# RULE DEVELOPMENT COMMITTEE ISSUE RESEARCH REPORT
## - FAILING SYSTEMS -

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**Research Requested by:** ☐ RDC ☒ TRC ☐ Other:

**Issue Subject:**
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**Specific WAC Section Reference, if WAC related:** **Section WAC 246-272-20501**

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**Topic & Issues:**

**Failing Systems**

QUESTIONS ASKED BY THE TRC
- Combine with Technical Issue #20 (Table VI Repairs)
- Does the presence of dye alone indicate presence of a failure or do we also need a positive bacteriological test result?
- Are cesspools failures?
- Are seepage pits failures?
- Should a sampling protocol for a repair of a failing system be placed in rule?
- Table VI only goes up to 100 feet for horizontal setbacks. Should we have something for situations with horizontal setbacks greater than 100 feet but with little or no vertical separation?

ADDITIONAL QUESTIONS THAT NEED ANSWERS
- Why is failure an issue for this rule development – what is wrong with the failure/repair sections of the current rule?
- What does the scientific literature say about this subject?
- Based on the literature review, what, if any changes should be made to the current rule?

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**Summary:**

Failures of on-site sewage treatment and disposal systems are a well-noted presence in the on-site sewage industry. When a failure produces poorly treated sewage on the surface of the ground, backing up into houses, or into surface water bodies, the public's health and environmental protection are placed at risk. In addition, the reputation and the potential for on-site technology as a viable, long-term solution for handling sewage is tarnished.

This report reviews the scientific literature for causes, rates, repair and prevention of failure. The topics of causes and prevention are two ends of the same issue. A list of literature findings appears in the body of the report. Specific failure and repair issues raised by the TRC and DOH staff are addressed, such as: Why is failure an issue for this round of rule development? Should Table VI be expanded beyond 100 feet of horizontal separation? Does the presence of dye alone indicate failure? Are cesspools and seepage pits failures? Should a sampling protocol for repairs be placed in rule?.

Cost information is not provided for this topic, as the cost of investigating and repairing failures is widely variable depending on the specific circumstance. Conclusions from the literature research on these topics are provided. For example, early investigators found the same causes of failures as are found today. To provide long-term on-site sewage service, they proposed, among other things, use of multiple compartment septic tanks, screened baffles, adequate size of absorption areas and designed-in dosing and resting of the absorption areas.

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## - FAILING SYSTEMS -

KEYWORDS:

Failure, repair, surfacing sewage

## Introduction:

In Washington state, a failure of an on-site sewage system is defined in two places:
1) The on-site rule (WAC246-272-01001) which says:

> **"Failure"** means a condition of an on-site sewage system that threatens the public health by inadequately treating sewage or by creating a potential for direct or indirect contact between sewage and the public. Examples of failure include:
>
> (a)Sewage on the surface of the ground;
> (b)Sewage backing up into a structure caused by slow soil absorption of septic tank effluent;
> (c)Sewage leaking from a septic tank, pump chamber, holding tank, or collection system;
> (d)Cesspools or seepage pits where evidence of ground water or surface water quality degradation exists; or
> (e)Inadequately treated effluent contaminating ground water or surface water.
> (f)Noncompliance with standards stipulated on the permit.

2) RCW 70.118.020, which defines failure somewhat differently:

> (3) "Failure" means: (a) Effluent has been discharged on the surface of the ground prior to approved treatment; or (b) effluent has percolated to the surface of the ground; or (c) effluent has contaminated or threatens to contaminate a ground water supply.

The on-site rules also contain a section on repair of failures. This section gives requirements for when a failure to an on-site sewage system occurs, and details when a system other than a fully conforming system may be installed. In the section dealing with systems not fully conforming to the requirements of the WAC, Table VI is used when the disposal component of the repair system cannot meet both the vertical separation requirements for a conforming system and the horizontal separation requirements to a surface water, well or spring that is not used for a public drinking water source.

In terms of failure, the scientific literature can be grouped into the following topic areas: failure rates, causes of failure, groundwater contamination, repairs and remedies, and prevention. Scientific literature is scarce on the other topics and questions within this technical issue. The TRC has developed a set of questions relative to this issue that will form the structure of this report. They are listed in the Topic & Issues Section of the report.

The purpose of this review is to synthesize the scientific literature available on the topic of failing on-site sewage systems. Technical Issue #20 is a subset question for this general topic and will be addressed here also. The findings will assist the TRC in making appropriate recommendations to the Rule Development Committee about failures. Twenty-five publications were collected and reviewed. These publications included peer-reviewed journal articles, other journal articles, conference proceedings and some miscellaneous sources. Conference proceedings and commissioned engineering reports comprise the largest group of publications. Even though they are not typically peer-reviewed, they provide useful information and many of the authors are recognized scientific experts in the field of on-site sewage.

This report will address the questions listed in an earlier section of this document and describe the scientific literature findings for each of these questions.

## Body:

BACKGROUND ON FAILURE CAUSES, RATES, REPAIR AND PREVENTION

**Causes**

Numerous studies have been conducted on the causes of on-site sewage system failure. McGauhey and Winneberger (1964a, 1964b, 1965) identify several basic conditions that must be met if a septic system is to function in a satisfactory manner: the soil must be sufficiently permeable, the soil must be appraised accurately for its percolative capacity, the system must be adequately sized, especially with respect to the relative importance of the sidewall and bottom areas, adequate consideration must be given to the organic fraction of the effluent, appropriate construction practices must be used, and intermittent dosing and draining of the drainfield is necessary for maintaining optimal infiltration rates. These researchers observe that the infiltration rates are a function of the clogging material, whereas the percolation rates are a function of the soil characteristics. Thus, the percolation test may give assurance that a particular soil can dispose of water, yet gives little evidence of its ability to accept wastewater.

Confirmation of these concepts was established in reports reviewed for Technical Issue 4, Pathway 1 (Drainfield reductions receiving highly pretreated effluent), especially in terms of the clogging zone controlling the infiltrative rate. Barnett (1982), from a study of on-site system failures in Tennessee, reported the top two causes of failure were undersized absorption areas and unfavorable soil capacity. Dewalle (1981), reporting on data from Washington state, lists unsuitable soil conditions and high water tables as the most frequent causes of failure. In a study of large systems in Washington state, Plews and DeWalle (1984) concluded that higher failure rates were associated with clay and clay loam soils, that failures are more likely to occur in the first 5 years of system life, that pretreatment with septic tanks is associated with fewer failures than pretreatment with extended aeration, that there is a higher incidence of failure with serial distribution vs. standard distribution, and that there is a higher incidence of failure associated with systems with design flows >6,000 gpd.

In a recent study (Sherman et al.1998) performed 3 independent analyses of repair data from Florida. They determined that failures within the first 5 years of life have a high proportion of hydraulic overloads and failures after 15 or more years of service are highly correlated with root clogging. Moreau (1981) reports on a procedure used in Maine, which provides a means of defining the cause or causes of system failure. However, he does not report any findings on the major causes of failure. Adams et al. (1998) describe a Failure Analysis Chart for Troubleshooting Septic Failures. While working through the flowchart, the user gathers information from the homeowner as well as observations from the field and identifies the likely causes of system failure by accumulating what they call “red flags”. These red flags are potential contribution causes of the failure. These authors likewise do not report any findings on the major causes of failure, but offer a systematic method for failure analysis. In a questionnaire survey of local and state agencies, Angoli (1998) reports that health agencies attributed the most common reason for failures to: age, unsuitable soils, lack of maintenance and pumping, high groundwater table and excessive water use.

**Rates of Failure**

Saxton and Zeneski (1979) developed a computer model to predict the number and distribution of failures. It can predict failures for 20 years into the future. Keys et al. report on a mass-balance model used to predict the life of gravel wastewater infiltration systems in a sand soil. Using multiple replicates of trenches they gathered ponding depth data vs. time, and long term falling head infiltration rates. Using these data in their model, they predicted these systems to have a life span of 7 years when loaded at of 4.1 cm/day (1.0 gpd/ft$^2$) and a life span of 11 years when loaded at 1.6 cm/day (0.39 gpd/ft$^2$). These loadings were based on bottom area of the trench. These numbers appear to be a very conservative estimate of system longevity when compared to the empirical findings described by other authors in this literature review.

Hill and Frink (1980) analyzed data from a county in Connecticut as a follow-up to a study of system longevity done in 1973. Major changes to the rules were established in 1961 and again in 1972. Their data show a 9-year increase in longevity in the population of all systems from 1973 to 1978 and show a decrease in the average rate of premature failures from 6.0 to 2.9%. These changes are attributed to increases in the size of systems required in 1961 and a requirement in 1972 for spring [seasonal high water table] percolation testing and deep pit observation.

In their studies of repair permit data in Florida, Sherman et al. (1998), analyzed 3 independent data sets. Their analysis revealed the average age at failure was between 18.01 years and 18.53 years. They also point out that this should not be construed as a measure of life expectancy, as only failure data were studied, not survival data. The mean age at failure in one of the jurisdictions increased by 10 years (to age 28.44 years) after a county ordinance was enacted in 1983. This ordinance was sweeping in the changes made in on-site sewage requirements. Some of the new requirements were: required engineered design of all new systems, limited daily design flows to <2000 gpd, septic tanks to have multiple compartments, 10 to 30% larger drainfields than required by the state, mound sands to meet a gradation specification, vertical separation increased from 24” to 36”, and minimum lot sizes increased to ½ acre with central water supply and 1 acre for private wells.

### Repair

There is little information in the literature specifically on this topic. The repair section of the current rules for Washington state is relatively detailed and explicit in its requirements when a failure occurs (WAC 246-272-16501). Wecker et al (1989) present their approaches to repairing failing systems. This article is mostly in terms of process rather than technical details. However, they emphasize a crucial point about repairing failed systems that is often bypassed: analysis of the failed system to determine the cause of failure. They describe processes for diagnosing problem systems so that the appropriate solution is applied. To apply a solution before understanding the root problem and its cause often results in incorrect or overkill repairs. Harkin et al. (1975) describe the use of hydrogen peroxide to renovate severely clogged drainfields and also advocate its periodic use to prevent severe clogging. This procedure, however, was later demonstrated to have only short-term benefits and long term negative consequences.

### Prevention

Several articles have been cited that delineate the major causes of system failure (McGauhey and Winneberger 1964a, 1964b, 1965, Hill and Frink 1980, Moreau 1981, Barnett 1982, DeWalle 1981, Plews and DeWalle 1984, Angoli 1998, Sherman et al. 1998). Logically, elimination of the causes of premature failure should provide a large measure of prevention. The following is a composite summary of these findings:

1. Site Evaluation
    - Soil evaluations during the season of highest water tables
    - Soil log excavations required to allow observation of water table, restrictive layers, and permeability.
2. Design
    - By experienced, knowledgeable professional
    - Size infiltrative area according to infiltration rate of the clogging zone.
    - Design infiltrative area for maximum hydraulic loading, or limit hydraulic loading to design capacity (as with timed dosing and resting).
    - Maximize the ratio of sidewall to bottom area (narrow trenches)
      - Sidewalls the most active absorption area
      - Allows for aeration of soil around and beneath the trench
    - Hold trenches high in the soil profile.
    - Loading of Infiltrative area
      - Load entire infiltrative surface at once (dosing with siphon or pump)
      - Divide infiltrative area into two sectors, each with capacity for one day’s hydraulic load.
      - Provide for weekly, monthly or longer resting periods to allow the infiltrative area to dewater. (manually switch between sectors).
      - Continuous inundation to be avoided
      - Avoid organic overloading
    - Minimize clogging materials (BOD, TSS)
      - Multiple (two) compartment septic tanks
      - Screening of effluent downstream from the baffle (effluent baffle screens)
      - Annual inspection and pump solids when needed
    - Maintain 2-3 feet vertical separation (allows for aeration of soil, adequate treatment, and for capillary tension to pull water into soil around the infiltrative area.
    - Limit flow to <2000 gpd (This recommendation recognizes that as systems become larger, additional requirements should be incorporated into the design and installation)
    - When mounds and sand filters are designed, sand media must meet a gradation requirement
3. Installation

  - Excavate infiltrative surfaces without smearing and without compaction
  - Use equipment with implements that minimize smearing
  - Trench when soil moisture is low
  - Avoid compaction by limiting equipment size and not driving on infiltrative surfaces
  - Installation is rigidly controlled and supervised and not left to the contractor
4. Operation, Monitoring and Maintenance
  - Monitor septic tank for solids accumulation and pump as needed
5. McGauhey and Winneberger (1965) propose that there be no abrupt change in particle size from gravel in the trench to the infiltrative surface and offer several possible design scenarios. Theses same objectives are achievable with adequate septic tank residence time and outlet baffle screens.

Additional Failure Prevention Items gathered by this author

- Septic tank must be water-tight and baffles must be maintained
- Pressure distribution systems must have timed dosing, timed resting and be monitored for clogged orifices.
- Sand based systems must have timed dosing and resting, level infiltrative surfaces, sand media meeting approved specifications. Sand filters with discharge pump vaults must have proper float switch settings to keep the liquid drained out of the filter media.
- Routine monitoring of the entire on-site system, not just the septic tank, and appropriate service and repair when needed.

McGauhey and Winneberger (1964a) also identify several basic conditions that must be met for a system to perform satisfactorily. For removing suspended solids and BOD, two of the major factors in development of a clogging zone, Laak (1980) advocated tanks with a detention period longer than 24 hours, an outlet configuration with a gas deflection baffle, maximized surface area/depth ratio, and with multiple chambers. Uebler et al. (1984) determined some failures could be prevented by paying attention to the characteristics of the hardpan in North Carolina soils.

## WHY IS FAILURE AN ISSUE FOR THIS ROUND OF RULE DEVELOPMENT?

The definition of failure in the current rule seems to be adequate and not particularly an issue. The problems, and therefore the areas needing attention, are related to (a) what serves as proof of contamination of surface water, and (b) what is needed to remedy or repair a failure where site and soil conditions do not allow a conforming repair. The issues of cesspools and seepage pits have also been raised as has the issue of a sampling requirement and protocol when repairs are made. These issues have arisen during the application of the present rule. The comments in the following sections are largely from staff analysis and not from review of the published literature.

### Table VI Repairs Beyond 100 Feet Horizontal Separation

The basic treatment assumption for on-site sewage systems is that a standard gravity system with 3 feet of vertical separation and a standard pressure distribution system with 2 feet of vertical separation will provide treatment meeting at least Treatment Standard 2 criteria ($BOD_5$ <10 mg/l, TSS < 10 mg/l, and fecal coliform < 800/100 ml) at the boundaries of the soil treatment envelope. When horizontal distances between disposal systems and site features identified in Table I of the rule cannot be met, additional mitigation measures are required, usually including enhanced treatment. For example, following Table I of the rule, section 246-272-09501(3) describes how the local health officer can reduce the minimum horizontal separation to 75 feet and still be a “conforming” system. One of the means of mitigation is enhanced treatment performance levels and assured operation. Reduction of the horizontal separation from 75 feet to 50 feet can be accomplished with a Class A waiver, which specifies pretreatment to Treatment Standard 2 without add-on (untested) disinfection, and the disposal component maintains a vertical separation of 3 feet with gravity and 2 feet with pressure distribution.

Where the replacement disposal component can be located more than 100 feet from a surface water, well, or spring (not a source of public drinking water) and where there is a minimum of 1 foot vertical separation, then there is no need to use Table VI, as a conforming system can be installed. The only additional cell needed for Table VI is in the row with less than 1-foot vertical separation and the horizontal separation is more than 100 feet. To mitigate the lack of vertical separation on these sites, the level of treatment required should be at least Treatment Standard 2.

To be consistent with Table IV requirements, several statements in Table VI need to be changed. For horizontal separations of 25-50 feet and vertical separation >2 feet, Treatment Standard 2 should be required. For horizontal separations >50 and less than or equal to 100 feet, all boxes in the column should contain Treatment Standard 2 to mitigate the lack of horizontal separation. The proposed changes are illustrated in the revised Table VI, below.

***TABLE VI*** *[Suggested Revision]*

***Requirements for Repair or Replacement of Disposal Components***
***Not Meeting Vertical and Horizontal Separations*** [1,2]

| Vertical Separation (in feet) | Horizontal Separation (in Feet[3]) | | | |
|---|---|---|---|---|
| | < 25 | 25 - ≤50 | > 50 - ≤100 | >100 |
| <1 | Treatment Standard 1 | Treatment Standard 1 | Treatment Standard 2[4] | Treatment Standard 2[4] |
| 1-2 | Treatment Standard 1 | Treatment Standard 2[4] | Treatment Standard 2[4] | |
| >2 | Treatment Standard 2[4] | Treatment Standard 2[4] | Treatment Standard 2[4] | |

[1] The treatment standards refer to effluent quality before discharge to unsaturated, subsurface soil.

[2] The local health officer may permit ASTM C-33 sand to be used as fill to prevent direct discharge of treated effluent to ground water, surface water, or upon the surface of the ground.

[3] The horizontal separation indicated is the distance between the disposal component and the surface water, well, or spring. If the disposal component is up-gradient of a surface water, well, or spring to be used as a potable water source, the next higher standard level of treatment shall apply unless treatment standard 1 is already being met.

[4] Mound systems are not allowed to meet Treatment Standard 2.

### Does The Presence Of Dye Alone Indicate Failure Or Is A Positive Bacteriological Result Also Needed?

The presence of dye in an outfall or surface water after it has been added to the sewer drain of a building merely indicates a hydraulic connection. Any normally operating on-site sewage system will eventually disperse its water component to the groundwater and then often to a surface water body, depending on the hydrology of the site. If the system is operating properly, the pathogens and most of the $BOD_5$ and TSS will be removed before the effluent commingles with the groundwater. Therefore, to demonstrate a failure of treatment, a concomitant positive bacteriological sample must also be obtained. The level and type of indicator organism is the subject of some debate. Another, less favored interpretation, is that any hydraulic connection between a wastewater source and a groundwater supply established by dye tracing can be viewed as "effluent…threatens to contaminate a ground water supply." (RCW 70.118.020, definition of "Failure"). However, does the presence of dye, without linked positive bacteriological samples, mean that the water must still be considered effluent?

Thurston County developed a methodology of dye testing combined with fecal coliform sampling that it used to track down on-site sewage systems contaminating shellfish harvesting areas (Vasey Engineering, 1996). Based on the studies conducted by Vasey Engineering, the county determined failures leading to surface water contamination by a positive dye test (usually observed indirectly by absorption in charcoal packets) and a positive fecal coliform sample. The number of fecal coliforms necessary to establish that a system was failing ranged from 200 cfu/100 ml with a single sample to a geometric mean of >29 with 5 samples. A flow chart ("Decision Tree") of fecal coliform ranges is provided in the report.

### Are Cesspools and/or Seepage Pits Failures?

The Washington state on-site rules prohibit the use of cesspools (WAC246-272-11501(4)(c)). On a national scale, EPA Class V Injection Well regulations prohibit new large capacity cesspools as of April 2000 and require existing large capacity cesspools to be phased out by 2005. In another EPA publication (EPA 2002), cesspools and drywells (seepage pits) are considered outdated and underperforming and can cause contamination problems. Seepage pits are also not permitted in Washington state except as allowed under certain repair conditions. They are deep, circular excavations that rely almost completely on sidewall infiltration. Because of their depth and relatively small horizontal profile they create a greater point source pollutant loading potential to groundwater than other soil absorption system geometries. In addition, they provide little treatment because they extend deep into the soil profile, where oxygen transfer is limited. They are not recommended (EPA 2002).

Although local health officers cannot approve designs for cesspools, there may be some existing systems in Washington. Likewise, local health officers may not permit seepage pits for new development, although in some cases may permit them for repairs. It is difficult to say that existing installations are, by definition, failures, as they must meet the definition of failure. It may be just as difficult to trace the cause of groundwater contamination from cesspools and seepage pits as it is to trace the cause to a septic tank/drainfield system. In areas where these types of systems are in place, diligent monitoring of downgradient wells should be practiced, and presence of fecal coliforms may indicate the need for dye tracing and other investigations of the cesspools and seepage pits in the recharge area.

### Should A Sampling Protocol For A Repaired System Be Placed In Rule?

Sampling usually means taking samples for analysis for physical and chemical parameters in the wastewater stream or in the groundwater downstream from the wastewater system. For regulatory purposes, grab samples are not meaningful. In order to provide a view of system performance, sampling must be done much more regularly and more frequently than an occasional grab sample. Therefore, placing a requirement for sampling of a repaired system is not an appropriate expenditure of time and money. A better use for the same time and money is regular monitoring of repaired systems so that services and repairs are provided when needed and before damage to the system occurs. Etnier, Nelson and Pinkham (2000) report that minimally maintained advanced pre-treatment units generally have twice the failure rate of minimally maintained conventional septic systems. Investing resources into maintenance rather than sampling protects public health more efficiently.

## Cost Information:

## Conclusions:

1. Causes of failure are many, and often more than one factor can be present in failed systems. Among those factors described in the literature are: improper appraisal of the receiving soil and other site conditions; system is undersized for the hydraulic and organic loadings; sidewall-to-bottom area ratio of the absorption area is ignored; poor construction practices; lack of intermittent dosing and resting; roots clogging the distribution lines; high groundwater; lack of maintenance and pumping; baffles and screens missing from the septic tank outlet; and use of seepage pits and cesspools.

2. Failure rates are markedly improved with: site evaluations that include high water table observations and restrictive layer searches; increased size of systems (for a given size house, etc); professional designs; septic tanks with multiple compartments; increase of vertical separation from 24” to 36”; and with adherence to sand specifications for sand filters and mounds.

3. Repair of failing systems must be preceded by an investigation of the root cause of the system failure.

4. Failure rates and mean age at failure should not be construed to mean the same as life expectancy for on-site systems. System survival should be considerably higher than the mean age at failure.

5. Table VI does not need to be expanded to a distance beyond 100 feet horizontal separation except for sites with less than 1-foot vertical separation.

6. The presence of dye alone is not sufficient evidence to declare that a system is failing.

7. EPA considers cesspools outdated and under-performing, and bans them for larger on-site systems by 2005. EPA likewise considers seepage pits outdated and under-performing, but does not ban them at this time. Seepage pits cannot be considered failures just by definition.

8. Placing a sampling protocol in rule for repaired systems is neither useful nor appropriate. However, appropriate system monitoring can help ensure proper system operation and determine when maintenance service is needed.

**References:**

Adams, A, Hoover, MT, Arrington, B, Young, G. 1998. FACTSS: Failure Analysis Chart for Troubleshooting Septic Systems, in Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.27-36.

The FACTSS (Failure Analysis Chart for Troubleshooting Septic Systems) flowchart was developed in response to the need for a systematic method to evaluate the cause of failure for on-site systems and to identify repair solutions that are appropriate to correct the problems. FACTSS is a detailed flowchart that guides users through nine steps for troubleshooting. It includes 92 decision points and 23 probable causes of system failure. A homeowner interview form and homeowner water use rating scale are also included. While working through the flowchart, the user gathers information from the homeowner as well as observations from the field and identifies the likely causes of system failure by accumulating what we call "red flags". These red flags are potential contribution causes of the failure. Then, FACTSS provides repair options, or solutions for each of the red flags identified during the troubleshooting process.

Angoli, T. 1988. National On-site Wastewater Treatment: A National Small Flows Clearinghouse Summary of On-site Systems in the United States, 1993, in Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.1-11.

In 1994, the National Small Flows Clearinghouse undertook the project of learning about the status of onsite systems across the country by contacting those in the local and state public health agencies who work with these systems every day. Approximately 3500 agencies were sent a questionnaire containing questions about onsite systems. The project objectives included determining the following for each state for the year 1993: the number of new onsite systems permitted; reasons for permit denial; number of onsite systems reported to have failed; reasons for system failure; new onsite system construction/installation cost; how often onsite system inspections are performed; and who has responsibility for onsite system maintenance.

The most common reasons given for permit denial were inadequate lot size, high water table, poor/inadequate soils, shallow bedrock, and central sewer availability. Health departments attributed failure of onsite systems to the following factors: age, unsuitable soils, lack of maintenance/pumping, high groundwater table, and excessive water use. Many health departments noted a correlation between failing systems and either inadequate or nonexistent regulations. One recurring observation made by the local health departments was that sites, which previously would never have been considered for onsite system use, are now being purchased, planned, and developed with onsite wastewater treatment in mind.

Barnett, EL. 1982. An Approach to Failing Subsurface Disposal System, in Proceedings of the 8th

National Conference on Individual On-site Wastewater Systems, NSF, Ann Arbor, MI. Pp. 195-199.

Describes Tennessee's experience with three types of subsurface disposal system failure: effluent surfacing, groundwater contamination and sewage backup into plumbing fixtures. Summarizes data compiled by county environmentalists for approximately 6,900 failing systems, the majority of which were more than five years old. The top two causes of failure were inadequate amount of line and unfavorable soil absorption capacity. Major sources of failure and possible remedies are discussed.

DeWalle, FB. 1981. Failure Analysis of Large Septic Tank Systems, Journal of Environmental Engineering Division, ASCE, 107(EE):229 -241.

Defines Washington State's Department of Social and Health Services large system design criteria and compares it with the regulations governing residential systems and with recently published data on wastewater generation and soil loading rates. Causes of system failure are reviewed. A summary of large and small system failure rates by county includes estimates of total cost for repairs statewide. Statistics defining the rate of installation of large and residential on-site systems versus an increase in population are presented. The article stresses the need to maintain records and study failure rates, using this information as the basis for revising design requirements and procedures for small and large septic tank soil absorption systems.

EPA. 2002. On-site Wastewater Treatment Systems Manual, EPA/625/R-00/008, Office of Water, Office of Research and Development, US Environmental Protection Agency, Pp. xv, 1-4, 1-8, 3-45, 4-4, 4-14.

Pages containing the words cesspool and seepage pit are referenced.

EPA. 1999a. EPA Fact Sheet: Class V Injection Wells.

EPA Announces New Regulatory Requirements for Certain Class V Injections Wells. For large-capacity cesspools, new cesspools are prohibited nationwide as April 2000 and existing cesspools will be phased out nationwide by April 2005.

EPA. 1999b. EPA: The Class V Underground Injection Control Study - Volume 5: Large-Capacity Septic Systems, EPA/816-R-041e, Office of Ground Water and Drinking Water, USEPA. 120 Pages.

The U.S. Environmental Protection Agency (USEPA) conducted a study of Class V underground injection wells to develop background information the Agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted. The final report for this study, which is called the Class V Underground Injection Control (UIC) Study, consists of 23 volumes and five supporting appendices. Volume 1 provides an overview of the study methods, the USEPA UIC Program, and general findings. Volumes 2 through 23 present information summaries for each of the 23 categories of wells that were studied (Volume 21 covers 2 well categories). This volume, which is Volume 5, covers Class V large-capacity septic systems.

Large-capacity septic systems (LCSSs) are an onsite method for partially treating and disposing of sanitary wastewater. Only those septic systems having the capacity to serve 20 or more persons-per-day are included within the scope of the federal UIC regulations.

LCSSs do not utilize a single design but instead are designed for each site according to the appropriate state and/or local regulations. Many conventional LCSSs consist of a gravity fed, underground septic tank or tanks, an effluent distribution system, and a soil absorption system. LCSSs may also include grease traps, several small septic tanks, a septic tank draining into a well, connections to one large soil absorption system, or a set of multiple absorption systems that can be used on a rotating basis.

LCSSs are used by a wide variety of establishments, including residential (multi-unit housing) and non-residential (commercial, institutional, and recreational) facilities. The characteristics of the sanitary wastewater from these establishments vary in terms of biological loadings and flow (e.g., daily, seasonal). Generally, the injectate from

LCSSs is characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD), nitrate, trace metals and other inorganics, limited trace organics, and biological pathogens.

Even with a fully functioning system, data indicate LCSS effluent may contain arsenic, fecal coliform, nitrate (as N), total nitrogen species (as N), and formaldehyde (in septic systems serving recreational vehicles) at concentrations above primary drinking water maximum contaminant levels (MCLs) or health advisory levels (HALs). The concentrations of aluminum, iron, manganese, and sodium may exceed secondary MCLs.

The effect of these constituents on USDWs depends in part on the characteristics of the injection zone. It is difficult to generalize about the injection zone for LCSSs because these systems have been constructed nationwide. Typically, LCSSs are located in well-drained soils; however, LCSSs have been located in areas with karst or fractured bedrock. The injectate from LCSSs receives partial treatment within the system (i.e., settling and biodegradation in the septic tank). However, attenuation occurs as the septic tank effluent travels through the soil media below the fluid distribution system, which is most commonly a leachfield. In particular, dissolved organic matter, pathogens, and some inorganic constituents can be attenuated in unsaturated soils below the soil absorption system.

The likelihood of ground water contamination resulting from LCSSs may be minimized by following best management practices (BMPs) relating to siting, design, construction and installation, and operation and maintenance. Careful siting and design of LCSSs are important because understanding site limitations can prevent future system failure. The construction and installation of the septic system is best left to professionals, so that the underlying soils are not damaged through compaction and the system is not constructed during periods of high moisture, both of which are likely to contribute to early system failure. Further, it is recommended that LCSSs be properly operated and maintained by conducting inspections and performing maintenance as appropriate, “resting” the soil absorption field, pumping the septic tank to remove solids as necessary, and limiting system loading (e.g., water conservation, reducing chemical use or addition). Owners or operators of LCSSs who follow such BMPs are likely to maximize the life of their system and lower the likelihood that their system would contaminate a USDW.

Nevertheless, contamination incidents caused by LCSSs have occurred. For example, in Racine, MO during 1992, two drinking water wells at a nearby church and school were contaminated by sewage from a LCSS, causing 28 cases of Hepatitis A. In Coconino County, AZ during 1989, failure of the leaching field (due to excessive flow) at a resort area resulted in approximately 900 cases of gastroenteritis. In Richmond Heights, FL during 1974, a drinking water well was contaminated by sewage from a nursery school, and resulted in approximately 1,200 cases of gastrointestinal distress. In addition, 24 other instances have been identified in which LCSSs failure and ground water contamination may have resulted. While there are surely other examples of LCSS failure across the U.S. beyond these known incidents, the prevalence of contamination cases appears low relative to the prevalence of these systems.

LCSSs are vulnerable to spills because any materials spilled or dumped down sinks, toilets, or floor drains connected to the sanitary waste system can enter the septic tank. Examples of the materials that may enter LCSSs include household cleaning products and wastes (e.g., cleaning solvents and spent solutions) that were either intentionally or accidentally spilled as well as chemicals dumped illicitly (e.g., waste oil). Once in the LCSS, these materials are not necessarily treated by the system and may be released to ground waters that may serve as USDWs. USDWs may also be vulnerable due to the large numbers of LCSSs operating nationwide. While the incremental effect associated with spills at each LCSS may be small, aggregating each of these spills may provide evidence of a broader contamination problem for USDWs.

According to anecdotal evidence, LCSSs are believed to be a frequently used onsite wastewater disposal option. Yet, until this study constructed the inventory model to estimate total numbers of LCSSs nationwide, no quantitative information on system prevalence was available. As discussed in Section 3.3, the inventory model estimated 353,400 LCSSs in the nation; with a 95 percent prediction interval, the range is 304,100 to 402,600.

In the future, the total number of systems is expected to increase as the population increases. USEPA found that construction and use of LCSSs will continue in areas where geological conditions are favorable and sewerage is not readily available or economically feasible. In addition, these systems will continue to be constructed because using LCSSs is an accepted and economically attractive practice. While some states are now encouraging owners of large systems to connect to municipal sewers (when such connections become available), there do not seem to be any states planning to ban LCSSs entirely.

USEPA also found that there are no consistent state definitions of regulations for LCSSs. While the 20 persons-per-day criterion is used to define systems subject to federal UIC regulation, states generally characterize large systems using flow definitions that range from 2,000 to 20,000 gallons-per-day (gpd). Regulation of LCSSs is also highly variable across states. Some states have stringent requirements for large systems. For example, Massachusetts and Minnesota both use 10,000 gpd as the cutoff for large systems and have strict requirements for siting, construction, and operation. Other states only require general construction permitting. For example, New Jersey and Iowa both use a 2,000 gpd threshold for large systems but only require that such systems meet specific construction standards. In addition, LCSSs may be regulated by local regulations that focus on enforcing state and/or county building and health ordinances.

### Etnier, C, Nelson, V, Pinkham, R. 2000. Economics of Decentralized Wastewater Treatment Systems: Direct and Indirect Costs and Benefits, Proceedings of the Decentralized Wastewater Management Research Needs Conference, Washington University, St. Louis, MO, May 19-20. Electric Power Research Institute, St. Louis, MO. 67 pages.

This paper describes important direct and indirect costs and benefits to be considered in decision making about decentralized wastewater treatment, as well as decision-making structures which in the future would integrate public health, environmental, engineering, and socioeconomic risks and benefits. Its purpose is to identify and prioritize research gaps in these areas: estimation of direct and indirect socioeconomic costs and benefits associated with various risk-reduction strategies; models and methods of risk assessment and decision making; and risk management options at the individual home or community level that are practical, politically acceptable, and cost effective. Thirty-three possible research projects are identified as important to decision making for decentralized wastewater treatment. Six of these are prioritized, based on their anticipated usefulness in providing basic information to the field, information to assess new directions the field is taking, and information to overcome existing obstacles to decentralized treatment. The six prioritized research projects separately address:

- the importance of national performance standards for the diffusion of decentralized wastewater treatment technology;
- hydrological impacts, and their associated economic implications, of wastewater treatment choices;
- lifespans, failure rates, and risks associated with decentralized and centralized solutions;
- economies and diseconomies of scale in different types of wastewater systems;
- cost effectiveness of management systems, including performance-based codes; and
- compatibility of decentralized treatment with smart growth.

### Fredrickson, DW. 1980. The Wisconsin Experience with Alternative Private Sewage Systems, in Proceedings of the Seventh National Conference on Individual Onsite Wastewater Systems, National Sanitation Foundation, Ann Arbor, MI Pp. 229-236.

This article describes various types of on-site systems and whether or not they are allowed in Wisconsin. Before a system is allowed by the state, it must be proven to renovate wastewater of nutrients, pathogens, and other contaminants. In addition, assurance must be made to the state that the system will function a long time with very little maintenance. Programs have been implemented in Wisconsin to clean up failing systems by generating funds from permit fees and general tax revenues.

### Harkin, JM, Jawson, MD, Baker, FG. 1975. Causes and Remedy of Failure of Septic Tank Seepage Systems, Proceedings of the 2nd National Conference on Individual On-site Wastewater Systems, NSF, Ann Arbor, MI. Pp. 119-124.

Hydrogen peroxide was used on failed septic systems in an attempt to unclog the seepage beds. Laboratory columns and field systems showed that hydrogen peroxide added directly to the seepage beds will solubilize sulfide depositions that clog soil pores. Preventive treatment is recommended over remedial treatment of failed septic systems.

### Hill, DE, Frink, CR. 1980. Septic System Longevity Increased by Improved Design, J. Water Pollution Control Federation 52(8):2199-2203.

The impact to septic systems due to changes in state and local regulations designed to improve their life span is investigated. Analyses of 3,156 systems show a nine-year increase in longevity in the population of all systems from 1973 to 1978 and a decrease in the average rate of premature failures form 6.0 to 2.0 percent in each year class of installation. Improvement was due to design changes in 1961 and the required spring percolation tests in 1972.

Keys, JR, Tyler, EJ, Converse, JC. 1998. Predicting Life For Wastewater Absorption Systems, Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI. Pp.167-176.

A mass-balanced model to predict system life and loading rates of gravel wastewater infiltration systems on a sand soil was developed. The functional life of a system was predicted using multiple regression analysis of ponding depths of wastewater versus time. Long term falling head infiltration rates to determine basal area loading rates and flow from within the systems.

Gravel filled systems in these sand soils have a predicted life of 11 years when loaded basally at 1.6 cm/day. The ponding depths of wastewater were found to increase an average of 27 mm/year. At a higher loading rate of 4.1 cm/day, the expected life was 7 years and the average ponding depth increase of 44 cm/year. The loss of "new" sidewall infiltrative area for a fixed length system is the limit of life expectancy measure.

The mass-balance model explained differences in flow rates for various biologically matted surface areas. Conductivities for these surface areas ranged from 0.02 (basal and lower sidewall areas) to 2.41 (upper sidewall and lip areas) cm/day.

From the model we determined that "new" upper sidewall soil was needed for infiltration as a basal loading rate of 1.6 cm/day. The additional sidewall needed to infiltrate wastewater not passing through the basal area agrees with the observed increase in ponding depth over time.

We found that the matted sidewall and lip are most efficient for movement of wastewater into the soil. The basal area had a lower conductivity than either the sidewall or lip areas. It still accounted for a significant amount of wastewater removal, is an important part of the system, and should not be ignored or downsized.

A system's life is limited by sidewall height and the conductivities of clogged areas. The clogged basal and sidewall areas need to accept the applied wastewater or eventually the trench will fill causing the system to fail.

Laak, R. 1980. Multichamber Septic Tanks, J. Environmental Engineering, ASCE, 106(EE3):539-546.

Discussion of the importance of efficient septic tank operation is presented, followed by a detailed review of past research involving septic tank compartmentation. European and current American practices are briefly cited. Concludes that multichambered septic tanks are superior to single chambered septic tanks with up to 50 percent less suspended solids and BOD in the tank effluent.

McGauhey, PH, Winneberger, JHT. 1964a. Studies of the Failure of Septic Tank Percolation Systems, J. Water Pollution Control Federation, 36(5): 593-606.

The objectives of the studies herein reported were to determine the causes of loss of infiltrative capacity of a soil which results in failure of a percolation system; gain an understanding of the mechanisms of soil clogging; and explore the ways in which soil clogging can be overcome or minimized in practice. To attain these objectives the investigation included a review of existing literature, a re-interpretation of data from previous work on groundwater recharge, laboratory and pilot scale experiments, and field observations.

McGauhey, PH, Winneberger, JHT. 1964b. Causes and Prevention of Failure of Septic Tank Percolation Systems, FHA No. 533, Federal Housing Administration, Washington DC. 66 pages.

Field clogging was identified as the greatest cause of failure in septic tank systems. Clogging is the result of a combination of physical, chemical, and microbiological factors. The report indicated that current construction practices and equipment can and often do, lead to smearing and compacting of the soil being excavated, thus promoting clogging and system failure. Remedies mentioned were equal dosing/resting periods and uniform loading of the drainfield absorptive areas. These aforementioned practices promote aerobic conditions in the drain field, precluding the soil clogging effects exhibited by ferrous sulfide and bacterial build-ups in the soil absorption area. Design of a narrow trench system was included in the report. It minimized the soil clogging conditions found in standard trench and seepage bed designs. Design requirements and construction details for systems discussed are provided, including pictures and schematic details.

McGauhey, PH, Winneberger, JHT. 1965. Final Report on a Study of Methods of Preventing Failure of Septic Tank Percolation Systems, SERL Report No. 65-17, Sanitary Engineering Research Laboratory, University of California, Berkeley. 33 pages.

This report summarizes the concepts and principles on which the septic tank system depends and to point the way to their application in system design. The overall purpose of the investigation was to discover the basic causes of failure of septic-tank percolation, or leaching, systems and to provide information necessary to formulate design criteria and operational measures which might preclude such failure or forestall it for a considerable period of years. Some of the factors causing failure of percolation fields are looked at from the perspective of preventing failure.

Moreau, EM. 1981. Subsurface Wastewater Disposal Systems - Remedies and Prevention of Failures, in Proceedings of the 8th National Conference on Individual On-site Wastewater Systems, NSF, Ann Arbor, MI. Pp. 211-228.

Describes site evaluation procedures according to Maine's plumbing and subsurface disposal rules. A step-by-step procedure for evaluating the site and in-house wastewater use provides the investigator with the means of defining the cause of system failure. Suggests corrective measures for the more common causes of onsite system failure.

Plews, GD and DeWalle, F. 1984. Performance Evaluation of 369 Larger On-Site Systems, Proceedings of the 4th National Symposium on Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MO. Pp. 372-381.

Investigation of 369 onsite systems in the state of Washington was performed to assess the extent and causes of system failures. The study combined an analysis of available records and field verification. The results included an assessment of geographic variables, design variables, operational variables, and system management as they related to system failures. Regulatory implications of the study are summarized.

Revised Code of Washington (RCW) 70.118.020. 1994. PUBLIC HEALTH AND SAFETY, On-site sewage disposal systems, Definitions.

This reference contains a definition of failure that is not exactly the same as the definition in WAC 246-272:

(3) "Failure" means: (a) Effluent has been discharged on the surface of the ground prior to approved treatment; or (b) effluent has percolated to the surface of the ground; or (c) effluent has contaminated or threatens to contaminate a ground water supply.

Salvato, JA. 1975. Problems and Solutions of On Lot Sewage Disposal in Proceedings of the Second National Conference on Individual Onsite Wastewater Systems, National Sanitation Foundation, Ann Arbor, MI 48106, Pp. 39-46.

Design, construction, operation and maintenance limitations of septic tank - soil/absorption systems, cesspools, mounds, ETA, and ET systems are reviewed. The advantages of on-site vs. conventional systems are briefly reviewed.

Saxton, GB, Zeneski, JM. 1979. Prediction of Septic System Failures, J. Environmental Engineering, ASCE, 105(EE3):503-509.

To conduct a cost-effective analysis for on-site wastewater disposal systems, a computer model was developed to predict the number and temporal distribution of single-family residential septic tank failures. The model can predict failures for the next 20 years and can be used as input for value and economic assessments, estimating sanitarian workloads, and predicting water quality.

Sherman, KM, Varnadore, W, Forges, RW. 1998. Examining Failures of On-site Sewage Treatment Systems in Florida, in Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp. 43-51.

The authors conducted three independent analyses of repair data collected in their jurisdictions. Two of the analyses came from repair permit databases in counties with large numbers of installations. The third analysis came from a survey of repair permit data statewide.

Florida has required mandatory repair permits for failing on-site sewage treatment and disposal systems since 1992. The permits capture information on the date of original systems installation, size and location system components, site features and cause of failure.

Sarasota County tracked many thousands of repair permits since 1975 and performed detailed analysis. Marion County chose 50 systems at random in 1990 and followed them in time. The analysis of statewide data shows causes of failure and the influence of drainfield size and aggregate type on failure rate.

All three studies use average age of system at time of failure as an index of system longevity. Secondly, a multi-modal phenomenon is routinely observed. The authors contend that system failures early are most often the result of hydraulic overload. Later in life in Florida, root clogging is most often the cause of system failure. Finally, all three studies have similar mean ages at failure, 18.01 years in Sarasota County, and 18.35 years in Marion County, and 18.53 years state wide. A ten-year increase in the mean age at failure in Sarasota County (to age 28.44 years) is credited to a county ordinance enacted in 1983.

Uebler, RL, Steinbeck, SJ, Crowder, JD. 1984. Septic System Failure Rate on a Leon (Hardpan) Soil and Feasibility of Drainage to Improve System Performance, in Proceedings of the 4th National Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. Pp.111-118.

Four sites in Brunswick County, North Carolina were monitored to determine the effectiveness of artificial drainage on Leon soils and to identify the soil characteristics limiting drainage response. In addition, 593 existing systems were surveyed to identify problems with Leon or other soil types. The seasonal high water table rose 15 to 30 cm above the first Bh (hardpan) in undrained soil, even though it did not act as a restrictive horizon. Thus, a seasonal high water table may be predicted by the presence of this horizon. If the Bh is massive, strongly cemented, hard and brittle, and thicker than 10 cm, the water table cannot be lowered sufficiently to meet minimum absorption field separation distances. Artificial drainage may be beneficial where the Bh is weakly cemented or less than 10 cm thick. The failure rate of septic systems in Leon soils is three times greater than for other soils surveyed.

Vasey Engineering. 1996. Standard Methods for On-site Sewage System Evaluation Using Dye Tracers, Report Prepared for Thurston County Environmental Health Division, Public Health and Social Services Department, Olympia, WA. 55 pages plus 4 Appendices.

This report is on a project whose purpose was to develop a standardized method to resolve classifications of “failure” and “non-failure” systems captured in sanitary surveys along shorelines. The first phase of the project was a statistical evaluation of the sanitary database to determine what subset, if any, of the study homes was more prone to failure and to assess the suitability of the existing survey methodology. The second phase was a special study that provided data to improve the resolution of the survey method and provided analysis of the usefulness of nutrient data associated with failure. The report also provides the results of the special study, correlations between dye, fecal coliform and other factors, recommendations for improved sampling protocol for the fecal coliform parameter, and recommendations for general improvements to the sanitary survey methodology.

Wecker, SC, Babin, KL, Mitchell, M. 1989. Thoughts on Repairing Failing Sewage Systems, in Proceedings of the 6th NW On-site Wastewater Treatment Short Course, University of Washington, Seattle. Pp. 15-34.

Three different professionals present their views on the repair of failed septic systems. A design engineer discusses how he analyzes, diagnosis and interacts with homeowners who have a failed system. An environmental health specialist discusses failures and design considerations for lake front properties. The third author presents a diagnostic chart for identification of failure causes.