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HYDRAULIC PERFORMANCE OF SUBSURFACE WASTEWATER DRIP SYSTEMS

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ABSTRACT

Subsurface drip is a wastewater management technology which optimally makes use of the shallow soil environment, allowing for effective utilization of the landscape for handling small to large wastewater inputs. This system allows for both the assimilation of wastewater and nutrient attenuation. Critical to long-term operational success is the continuing effective hydraulic performance of the drip tubing. Effluent flow rate from all emitters must remain near design values for the life of the system. Constituents of the effluent or surrounding soil must not clog the emitters, and the tubing interior must not become blocked. This is typically addressed through emitter design, use of chemicals impregnated into the emitters and/or tubing, air venting, and by prescreening delivered effluent and routine flushing of the distribution network.

A field assessment is presented of long-term hydraulic performance of drip tubing at five large subsurface wastewater systems operating in North Carolina six or more years. Field measurements collected periodically since system start-up include irrigation flow rates, flushing flow rates and flushing head losses. The computer program DRIPNET, previously developed by the author, is used to compare field measurements with design predictions to evaluate factors that have changed over time. The relationship of pretreatment method (septic tank-vs-sand filter), flushing regime and other design factors to hydraulic performance is presented. Long-term hydraulic performance of the systems was generally found to be excellent. Emitter clogging was observed at only two of the five sites, with the maximum reduction in emitter flow rate at any site measured to be 23 %. Optimal hydraulic performance was found to be associated with minimum initial flushing velocities in excess of 0.91 m/s (3 ft/s) with septic tank effluent and 0.46 m/s (1.5 ft/s) with sand filter effluent.
KEYWORDS: Drip irrigation, Wastewater, Subsurface distribution, Hydraulic characteristics

INTRODUCTION

Subsurface drip is an emerging alternative land-based wastewater technology with a great deal of merit. Interest level is reflected by the devotion of an entire day at the 1999 Annual Conference of the National On-Site Wastewater Recycling Association (NOWRA) to a Drip Distribution Forum. Advantages over other subsurface and surface effluent distribution systems include the potential for highly uniform distribution of effluent over the entire drainfield area; shallow distribution enabling effluent to be placed at maximum vertical distance above unsuitable soil horizons or wetness conditions, while keeping effluent from being exposed at the ground surface; injection of effluent from emitters at extremely slow rates which allow for soil uptake without the need for temporary storage or ponding within a trench or absorption through a trench/soil interface; and the potential to maximize nutrient attenuation by placing the effluent in the most biologically active soil/root zone. Research supporting these beneficial attributes includes works of Oron, et al (1991, 1988), Rubin, et al (1994), and Lesikar, et al (1998).

Subsurface drip systems typically consist of small diameter polyethylene tubing with integral emitters which "drip" effluent at small rates when dosed to the surrounding soil. Emitters are either pressure compensating ("PC") or non-pressure compensating (pressure dependent, or "PD"). Tubing is typically installed directly into native soil, instead of into an aggregate-filled trench, at shallow depths with a vibratory plow or narrow trenching machine.

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Effluent pretreatment prior to distribution to the drip field(s) is either solely anaerobic via passage through a septic tank, or aerobic, by passage through an aerobic treatment unit (ATU) or combination septic tank/sand filter. In both cases, effluent is also screened enroute from the dosing tank to the subsurface drip field(s) by passage through one or more 100-micron disk filters. System designers must select size and layout of the drip drainfield, type and spacing of tubing, type and spacing of emitters, pretreatment components, critical field appurtenances, pump flow rate and total dynamic head specifications, dosing regime (dose volume, timer-controlled-vs-demand distribution), filter (screen) backwashing and field flushing regiments, and overall system control and self -monitoring capabilities. While design criteria are rapidly evolving, there is not yet a consensus or established basis for addressing many of these issues. Current design criteria can be obtained from drip system manufacturers and from the approval documents authored by states that have established approval criteria, such as Mississippi, North Carolina and Georgia. Summaries of subsurface drip design criteria and associated issues have been presented by Converse (2000), Rubin and Harman (1997), Ruskin (1999), Sinclair, et al (1999) and Berkowitz (1999).

Limited research has been reported from operating subsurface drip wastewater systems, as the basis for evaluating and refining system design criteria, and to further assess the potential role of subsurface drip as a viable wastewater management option. Excellent work is underway at Texas A&M University that is helping fill in the research gaps. Recent results reported by Persyn, et al (1999) and Jnad (2000) provide a detailed assessment of hydraulic conductivity changes in soils surrounding drip emitters at two sites in use over five years. These types of studies provide a rational basis for establishing appropriate system sizing criteria. Other aspects of system design which have been evaluated include the importance of laterals being installed level, and concerns related to drainback of effluent into the lower laterals at the end of each scheduled dosing event (Amoozegar, et al., 1994, Berkowitz, 1999).

HYDRAULIC PERFORMANCE OF SUBSURFACE DRIP WASTEWATER SYSTEMS

For successful long-term performance of subsurface drip systems, the hydraulic performance of the field components – the emitters and tubing – must not significantly deteriorate over time. Hydraulic parameters of possible concern are reduction (or a significant increase) in the flow rate from the emitters; reduction in emitter flow rate uniformity; and the increase in head loss across the field during flushing which in turn results in a reduction in flushing efficiency due to a decrease in effective scour velocities. Even small reductions in emitter flow rate can substantially reduce the uniformity of effluent distribution across the drainfield, particularly if reductions are not evenly distributed (Persyn, 2000). Reduction in scour velocities can exacerbate emitter plugging and result in increasing non-uniformity of effluent distribution.

Factors contributing to clogging of drip emitters include levels of effluent suspended solids, chemical precipitation, growth of biofilms in the pipe network, sediment carried back into the emitters by flow reversal at the end of dosing cycles, and root intrusion (Adin and Sacks, 1991; Tajrishy, et al., 1994, Persyn, 2000). Similar factors could contribute to a head loss increase during flushing, such as by reducing the effective drip tube area by a build-up of biological slimes along the tubes or around the internal emitter “barbs”, and the accumulation of sediments which may enter through the emitters.

System design features and management schemes have been developed to maintain hydraulic performance. Emitters are typically designed with high internal velocities for flushing through solids that may enter their flow path and to impede root entry. One company impregnates their emitters with a herbicide to repel root entry. PC emitters may provide an effective physical block to root intrusion. Bactericides are used to reduce microbial growth in emitters and inside drip tubes. Routine flushing is widely accepted as necessary to both keep the drip laterals clean and to directly retard orifice plugging. There is no consensus between manufacturers or designers on what minimum scour velocities need to be maintained and how frequently flushing is needed. Persyn (2000) presents a detailed review of the issue and an in depth assessment of what can happen to emitter flow rate and distribution uniformity at two six-year old systems where design and management to prevent emitter clogging were not practiced. Remedial measures were also evaluated, including flushing and shock chlorination, which resulted in limited performance recovery after the fact.

Herein is presented a field assessment of the hydraulic performance of subsurface drip systems at five sites that have been operating in North Carolina for six or more years. These systems have been monitored periodically by the author from system start-up through Summer, 2000. System hydraulic performance and performance changes over time are compared, with inferences made on the importance of various design and management options.

DESCRIPTION OF SYSTEMS EVALUATED

The five systems evaluated were installed either as a repair for an existing malfunctioning subsurface system (Lake Wheeler, Pactolus) or as the replacement for a septic-tank/sand filter discharging system (Cedar Grove, Best and Vaughan). One system serves a mobile home park (Lake Wheeler) and the other four serve public schools. These five systems are all considered "Large" systems based upon the design flow of each being in excess of 11.4 m^3/d (3000 gpd). Plans and specifications for each system were prepared by licensed professional engineers, reviewed and approved by the State On-Site Wastewater Section prior to local health department permitting. All are required to have operation and maintenance by a licensed subsurface system operator, including weekly to monthly operator inspections, semiannual reporting of operator findings to the appropriate local health department, and inspection by the local health department at least annually.

All of the systems evaluated utilize small diameter drip tubing (1.45 cm I.D, 0.57-in) manufactured by Netafim, with PC “Bioline” (formerly “Ram”) emitters. Emitters are spaced on 61 cm (24 in) centers and have a design flow rate of 2.31 l/h (0.61 gph) at line pressures of 49 to 414 kPa (7 to 60 psi). All were “Perc-Rite”systems manufactured by Wastewater Systems, Inc., of Lilburn, Georgia. System designs were in accordance with North Carolina’s Innovative Approval for “Perc-Rite” issued to Wastewater Systems, Inc. by the State’s On-Site Wastewater Section (1996).

The systems utilize timer and flow controls which equally distribute pre-specified dose volumes to multiple field zones during each 24-hour period, and incorporate automatic field flushing. Field zones are flushed for three to five minutes after every 50 irrigation cycles or at least monthly. Programmable Logic Controllers (PLC’s) are utilized in concert with level control floats in the effluent dosing tank, pressure sensors, and an electronically monitored flow meter to control zone dosing and flush cycles, backwashing of pretreatment screens, and to sense failure conditions (high-water and dosing flow rate variance). Controls also record or print out information which enables the operator to monitor pump run times, number of doses, backwash and flushing events and flow volume delivered to each field zone between inspections.

Systems vary in extent of pretreatment (septic tank only-vs-septic tank-sandfilter), type of trench (direct injection-vs-placement in narrow aggregate-filled trench), and in their initial flushing scour velocities (less than 0.61 m/s [2 ft/s]-vs-0.91 m/s [3 ft/s]). Relevant aspects of each system evaluated are summarized in Tables 1 and 2:

Table 1: Subsurface Drip Sites in North Carolina Having Hydraulic Assessments

Name of System	County	Type of Facility	Date Start-up	Design Flow m^3/d (gpd)	Actual Flow m^3/d (gpd)	Soil Group	Ksat Data (cm/day)	Design LTAR	
								Areal cm/d (gpd/ft^2)	Linear Lpd/m (gpd/ft)
Lake Wheeler	Wake	67-lot mobile home park	Aug., 1993	49 (13000)	38-42 (10000-11000)	III-IV	Bt: 4 BC: .68	.61 (.15)	12.2 (.3)
Cedar Grove	Nash	320-student school	July, 1994	15 (4000)	9.5-13 (2500-3500)	II-III	Bt: 1.86 C: .54	.41 (.1)	15.5 (.38)
Pactolus	Pitt	700-student school	Dec., 1994	32 (8400)	15-19 (4000-5000)	I-III	E: 113 B: 5.8 C: 289	1.1 (.27)	44.4 (1.09)
Edward Best	Franklin	600- student school	July, 1993	23 (6000)	23+ (6000+)	IV	Bt: 0.80	.33 (.08)	6.5 (.16)
Vaughan	Warren	300- student school	March, 1994	14 (3600)	13-15 (3500-4000)	IV	Bt: 2.62 BC: .93	.33 (.08)	6.5 (.16)

Table 2. Component Details of Subsurface Drip Systems Evaluated

Name of System	Pretreatment Components		Trench/ Installation	Drip Field Characteristics				
	Septic Tank m^3(gal)	Sand Filter m^2 (ft^2)		# of zones	Total system tubing m (ft)	Tubing per zone m (ft)	# of lines per zone	Line lengths m (ft)
Lake Wheeler	60.5 (16000)	N.A.	Vibratory plow and trencher	4	13,236 (43,426)	3143-3317 (10,312-10,884)	40-72	30.5-99.4 (100-326)
Cedar Grove	29.5 (7800)	N.A.	Trencher (20cm[8 in] wide with aggregate)	4	31167 (10,392)	792 (2600)	13-16	49.4-70 (162-200)
Pactolus	31.8 (8400)	N.A.	Trencher (20cm[8 in] wide with aggregate)	4	2341 (7680)	585 (1920)	8	73.2 (240)
Edward Best	37.9 (10000)	520 (5600)	Vibratory plow	3	11,467 (37,620)	3822 (12540)	44	86.9 (285)
Vaughan	36.2 (9565)	167 (1800)	Vibratory plow	4	6913 (22,680)	1728 (5670)	27	64 (210)

The Computer Program DRIPNET was used evaluate field data collected. We previously reported on the development of DRIPNET for delineating key hydraulic parameters associated with subsurface drip field networks (Berkowitz and Harman, 1994). To utilize the program, all sites were conceptualized for simulation purposes as being of the form depicted in fig. 1.

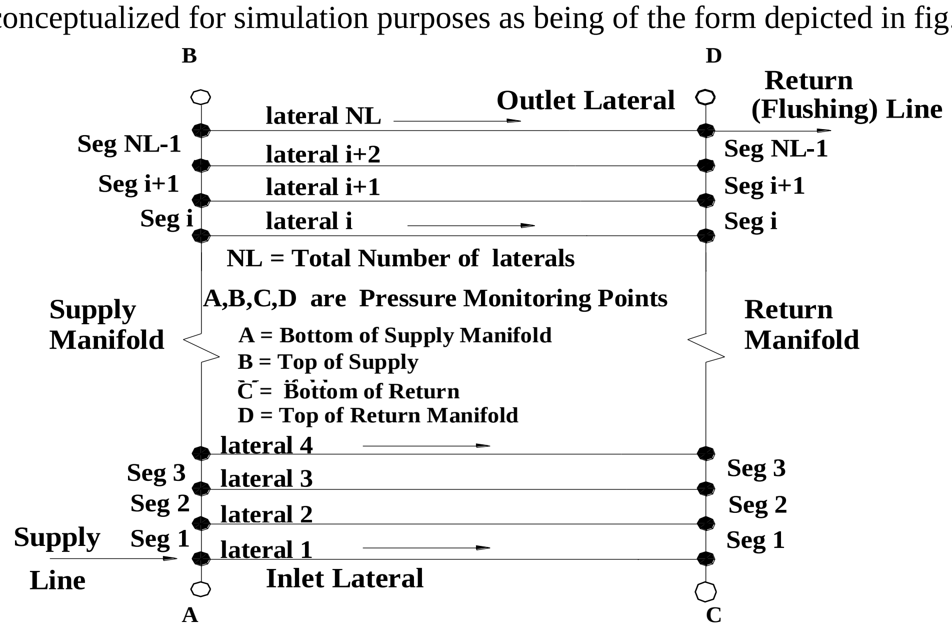


Figure 1: Field Pipe Network Utilized to Simulate System Hydraulic Performance by Computer Program DRIPNET

The procedure used to collect and evaluate data with the aid of DRIPNET is outlined in Table 3.

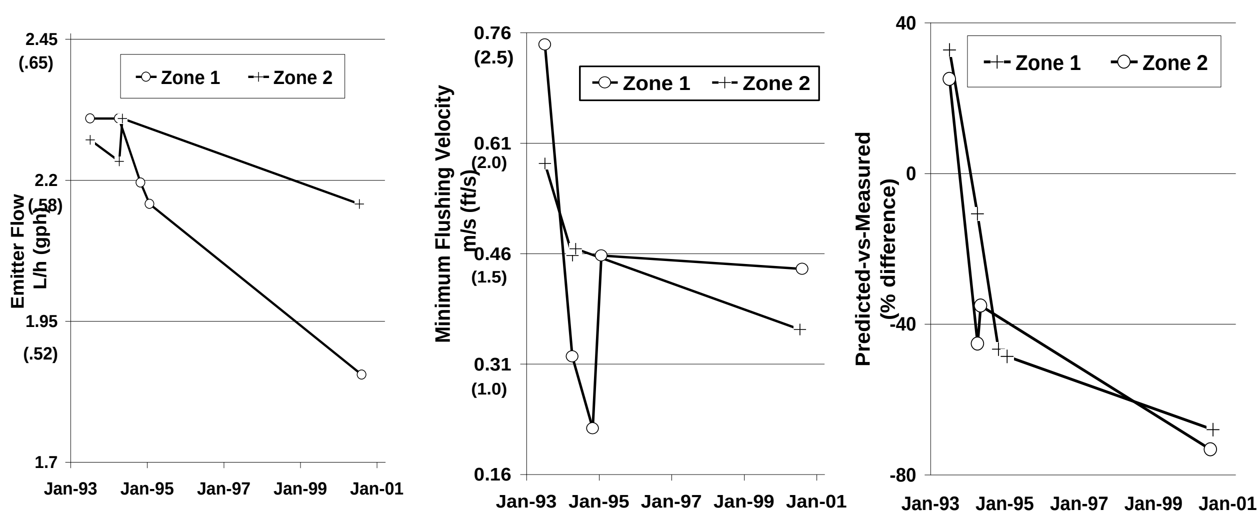
Table 3. Procedure Used to Evaluate Field Data to Assess System Hydraulic Performance

Step 1	Build Input File for each Field Zone, including the diameter and length of each manifold segment and lateral. "Laterals" contain drip emitters; "Manifolds" are non-perforated interconnecting pipes on inlet (supply) and outlet (return) ends of laterals.
Step 2	Concurrently measure irrigation and flushing flows and pressures at least at the inlet and outlet pressure monitoring points (Points "A" and "D" in Figure 1, above). The pressure difference is a measure of net head loss across the field pipe network during flushing (after adjusting to account for any elevation differences).
Step 3	"Calibrate" program simulation by adjusting inputted emitter flow and minimum scour velocity until predicted irrigation and flushing flows match field-measured flows.
Step 4	Compare program-predicted to actually measured head loss during flushing.

For each monitoring day values are obtained for emitter flow, flushing velocity and measured-vs-predicted head loss. By evaluating measurements made over time, information was be obtained on emitter clogging evidenced by reduction in the irrigation flow rate, and lateral clogging, as indicated by reduction in flushing flow rate and increase in network head loss during flushing.

RESULTS OF MONITORING AND DRIPNET SIMULATIONS AT EACH SITE

Results from monitoring and program analysis performed for multiple zones at each of these five sites are depicted in Table 4. Hydraulic performance appears to have varied, depending upon the combination of pretreatment level, system design and usage. Results for Lake Wheeler Mobile Home Park, Zones 1 and 2, are depicted in fig. 2.

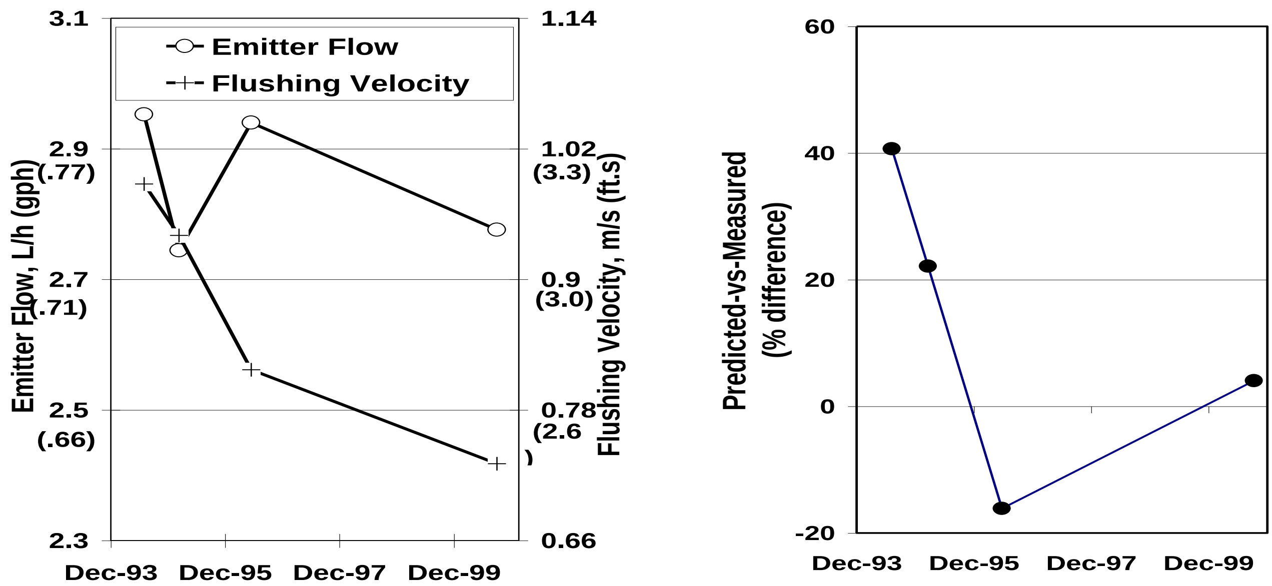


A. Emitter Flows **B. Flushing Velocity** **C. Flushing Head Losses**

Figure. 2. Hydraulic Assessment Results for Lake Wheeler Mobile Home Park, Zones 1 and 2.

Emitter flow rate has dropped in the seven years since start-up by 20 and 7 %, while flushing scour velocities have dropped by 42 and 37 % to 0.43 m/s and 0.37 m/s (1.4 and 1.2 ft/s, Zones 1 and 2, respectively). Also, the DRIPNET-predicted-vs-measured flushing network head loss has significantly changed. At start-up, the program over-predicts head loss by 33 to 25 % (Zones 1 and 2). . But in little more than a year, predicted head loss became less than measured losses, and the latest results show much higher measured losses than predicted. The most likely explanation is significant clogging of the drip tubing. Reduction in scour velocity is also most likely due to drip line clogging, although some deterioration in pumping efficiency may also be a contributing factor. Emitter flow reduction is most likely indicative of emitter clogging.

The two other sites receiving septic tank effluent only (Cedar Grove and Pactolus Schools) performed similarly to each other, so only results from Cedar Grove are shown (fig. 3).



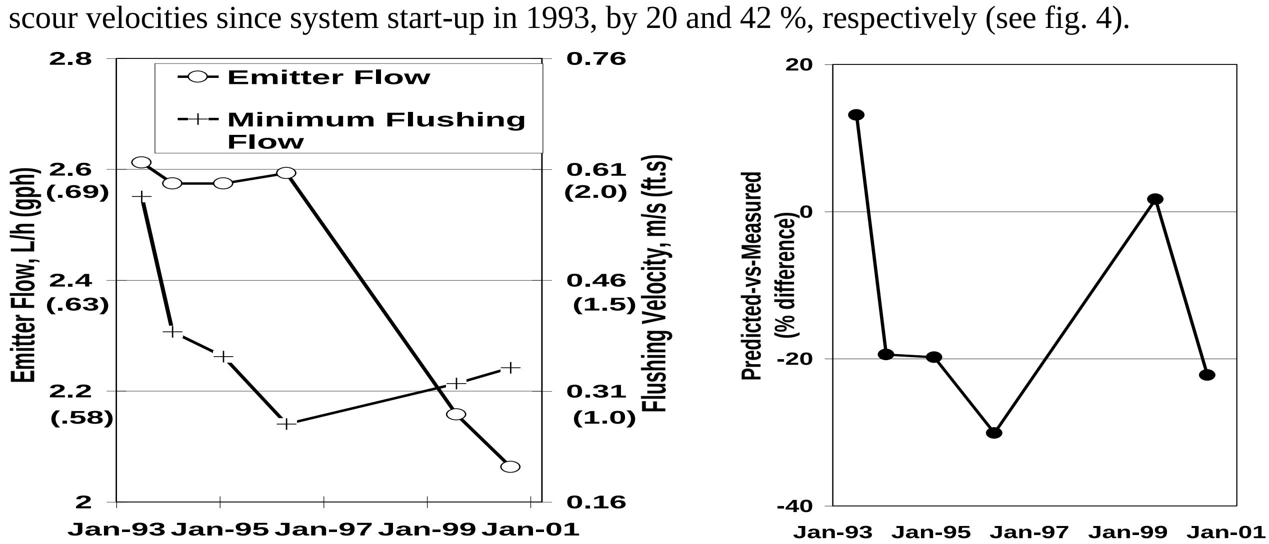
A: Emitter Flows and Flushing Velocities B: Flushing Head Losses

Figure 3. Hydraulic Assessment Results for Cedar Grove Elementary School

Emitter flow has shown very little change in its six-year operating period, and minimum flushing velocities, while dropping by an average of 28 %, were initially greater than 0.91 m/s (3 ft/s) and remains above 0.61 m/s (2 ft/s) in all zones. Predicted-vs-measured flushing network head losses similarly decreased, but much less dramatically than at Lake Wheeler. This would indicate only a modest amount of drip tube clogging and no appreciable emitter clogging. Some benefit may also be realized at these two school sites from the drip tubing (and thus the emitters) being surrounded by aggregate, possibly preventing the development of saturation zones and potential for clogging at the emitter-soil interface.

The final two sites evaluated (Edward Best Middle and Vaughan Elementary Schools) utilize sand filters in addition to septic tanks for pretreatment. However, they have in fact been subject to significantly different influent conditions. The Best system was subject to hydraulic upset due to severe infiltration/inflow via a leaky septic tank. Its sand filter also failed shortly after system start-up and was bypassed for significant periods until repairs were completed in 1997. The Vaughan School has been a model system, with well-maintained sand filter in continuous use and no excessive hydraulic loading problems since system start-up.

The differences between these two school systems are reflected in the hydraulic performance of their drip drainfields. At Best, there has been a significant reduction in emitter flow and flushing scour velocities since system start-up in 1993, by 20 and 42 %, respectively (see fig. 4).

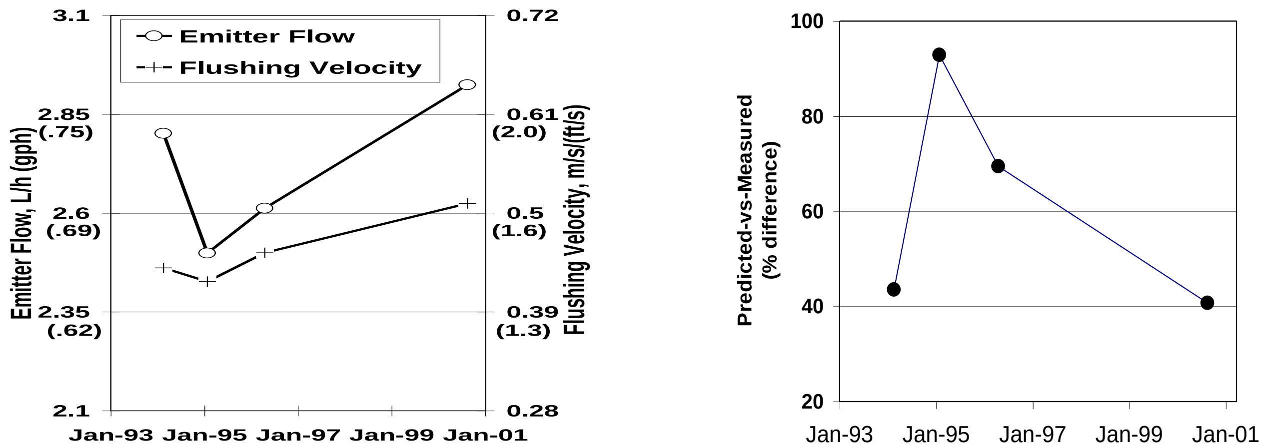


A. Emitter Flows and Flushing Velocities B: Flushing Head Losses

Figure 4. Hydraulic Assessment Results for Best Middle School (Zones 1 + 2)

Program-predicted flushing head losses relative to measured losses also have dropped, compared to start-up conditions. These data indicate some clogging of the drip tubing early in the life of this system, but do not show signs of further deterioration. The resulting flushing scour velocity dropped to be near 0.30 m/s (1 ft/s) early in the life of this system. Emitter flow, on the other hand, was nearly constant for the first three years of system operation and has only indicated partial clogging conditions on the 1999 and 2000 monitoring days.

The hydraulic data from Vaughan show, if anything, a slight increase in both emitter flow and flushing scour velocities (fig. 5).



A. Emitter Flows and Flushing Velocities **B. Flushing Head Losses**

Figure 5. Hydraulic Assessment Results for Vaughan Elementary School (Zones 1 - 4)

Scour velocities have been in the range of 0.46 m/s (1.5 ft/s) or higher. Predicted-vs-measured flushing head losses have been variable, but predictions remain higher than measured losses, indicating no sign of drip line clogging.

Long-term monitoring and observations at these sites also revealed in all cases good system hydraulic performance from the standpoint of system sizing relative to site-specific soil conditions. During the first year after system start-up, adjustments had to be made in locations of portions of the field zones at Lake Wheeler and Best, where lines had intersected soil areas with reduced permeability due to natural site variations (Best) or disturbance during construction (Lake Wheeler). The drainback phenomena was also discovered to be a critical concern, particularly by observations and further analysis of the Lake Wheeler system (Berkowitz, 1999). Otherwise, there have been few indications that the long-term acceptance rates of the soils at any of these five sites have been exceeded. The most significant operation and maintenance issues at these sites have revolved around periodic separation of pipe connections and the susceptibility of the electronic solenoid valves to malfunction and the PLC controllers to electrical storm damage.

CONCLUSIONS

The overall finding of this field assessment is that the long term hydraulic performance of the drip tubing and emitters serving these well managed subsurface drip wastewater systems has generally been excellent. The greatest reduction in emitter irrigation flow at any of the sites was 23 %. While this could mean uniformity of effluent distribution at this site has become compromised, this has not yet resulted in system malfunction. Most of the sites evaluated showed minimal change over time of the emitter flow rate, even when partial clogging of the drip tubing had become evident. The computer program DRIPNET also proved to be an excellent tool for accurately evaluating projected system performance, and performance changes over time.

Study findings indeed indicate clogging of subsurface drip tubing and emitters appears to occur independently to a variable degree, although the phenomena involved are likely interrelated. Lines develop some slime build-up relatively early in the life of the system, as reflected by reduction in flushing scour velocity and reduction in program-predicted flushing head loss, compared to measured head losses. This occurs to a lessor degree with higher quality effluent. Extent of line clogging when using only septic tank effluent (no sand-filter pretreatment) is also less where the initial flushing scour velocities were highest (greater than 0.91 m/s [3 ft/s]). At some sites, even though the initial flushing scour velocity was about 0.61 m/s (2 ft/s), line clogging lines has resulted in the scour velocity dropping closer to 0.30 m/s (1 ft/s).

The only evidence of any significant emitter clogging was found at two of the five sites -- Lake Wheeler and Best. Clogging is considered primarily the result of solids build-up inside the emitters. The drop in flushing scour velocities at these sites to be closer to 0.30 m/s (1 ft/s) than 0.61 m/s (2 ft/s), and the concurrent increased clogging of their drip lines may also be contributing factors. Levels of emitter clogging even at these two sites was much less than reported by Persyn (2000) from two poorly maintained sites in Texas, highlighting the benefits of good design and maintenance, including routine flushing.

Most successful hydraulic performance was associated with initial minimum flushing velocities in excess of 0.91 m/s (3 ft/s) when using septic tank effluent, and 0.46 m/s (1.5 ft/s) when using cleaner sand filter effluent. Even when the system design incorporates good routine flushing, periodic treatment of the tubing may be necessary to remove built-up biological solids from the drip tubes and emitters. Persyn (2000) investigated shock chlorination as a means of doing this. While it is currently being considered for application at the Best and Lake Wheeler sites, such measures must be administered carefully to prevent damage to the soil from sodium that would accompany a highly concentrated chlorine solution.

The interest in subsurface drip as an ideal effluent distribution system appears to be warranted based on the long-term hydraulic performance of operational systems. The applicability of this technology should increase for use in decentralized wastewater systems, as future research succeeds in further establishing proper system sizing criteria, and continuing improvements are made in the reliability of system components.

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Table 4. Hydraulic Assessment and DRIPNET Simulation Results

Site	Zone	Monitoring Date	Irrigation Flow		Emitter Flow		Flushing Flow		Scour Velocity		Measured Head Loss		Predicted Head Loss	
			L/m	gpm	L/h	gph	L/m	gpm	m/s	ft/s	kPa	psi	KPa	psi
LAKE WHEELER	1	8/6/93	204	54	2.3	0.61	625	165	0.74	2.4	379	55	503	73
		5/8/94	204	54	2.3	0.61	397	105	0.32	1.1	193	28	172	25
		11/30/94	197	52	2.2	0.58	333	88	0.22	0.7	207	30	110	16
		2/24/95	193	51	2.2	0.57	454	120	0.46	1.5	496	72	255	37
		9/7/00	167	44	1.9	0.49	416	110	0.44	1.4	669	97	214	31
	2	8/6/93	204	54	2.3	0.6	651	172	0.58	1.9	193	28	241	35
		5/10/94	189	50	2.2	0.59	568	150	0.46	1.5	290	42	159	23
		6/10/94	197	52	2.3	0.61	583	154	0.47	1.5	255	37	165	24
		11/30/94	193	51	2.3	0.6	379	100	0.22	0.7	48	7	63	9.1
		9/7/00	182	48	2.2	0.57	481	127	0.36	1.2	414	60	110	16
CEDAR GROVE	1	7/15/94	68	18	3.2	0.84	189	50	0.91	3.0	379	55	524	76
		2/24/95	61	16	2.8	0.75	182	48	0.91	3.0	427	62	496	72
		5/29/96	79	21	3.7	0.98	174	46	0.71	2.3	476	69	400	58
		9/14/00	51	13.5	2.4	0.63	151	40	0.76	2.5	427	62	345	50
	2	7/15/94	64	17	3.0	0.8	197	52	1.00	3.3	462	67	586	85
		5/29/96	53	14	2.5	0.65	170	45	0.88	2.9	517	75	448	65
		9/14/00	55	14.5	2.6	0.68	159	42	0.78	2.6	221	32	379	55
	4	7/15/94	57	15	2.6	0.7	197	52	1.05	3.5	379	55	607	88
		2/24/95	57	15	2.6	0.7	185	49	0.97	3.2	414	60	531	77
		5/29/96	57	15	2.6	0.7	170	45	0.86	2.8	545	79	441	64
		9/14/00	72	19	3.4	0.89	159	42	0.66	2.2	379	55	345	50
	3	7/15/94	53	14	2.5	0.65	220	58	1.03	3.4	317	46	441	64
		5/29/96	53	14	2.5	0.65	193	51	0.86	2.8	365	53	331	48
		9/14/00	49	13	2.3	0.6	155	41	0.63	2.1	379	55	207	30
PACTOLUS	1	12/6/94	45	12	2.8	0.75	125	33	0.98	3.2	558	81	710	103
		5/29/96	42	11	2.6	0.69	102	27	0.74	2.4	634	92	462	67
		9/14/00	45	12	2.8	0.75	110	29	0.79	2.6	586	85	524	76
	2	12/6/94	49	13	3.1	0.83	129	34	0.98	3.2	545	79	745	108
		5/29/96	45	12	2.8	0.75	106	28	0.74	2.4	545	79	483	70
		2/25/99	44	11.5	2.8	0.73	95	25	0.63	2.1	558	81	379	55
		9/14/00	45	12	2.8	0.75	117	31	0.88	2.9	558	81	614	89
	3	12/6/94	49	13	3.1	0.83	121	32	0.88	2.9	545	79	641	93
		5/29/96	45	12	2.8	0.75	106	28	0.74	2.4	510	74	483	70
		9/14/00	45	12	2.8	0.75	117	31	0.88	2.9	524	76	614	89
	4	12/6/94	49	13	3.1	0.83	114	30	0.79	2.6	545	79	552	80
		5/29/96	45	12	2.9	0.76	102	27	0.69	2.3	476	69	441	64
		9/14/00	44	11.5	2.8	0.73	110	29	0.81	2.7	558	81	538	78
EDWARD BEST	1	7/28/93	273	72	2.6	0.69	530	140	0.58	1.9	427	62	469	68
		3/4/94	269	71	2.6	0.68	450	119	0.41	1.3	379	55	303	44
		2/24/95	273	72	2.6	0.69	432	114	0.35	1.1	317	46	269	39
		5/15/96	269	71	2.6	0.68	424	112	0.34	1.1	352	51	262	38
		8/25/99	220	58	2.1	0.56	360	95	0.30	1.0	193	28	193	28
		9/12/00	208	55	2.0	0.53	367	97	0.35	1.1	290	42	214	31
	2	7/28/93	273	72	2.6	0.69	530	140	0.57	1.9	414	60	483	70
		3/4/94	269	71	2.6	0.68	439	116	0.37	1.2	365	53	296	43
		2/24/95	265	70	2.5	0.67	432	114	0.37	1.2	379	55	290	42
		5/15/96	273	72	2.6	0.69	371	98	0.19	0.6	290	42	186	27
		8/25/99	227	60	2.2	0.58	379	100	0.34	1.1	221	32	228	33
		9/12/00	220	58	2.1	0.56	371	98	0.34	1.1	269	39	221	32
VAUGHAN	1	3/18/94	132	35	2.8	0.75	261	69	0.47	1.5	172	25	228	33
		2/24/95	114	30	2.4	0.64	235	62	0.44	1.4	110	16	193	28
		5/15/96	125	33	2.6	0.7	254	67	0.46	1.5	124	18	214	31
		9/12/00	140	37	3.0	0.78	284	75	0.52	1.7	172	25	269	39
	2	3/18/94	129	34	2.8	0.73	254	67	0.45	1.5	193	28	214	31
		9/12/00	136	36	2.9	0.77	278	73.5	0.51	1.7	221	32	262	38
	3	3/18/94	132	35	2.8	0.75	250	66	0.42	1.4	124	18	200	29
		9/12/00	140	37	3.0	0.78	280	74	0.51	1.7	159	23	262	38
	4	3/18/94	129	34	2.8	0.73	246	65	0.42	1.4	97	14	200	29
		2/24/95	121	32	2.6	0.68	235	62	0.41	1.3	83	12	179	26
		5/15/96	121	32	2.6	0.68	246	65	0.45	1.5	124	18	207	30
		9/12/00	134	35.5	2.9	0.76	274	72.5	0.51	1.7	193	28	255	37