 year rainfall data from the ARS Network, and a field study of infiltration rates on four soil types and three grazing treatments.

CENTRAL BASIN STUDIES

Central basin studies are planned to complement the microwatershed studies to extend the interpretation of the hydrologic processes occurring on the microwatersheds to the entire basin. Central basin studies have been designed to provide information on the response of the major soil types that occur in the basin in terms of nominal infiltration and soil water depletion rates.

MODELLING APPROACH

Hydrologic models are validated by comparing the simulated hydrograph with the observed record. For grasslands, the conspicuous absence of developed channels points to the major difficulty of developing and validating a model of their hydrologic behavior. Although the rainfall input can be adequately characterized, the absence of channels precludes the accurate assessment of output. Obviously, the output occurs as the loss of water vapor, a much more difficult process to measure on an areal basis.

To model the hydrology of the central basin, a hierarchial simulation approach will be followed. Briefly, the approach begins by assembling independent models of the recognized processes in whatever form that they can be specified with a given state of knowledge. Some of them may be empirical, others theoretical, and still others, stochastic. Simulations would be carried out with the separate models to provide input (off-line) to each other. Reevaluation of parameters would be performed interactively until the submodels were inter-consistent. The output sequences of these models would then be aggregated, summarized, or used directly as information to another model in a higher echelon, where the level of abstraction, time scale, and spatial representation would be different from the lower echelon of submodels. The hierarchy of models would utilize existing computer programs and original codings to simulate the entire system.

The separate models for the different processes will be selected on the basis of their closeness to theory (where it exists), their clarity of physical interpretation, and for their parameter of function sensitivity to effects brought about through plant and cattle management. This will require screening models and applying either partial differential methods or numerical optimization techniques to determine sensitivity.

Because of the discrete nature of thunderstorm-events (both in time and in space) the simulation model will be a spatial, event-oriented model. Usually, most models operate continuously, using constant time increments at which the state of the system is calculated periodically, In contrast, event-oriented models recognize the recurrence intervals between events and perform calculations between events, independent of the length of the interval.

Synthesis of a simulation model like the one described will require that many data sets be generated. To do this, available data from the Agricultural Research Service will provide a basis. Such data now includes precipitation, temperatures, and soil water during the growing season. Also, data generation will be employed to utilize data presently being collected at the Pawnee Site and from other projects. This will include below- and aboveground biomass dynamics, plant pattern measurements, and micrometeorological measurements. Unknown relations and locally unavailable data will be simulated from literature results.

The model will be built to couple directly to a plant production model via the distribution of soil water tension at a specified depth. This model may be directly compared to the Stanford Watershed Model and the U.S. Geological Survey model. Using a common set of simulated input data, three models can be compared in terms of their sensitivity to "biotically" influenced parameters.

STATUS

Algorithms

An operating program for solution of kinematic cascades (spatially distributed over the basin) has been obtained and will be used as a subroutine in the main program. Given precipitation excess, the geometry of the planes, configuration of the cascades of flow, and estimates of the roughness parameter for each plane, the algorithm calculates the outflow from each plane as a function of time.

Topography

The basis for the kinematic solutions for overland flow is the set of cascading planes. To be meaningful, each plane should physically represent a soil/vegetation/grazing difference. To construct these planes, extensive use will be made of the specially prepared topographic map. This will provide the base for transferring vegetation and soil, and for using information to a common spatial reference. Additionally, the map will be used to locate existing ARS and Pawnee Site raingages.

The mapping was compiled on a 1 cm = 12 m (1 inch = 100 ft) horizontal scale and contoured at 0.6 m (2 ft) vertical elevations. The aerial photos from which the maps were compiled are 1:6000 photos, taken with a 155 mm (6 inch) lens to enhance vertical relief. The entire central basin is covered at a 1 cm = 12 m scale in six separate strips, each 1 m wide. A composite map on a 1 cm = 47 m (1 inch = 400 ft) scale was prepared from the individual strips.

The accuracy of this map allows precise definition of the watershed boundary and precise characterization of slope facets. At present, the map is being digitized by 3 m × 3 m (10 ft × 10 ft) cell elements for another specific project.

Precipitation

Continuous rainfall records are available for gages at microwatersheds 2, 5, 6, 7, and 8 from May 1970 to present. During the growing season, the gages are operated with a chart speed (~5 cm/hr) that permits accurate measurement of the high rainrates characteristic of thunderstorms. From October through March, gages are operated at a chart speed of about 4 cm per day.

Historical rainfall records for the growing season have been obtained from the Agricultural Research Service. The data represent storm amounts collected over a 39 km^2 area from 27 gages. The record begins in 1940 and continues. The data appear in Technical Report No. 74 (Smith 1971). This data and those from Technical Report No. 17 (Bertolin and Rasmussen 1969) will be used to generate distributions for amounts and times between events for simulation.

Infiltration

Simulated rainfall experiments were performed on the major soil series that occur in the central basin. These were accomplished through the cooperation of Frank Rauzi, Agricultural Research Service, SWC. The major soil series in the central basin are Ascalon, Shingle-Renohill complex, and an undifferentiated soil that occurs in the swales. For each pasture, three rainfall simulation runs were carried out on each soil series, making a total of 27 simulations. From the rainfall simulation, runoff was measured and infiltration was calculated as the difference between rainfall and runoff.

The equipment used for simulating rainfall was a raindrop applicator developed by the Soil Conservation Service (Ellison and Pomerene 1944). The unit used on the Pawnee Site was the same one used in the extensive collection of infiltration data in the Central and Northern Great Plains (Rauzi and Fly 1968). Basically, the unit consists of a spray nozzle, a drip screen, and a metal bordered runoff plot. Water is supplied at a constant rate, and runoff is measured every five minutes as a five-minute integrated sample. Ordinarily, runs continue for an hour.

The rainfall simulation data collected for each run consisted of the initial application rate, the elapsed time from t(0) until runoff began, 12 five-minute runoff volumes, and a final application rate at the end of one hour. During the simulation, the depth of the wetted profile was measured at five-minute intervals during the first 0.5 hour and at 10-minute intervals for the second 0.5 hour. For one plot, psychrometric tensiometers were installed at -5, -10, -20, and -30 cm. Soil water tensions were measured prior, during, and after the run. Prior check-out measurements were made during the previous afternoon. One-half hour before the run on the following day, tensions were again read. During the run, readings were taken at 5-minute intervals for the first 15 minutes and at 10-minute intervals for the remaining 45 minutes. After the application of water ceased, measurements were continued at hourly intervals for seven hours.

Descriptive information was measured for each plot. This included treatment, soil series, local plot slope, herbage weight by species, litter, and initial soil water content.

Infiltration was calculated as the difference between cumulative "rainfall" and accumulated runoff. Cumulative infiltration was then fitted to the first two terms of the Philip's model (Philip 1957*a*). The model is:

$$F = St^{\frac{1}{2}} + At ,$$

where F is the cumulative infiltration, t is time, and S and A are parameters. S and A are functions of soil water content and therefore are not really constant parameters. However, for the case at hand, soil water content was nominally the same for all plots, and for comparison, S and A were treated as constants. S is sorptivity, the property of the porous media embracing both absorption and desorption characteristics. In order of magnitude, A is equal to two-thirds the saturated conductivity (Philip 1957*b*). For the model fitted, the units of F are inches; the units of t are hours; the units of S are $\text{cm}/\sqrt{\text{hour}}$; and the units of A are cm/hour.

The data from three runs on the same soil series in a given treatment were pooled for the equations given in the following table. The coefficient of determination (R^2) for each of the nine equations was greater than 90%. The standard error of estimate varied between 2 and 4 mm.

Soil Series	Treatment	S	A
Ascalon	H	2.0	0.7
	M	1.0	4.0
	L	1.0	3.5
Shingle-Renohill	H	2.5	.0
	M	2.3	.0
	L	2.8	.0
Undiff.	H	2.0	0.7
	M	1.0	4.3
	L	1.8	2.5

Interpretation of these results indicates that the effects of moderate and light grazing on infiltration are indistinguishable on the three soil series. On the Ascalon and the undifferentiated soil series, heavy grazing has a pronounced effect on infiltration. On the Shingle-Renohill complex, infiltration was the same for all treatments. This result was not unexpected, since this soil complex contains about 25% clay in the 0 to 15 cm horizon (compared to 15% clay in the same horizon of the Ascalon and the undifferentiated soil series). Figures illustrating comparison of infiltration rates by soils, treatments, and soils and treatments combined appear at the end of this report in Appendix I.

Attention should be brought to the antecedent soil water prevailing at the time these runs were made. Soil water content (gravimetric) of the top 4 cm was about 4%. Very likely, this represents the condition for which infiltration is a maximum.

To examine the relative influence of S and A in the model, it is useful to compare them as standardized coefficients. The table below is similar to the previous one, except S and A are expressed as standardized coefficients. The interesting pattern to observe is: on the Ascalon and the undifferentiated soil series, under either the moderate or light grazing treatment, the A (gravity) term dominates the infiltration. It is three times as influential as the S' (capillary) term. On these same soils, but under the heavy grazing treatment, the relative importance of A' and S' is reversed, with S' dominating infiltration, being three times as important as A'. This implies that heavy use causes structural changes in the top layers of the soil that impede water movement through the surface layer. While there is some complementary relation between S' and A' on the Ascalon and the undifferentiated soils, S' completely controls infiltration on the Shingle-Renohill complex regardless of treatment.

Soil Series	Treatment	S'	A'
Ascalon	H	.75	.23
	M	.21	.79
	L	.23	.75
Shingle-Renohill	H	1.00	.00
	M	1.00	.00
	L	1.00	.00
Undiff.	H	.73	.26
	M	.24	.76
	L	.46	.54

Simple correlations in the following table illustrate interrelationships between plot, runoff, and infiltration characteristics.

	1	2	3	4	5	6	7	8
1	1				-.54	-.50		
2		1	.84			.55	-.68	.69
3			1			.66	-.70	.75
4				1	.53			
5					1			
6						1	-.63	.89
7							1	-.92
8								1

Number	Characteristic
1	local plot slope
2	plant litter
3	total herbage
4	time to ponding
5	time to runoff
6	infiltration at .5 hours
7	S
8	A

Signs of the correlations are those that would be expected. The high inverse relation between S and A points out their complementary nature.

The Philip model is only one of a large number of infiltration models. However, it is one of the more tractable, physically based ones. For comparison, the data will be fit to other commonly used models.

Soil Water Redistribution

One of the plots that received simulated rainfall was instrumented with psychrometric tensiometers before the run. The instrumented plot was on the Ascalon soil in the light-use pasture. A day before the run, tensiometers were placed at 5, 10, 20, and 30 cm and allowed to equilibrate. Microvolt readings were converted to water potential, using the standard manufacturers calibration of 0.47 μv/bar. The water potentials are all corrected to 25° C. Expected variation is in the neighborhood of ±2 bars in the 0 to 20 bar range, ±5 bars in the 20 to 40 bar range, and ±10 bars for potentials greater than 40 bars. An approximate response time for the units is between 20 and 40 minutes. A figure at the end of this report (Appendix II) displays the pattern of soil water tension during and after the simulated rainfall. Time was shifted 20 minutes to correct for response time.

Some extremely interesting inferences are suggested by examining the graph. For example, before the run, tension values at all depths measured were very high. Shortly after the rainfall simulation began, tension at 5 cm quickly went to 0 and remained there as long as water was applied. After the application of water ceased, tension increased phenomenally, and in three hours reached about 35 bars! This rapid loss of water accompanying the increasing tension is due almost entirely to evapotranspiration. Upon examining the soil temperature readings (that were taken each time the tensiometers were read), one is impressed with the observation that the soil temperature at 10 cm remains constant for nearly five hours after the end of the run and then begins to rise. This implies that during this time, all the energy that was delivered to the plot went into latent heat (evaporation) rather than into sensible heat (used to heat the soil).

Conventional wisdom about the availability of soil water to plants says that, nominally, growth and photosynthesis begin to be curtailed when soil water tension exceeds 2 bars and proceeds very slowly after 15 bars. If one compares the rapid changes of soil water tension after the simulated rain has ceased, one must be amazed at the situation faced by the plant.

Root biomass measurements taken two days before, in the same locale as the instrumented plot, revealed that 73% of the root biomass was in the top 10 cm, 14% in the 10 to 20 cm layer, 8% in the 20 to 40 cm layer, 2% in the 40 to 60 cm layer, and 3% in the 60 to 80 cm layer. Comparing root distribution and the pattern of soil water tensions, water would be in the available range to 90% of the roots (above 30 cm) for about 0.5 hours after the rain; to 40% of the roots (between 5 and 40 cm) for about four hours; and to about 20% of the roots after four hours (10 to 40 cm). It would be suspected that by noon of the following day, water would only be available to less than 5% of the roots (at depths below 40 cm). Of course, the conventional wisdom may be wrong. Blue grama may only *begin* to live at 15 bars! These comparisons only indicate that blue grama may either have a fantastic opportunistic strategy for utilizing such pulses of water or rely on a small percentage of deeper root biomass or both.

Runoff

Two thunderstorms occurred during the 1970 growing season that produced local runoff in the central basin. The runoff was local in the sense that no runoff entered the ephemeral lake. The first event occurred at 1340 MST on 12 July. Rainfall amounts varied from 1.7 cm to 3 cm. Maximum 2.5 minute duration rainrates varied from 9 cm/hr to 21 cm/hr.

Two thundershowers occurred prior to the runoff-producing event; one on 6 July (.2 mm) and one on 9 July (1 mm). Considering the small amounts and the evaporation between 9 and 12 July, the runoff-producing thunderstorm fell on dry soil. Runoff occurred on all microwatersheds. The following table presents the pertinent data for the thunderstorm of 12 July 1970. Hydrographs of this storm appear at the end of this report in Appendix III

Treatment	Microwatershed	Peak discharge (l/sec)	2.5 min rainrate (cm/hr)	Rain amount (cm)
H	1	7.0	No record*	2.5
	3	3.5	~9	2.8
M	6	0.7	~9	1.8
	7	0.5	~9	1.8
L	4	No record*	~9	1.7
	5	No record**	~9	1.7
0	2	0.5	~9	2.8
	8	0.3	~21	3.0

* Recorders removed by EG&G for testing

** Recorder malfunction

The second runoff event of the 1970 growing season produced runoff only at microwatersheds 1 and 3 (on the heavy use treatment). The event occurred at 1640 MST on 2 September. Rainfall amounts varied between 3 mm and 8 mm. Maximum 2.5 minute duration rainrates ranged between 1.2 and 4.5 cm/hr. Two days prior to this storm, the area received a .4 mm rain. Again, one is justified in assuming this event occurred on dry soils. Peak discharge (l/sec) for microwatersheds 1 and 3 were 0.02 and 0.08, respectively.

These two runoff events, plus two from the 1969 season, will be used in the kinematic wave solution to determine nominal values for the surface roughness parameter. These nominal values will be used for simulation.

LITERATURE CITED

Bertolin, G. and J. Rasmussen. 1969. Preliminary report on the study of the precipitation on the Pawnee National Grassland. U.S. IBP Grassland Biome Tech. Rep. No. 17. Colo. State Univ., Fort Collins, Colo. 34 p.

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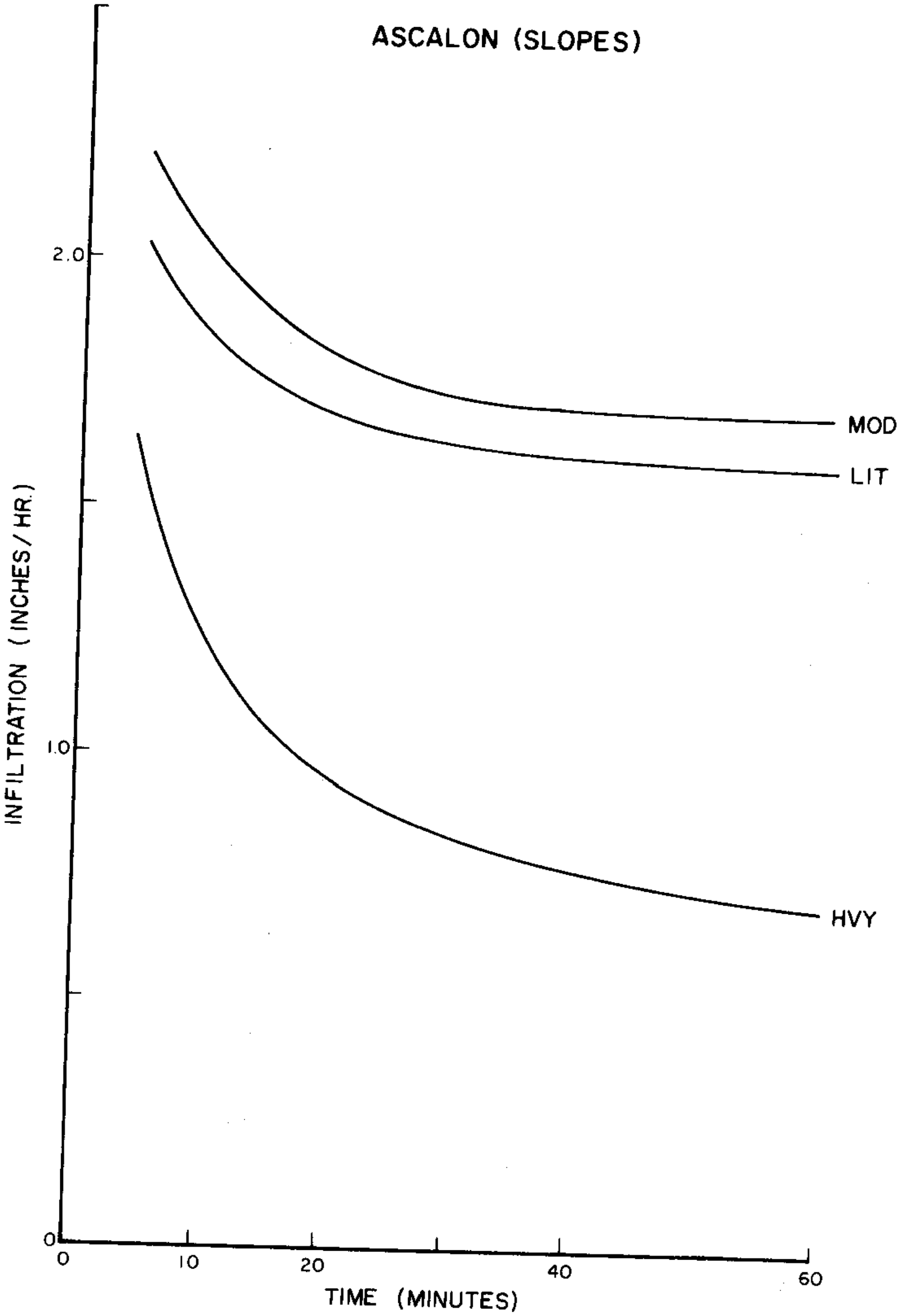
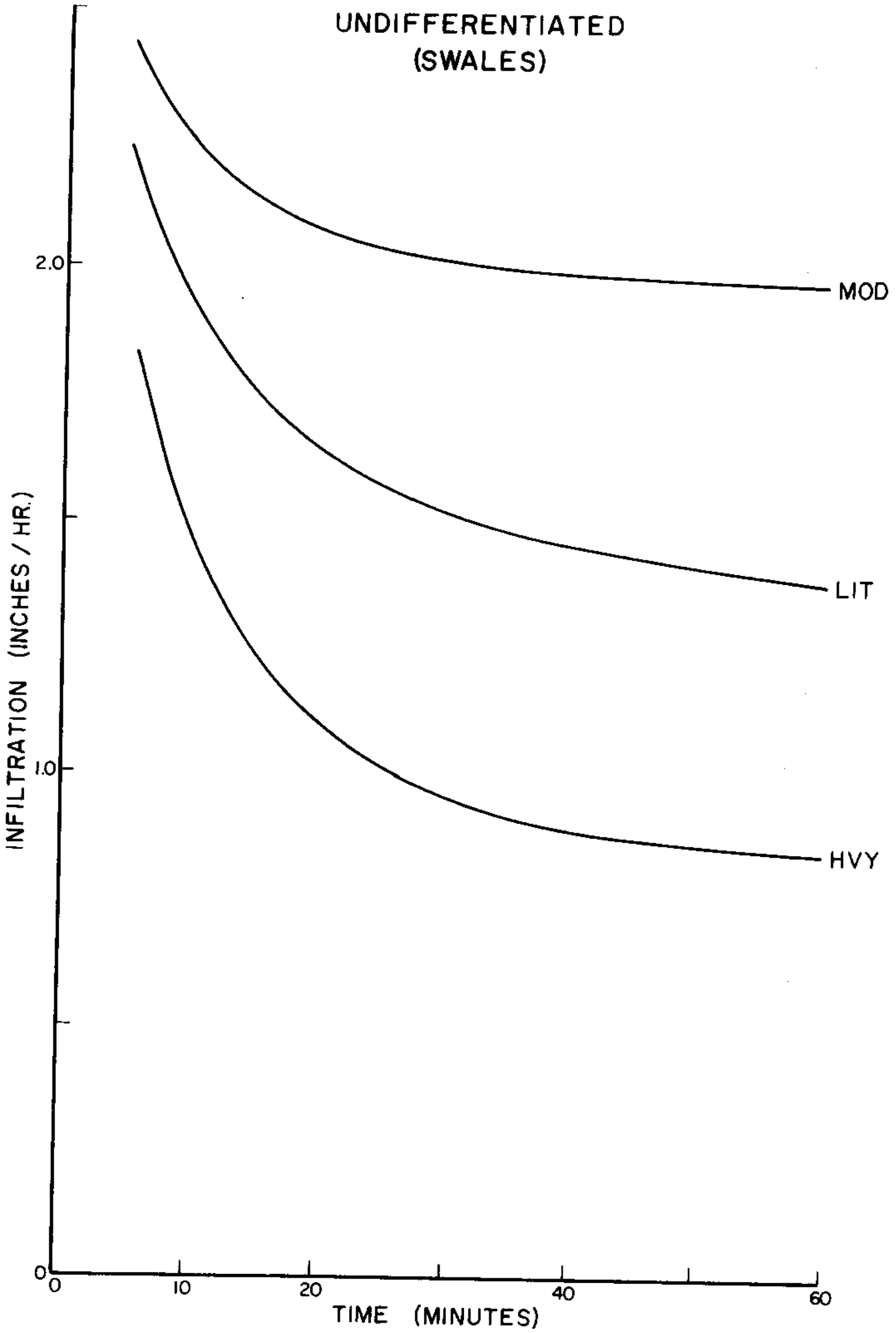
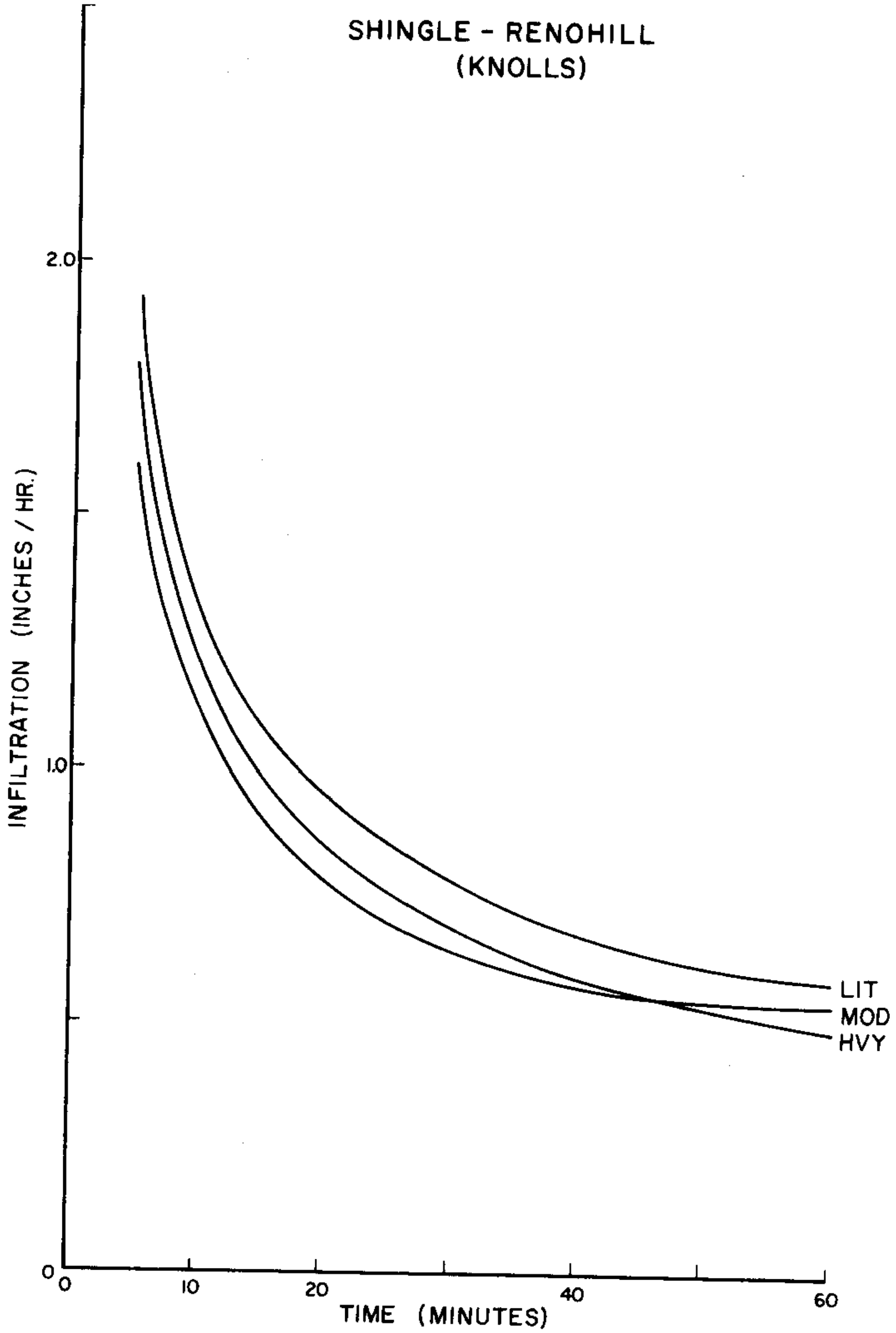
APPENDIX I

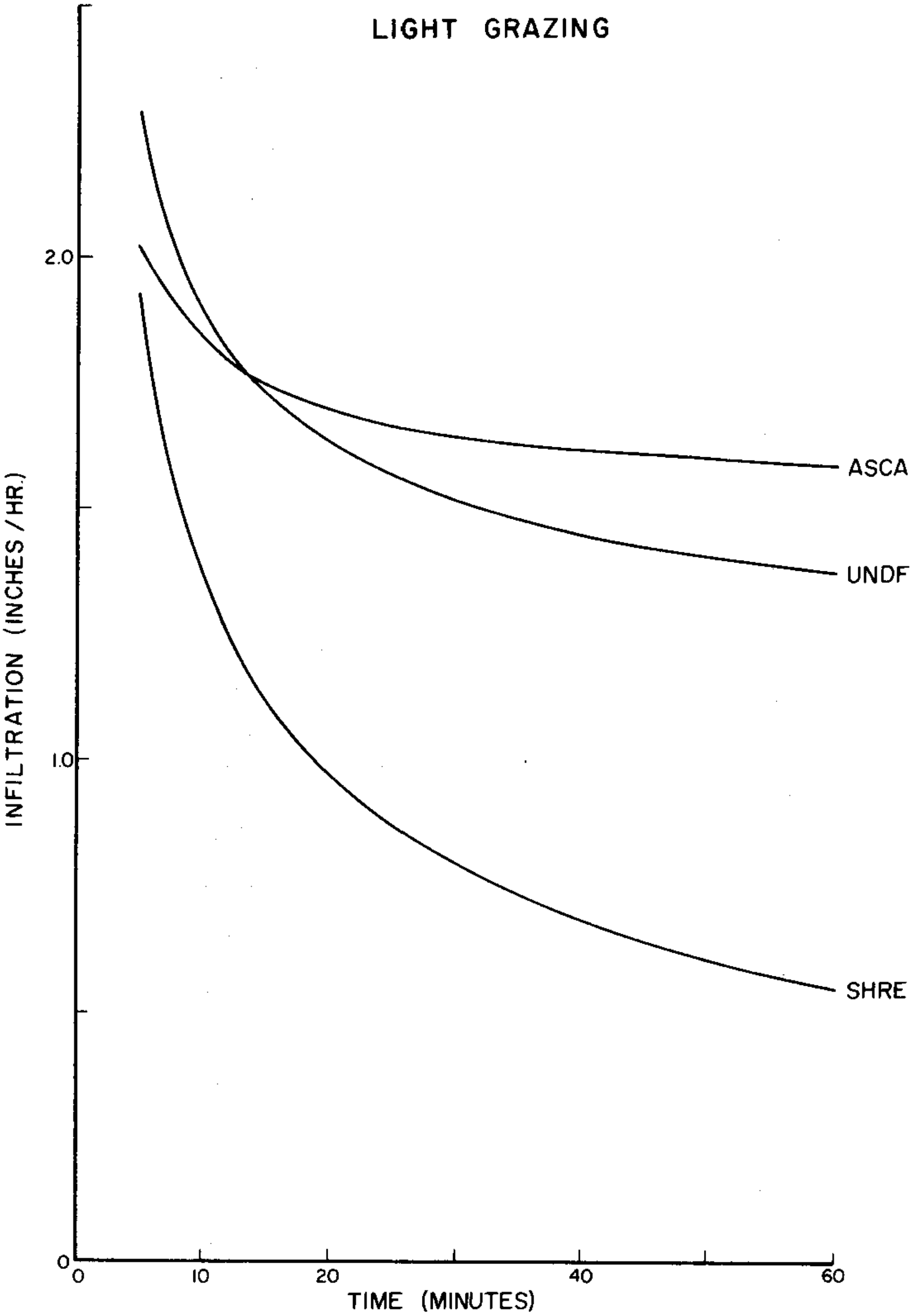
Figures Illustrating Comparison of Infiltration Rates


ASCALON (SLOPES)
INFILTRATION (INCHES/HR.)
2.0
1.0
0
TIME (MINUTES)
0
10
20
40
60
MOD
LIT
HVY

91


UNDIFFERENTIATED
(SWALES)
INFILTRATION (INCHES / HR.)
2.0
1.0
0
MOD
LIT
HVY
0
10
20
40
60
TIME (MINUTES)


SHINGLE - RENOHILL
(KNOLLS)
INFILTRATION (INCHES / HR.)
2.0
1.0
0
TIME (MINUTES)
0
10
20
40
60
LIT
MOD
HVY


LIGHT GRAZING
INFILTRATION (INCHES / HR.)
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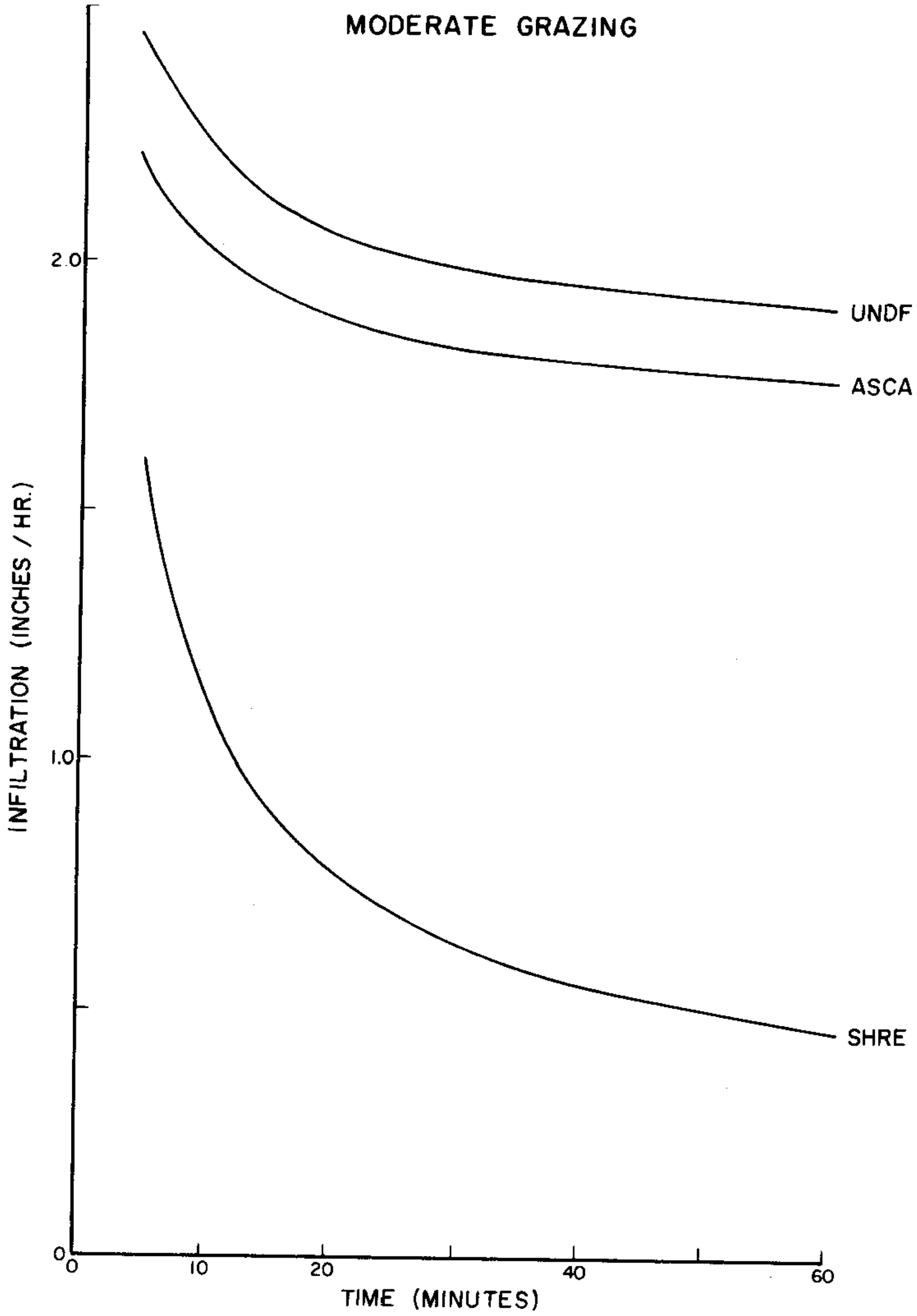
1.0
0
0
10
20
40
60
TIME (MINUTES)
ASCA
UNDF
SHRE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INFILTRATION (INCHES / HR.)
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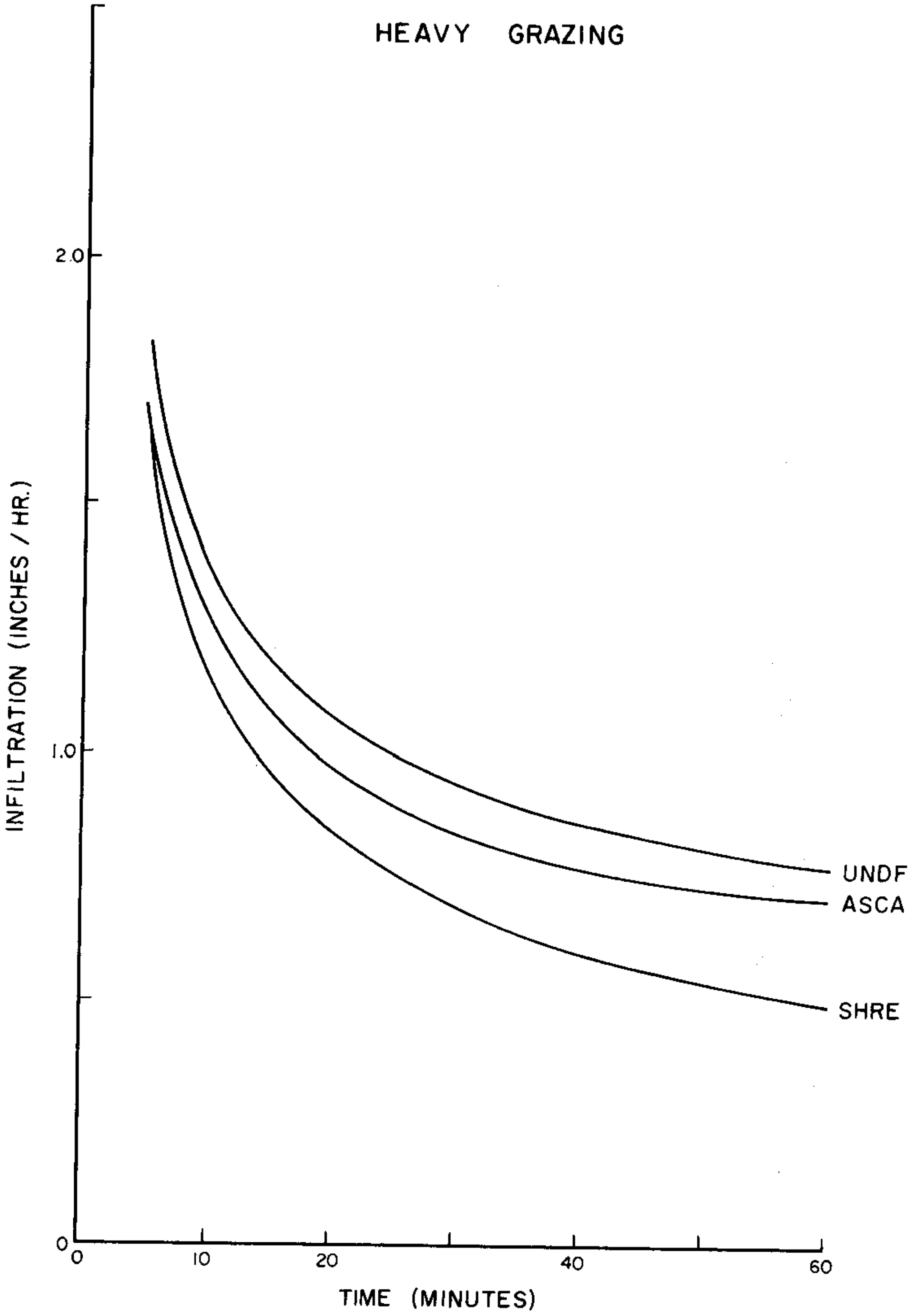
1.0
0
UNDF
ASCA
SHRE
0
10
20
40
60
TIME (MINUTES)

91


HEAVY GRAZING
INFILTRATION (INCHES / HR.)
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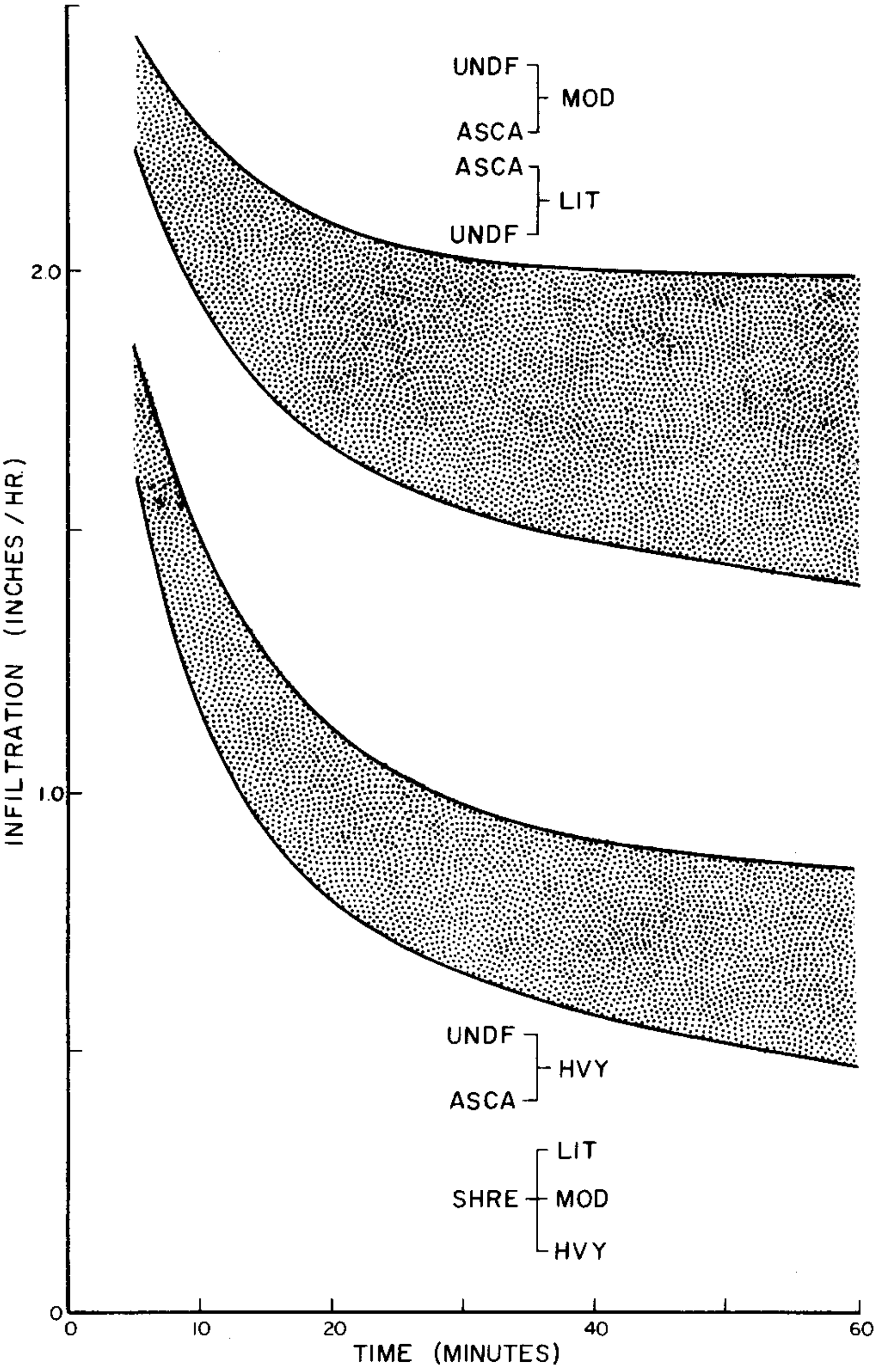
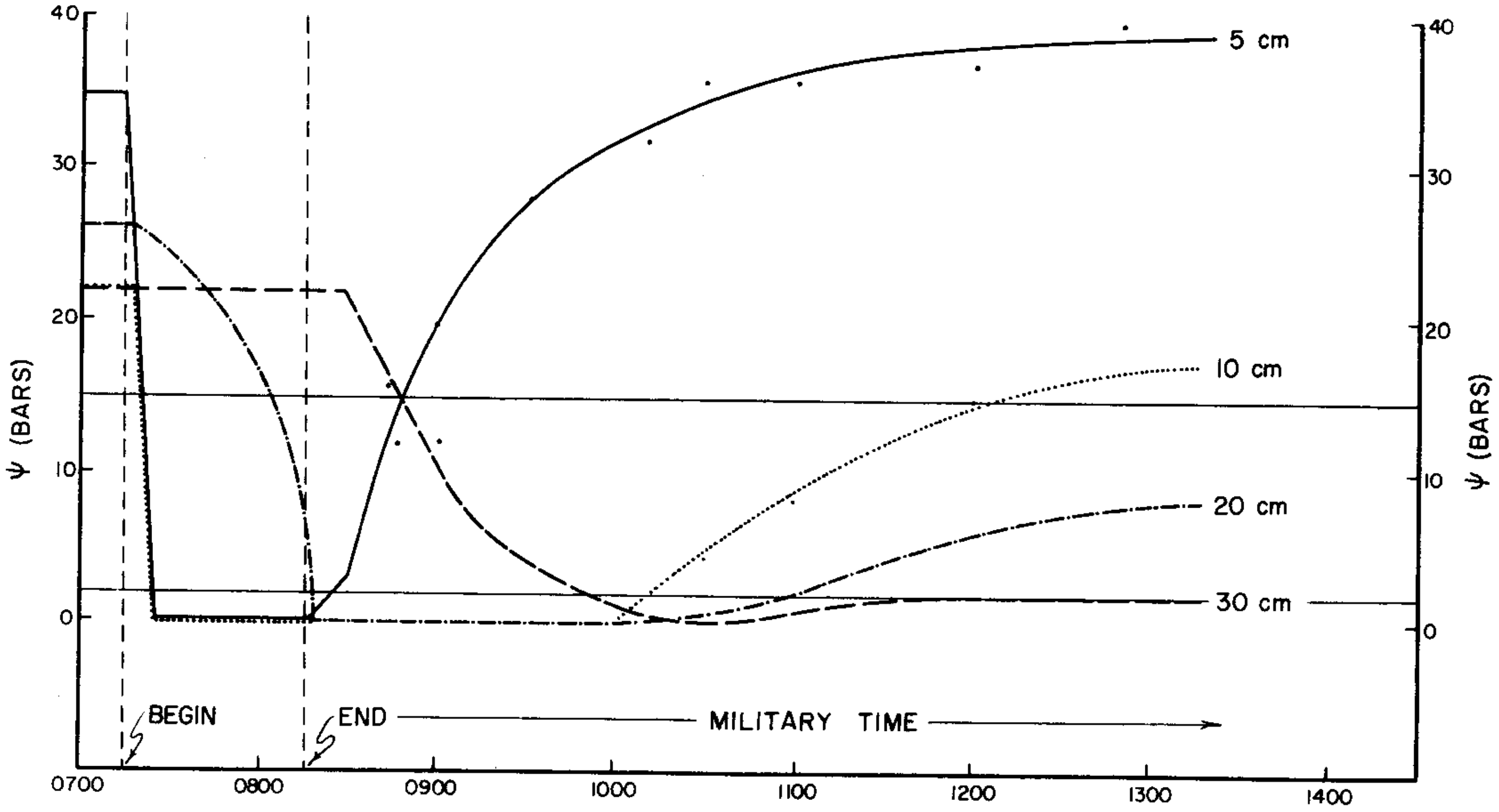
1.0
0
0
10
20
40
60
TIME (MINUTES)
UNDF
ASCA
SHRE


UNDF
ASCA
MOD
ASCA
UNDF
LIT
UNDF
ASCA
HVY
SHRE
LIT
MOD
HVY
INFILTRATION (INCHES / HR.)
2.0
1.0
0
0
10
20
40
60
TIME (MINUTES)

APPENDIX II

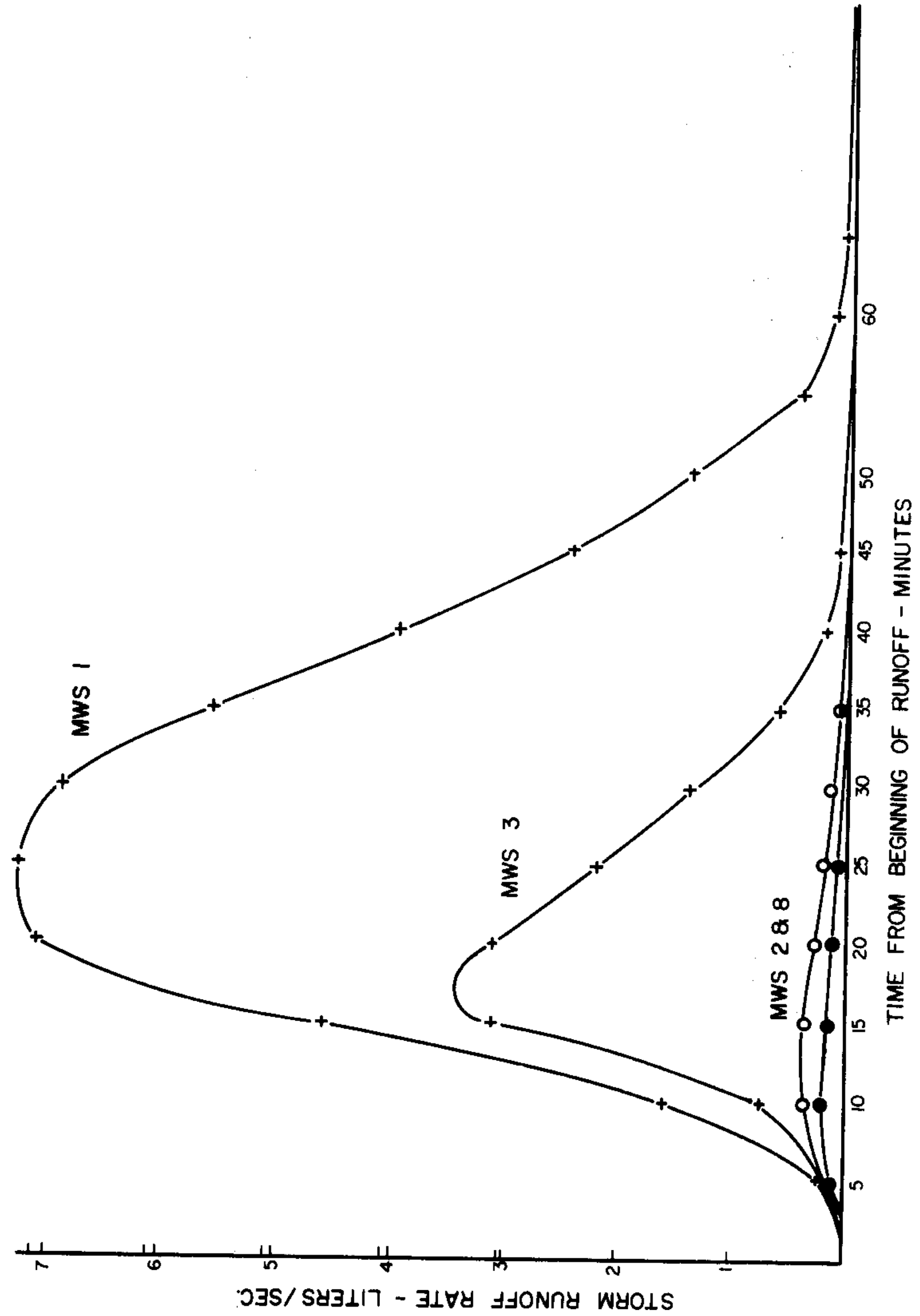
Pattern of Soil Water Potential Changes During and After Simulated Rainfall



LIGHT-USE PASTURE, ASCALON SANDY LOAM
25 JUNE 1970

APPENDIX III

Stormflow Hydrographs - Storm of July 12, 1970


STORM RUNOFF RATE - LITERS/SEC.
1
2
3
4
5
6
7
TIME FROM BEGINNING OF RUNOFF - MINUTES
5
10
15
20
25
30
35
40
45
50
60
MWS 1
MWS 3
MWS 2 & 8