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EVALUATION OF THE APPLICATION UNIFORMITY OF SUBSURFACE DRIP DISTRIBUTION SYSTEMS

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ABSTRACT

The goal of this research was to evaluate the application uniformity of subsurface drip distribution systems. Laboratory measured flow rates were determined for emitters from three separate lateral lines at three locations in Central Texas. Mean emitter flow rate was 2.34, 2.40, and 1.89 L/hr for sites A, B, and C, respectively under laboratory conditions. Uniformity varied widely within individual laterals and between sites. Sites A and C had unacceptable uniformity of wastewater and Site B had fair to good uniformity. Differences are probably attributed to lack of normal operating pressures in the drip laterals at Sites A and C. These low operating pressures might be attributed to design and/or installation problems.

KEYWORDS. Subsurface Drip Distribution, On-Site, Application Uniformity

INTRODUCTION

Onsite wastewater treatment systems serve approximately 25% of the US population and approximately 37% of new development (EPA, 1997). Traditional drain fields have continued to be used for wastewater dispersal, but two-thirds of the United State's soils are unsuitable for traditional drain fields (Perkins 1989). Some areas have high rainfall, high groundwater and/or heavy clay soils requiring alternative methods of wastewater distribution. Alternative wastewater distribution methods rely on uniform application of wastewater for final treatment and dispersal before wastewater reaches surface water or groundwater.

In marginal soils, uniform distribution of water, organic materials, nutrients, and pathogens allow for proper treatment of wastewater. Subsurface drip distribution has the potential for uniform application of wastewater over the entire dispersal area. Since uniform wastewater application is essential, excessive emitter plugging is a concern. Plugging factors affecting the performance of the distribution system include physical, biological and chemical properties of the wastewater and soil. In addition, drip systems require greater attention to system design and operation and maintenance.

The literature reveals several different approaches to assessing uniformity of drip distribution systems. ASAE (1999) presented statistical uniformity with the following equation:

$$U_S = 100(1 - V_q) \qquad (1)$$

where: U_S = statistical uniformity coefficient, %, and

V_q = manufacturing coefficient of variation.

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The coefficient of variation in this calculation refers to the depth of water applied. This statistical uniformity coefficient describes the uniformity of wastewater distribution assuming a normal distribution of flow rates from the emitters. In the case of emitters being plugged, ASAE (1999) standards calls for the calculation of the emitter discharge coefficient of variation, including emitter plugging as:

$$V_{qp} = \left[\frac{1}{(1-C)} \left(V_{qs}^{\;2} + 1 \right) - 1 \right]^{1/2} \qquad (2)$$

where: V_{qp} = emitter discharge coefficient of variation including emitter plugging,

C = proportion of emitters (decimal) completely plugged, and

V_{qs} = site conditions coefficient of variation.

Therefore, the statistical uniformity of the field considering plugging can be calculated by using V_{qp} in place of V_q in equation 1. For given site conditions, V_{qs} can be used in Equation 1 for V_q to determine the uniformity of a system. Application uniformity of a system is affected by hydraulic design, topography, operating pressure, pipe size, emitter spacing, and emitter discharge variability. Discharge variability is due to manufacturer's coefficient of variation, emitter wear, and emitter plugging ASAE (1999). The method acceptability depending on the range of statistical uniformity is shown in Table 1.

Table 1. Methods of comparison of statistical uniformity (ASAE, 1999).

Method Acceptability	Statistical Uniformity, U_s (%)
Excellent	100-95
Good	90-85
Fair	80-75
Poor	70-65
Unacceptable	<60

ASAE (1983) represents flow variation through the Christiansen Uniformity Coefficient:

$$C_u = 1 - \frac{\overline{\Delta q}}{\bar{q}} \qquad (3)$$

where: C_u = the uniformity coefficient,

$\bar{q}$ = the mean emitter flow, and

$\overline{\Delta q}$ = the mean absolute deviation from the mean emitter flow.

An additional method of evaluating the application uniformity of a system is described in Burt et al. (1997). This method uses a distribution uniformity using the average depth of application of the lower quartile over the average depth of application (equation 4). This method has been used by United States Department of Agriculture since the 1940s.

$$DUlq = \frac{Depth_{LQ}}{Depth_{ALL}} \qquad (4)$$

where: DUlq = distribution uniformity,

Depth_{LQ} = average depth of lower quartile, and

$Depth_{ALL}$ = average depth of all elements.

Lamm et al. (2002) utilizes this method in calculating the distribution uniformity of drip laterals applying wastewater from a beef lagoon. Distribution uniformities ranged from 54.3% to 97.9% for the tubing evaluated.

Subsurface drip dispersal systems are functioning all across the United States with different operation and maintenance procedures and site configurations. The goal of this research is to evaluate the application uniformity of drip laterals operating as a part of a subsurface drip distribution system.

Materials And Methods

The emitter flow rate testing apparatus used in this research is described in Persyn (2000). In general, the testing approach can determine flow rate in ten 3.04 m (10 ft) segments of drip tubing. Laterals are isolated using ball valves located before each lateral and a check valve at the end of each lateral. Water is supplied to the laterals from a 120 liter (30 gal) plastic tank with a 373-watt (1/2 hp) high head pump. Water discharged from individual emitters was collected in plastic containers located on a movable catch basin. Some modifications were performed to the testing apparatus. A 74 micron (200 mesh) screen filter was installed before the drip laterals in order to follow ANSI/ASAE Standard S553 Collapsible Emitter Hose (Drip Tape) Specifications and Performance Testing (ASAE, 2001b). An additional pressure gauge was installed 15.24 cm (6 in) below the drip tubing elevation, which resulted in setting the pressure gauge at 139.38 kPa (20.21 psi). The pressure gauge had an accuracy of ±0.5%. A ball valve was installed so that the same gauge could be used to measure pressure on the supply and return manifolds.

<u>Site Conditions</u>

Three different sites located in central Texas were evaluated in the study to determine the emission volume from emitters in a drip lateral during a ten minute dose event. Each of the sites evaluated used a mechanical filtration system prior to distribution to 2.34 L/hr (0.62 gph) Netafim Bioline drip tubing. Operation pressures measured at the site are shown in Table 2. Emitter spacing along the tubing was 61 cm (2 ft) and laterals were spaced every 61 cm (2 ft). Average climatic conditions for central Texas are; annual temperature of 20 degrees Celsius (69 degrees Fahrenheit), annual precipitation of 85.59 cm (33.7 in), and annual evapotranspiration of 159 cm (63 in).

Table 2. Average operation pressure for sites A, B, and C.

		Pressure kPa (psi)		
Lateral	Pump House	Group 1	Group 2	Group 3
Site A	372 (54)			
1		***[a]	***	***
2		56 (8)	54 (8)	40 (6)
3		79 (11)	63 (9)	57 (8)
Site B	***			
1		344 (50)	282 (41)	263 (38)
2		346 (50)	283 (41)	264 (38)
3		346 (50)	284 (41)	256 (37)
Site C	391 (57)			
1		92 (13)	78 (11)	79 (12)
2		93 (14)	82 (12)	78 (11)
3		88 (13)	***	32 (5)

[a] Indicates missing data points.

Site A served an intermediate/middle school for 3-5 years with a design flow of 45,424 liters per day (12,000 gpd). Secondary treated effluent is dosed to the drip field. The treatment process is a septic tank and advanced treatment system using a recirculating media filter. Before effluent is dosed to the drip field, it passes through a mechanical filtration system consisting of a bank of 4, 100 micron (140 mesh) disk filters. The drip field is set up with a total of 12 zones that are dual zone dosed. Zones 9 and 10 were examined in this study. Lines are flushed after 32 doses for zone 9 and 34 doses for zone 10 (figure 1). Laterals were randomly selected; lateral 1 was located at the end of zone 9, laterals 2 and 3 were located in the middle portion of zones 9 and 10, respectively. Each lateral consisted of two runs 50.3 meters (165 feet) in length looped together at the down slope end of the field for a total lateral length of 100.6 meters (330 feet). The laterals were installed 20 to 25 cm (8-10 in) deep in a sandy loam soil with a clay pan directly below the laterals. Both supply and return manifolds were located at the upslope end of the field.

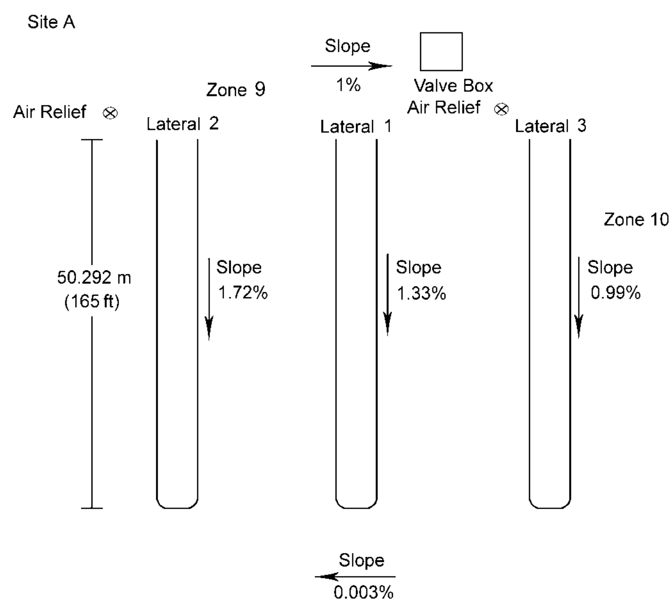

Figure 1. Orientation of drip laterals at site A.

Site B served an elementary school for seven years with a design flow of 37,854 liters per day (10,000 gpd). Primary treated septic tank effluent was dosed to the drip field. Secondary treatment was accomplished by the addition of Nibbler pods within the second compartment of the septic tank. Nibbler pods are a fixed film aerobic treatment unit. Before effluent is dosed to the drip distribution field it passes through a mechanical filtration system consisting of a bank of two 130 micron (120 mesh) disk filters. The drip field is set up with zones that are dual zone dosed. Laterals were excavated from zone 4 for this experiment and were randomly selected. Laterals are flushed after 55 doses for zone 4. Randomly selected laterals used in this experiment were located at the beginning of zone 4 and were spaced eight feet from each other (figure2). Each lateral consisted of two runs 73.1 meters (240 feet) in length looped together at the down slope end of the field for a total lateral length of 146.2 meters (480 feet). The laterals were installed 25 cm to 30.5 cm (10 to 12 in) deep in a sandy loam soil. Both supply and return manifolds are located at the upslope end of the field. The laterals of the system are placed along the contour of the slope at the site. Vacuum breakers were located on the supply and return manifold for each zone.

Site C served a middle school for 3-5 years with a design flow of 56,781 liters per day (15,000 gpd). Primary treated septic tank effluent is dosed to the drip field. Wastewater at Site C is treated with Nibbler pods located in the second compartment of the septic tank. Before effluent is dosed to the drip field, it passes through a mechanical filtration system using a bank of three 130 micron (120 mesh) disk filters. The drip field is set up with zones that are dual zone dosed. Laterals were excavated from zones 6 and 7 for this experiment. Laterals are flushed after 60 doses for zone 6 and 65 doses for zone 7. Laterals were randomly selected for this experiment with laterals 1 and 2 from zone 7 and lateral 3 from

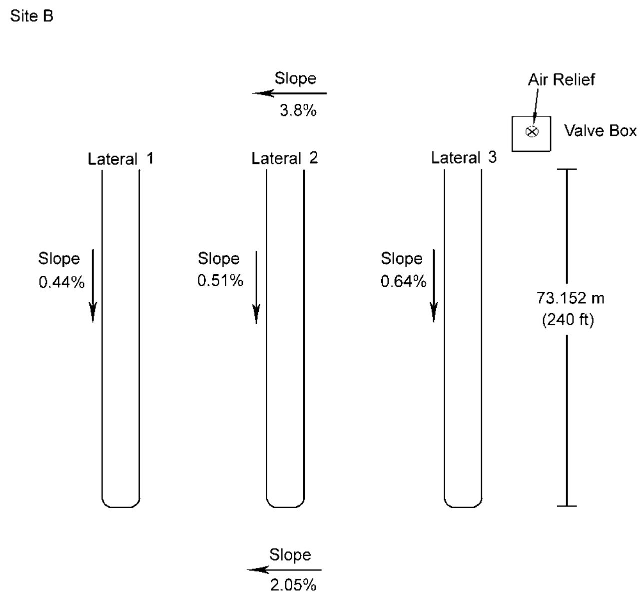

Figure 2. Orientation of drip laterals at site B.

zone 6 (figure 3). Laterals evaluated were spaced eight feet from each other. Laterals 1 and 2 were located at the down slope end of zone seven, while lateral 3 was located at the upslope end of zone 6. Laterals consisted of one run 120.7 meters (396 feet) in length. The laterals were installed 20 to 30.5 cm (8 to 12 in) deep in a clay loam soil. The supply manifold was installed at the down slope end of the field and the return manifold was installed at the upslope end of the field. The manifolds were constructed with the supply line entering the middle of the manifold. The laterals of the system are placed along the contour of the slope at the site. Before the drip lateral connected to the return manifold, the lateral raised up in elevation 22.86 cm (9 in) within a length of 30.5 cm creating a hump before the return manifold. Vacuum breakers were located on the supply and return manifold for each zone.

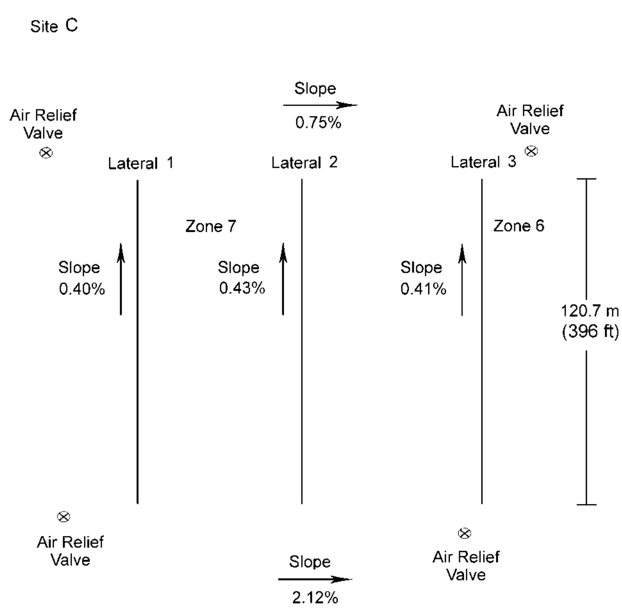

Figure 3. Orientation of drip laterals at site C.

Three sections of tubing were excavated along a drip lateral. The first section was at the beginning of the lateral; this included the first 12 emitters of the lateral. The second section was the middle of the lateral; this included the middle 12 emitters of the lateral. If the middle of the lateral was located at a looped end, this included the last six of the run and the first six emitters of the next run. The last section excavated included the last 12 emitters of the lateral. The tubing was excavated and left in the soil to evaluate the application uniformity in the field. Additional emitters were excavated at the end of the section to ensure a total of 12 emitters for evaluation from each section sampled during the test. If an emitter was damaged during excavation it was removed from the line and the line was repaired. If tubing damage during excavation did not result in a damaged emitter, the damaged section was removed and replaced using new tubing and barbed couplings. The location of the emitters and groups of emitters are illustrated in figure 4.

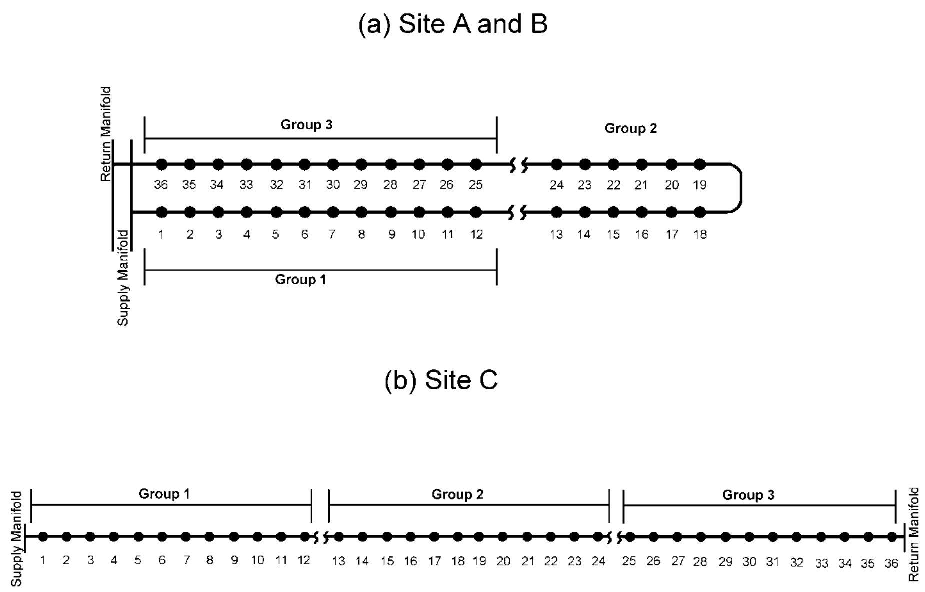

Figure 4. Location of emitters and groups for laterals collected from the field; (a) sites A and B, and (b) site C.

Under each emitter, soil was excavated allowing the placement of a 1.4 L (3 pint) plastic collection container. Pressure gauges were placed in the tubing at each of the different lateral sections to record operating pressure during each trial.

The location of the tubing was noted with a permanent marker. The tubing was placed into black plastic bags containing a small amount of water to maintain moisture during transport and storage. All tubing was evaluated within 14 days of being returned to the laboratory.

The emitters were evaluated at a pressure of 138 kPa (20 psi) and without a flushing velocity passing by the emitters. Water was collected from individual emitters in 1 liter plastic containers. The containers were weighed and the volume was determined using a density of water of 1 g/cm^3. The water collection period was set at five minutes (200 ml) to minimize error associated with the starting and stopping of the individual runs and residual water in containers. The water was collected from 6 emitters per line. After removing the container from under the emitters, the containers were weighed to determine the volume emitted. Before returning the container to the collection rack, containers were shaken to remove excess water. Emission volumes from the individual emitters were collected in triplicate and averaged to determine the emitter flow rate.

A sampling event was conducted by connecting all 36 emitters from each field set to the testing apparatus. The tubing was cut into six, 3.05 meter (10 ft) lengths containing 6 emitters per line. A line of new tubing was used in the testing apparatus to set pressures and flushing velocities before application to the field tubing. Sections of tubing 2.54 cm (1 in) in length were cut open and wrapped around the tubing and the support wire to more closely simulate a level line. Additional pieces of tubing were placed close to emitters to prevent lateral movement of water along the tubing. Prior to sampling, emitters were run for 2 to 5 minutes to allow air to escape the line. If air was observed leaving the emitter during testing, the test stopped and restarted. Fresh water was added to the pump tank between testing events, when different treatments were applied, and between different sampling runs. Laboratory conditions were between 20 and 30 degrees Celsius.

The emitter flow rate range was evaluated to determine the percentage of emitters within 10% of the published nominal flow rate of the emitters. The published flow range for any one emitter analyzed in this study could vary from 2.106 to 2.574 L/hr (0.56 to 0.68 gph).

Two different methods were utilized to evaluate the uniformity of the drip distribution systems. The first method, presented by ASAE (1999) is calculated as a function of the coefficient of variation considering emitter plugging. This ASAE standard has since been removed from publication in 2001. The second method used to evaluate uniformity of the drip lateral used the mean lower quartile of the sample as presented in Burt et al. (1997).

Statistical analysis was performed using SAS version 9.0 (SAS, 2002). Analysis of variance (ANOVA) using the generalized linear model procedure (PROC GLM) was used to determine significant differences among flow rates. Significant differences were determined at the 0.05 level.

RESULTS AND DISCUSSION

Site A had mean flow rates that were not significantly different among the three groups of an individual lateral (Table 3). This flow rate would be a parameter that is typically measured in the field, and for Site A, would have shown no concerns over application uniformity. However, the percentage of emitters above, within, and below ±10% of the design flow rate varied widely between laterals and groups within the same lateral. Calculation of the statistical uniformity and distribution uniformity showed a range of unacceptable to excellent method acceptability. Site A tended to have better uniformity on groups 1 and 2 compared to group 3. The variability at Site A may be attributed to the substantial reduction in operating pressure from the pump house (372 kPa or 54 psi) to the end of the lateral (40 kPa or 5.8 psi). Normal operating pressures are expected to be between 103-138 kPa (15-20 psi).

Site B had mean flow rates that were not significantly different among the three groups for laterals 1 and 2, but were significant for lateral 3 (Table 4). Groups 1 and 2 were had significantly higher mean emitter flow rates compared to group 3. The percentage of emitters above, within, and below ±10% of the design flow rate did vary, but in all cases a substantial number (58-92%) were within the range. Overall, the total lateral uniformity and site uniformity were rated fair to good. Group 3 of lateral 2 had the lowest uniformity; however, there were not any emitters completely plugged at Site B. The field pressure at all points was well above the normal operating pressure (256-346 kPa or 37-50 psi).

Site C had significantly different flow rates among the groups for lateral 1 and lateral 2 (Table 5). In fact, these differences would probably have raised a concern during a normal maintenance evaluation of the flow rate in the field. Lateral 3 did not have significantly different flow rates; however, it was located in a different zone. Uniformity was unacceptable for laterals 1 and 2, but was poor to good for all groups on lateral 3. As noted for Site A, the field pressure at Site C was substantially lower in the field (32-93 kPa or 5-14 psi) compared to the pump house (391 kPa or 57 psi).

CONCLUSIONS

Emitter flow rates and uniformity along laterals from three sites showed varying degrees of uniformity. Two sites (A and C) showed varying degrees of uniformity that would have been unacceptable in both cases. Emitter flow rate evaluation at Site A did not show significant differences, despite varying percentages of emitters out of the acceptable range of the design flow rate. This indicates a normal flow rate test during operation and maintenance would not have revealed any differences in uniformity throughout the field. Site C did have significant reductions on two laterals that would have probably resulted in the identification of uniformity problems within the field using a standard flow rate evaluation. It should be noted that these two sites (A and C) had relatively low field pressures that were generally under 103 kPa (15 psi); therefore, emitter plugging may have been a result of design or installation problems within the field. Site B had "acceptable" uniformity in the field and in many cases was rated good to excellent. Field pressure at Site B was also 256 kPa (37 psi) or greater at all points in the field, which verified proper design and installation of the drip distribution field.

These results show that routine monitoring of field flow rates may not always show differences in uniformity of wastewater application; however, problems with unacceptable distribution appear to be correlated with laterals that were below normal operating pressures.

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Table 3. Evaluation of emitter flow rates collected from three laterals at site A.

Group	N	Emitter Flow Rate				Range %			Emitters Plugged (%)	Statistical[a] Uniformity with Emitter Plugging	Method Accept.[b]	DUlq[c]	Method Accept.[b]
		Mean (L/hr)	Max (L/hr)	Min (L/hr)	C.V.	Above	Within	Below					
lateral A1													
1	12	2.39a*	2.60	2.17	0.06	8	92	0	0	94	Good-Exc.	92	Good-Exc.
2	12	2.24a	2.76	1.56	0.15	8	58	33	0	85	Good	81	Fair-Good
3	11	2.00a	4.09	0.00	0.80	64	0	36	17	2	UA	1	UA
Total	35	2.21	4.09	0.00	0.41	26	51	23	6	52	UA	50	UA
lateral A2													
1	12	2.50a	3.71	2.01	0.17	33	58	8	0	83	Fair-Good	87	Good-Exc.
2	12	2.21a	3.35	0.02	0.61	50	25	25	0	39	UA	3	UA
3	13	2.02a	4.86	0.02	0.83	38	23	38	0	17	UA	2	UA
Total	37	2.24	4.86	0.02	0.56	41	35	24	0	44	UA	15	UA
lateral A3													
1	12	2.70a	3.36	1.87	0.16	67	25	8	0	84	Fair-Good	80	Fair
2	12	2.56a	3.43	1.12	0.28	58	17	25	0	72	Poor-Fair	61	UA-Poor
3	12	2.43a	3.69	0.06	0.41	58	25	17	0	59	UA	46	UA
Total	36	2.56	3.69	0.06	0.29	61	22	17	0	71	Poor-Fair	62	UA-Poor
Site	108	2.34	4.86	0.00	0.43	43	36	22	2	54	UA	43	UA

* Means with different letter designations are significantly different ($p < 0.05$)

[a]Statistical uniformity was calculated using equation 1 and 2

[b]Method acceptability described in Table 1; UA=Unacceptable, Exc.=Excellent

[c]DUlq was calculated using equation 4

Table 4. Evaluation of emitter flow rates collected from three laterals at site B.

		Emitter Flow Rate				Range %							
Group	N	Mean (L/hr)	Max (L/hr)	Min (L/hr)	C.V.	Above	Within	Below	Emitters Plugged (%)	Statistical[a] Uniformity with Emitter Plugging	Method Accept.[b]	DUlq[c]	Method Accept.[b]
lateral B1													
1	12	2.62a*	4.58	2.15	0.26	25	75	0	0	74	Poor-Fair	85	Good
2	12	2.31a	2.67	1.94	0.09	8	67	25	0	91	Good-Exc.	88	Good
3	12	2.51a	2.87	2.18	0.08	42	58	0	0	92	Good-Exc.	91	Good-Exc.
Total	36	2.48	4.58	1.94	0.17	25	67	8	0	83	Fair-Good	87	Good
lateral B2													
1	12	2.24a	2.62	1.92	0.09	8	67	25	0	91	Good-Exc.	88	Good
2	12	2.31a	2.57	1.74	0.09	0	92	8	0	91	Good-Exc.	88	Good
3	12	2.16a	2.66	0.02	0.32	8	75	17	0	68	Poor	64	UA-Poor
Total	36	2.24	2.66	0.02	0.19	6	78	17	0	81	Fair-Good	80	Good
lateral B3													
1	12	2.42b	2.70	2.11	0.07	17	83	0	0	93	Good-Exc.	91	Good-Exc.
2	12	2.28b	2.50	1.98	0.06	0	92	8	0	94	Good-Exc.	92	Good-Exc.
3	12	2.73a	3.36	2.10	0.15	58	33	8	0	85	Good	80	Fair
Total	36	2.48	3.36	1.98	0.13	25	69	6	0	87	Good	86	Good
Site	108	2.40	4.58	0.02	0.17	19	71	10	0	83	Fair-Good	84	Fair-Good

* Means with different letter designations are significantly different ($p < 0.05$)

[a]Statistical uniformity was calculated using equation 1 and 2

[[b]Method acceptability described in Table 1; UA=Unacceptable, Exc.=Excellent

[c]DUlq was calculated using equation 4

Table 5. Evaluation of emitter flow rates collected for three laterals from site C.

Group	N	Emitter Flow Rate: Mean (L/hr)	Max (L/hr)	Min (L/hr)	C.V.	Range %: Above	Within	Below	Emitters Plugged (%)	Statistical[a] Uniformity with Emitter Plugging	Method Accept.[b]	DUlq[c]	Method Accept.[b]
lateral C1													
1	12	1.43a*	2.38	0.00	0.66	0	33	67	8	25	UA	8	UA
2	12	0.30b	2.26	0.00	2.27	0	8	92	75	N.A.	UA	0	UA
3	12	0.39b	1.98	0.00	1.56	0	0	100	50	N.A.	UA	0	UA
Total	36	0.71	2.38	0.00	1.27	0	14	86	44	N.A.	UA	0	UA
lateral C2													
1	12	1.81a	2.30	0.00	0.36	0	42	58	8	51	UA	49	UA
2	12	0.82b	2.35	0.00	1.12	0	8	92	75	N.A.	UA	0	UA
3	12	0.46b	2.25	0.00	1.85	0	8	92	50	N.A.	UA	0	UA
Total	36	1.03	2.35	0.00	0.96	0	19	81	44	N.A.	UA	0	UA
lateral C3													
1	12	2.05a	2.47	0.86	0.21	0	58	42	0	79	Fair	71	Poor-Fair
2	12	2.14a	2.52	1.74	0.11	0	50	50	0	89	Good	87	Good
3	12	2.22a	2.62	1.79	0.11	8	58	33	0	89	Good	85	Good
Total	36	2.14	2.62	0.86	0.15	3	53	42	0	85	Fair-Good	81	Fair-Good
Site	108	1.89	2.62	0.00	0.77	1	30	69	30	N.A.	UA	0	UA

* Means with different letter designations are significantly different ($p < 0.05$)

[a]Statistical uniformity was calculated using equation 1 and 2

[b]Method acceptability described in Table 1; UA=Unacceptable, Exc.=Excellent

[c]DUlq was calculated using equation 4