# DECENTRALIZED REUSE WITH SUBSURFACE DRIP IRRIGATION FIELDS ISSUES AND OPPORTUNITIES

David Venhuizen[1]

**Abstract:** Subsurface drip irrigation (SDI) has experienced increasing use as a wastewater management tool since it was first used for this application in the 1980's. Many address this technology as a "disposal" process, as simply a "better" or more efficient way to make the wastewater "go away". This paper focuses on using this tool to maximize beneficial reuse, using effluent to satisfy the irrigation and fertilization functions. But since the source water is wastewater, this entails review both of how to "best" serve those functions and of how to protect water resources from whatever pollutants remain in the effluent after treatment.

The degree of pretreatment required prior to dispersal is an evaluation based on the public health and environmental considerations that come into play in each situation. However, with SDI, there are also practical operational issues to be considered, most importantly prevention of emitter clogging. Those issues urge the use of pretreatment to produce a highly clarified effluent prior to dispersal. There is a whole school of thought—supplied and serviced by a number of equipment vendors—that it is merited to use SDI systems to disperse septic tank effluent, forcing it through physical filters to clarify it. However, the inelegance and inherent risk of this approach are obvious. It is also questionable strategy to dedicate resources to the expensive physical filtration devices, which leave most of the pathogens and nutrients in the water, instead of a pretreatment process that removes the majority of them. This pretreatment also renders the effluent more suitable as an irrigation resource. Therefore, the discussion in this paper is predicated on the presumption that effluent flowing into SDI systems is highly pretreated, thus highly clarified, water.

## Hydraulic Application Rates for SDI Reuse Systems

In small-scale wastewater systems, rarely is provision made for long-term storage of effluent, rather the amount generated each day is dispersed in fairly short order. Once injected into the soil, the water can only exit via one of two pathways – evapotranspiration (ET) or deep percolation. So if the system generates effluent without regard to variations in climate, the SDI system has to function as a "drainfield" some of the time. This is so without regard to the general climate at the site, as even during times when the ET rate is generally high, there will be rainy periods that fill up the soil moisture storage capacity. Under these conditions, any pollutants remaining in the effluent may percolate to a limiting condition, and thus impact upon public health or environmental values. This is more critical, of course, where there is little soil depth to a limiting condition, which is one condition that urges using SDI, as reviewed below.

Determining the "optimum" design hydraulic application rate (HAR) for a system to obtain significant irrigation benefit, while being mindful of the "drainfield" design issues, entails an analysis of site climate and the plants being irrigated. Such an analysis is presented here for a project in the Texas Hill Country, presuming the "crop" is turf. Since this analysis is for illustrative purposes only, derivation of inputs to this analysis are not detailed here. They are reviewed in a design report for this project, available to interested parties from the author.

[1] Principal, David Venhuizen, P.E., 5803 Gateshead Drive, Austin, Texas 78745, waterguy@ix.netcom.com

(Venhuizen, 1993) In Tables 1 and 2, $ET_o$ is the reference crop ET rate, $ET_{crop}$ is the ET rate for the specified crop, and $P_e$ is effective precipitation—the portion of rainfall that infiltrates into the soil and remains as water available to the crop.

Table 1. Monthly Evapotranspiration and Total Rainfall Data—Example System

| | $ET_o$ | | $ET_{crop}$ | Average Rainfall | |
|---|---|---|---|---|---|
| Month | mm/day | mm/month | mm/month | in./month | mm/month |
| January | 2.2 | 68 | 61 | 1.60 | 41 |
| February | 2.8 | 78 | 70 | 2.49 | 63 |
| March | 3.8 | 118 | 106 | 1.68 | 43 |
| April | 5.2 | 156 | 140 | 3.11 | 79 |
| May | 6.7 | 208 | 187 | 4.19 | 106 |
| June | 7.9 | 237 | 213 | 3.06 | 78 |
| July | 8.2 | 254 | 229 | 1.89 | 48 |
| August | 7.7 | 239 | 215 | 2.24 | 57 |
| September | 6.0 | 180 | 162 | 3.60 | 91 |
| October | 4.1 | 127 | 114 | 3.38 | 86 |
| November | 2.9 | 87 | 78 | 2.20 | 56 |
| December | 2.2 | 68 | 61 | 2.06 | 52 |

Table 2. Irrigation Loading Rates – Example System

| | $ET_{crop}$ | $P_e$ | $ET_{crop} – P_e$ | HAR | |
|---|---|---|---|---|---|
| Month | mm/month | mm/month | mm/month | cm/day | $gal/ft^2/day$ |
| January | 61 | 27 | 34 | 0.11 | 0.027 |
| February | 70 | 42 | 28 | 0.10 | 0.025 |
| March | 106 | 31 | 75 | 0.24 | 0.059 |
| April | 140 | 59 | 81 | 0.27 | 0.066 |
| May | 187 | 85 | 102 | 0.33 | 0.081 |
| June | 213 | 68 | 145 | 0.48 | 0.119 |
| July | 229 | 42 | 187 | 0.60 | 0.149 |
| August | 215 | 51 | 164 | 0.41 | 0.130 |
| September | 162 | 70 | 92 | 0.31 | 0.075 |
| October | 114 | 61 | 53 | 0.17 | 0.042 |
| November | 78 | 38 | 40 | 0.13 | 0.033 |
| December | 61 | 32 | 29 | 0.09 | 0.023 |

These calculations suggest setting the design HAR at about 0.4 cm/day (0.1 $gal/ft^2/day$) for this project. This is considered a compromise between effective reuse to serve irrigation demands and “overloading” the field through the winter, creating greater potential for pollutants to percolate to the limiting condition. Decreasing the HAR further would hold it at or below the average ET demand in more months, but with increasing costs for diminishing returns. Taking into account that some percolation losses would occur no matter how large the field were made, it is not considered cost efficient to employ the HAR which would evapotranspirate the average effluent load throughout the whole year. Also, lowering the HAR would decrease the portion of irrigation demands met by effluent in the peak months. So, the HAR is set at about 0.4 cm/day in this climate, and the SDI field must function as "drainfield" when ET demand is less than that, on either a short-term basis—e.g., rainy days during the summer—or a long-term basis, through periods when ET demand is low.

**Water Savings Potential with SDI**

Loading rates in the range of 0.4 cm/day result in irrigation applications of around 2.5 cm/week (1 inch/week), a little less than the average landscape plant water demands over the growing season in this part of Texas. (Borrelli, et al., 1998) Thus, most of the effluent routed to the SDI field would be effectively utilized to supply irrigation demand through the peak irrigation season, greatly defraying demands during the time when this would have the maximum benefit to the local and regional water economy.

An indication of the potential water savings available from this strategy was provided by an analysis conducted as part of a water conservation study prepared for the Barton Springs/Edwards Aquifer Conservation District. (Venhuizen, 1990) Water records for customers of a small water district were reviewed. Customers with significant differences in winter (December-February) and summer (June-August) usage were taken as an example group who maintained highly irrigated landscapes. Winter usage, presumed to be an estimate of wastewater flow, was deducted from total summer usage in each month during the May-September peak irrigation season. This provided an estimate of how much water these customers would have saved if wastewater system effluent had been used to defray irrigation demands. When these estimates were compared to their actual usage, it indicated that savings of 40% to 70% of total water demand through the peak irrigation season would have been realized. Clearly, the potential water savings from this strategy in this climate are anything but trivial.

**Hydraulic Function of SDI System as a "Drainfield"**

Understanding the hydraulic function of an SDI system as a "drainfield" requires an examination of soil moisture at the micro level, considering the flow out of each emitter. An SDI field is composed of drip hose runs on specified spacings, with emitters on each hose at specified intervals. A typical array has hose runs on 2-foot centers and emitters at 2-foot spacings on each hose, as illustrated in Figure 1. (Note that other spacings are employed to suit the needs of the landscaping being irrigated—e.g., closer hose and emitter spacings are used for turf if a high quality grass cover, free of "striping", is desired.) Therefore, on average, the water issuing from each emitter would "spread"—drawn by matric potential, the "suction" force created by capillary action of the soil pore spaces—to a little more than one foot from each emitter before the entire surface would become wetted, after which further emissions of water would continue to increase soil moisture level, eventually filling the voids to field capacity, the point at which capillary action can no longer counteract the force of gravity, and water would begin to drain downward.

However, if the soil were already at high moisture content—either from a recent rainfall or because ET rate had recently been lower than the rate of effluent application—then moisture level would be at, or would be driven above, field capacity around the emitter before the water could be spread to any distance away from it. When this occurs, water coming out of the emitter would percolate downward; that is, the SDI system would function as a "drainfield".

This dictates that the *instantaneous* emitter flow rate, expressed as flow out of the emitter over some prescribed radius around it, needs to be lower than the saturated hydraulic conductivity, or permeability, of the receiving soil. Note that this is a characteristic of the drip emitter used, unrelated to the overall field HAR. The situation is illustrated in Figure 2. If the soil is very wet—above field capacity—when the emitter begins to flow, the radius the water might spread before it begins to percolate downward under the force of gravity would be small.

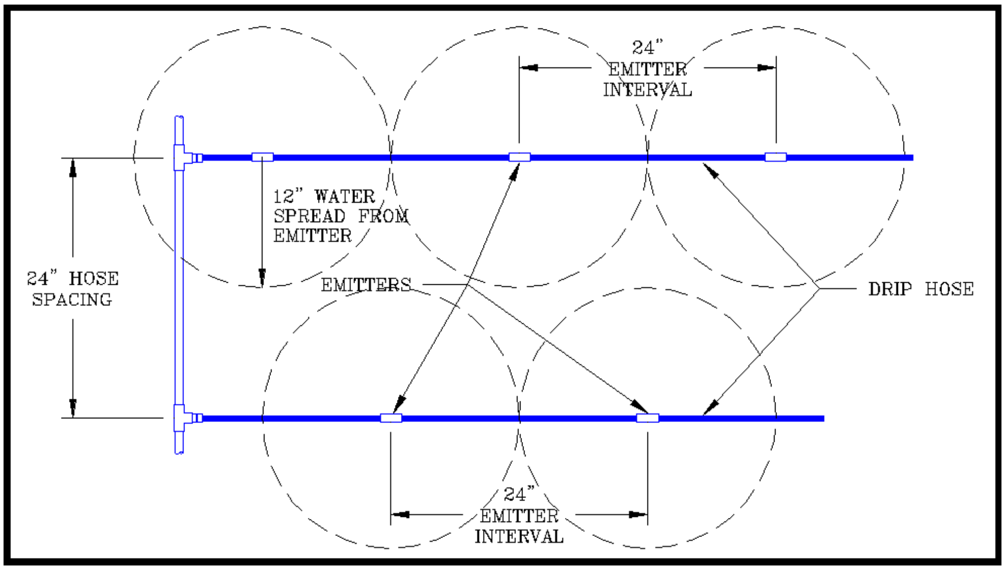


**Fig. 1. Typical SDI Hose and Emitter Layout**

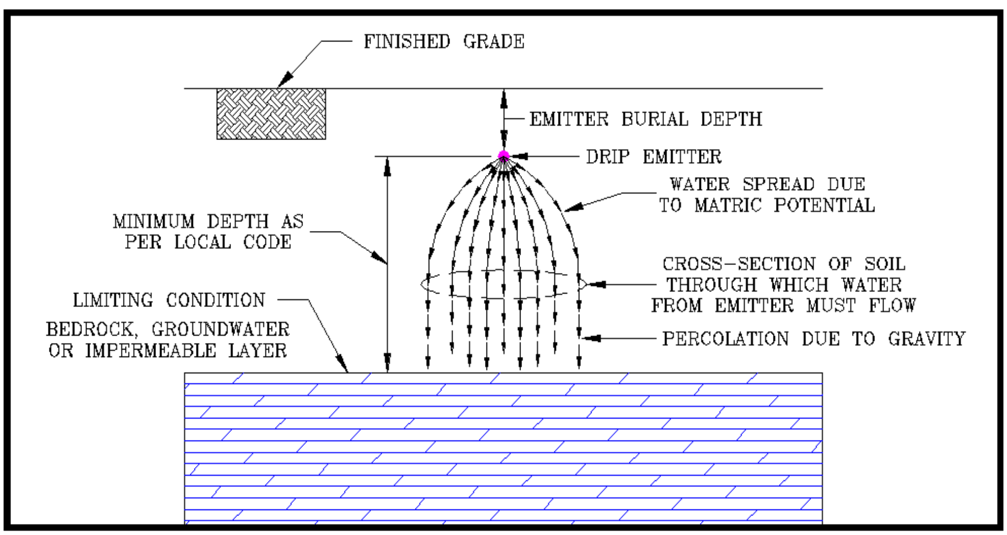


**Fig. 2. Percolation of Emitter Flow Under "Wet Soil" Conditions**

As an example, consider a pressure-compensating emitter with a flow rate of 0.53 gallons/hour (gph). This translates to a flow rate of 0.53 gal/hr x 1 $ft^3$/7.48 gal = 0.071 $ft^3$/hr. Presume that under high antecedent moisture conditions the radius around the emitter that water would spread before it all percolated downward is 6 inches. If so, then the area through which this flow must pass would be $0.5^2$ x pi = 0.79 $ft^2$. This would dictate that required permeability of the soil be at least 0.071 $ft^3$/hr/0.79 $ft^2$ = 0.09 ft/hr = 1.08 in/hr. This is in the 0.6 – 2.0 range listed in SCS soil surveys for loams, silt loams, and the like.

If the soil were "tighter" than this and the water could not percolate downward at that rate (or the soil were *so* wet that water coming out of the emitter could not spread even 6 inches, thus requiring that the permeability be even higher), then water may "pool" around the emitters under this "wet soil" condition. This "pooling" would create a hydraulic head that would cause the water to spread further, and at some point a balance between emitter flow rate and soil transmission rate would be established.

If, however, the effluent application time were "long", then some of the effluent may be forced to the surface before it could percolate. This urges the use of short dosing times, breaking the total daily flow into multiple doses if required. For the situation where each emitter "covers" 4 $ft^2$ (the "2 X 2" spacing noted above) and the HAR is 0.1 gal/$ft^2$/day, total daily flow out of the emitter would be 0.4 gallons. At an emitter flow rate of 0.53 gph, the dosing time would be 0.4/0.53 = 0.75 hr, or 45 minutes. By splitting this up into 3 doses per day, the run time would be reduced to 15 minutes, minimizing the amount of water that must be "held" in the soil, waiting for it to percolate away, and thus minimizing the potential for any of the effluent to surface. Hassan, et al. (2005) confirm that this is beneficial.

In a "well-drained" soil, such a "wet soil" condition would likely persist only during and shortly after a significant rainfall event. An analysis was done for a project in Austin, Texas, to estimate the percent of the time this condition might exist. (Venhuizen, 2002) Rainfall records were reviewed for an 8-year period, 1987-1994. While this period contained some "dry" years, the overall average rainfall for this period was slightly above the long-term average. The USDA definition of antecedent moisture condition (AMC) III was used as the definition of "high" antecedent moisture – defined as at least 2.1 inches of rainfall over the previous 5 days. (USDA, 1972) Adding the effluent application—at 0.1 gal/$ft^2$/day = 0.16 in/day, so it is noted that effluent applications by themselves would never drive moisture condition to AMC III, as 5 days flow would total to only 0.8 inch—to the rainfalls and using that as the AMC criterion, it was observed that AMC III would have existed on a total of 328 days over this 8-year (2,922-day) period, about 11% of the time. However, any rainfall at all occurred on only 101 of these days, or about 3.5% of the time. This then is an estimate of the *maximum* amount of the time that effluent application might induce surfacing of effluent-derived water.

Any hazard due to this condition would be vanishingly small. First, the run time each day would be a small fraction of the total time – 0.75/24 = 3.1% of the day in the example above. Second, when there is that much water already in the soil, the effluent addition would be a fairly minor fraction of the total soil water. Third, as this condition would occur for all but very "heavy" soils only during and shortly after a significant rainfall event, the likelihood of human exposure to any surfacing effluent-derived water is very low – people are highly unlikely to be rolling around in, or even walking over, the grass when the ground is *that* wet.

The preceding discussion was about what happens *while* the SDI system is being dosed. As noted, the time that flow issues from the emitter would be a small fraction of the day. If the water could not percolate at the rate applied, it would "pool" as noted previously and drain at the available rate over time. Note that the overall field average permeability required to accommodate the design HAR is 0.1 gal/ft$^2$/day X 1ft$^3$/7.48 gal = 0.134 ft/day = 0.00056 ft/hr = 0.0067 in/hr. If the instantaneous application rate were 1.08 in/hr, as estimated above for a "wet soil" condition, that implies the "effective application time" could be 1.08/0.0067 = 162 hours. There being only 24 hours in a day, clearly water could not be applied fast enough by the emitter to require that high of a permeability for anything but a minor fraction of the whole day. This confirms that even in soils with significantly lower permeability, the water *would* percolate – the only question is how much "pooling" would occur while the emitter is flowing, and how often these conditions would occur, given climatic conditions at the site.

**Treatment Function in SDI Systems**

An SDI system disperses effluent into the soil in a manner that allows whatever soil resources that are available to remove and assimilate pollutants as efficiently as practical. A review of the assimilation and elimination mechanisms operating in the soil/plant/water system shows that, for all the pollutants of concern, three factors can be controlled to make these mechanisms more effective (Venhuizen, 1995):

- Shallow dispersal into the biologically active soil horizon (the root zone);
- Low areal loading rates (HAR's), to reduce flow rate through the soil pores;
- Uniform distribution over the field area, with a dose/rest loading cycle, limiting the amount of water loaded per dose to minimize the degree of saturation.

SDI technology practically maximizes all these factors. As noted, once effluent is injected into the soil, it can only exit by one of two pathways—deep percolation or evapotranspiration. Pollution potential would be minimized by maximizing the ET losses at the expense of deep percolation losses. This would limit the movement of pollutants through the soil to a limiting condition (groundwater or bedrock). Even if much of the water eventually does percolate—which, as reviewed previously, it will during portions of the year in *any* climate—the pollutants would be held in the root zone longer, providing greater opportunity for the assimilation and elimination mechanisms to work on them. Evapotranspiration is itself enhanced by maximizing the three factors listed above.

When the aim is to maximize irrigation efficiency, drip emitters are installed well up in the root zone, typically only a few inches deep into the soil. They are installed directly into the soil, requiring no gravel envelope around them to receive and hold water coming out of them before it can be absorbed into the soil, because drip emitters flow at very low rates, typically less than 3.8 liters/hour (1 gph). Emitter spacing is typically quite close—as reviewed above, 61 cm (2 foot) spacing is typical. These factors provide a very slow, controlled, and uniform wetting of the soil throughout the root zone over the entire field area.

Drip hose is fairly inexpensive and being shallowly placed is relatively cost efficient to install, so increasing field area to provide a lower HAR—at irrigation rates—can be accommodated fairly cost efficiently. As noted, the system should be designed to deliver the total daily flow in small doses. This combination of small dose volumes and a low HAR—requiring a small daily flow out of each emitter—works together to minimize the degree of saturation imparted by each dose, thus minimizing the potential for deep percolation losses.

Evapotranspiration potential will be greater in hotter and drier climates, of course, which is why demand for irrigation water is greater in those climates. However, even in climates where significant ET losses do not occur through much of the year, these same design principles still result in the water being held in the root zone longer before percolating. In colder climates, where ET potential is limited to the growing season, this design would still limit annual mass loadings of pollutants by taking advantage of whatever ET losses do occur to minimize total deep percolation losses over the year. The design factors noted above would maximize soil treatment efficiency the rest of the time.

Of particular concern in some watersheds are nitrogen inputs. Some nitrogen in effluent routed to an irrigation system would be a fertilizer, a beneficial component rather than a pollutant. Any excess must be assimilated or eliminated in the soil, or it will percolate into environmental waters. Venhuizen (1995) reviewed the assimilation/elimination mechanisms and presented an analysis indicating that, in the climate of Washington Island, Wisconsin, effluent total nitrogen concentration should be reduced to about 20 mg/L in order to preclude leaching into a dolomite aquifer at concentrations sometimes exceeding 10 mg/L. In climates where ET is higher, and especially where there is significant ET demand year-round, significantly greater assimilation and elimination would be expected.

Almost all of the nitrogen in the effluent would transform to nitrate in the soil under all but highly saturated conditions—and as noted, given a "suitable" HAR, moisture level around the emitters would be below field capacity most of the time throughout the year. Once in the nitrate form, the nitrogen can only exit the root zone via one of three pathways – plant uptake, in-soil denitrification, or deep percolation. As noted, the SDI system minimizes percolation losses by design. In any case, with the effluent injected into the root zone, the opportunities are enhanced for plant uptake and for denitrification in anaerobic micro-sites—which are present even in well-drained, near-surface soils. (Venhuizen, 1995)

For all other pollutants, most importantly pathogens, it has been demonstrated that highly pretreated effluent—intermittent sand filter effluent in this instance—is "renovated" by flow through as little as 6 inches of soil, even when it is bulk-loaded onto a column of mound sand, a very coarse soil. (Stanbridge, et al., undated) For all the reasons just reviewed, a high degree of soil treatment is provided with greater assurance when the effluent is applied through an SDI system. The conclusion is that SDI, dispersing highly pretreated effluent, can be employed in marginal soil resources with minimal risk of hazards to public health or environmental values.

**SDI Installation and Maintenance**

Due to experiences with SDI systems that disperse septic tank effluent and effluent from pretreatment systems prone to periodic upsets, there is a general expectation that SDI systems "need" to include a complex prefiltration and control system that provides very frequent flushing of the drip lines. However, when preceded by a pretreatment system that will consistently and reliably produce a high quality, low turbidity effluent—e.g., a recirculating biofilter—a much less complex design employing an automatic flush valve, as illustrated in Figure 3, can be employed.

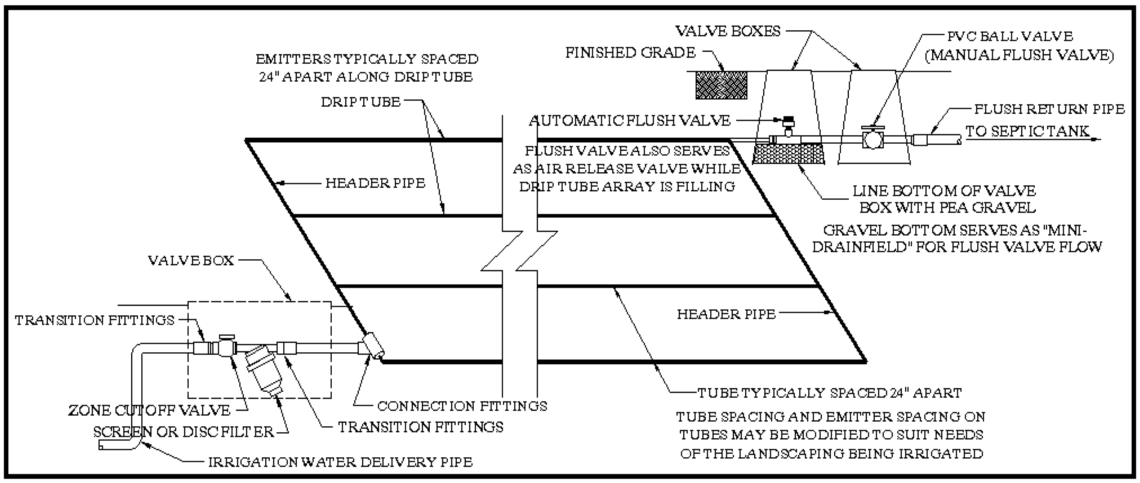


**Fig. 3. Typical Installation of SDI System Receiving High Quality Effluent**

With high quality effluent flowing to the drip irrigation hose, a simple screen or disc strainer suffices for prefiltration. The main function of this strainer is to intercept secondary growth solids (slimes that may grow on and slough off of the delivery pipe walls) and to serve as a "fail-safe" device in case maintenance of the treatment unit is neglected or secondary regrowth solids build up in the effluent tank. The field is generally designed with a number of zones, as dictated by the landscaping plan. A cutoff valve at each hose entry is suggested so that a zone can be isolated for repairs while the rest of the field remains in service.

A small flush flow is provided each time the drip hose array is pressurized by installing an automatic flush valve at the downstream end of the array. This valve remains open, serving as an air release valve, while the drip hose is filling. Just before the hose array completely fills up and fully pressurizes, a small squirt of water issues from this valve and then it closes. This allows any debris in the pipes to be flushed to the end of the line and out of this flush valve instead of being trapped in the hose and forced out of emitters.

To provide maintenance flushing of the drip hose, typically required only at very long intervals, a manual flush valve is also installed at the end of the hose array. This is opened when the zone is pressurized so that a high volume flush of the entire array is provided. This flush water is routed back to an appropriate tank in the pretreatment system so that any solids washed out of drip hose will be retained in the pretreatment system.

The strainers or filters at the drip hose entries must be observed, and cleaned if required, at fairly frequent intervals—e.g., every 3 months, but this may vary with the dependability of the treatment system and operating experience with that system. The automatic flush valves, which have proven to be very reliable, should also be checked during each maintenance interval. Experience has shown that the protection provided by the entry strainer and automatic flush valve is effective at preventing significant emitter clogging, even when the pretreatment system experienced problems resulting in poor quality effluent.

To assure that any emitter clogging which does occur is addressed in a timely manner, arrangements must be made to monitor the degree of emitter clogging over time. This would be done by either measuring the pump run time for a dose of a given volume or by measuring the instantaneous flow rate into a zone of the drip hose array. A reading that indicates degradation in flow rate below that observed when the system was installed would signal the onset of significant emitter clogging. This would trigger maintenance procedures.

The flow rate out of an emitter may degrade due to biological clogging or due to chemical clogging. The latter occurs when water remaining in the emitter labyrinth between doses evaporates and leaves behind the chemicals in it that are measured as total dissolved solids (TDS). Chemical clogging may be a significant liability only for waters with "high" TDS—to which wastewater may contribute, but this is mainly determined by the quality of the source water—and when conditions are conducive to the water in the emitter evaporating between doses. The latter is a problem in applications like vineyards, where the drip hose is exposed to full sun, but is rather unlikely in buried drip lines that are dosed very frequently. In an SDI system designed and operated as detailed above, therefore, chemical clogging is not likely to occur, so maintenance activities would focus first upon biological clogging.

This is addressed by dosing a strong chlorine solution into the drip hose array, assuring a sufficient volume of solution is injected to completely fill the volume of drip hose in the zone being serviced. After allowing the emitters to "soak" in this solution, the drip hose is flushed, then the flow test is repeated. If the flow test does not indicate that emitter clogging has been remediated, this procedure may be repeated using an acid solution to address chemical clogging.

**Regulatory Issues with SDI**

When dispersing high quality effluent in an SDI system, both the level of pretreatment provided and use of SDI as the dispersal process dictate that many restrictions created for septic tank effluent being dispersed in a drainfield become meaningless, or at least of far lesser concern. These include various setback and standoff requirements, and the very nature of "failure" and need for a redundant dispersal field area.

As noted previously, only a small standoff from a limiting condition is required with SDI dispersal of high quality effluent. However, many jurisdictions apply the standoff requirements for septic tank effluent drainfields to SDI. The most "progressive" rules appear to be in Texas, where a 12-inch standoff to groundwater and a 6-inch standoff to other limiting conditions are required. Based on the work of Standbridge, et al. (undated) and the factors reviewed by

Venhuizen (1995), these are quite sufficient to protect public health and environmental values, subject of course to appropriate nitrogen control in watersheds where that is of concern. This conclusion has been more recently corroborated by Hassan, et al. (2005) using in situ soil columns which were loaded at rates of 1.65 cm/day (0.4 gal/$ft^2$/day) and above.

However, these same rules also require that a drip emitter may be installed no closer than 10 feet from a slope break where a seep might occur. Setback regulations like this are essentially irrelevant to SDI systems receiving high quality effluent. Matric potential is the only force that can draw water laterally any distance from the emitter, but this would be highly unsaturated flow, and that would *never* produce a seep. There is no force that would cause water coming out of a drip emitter to be driven even one foot sideways, as saturated flow that could produce a seep, before it could traverse at least a 12-inch vertical depth through the soil. If the water is good to go into the groundwater after traversing the 12-inch vertical depth, what possible hazard could it pose even if it did surface in a seep at the edge of the field? The ideology driving such a rule, however, is that the slightest possibility of any seep containing *any* effluent-derived water is a hazard. This ideology is of course rooted in concerns about conventional dispersal fields receiving septic tank effluent. Engineering analysis of the actual situation is simply not considered, resulting in the application of these essentially irrelevant rules to SDI systems.

Another issue is the nature of how a drip irrigation field might "fail" and requirements for redundant field areas. As reviewed previously, there is a very small potential for effluent to be forced to the surface because the field is hydraulically overloaded. Therefore, concerns about "failure" focus upon the hydraulic function of the drip dispersal system, which essentially comes down to control and remediation of drip emitter clogging. Routing poorly treated water to the field might eventually result in the soil around the emitters also becoming "clogged", but that is highly unlikely to occur without emitter clogging having become problematic first. This simply highlights that the very first line of defense against any sort of field "failure" is to assure that the pretreatment system consistently and reliably produces a highly clarified effluent. Beyond that, controlling and remediating emitter clogging is a matter of ensuring a proper O&M protocol, and the regulatory system only needs to require the appropriate oversight to monitor, and respond if needed, to emitter clogging.

While those procedures are expected to maintain the drip emitters in acceptable operating condition for the life of the system, the ultimate fallback in case clogging becomes so severe that it cannot be remediated (which is likely to happen only if O&M procedures are neglected) is to replace the drip hose. This can be done by removing old hose and placing new hose on the same alignment, or by laying a new line of hose in the space between the original hoses. Since the "failure" is in the drip emitters, which are replaced, rather than in the soil, there is no need to provide a replacement area in another location. This is another regulatory issue, as some jurisdictions still require a complete redundant field area to be available. Hose replacement can be executed a zone at a time—or even a line of hose at a time if new hose is laid between the old hose lines—so the overall system does not have to be taken out of service to effect such a repair.

In some jurisdictions, rules for drip irrigation are written around a specific commercial "package" and the specification of equipment presupposes that the effluent routed to the drip irrigation field would be poorly treated, containing significant levels of solids. So all systems using drip irrigation, regardless of the quality and reliability of the pretreatment system employed, have to use a system that may be needlessly costly, needlessly complex—and thus needlessly failure-prone—and needlessly expensive to operate and maintain. The end result of these rules is that the use of SDI—the method that practically maximizes those three principles of optimal soil treatment noted previously—is retarded, almost certainly to the overall detriment of public health and environmental values.

**Examples of Installed SDI Systems**

As drip hose is made of flexible polyethylene, drip lines can be laid out in any number of configurations. This flexibility allows fields to fill any available landscaped area, to serve the irrigation needs of a variety of plant types. A few examples of field plans and installed SDI systems are shown in Figures 4-10.

Figure 4 shows the layout for a system serving a very large home and guest house, with a design flow rate of 2,500 L/day (660 gpd). The drip field covers an area of approximately 615 sq. m. (6,620 sq. ft.), resulting in a design HAR of 0.41 cm/day. The large area of drip field on the left side of the figure is a front yard covered with turf. This area is shown in the photo in Figure 5. A hose spacing of 18 inches and an emitter interval of 12 inches along each hose are used in this area to provide very uniform irrigation of the turf to avoid a "striping" pattern in the grass. The more irregular spaces wrapping around the back of the house are landscaped beds. This area is shown in the photo in Figure 6. This illustrates that the SDI system can be designed to accommodate a wide range of irrigation needs.

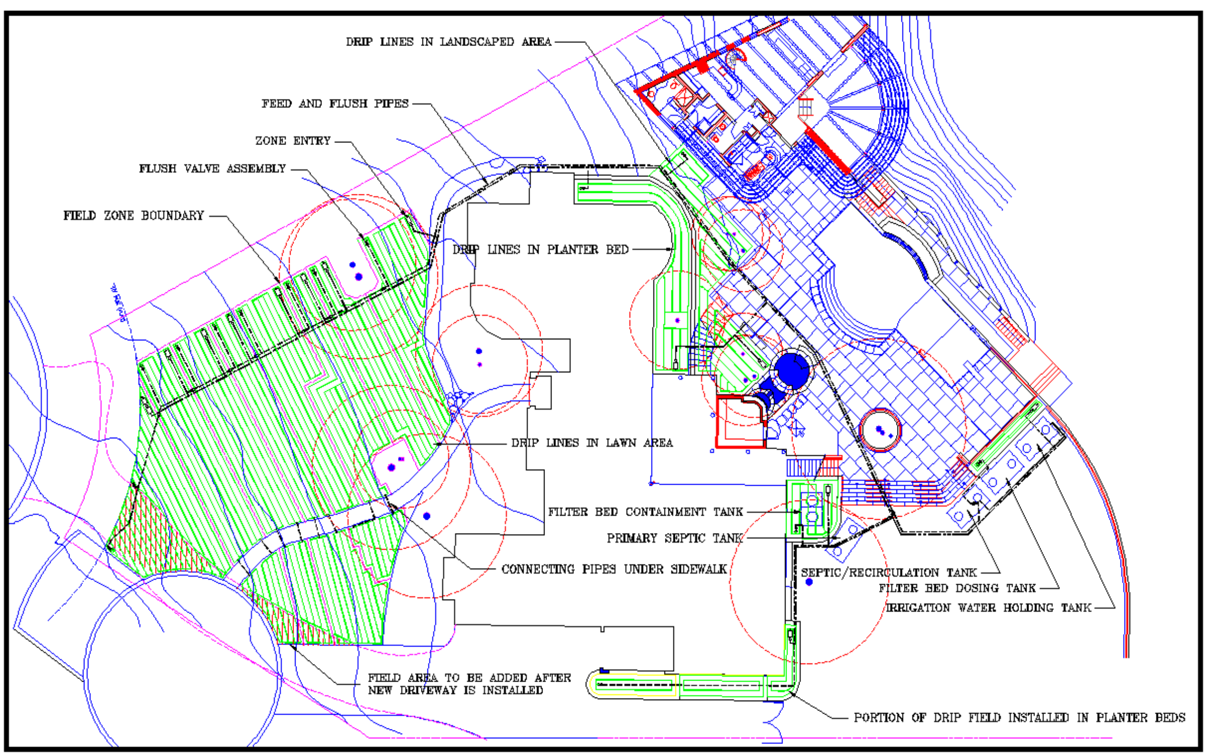


**Fig. 4. Example SDI System Layout Plan**

**Fig. 5. Installed SDI System in Turf Area**

**Fig. 6. Installed SDI in Landscape Planter Beds**

Figure 7 shows pictures of a part of the SDI field for another project, located in the driveway island. On the left is a picture taken during installation of the drip lines, showing the drip hose laid in trenches hoed out of fill material. Native soils on this site are thin and rocky, so imported fill soil was needed to assure at least 12 inches of soil between the drip lines and bedrock. On the right is a picture showing the same area after it had been restored with ground cover. Note how the drip hose works around the trees and tree wells. The field zone entry is contained in the valve box visible in the "after" picture.

**Fig. 7. SDI Field During Installation and After Completion**

Shown below is the SDI field layout plan at another house, this one with a design flow rate of 1,800 L/day (480 gpd) and a total field area in 5 zones—to serve a variety of landscaping—of 457 sq. m. (4,900 sq. ft.), resulting in a design HAR of 0.40 cm/day. Pictures of a portion of the field before and after installation and landscaping are shown in Figure 9, showing the severity of site conditions that are being routinely addressed with high quality pretreatment and SDI.

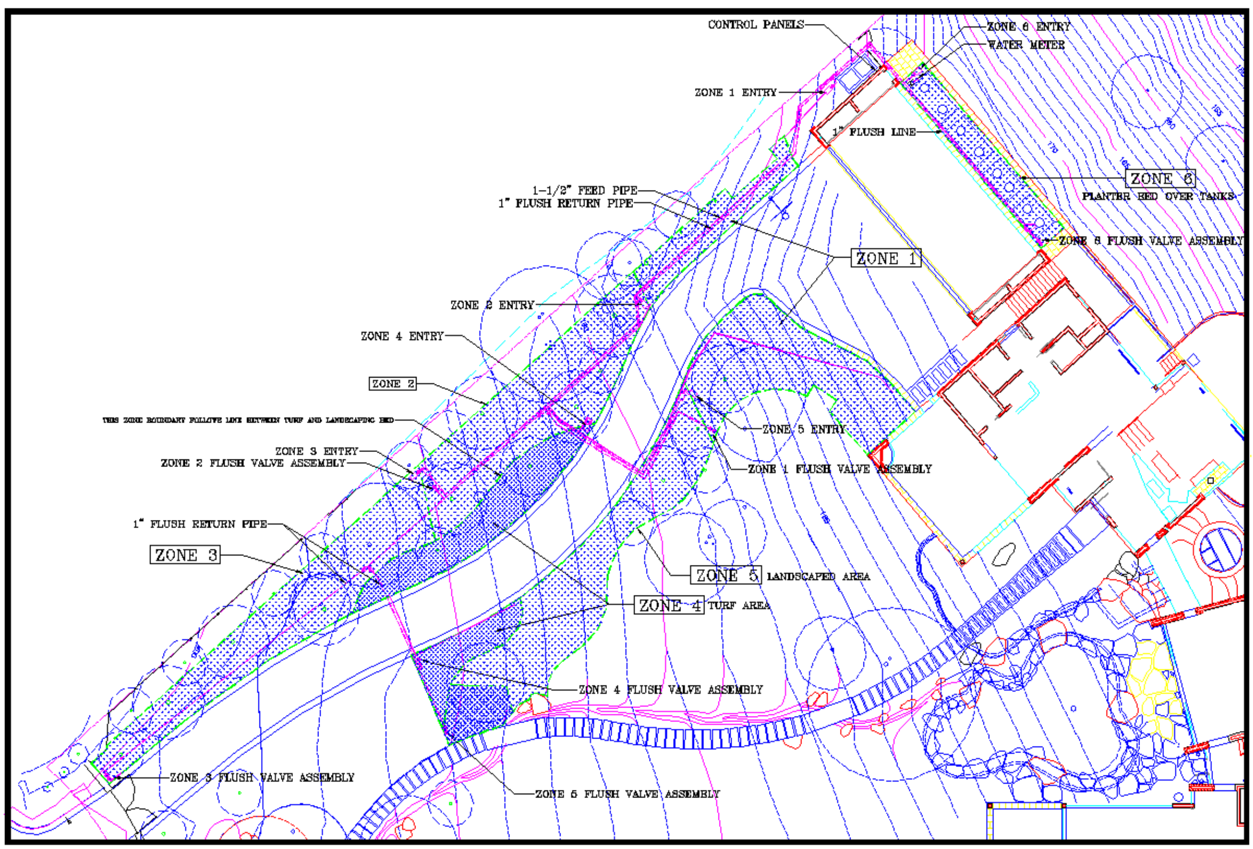


**Fig. 8. Example SDI Field Plan**

**Fig. 9. Field Area Before and After Installation and Landscaping**

Figure 10 shows the field area for a larger-scale system at an interstate highway rest stop. The total field area of approximately 5,100 sq. m. (55,000 sq. ft.) covers all the landscaping, including the shrubs around the sign, up to the buildings in the background. Wastewater generated in the restrooms is treated and dispersed in this field to defray irrigation demands. This illustrates that SDI can be applied in systems of any scale in any variety of circumstances.


**Fig. 10. Large-Scale SDI Field at Highway Rest Stop**

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