W-42

PROCEEDINGS OF THE

WATER HARVESTING SYMPOSIUM

PHOENIX, ARIZONA, MARCH 26-28, 1974

February 1975

ARS W-22

WESTERN REGION

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

SESSION V--Ron Reeve, Chairman

OPPORTUNITY FOR HARVESTING WATER FROM AND ALONG HIGHWAYS IN RANGELAND AREAS OF WYOMING 1/

C. E. Evans, D. A. Woolhiser, and Frank Rauzi 2/

INTRODUCTION

As one drives along the highways traversing Wyoming's extensive semiarid rangelands, one frequently notices a striking difference between the vegetation growing along the highway and that growing outside of the fenced rights-of-way. This contrast is caused by differential grazing and/or runoff from highway surfaces being utilized for improved plant growth. Perhaps these resources (land and water) could be better utilized by harvesting water from the highways and conveying it to storage or diverting it to adjacent lands. This runoff could be used for livestock water, supplemental irrigation for increased forage production, or for enhancing shrubs and vegetation for beautification or recreational purposes, wildlife habitat, or for a combination of these and other uses.

EVALUATION OF WATER HARVESTING OPPORTUNITY

Preliminary Evaluation

A preliminary evaluation of the potential for water harvesting from highways was made for the North Platte Basin in southeastern Wyoming. If we assume 95 percent runoff from highways during the 4 months, May to August, a mean water supply of approximately 3,100 acre-ft would be available from 5,800 acres of paved two- and four-lane highways. Although this quantity is only 0.2 percent of the water diverted for irrigation in the basin, its efficiency of use may be considerably higher than much of the water currently diverted for irrigation purposes. Additional water for livestock or for hay production could mean a great deal to ranches on upland watersheds where water is presently not available or is very expensive to obtain.

Analytic Methods

For a more realistic appraisal of water supply from pavement, we must consider precipitation as a stochastic process. A general stochastic model of daily precipitation, which has many attractive features for studies of this sort, has been presented by Todorovic and Woolhiser (4). They also considered a special case of the general model in which the occurrence of rainfall is specified by a Markov Chain and the distribution function of daily rainfall is negative-exponential. The temporal

1/ Contributions from Agricultural Research Service (ARS), U.S. Department of Agriculture (USDA), in cooperation with the Colorado State University Experiment Station, the University of Wyoming Experiment Station, and the Wyoming Highway Department.

2/ Area Director, Colorado-Wyoming; research hydraulic engineer, Fort Collins, Colo.; and soil scientist, Laramie, Wyo.; respectively, ARS, USDA.

and spatial variation of the parameters was considered by Woolhiser, Rovey, and Todorovic (6). This model was called the Markov Chain-Exponential (MCE) model. The distribution function of the total rainfall in n days is

$$F_n(x) = [(1 - q_0) - Rd] (1 - q_0)^{n-1}$$
$$+ \sum_{\nu=1}^{n} [R\ \phi_1(\nu,n) + (1-R)\ \phi_0(\nu,n)] \frac{\lambda^\nu}{\Gamma(\nu)} \int_0^x u^{\nu-1} e^{-\lambda u} du \qquad (1)$$

where q_0 is the probability of a dry day being followed by a wet day; x is the total depth of rainfall in n days; R is the probability that the day before the period begins is wet; $d = q_1 - q_0$ where q_1 is the probability of a wet day being followed by a wet day; $\phi_1(\nu,n)$ is the probability that ν wet days occur in an n-day period given the day before the n day period is wet; $\phi_0(\nu,n)$ is the probability of ν wet days in n days given the day before the n-day period is dry; λ is the parameter in the negative exponential distribution for daily rainfall; Γ denotes the gamma function; and u is a dummy variable. The analytic expressions for $\phi_0(\nu,n)$ and $\phi_1(\nu,n)$ are presented in Todorovic and Woolhiser (4).

Although equation 1 is complicated, it can be evaluated readily with a digital computer. Because it is based on a logical probablistic model of daily rainfall occurrences, other distribution functions can be derived that depend on the same parameters. If we assume that T inches of rain will be retained on a highway surface on each rainy day and that the remainder will run off, it can be shown that the distribution function for the total runoff in an n-day period will be the same as equation 1 except that the parameters, q_0, q_1, and R will be replaced by q_{0T}, q_{1T}, and R_T where

$$q_{0T} = \frac{e^{-\lambda T}[q_0(1 - q_1) + q_0 q_1(1 - e^{-\lambda T})]}{[1 - q_1 + q_0 (1 - e^{-\lambda T})]} \qquad (2)$$

$$q_{1T} = q_1 e^{-\lambda T} \qquad (3)$$

$$R_T = R\ e^{-\lambda T} \qquad (4)$$

Distribution functions of 14-day rainfall and 14-day runoff with a threshold T = 0.05 inch are shown in figure 1 for two periods at Gillette, Wyo. These distributions given an indication of the variability of the water supply. For example, the runoff from a paved surface would be less than 0.5 inch in approximately one year out of five during the 2-week period beginning May 24, and would be zero in approximately one year out of five during the 2-week period beginning July 19. The above rainfall model can also be utilized very effectively in simulation studies for storage design (2).

Simulation Techniques

Runoff from highways could be utilized in two ways, as supplemental irrigation water: (1) flood irrigation of the embankment form highway runoff, and (2) conveyance of highway runoff to leveled areas.

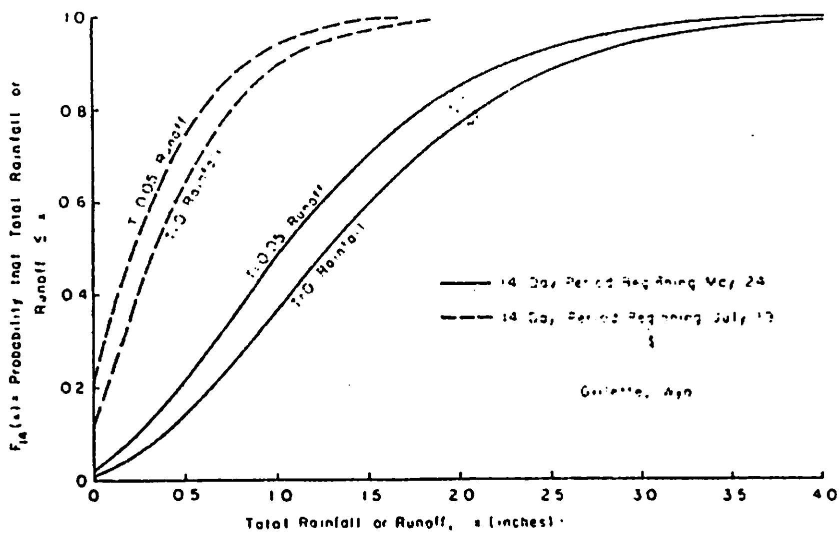

FIGURE 1.--Distribution functions of 14-day rainfall with and without a threshold.

Case 1

The first case can be investigated by using presently available hydrologic models. A typical interstate highway section is shown in figure 2a. Overland flow from the highway and a vegetated embankment was modeled by the kinematic cascade (5) and infiltration on the embankment by a method presented by Smith (3). Infiltration parameters were estimated for two soils, Maysdorf fine sandy loam and Renohill clay loam, using infiltrometer data obtained by Rauzi (unpublished data).

The amounts of water infiltrated at points 1, 2, and 3 on the embankment for two different rainfall inputs are shown in figures 2b and 2c. If all of the water had been infiltrated on the embankment and all had run off the highway and shoulders, 0.50 inch would have infiltrated for the 0.33 in/h rate and 1.50 inches for the 1 in/h rate. It can be seen from the figure that some water ran off the embankment for both storms for both soil types. However, approximately the same amounts infiltrated into both soils for the 0.33 in/h rate while the Maysdorf soil absorbed significantly more water from the higher intensity storm. This example shows that water running off highways will add very little to the soil water in embankments when the rainfall intensity is great enough to cause runoff from the embankment. Therefore, more water will be infiltrated into the embankment of the sandy loam than the clay loam soil. Simulations such as these, using natural rainfall intensity patterns, could be used to evaluate the effectiveness of highway runoff as a source of additional water for growing vegetation on embankments.

Case 2

Consider the definition sketch of figure 3. A highway surface area A_1, contributes runoff to area A_2, which also receives natural rainfall, x_1. The amount of water, z, per unit of area received by A_2 is

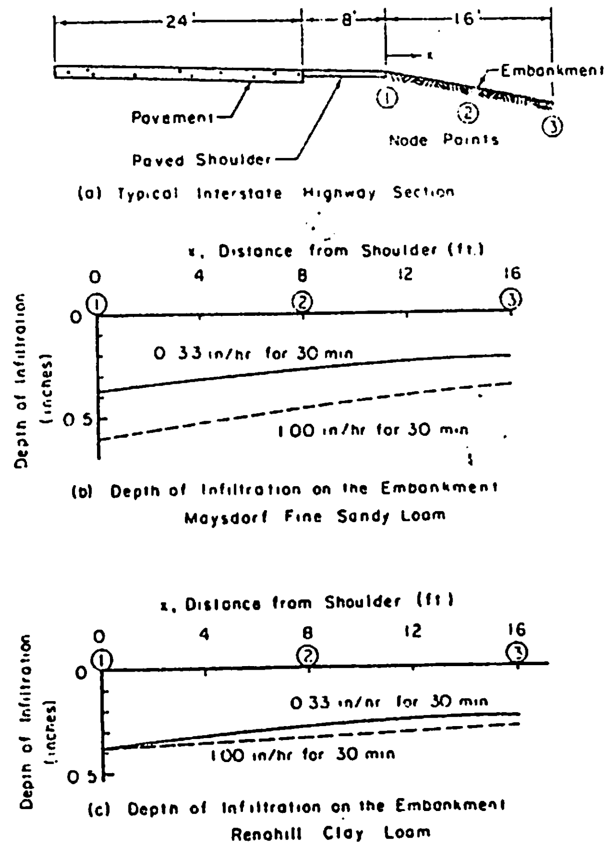

FIGURE 2.--Infiltration on highway embankments.

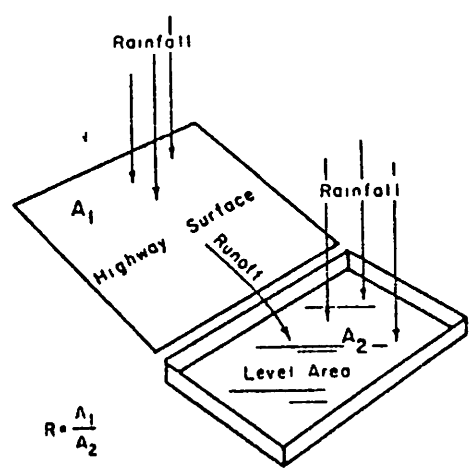

FIGURE 3.--Definition sketch of water harvesting system.

$$z = x_1 \quad \text{if} \quad x_1 \leq T$$
$$z = x_1 + r(x_1 - T) \text{ if } x_1 > T \qquad (5)$$

where $r = A_1/A_2$ and T is the runoff threshold.

The distribution function of total water applied to area A_2 is

$$\left.\begin{array}{ll} F(z) = 1 - e^{-\lambda z} & ; \ z \leq T \\ F(z) + 1 = e^{-\frac{\lambda}{(r+1)}(z+rT)} & ; \ z > T \end{array}\right\} \qquad (6)$$

Although this function could be used to develop an analytic expression similar to equation 1 for the total input to the area A_2 in n days, the expression would be extremely cumbersome. Therefore, Simulation techniques were used to obtain sample function of soil water content and distribution functions of the relative soil water content under natural rainfall conditions with two contributing area ratios, r = 1 and r = 2. The runoff threshold chosen was T = 0.5 inch. (See figs. 4 and 5.) The maximum effective water holding capacity for the top 2 feet of the Maysdorf fine sandy loam was assumed to be the water content at one-third atmosphere, ST2; the minimum was the water content at the wilting point, which was obtained from field observation, Q2. Evapotranspiration was modeled using an adaptation of a model developed by Hanson (1) with parameters calibrated for Gillette lysimeter data.

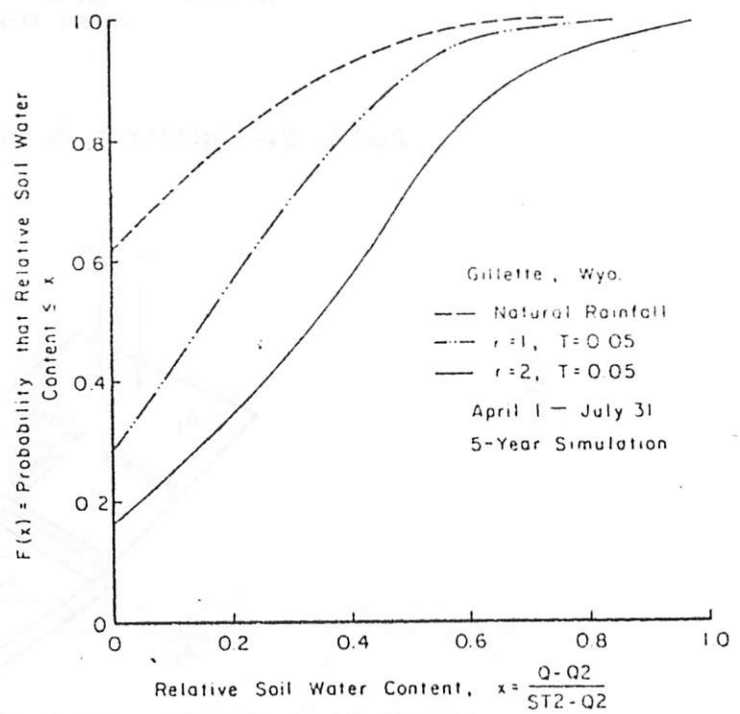

FIGURE 4.--Distribution functions of relative soil water content.

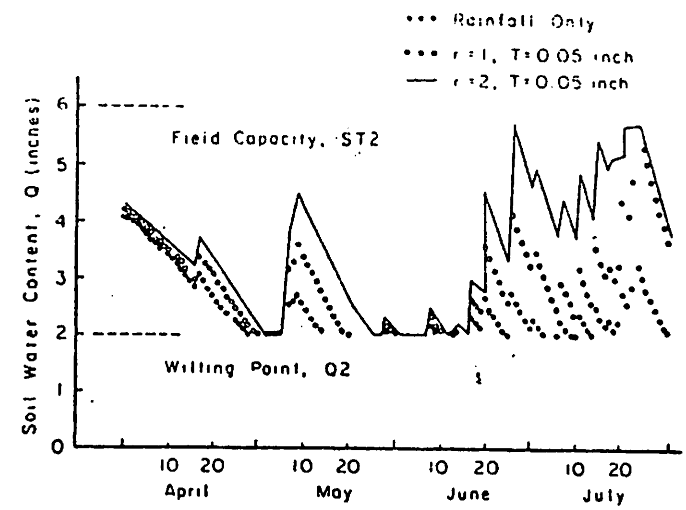

FIGURE 5.--Simulated soil water content of top 2 feet of soil, Gillette, Wyo., April-July 31.

An examination of figures 4 and 5 shows that water contributed from the highway does not prevent the soil water content in the top 2 feet from reaching the wilting point; however, it does reduce the amount of time the soil water content is at the wilting point. Unless storage facilities are provided, it appears that there is a limit below which the probability of wilting cannot be reduced by increasing the size of the contributing area. This limit exists because of the finite capacity for storage of water in the top 2 feet of soil. Once this zone has reached field capacity, any additional water added will go to deep percolation. This probability is a function of the water holding capacity of the soil, the evapotranspiration rate, the rainfall process, and the area ratio, r. It might be a useful indicator of the suitability of a crop or species to the modified soil-water environment. The effect of these water regimes on plant growth requires field evaluation. A plant growth model would also be useful in evaluating the potential of water harvesting from highways for crop growth.

FORAGE YIELD OBSERVATIONS ALONG HIGHWAYS

Forage yield observations along the rights-of-way of Interstate Highway 90, west of Gillette, in northeastern Wyoming, showed substantially greater production than was observed from adjacent native rangelands. These differences in herbage production show the beneficial effects that the highway runoff water has on the vegetation of the rights-of-way. The rangelands contiguous to the highway receive only natural precipitation amounting to 10 to 14 in/yr, of which approximately 25 percent occurs as snow in the winter months. Nordan crested wheatgrass and yellow blossom sweet clover are the predominating species in the medians and borrow areas, having been seeded in accordance with specifications of the Wyoming Highway Department.

Considerable acreages are involved in the total highway complex. The pavement of Interstate Highway 90 occupies 8 acres/mi, narrow medians comprise 3 to 4 acres, wide medians about 1[illegible] acres, and borrow areas make up the largest acreage, averaging from 27 to 41 acres/mi, depending upon the width of medians and rights-of-way. The major soil type in this area is Kenohill clay loam. During the construction of the interstate highway, soil from various depths was mixed and compacted; hence, the soil of the disturbed area bears little resemblance to the rangeland soil.

During the first week of July 1973, approximately 9 miles of the medians and borrow areas of Interstate 90 west of Gillette were harvested. Samples of hay bales weighed a few days after harvest showed an average weight of 55 lb/bale. Hay yields were computed to be 1.3 tons/mi of narrow median (0.37 tons/acre) and 2.8 tons/mi of wide median (0.9 tons/acre). Because of the variability of the topography, it was difficult to obtain a good estimate of forage yield from borrow areas. Estimates ranged from 3 to 8 tons/mi of highway (0.11 to 0.30 tons/acre). Thus, harvest under these conditions could be as high as 12 tons of quality hay per mile.

DISCUSSION

Exploratory studies of the water harvesting potentialities of sections of interstate highways in Wyoming have been initiated to determine the amounts of water available for harvest and the value of the water for livestock or for producing herbage on median strips and along the borrow areas of rights-of-way. Although a limited number of stock water ponds along interstate highways are fed by runoff from the pavements and many ranchers harvest the herbage from the borrow areas along highways near their operations, much of the water resource is wasted. Too often, runoff from highways is consumed by grasses and weeds that are difficult to harvest, percolates beyond the reach of vegetation in borrow pits, or collects in depressions and evaporates leaving unsightly and vegetation-damaging accumulations of salt along the rights-of-way.

A preliminary evaluation of the potential for water harvesting from highways in the North Platte Basin in southeastern Wyoming indicated a mean water supply during the 4 summer months of only 3,100 acre-ft from 5,800 acres of paved two- and four-lane highways. Although this quantity is only 0.2 percent of the water diverted for irrigation in the basin, and as such could not have a profound effect on the region's economy, the additional water for livestock or as a reliable source for hay production could stabilize the ranching operations on upland watersheds where water is not now available or is too expensive to obtain.

The variability of water supply from pavements was demonstrated using a stochastic model based on daily summer percipitation near Gillette. This appraisal showed runoff from paved surfaces to be less than 0.5 inch in one year out of five for the 2-week period beginning May 24 and zero in one year out of five for the 2-week period beginning July 19. Storage facilities would necessarily have to be provided if runoff from highways is to be utilized for livestock water. Stochastic rainfall models can be used in simulation studies to determine the amount of storage required to utilize highway runoff for livestock water supplies. They can also be used in conjunction with infiltration and surface runoff models to give a preliminary evaluation of the effectiveness of highway runoff as a source of additional water for plant growth on highway embankments or on leveled areas. Although some additional field data will be required to see if the parameters used in the simulations are reasonable, the simulation results are helpful in planning field research and will add to the value of short-term field data.

Various mixtures of native and introduced grasses with a legume have been seeded in the median and borrow areas along highways. In the Northern Great Plains, Nordan crested wheatgrass is used extensively. When crested wheatgrass is used in a mixture, it soon becomes dominant because of its aggressiveness and early growth. Yellow blossom sweet clover, a biannual, is often seeded because of its adaptability to a variety of sites. Although the Wyoming Highway Department does not recommend alfalfa in the seeding mixtures, it occurs widely along highway rights-of-way, undoubtedly as a result of foreign seed being scattered from vehicles. Once established, the alfalfa persists. In Wyoming, a thick layer of topsoil is usually spread over the raw soil before seeding. Surfaces are generally mulched with straw at 2 tons/acre and fertilized with 40 lb of N per acre.

As reported in the previous section, forage production along highways is highly variable and much of the growth produced is not, or cannot be, harvested for hay. On the more productive areas, as much as 12 tons of quality hay per mile of highway are being harvested. With proper fertilization, land leveling and shaping, better adapted plant species, and improved management, together with more effective use of the water harvested from paved surfaces, yields of herbage probably could be increased substantially. However, additional research data are needed to determine the magnitude of potential increases in herbage production.

In semiarid climates, like those prevailing on most of Wyoming's extensive rangelands, the land required for highway rights-of-way has only limited value in itself. Its greatest value can be the water that falls on it year after year. The precipitation that falls on the highway rights-of-way might be harvested and conveyed to adjacent lands for beneficial uses. These uses may include supplying water for livestock, irrigating forages, producing shrubs and vegetation for recreational purposes, growing habitats for wildlife, providing vegetation for beautification, or a combination of these or other uses.

ACKNOWLEDGMENTS

We are indebted to R. E. Smith for the infiltration simulation program and to E. Rovey for computer programming assistance.

LITERATURE CITED

(1) Hanson, C. L.
1973. Models for predicting evapotranspiration from native rangelands in the northern Great Plains. Ph.D. Dissertation, Utah State University, Logan.

(2) ______ Neff, E. L., and Woolhiser, D. A.
1974. Hydrologic aspects of water harvesting in the northern Great Plains. In Water Harvesting Symposium, Proc. Phoenix, Ariz. Mar. 26-28. U.S. Dept. Agr., Agr. Res. Serv. ARS W-22, 329 pp.

(3) Smith, R. E.
1972. The infiltration envelope: Results from a theoretical infiltrometer. Jour Hydrol. 17: 1-21.

(4) Todorovic, Petar, and Woolhiser, D. A.
A stochastic model of daily rainfall. In Symposium on Statistics in Hydrology Proc. Tucson, Ariz., 1971. U.S. Dept. Agr. Misc. Pub. (In Press.)

(5) Woolhiser, D. A., Hanson, D. L., and Kuhlman, A. R.
1970. Overland flow on rangeland watersheds. New Zeal. Jour. Hydrol. 9(2): 336-356.

(6) ________ Rovey, E., and Todorovic, P.
1973. Temporal and spatial variation of parameters for the distribution of N-day precipitation. Floods and Droughts. In Second Internatl. Symposium in Hydrology, Water Research Publication. Ft. Collins, Colo. Pp. 605-614.