AN ABSTRACT OF THE THESIS OF

Cynthia K. Gaines for the degree of Master of Science in Environmental Health Management presented on November 22, 2000. Title: A Shoreline Survey of On-Site Systems in the Tillamook Bay Watershed, Tillamook County, Oregon.

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Anna K. Harding

Tillamook Bay is used for recreational activities such as swimming and diving, as well as recreational clam harvesting. The bay is also used for one of Tillamook's most prominent industries, oyster harvesting. Bacterial contamination of Tillamook Bay has been a recognized problem since 1962. There are a number of known sources of bacterial contamination in Tillamook Bay including municipal wastewater treatment facilities, cattle and other livestock, and on-site systems. In order to comply with federal regulations and because of the serious consequences that contamination poses to the Tillamook economy, the Tillamook County Environmental Health Department conducted a shoreline survey of on-site systems in the Tillamook Bay Watershed. The purpose of this study was to determine the failure rate of on-site systems in a selected area of Tillamook County, Oregon. This shoreline survey was conducted in accordance with the minimum requirements for performing shoreline surveys in shellfish growing

areas, as set forth in Appendix B of the National Shellfish Sanitation Program Manual of Operations, 1995 edition. A total of 385 on-site systems were surveyed. This study used three sets of data to develop the on-site system profile of the area: (1) information gathered from the Tillamook County Community Development department files; (2) date acquired during a survey with on-site system homeowners; and (3) on-site inspection of the system. None of the on-site systems appeared to be failing, but the rates of marginal systems ranged from 1.7/100 to 6.4/100. The failure rate was lower than the expected rate of 6% to 7%; this is most likely due to the fact that the survey was conducted during the dry season when indicators of failing on-site systems are not apparent. Another possible explanation for the lack of failing on-site systems is that forty-nine systems were not surveyed because the owners chose to not participate in the survey. Recommendations for future surveys include using dye tracing to identify failing systems, surveying during the winter when failing systems are evident, knowing soil types before surveying, using questionnaires to elicit information from homeowners, and public education about on-site systems and their maintenance requirements.

Master of Science thesis of Cynthia K. Gaines presented on November 22, 2000

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Cynthia K. Gaines, Author

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A Shoreline Survey of On-Site Systems in the Tillamook Bay Watershed, Tillamook County, Oregon

by

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A THESIS

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This thesis is dedicated to the people
who have influenced my life the most,
my parents,
Michael and Barbara Gaines.

A SHORELINE SURVEY OF ON-SITE SYSTEMS IN THE TILLAMOOK BAY WATERSHED, TILLAMOOK COUNTY, OREGON

INTRODUCTION

Since the 1970s, water quality in the United States has improved significantly as a result of controlling discharges of point sources of pollution (Fisher, 1994; Moore & Freedman, 1995). However, 40% of the country's rivers, lakes and estuaries are not suitable for swimming and fishing (Fisher, 1994). A leading cause of diminished water quality is nonpoint pollution (Persciasepe, 1995). Nonpoint pollution is caused by runoff from many rural and urban land uses such as agriculture, construction, urbanization and on-site sewage disposal (Cooney, 1997; Fisher, 1994; Moore & Freedman, 1995).

On-site, or septic systems are designed for the disposal and treatment of household wastewater in areas that are not served by sewer systems and municipal wastewater treatment facilities. In areas where on-site systems are used, it is expected that the on-site systems are installed so as to protect the quality of groundwater and nearby surface water. This, however, is not always the case. In Tillamook County, 60% of the population is served by wastewater treatment plants; the other 40% use on-site systems for wastewater disposal (Jackson, 1985). There are an estimated 10,000 on-site systems in Tillamook County (W. Greenwood, personal communication, January 11, 1999). Many of these systems were installed prior to strict environmental regulations governing issues such as siting of septic systems and their proximity to surface and groundwater. The potential exists for ground and surface water contamination from on-site systems in this area. It is important to know if on-site systems are contributing to ground and surface water contamination because Tillamook Bay is an important resource for the local community and the state of Oregon.

Tillamook Bay is used for recreational activities such as swimming and diving, as well as recreational clam harvesting. The bay is also used for one of Tillamook's most prominent industries, oyster harvesting (Kruckeberg & Miller, 1998; Strittholt, Garono, & Frost, 1997). Good water quality is essential if the oysters are to be harvested and marketed.

Bacterial contamination of Tillamook Bay has been recognized as a problem since 1962. In an effort to improve water quality in Tillamook Bay, the Rural Clean Water Program was created in the early 1980s with the goal of identifying sources of bacterial contamination and developing a fecal coliform management plan. However, in spite of efforts of to improve water quality, Tillamook Bay frequently does not meet water quality standards (Newell, 1998; Tillamook Bay National Estuary Project [TBNEP], 1997).

There are a number of known sources of bacterial contamination in Tillamook Bay including municipal wastewater treatment facilities, cattle and other livestock, and on-site systems (Crane & Moore, 1986; Jackson, 1985; Stelma and McCabe, 1992; Stritthold et al, 1997; TBNEP, 1997). Studies suggest that on-site systems have contributed to the contamination of Tillamook Bay. Sanitary surveys conducted between 1974 and 1979, in Tillamook County, indicated a 20% failure rate for 184 inspected on-site systems. However later surveys found that only 8% of the surveyed systems were failing; of these, only 2% were contaminating surface water (Newell, 1998). In order to comply with federal regulations and because of the serious consequences that water contamination poses to the Tillamook economy, the Tillamook County Environmental Health Department conducted a shoreline survey of septic systems in the Tillamook Bay Watershed in 1998.

Purpose of the Study

The purpose of this study was to determine the failure rate of on-site systems in a selected area of the Tillamook Bay watershed and in each of the five drainage basins – Tillamook River, Trask River, Wilson River, Kilchis River, and Miami River – and Cape Meares, a high density housing area adjacent to the bay.

Research Questions

The following questions guided the direction of this study:

(1) What is the failure rate of on-site systems in a selected area of the Tillamook Bay watershed?

(2) What is the failure rate/rate of marginal on-site systems in each of the following drainage basins: Tillamook River, Trask River, Wilson River, Kilchis River, Miami River, and Cape Meares?

(3) What is the relationship between on-site system function and system location (upland or hydric)?

(4) What is the relationship between on-site system function and type of system (standard or alternative)?

Limitations of the Study

This study was limited by the researcher's inability to interview homeowners who chose to not participate in the study. The researcher was also unable to inspect the on-site systems of these homeowners. The lack of information about these systems could provide biased results by indicating a lower failure rate than that which truly exists.

Definitions

The following definitions apply to terms used in this study:

Plot Location:

Upland: Parcels that are not directly adjacent to Tillamook Bay, the Pacific Ocean, a river, or a creek.

Hydric: Parcels that are located directly adjacent to Tillamook Bay, the Pacific Ocean, a river, or a creek. Parcels that show evidence of hydrophilic vegetation.

System Type:

Standard: On-site system consists of a septic tank and absorption trenches. The septic tank might contain an effluent lift pump which discharges to standard absorption trenches up-slope from the septic tank.

Alternative: All on-site systems other than a standard on-site system.

System Function:

Operational: (An on-site system with) no visible signs of failure.

Marginal: (An on-site system with) thick, lush growth over the tank and/or absorption beds and the owner/tenant stated that the system functions sluggishly but does not discharge untreated effluent to the ground surface or to a surface body of water.

Failure: (An on-site system for which) untreated effluent is discharged directly to the ground surface or to a surface body of water.

Unknown: The components of the system cannot be located and the owner/tenant is not present at the time of the survey.

Environmental Impact of System:

None: The on-site system is operating without discharging untreated effluent directly to the ground surface or to a surface body of water.

Direct: The on-site system discharges effluent directly to a surface body of water.

Indirect: The on-site system discharges untreated effluent directly to the ground surface and this discharge could impact a surface body of water.

Unknown: The owner/tenant is not present to give information on the system location and the location of the system could not be determined.

LITERATURE REVIEW

Humans have been disposing of their wastewater on land and in waterways for centuries. Consequently, there has been a need to address the health-related issues of water pollution for almost the same length of time. The Romans recognized the benefits of good drainage and constructed an underground combined sewer in Rome (Burks & Minnis, 1994; Fuhrman, 1984). They also built similar systems, which used greywater to wash away excrement, in countries that they conquered (e.g. England) (Burks & Minnis, 1994). Although storm sewers existed in medieval Europe, it was forbidden to use them for the direct disposal of human waste. The waste was dumped into the streets and with the next rain, washed into the storm sewer and subsequently, into the nearest river. During this time, people also began to use privies and cesspools, both of which posed health problems; cesspools frequently overflowed and privies contaminated nearby wells (Burks and Minnis, 1994; Fuhrman, 1984). In the mid-1800s it was discovered that storing human waste near homes posed a threat to human health, so people began disposing of the waste in the storm sewers, where it was diluted and flushed to the rivers (Burks & Minnis, 1994). This accomplished nothing more than shifting the sanitation problem from the streets to the waterways, creating new public health concerns (Burks and Minnis, 1994; Fuhrman, 1984).

On-Site System Description

Properly designed and installed on-site systems are an efficient and economical means of disposing of domestic wastewater in areas not served by public wastewater treatment facilities. One quarter to one third of the houses in the United States rely on these systems for the disposal of domestic wastewater (Canter & Knox, 1984; Jury, Gardner, & Gardner, 1991; Reneau, Hagedorn, & Degen, 1989).

There are many different types of on-site systems, but the majority are conventional gravity flow systems. This system is comprised of a septic tank, a distribution box and soil absorption trenches. The wastewater flows from the house to the septic tank where solids settles out and scum floats to the surface. Anaerobic digestion, which reduces the amount of organic material in the effluent, occurs in the septic tank. Anaerobic digestion decreases the suspended solids, biological oxygen demand, and sludge volume, and converts much of the organic nitrogen to the ammonium form. Anaerobic digestion does not inactivate, nor significantly decrease the number of, pathogens in wastewater (Canter & Knox, 1984; Reneau et al., 1989). The effluent leaves the septic tank and flows to the distribution box, a watertight structure designed to distribute effluent concurrently to two or more disposal trenches in the absorption bed. The absorption bed is a series of disposal trenches which contain perforated distribution pipes that release the effluent to the soil where it is treated and disposed (OAR, 1999).

An important part of the on-site system mechanism is the formation of a biological mat on the trench bottom and side walls. The mat serves two purposes. First, it promotes uniform distribution of clarified effluent over the entire system. Secondly, it slows the rate at which wastewater percolates into the soil, allowing microbes to degrade organic contaminants in the effluent, as well as the contact time required to filter out pollutants (Postma, Gold, & Loomis, 1992; Salvato, 1992). A mat is formed when the pore spaces in a soil are filled, generally with larger microorganisms and their waste products or solids from the effluent (Kristiansen, 1981; Rea & Upchurch, 1980; Reneau et al., 1989). While the clogging mat is beneficial to an on-site system's function, it can also cause system failure by reducing the infiltration rate.

An on-site system is considered a failure when it "...discharges untreated or incompletely treated sewage or septic tank effluent directly or indirectly onto the ground surface or into public waters [including groundwater]" (OAR, 1999, p. 71-7). There are a variety of reasons that on-site systems fail. Generally, the biological mat begins to form where the effluent leaves the pipe and contacts the trench bottom. Over time, the mat progresses along the trench, hence the term creeping failure. Another result is accelerated biological mat formation which can decrease infiltration, again causing saturated flow conditions (Reneau et al., 1989). Failure occurs when the soil's capacity to absorb effluent is exceeded which causes the waste added to the distribution pipe to surface along the laterals. The raw effluent on the ground surface can then flow or be washed to a nearby surface waterbody.

A related issue is on-site system density; too many systems in an area can overwhelm the natural ability of the subsurface to receive and treat effluent prior to its movement into groundwater (Canter & Knox, 1985; Canter, Knox & Fairchild, 1987; Perkins, 1984). Areas with more than 40 systems per square mile have been designated by the US Environmental Protection Agency (EPA) as regions with a potential for groundwater contamination (Yates, 1986).

Oregon Administrative Rules (1999) require that on-site systems be located at specified distances, or setbacks, from various natural and manmade items. These items include house foundations, water lines, property lines, irrigation canals, wells, groundwater supplies, intermittent streams, and public surface waters. The setbacks are intended to provide an adequate distance for effluent treatment in the soil and to prevent pollution of nearby groundwater and surface waterways. Despite the setbacks and regulations governing on-site systems, pollution can occur when systems fail.

Biological Contaminants in On-Site Systems

On-site systems are potential sources of many pollutants such as nitrogen compounds, phosphates, synthetic organic compounds, metals, inorganic compounds, and organisms. Organisms are of particular concern in areas where the pollution of shellfish growing waters is possible, because shellfish filter large quantities of water while feeding and concentrate pathogens (Crane & Moore, 1986; Martinez-Manzanares, Morinigo, Castro, Balebona, Munoz, & Borrego, 1992).

Of the organisms present in effluent, pathogenic bacteria and viruses are of primary concern. Larger pathogens, such as protozoans and helminths, are more efficiently removed by soil filtration and, therefore, are less likely to migrate away from the absorption bed (Reneau et al., 1989).

Biological contaminants in effluent are removed by filtration, adsorption, sedimentation, and die-off. Die-off is simply the death of pathogens. Death can be caused by predation by pre-existing soil bacteria, nitrification or a change in the amount of oxygen present, or by the organism's inability to adjust to abrupt temperature changes. During unsaturated flow, large numbers of bacteria are removed by filtration which is caused by decreased pore water velocities and the resulting increase in surface contact per distance traveled, or by decreased pore diameter and volume. Uniform effluent distribution, well-drained soils, and in coarse soils the formation of a biological mat, are all factors that contribute to unsaturated flow (Canter et al., 1987; Reneau et al., 1989; Romero, 1970).

While some viruses are filtered from effluent during unsaturated flow conditions, the amount is significantly less than that of bacteria, due to the small size of viruses. Filtration of viruses increases as flow rate decreases. Adsorption to soil colloids is the primary method by which viruses are removed from effluent (Canter et al., 1987). Adsorption is principally influenced by clay content and type, cations, and ion species and strength. Clays have a high cation exchange capacity (CEC). Cation exchange capacity represents the total number of exchangeable cations that a surface will adsorb. As the CEC increases, so too does the ability of a clay molecule to exchange cations from its surface with cations in the surrounding soil solution (Jury et al., 1991). This phenomenon is important to the removal of viruses in on-site system effluent because the cations in solution form bridges with those on the surfaces of clay particles, reducing the electrostatic repulsion between the negatively charged viruses and soil particles, allowing the viruses to adsorb onto the soil particles (Canter & Knox, 1984; Reneau et al., 1989). Adsorption decreases with saturated flow conditions due to the increased flow velocity. Desorption of viruses by flushing with a solution of lower ionic strength has been demonstrated, but should not be an issue in properly sited on-site systems (Reneau et al., 1989).

Conditions Which Affect the Movement of Biological Organisms Through Soil

The most common indicators of fecal pollution are total and fecal coliforms (Martinez-Manzanares et al., 1992). Total coliforms are commonly found on plants and insects, in soil and old sewage, and in waters polluted at some time in the past. For this reason they are indicative of past pollution, not recent pollution. Fecal coliform, on the other hand, is found in the intestines of humans and other warm-blooded animals. Fecal coliform is indicative of recent and potentially harmful fecal pollution (Reneau & Pettry, 1975). *Clostridium perfringens* and *Escherichia coli* are among the other organisms whose movement through soil has been studied. *C. perfringens* is used as an indicator of past or intermittent contamination. It is able to survive indefinitely and can sporulate under conditions which are unfavorable to other bacterial organisms (e.g. coliforms) (Salvato, 1992).

Increased Time and Distance from Absorption Beds

Romero (1970) compiled a report that summarized the findings of many groundwater pollution studies. The pertinent findings included the following characteristics of the movement of biological organisms through porous media. Organisms move in the direction of flow of groundwater, however, they also moved in other directions during periods of recharge and/or pumping. The rate of removal of organisms with distance from the source was a function of the ability of the soil to filter them out. The type of soil in which biological contaminants were released influenced their subsequent travel. Removal efficiencies were highest in soils which were uniformly composed of very fine to fine sand with a high clay content. Biological pollutants traveled with groundwater a maximum distance of 15 to 30 meters (50 to 100 feet). The distance biological contaminants traveled in unsaturated soils was considerably less than that in saturated soils; the maximum distance traveled was approximately 3 meters (10 feet).

Postma et al. (1992) conducted a study to determine the migration and attenuation of contaminants, including fecal coliform and *C. perfringens*, from seasonally-used on-site systems. They found elevated numbers of fecal coliform six meters (20 feet) from the absorption beds. The elevated concentrations found at six meters were less than those found at two meters (6.5 feet) which suggests that some attenuation occurred as the distance from the septic system increased. The movement of *C. perfringens* followed approximately the same patterns as fecal coliform, with one exception. At one site, the authors consistently found elevated numbers of *C. perfringens* and no fecal coliform. This supports other studies which have determined that *C. perfringens* is a reliable indicator of septic system effluent due to its persistence in unfavorable conditions. In addition, the data demonstrate that the absorption bed did not adequately remove fecal coliform nor *C. perfringens* from effluent.

A study by Cogger and Carlile (1984) supports the results obtained by Postma et al. (1992). At a distance of 1.5 meters (5 feet) significantly higher concentrations of fecal coliform were found than at 7.6 meters (25 feet). The fact that fecal coliform was found outside of the absorption bed suggests that complete treatment of effluent did not occur in the absorption bed.

Reneau and Pettry (1975) studied the movement of total and fecal coliform through three Virginia Coastal Plain soils. At the first site they found a significant reduction in the concentration of total and fecal coliform as horizontal distance from the septic system increased. The decrease was attributed to soil filtration and bacteria die-off. At the second site the authors found decreased concentrations of total and fecal coliform as both depth and horizontal distance increased. The largest decrease in both total and fecal coliform occurred during the first 0.15 meters (0.5 feet) of migration. The third site also demonstrated a decrease in total and fecal coliform counts as horizontal distance increased. The decrease in fecal coliform density was more noticeable than that of total coliform. The data indicate that the number of fecal coliform was reduced within the first 13 meters (43 feet) of horizontal flow. The authors attribute the decrease in fecal coliform concentration to soil filtration. The results from all three of the sites in this study indicate that the effluent was incompletely treated prior to leaving the absorption bed.

Hagedorn, Hansen, and Simonson (1978) conducted a study which produced results similar to those already discussed. As in previously cited studies, the number of bacteria decreased as distance from the source (e.g. pit, absorption bed) increased. The authors also suggest that the bacteria could survive much longer than 32 days in wet and cool soil, conditions which are favorable to their survival.

Brown, Wolf, Donnelly, and Slowey (1979) investigated the movement of fecal coliform and coliphages to groundwater in three soils with three different sand contents. Fecal coliform was only occasionally detected at depths of 120 centimeters (4 feet), and was usually not present below 35 centimeters (1 foot). Their results indicate that fecal coliform counts decreased as distance from the absorption trenches increased. The results also indicate that fecal coliform counts decreased with time after application of effluent stopped, but some persisted at the trench/native soils interface for 19 days.

The six studies discussed in this section indicate that as time and distance from the source increased, bacterial counts decreased. Although the results indicate that some mitigation of bacteria occurred in the absorption beds, complete treatment of septic tank effluent did not occur.

Saturated and Macropore Flow

As discussed previously, unsaturated flow conditions increase filtration of organisms. Reneau et al. (1989) concluded from a literature review that under unsaturated flow conditions, adequate bacterial attenuation occurs within 0.9 to 1.2 meters (3 to 4 feet) of effluent flow through soils. However, under conditions of saturated flow, organisms can travel much greater distances more quickly, thereby minimizing filtration/absorption of organisms. Desorption of viruses has been demonstrated under saturated flow conditions (Reneau et al., 1989). Macropore flow occurs when there is rapid flow through macropores, or areas of high permeability, with slower subsequent movement through smaller pores to areas adjacent to the inoculation point. Macropore flow has also been shown to facilitate the rapid movement of minimally-attenuated biological organisms away from absorption beds (Rahe, Hagedorn, McCoy, & Kling, 1978; Reneau et al., 1989).

In a summary of many groundwater pollution studies, Romero (1970) stated that biological pollutants traveled with groundwater a maximum distance of 15 to 30 meters (50 to 100 feet). The distance biological contaminants traveled in unsaturated soils was considerably less than that in saturated soils; the maximum distance traveled was approximately 3 meters (10 feet).

Hagedorn et al. (1978) conducted a study in Lane County, Oregon in which they monitored the survival and migration of antibiotic-resistant *E. coli* and *Streptococcus faecalis* under conditions of saturated flow. The results were three-fold. First, the bacteria moved long distances in a relatively short period of time. Second, the concentrations of bacteria peaked at intervals associated with the rise of the water table following rain events. Third, both *E. coli* and *S. faecalis* survived in "appreciable numbers" (p. 58) over the course of the 32 day sampling period. Within the first 24 hours after inoculation, the bacteria traveled 300 cm (10 feet) and twice, traveled as far as 500 cm (16 feet) in that same time period. The results also indicate that the rate of subsurface flow under saturated conditions is faster than the authors expected. Additionally, as the water table rose, bacteria dispersed in all directions. However, much larger numbers of bacteria were found in the direction of flow, indicating that the bacteria were washed from the inoculation pits and moved as a pulse in the direction of flow.

Rahe et al. (1978) conducted a study which simulated the events that occur when an septic tank absorption bed is inundated. At one site *E. coli* was first recovered 15 meters (49 feet) downslope from the inoculation point, then later recovered 10 meters (33 feet) downslope. The results demonstrate the rapid transport of biological organisms under conditions of saturated flow. The authors suggested that the rapid downslope transport of *E. coli* was due to macropore flow.

Cogger, Hajjar, Moe, and Sobsey (1988) studied the treatment of septic tank effluent in sandy soils with high water tables. They found that depth to the water table had the largest effect on effluent treatment. At the site where the absorption bed had the shallowest water table, attenuation of fecal coliform was always poor. The authors suggest that this was due to the often saturated conditions and the concurrent anaerobic conditions which enhanced the survival and transport of fecal coliform. Their results indicate that saturated soils inhibit attenuation of organisms and facilitate their transport and survival.

Shellfish Sanitation

Clem (1994) provides a comprehensive history of shellfish sanitation and control. In late nineteenth century Europe, physicians and scientists established the link between the consumption of shellfish and enteric illness. A number of physicians observed that many of their patients with typhoid fever had eaten oysters grown in sewage-contaminated water. One physician recommended that legislation governing the harvesting and storage of oysters be enacted, but officials were reluctant to do so for fear of harming the oyster industry. Other scientists conducted extensive sanitary surveys of oyster growing areas and relay areas. The scientists discovered that the relay areas, where the oysters were fattened, were frequently near the mouths of rivers and urban areas where the oysters were exposed to raw sewage. They disseminated this information and published maps clearly delineating those areas known to be free of pollution. It was not until more typhoid outbreaks occurred in Europe and the oyster trade in England declined, due to bad publicity, that Parliament considered legislating the trade. However, due to jurisdictional disputes the legislation never passed. By the late 1800s it was widely accepted in Europe that humans could transmit typhoid to oysters via sewage, and then that the oysters, if eaten raw, could transmit typhoid back to a susceptible person.

It was not until the last half of the nineteenth century that water pollution control issues arose in the United States. As had been customary in Europe until the mid- to late-1800s, human waste and stormwater found their way to the nearest waterway. This did not present a problem for most of the country due to the low population density and the length of the waterways; the amount of waste dumped into the rivers was not so great as to prevent the rivers from purifying themselves (Fuhrman, 1984). However, the dumping of sewage into nearby waterways contaminated the waters of towns situated on estuarine rivers and bays (Clem, 1994).

During the late nineteenth century, the per capita consumption of oysters increased immensely in the United States. Despite the recognition of the link between raw, sewage-contaminated shellfish and enteric illness by European physicians, U.S. physicians did not acknowledge this relationship until just before the turn of the century. In 1894, an outbreak of typhoid fever occurred at Wesleyan University in Connecticut. The epidemiological investigation of the outbreak determined that the common factor among those affected was the consumption of raw oysters at a fraternity banquet. Further investigation led to the discovery of additional cases in students from other universities who had been visiting Wesleyan and partook of the oysters. Officials investigating the outbreak traced the oysters back to the supplier and conducted a sanitary survey of the relay site, a creek where the oysters had been deposited to "freshen and fatten" (Clem, 1994, p. 6). The sanitary survey revealed a private sewer outfall 300 feet from the oyster relay site. This sewer outfall served a house in which two people were suffering from typhoid fever (Clem, 1994).

This outbreak of typhoid fever sparked local interest in the issue and caused people to question the viability of the causative agent, then called *Bacillus typhi* (now *Salmonella typhi*), in oysters and seawater. One researcher conducted bacteriological studies to determine the survival of *B. typhi* under conditions similar to those present in the outbreak. He also studied the organism's ability to multiply in both oysters and seawater. The results indicated that *B. typhi* organisms live longer in the stomach and the juice of the oyster than in the water in which the oyster grows (Clem, 1994).

Interest in shellfish sanitation grew on a national scale as health officials in the United States became sufficiently alarmed by the continued reports of communicable diseases transmitted by shellfish, both in this country and in Europe. Health officials decided to survey the sanitary conditions of the shellfish industry. One researcher studied the effects of relaying polluted oysters to clean waters. The results suggested that relaying oysters from contaminated water to clean water might protect public health by decreasing the number of bacteria (*B. coli*) in the oysters (Clem, 1994).

By 1909, a few states had shellfish control agencies which conducted bacteriological tests on shellfish meat and liquor, and seawater. The Public Health Service and The Bureau of Chemistry also investigated shellfish growing areas. However, none of these agencies used the same method for bacteriological tests and, therefore, the results could not be compared. At the request of the American Public Health Association, these agencies worked to develop a "standard" method for shellfish-related bacteriological testing. Additionally, public health officials continued to conduct research into many aspects of shellfish sanitation - issues such as relaying and cleaning oysters, and harvesting during winter hibernation. This research, combined with the public health education campaign and improved water supplies and sanitation, led to a decrease in the prevalence of typhoid fever on the United States. Between 1916 and 1924, there were no reported typhoid fever outbreaks associated with shellfish (Clem, 1994).

The fact that people were not becoming ill from shellfish grown and fattened in estuarine and river water did not mean that those waters were not being polluted. With increasing frequency, states began to close or restrict harvests from productive shellfish beds because of the pollution levels. As shellfish beds were closed or restricted, it became increasingly difficult for the oyster industry to find clean, reliable beds from which to harvest oysters to meet the demand. Despite the restrictions placed on oyster harvesting an outbreak of typhoid occurred that drew the attention of the Public Health Service (Clem, 1994).

In December, 1924, a multifocal typhoid fever outbreak with significantly increased prevalence was noted in Chicago, New York, Washington DC, and ten other cities. Local health authorities requested that the Public Health Service conduct an epidemiological investigation. As in previous outbreaks of typhoid fever, consumption of raw oysters was the only common factor among those affected. Prior to the discovery that most of the sewage-contaminated oysters could be traced to one supplier, public health officials issued warnings not to eat raw oysters. Oyster sales plummeted, as did sales of other seafood. Due the severe decline in oyster sales, the industry petitioned the federal government to develop a program that would protect the public's health and allow safe interstate transport of oysters (Clem, 1994). In response to this request, the Surgeon General called a conference involving municipal, state and federal authorities, and representatives of the shellfish industry. The members of this conference formulated a program of public health controls for the shellfish industry; this program is the National Shellfish Sanitation Program (NSSP) (Clem, 1994; Leonard & Slaughter, 1990; U.S. FDA, 1995).

The NSSP is a voluntary cooperative effort among the federal government, states and the shellfish industry (Clem, 1994; Leonard & Slaughter, 1990; U.S. FDA, 1995). It is based on the assumption that there is an association between sewage-polluted shellfish growing waters and human illness (Leonard & Slaughter, 1990). The NSSP is designed to provide guidelines for the sanitary growing and processing of shellfish to ensure safe interstate transport of shellfish in order to protect public health. The responsibilities of each NSSP participant are explained in the following paragraph.

The responsibilities of the states are to adopt laws governing the sanitary control of the industry, conduct sanitary surveys of shellfish growing waters, enforce harvesting restrictions in polluted waters, inspect shellfish plants, conduct necessary laboratory investigations, and issue numbered certificates to shellfish dealers who are in compliance with the standards. The states must also forward a list of these certificates to the federal government (U.S. FDA, 1995). The shellfish industry agrees to harvest only from safe growing waters, maintain sanitary conditions in shellfish plants, properly label shellfish for transport with the state-issued certificates, and maintain records which demonstrate the origin and disposition of shellfish. When requested, these records must be made available to the control authorities (U.S. FDA, 1995). The role of the federal government is to review annually each state's shellfish sanitation control plan, determine if it meets the conditions set forth in the current NSSP Manual of Operations, and publish a monthly list of the valid interstate shipping certificate numbers (Leonard & Slaughter, 1990; U.S. FDA, 1995).

National Shellfish Sanitation Program guidelines require that shellfish growing waters be classified into one of five categories. These categories are based on the presence of potential or actual sources of pollution and levels of coliform bacteria in surface waters. Each state classifies its own waters. The classifications are as follows: **approved** – shellfish may be harvested at all times for direct marketing; **conditionally approved** - shellfish may be harvested when water meets the conditions for approved waters, otherwise the waters are temporarily closed to harvesting; **restricted** – shellfish may be harvested if subjected to suitable purification by relaying and the harvester has been granted a permit by the state; **conditionally restricted** – shellfish may be harvested only when water meets the criteria for restricted waters, otherwise the waters are closed to harvesting; and **prohibited** – shellfish intended for human consumption may not be harvested at any time (Leonard & Slaughter, 1990; U.S. FDA, 1995).

Tillamook Bay, Oregon Studies

Routine monitoring of Tillamook Bay, from 1969 to 1971, indicated that there might be a problem with fecal contamination in the Bay, particularly during heavy rain events. Due to potential intervention by the FDA and the possible loss of endorsement by the Oregon Shellfish Sanitation Program, the DEQ, which conducted most of the monitoring related to shellfish, increased monitoring at sewage treatment plants and in the oyster bed during rainy periods. This monitoring showed that, under flooding conditions, there were high total and fecal coliform counts in the oyster beds. Per recommendations from the FDA, additional monitoring was conducted in 1973. This study revealed that Tillamook Bay did not meet NSSP guidelines and that there was a potential hazard unless it could be demonstrated that the bacteria were not of direct fecal origin. Further studies were conducted over the next four years to determine the sources of bacterial pollution and to quantify the seasonality of pollution in the bay. The conclusions relevant to this study were the following: a large percentage of the total and fecal coliforms in water sample were of human and bovine origin, and that the levels of indicator organisms in shellfish samples from Tillamook's conditionally approved beds exceeded NSSP standards. In order to determine the sources and extent of bacterial pollution in Tillamook Bay, the Tillamook Bay Bacteria Study was started in 1979 (Crane & Moore, 1986; Jackson, 1985; Newell, 1998).

In 1982, Jackson and Glendening published the results of the Tillamook Bay Bacteria Study. The report addressed the water quality of each of the river subbasins that drain into the bay. For each of the subbasins the impact of on-site systems on water quality was addressed. The results indicated that the majority of bacterial pollution in the Tillamook River basin was from homes with farms near the river. No conclusive statements could be made about the contribution of failing or inadequate on-site systems. In the Trask River basin, two tributaries were identified as sources of elevated fecal coliform counts which affected the quality of water in the Trask River. The results were inconclusive, but suggest that failing or inadequate on-site systems were the most likely cause of the elevated fecal coliform counts. Most of the fecal sources in the Wilson River basin required saturated soil conditions to create a contaminated discharge. The sources identified in the report include on-site systems that fail under saturated ground conditions. No conclusive results could be drawn about the impact of on-site systems on water quality in the Wilson River. For both the Kilchis and Miami River basins no conclusive statement could be made about on-site system's contribution to the fecal bacteria in the rivers. The authors identified only those homes close to waterways as potential sources of fecal contamination.

The results from the Tillamook Bay Bacterial Study, in conjunction with previous studies, allowed officials to catalog several sources of bacterial contamination. The primary potential contributors of bacterial pollution to the bay were identified as sewage treatment plants, on-site systems, and dairy wastes. The contribution of on-site systems to bay pollution was estimated to be slight to moderate, specifically for areas of failing or nonexistent systems. Twelve direct failures were identified and shown to be chronic contributors of bacterial pollution because they were "fixed" by diverting waste directly to sloughs or ditches (A Comprehensive Source Control Program, n.d.; Crane & Moore, 1986; Jackson & Glendening, 1982).

In addition to determining the sources and extent of pollution in Tillamook Bay and the watershed, Jackson and Glendening (1982) reevaluated the County Subsurface Sewage Program for the period from January, 1974 to December, 1979. They reevaluated 184 sites that had been approved for an on-site system during that period. They found that 20% (37 sites) of the lots did not meet current on-site rules and should not have been issued permits for on-site system construction. The 20% figure was presumed to be an appropriate approximation of the failure rate for the entire County.

A subsequent bacterial analysis, for water years 1979 to 1987, revealed that the 20% failure rate was not accurate for the entire County. This analysis indicated that the failure rate was 8%, and that only 2% of those were polluting surface waters (Newell, 1998).

Since 1988, more than 1700 on-site systems have been inspected. The 1988 Tillamook River sanitary survey of 467 systems revealed 431 operational systems, 6 direct and 29 indirect failures, and 1 marginal system. In 1989, the Trask and Wilson Rivers were surveyed. The Trask River survey of 529 systems showed 519 operational systems and 10 direct failures. On the Wilson River, 491 systems were surveyed, 28 of which were direct failures. In 1991, 172 properties on the Kilchis River were surveyed. The survey revealed 119 operational systems, 9 direct, 11 indirect, and 9 unspecified failures, 14 marginal systems, and 10 unknowns. In 1991, 38 properties on the Miami River were also surveyed. Of those 38 systems, 27 were operational, 3 were direct failures, 5 were indirect failures, 1 was marginal, and 2 were unknowns. In 1996, 32 Bayocean Road properties were surveyed. Bayocean Road runs adjacent to Tillamook Bay and leads to the Cape Meares housing area. The survey revealed 20 operational systems, 1 direct failure, 5 marginal systems, and 6 unknowns. The failure rate for these sanitary surveys was 6-7%, which is similar to the 8% failure rate that the 1979-1987 sanitary surveys revealed (Newell, 1998).

METHODS

Survey Area and Site Selection

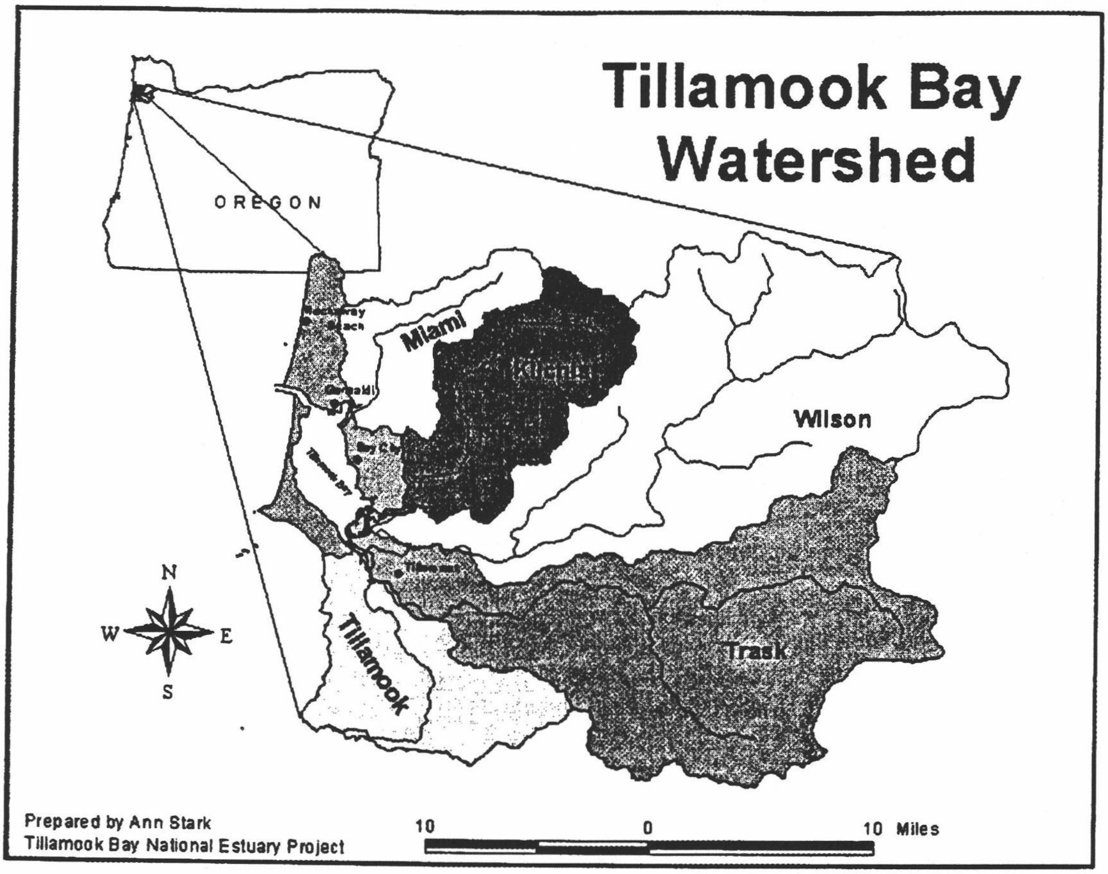
Tillamook Bay is a small, shallow estuary located on the northwest Oregon coast. It covers an area of approximately 13 mi^2. Five rivers – the Tillamook, Trask, Wilson, Kilchis, and Miami – flow into the bay from the south, east, and north. The Tillamook Bay Watershed drains 560 mi^2 of timber and dairy lands. Temperate rainforest comprises most of the watershed; the alluvial plains of the lower watershed are used primarily for dairy agriculture (Crane & Moore, 1986; Jackson, 1985; Leonard & Slaughter, 1990; Nelson, Follensbee, & Hinzman, 1998).

The U.S. Food and Drug Administration (FDA) requires that complete sanitary surveys be conducted at least every 12 years for all approved, conditionally approved, restricted, and conditionally restricted shellfish growing areas (U.S. FDA, 1995). The three components of a complete sanitary survey are as follows: (1) a shoreline survey; (2) an evaluation of the meteorological effects, hydrographic influences and geographic characteristics; and (3) the results of bacteriological water sampling (U.S. FDA, 1995).

This study was limited to conducting the shoreline survey and analyzing the data collected during the survey. This shoreline survey was conducted in accordance with the minimum requirements for performing shoreline surveys in shellfish growing areas, as set forth in Appendix B of the National Shellfish Sanitation Program Manual of Operations, 1995 revision (U.S. FDA, 1995).

The Tillamook County Community Development department made a decision that the survey area should include the lowlands surrounding Tillamook Bay. The city of Tillamook was excluded from the survey area because it is sewered and wastewater is treated at a treatment facility. Included in the survey were properties with on-site systems that are located: (1) on the lowlands and within 500 feet of any waterbody that drains into Tillamook Bay; and/or (2) in communities with a high housing density. The survey area, therefore, encompasses properties within 500 feet of the Tillamook, Trask, Wilson, Kilchis, and Miami Rivers; the Cape Meares subdivision; and other high housing density areas (e.g. Idaville). See the following map, which includes the watersheds of the five rivers: the Miami, Kilchis, Wilson, Trask, and Tillamook.

All properties located within the survey area were inspected unless they met one of the following criteria: (1) the on-site system had been installed and approved within the last five years; or (2) the on-site system had been repaired and approved within the last five years; or (3) the property owner declined to participate in the survey.



Map of the Tillamook Bay Watershed in Tillamook County, Oregon. Source: Tillamook Bay Environmental Characterization: A Scientific and Technical Summary. 1998. Produced by Ann Stark, Tillamook Bay National Estuary Project, Garibaldi, OR.

Data Collection

This study used three sets of data to develop the on-site system profile of the area: (1) information gathered from Tillamook County Community Development department files; (2) data acquired during a survey with on-site system homeowners; and (3) on-site inspection of the system.

Tillamook County Community Development Department Files

A list of all tax lots, or parcels, with an assessed value greater than zero dollars ($0) within the survey area was generated from the Tillamook County Assessor's database. Each parcel on the list was identified with township, section, range, and tax lot. It was assumed that the lots with an assessed value greater than zero dollars were developed and, therefore, might have an on-site system. Perusal of the files enabled the researcher to determine whether or not an on-site system had been installed on the lot, and if the on-site system required surveying. Decisions to survey the system were based on the type of system, installation and repair dates, and whether or not the system had been inspected and approved.

In order to ensure that the surveys were conducted on the correct tax lot, assessor's maps were used as a base for address maps created for the survey staff. Addresses, from the Tillamook County address maps, were transcribed onto the assessor's maps, creating address maps (Appendix A) for the survey staff. When a parcel did not need to be inspected it was recorded on the maps. It was also noted on the maps if an owner chose to not participate in the survey.

Frequently, addresses were found on the County address maps for which the Tillamook County Community Development department had no file. When this occurred, the address was recorded on the survey staff's address map, and the survey staff was asked to gather as much information as possible about the on-site system during the homeowner interview.

Survey Development

Survey forms (Appendix B) for each parcel in the survey area were created by the researcher and the Tillamook County Environmental Program Manager prior to surveying. The following information was recorded on the survey forms prior to surveying: township, section, range, tax lot, owner name and address, site address, and information on installation and repair from the Community Development files. It was later discovered that the survey staff found it difficult to locate the on-site system without a site map that detailed the location of the components of the system. Therefore, there were a large number of surveys returned to the researcher with "unknown" system function and "unknown" environmental impact. In order to reduce the number of "unknowns" caused by inadequate information on system location, a copy of a site plan indicating the location of the on-site system components was included on the survey form for the second round of surveys. Additionally, when possible, a site plan was located and attached to the survey forms for the first round surveys with "unknown" system function and environmental impact. These lots were resurveyed during the second round of surveys.

The remainder of the survey was designed so the survey staff could record, upon determination, the operational status of the on-site system, its environmental impact, and responses from the homeowner interviews.

A letter (Appendix C) was sent to the property owner of each parcel that required surveying. The letter explained the need for, and requested owner participation in, the survey. If the owners chose not to participate in the survey and notified the appropriate Tillamook County department, it was noted on the address maps so that the survey staff knew not to survey that lot.

In order to mail letters to property owners (see Survey Administration) address labels were printed from the assessor's database. Two problems were encountered. The first was that there were labels for properties which were not assessed a value greater than zero dollars, and were therefore not on the list of properties in the survey area, but for which there was an address that was in sequence with other houses on the street (i.e. in the survey area). This indicated that there might be an on-site system on the property that has not been inspected and approved. Letters were sent to these homeowners. The other problem was that some landowners own more than one parcel of land. In this case, property owners were sent only one copy of the letter.

Training of Survey Staff

Because the survey was conducted with volunteers from the community, training sessions were held to ensure that data were collected in a systematic and reliable manner. Volunteers were solicited from organizations and businesses in Tillamook for which water quality in Tillamook Bay is of interest.

The Tillamook County Environmental Program Manager conducted a two-part training program. The first part was a lecture in which volunteers were given information on the reasons for the survey, deadlines, and how to fill out the survey forms. The second part of the training involved a site visit to an existing septic system. Volunteers were given suggestions on how best to locate the components of an on-site system in the absence of a site map and how to identify marginal and failing systems.

Survey Administration and Absorption Bed Inspections

Surveys were conducted in late spring (April 27 – May 5, 1998) and late summer (August 10 – August 31, 1998). Ideally, the homeowner was present at the time of the survey. In this case, the survey staff identified themselves and briefly described the purpose of the survey. They then verified the location of the on-site system and the installation and/or repair dates included in the County files. The survey staff also inquired about the maintenance (e.g. pumping) schedule, if any, that the homeowner followed and asked about additive use. They also asked if the homeowner had problems with the on-site system slowing down or backing up, both of which can be indicators of a marginal system, or a system that is beginning to fail. Prior to inspecting the absorption bed, the survey staff confirmed that the inspection was acceptable to the homeowner. Absorption bed inspection consisted of the survey staff walking over the absorption bed looking for raw effluent on the ground surface, subsidence along the drainlines, or other disturbances which might indicate that the system function had been compromised. The survey staff also noted other discharges of waste that might negatively impact water quality.

If the homeowner was not present at the time of the survey, it was assumed that the site map indicating the location of the on-site system was correct and only the absorption bed inspection was done. When there was no site map and the homeowner was not present at the time of inspection, the survey staff tried to identify the location of the on-site system. When they were able to locate the system, they conducted an absorption bed inspection. The researcher made repeat visits to many of the lots where the on-site system could not be located in an attempt to conduct homeowner interviews and absorption bed inspections.

Reliability of Data Collection

Because seven individuals completed the surveys and absorption bed inspections it was necessary to ensure the reliability of the data. In order to demonstrate reliability of the data, the researcher independently surveyed the majority of the on-site systems previously surveyed by each of the other survey staff members. There were no inconsistencies found between the results of those surveys conducted by the researcher and those conducted by volunteers.

RESULTS

On-Site System Characteristics

Four hundred ninety three (493) tax lots were identified for the survey, using the methodology described in the previous chapter. However, some of these tax lots had more than one building with an on-site system, so the sample size for this survey increased to 509. Of these, 42 properties were not surveyed for the following reasons: the house was under construction (n=10), abandoned (n=2), or vacant (n=7); the house had been connected to a city sewer system (n=2); the property could not be located (n=6); the property had no structures on it (n=8); or the structure(s) on the property had no on-site system(s) (n=7). An additional 82 properties were not surveyed for one of the following reasons: the on-site system had been inspected and approved by the County On-Site Specialist within the last five years (n=33), the owner chose not to participate in the survey (n=46), or the data collector was potentially at risk upon entering a property (n=3). Therefore, 385 of the 509 properties were surveyed.

A summary of the results is shown in Table 1. Of the 385 on-site systems surveyed, 300 (77.9%) were classified as operational. Fourteen (3.7%) systems were classified as marginal. Seventy-one (18.4%) systems were classified as unknown.

Of the 385 on-site systems surveyed, 249 were in areas designated as upland location, and 136 were in areas designated as hydric. For the purpose of this study, upland location was defined as those areas for which the parcel of land was not adjacent to a waterway. Hydric locations were those parcels which were adjacent to a waterway, or which had hydrophilic vegetation.

The majority of the systems, 331 (86%), were standard septic systems. Thirteen (4%) were alternative on-site systems (e.g. sand filter), and 41 (11%) systems were unknown. Systems were classified as unknown when the type and location of the system was not recorded in the County files, nor could any information be gathered on site. For most of the properties classified as unknown, information could not be obtained from the landowner because they were not present at the time of the survey.

Research Questions

Failure Rates

The first research question investigated the failure rate of on-site systems in a selected area of the Tillamook Bay watershed. Failing on-site systems were defined as those which directly discharge untreated effluent to the ground surface or to a surface body of water. No failing on-site

Table 1: Summary of Results by Drainage Basin

		Tillamook River n=47 (%)	Trask River n=92 (%)	Kilchis River n=55 (%)	Wilson River n=59 (%)	Miami River n=27 (%)	Cape Meares n=105 (%)	Total N=385
System Function	operational	39 (83.0)	74 (80.4)	47 (85.5)	43 (72.9)	20 (74.1)	77 (73.3)	300
	marginal	3 (6.4)	3 (3.3)	2 (3.6)	1 (1.7)	1 (3.7)	4 (3.8)	14
	unknown	5 (10.6)	15 (16.3)	6 (10.9)	15 (25.4)	6 (22.2)	24 (22.9)	71
Soil Type	upland	22 (46.8)	47 (51.1)	46 (83.6)	29 (49.2)	15 (55.6)	90 (85.7)	249
	hydric	25 (53.2)	45 (48.9)	9 (16.4)	30 (50.8)	12 (44.4)	15 (14.3)	136
System Type	standard	44 (93.6)	82 (89.1)	54 (98.2)	54 (91.5)	23 (85.2)	74 (70.5)	331
	alternative	1 (2.1)	0 (0)	0 (0)	0 (0)	1 (3.7)	11 (10.5)	13
	unknown	2 (4.3)	10 (10.9)	1 (1.8)	5 (8.5)	3 (11.1)	20 (19.0)	41

systems were located during the course of this study. Therefore, the failure rate of on-site systems in the surveyed portion of the Tillamook Bay watershed was zero (0).

During the survey there were two on-site systems identified as possible failures. Both sites were inspected by the County On-Site Specialist and it was determined that neither was failing. One had what appeared to be dried septage on the ground in the area of the drainfield. This was identified as waste that was not of human origin. The other site appeared to be a collapsed septic tank with a wooden cover at ground level. It was determined that this on-site system was undergoing renovation. For final analysis, both systems were classified as operational.

Marginal Rates

The second research question asked what was the rate of failing and/or marginal on-site systems for each of the six designated drainage basins. The rate of failing systems in each of the drainage basins was zero (0). Marginal systems were defined as those with thick, lush growth over the tank and/or absorption bed and the owner/tenant states that the system is sluggish, but which do not discharge untreated effluent to the ground surface or to a surface body of water. The mean marginal rate was 3.75/ 100. The rate of marginal systems for each drainage basin will be addressed independently. Rates are given per 100 (rate/100) because this denominator provided more easily understood results (see Table 2).

Table 2: Rate of Marginal Systems by Drainage Basin

		Tillamook River	Trask River	Kilchis River	Wilson River	Miami River	Cape Meares
Marginal Systems	n/total surveyed	3/47	3/92	2/55	1/59	1/27	4/105
	rate (per 100)	6.4	3.3	3.6	1.7	3.7	3.8

Forty-seven (47) on-site systems in the Tillamook River drainage basin were surveyed. Three (3) of these systems were classified as marginal. Therefore, 3 of 47 systems were classified as marginal, and the rate of marginal on-site systems was 6.4/100.

Ninety-two (92) on-site systems in the Trask River drainage basin were surveyed. Three (3) of these were classified as marginal systems. The rate of marginal on-site systems in the Trask River drainage basin was 3.3/100.

In the Kilchis River drainage basin, 55 on-site systems were surveyed. Two of these systems were classified as marginal. The rate of marginal on-site systems was 3.6/100 in the Kilchis River drainage basin.

Fifty-nine (59) on-site systems were surveyed in the Wilson River drainage basin. On these 59 systems, one (1) was classified as marginal.

Therefore, the rate of marginal on-site systems in the Wilson River drainage basin was 1.7/100.

One (1) of twenty-seven (27) on-site systems was classified as marginal in the Miami River drainage basin. The rate of marginal on-site systems was 3.7/100.

One hundred five (105) on-site systems were surveyed in the Cape Meares area. Four (4) of these were classified as marginal systems. Therefore, the rate of marginal on-site systems in Cape Meares was 3.8/100.

System Function and System Location

The third research question addressed the relationship between on-site system function and soil type. As stated previously, of the 385 systems surveyed, 249 were located in upland locations and 136 in hydric locations (Table 3). Locations were classified as upland for those properties which are not directly adjacent to Tillamook Bay, the Pacific Ocean, a river, or a creek. Locations were classified as hydric for those properties which are adjacent to Tillamook bay, the Pacific Ocean, a river, or a creek, or by the presence of hydrophilic vegetation. The majority, 108 (79.4%) of 136 systems in hydric locations were operational; five (3.7%) were marginal, and 23 (16.9%) were unknown. Of those systems in upland locations, 192

(77.1%) were operational, 9 (3.6%) were marginal and 48 (19.3%) were unknown.

Analysis of the relationship between on-site system function and system location was conducted using the chi-square test, a type of contingency table. The chi-square test is used to evaluate whether observed frequencies reflect the independence of two qualitative variables. In this case, the qualitative variables were soil type and system function. The test was conducted at the 0.05 (α=0.05) significance level, with two degrees of freedom (df=2). The p-value was calculated using Microsoft Excel. The chi-square test produced a value of 0.33 (χ^2=0.33). With df=2, the p-value for this test is p=0.847. Because $p>\alpha$, the null hypothesis cannot be rejected; this indicates that system function is independent of system location. The implications of this result will be addressed in the discussion chapter.

In order to ensure that the chi-square test is valid, certain parameters must be met; no cells in the expected table may have a value less than one, and no more than 20% of these cells may have a value less than five. Due to the sample size (385), performing chi-square analysis was only possible for the analysis of the relationship between system function and system location; other comparisons produced expected values less than one and/or contingency tables with greater than 20% of expected cells less than five.

Therefore, the chi-square test was only used to analyze the relationship between system function and system location.

The following results are those for the systems in hydric locations (see Table 3). Within the Tillamook River drainage basin, 21 (84%) were operational, 1 (4%) was marginal and 3 (12%) were unknown. Within the Trask River drainage basin, 40 (88.9%) were operational, 2 (4.4%) were marginal and 3 (6.7%) were unknown. Within the Kilchis River drainage basin, 7 (77.9%) were operational, 1 (11.1%) was marginal and 1 (11.1%) unknown. Within the Wilson River drainage basin, 22 (73.3%) were operational, none were marginal and 8 (26.7%) were unknown. Within the Miami River drainage basin, 7 (58.3%) were operational, none were marginal and 5 (41.7%) were unknown. Within Cape Meares 11 (73.3%) were operational, 1 (6.6%) was marginal and 3 (20%) were unknown.

The following results describe those systems in upland locations (see Table 3). In the Tillamook River drainage basin 18 (81.8%) were operational, and 2 (9.1%) each were marginal and unknown. Within the Trask River drainage basin 34 (72.3%) were operational, 1 (2.1%) was marginal and 12 (25.5%) were unknown. In the Kilchis River drainage basin, 40 (86.9%) were operational, 1 (2.2%) was marginal and 5 (10.9%) were unknown. In the Wilson River drainage basin, 21 (72.4%) were operational, 1 (3.5%) was marginal and 7 (24.1%) were unknown. Within the Miami River drainage basin, 13 (86.7%) were operational, and 1 (6.6%)

Table 3: System Location versus System Function

		Tillamook River	Trask River	Kilchis River	Wilson River	Miami River	Cape Meares	Ave. %
Total Surveyed		n=47 (%)	n=92 (%)	n=55 (%)	n=59 (%)	n=27 (%)	n=105(%)	N=385
Hydric Location	o*	21 (84)	40 (88.9)	7 (77.8)	22 (73.3)	7 (58.3)	11 (73.3)	79.4
	m*	1 (4)	2 (4.4)	1 (11.1)	0 (0)	0 (0)	1 (6.6)	3.7
	u*	3 (12)	3 (6.7)	1 (11.1)	8 (26.7)	5 (41.7)	3 (20)	16.9
Subtotal		25	45	9	30	12	15	
Upland Location	o*	18 (81.8)	34 (72.3)	40 (86.9)	21 (72.4)	13 (86.7)	66 (73.3)	77.1
	m*	2 (9.1)	1 (2.1)	1 (2.2)	1 (3.5)	1 (6.6)	3 (3.3)	3.6
	u*	2 (9.1)	12 (25.5)	5 (10.9)	7 (24.1)	1 (6.6)	21 (23.3)	19.3
subtotal		22	47	46	29	15	90	

* o = operational; m = marginal; u = unknown

each was marginal and unknown. In the Cape Meares drainage basin, 66 (73.3%) were operational, 3 (3.3%) were marginal and 21 (23.3%) were unknown.

System Function and Type of System

The fourth research question addressed the relationship between on-site system function and type of system. As stated previously, the majority of the systems surveyed were standard on-site systems. Only 13 of the 385 systems surveyed were alternative (sand filter) on-site systems.

Of the 13 alternative systems surveyed, 12 (90.9%) were operational and 1 (9.1%) was functioning marginally. The marginal system was in the Cape Meares drainage basin, as were 10 of the operational systems. One of the remaining operational alternative on-site systems was in the Tillamook River drainage basin and the other was in the Miami River drainage basin (see Table 4).

The following results enumerate the system function for the standard systems in each of the drainage basins (see Table 4). In the Tillamook River drainage basin, 38 (86.4%) systems were operational, and 3 (6.8%) each were marginal and unknown. In the Trask River drainage basin, 73 (89%) were operational, 3 (3.7%) were marginal and 6 (7.3%) were unknown. Within the Kilchis River drainage basin, 47 (87%) were

Table 4: System Type versus System Function

		Tillamook River	Trask River	Kilchis River	Wilson River	Miami River	Cape Meares
Total Surveyed		n=45 (%)	n=82 (%)	n=54 (%)	n=54 (%)	n=24 (%)	n=85 (%)
Standard	o *	38 (86.4)	73 (89)	47 (87)	43 (79.6)	19 (82.6)	62 (83.8)
	m *	3 (6.8)	3 (3.7)	2 (3.7)	1 (1.9)	1 (4.4)	3 (4.1)
	u *	3 (6.8)	6 (7.3)	5 (9.3)	10 (18.5)	3 (13)	9 (12.1)
subtotal		44	82	54	54	23	74
Alter-native	o *	1 (100)	0 (0)	0 (0)	0 (0)	1 (100)	10 (90.9)
	m *	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (9.1)
subtotal		1	0	0	0	1	11

*o = operational; m = marginal; u = unknown

operational, 2 (3.7%) were marginal and 5 (9.3%) were unknown. In the Wilson River drainage basin 43 (79.6%) were operational, 1 (1.9%) was marginal and 10 (18.5%) were unknown. In the Miami River drainage basin, 19 (82.6%) were operational, 1 (4.4%) was marginal and 3 (13%) were unknown. In the Cape Meares drainage basin, 62 (83.8%) were operational, 3 (4.1%) were marginal and 9 (12.1%) were unknown.

Additional Information

Of the 385 on-site systems surveyed, 37 (9.6%) had been installed within the last five years, 43 (11.2%) within six to ten years, 20 (5.2%) within 11 to 15 years, 35 (9.1%) within 16 to 20 years, and 51 (13.2%) over

20 years prior to the survey. The date of installation was unknown for 199 (51.7%) of the on-site systems. For information on specific drainage basins see Table 5.

Table 5: Age of On-Site Systems

Age of system (years)	Tillamook River	Trask River	Kilchis River	Wilson River	Miami River	Cape Meares	Total
	n=47	n=92	n=55	n=59	n=27	n=105	N=385 (%)
<5	4	10	4	6	2	11	37 (9.6)
6 – 10	9	7	5	12	3	7	43 (11.2)
11 – 15	4	5	2	2	3	4	20 (5.2)
16 – 20	9	9	10	4	2	1	35 (9.1)
>20	9	20	3	9	9	1	51 (13.2)
Unknown	12	41	31	26	8	81	199 (51.7)

Eleven (2.9%) of the on-site systems had been pumped/maintained within the six months prior to the survey and 15 (3.9%) had been pumped between six months and one year prior to the survey. Sixteen (4.1%) had been pumped one to two years prior to the survey and 24 (6.2%) pumped three to five years prior to the survey. Thirty-one (8.1%) on-site systems had been pumped more than five years prior to the survey. Fifty-one (13.2%) of the systems had never been pumped. Maintenance for the majority of the systems, 237 (61.6%), was reported as unknown. For information on specific drainage basins see Table 6.

Table 6: On-Site System Maintenance (most recent pumping)

Last Service	Tillamook River	Trask River	Kilchis River	Wilson River	Miami River	Cape Meares	Total
	n=47	n=92	n=55	n=59	n=27	n=105	N=385 (%)
Within 6 months	2	3	3	2	1	0	11 (2.9)
6 months – 1 year	6	4	1	2	2	0	15 (3.9)
1 – 2 years	1	7	3	2	1	2	16 (4.1)
3 – 5 years	4	13	1	2	1	3	24 (6.2)
More than 5 years	3	11	4	9	1	3	31 (8.1)
Never	8	12	7	13	7	4	51 (13.2)
Unknown	23	42	36	29	14	93	237 (61.6)

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Discussion

Although a previous study reported that the expected failure rate of on-site systems in coastal communities is 6% to 7% (Newell, 1998), this rate of failure was not confirmed by this study. Instead, a failure rate of zero (0) was found. The apparent lack of failing on-site systems was most likely due to the fact that the survey was conducted during the summer months, when the water table was at its lowest. When the water table is low, effluent from failing on-site systems is absorbed into the soil and does not surface; when the water table is high, effluent has nowhere to go but to the surface, because the soil is already saturated with water (J. Federico, personal communication, May 15, 2000; Garreis, 1994).

Another possible explanation for the apparent lack of failing on-site systems is that forty-nine (49) systems were not surveyed because the owners chose to not participate in the survey. Out of a sample size of 434, 385 systems were surveyed and 49 systems were not surveyed. The 49 systems that were not surveyed represent 11.3%, and this number of systems could easily hide the expected 6% to 7% failure rate. Although the researcher suspects that owners who chose to not participate in the study may be more likely to have failing systems, the researcher was unable to confirm this in the study.

There were an additional 33 on-site systems that had been inspected and approved by the County within the last five years that were not surveyed. It is also possible, but less likely, that some of these systems had failed.

Participation in the survey was voluntary and as stated previously, 11.3% of homeowners in the designated survey area declined to participate. The letter sent to homeowners by the county indicated that if a problem were found it would need to be addressed by the homeowner. This information is necessary to ensure that improperly functioning on-site systems are brought into compliance, however it is possible that the letter discouraged participation in the survey due to its regulatory/enforcement tone.

The results of the Tillamook Bay Bacteria Study are inconclusive about the contribution of failing on-site systems to pollution in Tillamook Bay, however the data collected in the Trask River basin suggest that failing or inadequate systems were the most likely cause of elevated fecal coliform counts (Jackson and Glendening, 1982). The Tillamook Bay Bacteria Study, in conjunction with other studies, indicates that failing or nonexistent on-site systems contribute slightly to moderately to pollution in Tillamook Bay (A Comprehensive Source Control Program, n.d.; Crane & Moore, 1986; Jackson & Glendening, 1982). Jackson and Glendening's (1982) estimated 20% failure rate for on-site systems in the County was later revised to 6% to

7%, based on sanitary surveys conducted since 1988 (Newell, 1998). Despite the belief that there are many failing on-site systems, researchers have not been able to confirm rates greater than 6% to 7%. This is supported by Garreis (1994), who reports that sanitary surveys conducted in Maryland in 1988 and 1989 found failure rates of 0.3% and 1.4%, respectively.

The rates of marginal systems found in this study ranged from a low of 1.7/100 in the Wilson River drainage basin, to a high of 6.4/100 in the Tillamook River drainage basin: Two-thirds of the marginal rates were found to be between 3/100 and 4/100. The on-site system inspections conducted between 1988 and 1996 revealed a range of rates of marginal systems (Newell, 1998). In 1988, a survey of 467 on-site systems in the Tillamook River drainage basin revealed a marginal rate of 0.2/100 (1/467). A 1996 survey along Bayocean Road, which leads to Cape Meares, revealed that 6 of 32, or 18.75/100, systems were functioning marginally. Two other surveys revealed marginal rates of 2.6/100 (1/38) in the Miami River drainage basin and 8.1/100 (14/172) in the Kilchis River drainage basin. While the range of rates of marginal on-site systems in previous Tillamook County sanitary surveys is quite broad, the rate of marginal systems found in the current study is in keeping with previous findings.

Many of the systems which were classified as marginal in the current study were classified as such due to comments made by the homeowner or tenant about the speed with which plumbing fixtures drain (i.e. shower, tub). The "slowing down" of the on-site system indicates that the system is no longer functioning as well as it should or that the tank needs to be pumped. Other systems were classified as marginal due to thick, lush growth of grass along the drainlines. Thick, lush grass growth can indicate that effluent is not being adequately treated within the system, and that the plants are receiving additional nutrients from the effluent.

Rates of marginal on-site systems may be an indicator of the trend of on-site system function in a given area, particularly if the systems in an area were installed in the same time period. Given that this survey was conducted during the summer, the marginal rates calculated for this study might also indicate areas of potential failure during the winter months when the water table is highest.

In order to ensure that on-site systems function properly they must be maintained. Maintenance generally consists of an annual inspection and, depending on use, pumping every 3 to 5 years (Salvato, 1992). For the majority (61.6%) of systems surveyed, the date of last service (pumping) was unknown. Almost one-fifth (17.1%) had serviced their systems within the last five years, whereas 8.1% had serviced their systems more than 5 years prior to the survey. The remainder (13.2%) had never serviced their on-site systems. A study conducted in Washington found that for one-quarter (25.2%) of the on-site systems surveyed the date of last service was unknown and that 31% had never been pumped. Another one-third (29.5%) of the systems had been serviced within the five years before the survey and 14.4% had been serviced more than 5 years prior to the survey (Analyzing nonpoint, 1990). The results from the Washington survey differ from those of the current study. The wide range of dates of last service and the almost two-thirds majority of unknown last service indicate the varying levels of knowledge pertaining to on-site systems. The apparent lack of consumer knowledge suggests that there exists a potential for future problems; if homeowners are not knowledgeable about their on-site systems, they might have failing systems and not realize the consequences.

Canter and Knox (1984) state that the design age for many on-site systems is 10 to 15 years. The results of this study and another survey conducted in Washington neither support nor negate this statement. In this study 9.6% of the systems were less than five years old, 11.2% were between six and ten years old, 5.2 % were between 11 and 15 years old, and 9.1% were between 16 and 20 years old. The remainder were either more than 20 years old (13.2%) or had an unknown age (51.7%). A survey conducted in Washington found that 32% on the surveyed systems were less than five years old, 24% were between five and ten years old, 28% were between 10 and 20 years old, and 16% were more than 20 years old

(Analyzing nonpoint, 1990). There do not appear to be any patterns with the lifespan data available.

The age of the majority (9) of the marginally functioning systems in this study was unknown. However, one was installed two years prior to the survey and another, 13 years before the survey. The remaining three were installed more than 20 years before the survey. The data do not appear to demonstrate any patterns relating age to functionality nor maintenance status.

The majority (86%) of the systems surveyed were standard on-site systems. Thirteen (3.4%) of the 385 systems surveyed were alternative systems. Eleven (85%) of the alternative sand filter systems were in Cape Meares. Cape Meares is essentially at sea level and surrounds Cape Meares Lake; it has a very shallow water table. Sand filters have only been approved for use in Oregon since 1980 (Bushman, 1996), therefore, there are far fewer of this type of on-site system. However, the high water table in the Cape Meares area makes it an appropriate site for alternative systems. There are two possible explanations for the larger number of alternative systems in Cape Meares, both of which are based on the depth to the water table. The first is that lots developed since 1980 were most likely only approved for alternative systems, not standard systems. The second possible explanation is that alternative systems were the only approved replacement for houses with standard systems which had failed.

In this study, the level of functionality was classified as unknown for 18.4% of the systems surveyed. Previous studies indicate that 5.26% to 18.75% of the total on-site systems surveyed were classified as unknown (Newell, 1998). While the percentage of systems classified as unknown in this study is within the range found in previous studies it falls near the top of that range. The number of systems classified as unknown in the current study was due to the researcher's inability to speak with every homeowner and incomplete County records.

Oregon has stringent rules governing the siting of on-site systems because it has been demonstrated that the systems' function depends on soil and site characteristics. Soil texture, structure and consistence, as well as restrictive horizons and macropores, influence the ability of a soil to transport liquids and treat effluent. Optimal treatment of effluent occurs under conditions of unsaturated flow, whereas conditions of saturated flow decrease the attenuation of bacteria (Kleiss & Hoover, 1986, Salvato, 1992). Studies conducted by Canter and Knox (1984), Cogger and Carlile (1984), Cogger et al. (1988), and Stewart and Reneau (1988) support this. These authors demonstrated that soils with seasonally or permanently high water tables, conditions which lead to saturated flow in the absorption trenches, are unsuitable for on-site systems due to increased pollution of groundwater. Reneau et al. (1989) discuss the limitations to infiltration and effluent treatment caused by shallow water tables, restrictive horizons, and the intrusion of surface or groundwater into drainfields.

It has been demonstrated that system location and on-site system function are closely interrelated (Canter & Knox, 1984; Cogger et al., 1988; Harris, 1995; Reneau et al., 1989; Salvato, 1992; Stewart & Reneau, 1988). However, this was not confirmed in this study. The results of this study show that 79.4% and 77.1% of the systems surveyed in hydric and upland locations, respectively, were operational. Percentages of marginal systems in hydric and upland locations were found to be 3.7% and 3.6%, respectively. Results showed that 16.9% of hydric locations and 19.3% of upland locations had system function classified as unknown. These results do not support the existing literature, which would suggest that there should have been a significant difference in the number of failing systems in hydric and upland locations. These results are most likely due to the fact the survey was conducted during the summer when the water table was at its lowest and, therefore, did not reveal failing systems. Garreis (1994) supports this suggestion; she states that, "[t]he time of year plays an important role in detecting failing septic systems. Many systems, which malfunction in wet weather months when the ground water table is high, perform well during the hot, dry summer months" (p. 301).

The Tillamook Bay area receives approximately 90 inches of rainfall annually, most of which occurs between November and March (USDA, 1964). This rainfall recharges aquifers and replenishes soil moisture content during the winter months (Coulton, 1998; Coulton, Williams, & Brenner, 1996). Rainfall in Tillamook and the subsequent increase in soil saturation and rise of water tables pose a threat to the proper functioning of on-site systems, particularly those on land near rivers and other waterways – land classified as hydric in the current survey. Saturated flow causes inadequate treatment of effluent and enhances the rapid transport of microbial pollution (Hagedorn et al., 1978; Rahe et al., 1978; Reneau et al., 1989; Romero, 1970).

Microbial pollution is a problem in almost all shellfish growing waters in developed countries (Martinez-Manzanares et al., 1992). Eutrophication of estuaries, caused by high levels of nutrients, is also of concern (NOAA studies coastal water quality, 1997; Burroughs, 1993; Newell, 1998). Levels of bacteria and nutrients in water tend to rise simultaneously since both have the same sources. Eutrophication does not appear to be a problem in Tillamook Bay, however there have been reports of algal blooms in the lower reaches of the tributaries (Newell, 1998).

Shellfish harvesting in Tillamook Bay is frequently closed during storm events due to flood stage. The relationship between high bacterial concentrations and flood stage was established many years ago. Failing on-site systems have been identified as one of the potential contributors of bacterial pollution to Tillamook Bay (Crane & Moore, 1986; Newell, 1998;

Stelma & McCabe, 1992). While on-site systems are not the primary contributor of bacteria to Tillamook Bay, those which are improperly sited and/or improperly maintained may contribute significant numbers of microbes to the Bay.

Since the collection of data for this study in 1998, discussions have occurred with the Tillamook County On-Site Specialist. During these discussions, it was revealed that there are a number of failing on-site systems in the county, many in the area designated for the 1998 Shoreline Survey.

There has been no extensive, randomized surveying since 1998 but known problem areas are being investigated on a case-by-case basis. It has been demonstrated that many of the on-site systems investigated in this manner are failing. While the survey conducted for this study did not reveal these failing systems, they do exist.

Conclusions

A shoreline survey of 385 on-site systems was conducted in a designated area of Tillamook County in order to determine a failure rate, a marginal rate, and to address the relationship between system function and both system location and system type.

Previous studies indicate that a failure rate of 6% to 7% is to be expected, however, no failing systems were found. The apparent lack of failing systems is most likely due to the fact that the survey was conducted during the summer when the water table is lowest. A second possible reason is that 11.3% of the on-site systems in the designated area were not surveyed because the homeowners chose to not participate in the survey; the expected failure rate could have been hidden within this 11.3%.

The rates of marginal systems found in this study ranged from 1.7/100 the 6.25/100. These results correspond with marginal rates found in previous surveys conducted in the Tillamook Bay watershed. Rates of marginal systems may be an indicator of the trend in on-site system function in a given area. Since this survey was conducted during the dry, summer months the marginal systems found in this study might indicate areas of potential failure during the wet, winter months.

A variety of responses were received to questions pertaining to on-site system maintenance. The majority (61.6%) of homeowner did not know if their systems had ever been pumped and 13.2% were certain that maintenance had never occurred. The remaining quarter of respondents had had their systems pumped at least once. The variety of responses indicated a wide range of knowledge about on-site systems. The large percentage of responses that demonstrate an apparent lack of even basic knowledge about on-site systems suggests that homeowners might have failing or marginal systems and not realize it.

The age of approximately one-half (51.7%) of the systems surveyed was unknown. Approximately one-tenth of the systems were placed into each of the following age categories: less than five years old (9.6%), between six and ten years old (11.2%), and 16 to 20 years old (9.1%). The remaining systems are between 11 and 15 years old (5.2%) and 13.2% are more than 20 years old. No patterns were found when looking at the relationship between age and geographic region.

The majority (86%) of the systems surveyed were standard systems and a small percentage (3.4%) were alternative systems. For the remainder, no information was available. More than three-quarters (86%) of the alternative systems were in Cape Meares, a high density housing area with a shallow water table. Recently developed lots and those in which the previous on-site systems had failed could most likely only be approved for alternative systems, which would explain the larger number of these systems installed in this area.

On-site system function is dependent on soil characteristics such as texture, consistence, restrictive horizons and macropores, which influence the ability of a soil to transport liquid and treat effluent. The results of this study do not support the existing literature; chi square analysis indicated that system function was independent of system location. These results are most likely due to the fact that the survey was conducted during the summer, a time of year when systems that malfunction in the winter, function well.

Recommendations

Based on the results from this study, the following recommendations are made: Soil types should be known prior to surveying, in order to provide the researcher with adequate information about soil characteristics that influence how well on-site systems function. Shoreline surveys should be conducted during the rainy season due to fact that the water table is higher than during the dry months. As a result, on-site systems which might not exhibit signs of marginality or failure during the dry season would more likely be discovered. Additionally, dye tracing, which would easily enable the investigator to identify failing systems, should be used in conjunction with the absorption bed inspection and homeowner interview.

Potentially at-risk areas should be identified and surveyed. Potentially at-risk areas include, but are not limited to, those properties owned by people who chose to not participate in the survey, properties in areas that have a number of systems previously identified as marginal, and areas in which a number of systems have failed in the same time period. The investigation of know problem areas, conducted since 1998, demonstrates that identification and detailed surveying of at-risk areas is crucial to maintaining properly functioning on-site systems.

Public education about on-site systems would be beneficial for homeowners as well as regulators. In order to properly maintain an on-site system homeowners should know the location and type of the system, its age and its maintenance history and requirements.

The parameters of this study were set by the Tillamook County Health Department, which limited the researcher's control over data collection. The researcher was unable to follow up with the non-participants due to the voluntary nature of the survey. An alternate method of eliciting information about on-site system function is to mail questionnaires with open-ended questions pertaining to the impacts that on-site system function have on peoples' lives. The questions might cover standing water in bathtubs, toilets that don't flush properly, and location of on-site system.

BIBLIOGRAPHY

A comprehensive source control program for protecting shellfish waters. (n.d.). U.S. Environmental Protection Agency.

Analyzing nonpoint source pollution in a Puget Sound watershed: A cooperative project using geographic information systems (1990). Olympia, WA: Puget Sound Cooperative River Basin Team.

Brown, K. W., Wolf, H. W., Donnelly, K. C., & Slowey, J. F. (1979). The movement of fecal coliforms and coliphages below septic lines. Journal of Environmental Quality, 8(1), 121-125.

Burks, B. D., & Minnis, M. M. (1994). Onsite wastewater treatment systems. Madison, WI: Hogarth House, Ltd.

Bushman, J.L. (1996). Transport and transformation of nitrogen compounds in effluent from sand filter-septic system draintile fields. Unpublished master's thesis, Oregon State University, Corvallis, OR.

Canter, L. W., Knox, R. C., & Fairchild, D. M. (1987). Ground water quality protection. Chelsea, MI: Lewis Publishers, Inc.

Canter, L., & Knox, R. C. (1984). Evaluation of septic tank system effects on ground water quality. (Report No. EPA-600/S2-84-107). Ada, OK: U.S. Environmental Protection Agency.

Clem, J. D. (1994). Historical overview. C. R. Hackney, & M. D. Pierson (Eds.), Environmental indicators of shellfish safety (pp. 1-29). New York: Chapman and Hall.

Cogger, C. G., & Carlile, B. L. (1984). Field performance of conventional and alternative septic systems in wet soils. Journal of Environmental Quality, 13(1), 137-142.

Cogger, C. G., Hajjar, L. M., Moe, C. L., & Sobsey, M. D. (1988). Septic system performance on a coastal barrier island. Journal of Environmental Quality, 17(3), 401-408.

Cooney, C. M. (1997). EPA moves to clamp down on nonpoint sources of pollution. Environmental Science and Technology, 31(12), 553-554.

Coulton, K. (1998). Flooding. R. Hinzman, & S. Nelson (Eds.), Tillamook Bay environmental characterization: A scientific and technical summary (pp. 6-1 – 6-63). Garibaldi, OR: Tillamook Bay National Estuary Project.

Coulton, K.G., Williams, P.W, & Benner, P.A. (1996). An environmental history of the Tillamook Bay estuary and watershed. Portland, OR.

Crane, S. R., & Moore, J. A. (1986). A management strategy to reduce bacterial pollution in shellfish areas: A case study. Environmental Management, 10, 41-51.

Fisher, B. E. (1994). Downstream in America. Environmental Health Perspectives, 102(9), 740-745.

Fuhrman, R. E. (1984). History of water pollution control. Journal of the Water Pollution Control Federation, 56, 306-313.

Garreis, M.J. (1994). Sanitary surveys of growing waters. C.R. Hackney, & M.D. Pierson (Eds.), Environmental indicators and shellfish safety (pp. 289-330). New York: Chapman and Hall.

Hagedorn, C., Hansen, D. T., & Simonson, G. H. (1978). Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. Journal of Environmental Quality, 7(1), 55-59.

Hagedorn, C., McCoy, E. L., & Rahe, T. M. (1981). The potential for ground water contamination from septic effluents. Journal of Environmental Quality, 10(1), 1-8.

Harris, P. J. (1995). Water quality impacts from on-site waste disposal systems to coastal areas through groundwater discharge. Environmental Geology, 26, 262-268.

Jackson, J. E. (1985). Shellfish sanitation in Oregon: Can it be achieved through pollution source management? Perspectives on nonpoint source pollution (440/5-85-001, pp. 180-184) . Washington, DC: U.S. Environmental Protection Agency.

Jackson, Jr. J. E., & Glendening, E. A. (1982). Tillamook Bay bacteria study: fecal source summary report. Portland, OR: Oregon Department of Environmental Quality.

Jury, W. A., Gardner, W. R., & Gardner, W. H. (1991). Soil Physics (5th ed.). New York: John Wiley & Sons, Inc.

Kleiss, H.J., & Hoover, M.T. (1986). Soil and site criteria for on-site systems. In Utilization, treatment, and disposal of waste on land: Proceedings of a workshop held in Chicago, IL, 6-7 Dec. 1985. (pp. 111-129). Madison, WI: Soil Science Society of America, Inc.

Kristiansen, R. (1981). Sand-filter trenches for purification of septic tank effluent: I the clogging mechanism and soil physical environment. Journal of Environmental Quality, 10(3), 353-357.

Kruckeberg, J., & Miller, J. (1998). Human Uses. R. Hinzman, & S. Nelson (Eds.), Tillamook Bay environmental characterization: A scientific and technical summary (pp. 2-1 - 2-38). Garibaldi, OR: Tillamook Bay National Estuary Project.

Leonard, D. L., & Slaughter, E. A. (1990). The quality of shellfish growing waters on the west coast of the United States. Rockville, MD: Strategic Assessment Branch, Ocean Assessments Division, Office of Oceanography and Marine Assessment, National Ocean and Atmospheric Administration.

Martinez-Manzanares, E., Morinigo, M. A., Castro, D., Balebona, M. C., Munoz, M. A., & Borrego, J. J. (1992). Relationship between indicators of fecal pollution in shellfish-growing water and the occurrence of human pathogenic microorganisms in shellfish. Journal of Food Protection, 55 (8), 609-614.

Moore, R., & Freedman, P. (1995). Nonpoint sources. Water Environment and Technology, 7(9), 47.

Nelson, S., Follensbee, B., & Hinzman, R. (1998). Introduction. R. Hinzman, & S. Nelson (Eds.), Tillamook Bay environmental characterization: A scientific and technical summary (pp. 1-1 - 1-13). Garibaldi, OR: Tillamook Bay National Estuary Project.

Newell, A. (1998). Water quality. R. Hinzman, & S. Nelson (Eds.), Tillamook Bay environmental characterization: A scientific and technical summary (pp. 4-1 - 4-55). Garibaldi, OR: Tillamook Bay National Estuary Program.

NOAA studies coastal water quality (1997). Geotimes, 12.

Oregon Administrative Rules Chapter 340 -- Divisions 71 and 73. (1999). Oregon Department of Environmental Quality.

Perciasepe, R. (1995). The national perspective. Water Environment and Technology, 7(9), 48-52.

Perkins, R. J. (1984). Septic tanks, lot size and pollution of water table aquifers. Journal of Environmental Health, 46(6), 298-304.

Postma, F. B., Gold, A. J., & Loomis, G. W. (1992). Nutrient and microbial movement from seasonally-used septic systems. Journal of Environmental Health, 55(2), 5-10.

Rahe, T. M., Hagedorn, C., McCoy, E. L., & Kling, G. F. (1978). Transport of antibiotic-resistant *Escherichia coli* through western Oregon hillslope soils under conditions of saturated flow. Journal of Environmental Quality, 7(4), 487-494.

Rea, R. A., & Upchurch, S. B. (1980). Influence of regolith properties on migration of septic tank effluent. Ground Water, 18(2), 118-125.

Reneau, Jr. R. B., Hagedorn, C., & Degen, M. J. (1989). Fate and transport of biological and inorganic contaminants from on-site disposal of domestic wastewater. Journal of Environmental Quality, 18(2), 135-144.

Reneau, Jr. R. B., & Pettry, D. E. (1975). Movement of coliform bacteria from septic tank effluent through selected coastal plain soils of Virginia. Journal of Environmental Quality, 4(1), 41-44.

Romero, J. C. (1970). The movement of bacteria and viruses through porous media. Ground Water, 8, 37-48.

Salvato, J. A. (1992). Environmental Engineering and Sanitation (4th ed.). New York: John Wiley and Sons, Inc.

Stelma, G. N., & McCabe, L. J. (1992). Nonpoint pollution from animal sources and shellfish sanitation. Journal of Food Protection, 55, 649-656.

Stewart, L. W., & Reneau, Jr. R. B. (1988). Shallowly placed, low pressure distribution system to treat domestic wastewater in soils with fluctuating high water tables. Journal of Environmental Quality, 17(3), 499-504.

Stritthold, J. R., Garono, R. J., & Frost, P. A. (1997). Corvallis, OR: Earth Design Consultants, Inc.

Tillamook Bay National Estuary Project. (1997). Garibaldi, OR: Author.

U.S. Department of Agriculture. (1964). Soil survey Tillamook area Oregon (series 1957, no. 18). Washington DC: U.S. Government Printing Office.

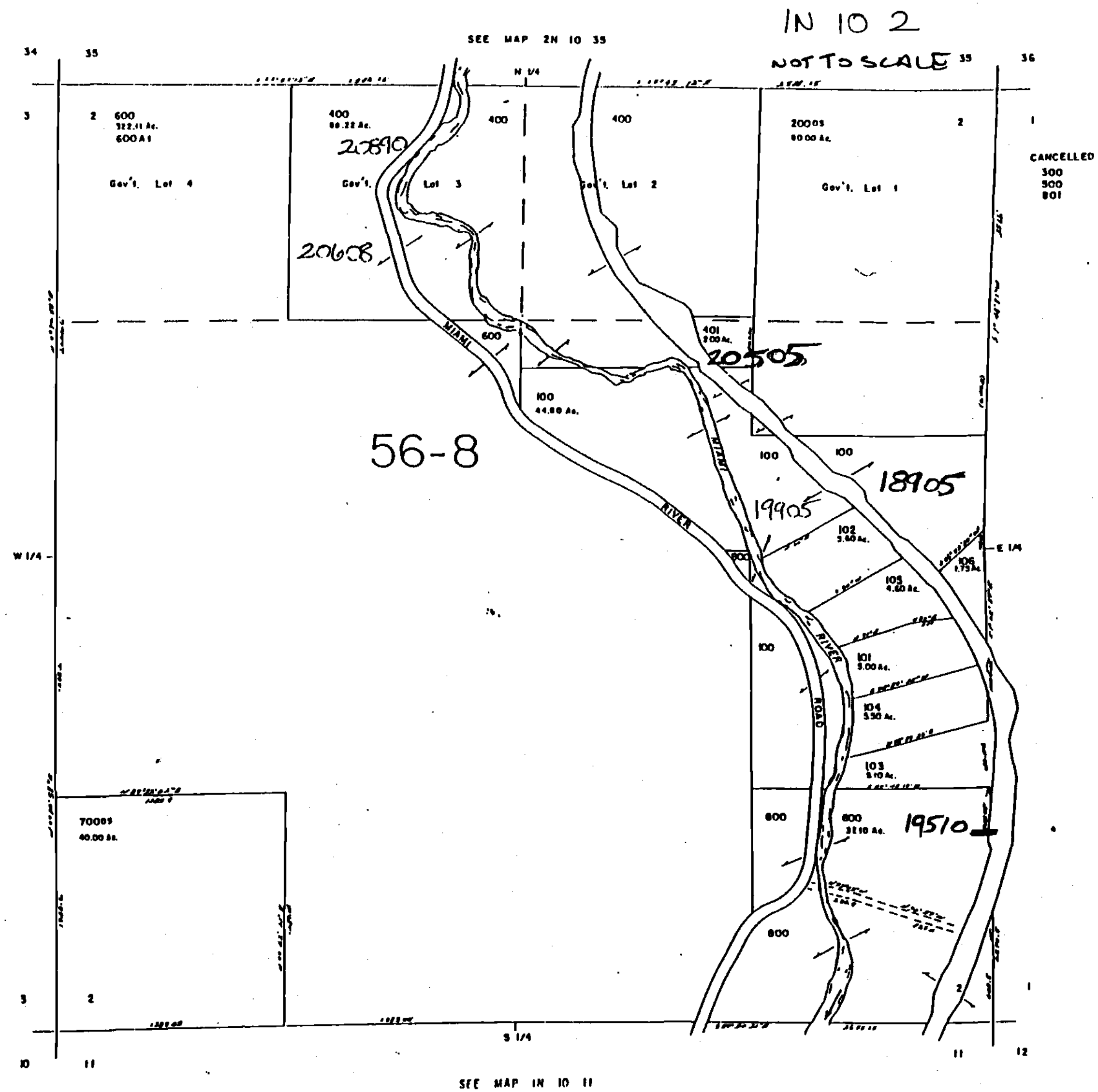
U.S. Food and Drug Administration. (1995). National shellfish sanitation program manual of operations. Washington, DC: Author.

Yates, M. V. (1985). Septic tank density and ground-water contamination. Ground Water, 23(5), 586-591.

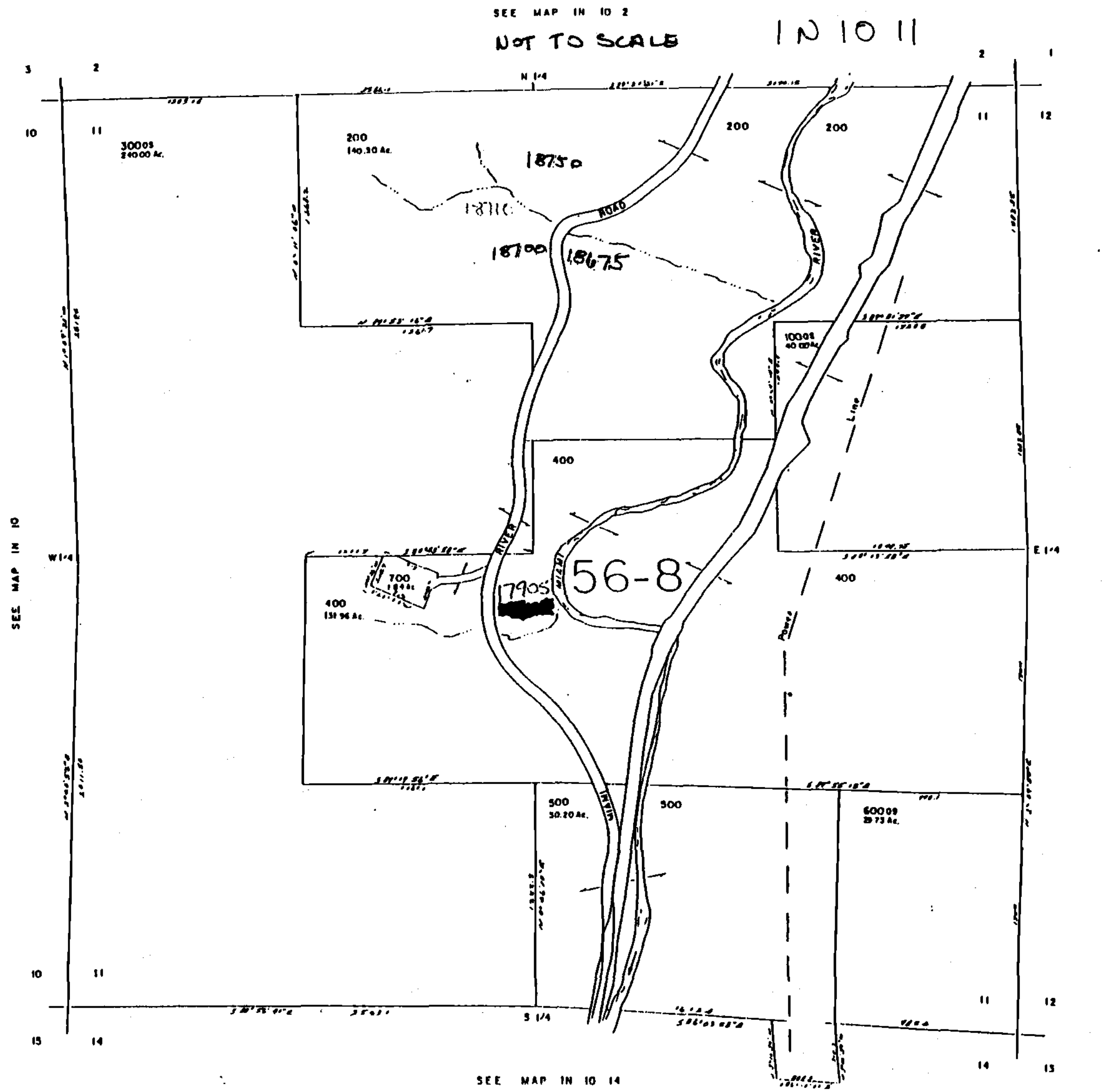
APPENDICES

APPENDIX A:

Sample Address Maps



1N 10 2
NOT TO SCALE
SEE MAP 2N 10 35
SEE MAP IN 10
SEE MAP IN 10 11
N 1/4
W 1/4
E 1/4
S 1/4
CANCELLED
300
500
801
600
600A1
Gov't. Lot 4
400
Gov't. Lot 3
Gov't. Lot 2
20003
Gov't. Lot 1
20890
20608
401
20505
100
56-8
18905
19905
102
105
106
101
104
103
800
19510
70003
MIAMI RIVER
MIAMI RIVER ROAD


SEE MAP IN 10 2
NOT TO SCALE
1N 10 11
N 1/4
200
140.30 Ac.
18750
18700
18675
ROAD
RIVER
300 05
240.00 Ac.
100 05
40.00 Ac.
400
W 1/4
E 1/4
SEE MAP IN 10
700
400
151.96 Ac.
17905
[redacted]
56-8
Power Line
500
30.20 Ac.
600 09
S 1/4
SEE MAP IN 10 14

APPENDIX B:
Sample Survey Form

TILLAMOOK BAY SANITARY SURVEY

DRAINAGE BASIN

Date: ______________________, 1998

[] Tillamook River [] Wilson River

Weather: ______________________

[] Trask River [] Miami River

Survey Team: ______________________

[] Kilchis River [] Other __________

____

Survey Access Authorized: [] Yes [] No

Soil Type: [] Upland [] Hydric

Legal Description: Tax Lot: _______. Section: _______. Township: _______. Range: ________ W.M.

Parcel Address: ______________________

Parcel Owner(s): ______________________

Owner(s) Telephone Number : ______________________

Owner(s) Mailing Address: ______________________

____

On-Site Wastewater System Type: **[] Standard** **Date Installed:** __________.19______

[] Alternative **Date Serviced:** __________.19______

On-Site System Function: [] Operational [] Marginal [] Failure

[] Unknown

Environmental Inpact of System: [] None [] Direct [] Indirect

[] Unknown

Comments: ______________________

____

____

Existing Development Sketch

APPENDIX C:
Sample Informational Letter Sent to Homeowners

Tillamook County

HEALTH DEPARTMENT

Robert H. Moore
Administrator

Land of Cheese, Trees and Ocean Breeze

PO Box 489
Tillamook OR 97141-0489
Phone: (503) 842-3900
Fax: (503) 842-3903
TDO Non-voice

July 1, 1998

Dear Tillamook Bay Watershed Resident:

Your assistance is requested in conducting a sanitary survey of developed parcels on Tillamook Bay and drainages discharging into the bay. The Food and Drug Administration (FDA) requires this survey to assure the bay continues to meet the Federal standards for a commercial shellfish harvesting area. Proof of good water quality ensures continued growth of the bay's commercial and recreation fisheries.

The Oregon Department of Agriculture is required to conduct the survey. Personnel from the Oregon Department of Agriculture, Oregon Department of Environmental Quality, Tillamook County Health Department, and the County Community Development Department will all be working on this project. Tillamook County oyster growers and volunteers will also be involved. We need your help to make this a truly cooperative effort.

A survey team consisting of two individuals will inspect your parcel in the area of the septic tank and absorption field. They will carry identification to present upon request. Your presence during this inspection is not mandatory but is welcome. The sanitary survey does not require inspectors to enter your home or excavate portions of your septic system. The inspection will consist of general observations of the onsite system (septic system) absorption field and septic tank. The survey team will be looking for any evidence that the septic system is discharging untreated effluent to the ground surface or a surface water source. If observed evidence is inconclusive, you may be contacted to arrange an appointment for a detailed inspection of the septic system.

Your participation in this sanitary survey is important and appreciated. The results of the survey will benefit all the residents of Tillamook County by helping to insure that high quality water sources discharge to Tillamook Bay. However, if you do not want to participate, please call or write us at the address below.by July 15, 1998.The survey team members will attempt to contact developed parcel owners for permission to enter the parcel prior to the initiation of the inspection. If there is no response to this notice, the survey team will assume you have no objections to the inspection.

If your septic system has an observed operational problem, the Tillamook County Health Department in conjunction with the County On-Site Wastewater Division will provide information to you regarding appropriate corrective measures.

Please feel welcome to contact Michael Cooney, Tillamook County Health Department at (503) 842-3907 to discuss any questions you have regarding this sanitary survey request. Your time and attention to this request are greatly appreciated.

DATED this 25th day of March, 1998

BOARD OF COMMISSIONERS FOR
TILLAMOOK COUNTY, OREGON

Gina Firman, Chairperson

Jerry A. Doye, Vice Chairperson

Sue Cameron, Commissioner

ATTEST: ____________________

BY: Special Deputy

Michael Cooney, Environmental Health Program Manager
Tillamook County Health Department
P.O. Box 489
Tillamook, OR 97141