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Additional submitted attachment is included below.

Comments from Edward Norum for Docket #: 17-AAER-08 Project Title: Sprinkler Spray Bodies
Center for Irrigation Technology
California State University, Fresno
September 18, 2017

Purpose

To develop a testing protocol that determines the irrigation water application efficiency for turf and landscape sprinklers. To set a minimum application efficiency of 65 percent for these sprinklers.

Product Technology Description

As a component of the sprinkler irrigation system, the sprinkler is responsible for distributing the irrigation water over the surface of the root zone with a minimum efficiency of 65 percent. The sprinkler is a hydraulic appliance consisting of a body with hydraulic connectors, a pop-up component, and a nozzle. Optional components include flow and pressure regulating features, and drainage check valves. Special body modifications can be included to position the nozzle at a height that properly indexes to the vegetation height.

Overview

While application rate efficiency data is admitted to being critical to the efficiency management of irrigation water supplies, there is currently no recognized testing protocol that meets this need. Further there is no recognized protocol that scientifically matches applied water to vegetative demands that satisfies vegetative quality objectives. A protocol is outlined that allows the irrigation system to meet quality demands while reflecting a commercial balance between system cost and application efficiency. An extensive series of distribution tests shows the current state of the commercial art to average at 65 percent. The test protocol has been developed, formalized and tested. It provides science based evaluation parameters and abandons historic parameters that are not scientifically defensible.

Methodology

Whenever possible, products should be tested in a manner that duplicates their actual field use as closely as possible. The sprinklers in this study were all tested in a full-scale layout on the smooth concrete floor at Fresno State's Center for Irrigation Technology (CIT) sprinkler test building.

The sprinkler spacing was a square grid with a distance of 15 ft between sprinklers. The PVC piping network was sized to keep velocities below 3.0 fps. Test pressures were as registered to an accuracy of 0.5 percent in the plumbing network into which the sprinklers were attached. Rain gauges had a 4-in. diameter and recorded applications to the nearest 0.01 in. Flow measurement accuracy was to 1.0 percent. The building environment represents a zero wind environment. Sprinkler run times were set to provide an average catchment of 0.50 to 0.75 inches. Environmental measurements included temperature, humidity, and barometric pressure.

Grid rain gauge spacing was 3.0 ft by 3.0 ft. The target area was 30 ft by 30 ft representing a model yard. It contained 100 evenly-spaced rain gauges (see Figure 1). The target area was

surrounded by a single row of rain gauges. The gauges were spaced to represent the catchment within three feet of the target boundary. Virtually no water droplets were detected beyond the rain gauge grid geometry. A special valving arrangement allowed for nearly instantaneous system start up and shut down.

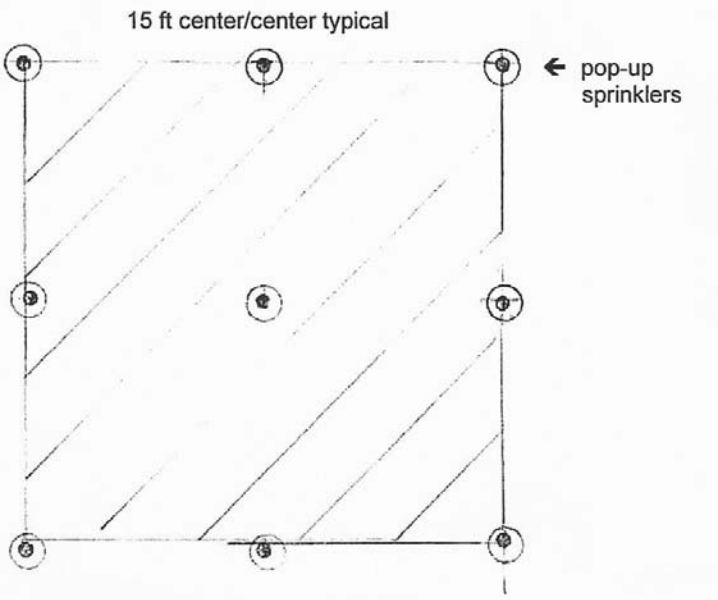

Figure 1. 30 ft x 30 ft square layout

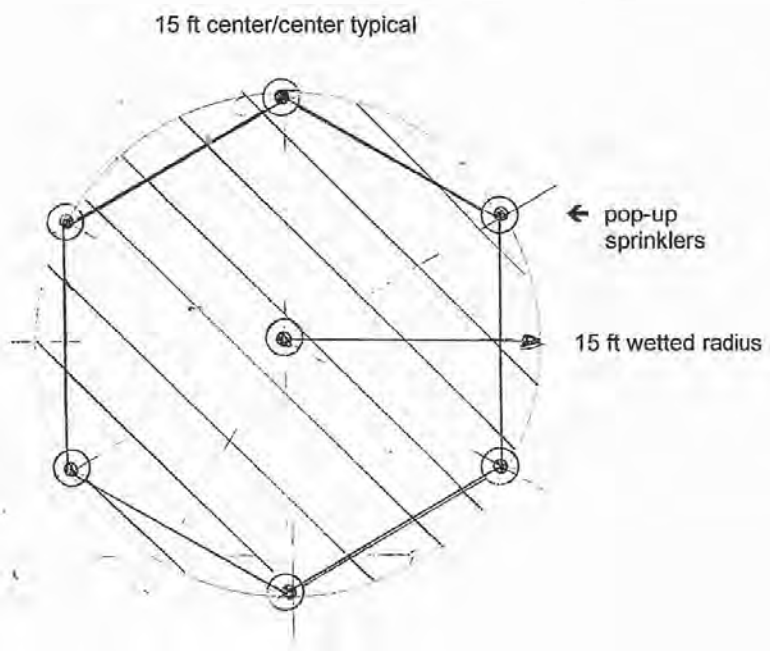

Figure 2. 30 ft circular layout

Inefficiencies in turf sprinkler performance result from: losses to deep seepage caused by pattern non-uniformities; losses due to over spraying of the target area; and losses to atmospheric evaporation. With the water distribution measured at the grass canopy, surface evaporation of drops that never reach the grass canopy is automatically accounted for. Strictly speaking, this evaporation loss should be accounted for because it could be caused by a variable in sprinkler design. Instrumentation to account for evaporation losses is prohibitively expensive.

Losses to deep seepage result from the repeated use of non-uniform patterns. Repeated use results in a tendency to index wet-on-wet and dry-on-dry spots between irrigation rounds. In practice, this is compensated for by over-irrigating the dry spot to maintain adequate dry spot quality. As a result of this over-irrigation, the wet spot will drive the surplus water through the wet spot into the subsoil. The formula for calculating this pattern loss (PL) is as follows:

(1) $$PL = \frac{\sum_1^{75}(x - x_i)}{100\,(\bar{x})}$$

Where: x_i = app rate at 75% of area
$\bar{x}$ = ave app rate

The calculation is shown graphically in Figure 3.

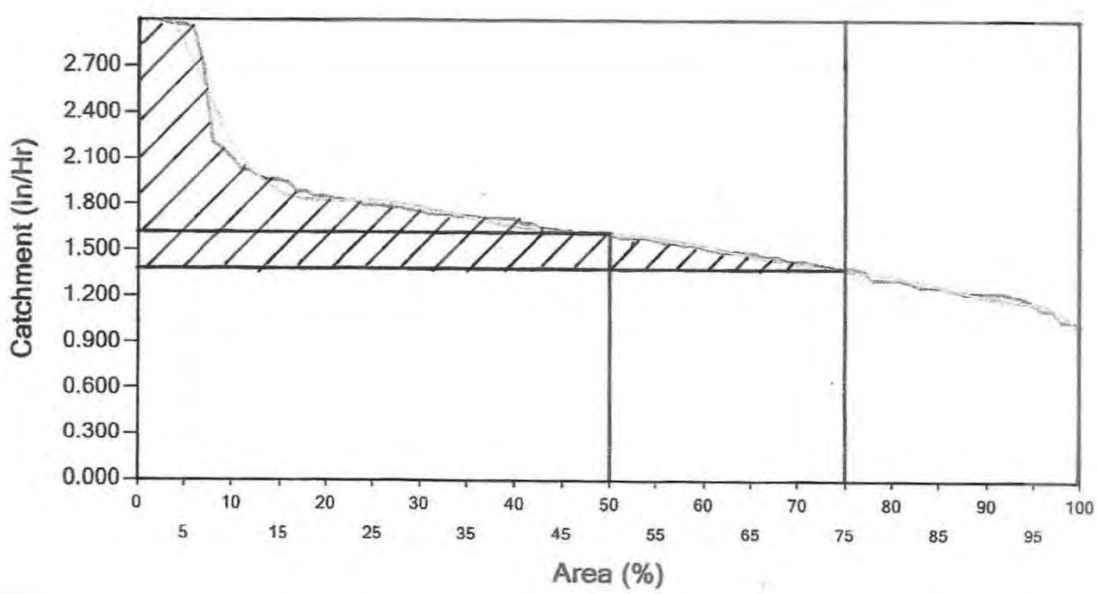

Figure 3. Graphical representation of formula

The 100 catchments are arrayed from wet (left side) to dry (right side). The pattern loss is represented by the shaded area in Figure 3. The concept makes the assumption that the commercial grass quality is adequate as long as 75 percent of the target area receives the scheduled amount of irrigation.

Overspray (OS) is directly related to the water caught in the rain gauges outside of the target area. The formula for the overspray losses is as follows:

(2) $$OS = \frac{\sum OS}{N\,(\bar{x}) + \sum OS}$$

The sprinkler application efficiency (SAE) combines the pattern and overspray losses in the following formula:

(3) $$SAE = (1.0 - PL)\,(1.0 - OS)\,100$$

The sprinkler application efficiency metric has physical significance and is useful in studies and regulations requiring a scientific characterization of the irrigation system water use efficiency.

Proposed Standard and Recommendations

The following is a discussion of the actual test results that led to the specifics of the actual suggested parameter values.

Representative Metrics

Table 1 shows the results of testing sprinklers in the manner proposed. The square target area is as shown in Figure 1. The round target area is as proposed in the SWAT testing protocol. The importance of combining the pattern loss and the overspray loss can be seen by comparing the results from square Test #2 with #3. Both tests have sprinkler application efficiencies over 80 percent. In Test #2, the overspray loss was negligible at 0.1 percent. With Test #3 however, the overspray loss was 6.2 percent. This degree of overspray is apparently required to develop the designed-in uniformity of the target area. The difficulty of designing for coverage on the round area is shown with a relatively low overall average sprinkler application efficiency of 68.4 percent (vs 78.6 percent for the square pattern).

Table 1. Selected Summary of Distribution Patterns

TEST #	SPRINKLER ID	TARGET SHAPE[1]	PRESSURE *psi*	FLOW RATE *gpm*	AVERAGE APPLICATION RATE[2] *in./hr*	EFFECTIVE APPLICATION RATE[3] *in./hr*	PATTERN LOSS[4] %	OVERSPRAY LOSS[5] %	SPRINKLER APPLICATION EFFICIENCY[6] %	DU
1	Test #1SHV	□	30	15.50	1.616	1.384	20.1	1.0	79.1	74.0
2	Test #1SU	□	30	15.38	1.606	1.400	19.3	0.1	80.6	74.3
3	Test #3IR	□	40	6.20	0.611	0.556	12.7	6.2	81.9	78.7
4	Test #5 IPF	□	30	15.80	1.627	1.279	25.4	2.0	73.1	62.5
5	Test #4 USN	□	30	12.60	1.253	1.085	21.2	0.9	78.1	65.1
						AVERAGE	**19.7**	**2.04**	**78.6**	**70.9**
1	Test #1SHV (7)	○	30	14.50	1.749	1.468	24.2	7.0	70.5	63.0
2	Test #1SHV (8)	○	30	13.53	1.862	1.399	33.6	0.2	66.3	28.9
3	Test #5 IR	○	40	4.59	0.641	0.490	27.6	6.0	67.9	40.5
4	Test #1 UPS	○	30	7.00	0.902	0.732	30.8	1.1	68.4	54.7
5	Test #4 IPA	○	30	15.06	1.823	1.449	23.6	10.0	68.7	63.6
						AVERAGE	**28.0**	**4.9**	**68.4**	**50.2**

1 See SWAT protocol 2 Average application rate 3 Effective application rate (75%) 4 Pattern loss 5 Overspray loss 6 Sprinkler application efficiency

This particular study provided a definition of results achievable by major manufacturers and the challenge presented by curved plot boundaries.

A second study was initiated, once again with both square and round targets. Over 100 tests were conducted to provide a characterization of the current “state of the commercial art” of the currently marketed sprinklers. The results were as follows:

> For sprinklers on square areas, the average application efficiency was 72.3 percent, and for sprinklers on round areas, the average application efficiency was 58.5 percent. This suggests that the rule states that all sprinklers be tested to certify an application efficiency of no less than 70 percent on square areas and 56 percent on round areas.

Analysis of Proposal

Setting a fixed minimum performance standard assures a level of performance commensurate with the current standard of the commercial art. Requiring the actual value at the near average of the commercial art will result in an overall improvement in water use efficiency. Periodic review of sprinkler performance capabilities will gradually result in ever improving water use efficiencies.

A series of tests were run to support the recommendation of the minimum of 70 percent application efficiency for square target areas and 60 percent for round target areas. The results of this test work are shown in Table 1 where the average values are 78.1 percent and 68.4 percent for the square and round shaped target areas respectively.

A further series of 120 tests were run on sprinklers from major manufacturers. The averages from these tests were 72.3 percent and 58.5 percent for the square and round target areas respectively.

The burden of the effect of establishing a 70 percent standard for square target areas and a 60 percent standard for round target areas would be shared across a major portion of the irrigation industry. Table 1 shows sprinkler application efficiency values over these values. This suggests that the standard is achievable given the technology currently available from irrigation manufacturers. Ultimately, the consuming public will be rewarded with reduced irrigation water bills and California will see an improvement in the utilization of water resources. The target threshold values should be reviewed and raised periodically as the technology evolves.

An improvement in irrigation efficiency results in a reduction in the energy required to pump the water. Energy required to pump water is directly related to the flow rate. A 10 percent reduction in flow rate results in a 10 percent reduction in energy.

Setting of the minimum performance standard requires the use of an existing test protocol developed by the Center for Irrigation Technology at California State University, Fresno.

The proposed sprinkler performance standard does not interfere with any other known state or federal standard or regulation.

Conclusion

The proposed performance standard is in harmony with the state of the commercial art. It allows the State to profit from the better capabilities offered by sprinkler manufacturers as did the testing protocol for characterizing fuel consumption by automobiles. These standards turn loose the natural creativity of American industry. The minimum performance standard of 70 percent for square areas and 60 percent for round areas as defined in the testing protocol will save water and imbedded energy.

Appended: SWAT-TWG August 10, 2017 memo

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MEMO TO: SWAT-TWG

FROM: Ed Norum

DATE: August 10, 2017

SUBJECT: Material for August 24, 2017 teleconference*

Table A1. Summary of Testing Protocol Results
*Note: Gallons used calculation added after committee meeting.

Figure A1 Hunter Pro-Spray without Pressure Regulation/15 ft. Nozzles (at 30 psi)

Figure A2 Hunter Pro-Spray without Pressure Regulation/15 ft. Nozzles (at 60 psi)

Figure A3 Hunter Pro-Spray with Pressure Regulation/15 ft. Nozzles (at 30 psi)

Figure A4 Hunter Pro-Spray with Pressure Regulation/15 ft. Nozzles (at 60 psi)

Figure A5 Hunter Pro-Spray with Pressure Regulation/15 ft. Nozzles (at 60 psi) 3D

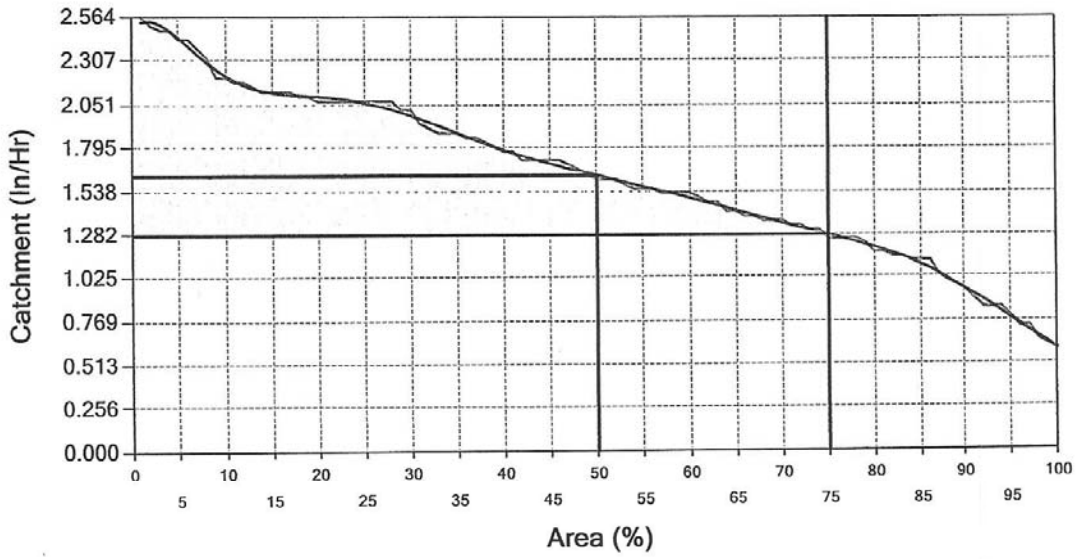
Figure A6 3D Plot Demonstrating Jet Interference

Figure A7 Overlapped Pattern from Figure 6 Developed by Hand Overlapping Single Catchment Pattern

Table 1. Summary of Testing Protocol Results*

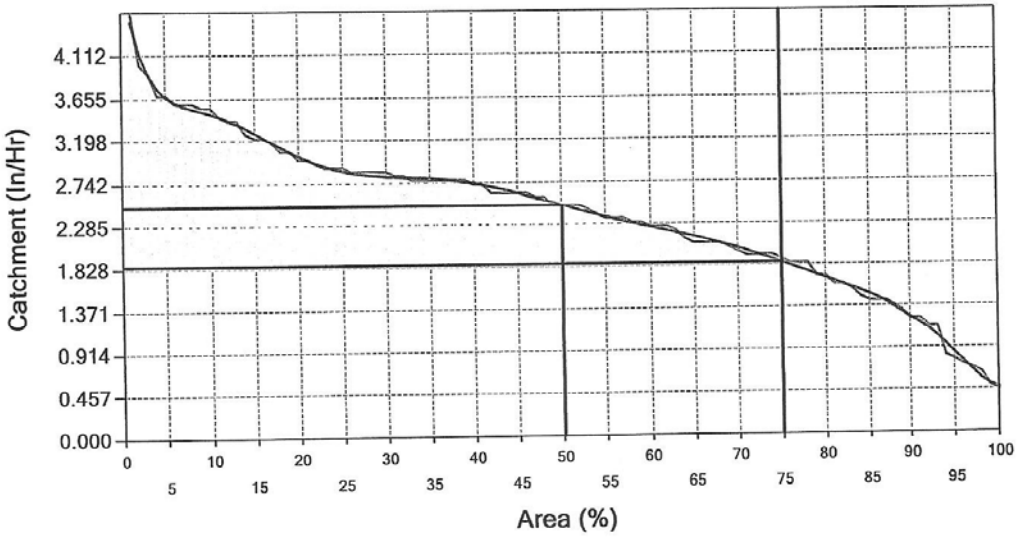
	HUNTER PRO-SPRAY 15 ft w/o pressure regulators		**HUNTER PRO-SPRAY 15 ft w/pressure regulators**	
	30 psi	**60 psi**	**30 psi**	**60 psi**
Flow rate, gpm	18.0	25.3	17.0	18.8
Average app. rate (in./hr)	1.63	2.50	1.56	1.82
Effective app. rate (in./hr)	1.28	1.86	1.18	1.41
Overspray loss (%)	1.0	5.0	0.6	2.6
Pattern loss (%)	26.6	29.7	28.7	26.2
Application efficiency (%)	72.7	66.8	70.9	71.9
Distribution uniformity (%)	60.5	53.0	60.7	59.0
Gallons/1.0 ETc	844	816	869	800
kW-hr/1.0 ETc	0.186	0.356	0.188	0.348
See Figure	Figure 1	Figure 2	Figure 3	Figure 4

* Table updated August 30, 2017



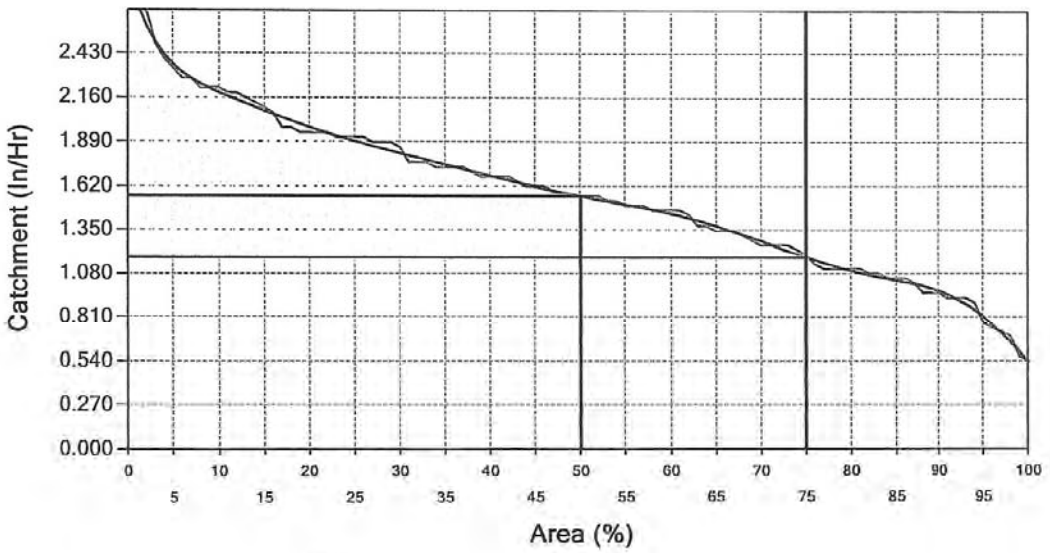
Pressure (psi):	30.0
Flow Rate (gpm):	18.00
Spacing (ft):	15.0 x 15.0
Area:	Square
Avg Application Rate (In/Hr):	1.630
Effective Application Rate (In/Hr):	1.279 (75.0 %)
Overspray:	1.0 %
Pattern Loss:	26.6 %
Application Efficiency:	72.7 %
Distribution Uniformity:	60.5 %
Notes:	SWAT 9 sprinkler installation

Figure A1. Hunter Pro-Spray® without pressure regulation/15 ft nozzles



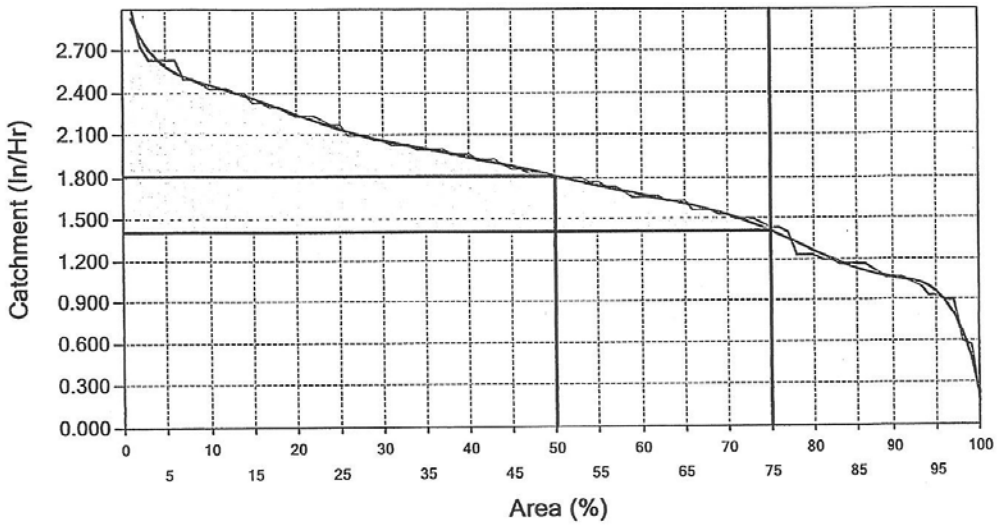
Pressure (psi):	60.0
Flow Rate (gpm):	25.30
Spacing (ft):	15.0 x 15.0
Area:	Square
Avg Application Rate (In/Hr):	2.499
Effective Application Rate (In/Hr):	1.858 (75.0 %)
Overspray:	5.0 %
Pattern Loss:	29.7 %
Application Efficiency:	66.8 %
Distribution Uniformity:	53.0 %
Notes:	SWAT 9 sprinkler installation

Figure A2. Hunter Pro-Spray® without pressure regulation/15 ft nozzles



Pressure (psi):	30.0
Flow Rate (gpm):	17.00
Spacing (ft):	15.0 x 15.0
Area:	Square
Avg Application Rate (In/Hr):	1.562
Effective Application Rate (In/Hr):	1.184 (75.0 %)
Overspray:	0.6 %
Pattern Loss:	28.7 %
Application Efficiency:	70.9 %
Distribution Uniformity:	60.7 %
Notes:	SWAT 9 sprinkler installation

Figure A3. Hunter Pro-Spray® with pressure regulation/15 ft nozzles



Pressure (psi):	60.0
Flow Rate (gpm):	18.80
Spacing (ft):	15.0 x 15.0
Area:	Square
Avg Application Rate (In/Hr):	1.816
Effective Application Rate (In/Hr):	1.411 (75.0 %)
Overspray:	2.6 %
Pattern Loss:	26.2 %
Application Efficiency:	71.9 %
Distribution Uniformity:	59.0 %
Notes:	SWAT 9 sprinkler installation

Figure A4. Hunter Pro-Spray® with pressure regulation/15 ft nozzles

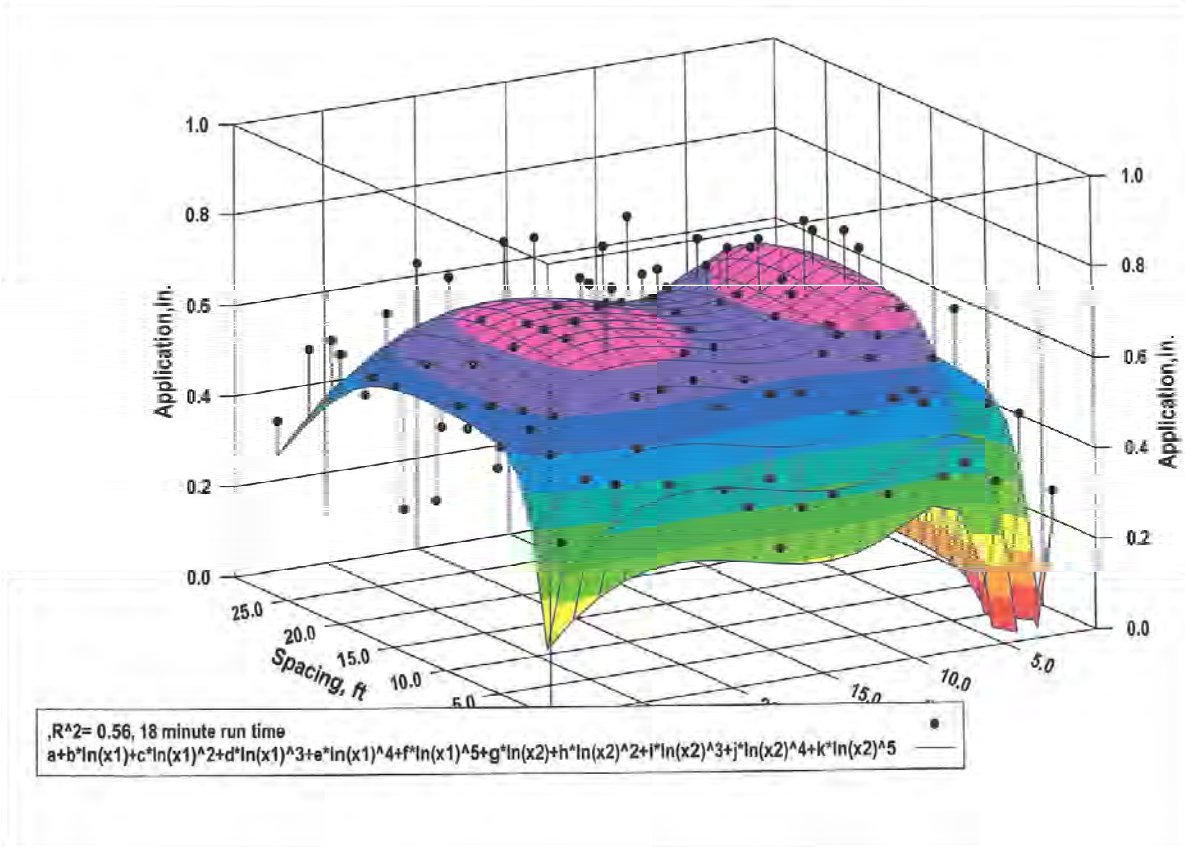


Figure A5. Hunter Pro-Spray® with pressure regulation/15 ft nozzles (3D)

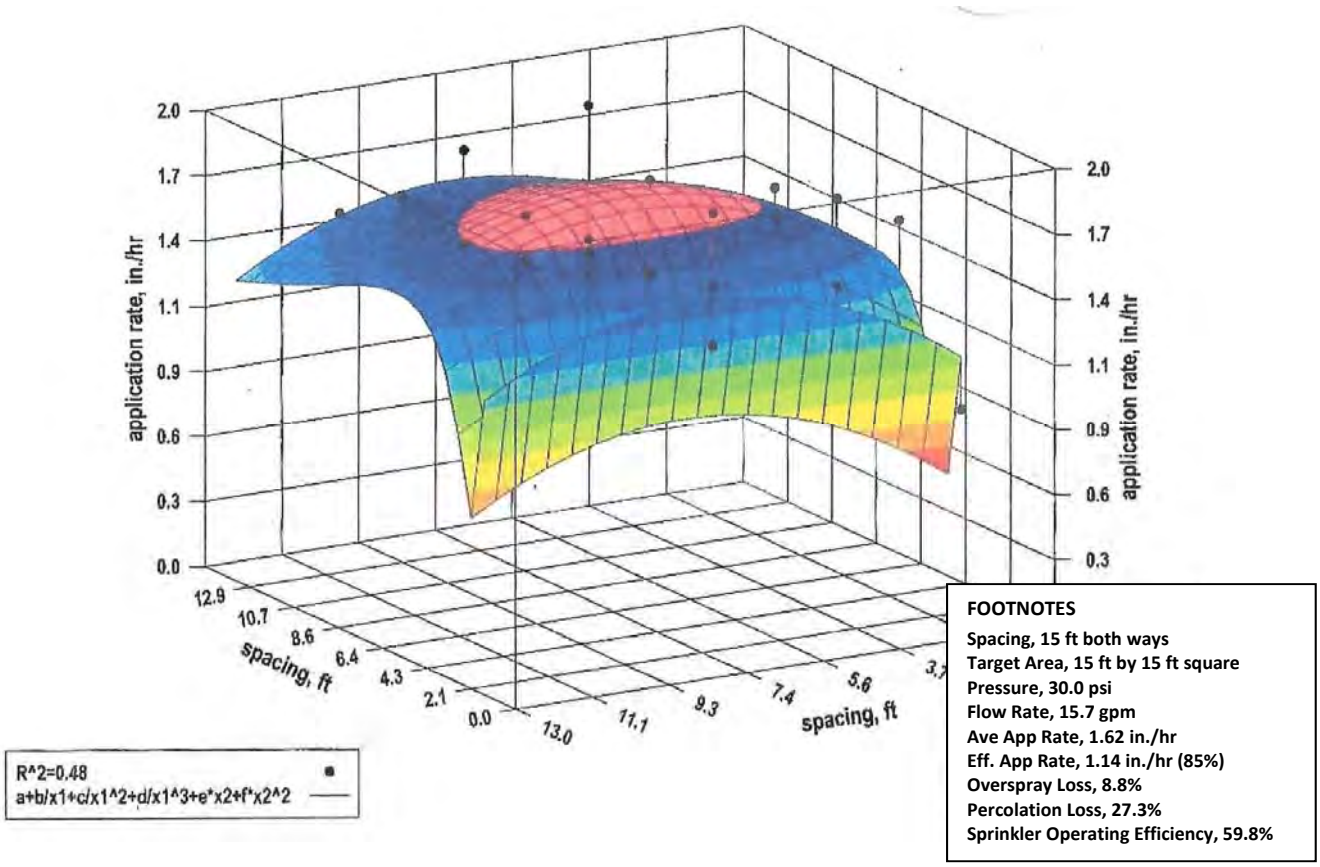


Figure A6. 3D plot demonstrating jet interference

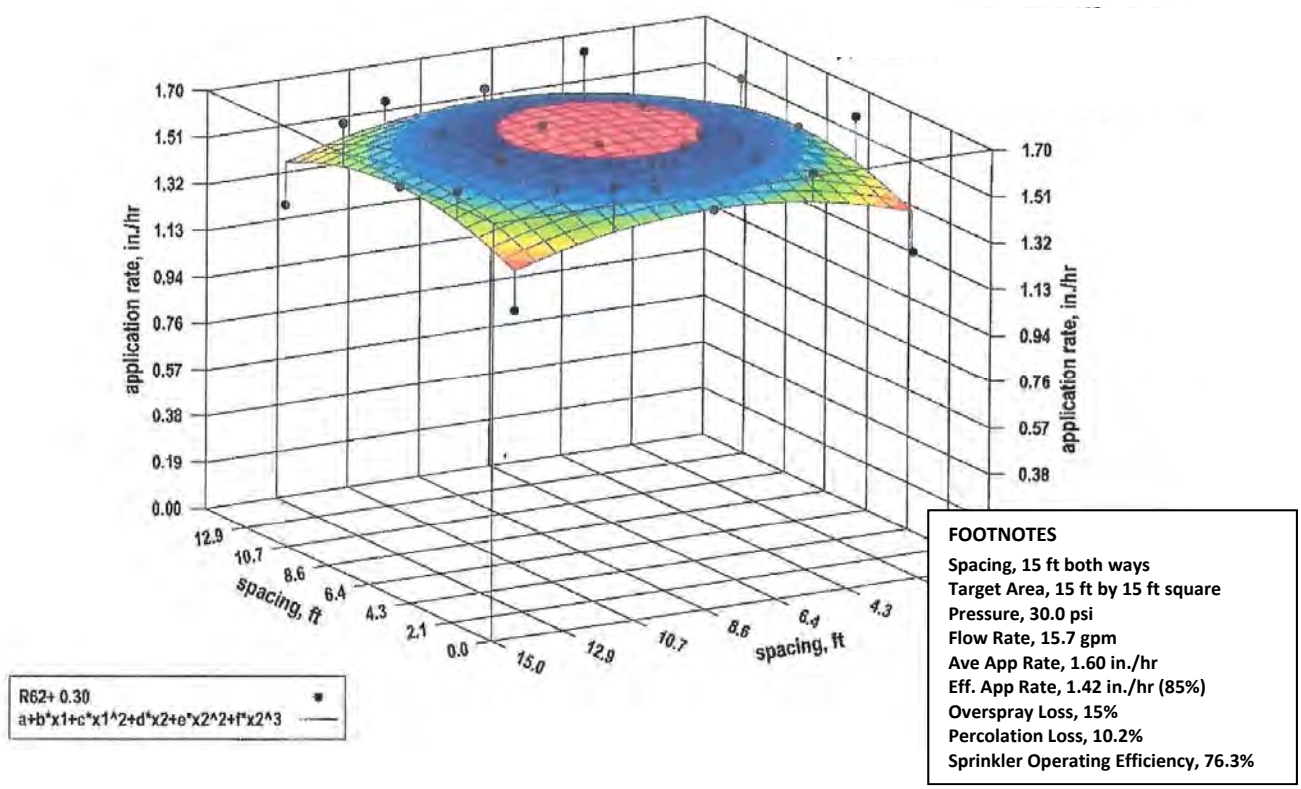


Figure A7. Overlapped pattern from Figure 6 developed by hand overlapping single catchment pattern

From the performance data shown in Table A1, it can be concluded that the use of a pressure regulating feature on these sprinklers has no measurable effect on the application efficiency of this sprinkler equipped with this nozzle. This test protocol fails to quantify the possible effect of aerial evaporation on application efficiency. This is a failure common to all sprinkler testing protocols currently in use. Data available on drop spectrums suggest that this loss may be on the order of one to five percent. The protocol developed for this work attempts to measure all drops that fall on the ground surface.