

DESIGN OF LARGE LOW-PRESSURE PIPE DISTRIBUTION SYSTEMS
IN NORTH CAROLINA

by

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Since first being introduced in 1974, the low-pressure pipe (LPP) system has steadily gained acceptance in North Carolina as a reliable alternative to the conventional septic tank system. Although initially designed for small domestic use on problem sites, during the past decade, developers and engineers have taken advantage of the improved performance of LPP systems for much larger types of facilities. Over 500 "large" LPP systems, with design flows greater than 3,000 gallons per day, are now in operation in North Carolina, with 50 - 80 new, large systems installed annually.

Several publications are available in the literature on the design and installation of LPP systems (Carlile 1979, Cogger et al. 1982), hydraulic theory and design criteria (Otis 1982, Berkowitz 1984), and performance (Hargett 1984, Amoozegar et al. 1986, Cashell et al. 1987). This paper will focus primarily on the experience with LPP systems in North Carolina. Recommendations and guidelines for the design and installation of LPP systems will be presented based on that experience.

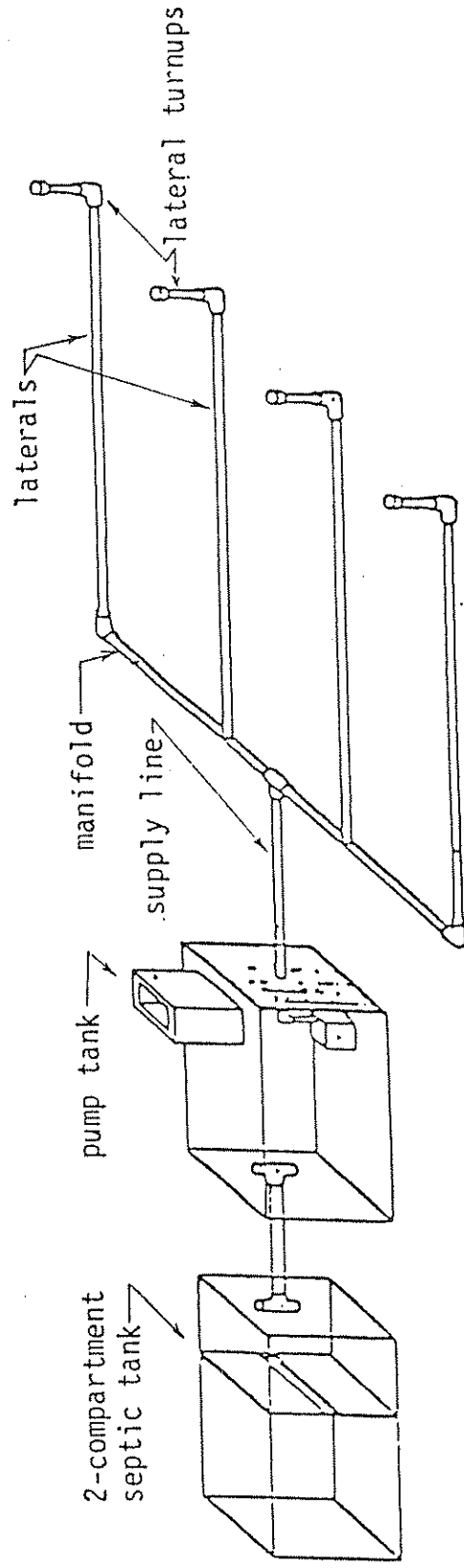
DESCRIPTION OF TYPICAL LPP SYSTEM

A typical LPP system consists of the following components:

- a. Septic tank, two-compartment design, as required for a conventional septic tank system;
- b. Pump or dosing tank, sized to provide a predetermined dosing volume and emergency storage capacity of 12-24 hours. One or more effluent pumps are provided with associated controls, including high-water alarm, level control switches and disconnect;
- c. Supply line, constructed of pressure pipe, typically Schedule 40 or SDR 26 PVC;
- d. Supply manifold, sized large enough to allow relatively uniform distribution among laterals;
- e. Laterals, usually small diameter PVC (1-inch - 2 inches) spaced on five-foot centers in shallow (18-24 inches deep), narrow (8-12 inches wide) trenches. Small orifices (1/8-inch - 1/4-inch) are drilled in each lateral, spaced 3-10 feet on center.

Effluent flows from the septic tank to pump tank from which it is pumped through the supply line and manifold to the laterals. From the laterals, effluent is discharged uniformly through the orifices into the drain field lateral trenches.

Figure 1 illustrates the layout of a typical LPP system.



From: Cogger, C., B. L. Carlile, D. Osborne, and E. Holland. 1982.

Figure 1. Typical low-pressure pipe distribution system.

ADVANTAGES OF LPP SYSTEM

The advantages of the LPP system over the conventional septic tank system are well documented in the literature (Cogger et al. 1982, Hargett 1984, Carlile 1979). These can be summarized as follows:

1. Improved distribution, by means of pressurized laterals discharging effluent uniformly throughout drain field.
2. Dosing and resting cycles, which help to maintain aerobic conditions in soil, providing better treatment and dispersion.
3. Shallow placement, which provides for maximum vertical separation from ground water and restrictive horizons, and disperses effluent in the most biologically active zone of soil.
4. Narrow trenches, which minimize disturbances to soil during installation and utilize sidewall absorption providing better aeration.
5. Smaller land area required, since site is more fully utilized for treatment and disposal.
6. Not restricted to gravity flow, allowing use of dislocated or higher drain fields.
7. Allows for unequal lateral lengths, since effluent is discharged at similar rate per unit length of lateral.

OPERATIONAL PROBLEMS WITH LPP SYSTEMS

Although the LPP system overcomes many of the limitations of the conventional septic tank system, a number of operational problems with small domestic LPP systems in North Carolina have been documented (Hargett 1984, Amoozegar et al. 1986). Experience with large LPP systems in North Carolina has demonstrated similar problems which are compounded by the size of the systems. Minor problems with small systems typically become much more serious problems when the design flow is increased by an order of magnitude. The major operational problems with large LPP systems observed in North Carolina are summarized below.

1. Excess Infiltration

Pump systems, in general, are highly susceptible to failure by hydraulic overloading as a result of infiltration. In poorly drained areas, or during periods of wet weather, leaky pump tanks become sinks for the surrounding ground water. Hargett (1984) observed that infiltration of ground and surface water was the most serious operational problem in a study of LPP systems in North Carolina. In large systems, which often include extensive collection sewers, the likelihood of infiltration may increase dramatically.

2. Faulty Hydraulic Design

In order for an LPP system to operate effectively, the pumps, supply lines, manifold, laterals, and orifices must all be properly sized and located. Some of the more common problems resulting from a poor or inadequate hydraulic design are included in Table 1.

3. Drainage

Fields must be protected from all surface runoff. Level sites with high ground-water tables are also susceptible to failure from ground-water mounding up into drain field trenches. On sloping fields, subsurface flow from higher areas can contribute to hydraulic overloading of trenches, particularly in the lower part of the field. This is the suspected cause for a number of LPP failures in North Carolina.

4. Improper Installation

Since the performance of LPP systems is so sensitive to changes in the hydraulic design, proper installation is critical. Sloping lateral trenches have been documented (Hargett 1984, Amoozegar et al. 1986), but any variance to the design can lead to poor performance or failure of the system. Some installation problems observed in North Carolina include incorrect orifice size and spacing, installation of undersized substitute pumps, incorrect adjustment of level control floats and pressure head, and installation of laterals at the wrong elevations.

5. Orifice and Lateral Clogging

The clogging of orifices is a problem that is becoming more and more apparent. Inadequate maintenance of the septic tank can allow solids to reach the drain field and block orifices. Based on recent inspections of older systems, there is evidence of slime buildup in long supply lines and in manifolds and laterals. It is suspected that the sloughing off of this slime may also contribute to orifice clogging. Grease and oil are an even greater threat in systems serving food-handling facilities. If orifices are too small or pressure head too low, orifice clogging can occur. Entrapped air can also block the flow of effluent to laterals. However, because air locking occurs only when lines are under pressure and effluent is flowing, it is more difficult to diagnose.

IMPORTANT DESIGN CONSIDERATIONS

SITE SELECTION AND FIELD LAYOUT

Because of the large volumes of effluent which must be disposed of, the movement of effluent through the soil is a primary concern in the design of large LPP systems. The importance of an extensive and thorough site evaluation to identify the best site available cannot be overemphasized. Once the site is selected, the design process must focus on how to best utilize the actual soil and site conditions to ensure the effluent moves through the soil and off the site.

TABLE 1
HYDRAULIC DESIGN PROBLEMS

<u>Design Fault</u>	<u>Result</u>
Undersized pump	: Field not pressurized; localized overloading
Oversized pump	: Excessive pressure head; pump inefficiency
Undersized supply line	: Excessive head loss; field not pressurized
Undersized manifold	: Nonuniform distribution to laterals
Undersized lateral	: Nonuniform distribution along lateral
Undersized orifice	: Orifice clogging
Oversized orifice	: Field not pressurized; localized overloading
Orifice spacing too great	: Localized overloading along lateral
Pressure head too high	: Excessive flow and losses; scouring of trench interface
Pressure head too low	: Field not pressurized; localized overloading
Lateral flows not balanced	: Overloading of some laterals
Too many control valves	: Difficult to regulate pressure head

Level sites

Topography plays an essential role in determining the subsurface movement of effluent. On level sites, assuming no other restrictions to flow, effluent travels from the trench down through the unsaturated zone to the ground-water table. As the effluent encounters the ground-water table, it begins to back up and spread out forming a mound below the drain field (Figure 2). The mound height continues to increase until steady-state conditions are achieved. This reduces the separation between trench bottom and water table, and may lead to ponding of trenches or surfacing of effluent.

Several approaches to predicting mound height are found in the literature. One of the more commonly used methods was developed by Hantush (Hantush 1967). This was later simplified (Finnemore et al. 1983) to the following form.

$$z_m = IC \left(\frac{L}{4}\right)^n \left(\frac{1}{Kh}\right)^{0.5n} \left(\frac{t}{S_y}\right)^{1-0.5n}$$
$$h = h_o + \frac{z_m}{2}$$

where z_m = maximum height of mound

- I = infiltration or application rate
- C, n = constants based on length-to-width ratio (L/w) of field
- L = length of field
- K = hydraulic conductivity
- h_o = initial aquifer elevation
- t = time since application began
- S_y = specific yield of soil

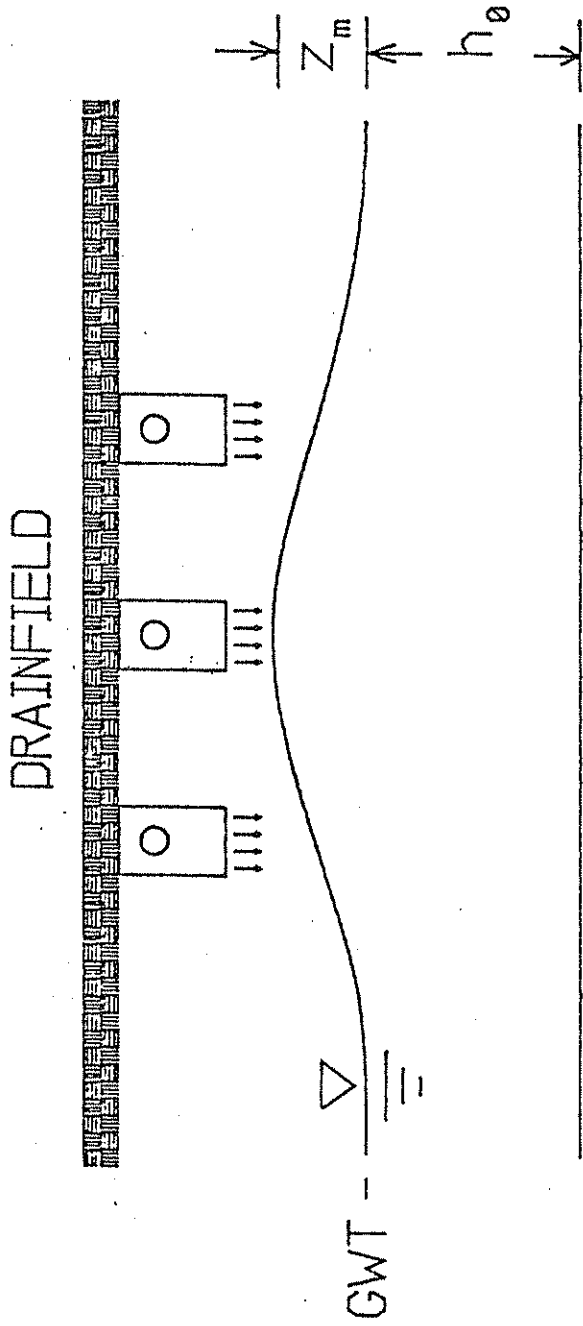
Values for the constant C vary from 3.42 for L/w = 1 to 0.59 for L/w = 8. Values of the constant n range from 1.71 for L/w = 1 to 1.78 for L/w = 8.

It is not the intent of this paper to discuss the merits of this or any other method for predicting ground-water mound height. This method, as well as others, does illustrate, however, the sensitivity of mound height to field size and configuration. For a fixed soil application or loading rate, as the flow increases, field size increases proportionally. Assuming a constant length-to-width ratio, it can be seen from the above equation that, as field size increases, mound height increases by the power of:

$$\left[\left(\frac{A_2}{A_1} \right)^{0.5} \right]^n$$

For example, for L/w = 1, if the field area is doubled, the mound height increases by a factor of 1.82. Thus, even for the same application rate, the mound height almost doubles.

If, on the other hand, the field size and flow are held constant and the length-to-width ratio is increased, mound height decreases. It is not as easy



$$z_m = IC \left(\frac{L}{4}\right)^n \left(\frac{1}{kh}\right)^{0.5n} \left(\frac{1}{S_y}\right)^{1-0.5n}$$

$$h = h_0 + \frac{z_m}{2}$$

Figure 2. Ground-water mounding.

to illustrate the relative reduction in height, but Finnemore et al. (1983) gives examples of mound height decreasing 10 - 20 percent by increasing L/w from 1 to 8.

From the above discussion, the importance of spreading out fields is clear. Mound height is minimized through the use of multiple fields. The greater the separation between fields, the less influence one will have on the other and the lower the ground-water mound will be. In addition, by designing long, narrow fields, mound height will be even further reduced.

If site limitations preclude spreading out or elongating fields, a mounding analysis can indicate how much the fields must be elevated to satisfy the minimum vertical separation requirements. This procedure has been carried out in some of the coastal areas in North Carolina.

Sloping Sites

On sloping terrain, ground water behaves much differently. Rather than spreading out, it will ultimately move in the same general direction down gradient. This movement can be described by Darcy's Law (Figure 3).

$$Q = KiA$$

where: Q is the flow

K is the hydraulic conductivity

i is the gradient

A is the cross-sectional area through which the flow occurs

The area, A, is the "window" of saturated soil which concerns us. Looking at Figure 3, for a uniform section of drain field, as A increases, the zone of saturation approaches the soil surface. The variables K and i are characteristics of the site and cannot be modified. Thus, to minimize the flow window and, in doing so, maximize the separation between trench bottom and saturated zone, the flow Q must be minimized. This is accomplished by minimizing the number of trenches up and down the slope. Once again, long, narrow fields along the contours are recommended. In North Carolina, as a general guideline, fields on sloping sites are limited to approximately 20 laterals, with the line lengths and number of fields adjusted to provide the required trench area.

On slopes with nonlinear contours, as depicted in Figure 4, the principle is the same, but ground water will converge or diverge with the slope. On diverging slopes, the flow window widens, thus increasing separation from the surface; on converging slopes, the window narrows and approaches the ground surface. It is obvious then that converging slopes should be avoided and diverging slopes preferred when possible. The layout can be further improved by locating fields on ridge tops or opposite sides of ridges to maximize the divergence of subsurface flow.

HYDRAULIC DESIGN

The hydraulic design of a low-pressure pipe system includes the determination of a number of design elements, such as orifice spacing, lateral length and size, manifold size, and pressure head. For most of these elements,

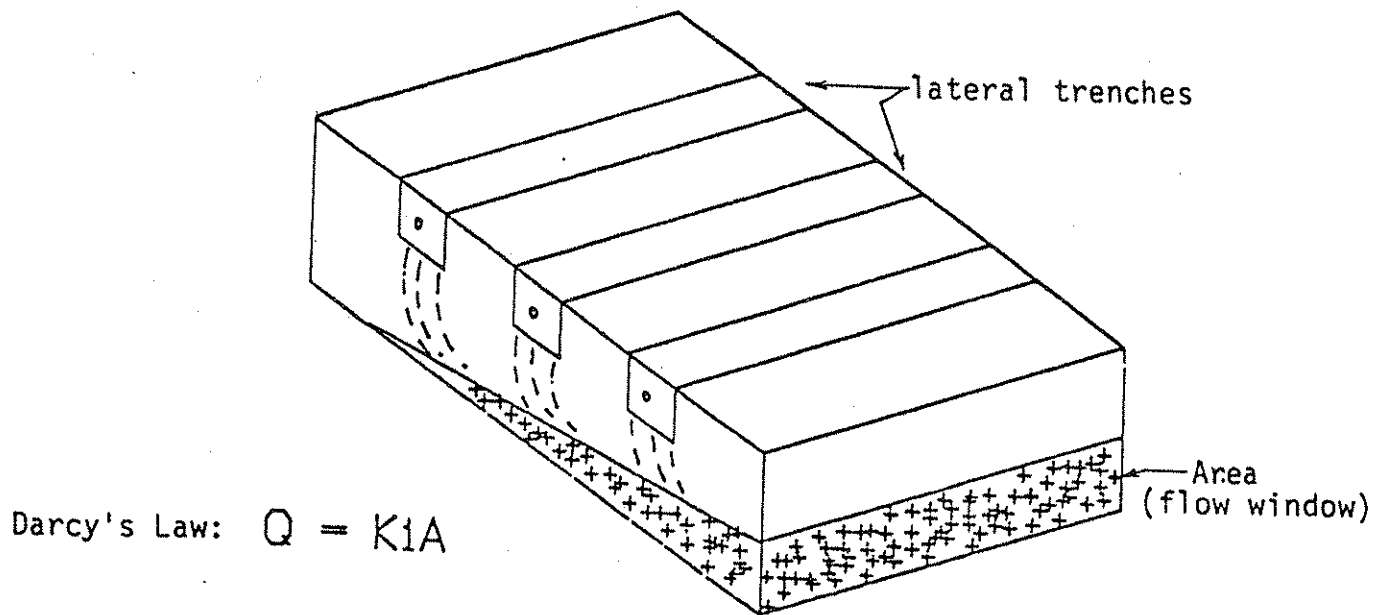
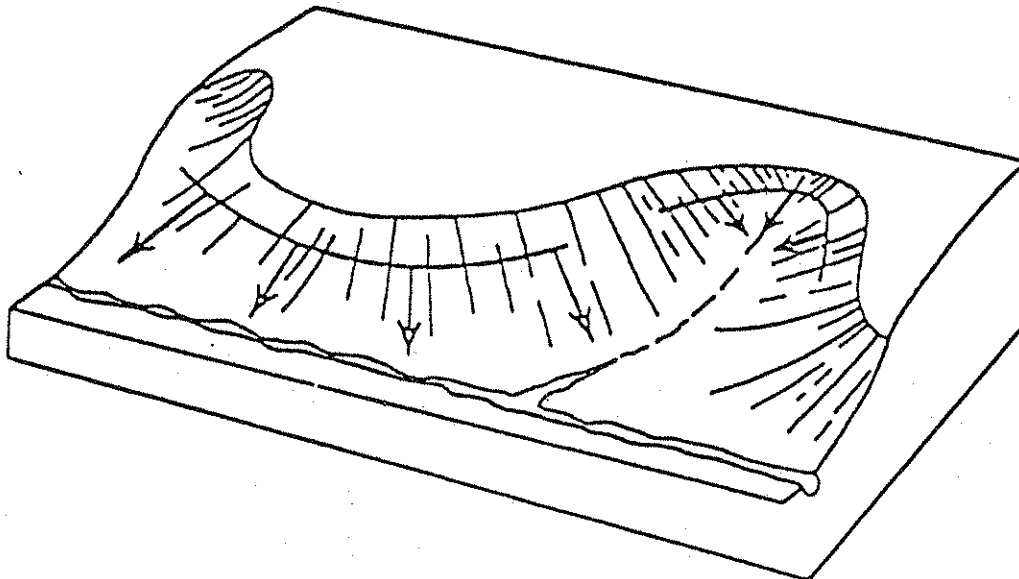


Figure 3. Subsurface flow on sloping site.



From: Tyler, J. E. and J. C. Converse. 1984.

Figure 4. Converging and diverging slopes.

there is a tradeoff between performance and cost. The designer must identify minimum performance standards and size the components accordingly. Appendix I summarizes some of the recommended hydraulic design criteria used in North Carolina. These are explained below.

Orifice Size and Spacing

Flow through an orifice can be determined using the orifice equation, which can be written as:

$$q = 11.79d^{2.05}h$$

where:

- q = orifice flow in gallons per minute
- d = diameter of orifice in inches
- h = pressure head in feet

There is no generally accepted analytical method for determining the most appropriate orifice size for a particular LPP system. Feasible sizes mentioned in the literature range from 3/32-inch to 5/8-inch (Carlile 1979, Otis 1982). Smaller orifices increase the likelihood of clogging. Larger orifices result in increased pumping requirements and head loss through the system. In North Carolina, the minimum recommended size is 5/32-inch for most facilities and 3/16-inch for food service facilities.

Maximum orifice spacing is limited by the type of soil. In soils with high permeabilities, orifices should be spaced more closely to minimize localized overloading of trench bottoms. For finer textured soils with low permeabilities, maximum spacing can be increased. Maximum recommended orifice spacings used in North Carolina are shown in Appendix II. There is no recommended minimum orifice spacing. It must be kept in mind, however, that the closer the spacing the higher the number of orifices and thus higher flows. In most installations on level sites, a five-foot spacing is used. On sloping sites, as explained below, orifice spacing varies.

Manifold size and spacing

Flow distribution through a pressurized manifold has been shown to be a function of frictional losses along the manifold, exit losses from the manifold, and entrance losses into the lateral (Otis 1981, Berkowitz 1984). By solving a series of simultaneous equations, the flow distribution for a specified number of laterals, lateral size, lateral flow, and manifold size can be determined. This is a lengthy procedure which is not practical to carry out on a routine basis, however. Berkowitz (1984) has developed a set of curves which can be used instead for sizing the manifold to allow a maximum flow variation of 15 percent among the laterals (Appendix III). These have been in use for several years in North Carolina with good results. For further discussion of manifold sizing, the reader is referred to Berkowitz (1984) and Otis (1982).

The manifold can be located along the edge of the ground absorption field or through the middle of the field. Locating the manifold at the edge simplifies installation. The effect of locating the manifold centrally is to divide laterals in half. This allows for a longer overall lateral length and, thus, is recommended for fields with long laterals.

If centrally located manifolds are used on sloping sites, steps must be taken to ensure that effluent from lateral trenches cannot seep into and flow down the manifold trench. Manifolds on sloping fields should also be fed from the lower end of the field when possible. By doing this, an uphill gradient can be maintained from supply line to the distal end of the manifold. This will help to reduce air blockages in the field, since it allows air to exit in the direction of the flow rather than against the flow. This may not eliminate the need for air release valves in the supply line, particularly if the supply line does not follow a constant gradient.

Lateral length and size

The hydraulic principles used in sizing laterals are similar to that for sizing manifolds. Otis (1982) has shown that the entrance and exit losses are negligible, however, and can be ignored, thus simplifying the design. For a specified orifice size, orifice spacing, and lateral size, the maximum lateral length can be determined which will allow a specified maximum flow variation from orifices. Using a 10-percent flow variation, Berkowitz (1984) has developed curves for determining the maximum lateral length for a number of orifice sizes, orifices spacings, and lateral sizes (Appendix IV). Otis (1982) has developed similar curves for larger orifice sizes. In North Carolina, 1 1/4-inch laterals are typically used up to lengths of 70 feet, and 1 1/2-inch laterals up to lengths of 100 feet. The reader is referred to Otis (1982) and Berkowitz (1984) for further discussion of lateral sizing.

Pressure head

To ensure optimal performance of an LPP system, the pressure head in the laterals must be maintained within certain limits. A minimum pressure head of 2 to 2.5 feet is recommended to minimize the effects of small variations in elevation along the lateral (Cogger et al. 1982, Otis 1982). As pressure head increases, flow and frictional losses also increase. For this reason, a maximum pressure head of five feet is recommended. Systems will function well with higher heads and, in fact, higher heads can reduce the likelihood of orifice clogging. But the increased pumping requirements and possible scouring of soil near the orifices (Cogger et al. 1982) can outweigh the advantages of higher pressure heads. Level fields in North Carolina are normally designed for a three-foot pressure head at the distal end of the laterals. In sloping fields, the highest laterals, as explained below, are usually designed for a two-foot pressure head.

Field size

As the size of the field increases, not only does the complexity of the hydraulic design increase, but problems associated with subsurface movement of effluent also become more severe. It is thus advisable to limit field size when possible. The general practice in North Carolina has been to limit field size by limiting total lateral length to 3,000 linear feet per field.

Design of sloping fields

LPP fields on sloping lots present a much more complex design problem. Lateral pressure heads vary with the lateral elevations. When the difference in elevation among laterals within a field is greater than two to three feet, it becomes necessary to divide the field into subfields in order to maintain

pressure heads within the limits of two to five feet. Each subfield is fed directly from the effluent supply line. A gate valve is also provided to adjust the pressure head within the subfield. The common practice in North Carolina is to adjust the pressure head in the highest line of each subfield to two feet. It should be noted that as the number of subfields increases, it becomes increasingly difficult to balance the flows among subfields. It is, therefore, recommended that the number of subfields be limited to three or four per field.

To compensate for differences in pressure heads among laterals, the orifice size, orifice spacing, or both, must be varied from lateral to lateral. In addition, the design must compensate for the overloading of lower lateral trenches, and the toe of the field. This occurs when the field is being pressurized and fills from bottom to top; when the laterals and manifold drain back at the completion of pumping; and as the result of ground water or effluent moving downslope through the soil. The practice in North Carolina has been to overdesign the flow to the upper laterals by 15 to 30 percent to account for this problem of overloading. Thus far, this method appears to be giving good results. However, it is an area with a definite need for research in order to develop a more analytical design method to account for these phenomena.

There is no "best" design for an LPP system on a sloping site. A trial and error method must be used to determine the orifice size and spacing of each lateral which will satisfy the specified design criteria. However, by using a simple decision rule and a systematic approach, such as that explained below, the process can be streamlined.

Installation of the laterals can be simplified if only one orifice size is used throughout the field and so it makes sense to design the field for one orifice size, if possible. Proceeding from highest lateral to lowest, the number of orifices per lateral is then decreased (and orifice spacing increased) within each subfield to compensate for the resultant increase in pressure head. Using this procedure, it is necessary to select a smaller orifice size only if the orifice spacing required to achieve the desired flow exceeds the maximum allowable spacing for the site. By means of a series of simple repetitive calculations, the field can in this way be designed lateral by lateral for any specified flow variation. A step-by-step outline of this design method is provided in Appendix V.

Due to the systematic nature of this method, it is easily adapted to the computer. A program written in BASIC has been developed by the author utilizing this design method. The user must specify lateral elevations and length, minimum orifice spacing, initial orifice size, percent flow variation, minimum pressure head, and other information relevant to the system. The output data includes the orifice size, orifice spacing, and lateral flow for each lateral as well as other design specifications. The program can also be used to design LPP systems for level sites and systems with unequal lateral lengths. A sample of some of the output is provided in Figures 6a and 6b. Interested persons should contact the author for more information.

DOSING SYSTEM DESIGN

In systems with multiple fields, a reliable means of alternately dosing each field is essential to ensure the longevity of the system. Several types of dosing systems have been installed in North Carolina using timers, solenoid valves, and other means of controlling the flow to the fields. The system which has proved to be the most reliable consists of the following features:

1. equal size fields with fixed dosing volume;
2. one pump/force main per field;
3. automatic alternator and elapsed time clocks;
4. "H" connection between pairs of force mains.

The dosing volume is established by means of level control floats within the pump tank and is thus identical for each of the equally-sized fields. With each pump cycle, the entire dose is delivered to a single field. A separate pump and force main is provided to allow each field to be dosed independently of the others. To simplify installation and maintenance, the same pump model, sized for the field with the highest pumping requirements, should be used throughout the dosing system. The automatic alternator sequentially activates the next pump on succeeding cycles. Elapsed time clocks allow the operator to compare total run time for each pump to ensure the alternator is working properly. The "H" connection, a valved interconnection between pairs of force mains, allows the manual alternation between all fields when a pump is being serviced. A lag pump-on level control float can also be installed to activate one or more of the other dosing pumps if, for some reason, the initial pump fails to activate. The lag pump float should be positioned at least as high as the high-water alarm float, however, to ensure that the operator becomes aware of the situation.

INSTALLATION

Even the most carefully designed LPP system will not perform satisfactorily without an equal degree of care in the installation. All phases of the installation require constant supervision. Each component of the system must be tested and checked before the system is put into operation. The importance of waterproofing and leakage testing all tanks, particularly the dosing tank, cannot be overemphasized. Collection sewers and manholes must also be checked for infiltration. Force mains should also be hydrostatically pressure tested for leakage. Laterals must be checked with a transit to ensure they are installed dead level. On sloping sites, each lateral line should be staked out and measured before installation. The field design must be adjusted to compensate for discrepancies in lateral elevations. Provisions must also be made to divert surface runoff and intercept ground water to prevent overloading of the fields.

OPERATION AND MAINTENANCE

All LPP systems require routine maintenance to ensure dependable, long-term performance. A maintenance schedule should be established from the onset and adhered to throughout the life of the system. An operator must be designated to regularly check the various components of the system. Table 2

TABLE 2

ROUTINE MAINTENANCE SCHEDULE

1. Collection system	6-12 months	check for infiltration and blockages
2. Septic tank	3-6 months	check for solids accumulation, blockages, or damage to outlet baffle, excess in/exfiltration
	1-3 years	pump septage as required
3. Dosing tank	2-4 weeks	check pumps, controls, and high-water alarm
	3-6 months	check for solids accumulation and pump as required; check for in/exfiltration
4. Supply lines, force mains	6-12 months	check for pipe exposure, leakage
5. Ground absorption	2-4 weeks	maintenance of field fields vegetative cover; repair broken lateral turnups
	3-6 months	check for erosion, surfacing of effluent
	6-12 months	check pressure head and flush out lateral lines

outlines a general maintenance schedule. A maintenance program should include, but certainly not be limited to, the procedures listed in this table.

DESIGN EXAMPLE

To illustrate some of the procedures and guidelines discussed above, a design example is presented. The example is taken from an actual project installed in 1986. The system serves a 350-employee factory with a design flow of 5,250 gallons per day.

The ten-acre site for the system included the crest of a hill with ridges and sideslopes extending to the northwest and southwest. Slopes ranged from approximately 2 to 12 percent. Prior to the site evaluation, a topographical map of the area with two-foot interval contours was prepared (Figure 5a). A 50 by 50-foot grid was drawn on the contour map. The site was then staked off at these intervals.

A soil/site evaluation was conducted over a three-day period using backhoe pits to determine soil suitability. The soil was found to be a clay ranging in depth from 22 to 48 inches. Several areas were found to be unsuitable with respect to depth to saprolite and depth to seasonal high water table. By using the grid system, the designer was able to pinpoint unsuitable areas on the contour map and design the system around them (Figure 5b).

The suitable soil was assigned a loading rate of 0.1 gallons per day per square foot for a low-pressure pipe system. The area of drain field was determined to be:

$$A = (5,250 \text{ GPD}) / (0.1 \text{ GPD/sq.ft.}) = 52,500 \text{ sq.ft.}$$

Using the criterion of five square feet per linear foot of trench, the total trench length was determined:

$$L_{\text{total}} = (52,500 \text{ sq.ft.}) / (5 \text{ sq.ft./l.ft.}) = 10,500 \text{ l.ft.}$$

A maximum lateral length of 3,000 linear feet is recommended per field. On this basis, it was decided to design four equally sized fields with a minimum lateral length of:

$$(10,500 \text{ l.ft.}) / (4 \text{ fields}) = 2,625 \text{ l.ft. per field}$$

Next, the actual fields were located on the contour map. The four fields were placed around the crest to take advantage of the diverging slopes, while avoiding the unsuitable areas. This guaranteed that the fields would drain away from one another (Figure 5c). Taking into account the space available between unsuitable areas, the designer settled on a layout of 19 laterals on five-foot centers, each 140 feet long for each field (Figure 5d).

$$(19 \text{ laterals/field}) \times (140 \text{ l.ft./lateral}) = 2,660 \text{ l.ft. per field}$$

As it turned out, in field number 1, it was necessary to split one lateral into two 70-foot laterals. Otherwise, all laterals were 140 feet in length.

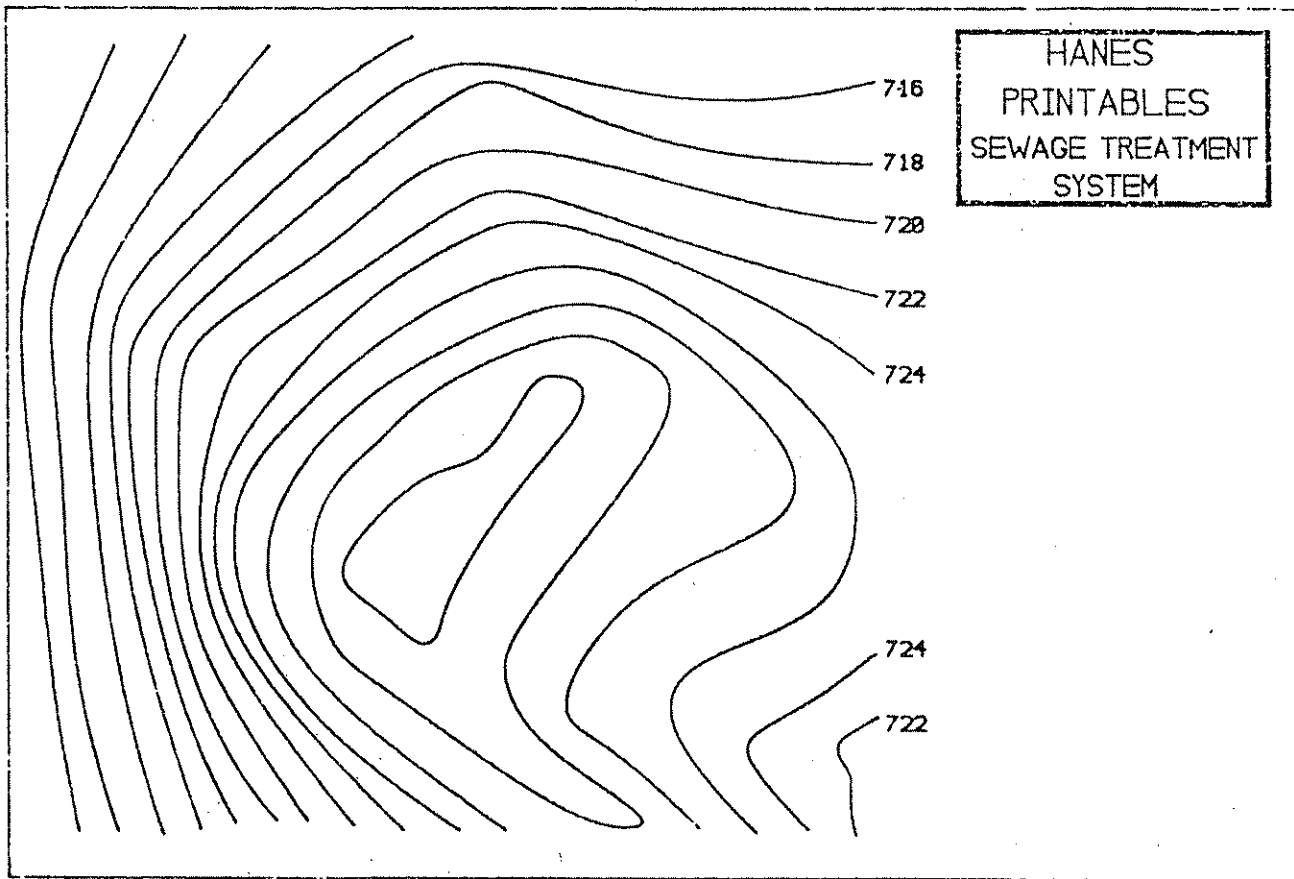


Figure 5a. Topographical map.

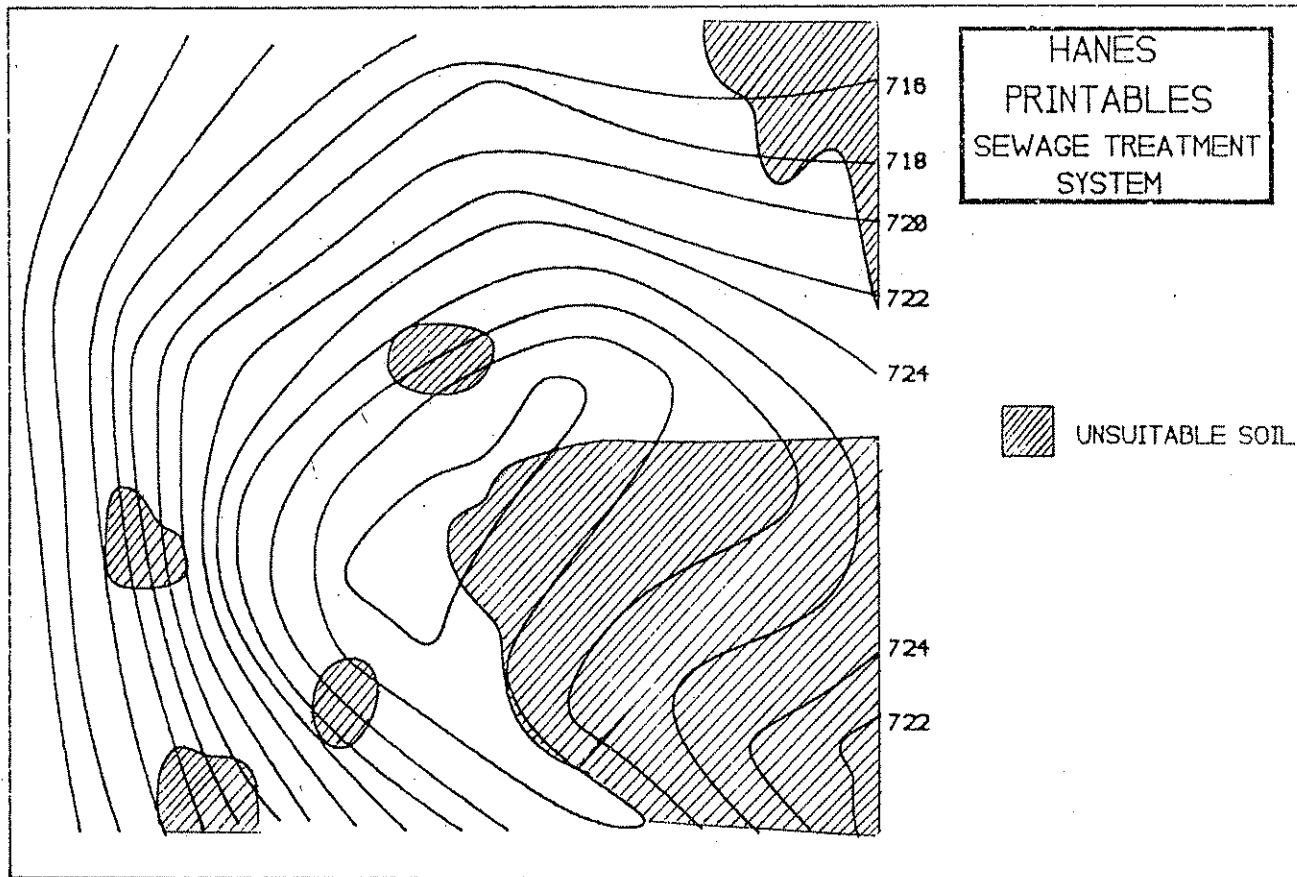


Figure 5b. Areas of unsuitable soil.

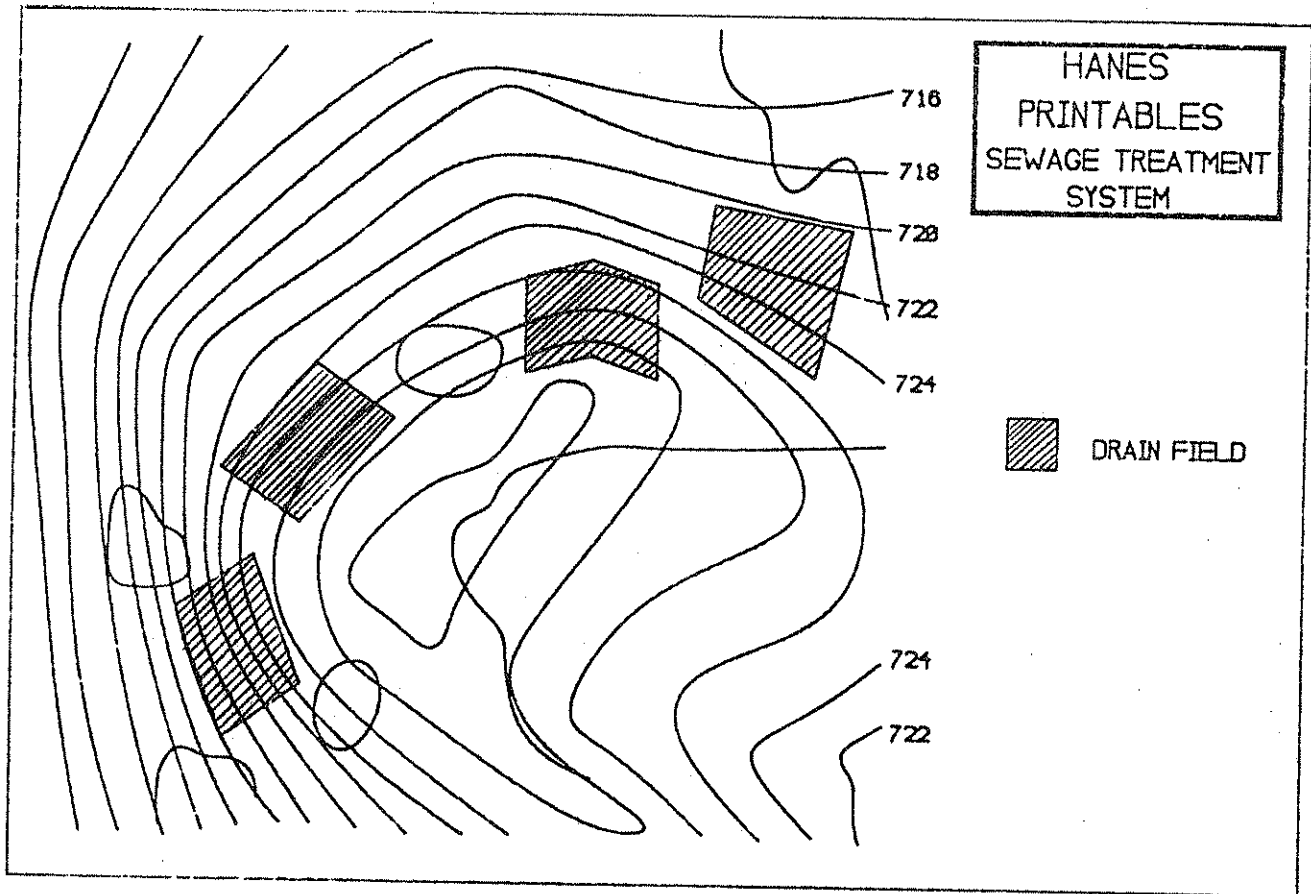


Figure 5c. Location of ground absorption fields.

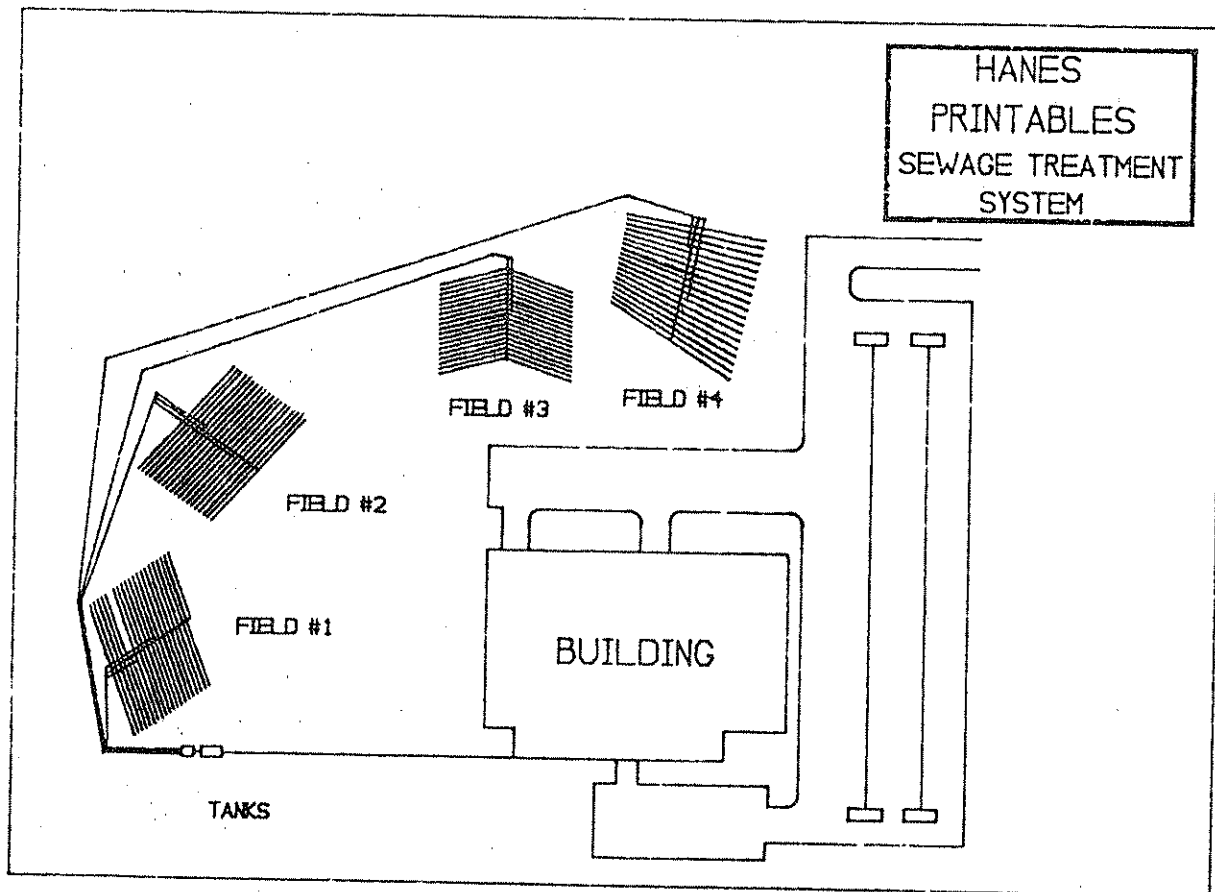


Figure 5d. Final layout of system.

The elevation of each lateral was determined. Due to differences in elevation, fields 1, 2, and 4 were divided into three subfields and field 3 into two subfields. The fields were then designed using the following criteria:

minimum pressure head	:	2 feet
orifice size	:	5/32 inch (0.156 inches)
minimum orifice spacing	:	5 feet
maximum orifice spacing	:	10 feet
flow variation in field	:	50 percent
lateral size	:	1 1/4 inch
manifold size	:	4 inch

Since the maximum number of laterals in any subfield was eight, four-inch diameter manifolds could be used throughout. With the manifolds located centrally, the effective lateral length was reduced from 140 feet to 70 feet. This allowed the use of 1 1/4-inch laterals. Laterals were designed for a flow variation of 50 percent. Although this is more than what is normally designed for, subsurface movement of effluent was expected to be a serious problem and so a higher flow variation was incorporated into the design.

Using the design procedure outlined in Appendix V, the field design is summarized in Figure 6a and 6b. (The actual design of the system differed slightly from this.) As can be seen from the summary, the majority of the laterals were designed for 0.156-inch orifices (5/32-inch). In order to maintain a maximum orifice spacing of 10 feet, however, it was necessary to design a few of the lower laterals for 0.125-inch orifices (1/8 inch).

The system was installed during the period of January to March, 1986. Although the contractor had never installed a low-pressure pipe system previously, by means of a systematic approach and under regular supervision by the local health department, the installation proceeded smoothly. A temporary work bench, 70 feet long, was set up so that the laterals could be drilled with the specified orifice size and spacing. After drilling, each lateral was then checked by the health department before being connected to the manifold and covered. All tanks were subjected to a 24-hour leakage test and supply lines were hydrostatically tested for leakage. Following certification by the engineer, a final inspection was carried out by the health department, during which time all controls were checked and lateral pressure heads adjusted.

After installation, an operator was assigned to maintain the system. Water usage is monitored and pumps, controls, and alarms are checked daily. Tanks are checked quarterly and pumped annually. Lateral lines are flushed out and pressure heads checked annually. Drain fields are regularly mowed throughout the year. The health department also conducts an annual inspection of the entire system. With the exception of a few lateral turnups having to be replaced, the system has had no problems despite its size, complexity, and the marginal soil conditions.

FIELD NO. 1

LAT. NO.	LENGTH	ELEV-ATION	PRESS. HEAD	HOLE SIZE	HOLE SPAC.	NO.OF HOLES	FLOW PER HOLE	FLOW PER LATERAL
1	70	725.50	2.00	0.156	5.00	14	0.41	5.68
2	140	725.00	2.50	0.156	5.83	24	0.45	10.89
3	140	725.00	2.50	0.156	5.83	24	0.45	10.89
4	140	724.50	3.00	0.156	6.67	21	0.50	10.44
5	140	724.50	3.00	0.156	6.67	21	0.50	10.44
6	140	724.00	3.50	0.156	7.37	19	0.54	10.20
7	140	724.00	3.50	0.156	7.78	18	0.54	9.66
8	140	723.50	4.00	0.156	8.75	16	0.57	9.18
9	140	722.50	2.00	0.156	6.36	22	0.41	8.93
10	140	722.00	2.50	0.156	7.37	19	0.45	8.62
11	140	722.00	2.50	0.156	7.37	19	0.45	8.62
12	140	721.50	3.00	0.156	8.24	17	0.50	8.45
13	140	721.00	3.50	0.156	9.33	15	0.54	8.05
14	140	721.00	3.50	0.156	10.00	14	0.54	7.51
15	70	720.00	2.00	0.156	7.78	9	0.41	3.65
16	140	720.00	2.00	0.156	7.78	18	0.41	7.30
17	140	720.00	2.00	0.156	8.24	17	0.41	6.90
18	140	719.50	2.50	0.156	10.00	14	0.45	6.35
19	140	719.50	2.50	0.156	10.00	14	0.45	6.35
20	140	719.00	3.00	0.125	7.37	19	0.32	6.06

TOTAL 2660 FEET

FLOW TO FIELD 164.17 GPM

FIELD NO. 2

LAT. NO.	LENGTH	ELEV-ATION	PRESS. HEAD	HOLE SIZE	HOLE SPAC.	NO.OF HOLES	FLOW PER HOLE	FLOW PER LATERAL
1	140	727.70	2.00	0.156	5.00	28	0.41	11.36
2	140	727.20	2.50	0.156	5.83	24	0.45	10.89
3	140	727.20	2.50	0.156	5.83	24	0.45	10.89
4	140	726.70	3.00	0.156	6.67	21	0.50	10.44
5	140	726.20	3.50	0.156	7.37	19	0.54	10.20
6	140	726.20	3.50	0.156	7.78	18	0.54	9.66
7	140	725.50	2.00	0.156	5.83	24	0.41	9.74
8	140	725.50	2.00	0.156	6.09	23	0.41	9.33
9	140	725.50	2.00	0.156	6.36	22	0.41	8.93
10	140	725.00	2.50	0.156	7.37	19	0.45	8.62
11	140	724.50	3.00	0.156	8.24	17	0.50	8.45
12	140	724.50	3.00	0.156	8.75	16	0.50	7.95
13	140	724.50	3.00	0.156	8.75	16	0.50	7.95
14	140	724.00	3.50	0.156	10.00	14	0.54	7.51
15	140	723.50	2.00	0.156	7.78	18	0.41	7.30
16	140	723.50	2.00	0.156	8.24	17	0.41	6.90
17	140	723.00	2.50	0.156	10.00	14	0.45	6.35
18	140	723.00	2.50	0.156	10.00	14	0.45	6.35
19	140	722.50	3.00	0.125	7.37	19	0.32	6.06

TOTAL 2660 FEET

FLOW TO FIELD 164.89 GPM

Figure 6a. LPP Design Example--design of fields 1 and 2.

FIELD NO. 3

LAT. NO.	LENGTH	ELEV-ATION	PRESS. HEAD	HOLE SIZE	HOLE SPAC.	NO.OF HOLES	FLOW PER HOLE	FLOW PER LATERAL
1	140	728.90	2.00	0.156	5.00	28	0.41	11.36
2	140	728.40	2.50	0.156	5.83	24	0.45	10.89
3	140	728.40	2.50	0.156	5.83	24	0.45	10.89
4	140	727.90	3.00	0.156	6.67	21	0.50	10.44
5	140	727.90	3.00	0.156	7.00	20	0.50	9.94
6	140	727.90	3.00	0.156	7.00	20	0.50	9.94
7	140	727.40	3.50	0.156	7.78	18	0.54	9.66
8	140	727.40	3.50	0.156	8.24	17	0.54	9.13
9	140	726.90	4.00	0.156	8.75	16	0.57	9.18
10	140	726.90	4.00	0.156	9.33	15	0.57	8.61
11	140	725.90	2.00	0.156	6.67	21	0.41	8.52
12	140	725.90	2.00	0.156	7.00	20	0.41	8.12
13	140	725.90	2.00	0.156	7.37	19	0.41	7.71
14	140	725.40	2.50	0.156	8.75	16	0.45	7.26
15	140	725.40	2.50	0.156	8.75	16	0.45	7.26
16	140	724.90	3.00	0.156	10.00	14	0.50	6.96
17	140	724.40	3.50	0.125	7.37	19	0.34	6.55
18	140	724.40	3.50	0.125	7.78	18	0.34	6.20
19	140	723.90	4.00	0.125	8.75	16	0.37	5.90

TOTAL 2660 FEET

FLOW TO FIELD 164.50 GPM

FIELD NO. 4

LAT. NO.	LENGTH	ELEV-ATION	PRESS. HEAD	HOLE SIZE	HOLE SPAC.	NO.OF HOLES	FLOW PER HOLE	FLOW PER LATERAL
1	140	724.20	2.00	0.156	5.00	28	0.41	11.36
2	140	723.70	2.50	0.156	5.83	24	0.45	10.89
3	140	723.70	2.50	0.156	5.83	24	0.45	10.89
4	140	723.70	2.50	0.156	6.09	23	0.45	10.43
5	140	723.20	3.00	0.156	7.00	20	0.50	9.94
6	140	723.20	3.00	0.156	7.00	20	0.50	9.94
7	140	722.70	3.50	0.156	7.78	18	0.54	9.66
8	140	722.20	4.00	0.156	8.75	16	0.57	9.18
9	140	721.70	2.00	0.156	6.36	22	0.41	8.93
10	140	721.70	2.00	0.156	6.67	21	0.41	8.52
11	140	721.20	2.50	0.156	7.78	18	0.45	8.17
12	140	721.20	2.50	0.156	7.78	18	0.45	8.17
13	140	720.70	3.00	0.156	8.75	16	0.50	7.95
14	140	720.70	3.00	0.156	9.33	15	0.50	7.45
15	140	720.20	3.50	0.125	6.67	21	0.34	7.24
16	140	719.70	4.00	0.125	7.37	19	0.37	7.00
17	140	719.20	2.00	0.156	8.75	16	0.41	6.49
18	140	719.20	2.00	0.156	9.33	15	0.41	6.09
19	140	718.70	2.50	0.125	6.67	21	0.29	6.12

TOTAL 2660 FEET

FLOW TO FIELD 164.41 GPM

Figure 6b. LPP Design Example--design of fields 3 and 4.

CONCLUSION

The design procedures and criteria discussed above have evolved over the years since North Carolina's first low-pressure pipe system was installed. Some have been developed as the direct result of scientific research; others as general guidelines and rules of thumb resulting from experiences with systems in operation. Although the procedures have given good results in North Carolina, they are by no means absolute. There is a serious need for further research before many of the problems encountered are fully understood and analytical methods are developed to predict performance under a variety of conditions.

REFERENCES

1. Amoozegar, A., C. H. House, K. C. Martin. 1986. Wastewater Distribution and Water Flow from Trenches in Low-Pressure Pipe Septic Systems. Proceedings of the 1986 Annual Meeting of the Soil Science Society of North Carolina. Raleigh, NC. pp 62-74.
2. Berkowitz, S. J. 1984. Pressure Manifold Design for Large Subsurface Ground Absorption Sewage Systems. Proceedings, Fourth National Symposium on Individual and Small Community Sewage Systems. American Society of Agricultural Engineers. New Orleans, LA.
3. Carlile, B. L. 1979. Use of Shallow, Low-Pressure Injection Systems in Large and Small Communities. Individual On-site Wastewater Treatment Systems. Proceedings of the Sixth National Conference. National Sanitation Foundation. Ann Arbor, MI. pp 371-385.
4. Cashell, Margaret M., D. D. Effert, and J. M. Morand. 1987. Alternate Wastewater Treatment and Disposal Systems on Severely Limited Sites. Cincinnati Center for Small Community Wastewater Systems Studies. University of Cincinnati, Cincinnati, OH 45221. pp 141-155.
5. Cogger, C., B. L. Carlile, D. Osborne, and E. Holland. 1982. Design and Installation of Low-Pressure Pipe Waste Treatment Systems. UNC Sea Grant College Publication. UNC-SC-82-03.
6. Finnemore, E. J., N. N. Hantzsche. 1983. Ground-Water Mounding Due to On-Site Sewage Disposal. Journal of Irrigation and Drainage Engineering. ASCE. Vol. 109. No. 2. pp 199-210.
7. Hantush, M. S. 1967. Growth and Decay of Groundwater Mounds in Response to Uniform Percolation. Water Resources Research. Vol. 3. No. 1. First Quarter. pp 227-234.
8. Hargett, D. L. 1984. Performance Assessment of Low-Pressure Pipe Wastewater Injection Systems. On-Site Wastewater Treatment, Proceedings of the 4th National Symposium on Individual and Small Community Sewage Systems. ASAE. pp 131-143.
9. Kaplan, Benjamin O. 1987. Septic Systems Handbook. Lewis Publishers. Chelsea, MI.
10. Otis, R. J. 1982. Pressure Distribution Design for Septic Tank Systems, Journal of the Environmental Engineering Division. ASCE. Vol. 108. No. EE1. pp 123-140.
11. Otis, R. J., J. C. Converse, B. L. Carlile, J. E. Witty. 1977. Effluent Distribution. Home Sewage Treatment. ASAE Pub. 5-77. St. Joseph, MI. pp 61-85.
12. Tyler, E. J. and J. C. Converse. 1984. Soil Evaluation and Design Selection for Large or Cluster Wastewater Soil Absorption Systems. On-Site Wastewater Treatment Proceedings of the 4th National Symposium on Individual and Small Community Sewage Systems. ASAE. pp 179-190.

APPENDIX I

Recommended Hydraulic Design Criteria for
Low-Pressure Pipe Systems

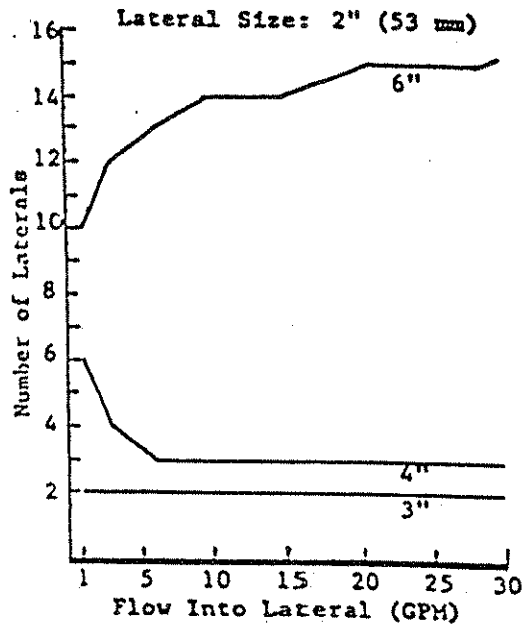
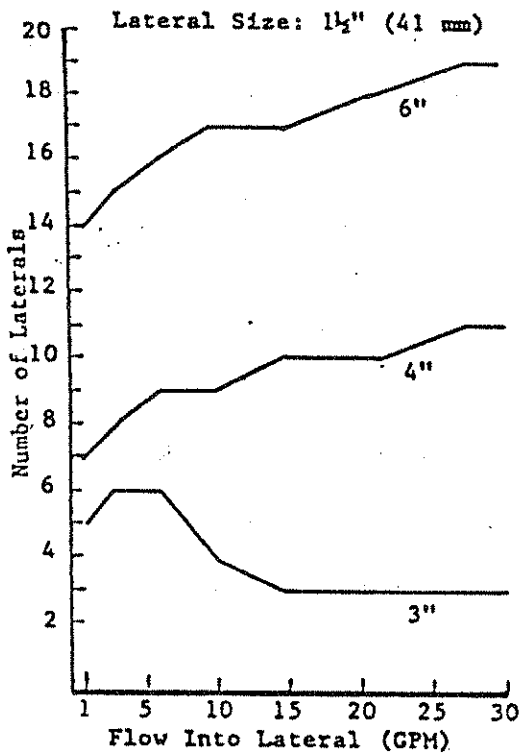
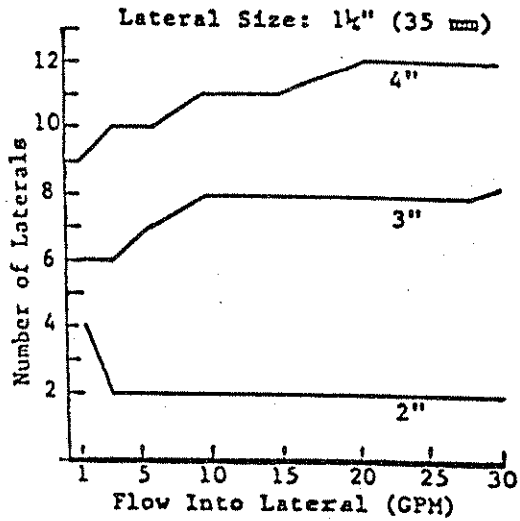
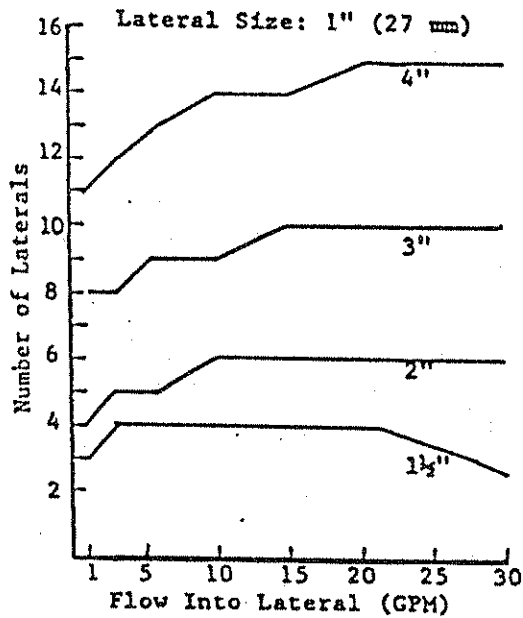
Maximum total lateral length per field	:	3000 linear feet
Maximum number of laterals on slope	:	20
Maximum number of subfields per field	:	3-4
Maximum lateral length	:	(See Appendix IV)
Minimum manifold size	:	(See Appendix III)
Minimum orifice size	:	5/32 inch (domestic systems)
	:	3/16-inch (food service)
Maximum orifice spacing	:	(See Appendix II)
Minimum pressure head	:	2 feet
Maximum pressure head	:	5 feet
Recommended pressure head	:	3 feet (level sites)

APPENDIX II

MAXIMUM RECOMMENDED ORIFICE SPACING
FOR LOW-PRESSURE PIPE DISTRIBUTION SYSTEMS

<u>Soil Group</u>	<u>Soil Textural Class</u>	<u>Maximum Orifice Spacing</u> <u>(feet)</u>
I	Sands	5
II	Coarse Loams	6
III	Fine Loams	8
IV	Clays	10

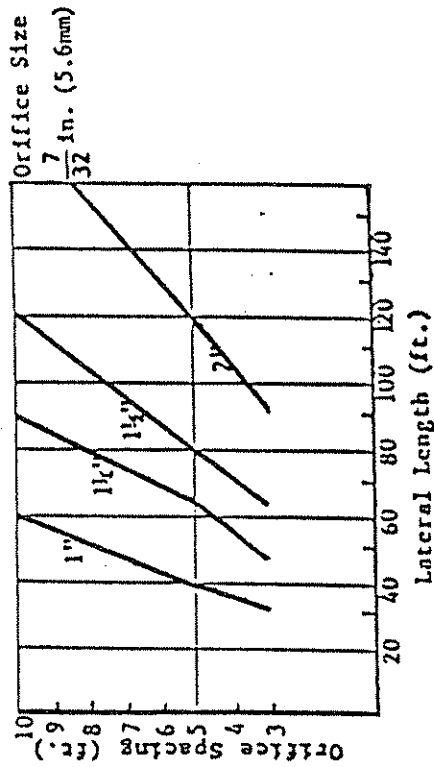
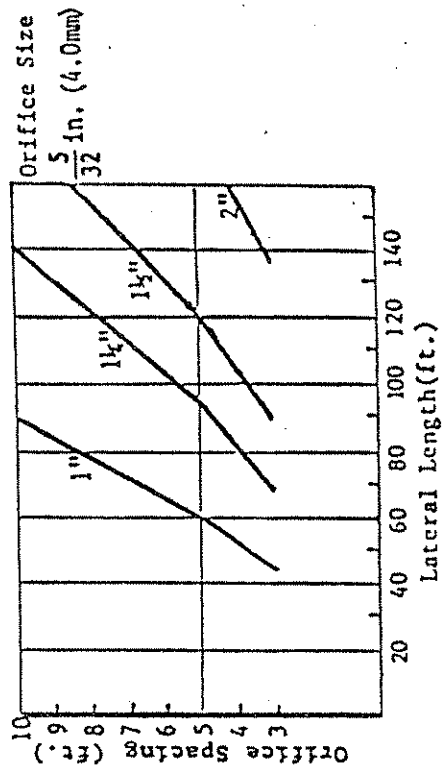
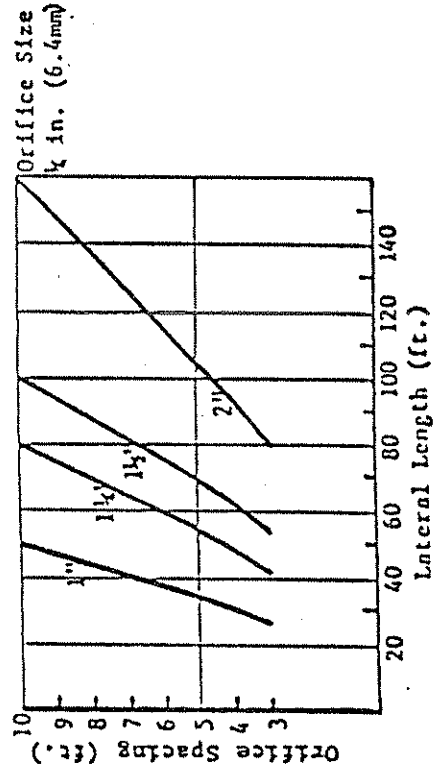
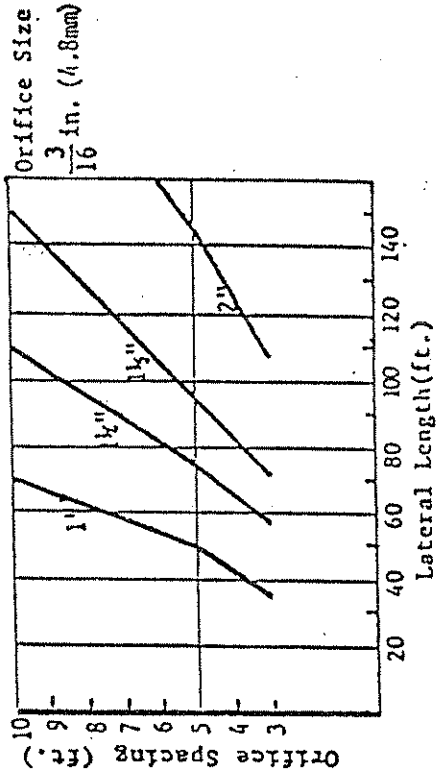
APPENDIX III



App. 3. Maximum Number of Different Sized Laterals For Low-Pressure Pipe Systems With Varying Sizes of Manifolds and Varying Rates of Flow Into Lateral (1 GPM = .0631 l/sec)

From: Berkowitz, S. B. 1984.

APPENDIX IV



App. IV. Maximum Length of Different Sized Laterals For Low-Pressure Pipe Systems With Varying Orifice Sizes and Spacings (1 ft. = .305 m)

From: Berkowitz, S. B. 1984.

APPENDIX V

LOW-PRESSURE PIPE DISTRIBUTION SYSTEM DESIGN PROCEDURE
FOR SLOPING FIELDS

Example--Field No. 4

Equation

N = 19 laterals
L = 140 linear ft. per lateral

Select 1 1/4" laterals with central manifolds

$d_1 = 5/32" = 0.156$ inches
 $S_1 = 5$ feet

$S_{max} = 10$ feet

With central manifold, working lateral length is $140/2=70$ feet
Maximum allowable for size and spacing = 95 feet.

Use 3 subfields beginning with laterals 1, 9, 17. See Fig. 6b.

Use 4-inch manifolds.

V = 50% = 0.50

1. Lay out field and determine number of laterals (N) and lateral lengths (L)
2. Select lateral pipe sizes and manifold location
3. Select initial orifice size (d_1) and initial (minimum) orifice spacing (S_1)
4. Specify maximum orifice spacing (S_{max}) See Appendix II.
5. Check Appendix IV to determine if lateral lengths are acceptable for specified lateral size, initial orifice size, and initial orifice spacing.
6. Identify subfields, based on maximum elevation difference of 3 feet between highest and lowest lateral in the subfield.
7. Determine manifold size for each subfield using Appendix III.
8. Select desired flow variation. (V)

9. Select pressure head in highest lateral (h_1) of each subfield and determine pressure head of each lateral based on relative elevation.
10. Determine flow per orifice in highest lateral using orifice equation.
11. Determine number of orifices in highest lateral (n_1) at the initial orifice spacing.
12. Determine flow in highest lateral (Q_1)
13. Determine desired change in flow (Δ) for each lateral.
14. Proceed to next lateral downslope, lateral i. Determine desired flow (Q'_i) in lateral i.
15. Determine flow per orifice (q_i) in lateral i.
16. Determine number of orifices (n_i) in lateral i. Round off to nearest integer.
17. Determine orifice spacing (S_i) of lateral i. Compare with maximum orifice spacing (S_{max}). If maximum orifice spacing is exceeded, repeat steps 15-17 using next smaller orifice size. If smaller orifice size is not feasible, redesign entire field using either a smaller initial orifice spacing or a larger initial orifice size. Otherwise, proceed to step 18.
- $h_1 = 2.0$ feet. See Figure 6b for remaining pressure heads.
- $q_1 = (11.79)(d_1)^2(h_1)^{0.5} = (11.79)(0.156)^2(2.0)^{0.5} = 0.406$ GPM
- $n_1 = L/S_1 = 140/5 = 28$ orifices
- $Q_1 = q_1 n_1 = (0.406)(28) = 11.36$ gpm
- $\Delta = (V)(Q_1)/N = (11.36)(0.50)/19 = 0.30$
- For lateral number 2
 $Q'_2 = 11.36 - [0.30(2-1)] = 11.06$ gpm
- $q_2 = (11.79)(0.156)^2(2.5)^{0.5} = 0.454$ gpm
- $N_2 = 11.06/0.454 = 24.36$ orifices use 24 orifices
- $S_2 = 140/24 = 5.83$ ft.spacing
- $5.83 < 10.0$
 Proceed to Step 18.

18. Determine actual flow (Q_i) in lateral i.

$$Q_i = (q_i)(n_i)$$

$$Q_2 = (0.454)(24) \\ = 10.89 \text{ gpm}$$

19. Repeat steps 14-18 for each lateral in field.

See figure 6b.

20. Determine flow for entire field (Q_t)

$$Q_t = \sum_{i=1}^{i=n} q_i$$

See figure 6b.

NOTE: If laterals are of unequal lengths, the field must be designed on the basis of unit flow (i.e., flow per linear foot of lateral). Follow the same procedure as above with the following changes:

1. Substitute unit flow of lateral 1 (Q_{u1}) for Q_1 in steps 13 and 14, where $Q_{u1} = Q_1/L_1$
2. Quantity determined in step 14 will then be the desired unit flow (Q'_{ui}) in lateral i. To determine the desired flow in lateral i (Q'_i) multiply desired unit flow by the length of lateral i.

$$Q'_i = (Q'_{ui})(L_i)$$

3. Proceed with step 15, etc.