Sprinkler Package Option Effects On Runoff - General Guidelines[1]

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INTRODUCTION

Farmers are used to managing many variables. They have to choose from many crop varieties, herbicides, insecticides, fertilizers, and tillage methods. They must determine the proper rate and timing of irrigation applications while dealing with changing weather, varying soils and fluctuating markets. Many long-term decisions, such as selecting a sprinkler package for a center-pivot system, are more complicated now since industry has developed many options. These options can be used to make very efficient irrigation systems possible but can also be a wasteful and costly selection if used under the wrong conditions. Low pressure sprinkler packages have become popular since low pressure requirements can minimize pumping costs.

While may properly designed and operated sprinkler packages have high application efficiencies, there has been a trend to place nozzles into the crop canopy and in some cases very close to the ground in order to eliminate most evaporation, drift losses, and canopy evaporation (Howell et. al., 1991, Schneider and Howell, 1993). Reducing the pressure and lowering the discharge point, however, has a distinct disadvantage in that this reduces the wetted diameter and increases the instantaneous application rate. The application rate for many low pressure systems greatly exceeds the soil intake rate and, unless sufficient surface storage is available to hold the water in place, water movement will occur. Water movement within the field and water movement off the field as runoff both reduce irrigation efficiency. Irrigators are combating this problem by: 1.) decreasing irrigation capacity, 2.) decreasing application depth, and 3.) increasing surface storage using appropriate residue and tillage management systems. However, there are limitations. Decreasing capacity, for example, raises the risk of crop water stress and yield loss if capacity falls too much below seasonal peak crop water use rates, especially on low water holding capacity soils. Decreasing application depth requires more frequent applications so increased canopy and soil surface evaporation losses occur. Great dependence on surface storage can also be a problem if tillage and residue management programs fail

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due to large rainfall events or cannot be placed due to weather conditions.

It is very important that the sprinkler packages be selected appropriately. There are many types of sprinkler heads which can be mounted in a variety of positions, with or without regulators, and using one of several splash pads. Mixing and matching of these options means hundreds of sprinkler package options are available (Jochens, 1991).

Runoff control should be a very important selection criteria. Evaporation and drift seem to be the major concern of irrigators, but runoff can be an order of magnitude larger if the sprinkler package is poorly matched to soil and capacity conditions.

This paper will focus on predicting runoff for various conditions which could then be used in selecting an appropriate sprinkler package.

CPNOZZLE

CPNOZZLE (Fairbanks and Kranz, 1989) is a computer program developed by the Northeast Research and Extension Center in Concord, Nebraska to quickly and easily determine potential runoff and its economic impact for center-pivot irrigation systems. The use of this program proves to be a valuable tool in making package selections and system design decisions.

CPNOZZLE offers two different analyses, the potential runoff analysis and the energy savings analysis.

Potential Runoff Analysis. The potential runoff analysis determines potential runoff for a given system. It requires the user to input the system length, the surface storage value or the field slope, the radius-of-throw of the sprinkler package, the application depth, the system output (capacity), and the Soil Conservation Service (SCS) Soil Intake Family. Once these values are determined and entered into CPNOZZLE, three output tables are provided. These output tables coincide with three different SCS Soil Intake Families. The table for each Soil Intake Family provides information for three system outputs (capacities) and ten distances from the pivot point, with the sprinkler wetted radius and the soil surface storage. The potential runoff percentage is given for each of these conditions. The weighted average potential runoff for the system is given at the bottom of the table. The application depth and system length are also noted below each table. CPNOZZLE will then offer to display intake and application rate curves. Figure 1 shows an example of the information provided by CPNOZZLE.

Energy Savings Analysis. The energy savings analysis requires the same inputs as listed above along with pumping lift, pivot operating pressure, and system efficiency. The analysis then provides two output tables showing the possible savings under various operating conditions and the system setup before and after changes to the center-pivot. Since the focus of this paper is on potential runoff, no examples of this option are shown.

CPNOZZLE VARIABLES

Not everyone owns or has access to a computer; therefore, a series of figures have been developed to provide the information from CPNOZZLE's Potential Runoff Analysis. For the purpose of limiting the number of figures required, several variables have been held constant or omitted.

System Length. The system length was held constant at a common length of 1280 feet, although a brief discussion of half-mile systems is presented later. CPNOZZLE provides potential runoff percentages at ten different distances along the system length and also gives a weighted average potential runoff percentage for the entire system. It is important to note that runoff percentages along the system are higher than the weighted average potential runoff which was used to draw the figures.

Surface Storage. The available surface storage choices on CPNOZZLE are 0.0, 0.1, 0.3, and 0.5 inches which coincide with field slopes of >5%, 3-5%, 1-3%, and 0-1%, respectively. The 0.0 inch surface storage (>5% field slope) has been omitted for the purpose of limiting the number of figures.

Application Amount. An application amount of 1.0 inch was used as the initial application amount. Depending on the percentage of runoff produced with the initial application amount, another run using either a 0.75 or 1.5 inch application amount was performed. If the runoff percentage with the 1.0 inch application amount was excessive, then the lower application amount was used to generate a new series of runoff curves. However if the initial runoff percentage was low, another series of curves using a 1.5 inch application amount were developed. Runoff, for the purposes of this paper, was defined as excessive when the weighted average was greater than 5 percent. Unacceptable levels of runoff can occur at the outer edge even with a low overall weighted average.

SCS Soil Intake Family. The available soil intake families on CPNOZZLE include 0.1, 0.3, 0.5, 1.0, 1.5, and 2.0. Again, to limit the number of figures, the 1.5 and 2.0 soil intake families have been omitted since their percentage of runoff is consistently very low for all different system configurations. Figures are provided for the 0.1, 0.3, 0.5, and 1.0 soil intake families.

RESULTS

The runoff analysis are shown for the standard length pivot in Figures 2 through 19 and are organized first by the soil intake family, and then by surface storage value. Figures 20 through 24 are for half-mile systems.

SCS Soil Intake Family 0.1. Figures 2 through 7 illustrate the data obtained for the 0.1 soil intake family. Figure 2 shows results for the low surface storage value of 0.1 inch. The only potential runoff values for this surface storage value that are close to acceptable occur at the low system capacity value and the high radius-of-throw value. Since predicted runoff was excessive, the results for an application amount of 0.75 inches are shown in Figure 3. Reducing application depth did increase the number of capacity and radius-of-throw options, but generally the only values close to acceptable are for low capacity and high radius-of-throw systems. For this combination of soil intake family and surface storage, the options for package selection and system design are minimal.

If surface storage is 0.3, then several package options, shown in Figure 4, with large wetted radius may be possible for medium to low system capacities. By reducing the application amount to 0.75 inch, shown in Figure 5, a system using a radius-of-throw of 30 feet or greater will have an acceptable runoff percentage for most system capacities. A system using a radius-of-throw of 20 feet will have an acceptable runoff percentage for system capacities at or below 600 GPM. System capacity would have to be limited to use most low wetted diameter nozzles. Low radius-of-throw values of 5 and 10 feet are unacceptable for this combination of surface storage and soil intake family.

Increasing to a high surface storage value of 0.5 inches and looking at the 1.0 inch application amount, Figure 6 shows that the radius-of-throws of 30 feet or greater have acceptable runoff percentages. The 20 foot radius-of-throw has acceptable runoff percentages for system capacities of 700 GPM or less. The 5 and 10 foot radius-of-throws have largely unacceptable runoff values. Since a fair number of wetted diameter options in Figure 5 were identified, the application amount was increased to 1.5 inches. However, Figure 7 shows that this management option would only have acceptable runoff percentages occur at very limited system capacities and high radius-of-throws. Figures 2 through 7 generally indicate that for the soil intake family of 0.1, the high radius-of-throw (high pressure) systems would minimize runoff potential and therefore would be required to have efficient irrigation. High pressure systems would be the best choice when selecting packages and designing systems for fields with this soil intake family.

SCS Soil Intake Family 0.3. Figures 8 through 13 show predicted runoff for 0.3 soil intake family soils. Figure 8 shows that for the low surface storage (0.1 inch) only the very high radius-of-throws will provide acceptable potential runoff percentages with high irrigation capacity. The 60 and 70 foot radius-of-throw lines are not shown; however, the 50 foot radius-of-throw is acceptable at capacities less than 800 GPM. 30 and 40 foot radius-of-throws may have applications with low system capacities. Figure 9 again illustrates that reducing application depth will allow use of lower pressure systems under more capacity conditions. Figure 10 shows that with medium surface storage (0.3 inch), 30 foot or greater radius-of-throws would largely eliminate excessive runoff. Twenty foot radius-of-throws would be limited to capacities of less than 600 GPM. Figure 11 shows results with a 1.5 inch application depth. Figures 12 and 13 show the potential runoff percentages for the high surface storage (0.5 inch) and indicate that, depending on the application amount, smaller radius-of-throws can be used with larger system capacities. Figure 12 shows us that when using an application amount of 1.0 inch on a field with high surface storage, any radius-of-throw above 20 feet can be used with any of the system capacities without worrying about potential runoff. However, with an increase in the application amount, only the lower system capacities (300 - 800 GPM) and the higher radius-of-throws (30 feet or greater) can be used without an unacceptable amount of potential runoff (Figure 13).

SCS Soil Intake Family 0.5. Figures 14 through 17 illustrate runoff predictions obtained for the 0.5 soil intake family and show that increasing soil intake properties increases the sprinkler package options even with high capacity. Since high intake soils tend to have low holding capacity, high capacity becomes more important. For the high capacity systems, the wetted radius should be 40 foot or greater (Figure 14). Increasing application depth (Figure 15) would require wetted radius of over 50 feet at very high capacity. Increasing surface storage (Figures 16 and 17) has the same effect as with lower intake family soils in that a smaller wetted radius can be used with additional capacities. Although the 5 and 10 foot radius-of-throws still produce generally unacceptable runoff percentages.

SCS Soil Intake Family 1.0. Figure 18 shows that for a high intake soil (1.0 family) a wetted radius of 20 feet or greater can be used for any capacity, even with low surface storage (0.1 inch), and a 10 foot radius package would be possible with limited capacity systems. Increasing surface storage (Figure 19) illustrates a condition where a 10 foot radius has wider applications and the 5 foot radius could be used with limited runoff problems for limited irrigation capacity systems.

HALF-MILE SYSTEMS

Some farmers are considering over-sized center-pivot systems, up to one half mile in length. These larger systems do have some appealing features. Operating a half-mile system compared to operating four of the smaller systems means less equipment to manage, fewer and larger corners, and better farming efficiency. But, increasing the system length magnifies the importance of runoff control.

Runoff predictions are provided for half-mile system lengths with 0.3 and 0.5 inch surface storage, 0.3 and 0.5 SCS Soil Intake families, and a 1.0 inch application amount.

0.3 SCS Soil Intake Family. Figure 20 shows the data for the 0.3 inch surface storage value, and Figure 21 shows the data for the

0.5 inch surface storage value for the 0.3 soil intake family. These figures show the same trend of shorter system lengths, that higher radius-of-throws reduce potential runoff. High surface storage is very important if small wetted diameters are desired by the irrigator, although extremely small throws (5 and 10 feet) cannot be recommended. Capacity of half-mile systems should be considered also, although it will not be fully discussed. Capacity is often limited to reduce runoff potential and keep friction losses down. However reducing capacity increases crop stress risk.

<u>0.5 SCS Soil Intake Family.</u> Figures 22 and 23 illustrate the data obtained for the 0.5 soil intake family using a medium surface storage value, and a high surface storage value respectively. As before, increases in the surface storage value and radius-of-throw provide reduced potential runoff. Figure 23 does illustrate that with good intake soil and high surface storage from level grades, high residue and/or tillage practices, a 10 foot radius may be possible with up to 2400 GPM capacities. This level of capacity approaches the recommended minimum capacity depending on crop and location. Higher frequency (lower application depth) would be recommended for small radius-of-throws on long systems.

POTENTIAL RUNOFF ALONG THE SYSTEM LENGTH

As was mentioned previously, the weighted average of the potential runoff percentages along the system was used to create the figures. The estimated potential runoff percentages along the length of the system increases with the distance from the pivot point. Figure 24 shows the potential runoff percentages for various distances along a half-mile system using a surface storage value of 0.3 inch, a 1.0 inch application amount, the 0.5 SCS Surface Intake family, a 20 foot wetted radius, and a 2200 GPM system capacity. This corresponds to the data shown in Figure 22. If we look at the potential runoff for the 20 foot radius and the 2200 GPM system capacity in Figure 22, we see that the potential runoff percentage is approximately 5 percent. Figure 24 shows that actual runoff percentage values begin increasing at 1584 feet from the pivot point and is estimated to be over 14 percent at the outer edge. This illustrates that the series of figures using the weighted average runoff are useful as guidelines, but cannot fully represent the runoff potential. Runoff control problems are generally at the outer edge of the system and estimating the magnitude at this point would require a full analysis.

SUMMARY

CPNOZZLE, a computer software program that estimates irrigation runoff, was used to develop a series of runoff charts. Surface storage, soil intake, application depth, wetted radius and system capacity were the variables used for runoff predictions. As expected, tight soils with little surface storage have high runoff potential, even if system capacity is limited. For these soils, sprinkler package and capacity options are limited. Options on packages and irrigation capacity increase with increasing soil intake and surface storage. Results show, however, situations where runoff could be a problem can exist under any sprinkler package. Results presented are also for the average weighted runoff for the entire system. Unacceptable runoff amounts may occur at the outer edges of the system even if the overall average is low. The model also assumes uniform field conditions. Final design and package selections must consider individual field characteristics.

REFERENCES

Fairbanks, K. and W. L. Kranz. 1989. Estimating Potential Runoff from Center Pivots. ASAE Paper No. 89-3516. Winter Meeting.

Howell, T. A., A. D. Schneider and J. A. Tolk. 1991. Sprinkler evaporation losses and efficiency. Proc. Central Plains Irrigation Short Course. North Platte, NE. Feb. 5-6, 1991. p. 69-89.

Jochens, L. 1991. Characteristics of Sprinkler Packages. Proc. Central Plains Irrigation Short Course. North Platte, NE. Feb. 5-6, 1991. p. 59-63.

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Figure 1. Example Printout from CPNOZZLE'S Potential Runoff Analysis.

PERCENT POTENTIAL RUNOFF
0.1 SCS Intake Family

System length feet	Wetted Radius feet	Surface Storage in	900 gpm	1000 gpm	1100 gpm
128	30	0.5	0.0%	0.0%	0.0%
256	30	0.5	0.0%	0.0%	0.0%
384	30	0.5	0.0%	0.0%	0.0%
512	30	0.5	0.0%	0.0%	0.0%
640	30	0.5	0.0%	0.0%	0.9%
768	30	0.5	0.6%	2.4%	3.9%
896	30	0.5	3.2%	4.9%	6.3%
1024	30	0.5	5.3%	6.9%	8.3%
1152	30	0.5	7.1%	8.6%	10.0%
1280	30	0.5	8.6%	10.2%	11.5%
Weighted Average Potential Runoff			3.4%	4.5%	5.6%
Hours per revolution			59	53	49

1.0 in application amount, 1280 feet system length

Figure 2. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 1.0 in., Intake Family - 0.1, System Length - 1280 ft.

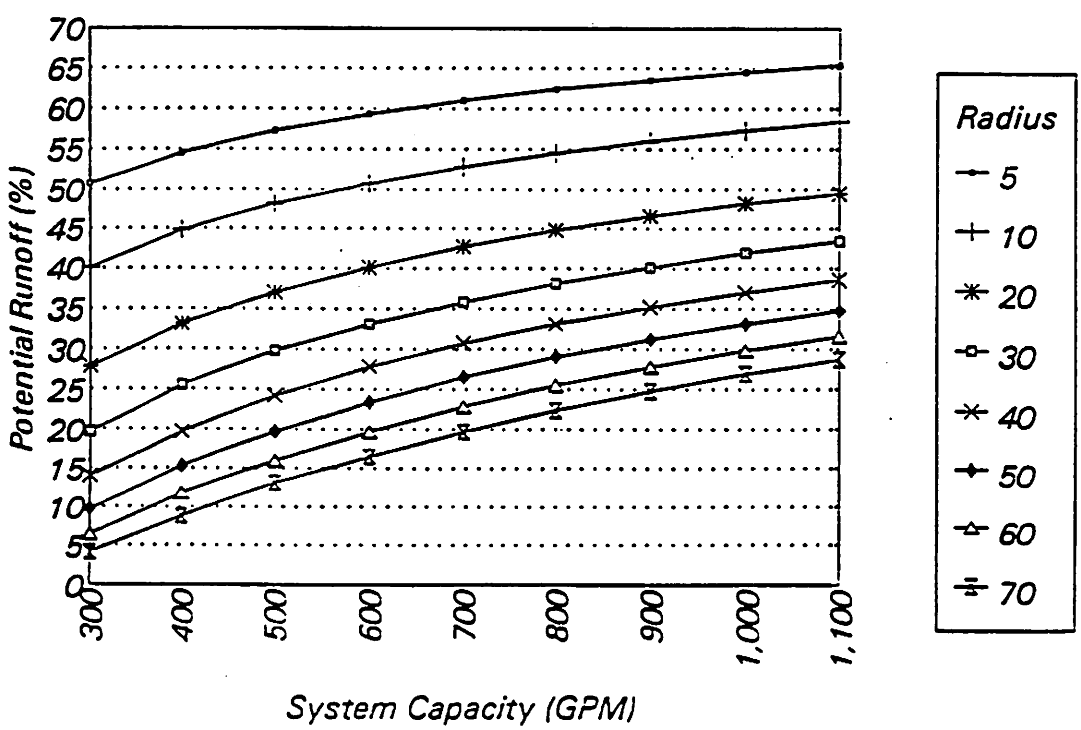

Figure 3. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius.
Storage - 0.1 in., App. Amt. - 0.75 in., Intake Family - 0.1, System Length - 1280 ft.

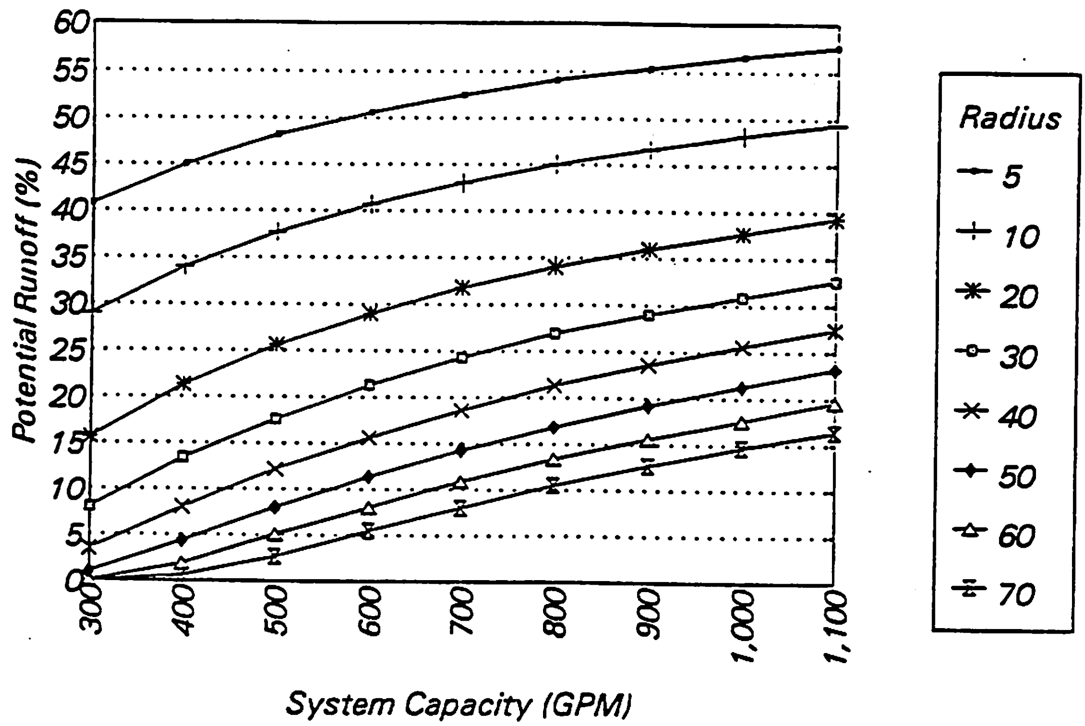

Figure 4. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius.
Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.1, System Length - 1280 ft.

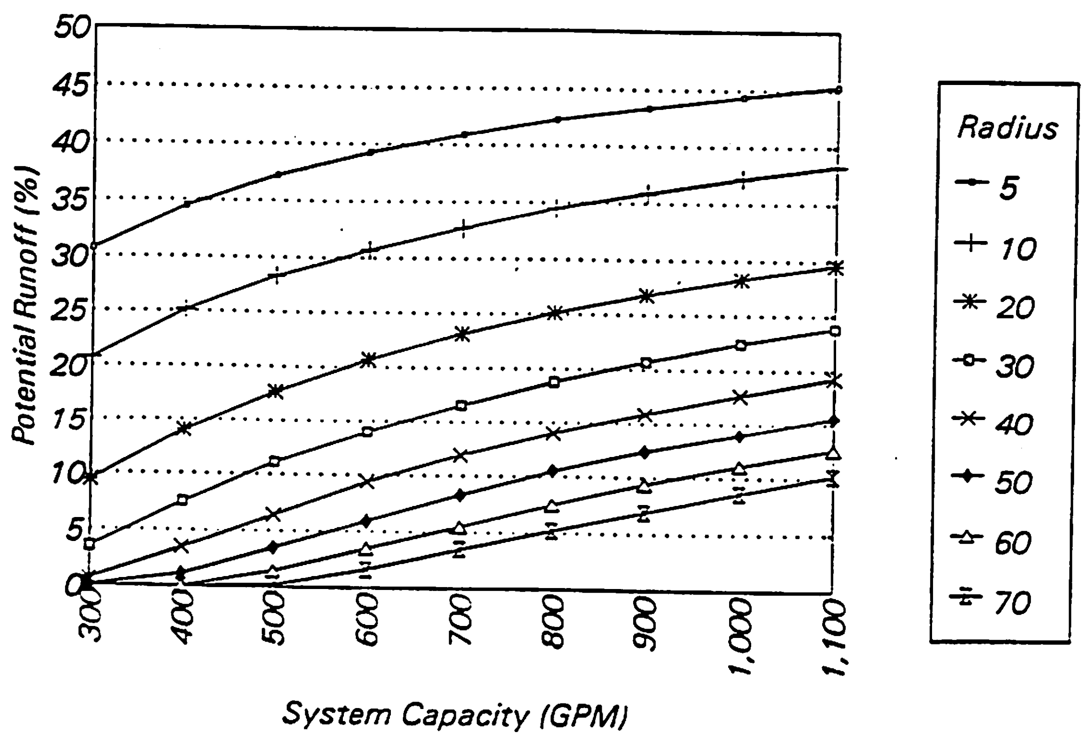

Figure 5. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 0.75 in., Intake Family - 0.1, System Length - 1280 ft.

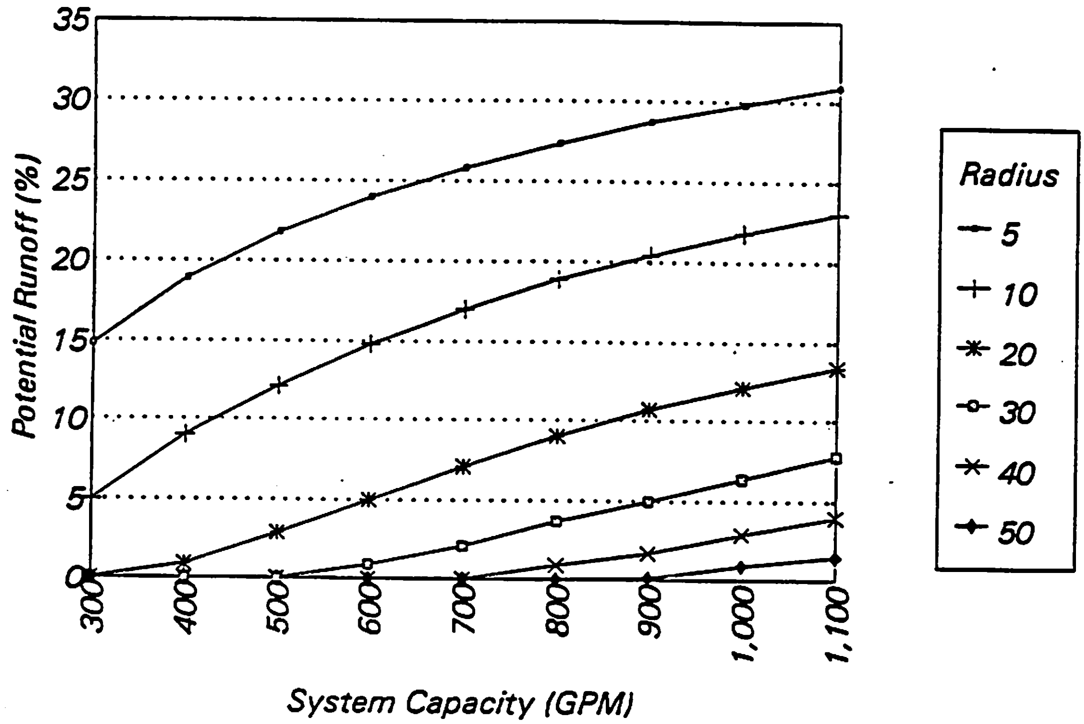

Figure 6. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.0 in., Intake Family - 0.1, System Length - 1280 ft.

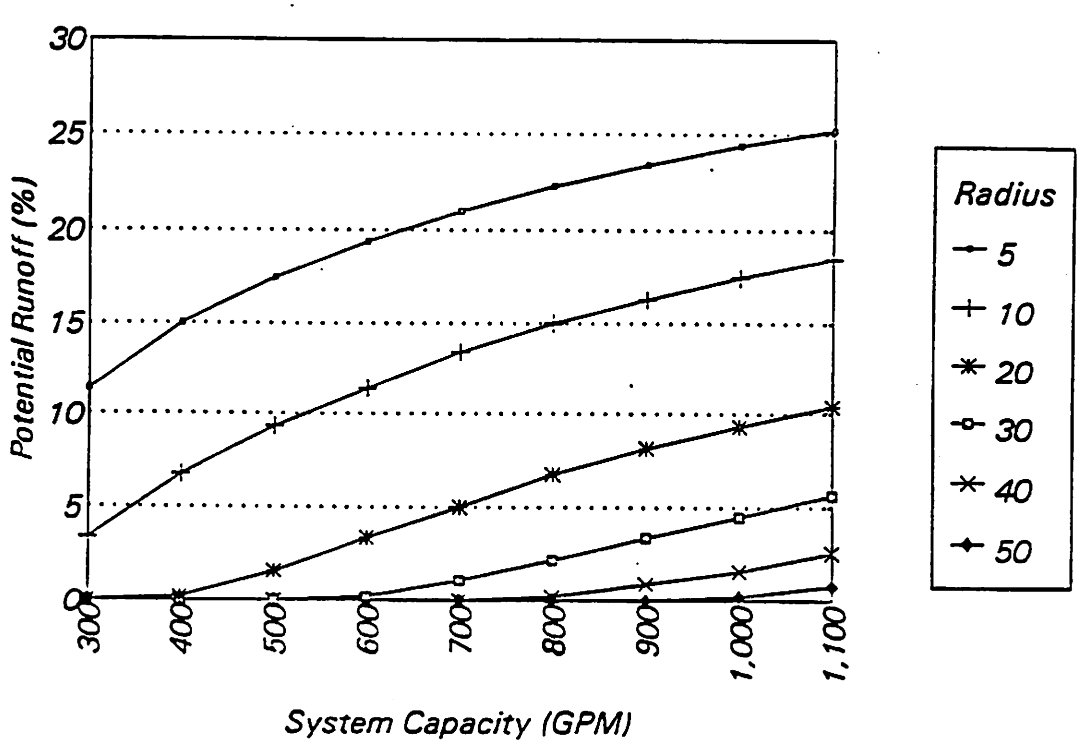

Figure 7. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.5 in., Intake Family - 0.1, System Length - 1280 ft.

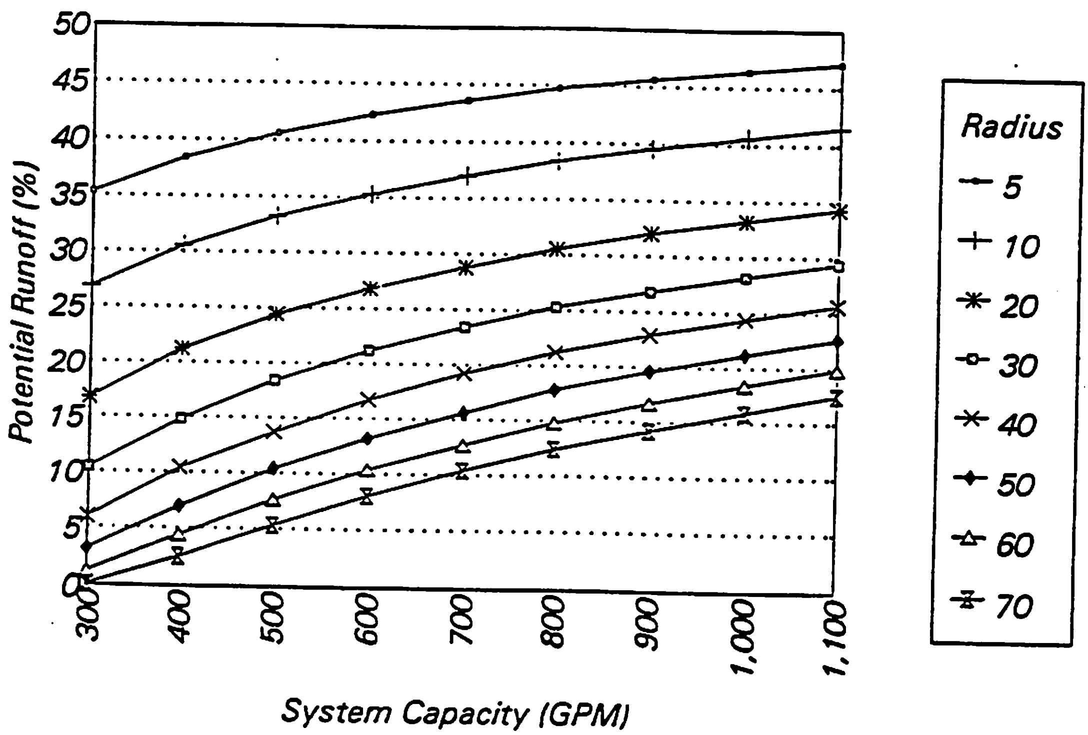

Figure 8. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 1.0 in., Intake Family - 0.3, System Length - 1280 ft.

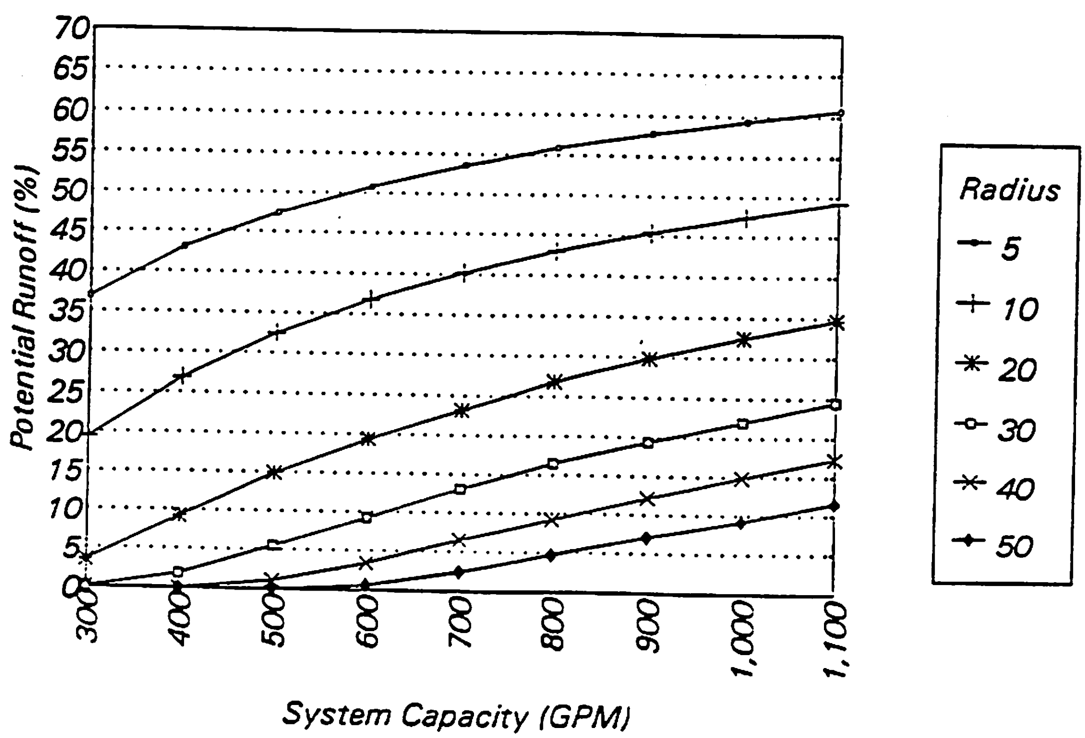

Figure 9. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 0.75 in., Intake Family - 0.3, System Length - 1280 ft.

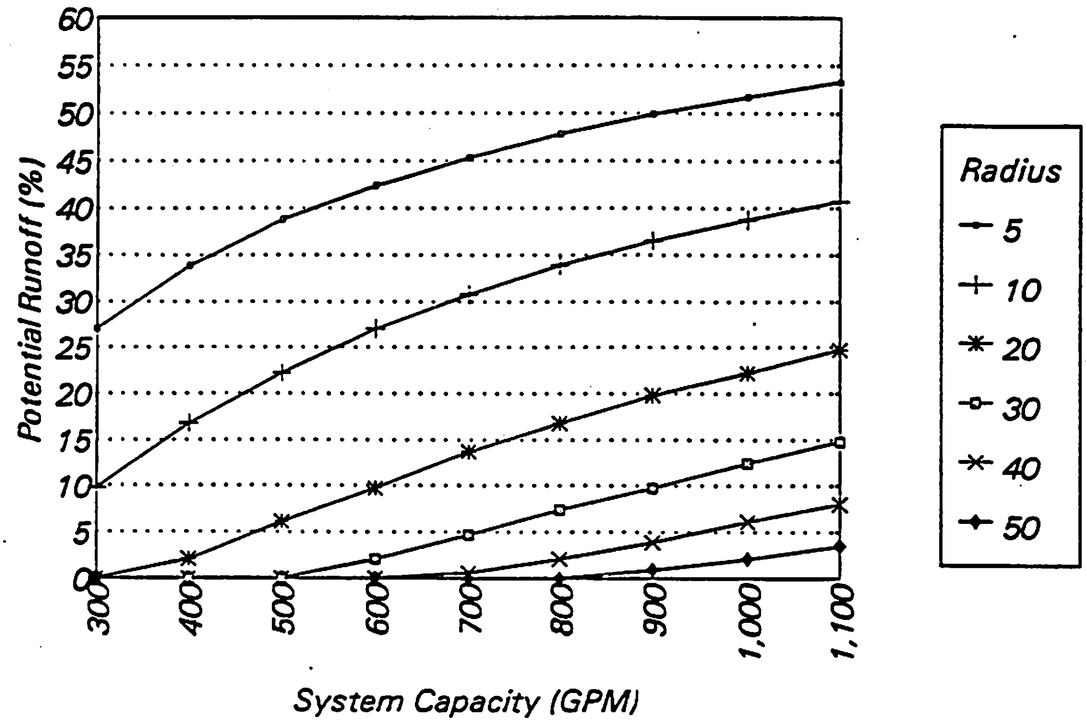

Figure 10. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.3, System Length - 1280 ft.

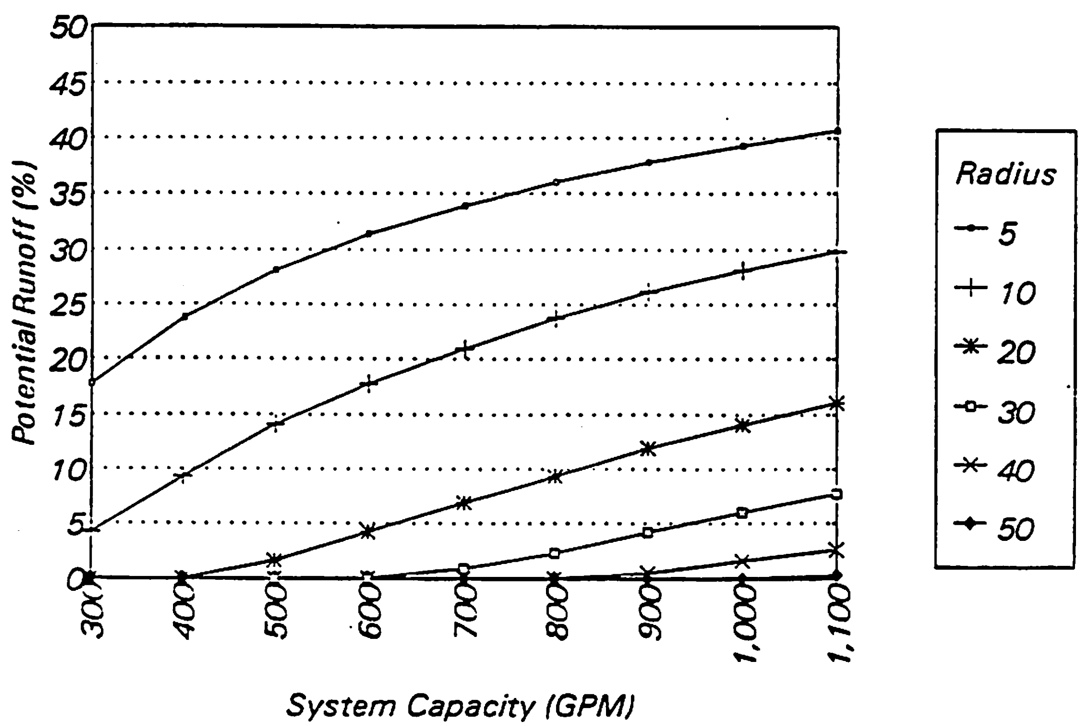

Figure 11. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.5 in., Intake Family - 0.3, System Length - 1280 ft.

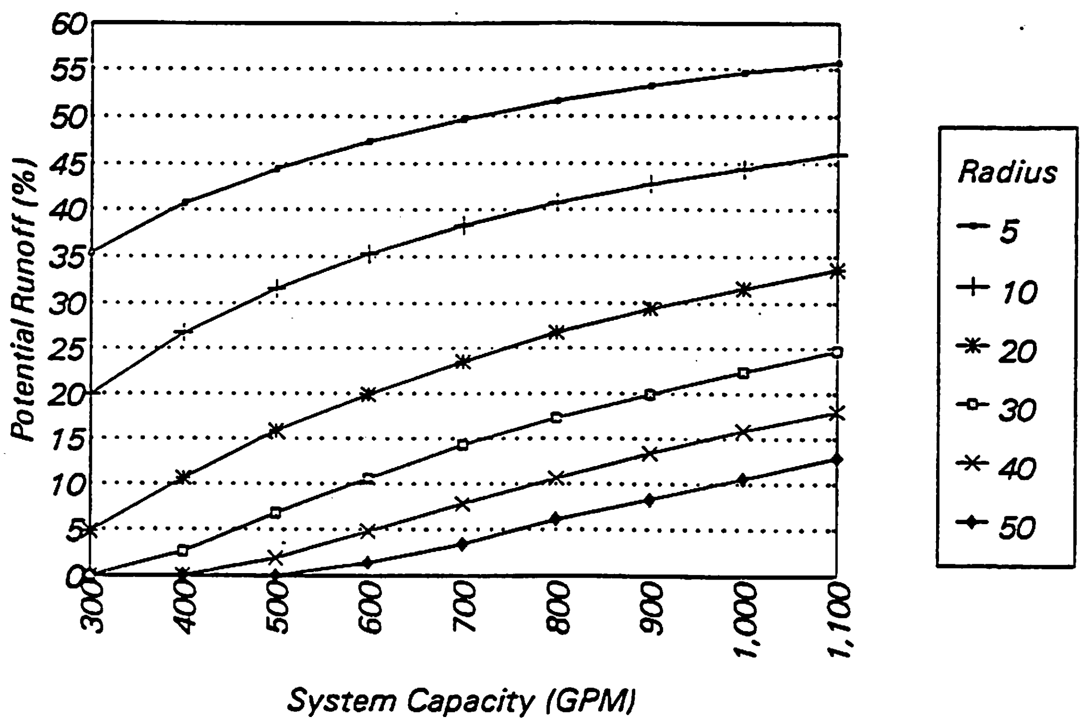

Figure 12. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.0 in., Intake Family - 0.3, System Length - 1280 ft.

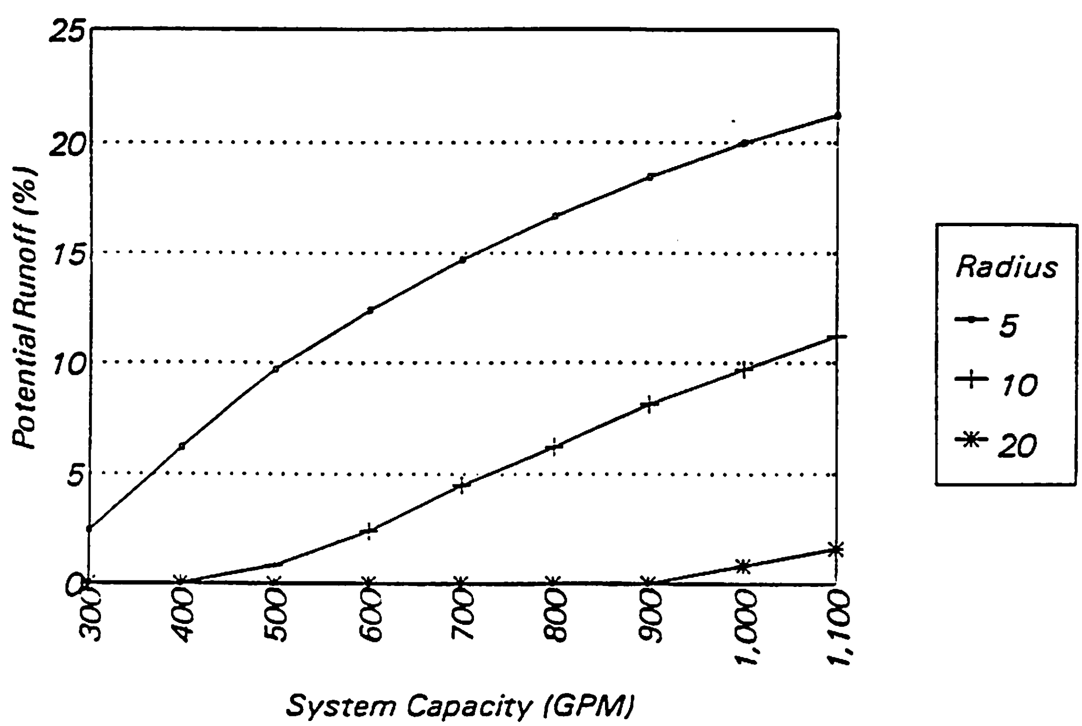

Figure 13. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.5 in., Intake Family - 0.3, System Length - 1280 ft.

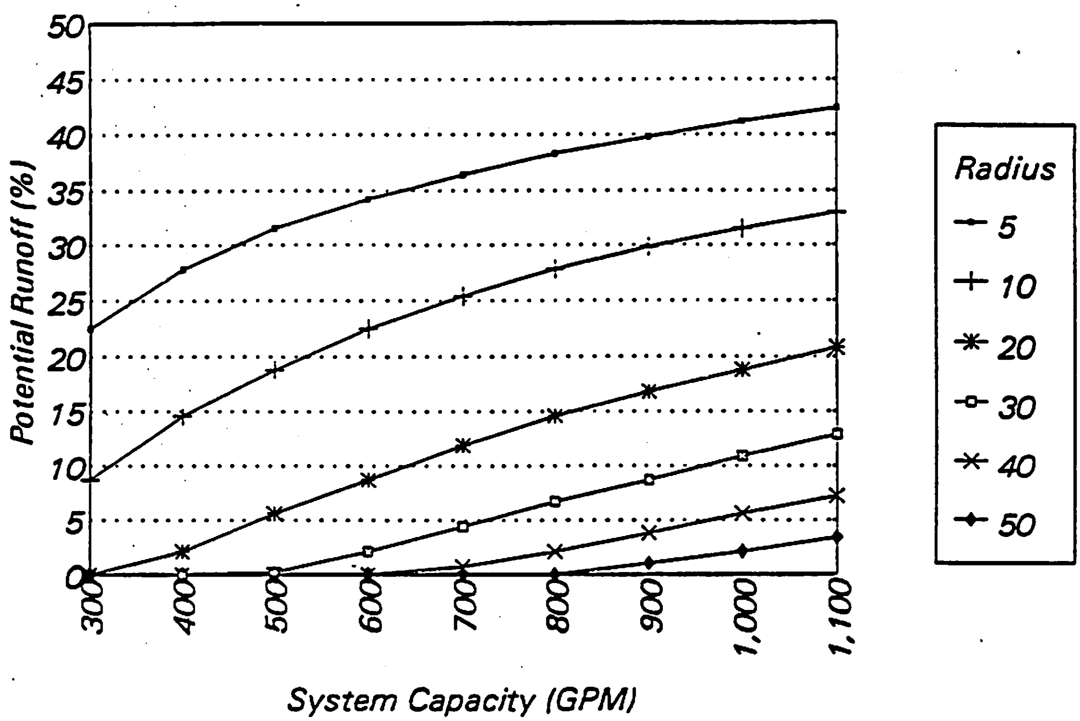

Figure 14. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 1.0 in., Intake Family - 0.5, System Length - 1280 ft.

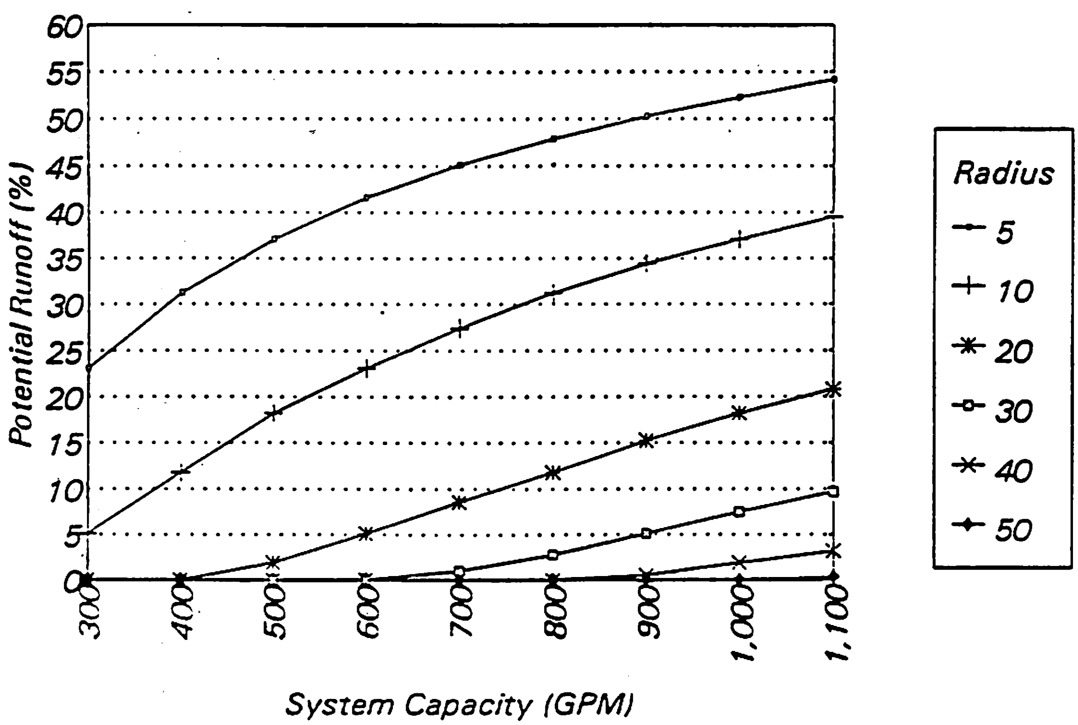

Figure 15. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 1.5 in., Intake Family - 0.5, System Length - 1280 ft.

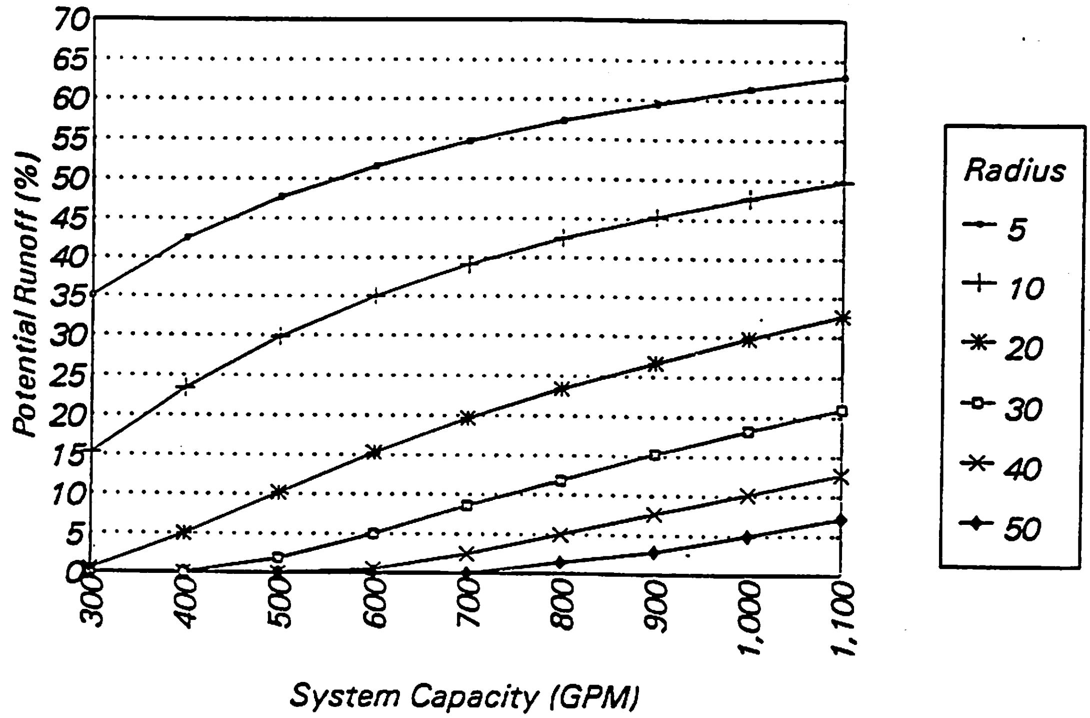

Figure 16. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.5, System Length - 1280 ft.

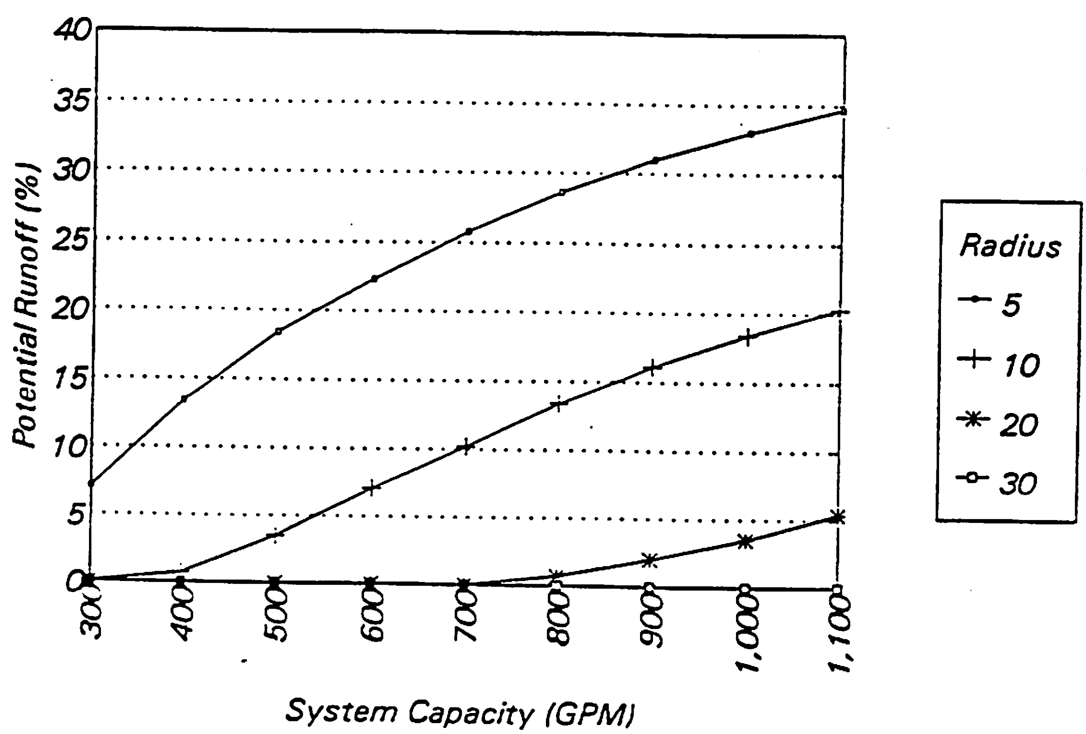

Figure 17. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.5 in., Intake Family - 0.5, System Length - 1280 ft.

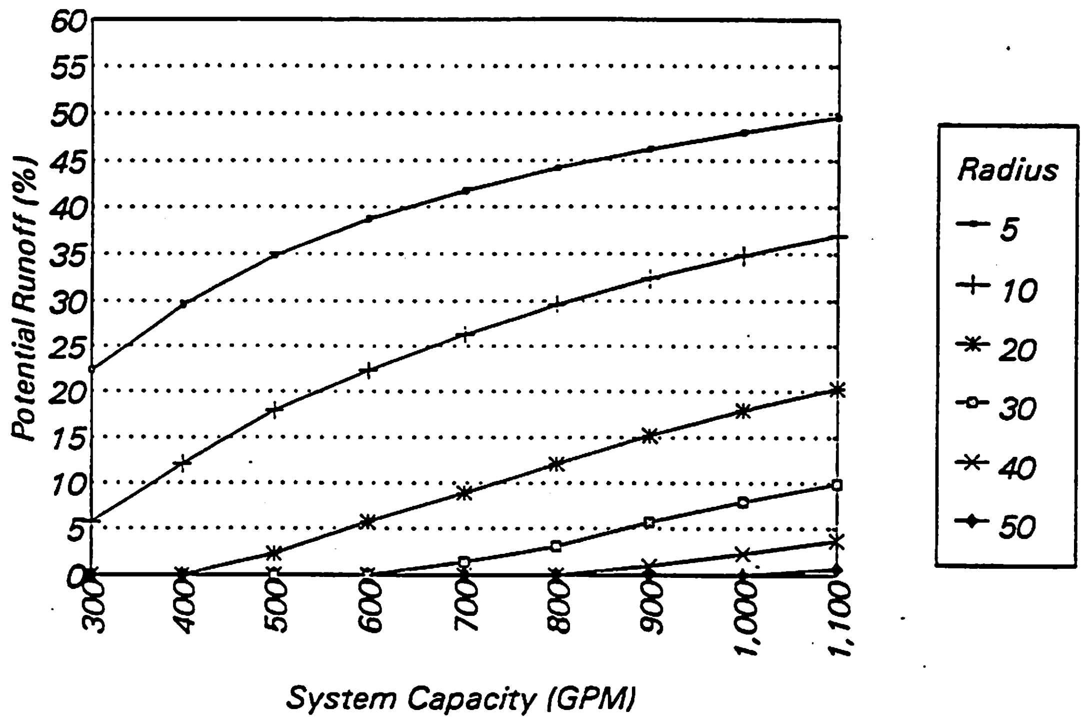

Figure 18. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.1 in., App. Amt. - 1.0 in., Intake Family - 1.0, System Length - 1280 ft.

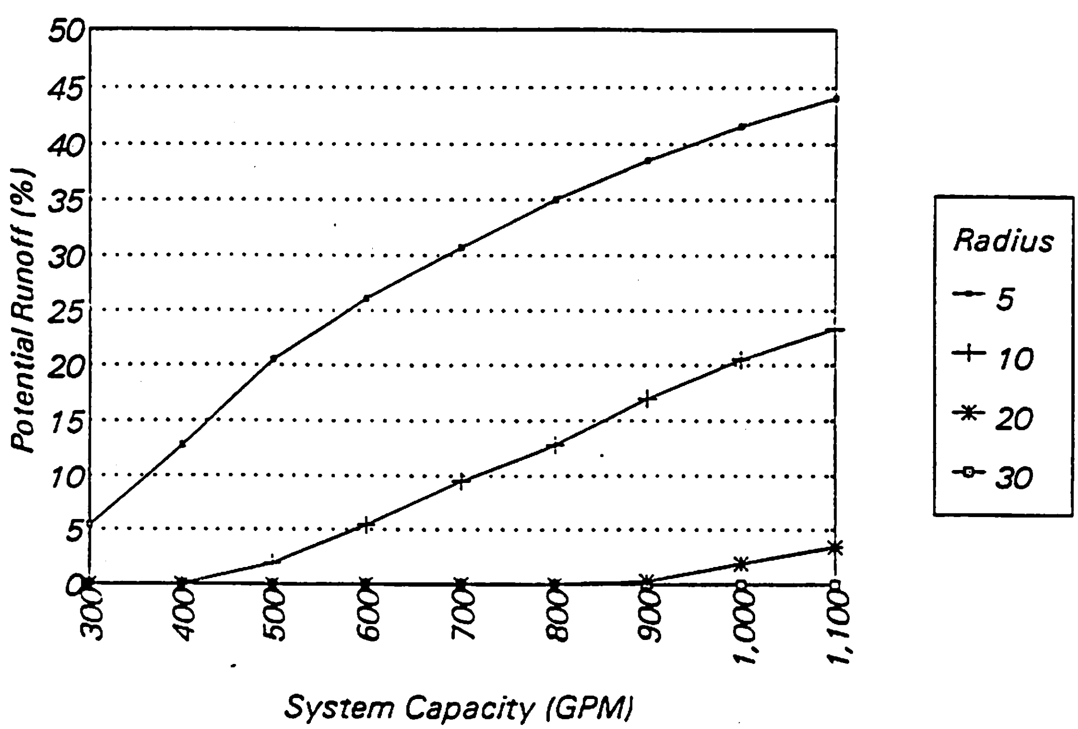

Figure 19. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 1.0, System Length - 1280 ft.

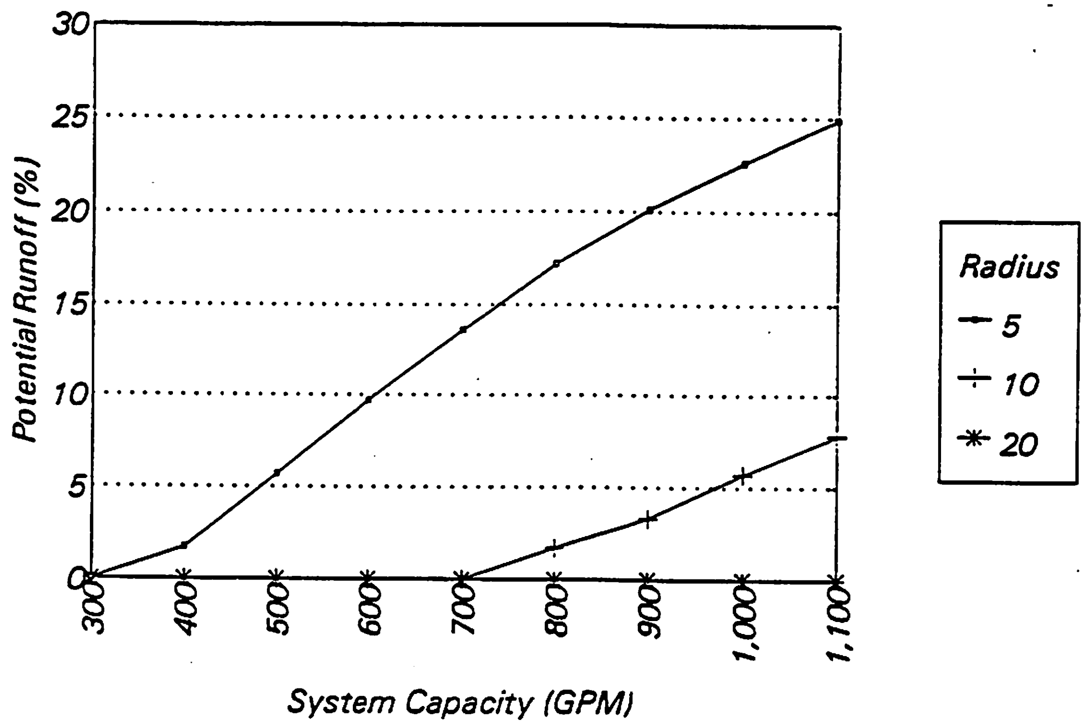

Figure 20. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.3, System Length - 2640 ft.

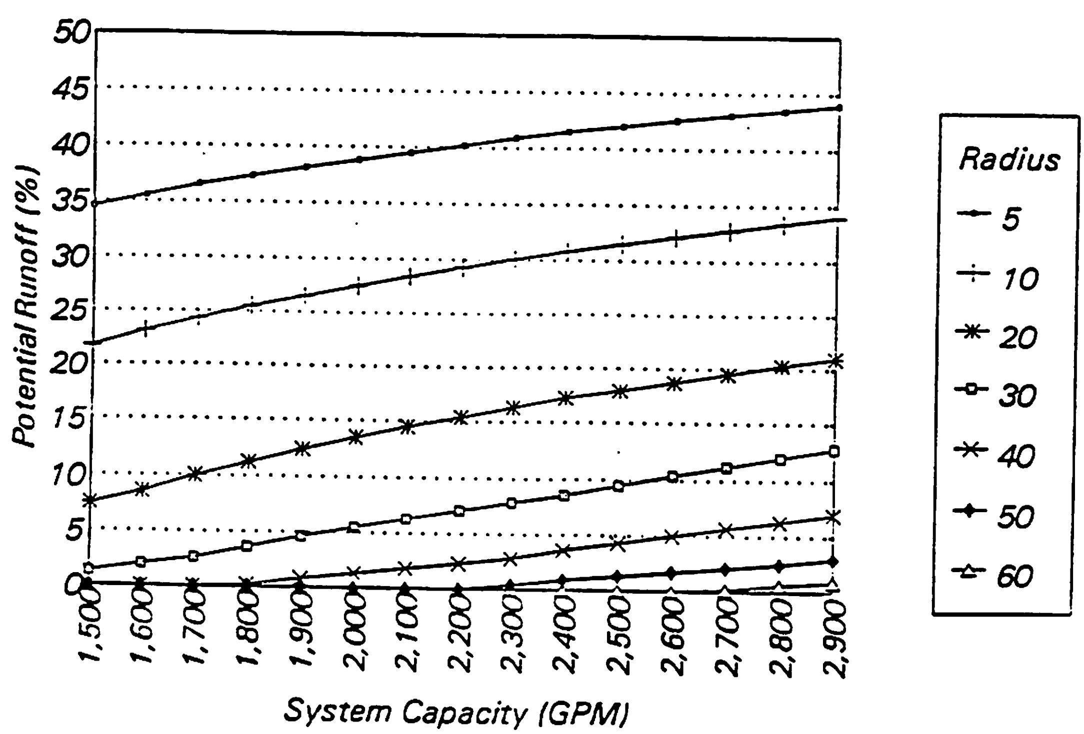

Figure 21. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.0 in., Intake Family - 0.3, System Length - 2640 ft.

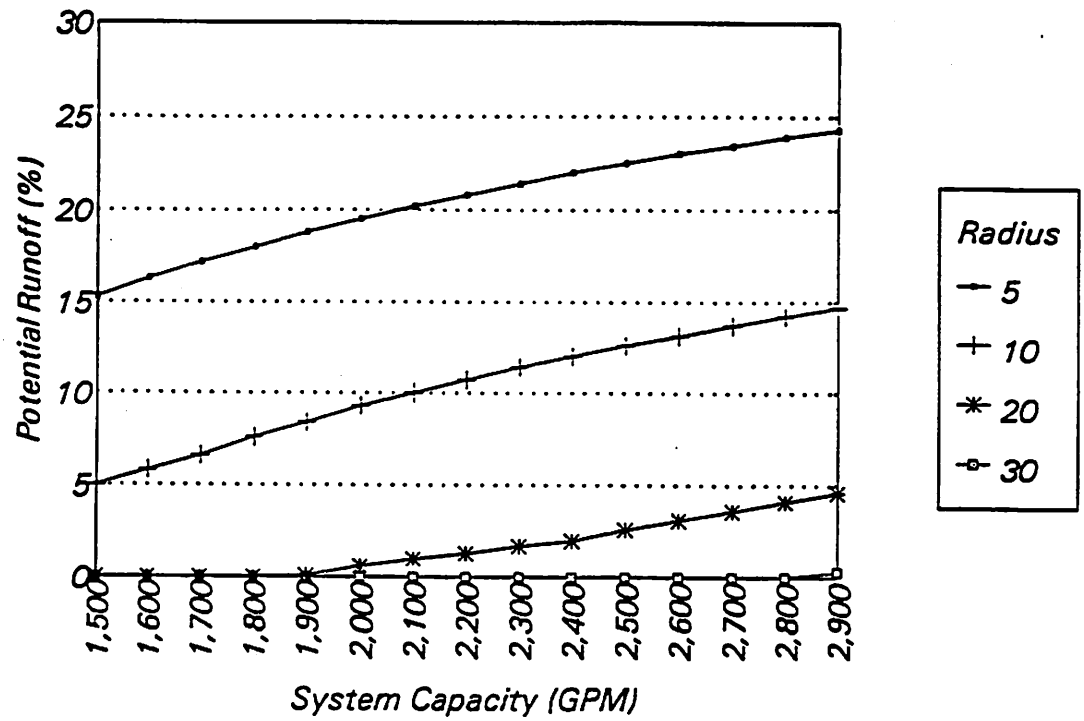

Figure 22. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.5, System Length - 2640 ft.

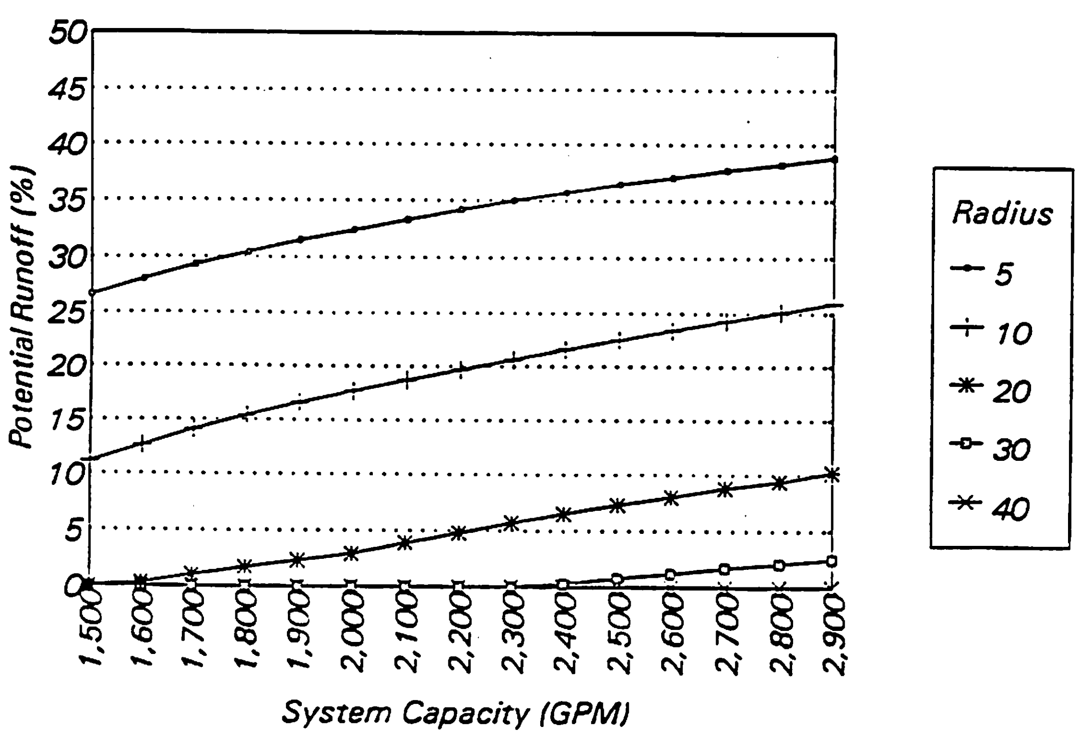

Figure 23. Predicted Irrigation Runoff Potential for Various System Capacities and Wetted Radius. Storage - 0.5 in., App. Amt. - 1.0 in., Intake Family - 0.5, System Length - 2640 ft.

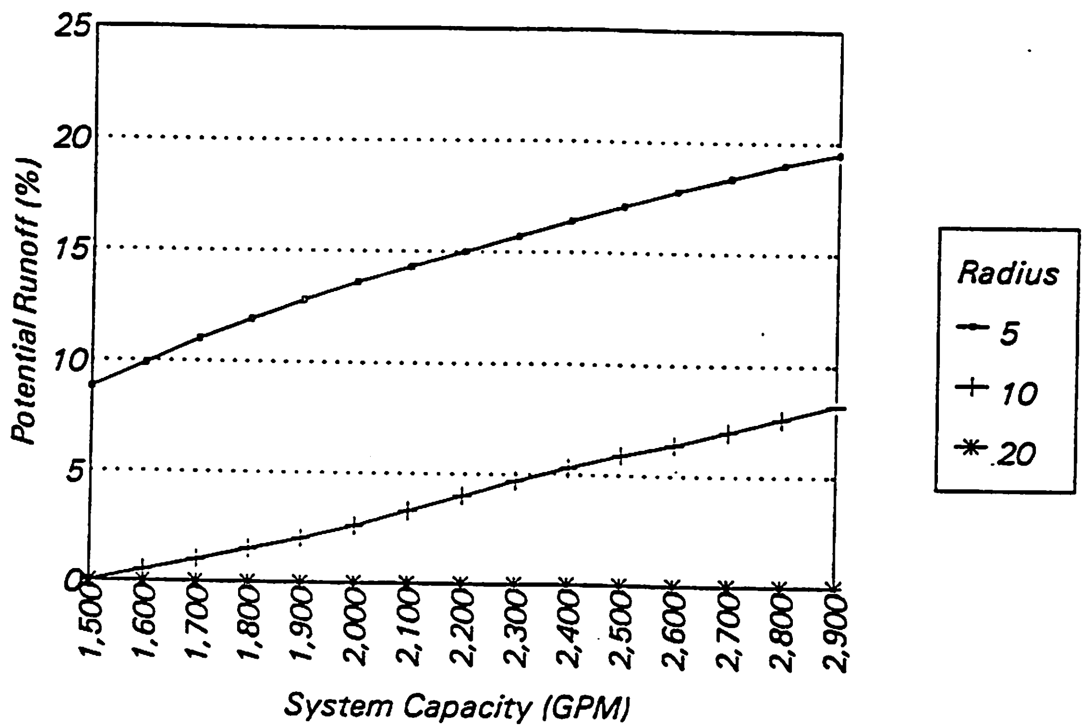

Figure 24. Predicted Irrigation Runoff Potential for Various Distances Along the System. Storage - 0.3 in., App. Amt. - 1.0 in., Intake Family - 0.5, Wetted Radius - 20 ft.