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COMPUTER PROGRAM FOR EVALUATING THE HYDRAULIC DESIGN OF SUBSURFACE WASTEWATER DRIP IRRIGATION SYSTEM PIPE NETWORKS

S. J. Berkowitz, P. E., and J. R. Harman, P. E.*

ABSTRACT

Drip irrigation is an exciting technology beginning to be applied in the southeastern United States for the subsurface treatment and disposal of wastewater effluent. Israel has many more years of experience with this system, albeit under significantly different climatic and soil conditions. Subsurface drip irrigation combines favorable characteristics of some other commonly used systems such as low pressure pipe and spray irrigation, with many of its own unique beneficial features. A principal hydraulic objective of the drip system designer is to achieve uniform effluent distribution throughout the drainfield over the life of the system. Technological breakthroughs including pressure compensating emitters and automatic field flushing techniques have greatly enhanced the potential for this objective to be met.

We have developed and tested a computer program to predict the hydraulic performance of any proposed drip irrigation system pipe network which incorporates use of pressure compensating emitters and automatic field flushing. A modified Hardy-Cross technique is utilized to predict the actual distribution of flow through each dripper line during field flushing cycles. Program outputs include the basic flow, velocity and pressure parameters resulting from the specific layout selected, and detailed information which enable logical design modifications to be made. The program can thereby be used iteratively to develop an optimal hydraulic design. Model parameters in the program have been calibrated and validated at

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* S. J. Berkowitz, Head, On-Site Wastewater Engineering Branch, On-Site Wastewater Section, NC Division of Environmental Health, Raleigh, NC; and J. R. Harman, Wastewater Systems, Inc., Raleigh, NC

operational drip system installations in North Carolina. To be presented herein are the critical hydraulic design parameters for drip irrigation systems, documentation for the computer program developed, examples of program applications and field testing, and design recommendations based on our experience to date. The program has also been made available in the public domain.

KEYWORDS. Drip Irrigation, Wastewater, Pipe Networks, Subsurface

INTRODUCTION

Uniform distribution of effluent in subsurface wastewater treatment and disposal systems has well established advantages (Otis, et al. 1977, Hargett et al. 1982). These include reduced clogging of the soil interface and enhanced treatment due to the uniform distribution of effluent throughout the entire ground absorption area and effective utilization of the uppermost soil horizons. The low pressure pipe (LPP) distribution system has become a commonly used method to uniformly distribute effluent in subsurface systems. LPP systems utilize a small diameter pipe network within aggregate-filled trenches. Orifices in the pipe network are sized and spaced to compensate for elevation (and thus pressure head) variations between laterals, and the tendency for the lowest lines to receive a disproportionate share of effluent at the beginning and end of each dosing cycle. Field testing has demonstrated the water quality benefits of LPP systems (Cogger and Carlile, 1984, Stewart and Reneau, 1988). Hydraulic design principles have been well established (Otis, 1982, Berkowitz, 1985, Mote, et al. 1985) and system design guidelines developed (Cogger et al. 1982, Marinshaw, 1988).

Practical experience with LPP systems has proven to be problematic (Hargett, 1985, Hoover and Amoozegar, 1989). Although designed to uniformly distribute effluent throughout the drainfield area, mechanical difficulties and system maintenance neglect have made this objective difficult to achieve. Solids accumulation and biofilm formation in the pipe network, root impaction and rock/particulate shadowing of the orifice openings often leads to a significant reduction in the number of effective orifices, causing overloading near the few orifices which remain unblocked. This problem is greatly exacerbated when a routine flushing protocol is not strictly followed. On sloping lots, the potential to overload the lowest laterals is high. These lower lines are subject to higher pressure heads and are thus the last to have holes plugged. Also, the effluent remaining in the pipe network at the end of each dose cycle will flow by gravity preferentially into the lower lines unless special prevention methods are taken.

Drip irrigation is increasingly being considered as an alternate method of achieving uniform, shallow distribution of wastewater effluent in subsurface systems. Drip irrigation systems typically include small diameter polyethylene tubing with integral emitters which allow liquid to drip into surrounding soils at an extremely slow rate. While comparative sizing criteria have not yet been fully established, soil and areal loading rates currently recommended for subsurface wastewater drip irrigation systems are comparable to those for LPP systems. Some main differences are the placement of drip laterals typically on two-foot centers compared to five foot centers for LPP trenches; direct burial of drip laterals in native soil, as opposed to in an aggregate-filled trench; five to 10 times the emitters compared to LPP orifices typically present; emitter flow rates less than two percent of typical LPP orifice flow rates; and total field dosing rates 10 to 20 percent of the dosing rates for a comparable LPP field.

Drip irrigation was invented and initially applied in Israel as a means of efficiently irrigating arid lands for agricultural production while minimizing evaporative losses. Partially treated wastewater is commonly used in small and large scale drip irrigation systems. About two-thirds of the municipal wastewater effluent generated in Israel today is reused, with a significant portion applied to crops by drip irrigation (Avnimelech, 1994). Drip emitters, tubing, filtration and control systems have been developed to a high level of sophistication. One of the most significant technological breakthroughs has been the development of pressure compensating emitters, which enable the discharge rate per emitter in an entire field to be the same, regardless of the internal pressure variations in the pipe network or relative elevation differences. Subsurface drip irrigation of effluent has been more recently applied and is currently being promoted in Israel as a means for reducing crop contamination risk, for making water and nutrients available directly adjacent to crop roots, and for further reducing surface evaporative losses and runoff potential (Oron et al. 1991, Oron et al. 1988).

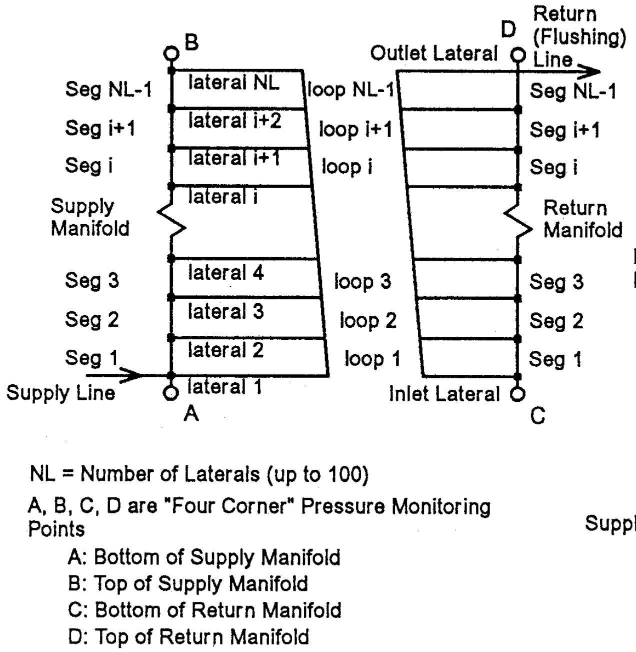
Extensive research has been devoted to preventing the clogging of drip emitters used in the irrigation of wastewater effluents. Previous work has focused on problems associated with the use of effluent stored in reservoirs (Adin and Sacks, 1991). Significant clogging factors include effluent suspended solids, chemical precipitation, and growth of biofilms in the pipe network. Sediment carried back through the emitters at the end of irrigation cycles or when soils around the emitters are periodically saturated also contribute to clogging. Particulates in the effluent can be effectively controlled by various types of filters. The most effective method to control biofilm buildup and remove particulates which may build up or enter the lateral network is through the efficient routine lateral flushing. Drip systems can be designed to be flushed manually or automatically. Due to the number of laterals typically present, automated flushing is desirable and can be readily incorporated, thanks to the concurrent technological advancement of automated control systems. Current accepted practice calls for automatic flushing of drip laterals every two to four weeks achieving a minimum scour velocity of two feet per second, flushing long enough to fill all lines and achieve several pipe volume changes in every lateral. Critical design considerations thus include the proper coordination of system layout, pipe network sizing, and pump selection which take both irrigation and flushing requirements into account.

COMPUTER PROGRAM DRIPNET

A computer program, DRIPNET, was developed to delineate the key hydraulic parameters associated with any proposed subsurface drip irrigation system field network which utilizes pressure compensating emitters and automatic field flushing. Flow and head losses during field irrigation and flushing cycles are simulated. Program outputs can be used to determine the pumping system's minimum design requirements, to properly set the control system parameters to meet desired design criteria and to evaluate design options and guide network design modifications.

Basic features and assumptions

The drip field pipe network conventions assumed by DRIPNET are depicted in Figs. 1 and 2.



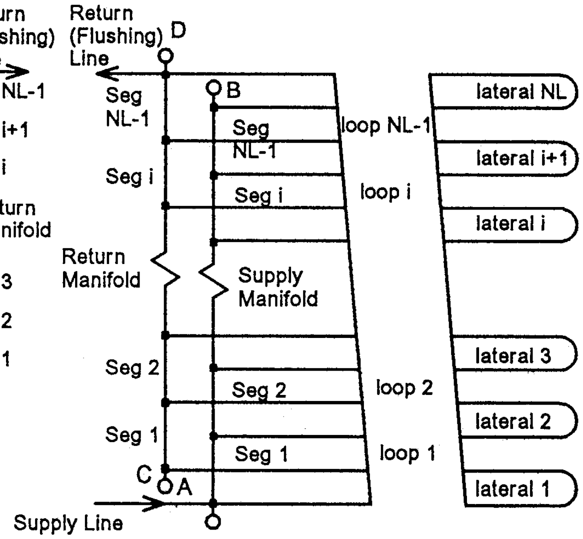


Figure 1. Field Pipe Network Assumed by DRIPNET

Figure 2. Field Pipe Network Looped Laterals

Any real field network can be readily converted to one which fits these conventions. While Figs. 1 and 2 show the supply line feeding the supply manifold at the first lateral and the return line leaving the return manifold at the last lateral (which is often the design convention of choice), these entrance and exit points can be set at any lateral desired. The basic limitations on the field network design are shown in Table 1. Elevation information is not required and not critical to program results, although it must be considered independently when determining pump total dynamic head design requirements.

Table 1. DRIPNET Limitations and Design Conventions

Number of field laterals:	Maximum of 100
Length of laterals (in feet):	No limitations (and each may be different)

Number of loops in each lateral:	No number limitation (and each may vary)
Lateral spacing (in feet):	No limitation, and fully variable
Elevation limitations:	Elevation information not required
Lateral inside diameter (in inches):	Must input inside diameter which is presumed constant throughout network
Emitter spacing (in feet):	Must input spacing which is presumed constant throughout network
Emitter flow (in gallons per hour):	Must input flow which is presumed to be constant for each emitter in network
Supply and return manifold inside diameters (in inches) and lengths (in feet):	Must input unique size and length of each segment (and each may vary independently)
Minimum design flushing scour velocity (in feet per second);	Must be inputted and can be varied for each program run

The program is written in BASIC and is most efficiently run on a computer with rapid computational capabilities. We utilize an IBM 486 Model 433 DX/D with a math co-processor, which completes a run on most practical sizes of system networks in a matter of minutes.

Inputs

Network designs to be simulated can either be inputted during a program run (feasible if the network is small), or as a pre-created project-specific ASCII file. For large field networks, an ASCII file is constructed which contains:

- the length and number of loops for each lateral
- the diameter and size of each supply manifold segment

- the diameter and size of each return manifold segment

Information which can vary for each run must also be inputted, including:

- number of laterals, total lateral length, and lateral diameter
- emitter spacing and flow
- inlet and outlet lateral number
- minimum flushing scour velocity
- head loss adjustment factors for supply manifold, return manifold and laterals
- desired accuracy for Hardy-Cross iterations
- input and output file names

PROGRAM COMPUTATIONS

Head loss

Contributions to head loss are assumed to include:

- Friction loss in each segment of supply manifold (function of segment flow rate, length and inside diameter), and in each return manifold segment (only applicable during flushing simulation)
- Entrance loss into each lateral from the supply manifold
- Friction loss in each segment of lateral between emitters (function of segment flow rate, emitter spacing and lateral inside diameter)
- "Barb" loss attributed to flow passage by each internal emitter.

Friction in each manifold and lateral segment is computed by the Hazen-Williams Equation, assuming a "C" factor of 140. The equation form utilized is as follows:

$$HL = \frac{(0.00113)(L)(Q^{1.85})}{D^{4.87}}$$

Where HL = head loss, ft.

L = segment length, ft.

Q = segment flow rate, gallons per minute

D = segment inside diameter, inches

Entrance losses are computed by the empirical formula derived in the classic paper on dividing flow manifolds by Hudson, et al. (1979):

$$EHL = \left[A\left(\frac{Vm}{Vl}\right)^2 + B \right] \frac{Vl^2}{2g}$$

Where EHL = entrance head loss, ft.

Vm = manifold velocity, upstream from lateral, ft. per second

Vl = lateral velocity downstream from manifold, ft. per second

g = gravitational acceleration, assumed to be 32.174 ft. per second per second

A, B = constants derived by Hudson to be 0.9 and 0.4 for "long" laterals, respectively

"Barb" losses are based on data provided by Netafim for RAM emitters with 0.6 gallons per hour nominal flow in half-inch nominal size tubing (Bisconer, 1992).

$$EMHL = 0.75\frac{(V^2)}{2g}$$

Where EMHL = emitter head loss, psi

V = velocity in lateral segment upstream from emitter, ft. per second

g = acceleration of gravity, assumed to be 32.174 ft. per second per second

Flows

During irrigation, flow out of each emitter is presumed to be equal, and thus flow per linear foot of lateral is considered to be equal throughout the network. During irrigation, it is assumed that flow in the return manifold line is zero. During flushing, in addition to the constant emitter flow which continues, the return line is opened, allowing flow through the network to be returned to the pretreatment system. Total network inflow during flushing is initially estimated to be the total emitter flow plus the flow required to achieve the minimum scour velocity at the distal end of each lateral. A mass balance is applied to compute the initial flow in each supply and return manifold segment. The Hardy-Cross (H-C) technique is then applied to establish the actual flow through each segment of the network. The H-C method is premised on the principle that the head loss around any interconnected pipe loop is zero (Streeter and Wylie, 1975). In order for this to occur, flow must be greater in some laterals and less in others to compensate for variable head losses associated with the variable flow rates in the supply and return manifold and adjacent lateral segments. For every iteration, the H-C method results in a correction factor which is applied to adjust flows in each leg of every loop. Head loss and flow corrections are recomputed and applied iteratively until the head loss around every loop in the network approaches zero within an established tolerance limit. The form of the H-C adjustment factor used is as follows:

$$DQ = \left(-\frac{1}{2}\right)\frac{(DQT)}{(DQB)}$$

Where: DQ = flow adjustment factor for iteration for each loop

$$DQT = \sum_{i=1}^{n} THL_i$$

Where: THL_i = total head loss in segment i (positive for flow in a clockwise direction)

n = total number of segments in loop

$$DQB = \sum_{i=1}^{n} \left| \frac{THL_i}{Q_i} \right|$$

Where: Q_i = segment i flow

Iterations are repeated applying increasingly tighter H-C tolerance limits until the head loss along the flow path extending from the inlet point, up through the supply manifold and across the outlet lateral is essentially equivalent to the head loss along the flow path extending across the inlet lateral and up the return manifold to the outlet point. After the flow distribution solution is achieved, the actual flushing velocity at the distal end of each lateral is recomputed. If any are now less than the desired minimum scour velocity, the total flow to the network is incremented by at least two percent, and the actual distribution of flows within the network again solved iteratively by the H-C technique. This is repeated until all individual lateral flushing flows exceed the minimum inputted scour velocity.

Outputs

Program outputs are both printed on the screen and written into an ASCII file. Outputs include a repetition of the input parameters, and all critical information relevant to the design, including:

- Inflow, emitter flow, outflow and distal velocity in each lateral during flushing
- Flow and velocity in each supply and return manifold segment during flushing
- Total network inflow during flushing, emitter flow, and return flushing flow
- Manifold, lateral and total network volume; estimated network fill time and detention time in the longest lateral during flushing
- Head losses during irrigation in the supply manifold, longest lateral and total.
- Head losses during flushing in the supply manifold, return manifold, inlet lateral, outlet lateral, and total network head losses

PROGRAM VERIFICATION

The program was developed to evaluate and help establish design parameters for large subsurface drip systems being proposed for use in North Carolina. At five operational sites, field testing has been completed to compare system performance with program predictions (Table 2).

TABLE 2: SUBSURFACE DRIP SITES USED FOR PROGRAM VERIFICATION*

Name of system	County	Type of Facility	Design flow (GPD)	# of zones	Total system tubing (ft)	Tubing per zone (ft)	# of lines per zone	Line lengths (ft)

Lake Wheeler	Wake	Mobile Home Park	6000	3	37,620	12,540	44	285
Edward Best	Franklin	Middle School	13,000	4	43,426	10,800-10,884	40-72	120-326
Vaughn	Warren	Elementary School	4000	4	22,680	5670	27	210
Three Springs	Chatham	Group Home/Camp	3925	4	19,754	3694-6080	17-33	89-360
Gunpowder	Caldwell	Subdivision	9600	5	27,080	6720-6820	24-31	180-320

*All utilize half-inch (nominal) drip laterals with 0.6 GPH emitters (nominal) on 2-foot centers. Laterals are installed on 2-foot centers except at Lake Wheeler, where laterals are on 3-foot centers. Pretreatment includes septic tanks for all, intermittent sand filtration for Edward Best and Vaughn, and recirculating sand filtration for Three Springs and Gunpowder. Field configurations are standard (Fig.1), except for Three Springs which looped laterals (Fig. 2), and Lake Wheeler which includes some looped lines in one zone.

Measurements taken include irrigation and flushing flow rates to each zone and simultaneous pressure measurements at the "four corners" of the zone pipe network, which are at the bottom and top of the supply and return manifolds. Field measurements of relative elevations at the "four corners" were also made. Program input factors were varied until the predicted irrigation and flushing flows matched the corresponding flows measured. The measured pressure variations (adjusted for elevation differences) could then be directly compared to predicted head losses (Fig. 3).

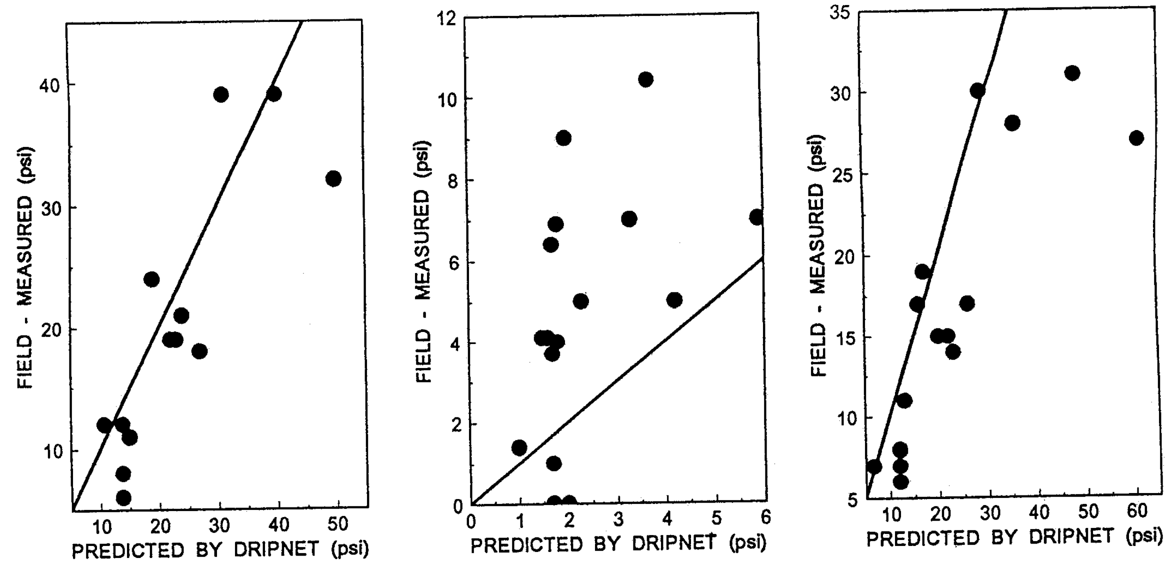


Fig. 3A. Total Network Head Loss

Fig. 3B. Supply Manifold Head Loss

Fig. 3C. Outlet Lateral Head Loss

Figure 3. DRIPNET Verification Runs at Five North Carolina Sites

Degree of correspondence varied between sites and to a lesser extent between zones at the same site. The following conclusions can be drawn from these verification tests:

- Overall degree of correspondence justifies use of DRIPNET for subsurface drip system design and evaluation purposes.
- Manifold (supply and return) head losses appear to be underestimated.
- Lateral head losses appear to be overestimated.

PROGRAM APPLICATION

DRIPNET has proven to be a valuable tool to aid in optimizing system design, evaluating system installation, and in the evaluation of operating system performance.

Design

As with any wastewater system, many trade-offs must be made in choosing a subsurface drip system design. DRIPNET enables the designer to understand the consequences of the selected design and necessary modifications which become apparent. Design information provided include:

- Information needed to select pump capacity requirements for both irrigation and flushing conditions, including the flows required and network head losses which must be overcome (elevation head and supply line and return line head losses must be added on separately). Number, size and configuration of zones in the system can be varied to arrive at the ideal field scheme and irrigation and flushing operating regimes.
- Changes needed in supply and return manifold segment sizes to keep flushing velocities within a desired range (eg: 2-10 feet per second) in order to provide for effective scouring while limiting excessive friction loss.
- Information needed to select the minimum dosing volume to assure most flow is delivered after the network is fully pressurized. (eg: to assure at least 80 percent of each dose is pumped after the pipe network is filled, the volume per dose must be greater than: [5 x (Mv + Lv)], where Mv is the supply and return manifold pipe pipe volume, and Lv is the total lateral volume; Mv and Lv are included in outputs).
- Information necessary to select the minimum flushing time. For example, the flush time selected should be long enough to fill the network and then continue flushing until at least two pipe volumes have passed through the longest lateral (network fill time and longest lateral detention time included in DRIPNET outputs).

Installation and performance testing

During the testing of a newly installed system and subsequent testing of operational systems, by comparing measured to predicted values of the "four corners" pressures and corresponding head losses, the presence of blockages or breaks becomes evident. The program's utility in this regard has been well established during installation and performance testing at a number of the North Carolina subsurface drip sites. The critical importance of **keeping all construction debris** out of the supply lines, manifolds and lateral tubing can also not be overstated.

FUTURE WORK

We continue to test and improve the DRIPNET program to incorporate updated product specifications, to utilize more accurate algorithms, and to incorporate design modifications in field layout developed in response to the experience being gained with existing systems. An algorithm improvement will be to use the more precise Darcy-Weisbach friction loss equation, with a variable "f" factor as a function of changes in the Reynolds number (Hathoot et al. 1993).

PROGRAM AVAILABILITY

DRIPNET is available from the National Small Flows Clearinghouse at West Virginia University. The program has been copyrighted by the first author. Any inquiries or suggestions on program improvements are solicited and will be much appreciated.

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