Adaptability of selected Montana soils for septic tank sewage disposal
by Alfred Phillip Keppner

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
Excavation of septic tank filter fields and analysis of soil samples suggested that most nitrogen and phosphorus in sewage effluent accumulated within 5 meters of the point of input to the, soil.

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The total nutrient load, in terms of nitrogen and phosphorus, for the Gallatin Canyon was calculated with respect to present human activity and projected human activity in 1985. Increase in residents appears to be the greatest concern with respect to increases of nitrogen and phosphorus disposal as compared to travellers or the Big Sky development.

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Signature Alfred Phillip Keppner, Jr.

Date 10 August, 1972

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FOR SEPTIC TANK SEWAGE DISPOSAL

by

ALFRED PHILLIP KEPPNER, JR.

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

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INTRODUCTION

Green photosynthetic plants in terrestrial and aquatic environments produce their substance from carbon dioxide, water, and minerals with the utilization of solar energy. Directly or indirectly all living creatures derive subsistence from these plants. Part of this material is excreted and all ultimately reverts back to the environment to be decomposed by microorganisms. Compounds of nitrogen and phosphorus are produced which can be utilized by plants once again.

There is no avoiding this cycle which is something man is prone to forget, especially the modern city dweller with his municipal sewage system. All organic material is eventually returned to the land, the water, or the air. Man may not be able to escape this cycle, but he can alter it violently.

In sewage treatment the nutrient end-products are produced by controlled microbiological systems. Any factor which is resistant to natural or engineered treatment processes is said to be refractory to such processes. Of particular interest in this group of compounds are common nitrates and phosphates which serve as fertilizers in the natural cycle of growth and decay. By means of improper disposal they may enter an aquatic environment. This can stiumlate a profuse growth of algae in water, thus increasing the biological oxygen demand of lakes and of streams and leading to eutrophication.

The soil mantle has been acknowledged as a natural filter with a capacity to dispose of sewage wastes. Each soil has its own particular chemical and physical properties, and each soil has its own accommodation for constituents of sewage effluents. This axiom is valid for all nutrients including phosphorus and nitrogen.

The primary source of phosphate is synthetic detergents. Their use began in the early 1940's and increased to an approximate 1.8×10^9 kg/yr within the next 25 years. Of this vast amount 75 percent of the active ingredients were alkylbenzenesulfonate or ABS. The U. S. Public Health Service found that biologically active sand systems were capable of degrading ABS (105). The University of California confirmed this with studies on finer soils (69) and in field investigations at Caltech (82).

However, due to the refractory nature of ABS to conventional treatment processes, strong public opinion precipitated proposed legislation prohibiting manufacture and sale of ABS. Industry responded to the situation by an intensive search for a biodegradable substitute for ABS and in 1965 began using a new product, linear alkylsulphorate or LAS. From the standpoint of wastewater disposal in the soil mantle, a septic tank system with a properly engineered drain field can remove up to 97.4 percent of the LAS as compared to only 73.9 percent of the ABS (77). With improperly engineered systems or installation on unsuitable sites, this material may enter groundwater or reach surface water.

It is conceivable that nitrogen in the form of nitrates could enter groundwater or reach surface water if septic tank drain lines are installed in unsuitable soils or are improperly engineered. The addition of phosphorus or nitrates to the surface water could lead to eutrophication.

Nitrate in drinking water has been associated with a sometimes fatal blood disorder in infants called methemoglobinemia. Up to 1970 approximately 2,000 cases have been reported in Europe and North America with about 7 to 8 percent being fatal (144). These figures represent only a fraction of observed cases for the disease is not contagious and need not be reported.

For sewage disposal in the soil the septic tank drain fields is the adsorption system. A subsurface tile structure is installed to facilitate a uniform distribution of effluent into the soil. The effluent is discharged from near the top of the septic tank and passes through these perforated tiles. Criteria used to rate a soils ability to dispose of sewage effluent are based upon its capacity to absorb it.

The 6 most important factors in determining the suitability of a soil as a septic tank absorption field are (a) permeability of the subsoil, (b) depth to impervious layers, (c) flooding hazard, (d) the level of groundwater, (e) slope, and (f) local experience and records of performance of existing filter fields (123). The United States Soil Conservation Service soil limitation classes for septic tank filter fields based upon the above criteria are given in Table 16.

A quarter of all new homes are being equipped with septic tanks, and nearly 15 million families now depend on them (50). If this effluent is improperly disposed of into the soil, compounds of nitrogen and phosphorus can create detrimental environmental circumstances for individuals and society.

It was the purpose of this study to examine 5 Gallatin County soil series to ascertain the extent of nutrient spreading in operating septic tank drain fields and to determine their ability to accommodate nitrates and phosphorus. The conclusions reached from the study combined with counsel from the literature will be used to predict the adaptability of six developable Gallatin Canyon soil series for the disposal of domestic sewage effluent. Operating septic tank systems were unavailable for study on these soils.

With projected development in Gallatin Canyon in the near future, it would be prudent to consider the sources of additional nutrients to the Gallatin Canyon ecosystem from wastes. Therefore, an evaluation of the nutrient load from man and from elk was compiled for the present and for predicted occupation in 1985 and presented in Tables 1 to 15.

Finally, based upon this study and related research reported in the literature some future studies are proposed.

LITERATURE REVIEW

Most studies relating to the soil's ability to dispose of sewage effluent have involved applying domestic sewage, after various degrees of treatment, directly to the soil through the surface or by the use of soil columns of various sizes. Biological contamination was the primary consideration in most of the earlier studies.

One of the earliest experiments was conducted by the city of Los Angeles in the early part of the 1930's (47). In this study sewage was given primary and secondary treatment before being introduced into the ground. In 1949 the County of Los Angeles carried out more extensive tests (6) where bacterial contamination of percolate was reported to be reduced to a level below the maximum permitted by the U.S. Public Health Service Standards after a movement downward of 213 cm. Studies of surface spreading at Whittier and Azusa, California (79) led to the conclusion that water of a bacterial quality suitable for drinking purposes can be obtained by passage through a minimum of 91 to 213 cm of fine textured soil.

One of the most recent and thorough studies of reclamation of water from sewage effluents was the Santee Project near San Diego, California. Here tertiary treated sewage was pumped to 6 percolation beds in parallel across a shallow stratum of sand and gravel confined to an old stream bed. The infiltered water moved down this channel to an interceptor trench dug across the channel at 457 m, passing enroute sampling wells at 61 and 122 m. Most bacteria and virus removal occurred within the first 61 m. This study did not show at what distance the infiltrate reached U. S. Public Health Service drinking water standards, but it did illustrate removal of bacteria in a very coarse medium.

Further biological studies in Colorado by Romero (106) illustrate some outstanding characteristics of movement of pollutants through porus media. Basically he found that (a) pollutants travel with the flow of water; they do not travel or move against the current, (b) that pollutants can move in a direction opposite to that of normal groundwater gradients during times of recharge, (c) that bacteria and virus are removed by their inability to adjust to abrupt temperature changes, by oxygenation and nitrification, and destruction by pre-existing soil microorganisms, (d) that aquifer materials best suited for the removal of biological contaminants are those uniformly composed of very fine grained sand with a high clay content, (e) that for an ideal system the maximum length of travel of biological pollutants with groundwater ranges between 15 and 30 m, (f) that pollution travel in nonsaturated systems is considerable less than that in saturated systems in that maximum lengths of travel appear to be in the vicinity of 3 m, and (g) that bacteria and/or virus infested pollutants might travel farther than predicted if nutrient laden waters are intercepted during the course of penetration for nutrients stimulate reproduction.

In the early 1950's field investigations of sewage reclamation by surface spreading were conducted by the Sanitary Engineering Research Laboratory of the University of California. Extensive chemical and bacteriological investigations were made to determine the efficiency of sewage reclamation (29). On a sandy loam soil sewage could be chemically reclaimed at application rates of 1.5 ml/1 cm^2. They also demonstrated that bacteriologically safe water can be produced by passing effluent from primary treated sewage through a minimum of 122 cm of the soil under study.

An investigation of sewage spreading on 5 California soils was conducted by the University of California Sanitary Engineering Research Laboratory after the conclusion of the studies on the sandy loam soil. Here 91 by 151 cm lysimeters were filled with soil and sewage effluent allowed to pass. It was discovered that coliform bacteria removal was generally higher in the fine textured soils. Also cation exchange took place to a considerable degree during sewage spreading, the most common effect being the substitution of sodium, potassium, and ammonium ions for calcium and magnesium (110).

Extensive studies have been conducted on maintaining the infiltrative capacity of a soil system by the Sanitary Engineering Research Laboratory of the University of California (79). The conclusions reached to date are as follows: (a) the infiltrative surface should be no less permeable than any undisturbed parallel plane within the system, (b) the soil surface should be managed in such a fashion as to disperse clogging material, (c) there should be no abrupt change in particle size between coarse trench fill or surface cover material and the soil at the infiltrative surface, (d) the infiltrative system should provide a maximum of sidewall surface and a minimum of bottom surface, (e) continuous inundation of the infiltrative surface must be avoided, (f) aerobic conditions should be maintained in the soil system, (g) the entire infiltrative surface should be loaded uniformly and simultaneously, and (i) the amount of suspended solids and nutrients in the applied wastewater should be minimized.

The use of sewage effluent for irrigation purposes as a method of disposal has been considered most extensively by the Pennsylvania State University. Pennypacker et. al. (98) showed that using secondary effluent to irrigate forest land ABS concentration decreased below U. S. Public Health Service Standards for potable water after travel through a minimum of 0.9 m of mineral soil when effluent application was 10 cm/wk.

Parizek and Myers (96) summarized the work reported to date by Kardo (62) (63), Sopper (116), and Sopper and Sagmuller (119). They state that uniform distribution of the returned effluent is a necessity throughout the entire year, which frequently includes periods of freezing temperatures. The rate of application must be slow enough and the amount small enough to insure infiltration and removal of the pollutants. In the Pennsylvania State study the application rate was

6.35 mm/hr, the most frequently used amount was 5 cm/wk, and satisfactory distribution was achieved down to temperatures of -24.5°C.

The renovation zone must remain efficient from year to year and throughout the entire year. In properly managed cropland renovation areas, the nutrients taken from the wastewater are removed from the area with the harvested crops. At Pennsylvania State a high degree of renovation is being achieved after over 762 cm of effluent have been applied during 5 years.

Winter irrigation requires special attention to management detail. Nutrients must not be added faster nor in greater amounts than can be adsorbed and retained in the upper soil profile for summer use.

Disposal of sewage effluent through irrigation of forest stands seems to be feasible from the standpoint of tree growth. Coniferous species adapted to moist sites would be the most desirable for use in this type of project (118). Also considered in the Pennsylvania State studies was the beneficial aspects of raising soil p^H on acid sites with sewage effluent, especially strip mined areas (117).

For years percolation tests have been used to estimate the hydraulic conductivity of the soil to give an indication of its ability to accept sewage effluent from septic tanks. The best known and most widely employed estimate of hydraulic conductivity of the soil is the auger hole percolation test which is described in the Public Health Service's "Manual of Septic-Tank Practice" (76). This is an on site attempt to determine the capacity of a soil to accept water. Henry Ryon (108) is considered as the one who first devised the percolation test in 1926. Fedrick (40) published Ryon's work in 1948. His test consisted of digging a hole 31 cm square and 46 cm deep. The hole was saturated and excess water allowed to seep into the ground. The hole was then filled with water to a depth of 15 cm and the time required for the water surface to lower 2.5 cm was observed.

Kiker (66) noted in 1953 that, "Ryon recognized that there was an initial blotting effect at the beginning of tests in dry soil. He emphasized the necessity of having the soil thoroughly wet before measuring the percolation rate". Ryon did not describe an explicit procedure for presoaking a test hole.

To explore the reliability of this method to indicate whether a septic tank installation will fail, the Robert A. Taft Sanitary Engineering Center of the Public Health Service reported results of field studies utilizing the same techniques as Ryon. The loading rate of each system was determined and its history noted (18). A comparison of data on percolation rates, loading rates, and age indicated a large coefficient of variability. They suggested that the variability of the data demonstrated that the relationship between percolation rates and sewage loading rates was a poor indicator for accurate design criterion.

Persinger and Yahner (99) in Indiana found a highly significant correlation on glacial outwash, glacial till, and lucustrine soils between percent sand and percolation rates. They infer that with a knowledge of the characteristics of each soil series, soil texture inferred from soil maps can be a substitute for percolation rates within broad limits.

Ryon's original percolation test has been subject to modification through the years. All state health departments adopted standard procedures. With various modifications these were used by numerous agencies having authority over septic tank installations. The U. S. Public Health Service through the Robert A. Taft Sanitary Engineering Center has modified the procedure as a result of experimental studies (16), (17), (138), (139). This was an attempt to reduce the coefficient of variability. Its current provisions are found in the U. S. Public Health Service's "Manual of Septic-Tank Practice". It can also be found in the Montana State Department of Health regulations (85).

At the University of Wisconsin in Madison, it has been demonstrated that the falling head procedure for the determination of percolation rates can reduce the coefficient of variability to 35 percent (22). The double tube method described by Bouwer (23), (24), (25) and modified in 1967 (26) was used in a Wisconsin study to determine the hydraulic conductivity (K) values for saturated soils being used as seepage beds for septic tank systems. Soil moisture tensions were also recorded around operating, partly filled seepage beds in different soils indicating the occurance of low folow rates through unsaturated soils due to crusting at the soil interface of the seepage beds.

A field experiment (22) with dosing of effluent was made to demonstrate that system management will determine which K values from a measured range applies at any given time. Using the Bouwer double tube method, they proposed that the measurement of hydraulic conductivity *in situ* as a function of soil moisture tension be used as a field test to determine soil potential for effluent disposal.

It has been well documented that phosphorus from fertilizer moves very little in soils. This implies that soils can be used to reduce the level of phosphorus in sewage effluent. The Pennsylvania State University studies (95) confirmed the validity of that statement. The same mechanism should function either when spreading by sprinkler irrigation to a large area or seepage from the drain field of a septic tank system.

Olsen and Watanabe (91) have suggested a method for the application of the Langmuir isotherm to the study of phosphorus adsorption by soils. The Langmuir equation was developed (73) through the kinetic theory of gases to describe adsorption of gases on solids. Studies in Maine (48) indicate that the Langmuir equation can be used to describe the relationship between phosphorus retention and concentration. Ellis and Erickson (38) present a simplified derivation of the equation for the case of phosphorus adsorption by soils. It is a linear form of the equation expressed as: $\frac{(p)}{x/m} = \frac{1}{Kb} + \frac{(p)}{b}$ where (p) is the activity of phosphorus in solution in moles/liter, x/m is the mg phosphorus adsorbed per 100 grams soil, b is the maximum amount of phosphorus that will be adsorbed by a given soil, and K is a constant.

Removal of phosphorus from sewage effluent by soils depends not only upon the adsorption maximum of soils but also on the level of phosphorus in the soil solution at equilibrium. Ellis and Erickson suggest the use of the method of White and Beckett. Gillham and Webber (46) found that over 90 percent of the inorganic nitrogen in contaminated groundwater was in the nitrate form. To lend credence to this widely accepted idea, Preul and Schroepfer (103) conducted extensive experiments using water containing 25 mg/l ammonium nitrogen and neglibible concentrations of nitrite and nitrate nitrogen as representative of wastewater that might be released for disposal in the soil. This hypothesis was verified by Babbitt and Baumann (7) and McGauhey (77). They found that the major part of nitrification took place in the initial 60 cm from the source with adsorption of ammonia accounting for most of the remainder of nitrogen. After operation of a system for about 2 weeks, which was required to develop the microbial populations, adsorption was of minor significance and nitrification was the totally dominant factor.

METHODS

The Amsterdam series was selected for study because it has developed over extensive areas of Gallatin County. The Amsterdam series consists of Typic Cryoborolls developing from aeolian deposits of Tertiary age. The typical profile (88) has a dark greyish brown silt loam Ap horizon, brown prismatic heavy silt loam B2 horizon, thin light yellowish brown prismatic silt loam B3ca, and a pale yellow silt loam IIC2ca horizon containing considerable shards of volcanic glass.

Residential development is common in Gallatin Canyon at the base of hills where there is a gradation from a soil developed on the slope to a soil developed on the valley floor. One such site was selected in a gradation between Leavitt and Bigel soils. The Leavitt series (88) is a member of the fine-loamy mixed family of Argic Cryoborolls. Generally they have a very dark grey stony loam A horizon, a greyish brown cobbly heavy clay loam B2t horizon, and a strongly calcareous, cobbly, heavy clay loam Cca horizon. The Bigel series (88) is a member of the loamy-skeletal, mixed family of Argic Cryoborolls. They have a dark greyish brown cobbly loam A horizon, a brown very gravelly and cobbly clay loam B2t horizon, and a loamy sand and gravel C horizon.

Extensive areas of Gallatin Canyon are occupied by an association of Bearmouth and Bigel soils. These sites are generally level and are favored for development. Therefore a septic tank system installed on these soils was selected for study. The Bearmouth soils (88) are members of the sandy-skeletal mixed family of Typic Cryoborolls. They have a dark greyish brown very gravelly loam A horizon overlying loamy sand and gravel at depths of around 30 cm.

Extensive areas of Huffine soils exist in Gallatin County. Although these are plagued by seasonal high water, they are favored for development because of their proximity to Bozeman. Therefore, it was deemed advisable to investigate a Huffine site. They are members (88) of the fine-silty over sandy or sandy-skeletal mixed family of Argic Cryoborolls. Typically they consist of granular, dark grey, silt loam A horizons, prismatic-blocky structure, silty clay loam B2t horizons, silt loam C horizons with prominent accumulations of calcium carbonate, and sand or sand and gravel substrata at depths of 50 to 100 cm.

The level areas adjacent to the Gallatin River are coveted as sites for development because of their proximity to aquatic environs. Therefore a septic tank installation on this alluvial material was studied.

Other soils in Gallatin Canyon, not already considered, that have development potential are Hanson, Hobacker, and Michelson. They occupy areas in private ownership and have some areas with slopes of less than 15 percent.

The Hanson soils are members of the loamy-skeletal, carbonatic family of Calcic Cryoborolls. Typically, Hanson soils have a dark greyish brown cobbly loam A horizon overlying very strongly calcareous very cobbly loam C horizons.

The Hobacker series (88) is a member of the loamy-skeletal, mixed family of Pachic Cryoborolls. Typically, they have a very dark greyish brown loam A horizon and very cobbly and gravelly lower A and C horizons that are calcareous.

The Michelson soils (88) are members of the fine-loamy, mixed family of Argic Cryoborolls. Generally they have a dark greyish brown loam A horizon, a brown, clay loam B2t horizon; and a prominent, very pale brown Cca horizon of loam and clay loam.

Field Procedures

A reconnaissance at each site under investigation ascertained the soil limitation class or each soil for the following factors: (a) the depth to impervious layers, (b) flooding hazard, (c) groundwater level, and (d) slope. Since permeability of the subsoil is a determining parameter for the extent to which sewage effluent will spread, percolation tests were performed at each site.

Since the auger hole method is the most universally adopted procedure for indicating percolation rates (27) (54), it was decided to use it in this study.

Excavations of a septic tank filter field at each site provided a method to determine the extent of sewage spreading in both a downward and outward direction. Pits were dug in the downslope direction utilizing hand tools, and soil samples were collected at regular intervals. Unbranched drain lines were selected so the point of sewage input could be determined. Locations of soil samples collected are given in Tables

18, 20, 22, 24, and 26 and in FIGURES 1 to 11.

These samples were analyzed for texture, water retention at saturation, electrical conductivity, pH, sodium bicarbonate soluble phosphorus, nitrate nitrogen, soluble potassium, soluble calcium, soluble magnesium, soluble sodium, and, on samples from one site, total phosphorus.

Laboratory Procedures

In the laboratory mechanical analysis was performed to determine soil particle size for each soil sample utilizing the Bouyoucos hydrometer method as described by Millar et. al. (84). Readings were taken at 40 seconds and 2 hours so results would correspond to the U. S. Department of Agriculture textural classification system.

Saturated moisture percent was determined by measuring the weight of water necessary to bring 100 grams of soil to saturation. Electrical conductivity was measured on saturated extract using a Serfass Conductivity Bridge Model RCM 15B1. Soil pH was determined on saturated paste using a Corning Model 12 Research pH Meter with a glass-calonel electrode pair.

Bicarbonate soluble phosphorus is the form that can be expected to move in the soils under study for they are chemically dominated by calcium. The procedure used is the extraction method of Olsen (89) and the ascorbic acid method of color development (4) (135). Readings were taken on a Bausch and Lomb Spectronic 20 spectrophotometer.

Many methods of nitrate determination are available to the researcher. Ferguson and Sowden (44) give a comparison of methods of determining nitrogen fractions in soils. A rapid method described by West (140) and perfected by Sims and Jackson (113) is a colorimetric determination utilizing chromotropic acid for color development. Being a relatively new procedure few investigators have used it and others may find difficulty in the interpretation of results. The phenoldisulphonic acid method is rapid for nitrate determination and is widely used. The results can be interpreted by many. Therefore, the phenoldisulphonic acid method was the procedure used (21).

Soluble salts may accumulate in soil that has been saturated with effluent. High sodium concentration would cause dispersal of the clays and hence failure of the system to accept effluent. The amounts of calcium would influence precipitation of phosphorus. Soluble salts were determined by standard methods described by Jackson (60) and Black et. al. (21) utilizing the 290-B Perkin-Elmer atomic absorption spectrophotometer to analyze filtrates for potassium, calcium, magnesium, and sodium.

The sodium carbonate fusion method described by Jackson (60) was used to extract total phosphorus from samples at one site. The ascorbic acid method of color development as used in the sodium carbonate soluble phosphorus determination was employed in this analysis. Readings were taken on the Bausch and Lomb Spectronic 20 spectrophotometer.

RESULTS

Amsterdam Soils

The septic tank system on this site was in operation for approximately 12 years serving a family of 5 that uses a washer but no garbage disposal. If the average person produces 200 liters of waste per day (77), approximately 4.38×10^6 liters of effluent have been added to the system. Using the average sewage analysis given by Babbitt and Baumann (7) as shown in Appendix Table 17, 219 kg of total nitrogen and 45 kg of phosphorus have entered the filter field. The auger hole percolation rate of the Amsterdam soil at this site was 12.3 cm/hr.

The data indicate that nitrates (Appendix Table 19 and Figure 1) have accumulated in the first 5.5 meters from the point of effluent input as indicated by a slight accumulation of 12.8ppm nitrate at the 267 cm depth located 5.5 meters from the drain line. Most nitrates accumulated within 2.5 meters of the point of input as illustrated by comparison of data for nitrate 1 meter above line and nitrates in the soil at similar depths 2.5 and 7.5 meters from the drain line. At depths of 15, 35, 61, and 91 cm, nitrate concentrations above the line are 51.5, 62.5, 26.5, and 15.5 ppm respectively while at the same depths 2.5 meters from the line, concentrations are 24, 4.4, 2.0, and 3.8 ppm respectively and at 7.5 meters 5.5, 1.0, 1.0, and 1.0 respectively. Figure 1 illustrates that nitrates near the point of input tend to accumulate more in the upper horizons due to upward movement of water as influenced by the vegetation.

Soluble phosphorus has accumulated in the first 2.5 meters from the drain line. The data (Table 19 and Figure 2) shows that at 5.5 meters from the line there is no difference in bicarbonate soluble phosphorus when compared to an unaffected area at 7.5 meters from the drain line. The affected area also shows an increase of total phosphorus (Table 19 and Figure 3) which is reasonable since an estimated 45 kg of phosphorus has been produced over the past 12 years.

From the data (Table 19) it can be seen that pH was not affected significantly by the addition of effluent. This is not surprising as effluent pH averages between 7.2 and 7.6 (77) and the Amsterdam soil is near neutral in the upper horizon to about 7.5 in the C_{ca}. The effluent added is approximately the same pH as the soil. The saturated moisture percent was not changed by the addition of septic tank effluent (Table 19). This would indicate that the system is operating properly and keeping organic material in the septic tank.

The electrical conductivity of the saturation extract ranged from a high of 3.75 mmhos/cm to a low of 0.35 mmhos/cm. The sodium adsorption-ratios were all low ranging from a low of 2.3 to a high of 6.1. This is to be expected as no water softener utilizing sodium salts has been used on the premises.

Leavitt-Bigel Soils

This site is located at the base of a gently slope in a gradation between Leavitt and Bigel soils. The septic tank and drain field have been in operation for approximately 11 years serving a family of 3 with a washer but no garbage disposal. Approximately 2.4 x 10^6 liters of effluent have been added to the system containing 120 kg of total nitrogen and 24 kg of phosphorus. The auger hole percolation rate at this site is 8.2 cm/hr.

The data (Table 21 and Figure 4) indicate that nitrates have traveled outward approximately 1.5 meters and downward 2 meters. Nitrate concentration at this point is 12.2 ppm while $\frac{1}{2}$ meter below this point it is only 1.5 ppm. Unlike the soil at the Amsterdam site, there was no large accumulation of nitrate in the upper horizon. The vegetation cover was sparse due to heavy use by horses and frequent trampling by men and machinery.

Data on soluble phosphorus (Table 21 and Figure 5) demonstrate little movement or accumulation beyond one half meter from the drain line or 1 meter below the line. Concentration at this point is 38.4 ppm while at 1 meter deep and 1.5 meters from the line the concentration is 33.6 ppm, and at one meter deep and 2.5 meters from the line it is 29.4 ppm. In an unaffected area 3.5 meters from the line and 3 meters deep the concentration of sodium bicarbonate soluble phosphorus is 24.3 ppm indicating little change 1.5 meters from the line when compared to an area unaffected by sewage effluent.

Soil pH within 0.5 meter of the drain line was lower than in samples at similar depth but farther from the drain line. This may be caused by the high reducing conditions created by constant saturation. Since this is not a significant distance from the line to affect management decisions and the first one half meter of soil has been disturbed, this fact has no significance. The saturation moisture percent was not changed by the addition of septic tank effluent.

The electrical conductivity of the saturation extract ranged from a high of 1.5 mmhos/cm at the sampling point nearest the area of effluent input to a low of 0.25 mmhos/cm. At this site the sample most saturated with effluent had the highest electrical conductivity which illustrated the fact that it had the highest concentration of soluble salts. The sodium adsorption ratios ranged from a low of 0.8 to a high of 10.0 indicating accumulations of sodium.

Bigel-Bearmouth Soils

This site is in the Bigel-Bearmouth association where the two soils are intermingled. The septic tank system has been in operation a minimum of 10 years on a seasonal basis by an average of 8 persons for about 4 months of the year. No washer or garbage disposal has been in use. Approximately 9.6×10^5 liters of effluent has been introduced into the system containing 48 kg of nitrogen and 9.6 kg of phosphorus. The auger hole percolation rate at this site is 7.1 cm/hr.

Data (Table 23 and Figure 6) indicate that nitrates have travelled at least 3 meters from the input point although this increase (2.5 ppm) is small compared to samples from unaffected areas (1.0 ppm). Most nitrates have accumulated within 2 meters of the drain line as noted by a concentration at 90 cm depth 2 meters from the line of 8.8 ppm. At the same distance from the line and 155 cm deep the concentration is only 3.3 ppm.

At this site rock was encountered at the bottom of each test hole. That is why excavation was not continued to greater depths. It is noted that nitrate has accumulated at the depth of the rock as illustrated in FIGURE 6. One half meter from the drain line and 95 cm deep nitrate concentrations of 14.8 ppm were found. An area unaffected by effluent 5 meters from the line at a depth of 90 cm had a concentration of 1.0 ppm.

Data on sodium bicarbonate soluble phosphorus (Table 23 and Figure 7) demonstrate maximum lateral movement of 3 meters but most accumulation is in the first 2 meters. At 5 meters from the input point in an area unaffected by effluent, bicarbonate soluble phosphorus concentrations at 90 cm was 13.1 ppm as compared to a concentration of 31.8 ppm meters distance and 90 cm deep. Greater accumulations at 2 meters from the line are in evidence. As in the case of nitrate, sodium bicarbonate soluble phosphorus has accumulated at the depth of the rock as illustrated in FIGURE 7.

The soil pH was highest in areas of sewage accumulation which were also calcareous. The electrical conductivity of the saturation extract ranged from a high of 1.4 mmhos to a low of 0.5 mmhos/cm indicating low concentrations of soluble salts. It was highest at the point of sewage input, but was nearly as high in the C_{ca} horizon. The sodium adsorption ratios were low ranging from 7.0 to 3.1.

Huffine Soils

The septic tank system on this site has been in operation for 3 years serving a commercial enterprise with only domestic wastes being disposed of through the system. It has been estimated that $4.4 \cdot 10^5$ liters of effluent have entered the drain field containing 22 kg of nitrogen and 4.4 kg of phosphorus. The auger hole percolation rate at this site was 4.7 cm/hr.

In the spring and during the irrigation season groundwater rises to within 46 cm of the surface. This has a profound effect on the spreading of sewage in the drain field. The movement of nitrates is not in evidence as the concentration in the site is 1.5 ppm or less except in the surface horizon near the drain line where the concentration is 4.4 ppm (Table 25 and Figure 8).

This same phenomenon can be observed (Table 25 and Figure 9) for sodium bicarbonate soluble phosphorus. The highest concentration of bicarbonate soluble phosphorus is at the 20 cm depth only 30 cm on each side of the drainage line. The concentrations are 31.8 and 35.5 ppm respectively. Only 3.5 meters from the line the concentrations at 20, 60, 100, 130, and 135 cm depths are 14.5, 13.8, 20.6, 11.5, and 14.5 ppm respectively giving a rather uniform concentration in the profile.

Soil pH was not significantly affected by the introduction of sewage effluent (Table 25). As in the case of the Amsterdam soils, effluent of pH 7.2 to 7.6 is being introduced into a soil of similar pH. The saturated moisture percent was not changed by the addition of septic tank effluent either.

The electrical conductivity of the saturation extract (Table 25) ranged from a high of 1.6 to a low of 0.4 mmhos. The highest electrical conductivity value was at the sample site nearest the tile line indicating the introduction of soluble salts into the system. The sodium adsorption ratio varied from a high of 10 to a low of 2.7 with the highest value being in the sample profile nearest the line. This indicates the addition of sodium to the soil system by effluent.

Alluvial Soils

This site is located in a low plain near the Gallatin River. It has about 1.0 meter of fine alluvial material over gravels. The groundwater generally was encountered at 60 to 90 cm depth preventing deeper excavation. In the spring of the year water rises to near the surface. The auger hole percolation rate at this site is 3 cm/hr.

The septic tank system at this site has been in operation for approximately 2 years serving 2 people with a washer but no garbage disposal. About 2.9 x 10^5 liters of effluent have been added to the system containing 14.5 kg of nitrogen and 2.9 kg phosphorus.

At the 20 cm depth just one half meter from the input point, the nitrate concentration is 59.1 ppm while concentrations of other samples vary from 9.2 to 1.0 (Table 27 and Figure 10). The only 2 samples with concentrations over 2.5 ppm are in the upper 15 cm where there is an accumulation of organic matter. These concentrations are 9.2 and 7.5 ppm.

Sodium bicarbonate soluble phosphorus (Table 27 and Figure 11) has concentrated near the line (103 ppm) while just 1.5 meters from the line the concentrations at 15, 45, and 65 cm depths are 16.3, 8.3, and 9.8 ppm respectively. The sodium bicarbonate soluble phosphorus has not traveled over a meter at this the most mesic site studied.

The soil pH was higher close to the tile line. The saturation moisture percent has not been affected by the addition of sewage (Table 27).

The electrical conductivity of the saturation extract ranged from a high of 1.80 to a low of 0.85 mmhos/cm. The sodium adsorption ratio varied from a high of 5.4 to a low of 1.5.