SURVIVAL AND TRANSPORT OF ENTERIC BACTERIA AND VIRUSES IN THE NEARSHORE MARINE ENVIRONMENT - AN ANNOTATED BIBLIOGRAPHY

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INTRODUCTION

This bibliography was prepared as part of the U.S. EPA Buzzards Bay Project by staff members of the Barnstable County Health and Environmental Department. Although the original intent in compiling this literature was for use in preparing a report on the investigation of coliform sources in Buttermilk Bay, it was realized that annotations of the literature used therein could serve as summary of the state of knowledge relative to enteric bacteria and virus survival in the marine environment. In addition to literature relative to this specific subject, research on the survival and entrainment of biological components of sanitary wastes in groundwater is included so that the implications of on-site subsurface sewage disposal systems near surface waters could be appraised.

In considering environmental studies involving bacteriological monitoring, there are at least two basic concepts which should be understood by the reviewer. Most importantly, the concept of an indicator organism should be clearly understood. Regarding water quality in shellfish harvesting areas, the density of a biological indicator organisms has historically been the basis for many of our conclusions regarding water quality. An indicator organism is a biological component (virus or bacteria) which has been shown, in its occurrence, to exhibit a correlation with the occurrence of another organism or set of organisms. In shellfish harvesting areas, this correlation is with the enteric pathogens. Indicator organisms are necessary due to the fact that direct measurement of the many pathogens is precluded by the lack of cost-effective reliable methods for enumeration. In addition to the availability of enumeration techniques, the existence of a large number (over 100 enteric pathogenic viruses alone) of agents renders their direct measurement impractical.

There is no doubt that the current indicator system used in Massachusetts and many states (fecal coliform) has been the subject of much controversy. The issue can generally be dissected into questions. Initially, the question of fecal specificity arises. The fecal coliform group contains some organisms (notably thermotolerant Klebsiella sp.) which have been shown in papers reviewed herein to be non-fecal specific. The second, and more complex issue, is the use of the indicator applied in situations where non-point source pollution has been shown to be the primary cause. The lack of epidemiological studies linking the occurrence of enteric diseases with impact by non-point sources is notably lacking. Despite these shortcomings, it is evident that the present indicator, fecal coliform, will continue to be used until such time as the body of scientific investigation presents an adequate alternative.

An additional aspect of reviewing the studies herein could best be expressed by these authors as a cautionary note. It is important to understand that there are many variables affecting the survival of enteric pathogens and indicator organisms in groundwater and the marine environment. This fact, and the fact that enumeration techniques for many enteric pathogens have undergone significant improvements in recent years should compel the reviewer to consider the date of the study reviewed and site-specific variables which may make direct transference of conclusions to another study area inappropriate. This can clearly be seen when reviewing information on viruses. The field of environmental virology is still in its embryonic state, and enumeration/culture techniques of recent years have far surpassed those of prior years rendering some comparisons inappropriate based simply on the date of the study.

For ease of reference, the bibliography is broken into several sections: bacterial and viral survival and transport in marine waters; bacteria and virus survival and transport in groundwater; effect of stormwater on bacteriological quality of coastal water; effect of waterfowl bacteriological quality of coastal water; and effect of marine craft usages on bacteriological quality of coastal water. Each section includes both historical work and current research on parameters affecting water quality. The brief annotations are intended to summarize the results of each study and allow readers to identify those papers they wish to read in greater depth.

We express our gratitude to members of a number of state and federal agencies, who through the process of report review and interest have forwarded to us some of the articlespresented herein. Dr. James Vaughn of the Brookhaven National Laboratory, whose work is reviewed herein, provided for an important initial insight into the issue of entrainment of enteric organisms in groundwater both through correspondence and supplying us with copies of relevant work in the area. Ira Somerset of the United States Food and Drug Administration following review of our initial reports in Buttermilk Bay pointed us toward some of the "gray" literature on marine craft usage and also fecal indicator survival in the marine environment literature. We also thank the numerous shellfish wardens, biologists, members of the Shellfish Sanitation Program of the southeastern region of D.E.Q.E. and interested individuals who periodically dug through their files for literature supporting this project.

We hope this list will serve as a good introduction to the existing scientific literature and will assist the reader in identifying sources of information which can be applied to maintain and improve our coastal water quality.

BACTERIA AND VIRUS SURVIVAL AND TRANSPORT IN MARINE WATERS

Akin, E. W., W. F. Hill, Jr., G. B. Cline and W. H. Benton. 1976. The loss of poliovirus 1 infectivity in marine waters. Water Research. 10:59-63.

Poliovirus 1 showed a typical loss of 3 logs of infectivity in 3-5 days at 24 C in marine water from Gulf of Mexico. Viral infectivity loss occurred in raw, filter-sterilized and autoclaved marine water and artificial seawater 1,10,20 g/kg salinity. 6 Figs. 14 Refs.

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Bellair, J. T., G. A. Parr-Smith and I. G. Wallis. 1977. Significance of diurnal variations in fecal coliform die-off rates in the design of ocean outfalls. JWPCF 49:2022-2030.

Light is reported to be an important factor in reducing fecal coliform. Time required for fecal coliform density to decrease by 90% (T-90) varied from a max of 40 hrs during the night to 1.9 hours just before noon. Equation for T-90 and light intensity given: $T\text{-}90 = 3.4 \times I^{-0.42}$ where I=hourly solar radiation in MJ/m^2 10 Figs. 10 Refs.

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Bitton, G., R. Fraxedas and G. E. Gifford. 1979. Effect of solar radiation on poliovirus: preliminary experiments. Water Research 13:225-228.

Solar radiation was found to have some inactivating effect on poliovirus type 1 in the absence of any natural or synthetic photosensitizing agent. Photoinactivation of poliovirus in lake water was retarded by the presence of blue-green algae. Light inactivation was less important at a depth of 6 inches. Clay displayed a protective effect against light and thermal deactivation. 5 figs., 15 refs.

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Borrego, J. J. and P. Romero. 1985. Coliphage survival in seawater. Water Resources 19:557-562.

Maximum coliphage inactivation was observed in both untreated natural and heavily polluted marine waters; coliphages showed maximum resistance to inactivation in filtered and autoclaved clean and polluted seawater. In vitro study. 6 figs., 35 refs.

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Borrego, J. J., F. Arrabal, A. de Vicente, L. F. Gomez, P. Romero. 1983. Study of microbial inactivation in the marine environment. JWPCF 55:297-302

Coliphages showed greater resistance to marine environment than their bacterial host, *E.coli*. Rate of bacterial inactivation in descending order was: total coliforms (inactivated soonest) fecal coliform, Salmonella-Shigella, coliphages and fecal streptococci. 6 Figs. 19 Refs.

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Carlucci, A. F. and D. Pramer. 1959. Factors affecting the survival of bacteria in seawater. *J. Appl. Microbiol.*. 7:388-392.

Literature review; 58 references for work prior to 1959. Reviewed effects of 1)adsorption/sedimentation; 2)sunlight--bacteria died rapidly in shallow layers of seawater exposed to midsummer sunlight; the lethal effect did not extend > 20 cm.; 3)lack of nutrients-- organic nutrient addition decreased death rate of *E. coli.*; 4) toxic substances; 5) bacteriophages and predators; 6)sterilization

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Chamberlin, C.E. and R. Mitchell. 1978. A decay model for enteric bacteria in natural waters. pages 325-348 In: R. Mitchell, ed. 1978. *Water Pollution Microbiology* Volume 2. John Wiley and Sons, Inc. New York.

Literature review of the factors affecting coliform die-off rates. Light intensity is single most important factor in bacterial die-off. 61 refs.

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Coleman, R. N., J. N. Campbell, F. D. Cook and D. W. S. Westlake. 1974. Urbanization and the microbial content of the north Saskatchewan River. *Appl. Environ. Microbiol.* 27:93-101.

The major effect of small unsewered towns along the river is to supply nutrients which support growth of indigenous river flora. The effect of large urban centers, which release primary and secondary sewage, is to provide nutrients and an innoculum of *E. coli*. 14 figs., 13 refs.

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Davenport, C. V., E. B. Sparrow, and R. C. Gordon. 1976. Fecal indicator bacteria persistence under natural conditions in an ice-covered river. *Appl. Environ. Microbiol.* 32:527-536.

After 7.1 days at 0 C under ice cover, the relative survival rate was total coliform <fecal coliform <fecal strep with 8.4%, 15.7% and 32.8%, respectively, of the initial populations remaining viable. These rates are higher than previously reported and

suggest that survival rate is best at 0 C under ice cover. MPN and MF did not provide comparable results near the pollution source. 11 figs., 44 refs.

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Edmond, T.D., G.E. Schaiberger, and C.P. Gerba. 1978. Detection of enteroviruses near deep marine sewage outfalls. Marine Pollution Bulletin 9:246-249.

Human enteric viruses are present in significant numbers around non-treated sewage outfalls as well as in secondarily treated, chlorinated sewage outfalls. Average viral concentration was only 1-2 $\log_{10}$ less at outfalls discharging chlorinated effluent than at outfalls discharging untreated effluent. 3 figs., 19 refs

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Faust, M. A. 1976. Coliform bacteria from diffuse sources as a factor in estuarine pollution. Water Research 10:619-627.

A rural watershed area of 849 ha, with an animal population of 0.6 animal/ha, discharged between 7.5×10^6 and 669×10^6 fecal coliform/ha/day to the estuary; rate was seasonal and depended on water flow. Persistence of bacteria in the estuary may increase the pollution level contributed by the watershed, especially at low temperatures. Estimates worked out for dilution volume per hectare of farmland necessary to meet shellfish standard of 14 FC per 100 ml. 7 figs., 35 refs.

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Faust, M. A., A. E. Aotaky and M. T. Hargadon. 1975. Effect of physical parameters on the in situ survival of *Escherichia coli* MC-6 in an estaurine environment. Appl. Environ. Microbiol. 30:800-806.

Survival of *E. coli* as affected by time, water temperature, dissolved oxygen, salinity, and montmorillonite. Relationship between pairs of variables was studied. Bacterial survival varied seasonally; water temperature was most important factor in predicting survival. 6 figs., 25 refs.

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Fujioka, R. S., P. C. Loh and L. S. Lau. 1980. Survival of human enteroviruses in the Hawaiian Ocean environment: evidence for virus-inactivating microorganisms. Appl. Environ. Microbiol. 39:1105-1110.

Evidence indicates that a virus-inactivating agent(s) of a microbiological nature was present in both clean and sewage-polluted seawaters, but not present in fresh mountain stream waters. Antiviral activity lost when samples were subject to boiling, autoclaving or filtration through .22 or .45 but not 1.0 micron filter. Data suggest that antiviral activity of seawater was is related to growth activities of microorganisms. 8 figs., 10 refs.

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Fujioka, R.S., H. H. Hashimoto, E. B. Siwak and R. H. F. Young. 1981. Effect of sunlight on survival of indicator bacteria in seawater. Appl. Environ. Microbiol. 41:690-696.

In the absence of sunlight, fecal coliform and fecal strep survived for days, whereas in the presence of sunlight 90% of FC and FS were inactivated within 30-90 min and 60-180 min., respectively. Bactericidal action of sunlight penetrated 3.3 m of clear seawater suggesting visible rather than UV light was responsible . FS were more stable than FC; T90 with no light was 21-48 h for FC and 36-84 h for FS. 6 figs., 15 refs.

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Gameson, A.L. H. and J.R. Saxon. 1967. Field studies on effect of daylight on mortality of coliform bacteria. Water Research 1:279-295.

The logarithm of the coliform count was found to decrease fairly regularly with increase in the cumulative radiation. Surface radiation required to produce 90 % mortality increased with advancing season, from April to September. 12 figs., 7 refs.

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Gerba,C.P. and G.E. Schaiberger. 1975. Effect of particulates on virus survival in seawater. JWPCF 47:93-103.

Data demonstrates a loss of viral titer when seawater is filtered or centrifuged, or when fine clays and sediments are added to seawater. Presence of organic matter was shown to cause viral de-adsorption from clay particles. Data suggests that viral survival is enhanced by viral adsorbtion to suspended particulates in water. 13 figs., 18 refs.

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Gerba, C. P. and J. McLeod. 1976. Effect of sediments on survival of Escherichia coli in marine waters. Appl. Environ. Microbiol. 32:114-120

Sediment prolongs the survival time of coliforms in marine waters, and at times can support coliform growth. Longer survival in sediment attributed to higher organic content of sediment than seawater. There were sufficient nutrients in the sediments in areas of sewage effluent discharge, as well as areas free from this type of pollution, to support bacterial growth. 6 figs., 20 refs.

Gerba C. P., S. M. Goyal, E. M. Smith and J. L. Melnick. 1977. Distribution of viral and bacterial pathogens in a coastal canal community. Marine Pollution Bulletin 8:279-282.

In waters receiving secondarily treated sewage effluent, generally 100-1000 times more coliform and 10-100 times more fecal coliform were detected in the sediment than in the water column. Enteroviruses also in greater concentration in sediments. 4 figs., 17 refs.

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Gerba, C. P., J. B. Rose,and S. N. Singh. 1985 Waterborne gastroenteritis and viral hepatitis. Crit. Rev. Env. Control 15:213-236.

Literature review of epidemiological work on these two diseases, including information on viral survival in the environment. 5 figs., 167 refs.

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Gorden, R. W., and C. B. Fliermans. 1978. Survival and viability of *Escherichia coli* in a thermally altered reservoir. Water Research 12:343-352.

E. coli survived and grew in diffusion chambers in both aerobic and anaerobic portions of the water column in a reservoir receiving thermal effluent. *E. coli* survived and grew for 2-3 weeks in both ambient and thermally altered water at each depth tested. Results suggest that presence of *E. coli* is not an indicator of recent fecal contamination. 9 figs., 29 refs.

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Goyal, S. M. 1984. Viral pollution of the marine environment. Crit. Rev. in Env. Control 14:1-32.

Extensive literature review of viruses in marine environment, including information on waterborne disease outbreaks, fate and transport of viruses in the environment, and methods for viral detection. Discusses need to reevaluate coliform index in view of recent information on waterborne viral illness. 20 figs., 148 refs.

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Goyal, S. M., C. P. Gerba, J. L. Melnick. 1978. Prevalence of human enteric viruses in coastal canal communities. JWPCF 50:2247-2256.

Strong positive correlation found between virus concentration in water and MPN of presumptive total coliforms in sediment. Indicator bacteria and *Salmonella* were more abundant in sediments than overlying waters. No correlation between virus numbers in overlying waters with coliform bacteria indicators. Sediments may act as reservoirs for coliforms and viruses. 7 figs., 46 refs.

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Goyal, S. M., C. P. Gerba and J. L. Melnick. 1979. Human enteroviruses in oysters and their overlying waters. Appl. Environ. Microbiol. 37:572-581.

No significant relationship was demonstrated between virus concentration in oysters and the bacteriological and physiochemical quality of water and shellfish. Greater numbers of bacteria were isolated after rainfall; turbidity was related statistically to organic content and fecal coliform number in water. Authors postulate this may be due to the release of sediment bound bacteria into the water column after rainfall. Current bacteriological standards for shellfish waters do not accurately reflect occurrence of enteroviruses. 6 figs., 44 refs.

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Goyal, S. M., W. N. Adams, M. L. O'Malley and D. W. Lear. 1984. Human pathogenic viruses at sewage sludge disposal sites in the middle atlantic region. Appl. Environ. Microbiol. 48:758-763.

Human enteric viruses associated with sewage sludge disposal were isolated from sediments up to 17 months after sludge dumping ceased. A protective sludge-sediment matrix and generally low (ca. 7C) temp may have contributed to the prolonged survival. No correlation seen between indicator bacteria and viruses. 7 figs., 31 refs.

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Grimes, D. J. 1975. Release of sediment-bound fecal coliforms by dredging. Appl. Microbiol. 29:109-111.

Fecal coliform concentrations increased significantly in vicinity of dredging in Mississippi River; disturbance of sediments by dredging results in release of sediment bound coliforms. 3 figs., 5 refs.

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Hazen, T. C., and G. W. Esch. 1983. Effect of effluent from a nitrogen fertilizer factory and a pulp mill on the distribution and abundance of Aeromonas hydrophila in Albemarle Sound, North Carolina. Appl. Environ. Microbiol. 45:31-42.

Survival of A. hydrophila was increased in pulp mill elluent and decreased in nitrogen fertilizer factory effluent. A. hydrophila numbers were positively correlated with phytoplankton density and thus indirectly by concentrations of nitrate, phosphate and organic carbon. Fecal coliform densities were significantly higher at outfall and downstream from both effluents, and frequently exceeded recreational water standards. 13 figs., 35 refs.

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Hendricks, C. W. 1971. Enteric bacterial metabolism of stream eluates. *Can. J. Microbiol.* 17:551-556.

River bottom sediments were eluted with phophate buffer and found to contain hexose, protein and ammonia-nitrogen 4-6 times that of overlying water. Selected strains of enterobacteriaceae (including *E. coli*) were able to utilize these nutrients. 7 figs., 21 refs.

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Hendricks, C. W. 1971. Increased recovery of *Salmonellae* from bottom sediments versus surface waters. *Appl. Microbiol.* 21:379-380.

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Hendricks, C. W. 1972. Enteric bacterial growth rates in river water. *Appl. Microbiol.* 24:168-174.

Demonstrated the growth of selected enteric bacteria in stream water below a sewage outfall. Maximum growth occurred at 30 C, while some growth occurred at 20 and 5 C. Generation times are given for individual bacteria. 7 figs., 25 refs.

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Hendricks, C. W. and S. M. Morrison. 1967. Multiplication and growth of selected enteric bacteria in clear mountain stream water. *Water Resources.* 1:567-576.

Growth of enteric bacteria, including *E. coli*, most pronounced at 16 C. River bottom sediment extract contained enough nutrients to support growth. 9 figs., 11 refs.

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Herrmann, J. E., K. D. Kostenbader,Jr and D. O. Cliver. 1974. Persistence of enteroviruses in lake water. *Appl. Environ. Microbiol.* 28:895-896

Two enteroviruses were inactivated more rapidly in lake than in sterile lake water. Virus coat proteins were degraded and perhaps used by microorganisms. 2 figs., 6 refs.

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Hill, W. F.,Jr., E. W. Akin, W. H. Benton and F. E. Hamblet. 1971. Viral disinfection of estuarine water by UV. *Journal Amer. Soc. Civil Eng.* SA 5:601-615.

UV light at 253.7 nm. effective in deactivating common enteric viruses. 7 figs., 34 refs.

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Hood, M. A. and G. E. Ness. 1982. Survival of *Vibrio cholerae* and *Escherichia coli* in estuarine waters and sediments. *Appl. Environ. Microbiol.* 43:578-585.

Sediment chambers used. For *V. cholerae*, growth and extended periods of survival occurred in sterile sediments, sterile waters and non-sterile waters, but not in non sterile sediments. In contrast, *E. coli* decreased rapidly in both sterile and non-sterile marine waters. Suggest that *V. cholerae* survives better in estuarine waters than *E. coli*. 9 figs., 20 refs.

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Jensen, P., A. Rola, and J. Tyrawski. Tidal wetlands and estuarine coliform bacteria. pp 385-399 in Hamilton, P. and K. B. MacDonald *Estuarine and Wetland Processes with Emphasis on Modeling*

High concentrations of total and fecal coliform were found in estuarine waters which had large areas of adjacent tidal wetlands. Organic nitrogen exhibited high positive correlation with bacterial numbers. Tidal wetlands export large amounts of organic nitrogen; authors hypothesize that tidal wetlands create an environment suitable for survival or growth of coliforms. 6 figs., 29 refs.

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Jones, G. 1964. Effect of chelating agents on the growth of *Escherichia coli* in seawater. *J. Bacteriol.* 87:483-499.

Evidence was found for the toxicity of heavy metals toward *E. coli* in natural seawater. Heavy metals appear to inhibit growth but not respiration. 13 figs., 59 refs.

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Kadlec, R. H. and D. L. Tilton. 1979. The use of freshwater wetlands as a tertiary wastewater treatment alternative. *CRC Critical Reviews in Environmental Control* Vol :185-212

Extensive review article of research on use of freshwater wetlands for sewage treatment. Includes information on removal of nutrients, bacteria and viruses. 71 refs.

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Kaneko, T. and R. R. Colwell. 1975. Adsorption of *Vibrio parahaemolyticus* onto chitin and copepods. *Appl. Microbiol.*

29:269-274.

V.parahaemolyticus was found to adsorb onto chitin. *E. coli* and *Pseudomonas fluorescens* did not. Adsorption efficiency greater in lower salinity water. Adsorption is one of major factors in determining distribution of *V. parahaemolyticus* in estuary.
6 figs, 13 refs.

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Kapuscinski, R. B., and R. Mitchell. 1983. Sunlight-induced mortality of viruses and *Escherichia coli* in coastal seawater. *Environ. Sci. Technol* 17:1-6.

Solar radiation can be an important agent controlling the distribution and abundance of *E. coli* and viruses in seawater. Wavelengths > 370 nm can cause mortality. The depth for a 10-fold reduction exceeds 5m even in productive water. 6 figs., 48 refs.

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Ketchum, B. H., J. C. Ayers and R. F. Vaccaro. 1952. Processes contributing to the decrease of coliform bacteria in a tidal estuary. *Ecology* 33:247-258.

Dilution, predation and the bactericidal action of seawater account for more than 99% of the decrease in coliform bacteria numbers; of these, bactericidal action is most important.
9 figs., 17 refs.

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LaBelle, R. L., and C. P. Gerba. 1979. Influence of pH, salinity and organic matter on the adsorption of enteric viruses to estuarine sediment. *Appl. Environ. Microbiol.* 38:93-101.

Greater than 99% of enteric viruses added to estuarine sediment became adsorbed to sediment; this association may play a major role in viral hydrotransportation and survival. The presence of soluble organic matter in the form of secondary sewage effluent or humic acid did not effect the pattern of adsorption. 14 figs., 29 refs.

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LaBelle, R. L. and C. P. Gerba. 1980. Influence of estuarine sediment on virus survival under field conditions. *Appl. Environ. Microbiol.* 39:749-755.

Virus adsorption to sediment greatly increased survival time. The time required to inactivate 99% (T-99) of poliovirus increased from 1.4 days in seawater alone to 6 days for virus adsorbed to sediment at an unpolluted site; at a polluted site T-99 increased from 1 h to 4.25 days by virus adsorption to sediment. 3 figs., 25 refs.

Labelle, R. L., C. P. Gerba, S. M. Goyal, J. L. Melnick, I. Cech and G. F. Bogdan. 1980. Relationships between environmental factors, bacterial indicators and the occurrence of enteric viruses in estuarine sediments. Appl. Environ. Microbiol. 39: 588-596.

Statistical analysis of the relationship between viruses in seawater or in sediment and other variables measured yielded only one significant association: the number of viruses in sediment was found to be positively correlated with the number of fecal coliforms in the sediment. Viral numbers in sediment were not correlated with total coliform or Clostridium in sediment or water; or with fecal coliform in water; or with pH, turbidity, rainfall, or salinity. 5 figs., 41 Refs.

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LaBelle, R. L. and C. P. Gerba. 1982. Investigations into the protective effect of estuarine sediment on virus survival. Water Res. 16:469-478.

Study using Polivirus 1 (LSc strain). Sediment was capable of protecting virus from inactivating effects of microorganisms, heat and salt. Anaerobic environment did not influence virus survival. Addition of bacterial nutrients enhanced virus survival, possibly by virus adsorption to resulting bacterial populations; however organic material naturally present in sediment did not enhance virus survival in seawater. Virus adsorption to sediment appears to be the most important interaction that retards virus inactivation. 10 figs., 38 Refs.

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LaLiberte, P. and D. J. Grimes. 1982. Survival of Escherichia coli in lake bottom sediment. Appl. Environ. Microbiol.. 43:623-628.

The study demonstrated the extended survival of sediment-bound E. coli, in both sand and silty-clay sediments. 3 figs.,39 refs.

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Landry, E. F., J. M. Vaughn, T. J. Vicale and R. Mann. 1983. Accumulation of sediment-associated viruses in shellfish. Appl. Environ. Microbiol. 45:238-247.

Shellfish accumulation of sediment-bound viruses was minimal when sediments remained undisturbed. Incidence of viral uptake by shellfish was higher when sediments were intentionally resuspended. Study suggests that virus sampling be conducted near the sediment-water interface rather than mid-depth or at the surface. 6 figs., 20 refs.

Lessard, E. J., and J. M. Sieburth. 1983. Survival of natural sewage populations of enteric bacteria in diffusion and batch chambers in the marine environment. *Appl. Environ. Microbiol.* 45:950-959

Survival of *E. coli* and enterococci were correlated with temperature. In relatively low-nutrient estuarine waters, temperature may exert major control on coliform populations. Enterococci survived longer than *E. coli* in the estuary, but less well in the more eutrophic salt marsh. 7 figs., 44 refs.

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Liew, P. F. and C. P. Gerba. 1980. Thermostabilization of enteroviruses by estuarine sediment. *Appl. Environ. Microbiol.* 40:305-308.

Polio 1 and Echo 1 viruses evaluated. Poliovirus survival was prolonged at 24 and 37 C but not at 4 C in the presence of sediment. Prolonged survival was likely due to adsorption. Poliovirus detected on day 33 at 24 C with sediment but not at day 18 without. Adsorption of enteroviruses to estuarine sediment protects against thermal deactivation. 5 figs., 17 refs.

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Lo, S., J. Gilbert and F. Hetrick. 1976. Stability of human enteroviruses in estuarine and marine waters. *Appl. Environ. Microbiol.* 32:245-249.

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Malina P., and B. P. Sagik, eds. 1974. *Virus Survival in Water and Wastewater Systems* Center for Research in Water Resources, Austin, TX.

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Matossian, A. M. and G. A. Garabedian. 1967. Virucidal action of sea water. *American Journal of Epidemiology.* 85:1-8.

Early paper indicating that seawater showed definite virucidal property hypothesized to be due to the combined effect of its chemical composition and an unknown inhibitory substance. 6 figs., 15 refs.

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Matson, E. A., S. G. Hornor,and J. D. Buck. 1978. Pollution indicators and other microorganisms in river sediment. *JWPCF* 13-19.

Higher numbers of microorganisms found in sediments than overlying waters; populations found were sufficient to be considered a health hazard under existing standard indicator densities. Discusses role of resuspension of sediments. 10 figs., 21 refs.

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McCambridge, J. and T. A. McMeekin. 1980. Relative effects of bacterial and protozoan predators on survival of *Escherichia coli* in estuarine water samples. *Appl. Environ. Microbiol.* 40:907-911.

E. coli cells inoculated into natural estuarine water were reduced from 10^8 bacteria per ml to less than 10 after 10 days when protozoa were present, and to 10^4 bacteria per ml when no protozoa were present. 4 figs., 16 refs.

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McCambridge, J., and T. A. McMeekin. 1981. Effect of solar radiation and predacious organisms on survival of fecal and other bacteria. *Appl. Environ. Microbiol.* 41:1083-1087.

Decline in *E. coli* numbers in estuarine waters was significantly greater in presence of both naturally occurring microbial predators and solar radiation than when either factor acted independently. Susceptibility of bacteria to light induced decay varied as follows: *Klebsiella pneumonia*> *E. coli*> *Salmonella typhimurium*, *Streptococcus faecium*. 4 figs., 14 refs.

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Metcalf, T. G. and W. C. Stiles. 1964. The accumulation of enteric viruses by the oyster *Crassostrea virginica*. *Journal of Infectious Diseases* 115:68-76.

Virus remained relatively stable within oyster tissues stored at 5 C for at least 28 days. Of all tissues examined, the digestive gland showed the greatest retention of virus. There was no multiplication of the virus, but simply retention. 8 figs., 9 refs.

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Metcalf, T.G. and W.C. Stiles. 1968. Enteroviruses within an estuarine environment. *American Journal of Epidemiology* 83:379-391.

Virus-carrying oysters immersed in estuary waters with temperatures less than 7 C retained fully infectious enteroviruses for at least 4 months during the winter season. 8 figs., 19 refs.

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Metcalf, T. G., C. Wallis and J. L. Melnick. 1974. Virus enumeration and public health assessments in polluted surface water contributing to transmission of virus in nature. *In:*

Malina and B. P. Sagik (eds.), Virus Survival in Water and Wastewater Systems. Center for Research in Water Resources, Austin, Texas.

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Mitchell, R., ed. 1978. Water Pollution Microbiology Volume 2. John Wiley and Sons, New York.

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Mitchell, R. 1968. Factors affecting the decline of non-marine micro-organisms in seawater. Water Research 2:535-543.

Literature review on the subject, notably downplaying the role of light-induced mortality. 48 refs.

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Mitchell, R., R. Yankofsky and H. W. Jannasch. 1967. Lysis of Escherichia coli by marine microorganisms. Nature 215:891-8932.

Supports a hypothesis that indigenous microflora play a major role in the elimination of E. coli from the environment. Decrease in the number of E. coli was strongly affected by the size of the microbial population; almost no decrease was detected in autoclaved water. 3 figs., 7 refs.

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O'Brien, R. T. and J. S. Newman. 1977. Inactivation of polioviruses and coxsackieviruses in surface water. Appl. Environ. Microbiol. 33:334-340.

Viral inactivation rates were primarily affected by water temperature. There was differential stability among the viruses. Lower temperatures stabilized the virus but the mechanism is not known. 8 figs., 18 refs.

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Pike, E. B., A. L. H. Gameson and D. J. Gould. 1970. Mortality of coliform bacteria in sea water samples in the dark. Rev. Intern. Oceanogr. 18/19:97-106.

In seawater, mortality rate of coliforms was approximately doubled by a 10 C rise in temperature. The resistance of coliform to die-off in seawater may vary with the source of the sewage. 1 fig., 8 refs.

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Rao, V. C., K. M. Seidel, S. M. Goyal, T. G. Metcalf, and J. L. Melnick. 1984. Isolation of enteroviruses from water, suspended solids, and sediments from Galveston Bay: survival of poliovirus and rotavirus adsorbed to sediments. Appl. Environ. Microbiol. 48:404-409.

The distribution of enteroviruses among water, suspended solids and compact sediments in a polluted estuary was examined. Viruses were found adsorbed to: 72% of the suspended solids tested, 47% of the fluffy sediments (uppermost layer of bottom sediments), and only 5% of the compact bottom sediments. Virus was found in only 14% of the water samples tested. Viruses remained infectious for 9 days when suspended in water but for 19 days when adsorbed to solids. 7 figs., 34 refs.

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Rittenberg, S. C., T. Mittwer and D. Ivler. 1958. Coliform bacteria in sediments around three marine sewage outfalls. Limnology and Oceanography. 3:101-108

In areas of sewage outfalls, coliforms were found in sediments in areas beneath the path of movement of the effluent in the overlying water. Survival time in sediment not quantified. 5 figs., 17 refs.

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Roper, M. M., and K. C. Marshall. 1974. Modification of the interaction between Escherichia coli and bacteriophage in saline sediment. Microbial Ecology 1:1-13.

In marine sediments, E. coli appeared to be protected from phage attack by presence of sediment and other sorbed colloidal materials. The protection of E. coli and possibly other fecal bacteria may result in their accumulation in marine sediments, producing a possible health hazard in estuaries and lagoons if the bacteria are desorbed following dilution as a result of heavy rainfall. 8 figs., 27 refs.

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Roper, M. M. and K. C. Marshall. 1978. Effects of a clay mineral on microbial predation and parasitism of Escherichia coli. Microbial Ecology 4:279-289.

Clay can inhibit the normal predation of E. coli by predators.

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Sayler, G. S., J. D. Nelson Jr., A. Justice and R. R. Colwell. 1975. Distribution and significance of fecal indicator organisms in the upper Chesapeake Bay. Appl. Environ. Microbiol. 30:625-638.

Significant portions (>80 %) of the fecal indicator organisms were directly associated with suspended sediment. Counts however were not found to be correlated with suspended sediments. Prolonged survival of fecal strep in sediments was noted. 13 figs., 13 refs.

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Shuval, H. I., A. Thompson, B. Fattal, S. Cymbalista and Y. Weiner. 1971. Natural virus inactivation processes in seawater. ASCE SA5:587-599.

Enteroviruses are more resistant to inactivation processes in the marine environment than coliform organisms. The time at which the rapid inactivation phase of viruses starts appears to be closely associated with the period of logarithmic growth and maximum bacterial concentration in the seawater.

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Sinclair, J. L., and M. Alexander. 1984. Role of resistance to starvation in bacterial survival in sewage and lake water. Appl. Environ. Microbiol. 48:410-415.

The results show that Streptococcus faecalis, S. aureus and Streptococcus sp. readily lost viability in the absence of organic nutrients. Bacterial populations dropped 2-4 orders of magnitude in 1 to 4 days. Bacterial populations did not drop when added to samples of sterile sewage, probably due to availability of nutrients and removal of competitors. 5 figs., 17 refs.

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Sjogren, R. E. and M. J. Gibson. 1981. Bacterial survival in a dilute environment. Appl. Environ. Microbiol. 41:1331-1336.

Suggests that lowering pH can prolong survival of E. coli in a dilute environment. 6 figs., 30 refs.

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Smith, E. M., C.P. Gerba, and J.L. Melnick. 1978. Role of sediment in persistence of enteroviruses in the estuarine environment. Appl. Environ. Microbiol. 35:685-689.

Echovirus 1, coxsackie viruses B3 and A9 and poliovirus 1 survived longer when associated with sediments than when suspended in estuarine water. When the estuarine water was polluted with secondarily treated sewage effluent, virus survived for prolonged periods in sediments, but not in the overlying water. 5 figs., 24 refs.

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Tsai, Shiow-Chuan, R. D. Ellender, R. A. Johnson, and F. G. Howell. Elution of viruses from coastal sediments. 1983. Appl. Environ. Microbiol. 46:797-804.

Variations in the ability to elute viruses off sediments were due to differences in pH, virus types and composition of sediments.

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Vaccaro, R. F., M. P. Briggs, C. L. Carey, and B. H. Ketchum. 1950. Viability of *Escherichia coli* in sea water. *American J. of Public Health.* 40:1257-1266.

Bactericidal properties of raw, fresh seawater exhibited seasonal variation; the time required for the disappearance of 90% of introduced *E. coli* was 6.0 days in early November and 0.6 days in July. When the organic content of raw water was raised approx. tenfold by enrichment with peptone, the average time for the mortality of 90 % of the coliform population was about 3 times that of raw water. 7 figs., 13 refs.

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Valdes-Collazo, L., A. J. Schultz, and T. C. Hazen. 1987. Survival of *Candida albicans* in tropical marine and fresh waters. *Appl. Environ. Microbiol.* 53:1762-1767.

In near-shore coastal waters, survival of *E. coli* was enhanced by effluent from a rum distillery. Authors conclude that *E. coli* is not a good indicator of recent fecal contamination in tropical waters. 7 figs., 32 refs.

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Van Donsel, D. J. and E. E. Geldreich. 1971. Relationships of Salmonellae to fecal coliforms in bottom sediments. *Water Resources* 5:1079-1087.

Fecal coliform concentrations showed a 100 to 1000 fold increase in mud compared with overlying water. Survival of Salmonellae in mud closely parallels that of fecal coliform. 5 figs., 21 refs.

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Vasconcelos, G. J., and R. G. Swartz. 1976. Survival of bacteria in seawater using a diffusion chamber apparatus in situ. *Appl. Environ. Microbiol.* 31:913-920.

Using natural seawater, bacterial mortality was shown to be inversely related to water temperature. Nutrients were not controlled. For *E. coli.*, the highest fatalities were found to occur among cells exposed to 14.5 C as opposed to 8.9 C. 9 figs., 25 refs.

Vasconcelos, G. J., and N. C. Anthony. 1985. Microbiological quality of recreational waters in the pacific northwest. *JWPCF* 57:366-377

5 year study of microbiological water quality indicators including total coliform, fecal coliform, *E. coli*, fecal streptococci, enterococci, enteroviruses, and physiochemical parameters including pH, temperature, turbidity, and nutrient levels. 7 figs., 34 refs.

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Vaughn, J. M., E. F. Landry, M. Z. Thomas, T. J. Vicale and W. F. Penello. 1979. Survey of human enteroviruses occurrence in fresh and marine surface waters on Long Island. *Appl. Environ. Microbiol.* 38:290-296.

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Volterra, L., E. Tosti, A. Vero, and G. Izzo. 1985. Microbiological pollution of marine sediments in the southern stretch of the Gulf of Naples. *Water, Air, and Soil Pollution* 26:175-184.

Sediments show 100-1000 times the number of indicator organisms as overlying waters. 9 figs., 9 refs.

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Watkins, W. D., and V. J. Cabelli. 1985. Effect of fecal pollution on *Vibrio parahaemolyticus* densities in an estuarine environment. *Appl. Environ. Microbiol.* 49:1307-1313.

Numbers of *V. parahaemolyticus* were positively correlated with fecal pollution, including levels of *E. coli*, *Clostridium perfringens*, and enterococci. This is probably due to biostimulation of food chain by addition of wastewater effluents. 10 figs., 28 refs.

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Won, W. D. and H. Ross. 1973. Persistence of virus and bacteria in seawater. *J. of Environ. Engineering Division American Society Civil Engineers.* 99:205-211.

The addition of low concentrations of organic substances, including feces, to seawater enhanced survival of *E. coli* at 3-5 C. At 22 C, organic substances promoted growth of *E. coli*, allowing a 40 fold increase and enabling persistence up to 18 weeks. Apparently at this temperature the organic material overwhelmed bactericidal qualities of the seawater permitting growth. Addition of organics did not enhance virus survival. 7 figs., 9 refs.

BACTERIA AND VIRUS SURVIVAL AND TRANSPORT IN SOIL AND GROUNDWATER

Allen, M. J. 1981. Microbiology of ground water. JWPCF 53:1107-1109.

Literature summary on the entrainment of pathogens and indicator organisms in groundwater. 23 refs.

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Asano, T., ed. 1985. Artificial Recharge of Groundwater Butterworth Publishing, Boston.

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Bitton, G. 1975. Adsorption of viruses onto surfaces in soil and water. Water Research 9:473-484.

Literature review. Viruses act as electrically charged colloidal particles which may adsorb to surfaces outside the host cells. The sorptive interactions between viruses and surfaces influence the behavior of viruses in soil and other environments. 8 figs.

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Bouwer, J., J. C. Lance, and M. S. Riggs. 1974. High-rate land treatment II: water quality and economic aspects of the Flushing Meadows project. JWPCF 46:844

Most fecal coliform were removed in the first 2 ft (60 cm) of soil. Infiltration of fecal coliforms was slightly higher when initial flooding followed a dry period.

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Brown, K. W., H. W. Wolf, K. C. Donnelly, and J. F. Slowey. 1979. The movement of fecal coliforms and coliphages below septic lines. J. Environ. Qual. 8:121-125.

Septic effluent was applied to subsurface to three soil types of 80, 41 and 7.6 % sand content. Applied effluent averaged 1.108 x 10^6 plus or minus 1 x 10^4 FC/100 ml. Fecal coliform were present in leachate collected 120 cm below septic lines only on a few occasions. Coliphages also showed limited mobility. 7 figs., 13 refs.

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Burge, W. D. and N. K. Enkiri. 1978. Virus adsorption by five soils. J. Environ. Qual. 7:73-76.

Adsorption rate of virus to soil was correlated with cation exchange capacity, specific surface areas, organic content and pH of soil. Soil which did not adsorb virus had coarsest texture and highest pH. High negative correlation with pH is due to the amphoteric nature of virus coats; lowering soil pH increases the postive charge on the virus particle making it more likely to adsorb to soil surface. 7 figs., 14 refs.

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Dizer, H., A. Nasser, and J. M. Lopez. 1984. Penetration of different human pathogenic viruses into sand columns percolated with distilled water, groundwater, or wastewater. Appl. Environ. Microbiol. 47:409-415.

Enteroviruses and rotavirus SA11 were applied to 80 cm sand columns at a number of infiltration velocities. Tertiary treated effluent showed best adsorption; adsorption was poor for secondary effluent, probably due to increased organic content. Presence of surfactants significantly reduced adsorption. Results indicate that sand, even of low clay content, and at infiltration velocities of 0.5 to 5 m/day, is an excellent material for the elimination of viruses from contaminated waters. 7 figs., 22 refs.

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Duboise, S. M., B. E. Moore, C. A. Sorber, and B. P. Sagik. 1979. Viruses in Soil Systems. CRC Critical Reviews in Microbiology 245-285.

Extensive literature review of behavior of viruses in soils. Summary discussion points out the need for site-specific data to predict viral behavior. 9 figs., 301 refs.

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Duboise, S. M., B. E. Moore, and B. P. Sagik. 1976. Poliovirus survival and movement in a sandy forest soil. Appl. Environ. Microbiol. 31:536-543.

Ionic strength and pH of soil water greatly affect poliovirus adsorption to soil. Cycles of rainfall and effluent application, resulting in ionic gradients, caused viral elution off soils. Poliovirus survived in soil at 4 C to 20 C for up to 84 days. 9 figs., 21 refs.

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Duda, A. M., and K. D. Cromartie. 1982. Coastal pollution from septic tank drainfields. J. Environ. Eng. Div., Amer. Soc. Civil Eng. 108:1265-1279.

Septic tank drainfields installed in unsuitable soils were implicated as a major source of coliform contamination of coastal waters. Higher levels of indicator bacteria were found in catchments with greater number of septic systems, in both wet and dry conditions. Authors calculate that densities of more than 0.15 septic drainfields per acre (equals one septic drainfield per 7 acres watershed) result in bacterial levels high enough to cause shellfish closure. 8 figs., 17 refs.

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Edmond, R. L. 1976. Survival of coliform bacteria in sewage sludge applied to a forest clearcut and potential movement into groundwater. Appl. Environ. Microbiol. 32:537-546.

Fecal coliform applied to soil persisted for at least 204 days. In summer, aftergrowth of low numbers of fecal coliforms was noted. Die off rates were highest in winter. Both total and fecal coliforms migrated to soil beneath surface, but few moved more than 5 cm. 10 figs., 12 refs.

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Farrah, S. R., G. Bitton, E. M. Hoffmann, O. Lanni, O. C. Pancorbo, M. D. Lutrick, and J. E. Bertrand. 1981. Survival of enteroviruses and coliform bacteria in a sludge lagoon. Appl. Environ. Microbiol. 41:459-465.

Enteroviruses are efficiently retained by sludge-soil mixtures; viruses were not detected in 40-60 foot wells monitored at the site. 6 figs., 17 refs.

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Funderburg, S. W., B. E. Moore, B. P. Sagik and C. A. Sorber. 1981. Viral transport through soil columns under conditions of saturated flow. Water Research 15:703-711.

Movement of poliovirus 1, reovirus 3 and bacteriophage 0X174 was studied in 8 different soils. Adsorption and entrainment were related to soil cation exchange capacity (CEC), organic content, percent clay, pH, and specific surface area. Poliovirus recovery was correlated with low CEC and high organic carbon and clay content. Recovery of 0X174 was related to low CEC and low organic carbon. Soil CEC values of 23 meq/ 100 g were sufficient to remove at least 99% of poliovirus within 33 cm. 6 figs., 22 refs.

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Gerba, C. P., C. Wallis, J. L. Melnick. 1975. Fate of wastewater bacteria and viruses in soil. J. of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 101:157-175.

Literature summary. Soil moisture content, temperature, pH, availability of nutrients and antagonism are the principle factors influencing the survival of enteric bacteria in soils. The amount of information on virus survival in soil is very limited, but viruses appear to survive at least as long, if not longer than enteric bacteria. 5 figs., 63 refs.

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Gerba, C. P., and J. C. Lance. 1978. Poliovirus removal from primary and secondary sewage effluent by soil filtration. Appl. Environ. Microbiol.. 36:247-251.

Primary and secondary sewage effluent applied to 240 cm soil column, using loamy sand. Adsorption of virus to soil, and desorption by distilled water were similar for both effluents. The greater concentration of organics in primary effluent did not appreciably affect the removal of poliovirus by the soil. 5 figs., 22 refs.

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Gerba, C. P., and S. M. Goyal. 1985. Pathogen removal from wastewater during groundwater recharge. pp 283-317 in T. Asano, ed. Artificial Recharge of Groundwater, Butterworth Publishing, Boston, 1985.

Review of recent information on variables affecting microorganism survival and movement through soil, and fate of pathogens in subsurface waters, including results of field studies. 12 figs., 99 refs.

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Gerba,C. P., and J. F. McNabb. 1981. Microbial Aspects of Groundwater Pollution. ASM News 47:326-329.

Overview of the problems associated with groundwater microbiology. Cites studies documenting coliform travel in groundwater a distance of 900 m from site of application, and viral travel to 408 m. 21 refs.

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Gilbert, R. G., C. P. Gerba, R. C. Rice, H. Bouwer, C. Wallis, and J. L. Melnick. 1976. Virus and bacteria removal from wastewater by land treatment. Appl. Environ. Microbiol. 32:333-338.

Secondary sewage effluent was land-applied. After percolation through 9 meters of sandy loam soil no viruses or Salmonella spp. were detected in well samples, and the number of fecal coliform, fecal streptococci and total bacteria were decreased by 99.9%. 6 figs., 19 refs.

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Goyal, S. M. and C. P. Gerba. 1979. Comparative adsorption of human enteroviruses, simian rotavirus, and selected bacteriophages to soils. *Appl. Environ. Microbiol.* 38:241-247.

Viral adsorption to soil shows high variability among viral types, and among different strains of the same virus. Adsorption was also influenced by soil type and soil pH; soils with pH less than 5 were generally good adsorbers. Results emphasize that no one virus or soil can be used as sole model for predicting viral adsorption. 6 figs., 30 refs.

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Hagedorn, C., D. T. Hansen and G. H. Simonson. 1978. Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. *J. Environ. Quality*. 7:55-59.

E. coli and *Streptococcus faecalis* survived in groundwater to 32 days. Neither bacteria was detected in wells 30 m distance on day 32, but sufficient time may not have elapsed for travel in groundwater to this distance. Rainfall caused a peak in the bacterial numbers in wells. 5 figs., 8 refs.

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Hurst, C. J., C. P. Gerba and I. Cech. 1980. Effects of environmental variables and soil characteristics on virus survival in soil. *Appl. Environ. Microbiol.* 40:1067-1079.

Primary factors affecting virus survival in soils were temperature and viral adsorption to soil. Viral survival was also dependent on soil moisture, presence of aerobic microorganisms, soil levels of resin-extractable phosphorus, exchangable aluminum, and soil pH. 12 figs., 18 refs.

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Hurst, C. J., C. P. Gerba, J. C. Lance, and R. C. Rice. 1980. Survival of enteroviruses in rapid-infiltration basins during the land application of wastewater. *Appl. Environ. Microbiol.* 40:192-200

Poliovirus type 1 and Echovirus 1. Viruses exhibited a differential downward migration; 100 times more poliovirus than echovirus migrated 5-10 cm. after 5 days. Results indicate that the rate of virus inactivation was dependent on rate of soil moisture loss; drying cycles during the land application of wastewater enhance virus inactivation in soils. Maximum survival measured was 60 cm. 9 figs., 25 refs.

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Keswick, B. H. and C. P. Gerba. 1980. Viruses in Groundwater. *Environmental Science & Technology* 14:1290-1297.

Literature summary with many useful charts for entrainment of viruses in groundwater, including the effects of various parameters on entrainment. 7 figs., 56 refs.

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Kibbey, H. J., C. Hagedorn, and E. L. McCoy. 1978. Use of Fecal Streptococci as Indicators of Pollution in Soil. Appl. Environ. Microbiol. 35:711-717.

Streptococcus faecalis survived up to 12 weeks in soil under cool, moist conditions (4 and 10 C). Freeze-thaw cycles killed the bacteria. Bacteria exhibited variation in die-off among soil types. 8 figs., 15 refs.

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Lance, J. C., C. P. Gerba, and J. L. Melnick. 1976. Virus movement in soil columns flooded with secondary sewage effluent. Appl. Environ. Microbiol. 32:520-526.

Poliovirus 1 in sewage effluent traveled a maximum of 160 cm through a 250 cm column packed with calcareous sand. Most viruses were adsorbed in the top 5 cm of soil. Flooding with deionized water caused desorption from the soil and increased virus movement in the soils. 99.99 % or more removal of virus would be expected after passage of secondary effluent though 250 cm of calcareous sand unless heavy rains fell within 1 day of application. 9 figs., 16 refs.

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Lance, J.C., C. P. Gerba and S. S. Wang. 1982. Comparative movement of different enteroviruses in soil columns. J. Environ. Qual. 11:347-351.

Travel of Echo 1, Echo 29, and Polio 1 viruses through 250 m soil columns. Greater than 99.9% of viruses were removed by 160 cm. Virus movement thru loamy sand roughly parallels travel of fecal coliform. 8 figs., 15 refs.

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Lance, J. C. and C. P. Gerba. 1984. Virus movement in soil during saturated and unsaturated flow. Appl. Environ. Microbiol. 47:335-337.

Movement of poliovirus during unsaturated flow of sewage thru 250 cm. soil columns was much less than during saturated flow. Viruses moved 160 cm under saturated flow, vs. 40 cm during unsaturated flow. 4 figs., 13 refs.

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Landry, E. F., J. M. Vaughn, M. Z. Thomas and C. A. Beckwith. 1979. Adsorption of enteroviruses to soil cores and their subsequent elution by artificial rainwater. Appl. Environ. Microbiol. 38:680-687.

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Lo, S. H., and O. J. Sproul. 1977. Polio-virus adsorption from water onto silicate minerals. Water Research 11:653-658.

The presence of proteinaceous materials decreased the ability of silicate minerals to adsorb virus; extraneous organic material not only competed for adsorption sites but also desorbed the virus from the minerals. Organics in treated wastewater reduced the total adsorption capacity and rate of adsorption. 6 figs, 18 refs.

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Mack, W. N., M. SA. Yue-Shoung Lu., D. B. Coohon. 1972. Isolation of poliomyelitis virus from a contaminated well. Health Services Reports 87:271-274.

Poliovirus was isolated from drinking water from a well located more than 300 feet from the edge of a sewage drainfield. However, the well casing was in limestone so that percolation through soil may not have been involved. Actual source of virus in the well water was not determined. 2 figs., 4 refs.

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Mallmann, W. L., and W. Litsky. 1951. Survival of selected enteric organisms in various types of soil. American J. of Public Health 41:38-44.

The longevity of coliform organisms, typhoid bacilli and enterococci in soil was prolonged with an increase in the organic content of the soil. Coliforms were found to persist in soil for long periods, while enterococci died out rapidly. 5 figs.,13 refs.

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Marzouk, Y., S. M. Goyal, and C. P. Gerba. 1980. Relationship of viruses and indicator bacteria in water and wastewater of Isreal. Water Research. 14:1585-1590.

No correlation was found between indicator bacteria and the presence of viruses in groundwater. Suggests that the expected movement of viruses vs. bacteria in groundwater should be different. 5 figs., 33 refs.

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McConnell, L. K., R. C. Sims, and B. B. Barnett. 1984. Reovirus removal and inactivation by slow-rate sand filtration. _Appl. Environ. Microbiol._ 48:818-825.

McFeters, G. A., G. K. Bissonnette, J. J. Jezeski, C. A. Thomson, and D. G. Stuart. 1974. Comparative survival of indicator bacteria and enteric pathogens in well water. _Appl. Microbiol._ 27:823-829

Comparative survival of various bacteria in flowing well water was as follows: _Aeromonas_ sp. > the shigellae > fecal streptococci > coliforms = some salmonellae > _Streptococcus equinus_ > _Vibrio cholerae_ > _Salmonella typhi_ > _Streptococcus bovis_ > _Salmonella enteritidis_. 6 figs., 21 refs.

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Melnick, J. L., and C. P. Gerba. 1980. The Ecology of Enteroviruses in Natural Waters. _Critical Rev. Environ. Control._ 10:65-93.

Extensive literature review. Topics include occurrence of enteroviruses in surface, marine, and groundwaters, mechanisms of viral transport, and viral survival in natural waters. 11 figs., 146 refs.

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Moore, B. E., B. P. Sagik, and C. A. Sorber. 1981. Viral transport to ground water at a wastewater land application site. _JWPCF_ 53:1492-1502

Sewage effluent was applied to calcereous well-drained soils with moderate permeability (1.5-5.1 cm/h), soil pH of 7.7-9.0, and CEC of 25-50 meq/100 g. Fecal coliform and fecal streptococci were reduced by 90% with 0.46 m. infiltration depth. Enteric viruses were found to travel to a depth of at least 1.37 m. 9 figs., 13 refs.

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Moore, J. A. and G. R. Beehier. 1984. A study of the pollution potential of land-spread septage. _J. Environ. Health_ 46:171-175.

Saturated flow conditions in sandy soil resulted in movement of fecal coliforms to shallow (3 meter) water table. 2 figs., 14 refs.

Moore, R. S., D. H. Taylor, L. S. Sturman, M. M. Reddy, and G. W. Fuhs. 1981. Poliovirus Adsorption by 34 Minerals and Soils. _Appl. Environ. Microbiol._ 42:963-975.

A strong negative correlation was found between poliovirus adsorption and both the content of organic matter and the available negative surface charge on the substrates. The effects of surface area and pH were not strongly correlated with viral adsorption. 11 figs., 44 refs.

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Rebhun, M., J. Schwartz. 1968. Clogging and contamination processes in recharge wells. _Water Resources Research._ 4:1207-1217.

Found coliform multiplication in wells. High coliform counts found in the repumped water were the result of bacterial multiplication (growth) on the accumulated organic matter (consisting mostly of algal cells) which serves as a nutrient. 12 figs., 7 refs.

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Reneau, R. B., and D. E. Pettry. 1975. Movements of coliform bacteria from septic tank effluent through selected coastal plain soils of Virginia. _J. Environ. Qual._ 4:41-44.

Coastal plains soils considered "marginally conducive" for sanitary disposal, due to seasonally fluctuating water tables and/or restricting layers, were investigated. Lateral movement of fecal coliform to at least 13.5 meters was observed, but fecal coliform did not penetrate confining layers to reach groundwater. 4 figs., 18 refs.

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Schaub, S. A., and C. A. Sorber. 1977. Virus and bacteria removal from wastewater by rapid infiltration through soil. _Appl. Environ. Microbiol._ 33:609-619.

Wastewater applied to plots of unconsolidated silty sand and gravel. Indigeneous enteroviruses and coliphage f2 tracer were sporadically detected in groundwater to horizontal distances of 600 ft from the application zone. Fecal strep which penetrated the surface layer also travelled this distance. Enteric indicator bacteria were concentrated on soil surface by filtration on soil surface mat. 12 figs., 15 refs.

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Schaub, S. A., and B. P. Sagik. 1975. Association of enteroviruses with natural and artificially introduced colloidal solids in water and infectivity of solids-associated virions. _Appl._

Microbiol. 30:212-222.

Encephalomyocarditis viruses adsorb to introduced organic and inorganic material over a wide range of pH and with various concentrations of metal cations. Clay-adsorbed viruses maintained their infectivity. 9 figs., 41 refs.

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Scheuerman, P. R., G. Bitton, A. R. Overman, and G. E. Gifford. 1979. Transport of viruses through organic soils and sediments. *Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers* 105: 629-641.

Wetland organic soils (cypress domes) appear not to be suitable for application of wastewater for treatment. The presence of humic substances originating from these black organic sediments was shown to interfere with the sorptive capacity of soils and sediments toward viruses. 10 figs., 14 refs.

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Sinton, L. W. 1986. Microbial contamination of alluvial gravel aquifers by septic tank effluent. *Water, Air, and Soil Pollution* 28:407-425.

Fecal coliform were shown to travel 9 m from a 5.5 m deep soakage pit in an unconfined aquifer, and 42 m from an 18 m deep injection bore in a confined aquifer. Fecal coliform levels were reduced by a factor of 3 within the septic tank. 10 figs., 26 refs.

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Sobsey, M. D., C. H. Dean, M. E. Knuckles and R. A. Wagner. 1980. Interactions and survival of enteric viruses in soil materials. *Appl. Environ. Microbiol.* 40:92-101.

Clayey soils efficiently adsorbed poliovirus and reovirus from wastewater over a range of pH and total dissolved solids levels. Sands and organic materials were relatively poor adsorbents, though in some cases their ability to adsorb increased at low pH and with the addition of total dissolved solids or divalent cations; however, they did give > 95% virus removal from intermittently applied, unsaturated flow wastewater. Simulated rainfall through columns easily eluted viruses off sandy soils, but did not elute viruses from clayey soils. 10 figs., 24 refs.

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Stiles, C. W., and H. R. Crohurst. 1923. The principles underlying the movement of *Bacillus coli* in ground-water, with resulting pollution of wells. *Public Health Report* 38:1350-1353.

E. coli was found to travel up to 65 feet after being added to the saturated zone in fine sand (effective grain size of 0.13 mm)

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Tate, R. L., III. 1978. Cultural and environmental factors affecting the longevity of *Escherichia coli* in histosols. *Appl. Environ. Microbiol.* 35:925-929.

The number of viable *E. coli* cells found in Pahokee Muck was approximately threefold greater than that found in Pompano fine sand after 8 days incubation. Greatest coliform survival was seen under anaerobic conditions. Coliform die-off appears to be controlled by biotic factors, including protozoa. Increased coliform survival in histosol compared to mineral soil was due to the higher organic content of the histosol. 6 figs., 15 refs.

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Temple. K. L., A. K. Camper, and G. A. McFeters. 1980. Survival of two enterobacteria in feces buried in soil under field conditions. *Appl. Environ. Microbiol.* 40:794-797.

Authors show persistence of fecal bacterial viability in feces to at least 8 weeks (10^6 reduced to 10^3 or 10^4) under field conditions during a snow free period.

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Vaughn, James M. and E. Landry. 1983. Viruses in soil and groundwater. In G. Berg (Ed.) Viral Pollution of the Environment. Chapter 9. CRC Press. Boca Raton, Florida.

A comprehensive review of the literature on the subject. Useful summary tables presented. 3 figs, 182 refs.

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Vaughn, J. M., E. F. Landry, C. A. Beckwith and M. Z. Thomas. 1981. Virus removal during groundwater recharge: effects of infiltration rate on adsorption of poliovirus to soil. *Appl. Environ. Microbiol.* 41:139-147.

Tertiary-treated effluent was applied to recharge basins. High infiltration rates (75-100 cm/hr) resulted in movement of substantial numbers of poliovirus to groundwater. Infiltration rates of 6 cm/hr. significantly improved virus removal; highest viral removal efficiency was seen at very low infiltration rates of 0.5-1.0 cm/hr. 9 figs., 23 refs.

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Vaughn, J. M., E. F. Landry and M. Z. Thomas. 1983. Entrainment of viruses from septic tank leach fields through a shallow, sandy soil aquifer. *Appl. Environ. Microbiol.* 45:1474-1480.

Authors document travel of human enteroviruses from a subsurface wastewater disposal system in an area of sandy unconsolidated soil with a shallow aquifer. Enteroviruses were detected at a lateral distance of 67.05 m and at aquifer depths of 18 m. Virus occurrence was not correlated with total or fecal coliform numbers. 5 figs., 25 refs.

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Vaughn, J. M., E. F. Landry, L. J. Baranosky, C. A. Beckwith, M. C. Dahl, N. C. Delihas. 1978. Survey of human virus occurrence in wastewater recharged groundwater on Long Island. Appl. Environ. Microbiol. 36: 47-51.

Secondary- and tertiary-treated effluent was applied to recharge basins in sandy unconsolidated soil. Viruses were detected in groundwater where the recharge basins were located less than 35 feet (10.6 m) above the aquifer. Lateral entrainment of viruses to 45.7 m was noted at one site. 9 figs., 22 refs.

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Wang, D-S, C. P. Gerba, and J. C. Lance. 1981. Effect of soil permeability on virus removal through soil columns. Appl. Environ. Microbiol. 42:83-88.

Secondarily treated wastewater was applied to 100 cm soil columns. Viral removal was primarily determined by flow rate. At 33 cm/day sandy loam removed 99% seeded poliovirus in first 7 cm. At 300 cm/day rubicon sand removed less than 90% in 100 cm. This study suggests that the rate of water flow thru the soil may be the most important factor in predicing viral movement into the groundwater. 9 figs., 23 refs.

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Wellings, F. M., A. L. Lewis, C. W. Mountain, and L. M. Stark. 1975. Virus consideration in land disposal of sewage effluents and sludge. Florida Scientist 38:202-207.

Virus was shown to survive in groundwater for at least 28 days. 3 figs., 11 refs.

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Wellings, F. M., A. L. Lewis, C. W. Mountain, and L. V. Pierce. 1975. Demonstration of virus in groundwater after effluent discharge onto soil. Appl. Microbiol. 29:751-757.

Secondary effluent was discharged to a cypress dome; underlying soil strata was organic matter, sand and relatively impermeable sand/clay layers. Study found viral percolation to 3.05 m depth, and 7 m subsurface lateral movement of virus. Virus survived at least 28 days in groundwater. 4 figs., 20 refs.

Yates, M. V., C. P. Gerba, and L. M. Kelley. 1985. Virus persistence in groundwater. Appl. Environ. Microbiol. 49:778-781.

Temperature was found to be the single best predictor of virus persistence in groundwater. At lower temperatures (approx. 4 C) both poliovirus 1 and echovirus 1 persisted for up to 28.8 days before a 1 LTR (log titre reduction) took place. At 26 C, poliovirus survived 3-5 days before a 1 LTR took place. 3 figs., 19 refs.

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Crane, S. R., J. A. Moore, M. E. Grismer and J. R. Miner. 1983. Bacterial pollution from agricultural sources: A review. Trans. Amer. Soc. Agric. Eng.. 26:858-866.

For agricultural land use, frozen ground decreases infiltration and increases stormwater loading. Good Summary of total coliform, fecal coliform, fecal strep, and total enterococci concentrations in a variety of animal manures. Even if best management practices are followed, 10^3 - 10^5 organisms/100 ml should be expected as background. 4 figs., 82 refs.

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Gerba, C. P. and G. Schaiberger. 1973. Biscayne Bay: bacteriological data interpretation. Florida Scientist 36:104-109.

Peaks of fecal coliform abundance are correlated with periods of heavy rainfall. 3 figs., 13 refs.

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Hagedorn, C., D. T. Hansen and G. H. Simonson. 1978. Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. J. Environ. Quality. 7:55-59.

E. coli and Streptococcus faecalis survived in groundwater to 32 days. Neither bacteria was detected in wells 30 m distance on day 32, but sufficient time may not have elapsed for travel in groundwater to this distance. Rainfall caused a peak in the bacterial numbers in wells. 5 figs., 8 refs.

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Najarian, T. O., T. T. Griffin, and V. K. Gunawardana. 1986. Development impacts on water quality: a case study. Journal of Water Resources Planning and Management 112:20-35.

Discusses use of STORM, a U.S. Army Corp. of Engineers computer model, to predict pollutant loadings to surface and subsurface waters from a proposed large-scale residential development. 14 figs., 17 refs.

Schillinger, J. E. and J. J. Gannon. 1985. Bacterial adsorption and suspended particles in urban stormwater. *JWPCF* 57:384-389.

More than 50 % of stormwater bacteria studied do not settle or become associated with settling sediments. However, an average of 16-47% do get into the sediments and can accumulate, and should be considered when assessing health risk. 7 figs., 28 refs.

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United States Environmental Protection Agency. 1983. *Results of the Nationwide Urban Runoff Program . Volume I - Final Report.* *Water Planning Division, U.S. EPA,* Washington, D.C. 200 pp. NTIS Accession Number PB84-185552.

Extensive summary of conclusions from NURP program. Discusses characteristics of urban runoff, effects of runoff on quality of receiving waters, and stormwater management and runoff controls.

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United States Environmental Protection Agency. 1985. *Perspectives on Nonpoint Source Pollution.* Office of Water Regulations and Standards, U. S. EPA, Washington, D.C. 514 pp. EPA 440/5-85-001.

Proceedings of a national conference. 133 papers on topics including: monitoring and assessment techniques; legal aspects of nonpoint source pollution; institutional/financial aspects of nonpoint source control; groundwater quality; lake quality; estuarine quality; streams and rivers; economics of nonpoint source pollution; agricultural issues; urban runoff; urban hydrologic modification and septic tanks; land use management and assessment; case studies; data availability and needs; and water quality criteria and standards.

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Van Donsel, D. J., E. E. Geldreich and N. A. Clarke. 1967. Seasonal variations in survival of indicator bacteria in soil and their contribution to storm-water pollution. *Appl. Microbiol.* 15:1362.

Study on survival of *E. coli* and *Streptococcus faecalis* in outdoor soil plots. During summer, fecal coliform survived slightly longer than fecal strep; in autumn, survival was the same; and in spring and winter fecal strep survived much longer than fecal coliform. In summer and autumn both organisms at a protected hillside site survived about twice as long as at an exposed lawn site. Some aftergrowth of fecal and non-fecal organisms was observed as a result of temperature and rainfall variations; this may contribute to variations in bacterial counts in storm-water which have no relation to sanitary history of drainage area. 4 figs., 27 refs.

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Whipple, W., N. S. Grigg, T. Grizzard, C. W. Randall, R. P. Shubinski, and L. S. Tucker. 1983. Stormwater Management in Urbanizing Areas Prentice-Hall, Inc. Englewood Cliffs, N.J. 234 pp.

Chapter titles include: Introduction; Governmental Aspects of Stormwater Management; Storm Hydrology and Changing Land Use; Runoff Pollution; Stormwater Models; Erosion and Stormwater; Detention and Flow Retardation Devices; Floodplain and Channel Management; and General Planning and Management Aspects.

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Wisconsin Department of Natural Resources. 1983. Evaluation of urban nonpoint source pollution management in Milwaukee County, Wisconsin Volume 1: Urban stormwater characteristics, sources, and pollutant mangement by streetsweeping. Volume 2: Feasibility and application of urban nonpoint source water pollution abatement measures. Wisconsin Dept. of Natural Resources, Madison, Wisconsin.

Report produced as part of NURP program. Volume 1 compares commercial, industrial, agricultural, high and medium density residential areas, and highways as sources of toxic metals, suspended solids, and phosphorus in stormwater. Concludes that pollution control program must be tailored to specific land uses. Volume 2 discusses applicability and economic considerations in use of streetsweeping, stormwater storage basins, and catch basin cleaning as methods for abatement of nonpoint stormwater pollution.

EFFECT OF WATERFOWL ON BACTERIOLOGICAL QUALITY OF COASTAL WATERS

Brierley, J. A., D. K. Brandvold and C. J. Popp. 1975. Waterfowl refuge effect on water quality: 1. Bacterial bacterial and high sediment concentration water typical of the southwestern U.S. An increased number of coliforms correlated with increased nutrients in flowing water was also found. 8 figs., 9 refs.

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Hill, G. A. and D. J. Grimes. 1984. Seasonal study of a freshwater lake and migratory waterfowl for *Campylobacter jejuni*. *Can. J. Microbiol.* 30:845-849.

No *Campylobacter* were isolated from water, sediment, or bird cecal samples gathered in migratory waterfowl roosting pools. High fecal coliform counts in water followed moderately heavy rainfalls on two occasions, and was attributed to a sudden influx of waterfowl on another occasion. 2 figs., 32 refs.

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Hussong, D., J. M. Damare, R. J. Limpert, W. J. L. Sladen, R. M. Weiner and R. R. Colwell. 1979. Microbial impact of Canada geese (*Branta canadensis*) and whistling swans (*Cygnus columbianus columbianus*) on aquatic ecosystems. *Appl. Environ Microbiol.*. *37:14-20.*

Authors estimate that in a 24 h period a single swan will eliminate up to 10^9 fecal coliform and a goose will eliminate up to 10^7. Wild birds, as opposed to captive birds, found to harbor significantly more fecal coliforms than fecal streptococci. Neither *Salmonella* or *Shigella* were isolated from migratory waterfowl. 3 figs., 24 refs.

EFFECT OF MARINE CRAFT ON BACTERIOLOGICAL QUALITY OF COASTAL WATERS

Faust, M. A. 1978. Contribution of pleasure boats to fecal bacteria concentrations in the Rhode River estuary. unpubl. ms., Chesapeake Bay Center for Environmental Studies, Edgewater, MD.

In an estuarine area, bacterial concentrations rose from 3 to 28 fecal coliforms per 100 ml, and from 7 to 68 fecal streptococci per 100 ml after the arrival of pleasure boats for the weekend. Author calculates that 10-20 x 10^4 m^3 of water is required per boat to keep fecal coliform levels below the shellfish limit of 100 FC/ 100 ml. 4 figs., 20 refs.

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Garreis, M. J., F. A. Pittman, D. L. Elmore, R. L. Robison II. 1979. Marina impact on water quality in Kent Island Narrows, Maryland. Environmental Health Administration, Maryland Department of Health and Mental Hygiene. EH:WSC:GS #2.

Water taken from each of 6 marinas tested was found to have significantly higher total and fecal coliform than surrounding waters. Three marinas catering primarily to pleasure craft had higher levels of fecal coliform in marina waters on days following a weekend or holiday than on weekdays. No water from any of the marinas sampled met required standards for shellfish growing waters (14 FC MPN/ 100 ml). 15 figs., 9 refs.