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THESIS

COMPOSITE LAND USE IMPACTS ON WATER QUALITY ON A DIVERSELY DEVELOPED WATERSHED

Submitted by

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Department of Earth Resources

In partial fulfillment of the requirements
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We hereby recommend that the Thesis prepared under our supervision by PETER J. GOWEN entitled

COMPOSITE LAND USE IMPACTS ON WATER QUALITY
ON A DIVERSELY DEVELOPED WATERSHED

be accepted as fulfilling in part requirements for the degree of Master of Science.

COMMITTEE ON GRADUATE WORK

ABSTRACT OF THESIS

COMPOSITE LAND USE IMPACTS ON WATER QUALITY ON A DIVERSELY DEVELOPED WATERSHED

The purpose of this study was to assess the composite land use effects on water quality on a diversely developed tributary to the South Platte River in the Colorado Front Range. Data were collected over a two-year period to assess impacts of mountain home development, grazing and lake-based recreation on suspended solids, specific conductance, total dissolved solids, nitrate, chloride, fecal coliform and fecal streptococcal bacteria. Four specific treatment areas were evaluated for both their local and composite impact on the selected constituents. Treatments included grazing, road-fill encroachment, lake-based recreation and extended primary sewage treatment. Additional sites were selected to characterize the water quality of strategic locations in the watershed. Cluster analysis was employed to aid the interpretation of the composite land use effects on water quality.

Findings at the four treatment sites showed significant increases in fecal streptococcal bacteria densities at the grazing sites, considerable suspended solids delivered to the creek during runoff events at the road sites, no substantial effect on stream water quality from lake-based recreation and significant increases in suspended solids, total dissolved solids, specific conductance, nitrate and chloride at the sewage lagoon treatment sites. Differences in the composite land use effects on water quality could only be discerned by comparing the water quality of the tributaries to the main stream. Water quality differences related to land use were found with suspended solids, nitrates, chlorides, fecal coliform and fecal streptococcal bacteria. No substantial differences in water quality were found between the three clusters on the Trout Creek main stem. General water quality of the watershed was good and no serious water quality problems were indicated.

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INTRODUCTION

Rapid population and economic growth in Colorado's Front Range urban corridor is stressing the region's natural resources. An important key to the general welfare is the abundance and quality of the water resource. With numerous competing uses for the same limited supply, it becomes imperative that resource managers understand the consequences of their land management decisions on subsequent downstream uses. This study was conducted to evaluate water quality consequences resulting from mountain home development, ranching and increasing recreational activities in the Trout Creek watershed of Colorado's Front Range.

Historically, most water quality studies have been directed towards specific treatments and identifying cause and effect relationships. Little has been done to evaluate the composite land use effects on water quality. As part of a long-term study, the United States Forest Service Rocky Mountain Forest and Range Experiment Station in cooperation with the Department of Earth Resources, Colorado State University,sought to establish baseline conditions of how existing land use effects water quality. The objective of this study was to assess current composite land use impacts on water quality in the Trout Creek watershed by comparing water quality constituents in both Trout Creek and its major tributaries. Index stations considered to be representative of the composite upstream drainage basin were evaluated along with specific treatment areas to determine water quality interactions and their impacts within the watershed.

DESCRIPTION OF THE STUDY AREA

General Location of the Study Area

The Trout Creek watershed located in Teller and Douglas Counties in the Colorado Front Range was selected as the study area (Fig. 1). Originating on the northwest flank of Pikes Peak about 25 km northwest of Colorado Springs, Trout Creek flows generally north and is tributary to the South Fork of the South Platte River near Deckers, Colorado. Woodland Park is the only incorporated city within the basin and is located in its headwaters region.

Watershed Characteristics

Precipitation

Annual precipitation in the watershed ranges between 35 and 50 cm per year with a long term average of 39 cm at the Manitou Experimental Forest Headquarters (Gary, 1975). Two types of storm patterns commonly occur in the area. More dramatic and intense are the summertime convective events occurring most frequently in July and August. Gary (1975) cites a study during the period 1940-1949 where the maximum rainfall intensity for a 10-minute period was 11 cm per hour on the Missouri Gulch watershed, a small tributary to Trout Creek. A second, but also important kind of storm pattern results from the passage of large air masses. In general, the fronts pass from west to east, however, occasionally upslope conditions occur. Precipitation associated with these frontal events is relatively low intensity-high duration in nature.

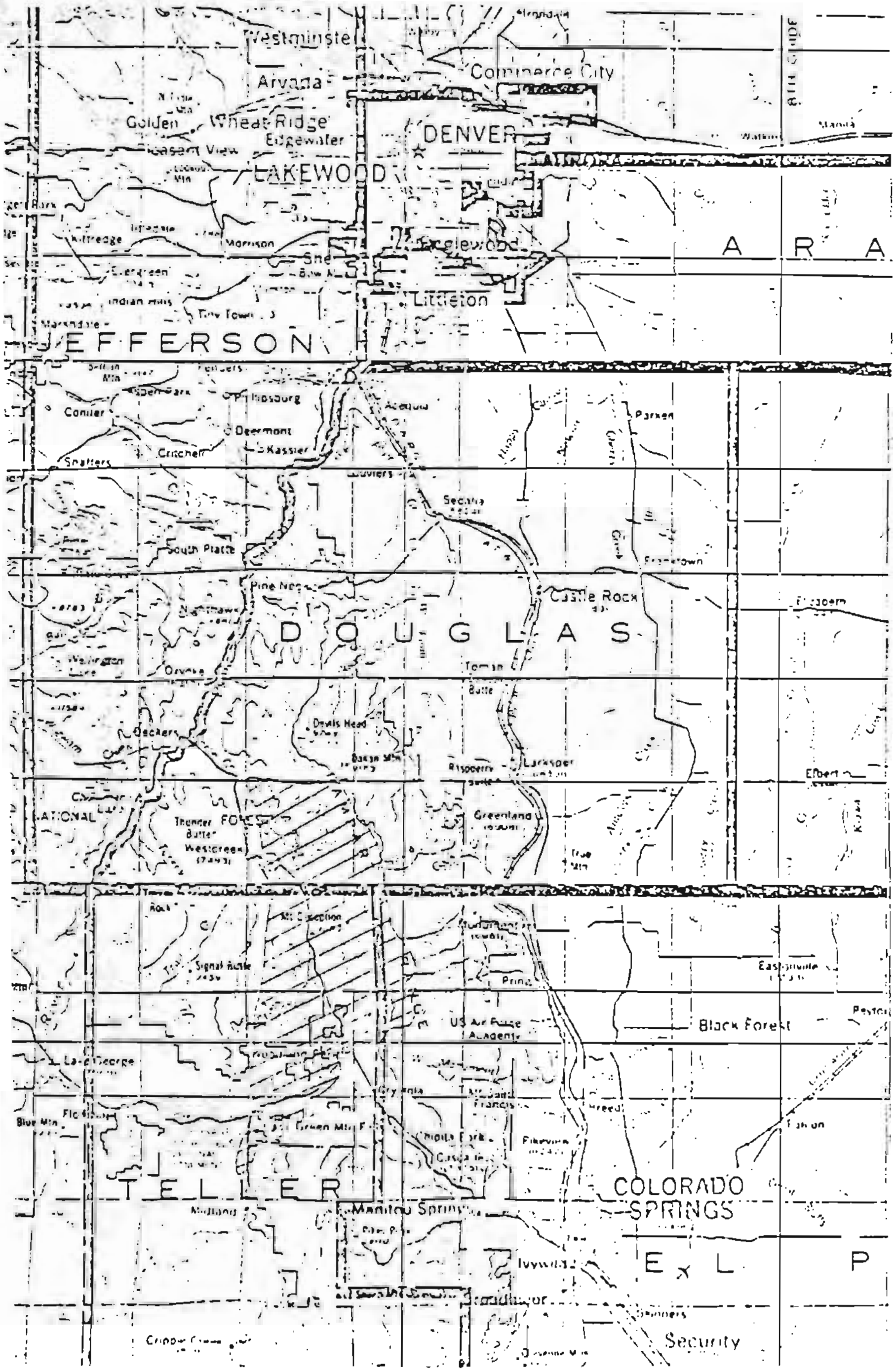

Figure 1. General location of Trout Creek watershed.

Winter precipitation most frequently is in the form of snow. Accumulated snow does not attain great depths in the lower elevations as snow frequently melts within days. Snowpacks at higher elevations store substantial quantities of water which are released at time of melt in April and May.

Precipitation is unevenly distributed throughout the year. July and August are the wettest months averaging about 21% and 17% of the annual total due primarily to frequent convective storms (Gary, 1975). December is the driest month averaging only about 2% of the total annual precipitation.

Geology

Trout Creek is the principal drainage for a graben known locally as Manitou Park. The park is approximately 50 km long and 7 km wide with a south to north orientation. Relief ranges from 3200 meters at Rasberry Mountain in the southern extremity of the basin to approximately 2200 meters at the confluence of Trout Creek and West Creek. The ridges forming the eastern and western borders of the watershed average between 430 and 460 meters above the valley floor.

The dominant rock formation of the area is Pikes Peak Granite. In the southern part of the basin, the Pikes Peak Granite is covered with west dipping Paleozoic sediments covered by a veneer of gravelly soil (Marcus, 1973). The central portion is filled by thick alluvial deposits which extend as far north as Rainbow Falls Park where Trout

Creek begins a 240 meter descent through a granite canyon reaching the West Creek confluence in approximately six kilometers.

The alluvial deposits of the central portion of the basin are very mobile. Spring snowmelt freshets redistribute large quantities of these deposits through active channel and bed migration. Intense summer convective storms move large quantities of sediment, particularly through the intermittent channel network from the east and west flanks of the basin and have caused gullying in several intermittent and ephemeral channels tributary to Trout Creek.

Considerable beaver activity plays an important role in the stability of the fluvial systems. Small beaver dams are found up and down the entire Trout Creek drainage system. The dams offer a pronounced stabilizing influence on the fluvial system until such time that a dam fails as a result of high flows or old age. Some of these dam failures can have a major effect on the stream as was the case in spring of 1980 when high snowmelt and storm flows washed out a large number of beaver dams creating new channels and choking channels with sediment.

Soils

Most of the soils in the watershed are derived from the Pikes Peak Granite (Marcus, 1973). These soils are coarse grained and highly permeable. Headwater regions of the intermittent streams of the east and west flanks of the watershed are well forested. Where the soils are undisturbed by man there is little erosion

(Marcus, 1973). Most all the soil is susceptible to severe erosion when the vegetative cover is removed (USFS-RMFRES, 1966).

Vegetation

Vegetation of the area is typical of the Montane Life Zone. Berndt in a 1960 study of precipitation and streamflow considered the Missouri Gulch watershed as representative of the general area. His breakdown of vegetation types were approximately 25% Lodgepole pine, Englemann spruce, 30% Ponderosa pine-Douglas-fir with the remainder a mixture of aspen, shrubs, grass, erosion pavement and bare rock (Gary, 1975). The pines dominate the south and west facing slopes whereas the spruce and fir dominate the north facing slopes. Grasses and shrubs dominate the alluvial terrace deposits at the lower elevations.

Hydrology

Average annual runoff for a 19 year period on the Missouri Gulch watershed was reported to be 5.6 cm (Gary, 1975). Although Missouri Gulch is a steeper watershed with a higher percent forest cover than Trout Creek, the annual average runoff for Trout Creek is likely fairly close to that figure as this represents approximately 10 to 15% of annual precipitation.

Runoff pattern for Trout Creek is a typical snowmelt regime. Flow is lowest in late fall and early winter with the peak occurring in April or May. Superimposed on this general runoff pattern are the effects of either intense convective storms or frontal storms. An average of three to five storms each year have sufficient intensity to effect runoff (Gary, 1975). A hydrograph for Trout Creek just above the confluence with West Creek for the 1980 water year is presented in Figure 2 (Gary, 1980). Long-term flow measurements are unavailable for Trout Creek.

Land Use

Historical land uses in the watershed include fur trading (early 1800's), mining (late 1800's), commerical logging (1860-present), farming (1900-1930's) and grazing (1880 - present) (United States Forest Service, RMFRES, 1960). The mining activity of the late 1800's was the primary economic activity which stimulated farming and commercial logging. Commerical logging of the Ponderosa pine stands began in 1860 but was mostly discontinued in 1900 when few merchantable stands remained (Love, 1958). Grazing had its peak activity between 1880 and 1890. Major decreases in forage resources during the 1930-1950 period, forced dramatic reductions in numbers of grazed animals. During the same period many farming operations which were initiated in the late 1800's and early 1900's failed due to inherent low soil fertility, erratic moisture and depressed economic conditions (Love, 1958). Gully erosion was extensive between 1930 and 1950 as Love (1958) claims that it was responsible for 60% of sediment in stream channels and reservoirs at the time of his publication.

Today, grazing and commercial logging operations are at a much lower level than in the past. Cattle herds have been reduced to

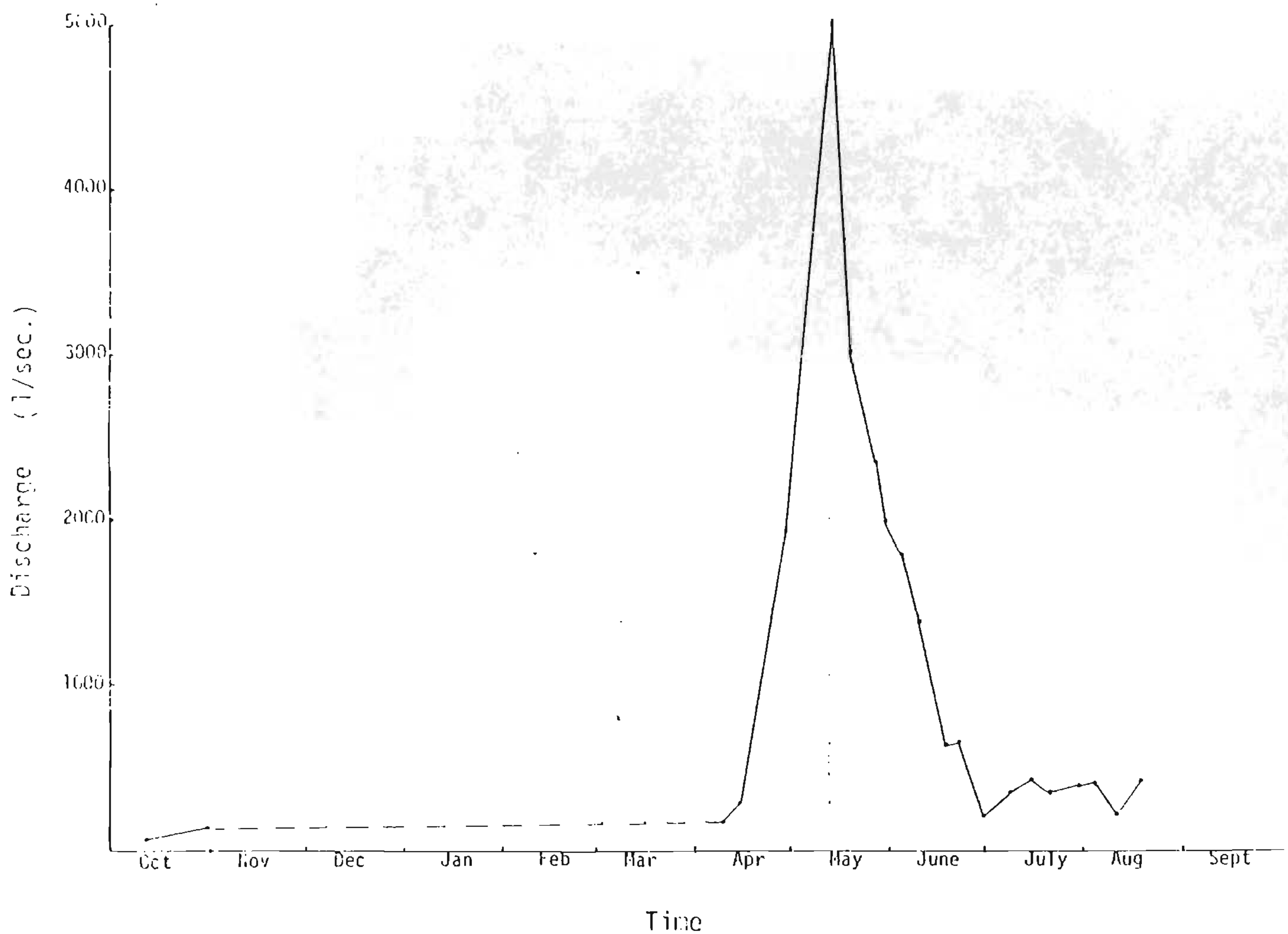

Figure 2. Trout Creek above West Creek 1980 hydrograph.

less than half of the peak size and shorter grazing seasons have been adopted (USFS-RMFRES, 1966). Current grazing intensities are generally light to moderate with less than 40% utilization of perennial grass and sedge herbage based on casual field observations. Small timber harvest operations continue in the watershed. In 1980 a 2.6 square kilometer partial cut of ponderosa pine occurred in White Spruce Gulch (tributary to Trout Creek just south of Missouri Gulch). A much smaller sale of Ponderosa pine between the west side of Trout Creek, just south of Rainbow Falls Park and State Highway 67 occurred in 1979. These small timber sales were specifically designed to minimize watershed damage and their impact is not considered important. Free use firewood harvests sponsored by the Pike National Forest are located in several areas throughout the watershed. These too are closely monitored to prevent watershed damage and their impact is considered negligible.

Other current land uses within the watershed include residential development and recreation. Urbanization is concentrated in the area around Woodland Park and Divide. Numerous subdivisions have been recently constructed and work continues. Road systems are already in place awaiting housing construction in the upper regions of Mule Creek and nearby areas of Trout Creek. Recreationists from Woodland Park, Colorado Springs, and various points of Colorado, and out of state can be observed throughout the watershed. Common activities include camping, fishing, picnicking, horseback riding, hunting, off-road vehicle riding and sightseeing. Overnight camping is restricted to developed campsites by the Pike National Forest, but day use recreation can be found nearly anywhere within the watershed. Heaviest day use recreation is at the Manitou Lake Recreation area.

STUDY DESIGN

The study was conducted in three phases. Phase 1 developed the conceptual framework for the two field seasons that were to follow. The watershed was evaluated for generalized land use and all possible station sites were evaluated. Sub-basins of potential interest were defined and described from maps and field inspection. Phase 2 was the first sampling season. The purpose of this phase was to prepare a reconnaissance level characterization of the water quality of the basin in preparation for detailed analysis of composite land use impacts on water quality and to assess the water quality impacts of several specific land use treatments. Phase 3 was the second and final field season and its objective was to characterize the composite effects of various land uses on water quality of the Trout Creek stream system. Since Phase 1 was only a preliminary planning step it will not be further described.

Reconnaissance Study

The main purpose of this phase was to conduct a reconnaissance level survey of the water quality of the watershed and to isolate several land-use treatments and evaluate their impact on water quality. Specific land use activities considered included intensive livestock grazing, road-fill encroachment, extended primary domestic sewage treatment and lake-based recreation.

Three levels of stations were established during the reconnaissance study, each sampled at a different intensity. Most frequently sampled were the primary level stations from which data were collected at least once per week. Occasionally, additional sampling for assessment of storms, diurnal effects and sampling variation was conducted on the primary level stations in addition to the routine weekly sampling. Secondary level stations were sampled bi-weekly while tertiary sites were sampled monthly.

Primary stations were monitored to evaluate water quality impacts at the four treatment areas. The first of the treatment areas was a flood irrigated pasture used for livestock grazing on the Glen Johnston Ranch near Divide, Colorado (Figure 3). Stations 1 and 2 were located above and below the pasture respectively. Nitrate, fecal coliform and fecal streptococcal bacteria were constituents of primary concern. Four stations were located in an area of road-fill encroachment of Trout Creek along County Road 23 (Figure 3). Two specific encroachment sites were isolated by locating stations above and below each area. Stations 5 and 6 isolated the first area while stations 7 and 8 isolated the second. The sites were spaced close enough such that stations 6 and 7 could be used to identify changes of suspended solids between the two encroachment areas. All four road sites were within one kilometer of each other. A third treatment area was designated at the Woodland Park north slope sewage treatment lagoons along State Highway 67 (Figure 3). Station 10 was located on Trout Creek approximately 100 meters upstream from the southwest corner of the south lagoon with station 9 approximately 100 meters upstream of station 10. Station 11 was located approximately 100 meters downstream of the northern most lagoon. Station 12

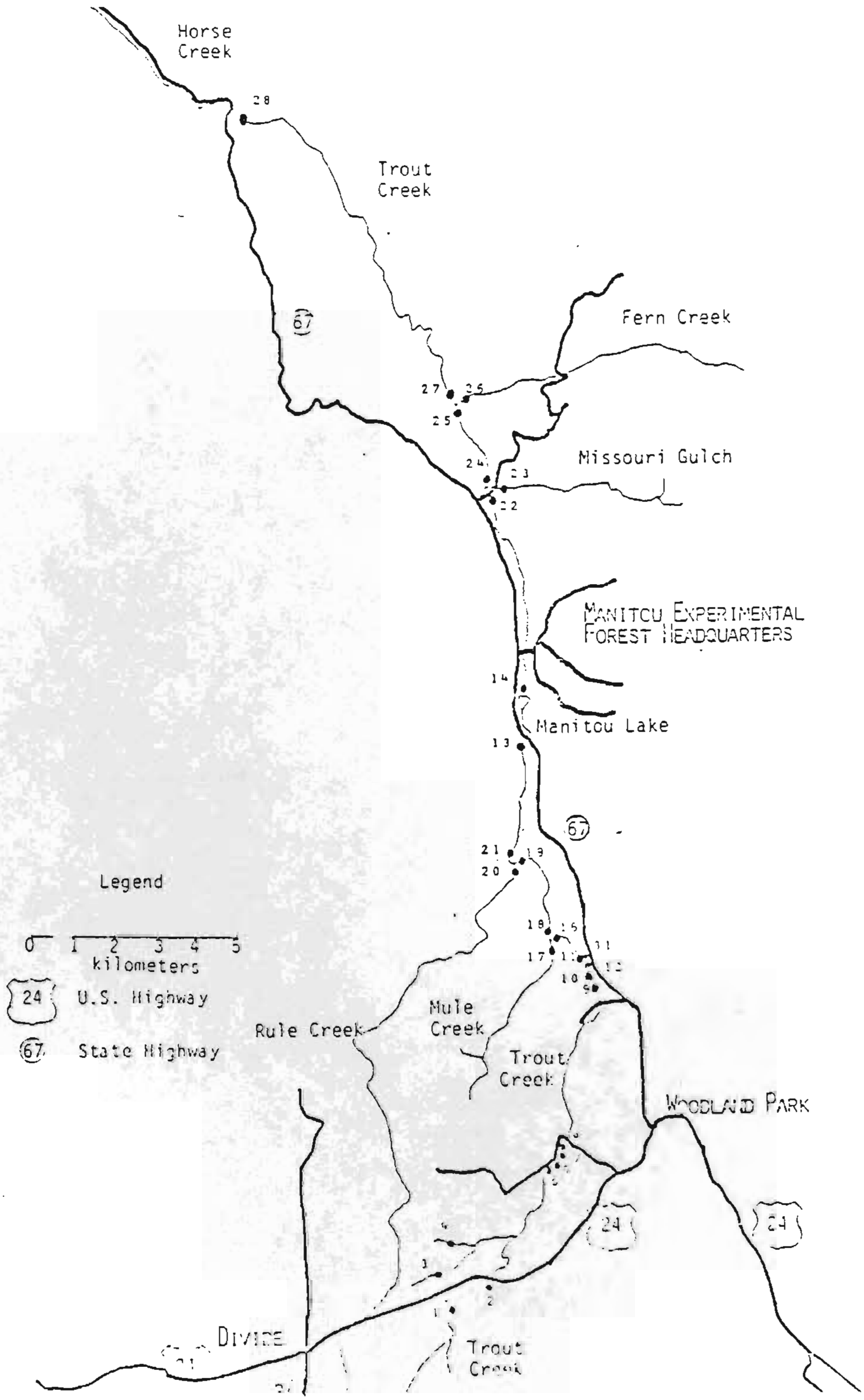

Figure 3. Sampling station locations.

was established off Trout Creek in a seepage area directly west of the middle lagoon. The main interest in the lagoon treatment areas was to determine what impact, if any, wastewater treatment lagoons had on the nitrates, total dissolved solids and fecal coliform and fecal streptococcal bacteria levels in Trout Creek. The final treatment area was Manitou Lake, a popular day-use recreation area near the Manitou Experimental Forest Headquarters. Stations 13 and 14 were established on Trout Creek above the lake at the highway bridge and just below the dam respectively (Figure 3). Fecal coliform and fecal streptococcal bacteria densities were the constitutents of major interest, but nitrate was also observed.

Secondary stations served as the watershed reconnaissance stations. Stations 2, 8, 10 and 11 already described as primary stations also served as reconnaissance stations. Additional secondary stations were established upstream on Trout Creek and on the tributaries of Trout Creek at Mule Creek (Stations 16 and 17), Rule Creek (Stations 19 and 20), Missouri Gulch (Stations 22, 23), Fern Creek (Stations 25, 26) and at West Creek (Station 28) (Figure 3). Measured variables included: discharge, temperature, specific conductance, total dissolved solids, nitrate, orthophosphate, fecal coliform and fecal streptococcal bacteria.

Tertiary level stations were designed to supplement the information of the watershed reconnaissance stations. Two tertiary sites were established at springs on the Glen Johnston Ranch (Stations 3 and 4), while the four remaining tertiary sites were located on

Trout Creek below its confluence with Mule, Rule and Fern Creeks and Missouri Gulch (Figure 3). Measured variables at tertiary stations were much the same as on secondary sites with the exception that discharge and suspended solids were not measured at the spring sites on the Glen Johnston Ranch.

As a result of the reconnaissance level work conducted in Phase 2, several sub-basins were selected for more detailed analysis during Phase 3. Selected sub-basins included the Trout Creek tributaries of Mule Creek, Rule Creek, Missouri Gulch and Fern Creek. Sub-basins on the Trout Creek mainstem include the upper, middle and lower portions of the drainage system. Sub-basin descriptions and their land uses are presented in the following sub-section. Land use descriptions are based on areal and field observations made over the course of the two year study.

Sub-basin Description

The Upper Trout Creek sub-basin is represented by four stations. They are stations 2, 3, 4, and 8. Located in the headwaters of the system, the sub-basin is primarily rural in nature as it is upstream of most of the residential subdivisions centered around Woodland Park. Grazing is most dominant use on the Glen Johnston ranch which comprise over 70% of the area. Station 2, previously described under the grazing treatment discussions, represents an area of intense livestock grazing. The irrigated pasture immediately upstream serves as a winter feeding ground for about 60 livestock and is used to grow hay during the summer. Stations 3 and 4 are headwater spring sites designed to illustrate groundwater conditions in the upper watershed. Both sites are subject to light grazing use with light residential development (one house per two hectares) upslope. Station 8 represents the composite water quality as it leaves the sub-basin. Grazing is still the dominate use of its contributing watershed, but unlike station 2, there is no grazing in the immediate area.

The middle Trout Creek sub-basin is heavily influenced by Woodland Park and its north slope sewage lagoons. This is the most urbanized region of the watershed as the entire north slope of Woodland Park and surrounding area contributes to this sub-basin. Domestic wastewater from this drainage area is treated at the sewage lagoons. The sub-basin is represented by stations 10, 11, 16 and 19. Stations 10 and 11, previously described in the lagoon treatment discussion, isolate the direct lagoon discharge as they are located upstream and downstream of the effluent discharge respectively. Heavy livestock grazing was observed in the area during the 1979 field season, while no cows were present during the 1980 sampling season. Trout Creek stations above Mule Creek (Station 16) and Rule Creek (Station 19) represent the recovery zone from the sewage lagoons. Intervening land uses between the sewage lagoons and station 16 consisted of growing hay and grazing seven and three animals for the 1979 and 1980 season respectively. Between Mule Creek and Rule Creek on Trout Creek, approximately 125 head of cattle were grazed during July 1980, but none were observed at any other time. A summer camp for handicapped children is located several hundred meters upstream of station 19. Its septic tank and leach field failed and was replaced in July 1980, but care was taken by the contractor to prevent any discharge to Trout Creek and there was no indication that any effluent had reached the stream. While light grazing occurs within this sub-basin, the dominant land use is the urbanization of the Woodland Park area.

The lower Trout Creek sub-basin is a rural area of very little residential development dominated by forest management and grazing. The effects of the Woodland Park sewage treatment lagoons are undetectable. This sub-basin is represented by Stations 22, 25 and 28. Stations 22 and 25 located 2.5 km apart at the Trout Creek confluence with Missouri Gulch and Fern Creek, reflect the moderate grazing intensities on the Manitou Experimental Forest. The two most recent timber harvests have been located in this area as well. Station 28 is the final downstream station of this study. Several substantial fish rearing ponds are located at a private fish hatchery 1 km downstream of Station 25. Below the hatchery, Trout Creek flows through a steep-walled canyon before being impounded by numerous beaver dams just upstream of Station 28. Several residential units are located near Trout Creek approximately 2 to 3 km upstream of Station 28, but otherwise the area is undeveloped.

Four tributary sub-basins were selected for intensive study for Phase 3. Mule Creek is the first major tributary to Trout Creek in the study area. Its watershed is nearly completely forested with only a small amount of residential development in the headwaters along its divide with Rule Creek and Upper Trout Creek. More development is planned as a subdivision road system has already been constructed in this area. Substantial recreation use was observed near its confluence with Trout Creek, as a well worn trail parallels the creek and fresh evidence of recent horse use was commonly found. Rule Creek is the largest of the Trout Creek tributaries. Its drainage area is comparable to that of Trout Creek above its Rule Creek confluence. Grazing is prevalent in the upstream area near Divide, but the lower portion of the basin is well forested with only minor grazing except in the immediate area of its confluence with Trout Creek. Livestock had access to the confluence area during most of July 1980 as evidenced by frequent observations of fresh fecal deposits. Rule Creek and Trout Creek would be quite similar in the area of their confluence were it not for the influence of Woodland Park on Trout Creek. Missouri Gulch is the smallest of the tributaries considered. It went dry in July of both 1979 and 1980. Its watershed is essentially in pristine condition with no observed residential development. It is mostly forested and has a few gravel access roads, but had no active harvest operations at the time the study was being conducted. The Fern Creek sub-basin is another essentially pristine area. With a larger drainage area than Missouri Gulch, its flow was sustained throughout the duration of the study. It too is mostly forested with little activity occurring in the basin.

Only the four selected tributaries contribute substantial flows to Trout Creek in the study area. All but Rule Creek represent essentially pristine areas. Rule Creek is similar to Trout Creek in drainage area, discharge and land use with the major exception of the influence of Woodland Park on Trout Creek. Together, the tributaries represent an opportunity to compare water quality of relatively undeveloped watersheds with the more developed Trout Creek.

Composite Effects Study

Phase 3 was undertaken to take a more intensive look at basin index stations to characterize the composite effects of various land uses on water quality. Fifteen stations described previously under sub-basin descriptions were sampled for suspended solids, specific conductance, total dissolved solids, nitrate, chloride, fecal coliform and fecal streptococcal bacteria. The specific treatment study at the sewage treatment lagoons was continued and supplemented by additional sampling to determine the effect of the lagoons on Trout Creek in the area. The suspended solids study at the road treatment area was continued in hopes of obtaining storm samples. The grazing and day use recreation treatment studies were discontinued because there was no grazing in the treatment area and there had been a demonstrated lack of any impact from lake based recreation during the reconnaissance study. Stations dropped from the previous years sampling program included: Upper Glen Johnston (Station 1), Lagoon 1 (Station 9), Upper Lake (Station 13). Lower Lake (Station 14), Trout Below Mule (Station 18), Trout Below Rule (Station 21), Trout Below Missouri Gulch (Station 24), and Trout Below Fern (Station 27). One new station was added. Since the third sewage lagoon was discharging directly into Trout Creek, it was sampled on a regular basis and designated Station 31. All designated Phase 3 stations were sampled weekly.

In addition to the sampling sites designated in the Phase 3 study plan, numerous miscellaneous sites were sampled on an irregular basis. These sites focused on three areas. The first was the area around the lagoons. On three different occasions an intensive survey was conducted from just above the sewage lagoons down to Trout Creek at the Experimental Forest Headquarters in order to establish a longitudinal nitrate profile for the area. A similar, but less intensive survey was conducted on three occasions to establish a longitudinal nitrate profile from the first spring site on the Glen Johnston ranch, downstream through a small stock pond and 50 meters downstream of the pond. The third group of miscellaneous observations were taken on groundwater samples in the vicinity of two cooperating landowners who were interested in nitrate levels and how they might relate to possible toxic effects on livestock. All three sets of miscellaneous observations were designed to supplement the system-wide information provided by the index station.

The Phase 3 sampling program was designed to accommodate paired station analysis using classical paired t-tests and regressions on paired observations of a given variable. Paired t-tests were used to test for significant differences in water quality variables between station pairs. By plotting each constituent for each station against the same for selected paired station and computing a linear regression equation, relationships between one station pair can be compared with relationships of other station pairs. Differences between station pairs can be expressed in terms of differences in the slopes and intercepts of the regression lines. The hypothesis is that the differences in slopes and intercepts can be accounted for by differences in land use.

METHODS AND PROCEDURES

Field Procedures

Discharge was regularly measured with each station visit using the cross-sectional area-velocity method. A direct reading Marsh-McBirney Model 201 current meter was used for velocity measurements in conjunction with a top setting wading rod. The number of verticals taken across each section was a function of stream width and flow conditions. When stream width was greater than 1.5 meters and not limiting, the number of verticals ranged from fifteen to twenty-five. Under extreme low-flow conditions, the verticals were spaced as close as 0.5 dm apart and may have totalled as few as five per cross section. Under low flow conditions at site 2, discharge was measured by capturing the entire flow of the stream in a pan for a specified time and measuring the volume with a graduated cylinder.

Suspended sediment samples were collected using a USGS DH-48 depth integrating sediment sampler when flow conditions permitted. When flow was so low that the DH-48 could not be used, samples were taken by holding three well rinsed fingers over the mouth of the bottle and slowly lowering the bottle at several verticals across the section.

Bacteria samples were collected in distilled water rinsed-sterilized plastic bottles. Samples were taken from just below the water surface with a single sweeping motion across the entire section taking care not to contaminate the sample bottle. Collected samples were immediately chilled in an ice cooler and were generally delivered to the lab within three hours. Plating frequently occurred within the first four hours of sample collection but always within six hours.

Temperature and specific conductance were measured and recorded at each site. Temperature was measured with a laboratory grade pocket thermometer. Measurements were protected from direct solar radiation and were recorded to the nearest 0.5° celsius. Specific conductance was measured using a Beckman "Solu Bridge" portable conductivity meter, in micromhos/cm at $25^{\circ}C$. Several measurements were taken at each site until the conductivity readings were within 2% of the mean.

Laboratory Procedures

Generally, laboratory procedures were performed at the Manitou Experimental Forest Headquarters in accordance with Standard Methods for the Examination of Water and Wastewater - 14th Edition (APHA, et al., 1975). Standards were analyzed on each procedure for which they could be developed and were run in at least triplicate such that the analytical variation could be assessed. Specific procedures and their analytical variation will be briefly described in the following section along with any departures from the generally accepted technique.

Suspended Solids

Suspended solids measurements were performed in accordance with the procedure "Total Nonfiltrable Residue Dried at 103-105^{o}C" (APHA, et al., 1975). Two hundred fifty milliliter samples were filtered during the 1979 field season but 350 ml samples were used during 1980 since additional filtrate was required to conduct subsequent analyses for total dissolved solids, chloride and nitrate. Published accounts of the precision of the procedure include a standard deviation of ± 5.2 mg/l at 15 mg/l (coefficient of variation = 33%) and ± 24 mg/l (coefficient of variation = 10%) at 242 mg/l (APHA, et al., 1975). Laboratory results of this study revealed that for a mean of 4.8 mg/l the standard deviation was ± 1.2 mg/l and the coefficient of variation was 25%. The results presented here are considered to be within the accepted precision for the procedure.

Total Dissolved Solids

Total dissolved solids were analyzed using the "Total Filtrable Residue Dried at 103-105 C" procedure of <u>Standard Methods for the Examination of Water and Wastewater</u>, 14th Ed (APHA, et al., 1975). One hundred milliliter filtrate samples were used. APHA states that with standard samples containing 134 mg/l filtrable residue the standard deviation was found to be ± 13 mg/l (APHA, et al., 1975). A series of ten standards with a concentration of 120 mg/l was run and the standard deviation was found to be ± 12 mg/l with a coefficient of variation of 10%. These results were again within the expected range of the standard procedure.

Nitrates

Nitrates were analyzed using two different procedures for the two field seasons. During the 1979 field season a procedure developed by the Hach Chemical Company as a modification to the cadmium reduction method was employed. This procedure, known as the Hach low range nitrate-nitrogren is performed by adding premeasured powder reagents to samples according to instructions described by Hach (Hach, 1975). The major advantage of the procedure is that it is much simpler than the standard procedure, however, the sensitivity of the technique is lower when compared to the more elaborate standard procedure as described by APHA, et al., (1975). Only approximately 35% of all samples collected were within the detectible limit for the 1979 field season. This approach was acceptable during the watershed reconnaissance phase of the study during the 1979 field season but was inadequate for the more detailed work of the 1980 season.

During the 1980 field season nitrate analyses were performed using the Cadmium Reduction Method of Standard Methods (APHA, et al., 1975). Early in the summer problems were encountered in maintaining the flow rate through the columns in the required range. When the columns were reamalgamated for the first time, they were repacked in 1 cm internal diameter burettes instead of the standard column arrangement described in Standard Methods. The burettes enabled the analyst to precisely control the flow rates in the columns within the required range of 5 to 8 ml per minute, saving considerable time. Other than the modification just described, all other aspects of the procedure were performed in accordance with the standard procedure.

Samples were chilled in the field and were generally delivered to the lab within four hours of collection. Samples were stored at the lab at 4°C until filtered with distilled water rinsed glass fibre filter pads prior to analysis. Samples were run once per week with half of the samples analyzed within 24 hours, with the remaining samples analyzed within 48 hours. The samples collected in the vicinity of the sewage lagoons, Mule Creek and Rule Creek were always analyzed with 24 hours of collection. The remaining samples were frequently held up to 48 hours before analysis. In no case was the holding time greater than 48 hours. The same routine was followed each week.

Analytical technique of the project was tested by preparing five different concentrations of standards and running each in triplicate. A one-way analysis of variance test revealed that there was no significant difference in the precision of the procedure at the various concentration levels at the 10% confidence level. (F statistic = 2.58 versus a critical value of F = 2.61 with 4 and 10 degrees of freedom.) A paired t-test revealed no significant differences between the measured concentration and the standard concentration (t-statistic of 1.749 compared to a critical value of 1.761 with 14 degrees of freedom). On concentrations ranging from 0.01 to 0.45 mg/l NO_3-N, the 90% confidence interval for the difference between the standard sample and measured sample was calculated to be ± 0.007 and the coefficient of variation was 15%. For concentrations greater than 0.5 mg/l NO_3-N dilutions would have to be made and the width of the confidence interval increases directly with the proportion of dilution water.

Phosphates

During the 1979 field season phosphates were measured in accordance with the low range orthophosphate procedure described in Hach (1975). The sensitivity of the procedure was inadcquate for the concentrations found in the study area. Approximately 13% of all measurements made were in the detectable range and nearly all of those were at only two out of a total of 28 stations. With the orthophosphate concentrations so low, it was decided to discontinue the measurement of phosphate for the 1980 field season.

Chlorides

Chlorides were determined using the Argentometric Method as described in Standard Methods (APHA, et al., 1975). For a series of five standard dilutions ranging from 0 to 10 mg/l, blind titrations were performed in triplicate at each concentration. The standard deviation for the difference between the standard concentration and the measured concentration was 0.67 mg/l, the mean difference was 0.01 mg/l while the 90% confidence interval was calculated to be ± 0.3 mg/l.

Fecal Coliform Bacteria

Fecal coliform bacteria were analyzed using the Fecal Coliform Membrane Filter Procedure as described in Standard Methods (APHA, et al., 1975). The M-FC broth was a commercial preparation manufactured by Difco Laboratories. Petri dishes were prepared prior to the weeks sampling but were always used within 96 hours of preparation. Samples were chilled immediately in the field and were delivered to the laboratory usually within four hours but always within six hours of sample collection. Membrane filtration and plating was frequently performed immediately upon arrival to the lab but always within two hours.

During the October 1979 and January 1980 sampling runs, a delayed incubation technique was employed so that the plates could be incubated and counted in Fort Collins. The procedure is described as the "Delayed-Incubation Fecal Coliform Procedure" in Standard Methods, (APHA, et al., 1975). The holding time on the vitamine-free casitone transport medium for both sampling runs was less than the maximum limit of three days specified in the instructions.

Fecal Streptococcal Bacteria

Fecal streptococcal bacteria were analyzed in accordance with the "Membrane Filter Technic Test for the Fecal Streptococcal Group" described in Standard Methods (APHA, et al., 1975). As with the fecal coliform media, the KF Streptococcus Agar employed was a commercial preparation of Difco Laboratories. Shelf time of prepared plates was considered to be two weeks and plates not used within the two-week period were discarded (Millipore, 1973). The delayed incubation procedure for the October 1979 and January 1980 sampling runs used the KF Streptococcus Agar as described by Millipore (1973).

Sampling Variation

On several occasions during the 1979 field season special sampling runs were made to evaluate sampling error and analytical error. Analysis of variance testing was conducted on nitrates, suspended solids, total dissolved solids, fecal coliform and fecal streptococcal bacteria. In all cases, except nitrate where concentrations (using the Hach procedure) were less than detectible limits, the variation between samples was insignificant compared to the variation within each sample at the $\alpha = 0.1$ level (Appendix A-C). Diurnal sampling was conducted on suspended solids, total dissolved solids, fecal coliform and fecal streptococcal bacteria. No significant diurnal pattern was observed with any variable (Appendix D).

Statistical Procedures

Statistical procedures used throughout the entire project effort include paired t-tests, grouped t-tests and analysis of variance (ANOVA). While a number of statistical package programs have been used, the package program used most extensively, has been the 'Statistical Package for the Social Sciences" (SPSS) which is available through the Colorado State University Computer Center

(Nie, 1975). The cluster analysis routine employed for the basin-wide composite effects interpretation is a program developed by Veldman (1967). Other systems used include "Minitab", an interactive package available through the CSU Computer Center, a statistical package developed by Hewlett Packard for use on their HP-67 model hand calculator, and hand calculations based on formulas found in the statistics text by Snedecor and Cochran called Statistical Methods (Snedecor and Cochran, 1967).

Most of the data dealt with in the discussion and results section are not normally distributed. This was evident by plotting histograms and observing that the variances were larger than the means, and that third moments frequently exceeded 3. Since parametric statistical procedures require normal populations, log transformations have been made on nearly all occasions. Resulting histograms are much improved and variances are consistently smaller than the means. Third moments are consistently less than 1 and always less than 2. Instances where log transformations have not been made will be specifically noted in the text.

All statistical analyses have been conducted at the 10% confidence level. Two tailed tests have been used in all cases.

RESULTS AND DISCUSSION

Discussion of the study results will be addressed in two sections. The first will consider the specific treatment areas while the second will cover the composite land use effects on water quality within the Trout Creek drainage system.

Specific Treatments

Grazing

The grazing treatment study was conducted on the Glen Johnston ranch during the 1979 field season at stations 1 and 2 (Figure 4). The pasture studied is approximately 1 km long and several hundred meters wide. It is irrigated in the summer for growing hay and is used in the winter as a feeding ground for about 60 cattle. During the 1979 field season, there were no livestock in the pasture, but substantial quantities of fecal material were present as a result of the previous winter's cattle confinement.

Previous investigations on grazing effects on water quality conducted on the Manitou Experimental Forest and reported by Johnson, Gary and Ponce (1978) indicated only minor effects on water quality. Their findings revealed small but statistical significant increases in both fecal coliform and fecal streptococcal bacteria densities when livestock were first introduced to a pasture with a fairly quick return to previous bacteria densities once the livestock were removed. No significant differences were observed with dissolved oxygen, suspended solids, total dissolved solids,

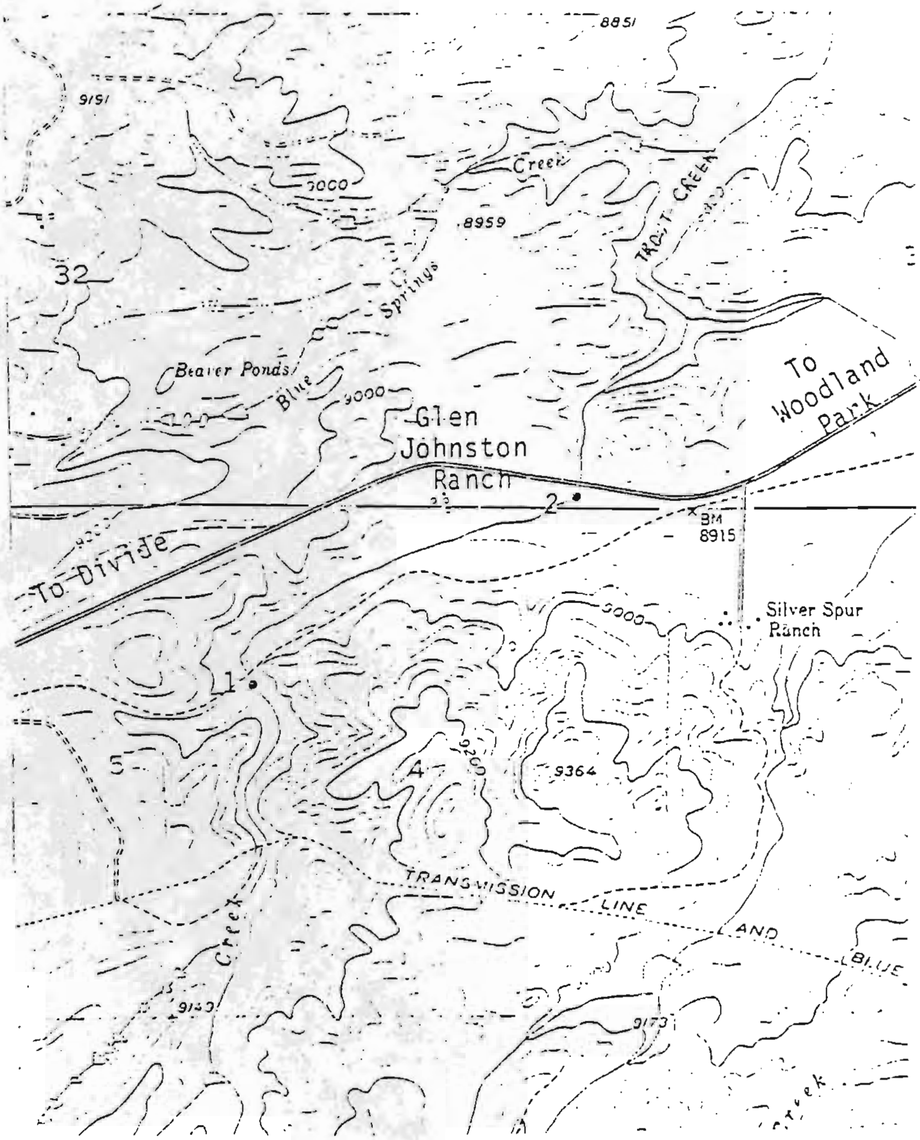

Figure 4. Grazing sites.

specific conductance, nitrate and orthophosphate. Stephenson and Street (1978) found that the occurrence of fecal coliform bacteria in a southwest Idaho rangeland watershed was directly related to presence of livestock with levels increasing soon after the introduction of livestock and remaining high several months after the livestock had been removed. They also observed a decrease in bacterial concentrations in a downstream direction which was attributed to a natural self-purifying process. Milne (1974) reported that a livestock wintering operation showed little increase in fecal coliform bacteria levels where livestock activity was dispersed, but where livestock activity was concentrated, fecal coliform bacteria densities increased significantly.

Summary statistics for the upper and lower Glen Johnston ranch sites (Stations 1 and 2) are presented in Table 1. Discharge decreased between the two sites due to flood irrigation. Discussion of the water quality constituents follows.

Suspended solids measurements represent base flow conditions and are low at both sites. Although the difference in the mean values of 3 and 6 mg/l between the upper and lower stations is statistically significant (Table 2) it should not be considered a function of the grazing activity as 1) there were no livestock in the pasture at the time of sampling, 2) the coefficient of variation of the analytical

Table 1. Summary Statistics for 1979 Paired Grazing Sites (Stations 1, 2).

UGJ(1)	Discharge (l/sec)	Suspended Solids (mg/l)	Temp (°C)	Specific Conductance (µmhos/cm)	Total Dissolved Solids (mg/l)	Nitrate (µg/l)	Fecal Coliform (col/100 ml)	Fecal Streptococci (col/100 ml)
Mean	15	3	16.5	146	98	-	38	570
Median	21	0	17.0	142	100	-	24	340
Std.Dev.	11	4	5.5	15	23	-	36	650
Range	1-44	0-12	8-22	120-165	64-141	<160-185	0-123	38-2400
n	23	8	22	13	21	22	18	18
LGJ(2)								
Mean	7	6	16	216	143	-	52	1200
Median	8	2	16	215	131	-	22	380
Std.Dev.	5	8	5	29	25	-	72	2000
Range	1-25	0-19	8-21	170-255	105-190	<150-165	3-280	30-6700
n	23	8	22	13	21	22	18	18

Table 2. Paired t-tests for grazing treatment (Stations 1, 2) using log transformed data.

Variable	Number of samples	$\mu_1-\mu_2$	$s_{\mu_1-\mu_2}$	t	Significant at α= 0.1
Discharge	15	.14	0.24	2.25	*
Suspended Solids	9	-0.24	0.28	-2.57	*
Temperature	15	0.003	0.04	0.02	N.S.
Specific Conductance	14	-0.16	0.06	-9.70	***
Total Dissolved Solids	14	- .13	0.05	-8.99	***
Fecal Coliform	16	-0.009	.79	0.00	N.S.
Fecal Streptococci	16	- .28	.37	2.92	*

N.S. Not significant

* Significant

** Very significant

*** Very highly significant

procedure is quite high in this range and 3) the difference is probably more a function of the upper site being an undisturbed sample, while the lower site was located below a culvert where during periods of low flow water fell from the culvert into a small plunge pool. A small spring discharge with a substantial nitrate concentration entered the creek at the plunge pool. The samples were collected downstream so the effect of this spring would be included.

Specific conductance and total dissolved solids significantly increased between the two sites (Table 2). Despite this increase, the ratio of total dissolved solids/specific conductance remained constant between the two sites (0.67 at station 1 compared to 0.66 at station 2). This indicates the same process of dissolution of inorganic substances appears to be operating at both sites. The increase in specific conductance and total dissolved solids is a likely result of the flood irrigation process where the water is given a greater opportunity to leach soluble salts from the soil.

Fecal streptococci densities show a significant increase between the two stations while fecal coliform densities do not. Fecal streptococci measurements were much more variable at station 2 than station 1. This is evident by comparing the standard deviations of 650 for site 1 to 2000 for site 2. Median values are very close for the two sites (340 colonies/100 ml at site 1 compared to 380 colonies/100 ml at site 2). The fecal coliform/fecal streptococci ratio strongly supports the conclusion that the fecal contamination is related to the presence of livestock. It appears that the effect demonstrated by this treatment area on the fecal streptococci densities is to increase the magnitude but mostly the variability of the densities probably through the variations inherent in the flood irrigation process.

The grazing treatment had little effect on water quality, a finding similar to that of Johnson, Gary and Ponce (1978). The only observed effect was solely in the fecal streptococcal bacteria densities. Specific conductance and total dissolved solids significantly increased through the study area, but it was shown that this increase was likely independent of the grazing. Nitrate and phosphate concentrations were consistently below the detection limits of the analytical procedure employed. Fecal coliform bacteria densities were uneffected while an increase in magnitude but mostly variability of streptococci densities was observed, consistent with the findings of Stevenson and Street (1978) that bacteria populations can remain viable up to several months after the removal of livestock.

Road Fill Encroachment

Forest road systems have long been recognized as major sources of suspended solids and it is well documented that the water quality from forest watersheds is affected by the number, location and construction and maintenance practices of forest roads (EPA, 1975). Soil mass movement is considered by EPA (1975) to be the most common and significant factor in water quality degradation from roads and increased suspended solids concentrations. In most cases, the soil mass movements are caused by undercutting unstable slopes, improperly constructing embankments and drainage system failures.

Suspended solids concentrations are highly dependent on stream discharge as a threshold energy level must be met before suspended solids can be transported. In evaluating road impact on suspended solids, these low-flow conditions can either be included or excluded. Beschta (1978) elected to eliminate low flow values in his work in evaluating the effects of logging and road construction in a long term study in the Oregon Coast Range. Others have also reported low suspended solids concentrations under base flow conditions and stratified their samples to consider wet weather and dry weather flows separately (Skau and Brown, 1974). The effort considered here is to evaluate the local and composite effect of forest roads in the Trout Creek watershed under both wet and dry weather.

The four road stations were designed to isolate two areas where a county gravel road encroaches on the Trout Creek channel and one area where the immediate stream channel is well removed from the road (Figure 5). Suspended solids concentration at all four stations were low, with most reflecting dry weather or base flow conditions (Table 3). Although the discharge at two of the four stations was significantly greater ($\alpha = 0.1$) in 1980 than in 1979, suspended solids concentrations were not significantly different between years at any station at the 10% confidence level. Using paired t-tests with log transformed data at the $\alpha = 0.1$ level, a significant increase

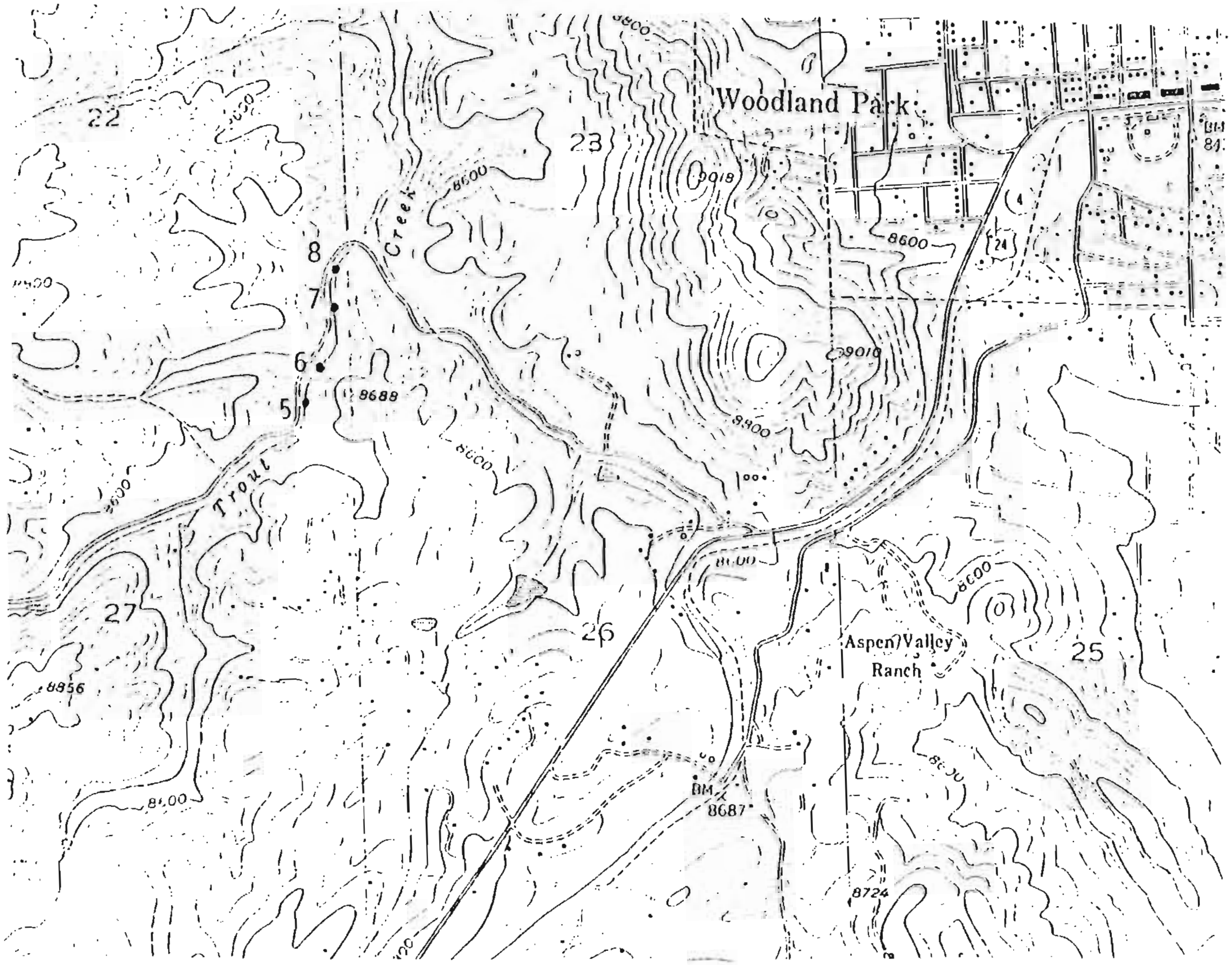

Figure 5. Road fill encroachment sites (Stations 5, 6, 7, 8)

Table 3. Summary statistics for road sites (Stations 5, 6, 7, 8)

	1979		1980		1979 and 1980 Combined	
	Discharge l/sec	Suspended Solids mg/l	Discharge l/sec	Suspended Solids mg/l	Discharge l/sec	Suspended Solids mg/l
Station (5)						
Mean	13	7	130	12	45	8.8
Median	3	6	15	11	3	6.5
Std. Dev.	24	8	180	9.4	110	8.4
Range	1-130	0-39	1-440	3.1-40	1-440	0-40
n	34	28	14	13	48	41
Station (6)						
Mean	12	9	130	13	45	10
Median	3	6	15	12	4	8.3
Std. Dev.	19	10	180	8.3	110	9.2
Range	2-94	0-45	1-440	3-37	1-440	0-45
n	34	28	14	13	43	41
Station (7)						
Mean	16	7	130	11	45	7.9
Median	4	5	15	10	4	6.0
Std. Dev.	21	9	180	6.9	110	8.6
Range	2-82	0-44	1-440	3.4-30	1-440	0-44
n	37	28	14	13	51	41
Station (8)						
Mean	16	5	140	15	50	8.2
Median	3	3	15	9.2	7	5.2
Std. Dev.	20	5	200	14	120	10.2
Range	2-98	1-13	1-520	4.1-61	1-520	0.8-61
n	43	28	16	14	59	42

was found at the first encroachment area, and a significant decrease in suspended solids concentration was found at the intervening recovery zone between the two encroachment areas (Table 4). No significant change was found at the second encroachment area. One way analysis of variance between the four stations failed to show a significant difference in suspended solids concentrations (F statistic = 0.8 compared to a critical value of 3.2 for 3 and 150 degrees of freedom).

While the tabulated data represent base flow conditions fairly well, runoff events have more dramatic effects. Visual evidence strongly indicated that large quantities of sediment were transported through the system during the peak flow period of 1980. Major changes in channel configuration, many recently cut banks, obliteration of nearly all previously existing pools and numerous new sediment deposition areas were all witnessed in the treatment area at the first visit of the 1980 field season.

High flows supply the energy necessary to move this material. Much sediment is brought into the channel by runoff of summer convective storms. Although no storms could be sampled during the two-year study, two storms during July and August 1979 were observed to have washed substantial portions of the road fill into the creek. Alluvial fans from the runoff channels were large enough to actually divert the flow of the creek around them. Suspended solids concentrations at all the sites were back to normal shortly after the storm event once the runoff subsided.

Table 4. Paired t-tests for road sites for log transformed suspended solids.

Station Pairs	Number	$\mu_1-\mu_2$	$s\,\mu_1-\mu_2$	t	Significant at α= 0.1
5, 6	40	-0.06	0.197	-2.063	*
6, 7	40	0.13	0.282	2.838	**
7, 8	40	-0.01	0.284	-0.328	N.S.

N.S. Not significant

* Significant

** Very significant

Since these intense summer convective storms are of short duration, their runoff is generally sufficient to move the sediment only a short distance downstream except for extreme events. The sediment is then stored until it can be transported by the next high flow. Most of the sediment redistribution occurs during snowmelt peak flows when high flows are sustained and the energy necessary for transport is available. This appears to be the case throughout the Trout Creek watershed as well as in this treatment area.

The net effect of the road fill encroachment is to serve as a source area for sediment during runoff events. Summer convective storms supply the energy which can move substantial quantities of sediment, but their specific impacts are very difficult to monitor due to their unpredictable and sporadic nature. Base flow conditions result in very little sediment transported through the hydrologic system.

Lake Based Recreation

Day-use and overnight recreation areas have been found to have mixed effects on water quality. Brickler and Utter (1975) found that sewage disposal facilities were the major source of water contamination in developed recreation sites in Arizona. Johnson and Middlebrooks (1975) observed sharp increases of fecal coliform bacteria densities at picnic and camp grounds during high use periods in Utah's Wasatch Front followed by sharp declines at the end of the recreation season. Aukerman and Springer (1976) found statistically insignificant increases in fecal coliform bacteria densities at eight recreational study sites in the Colorado Front Range west of Fort Collins. Ponce and Gary (1979) reported that intensive day-use recreation at Manitou Lake on the Manitou Experimental Forest had no measurable effect on the water quality of the lake itself.

The Manitou Lake Recreation Area receives substantial day-use recreation usage, particularly on summer weekends. Ponce and Gary (1979) observed a decrease in total coliform and fecal coliform densities between the lake inlet and outlet, probably due to ultraviolet radiation disinfection. The study undertaken here, looked beyond the recreational impact on the lake and considered effects on Trout Creek immediately below the lake.

Paired stations were located in a running water site at the highway bridge above the lake and on Trout Creek, 50 meters downstream of the lake outlet dam (Figure 6). Summary statistics are presented in Table 5. While discharge apparently increased between the two sites, it should be noted that beaver activity at the upper lake site made it impossible to measure the entire flow into the lake. During low flow conditions, there was an easily observed increase in lake outflow compared to that flowing in without any observed change in water level of the lake. The source of this additional water is likely groundwater flow. Substantial quantities of groundwater are presumed to flow in close association with surface flow through the thick coarse alluvial deposits in the valley bottom. Construction of the man-made lake has likely intercepted the groundwater flow. Deeper springs apparently also discharge

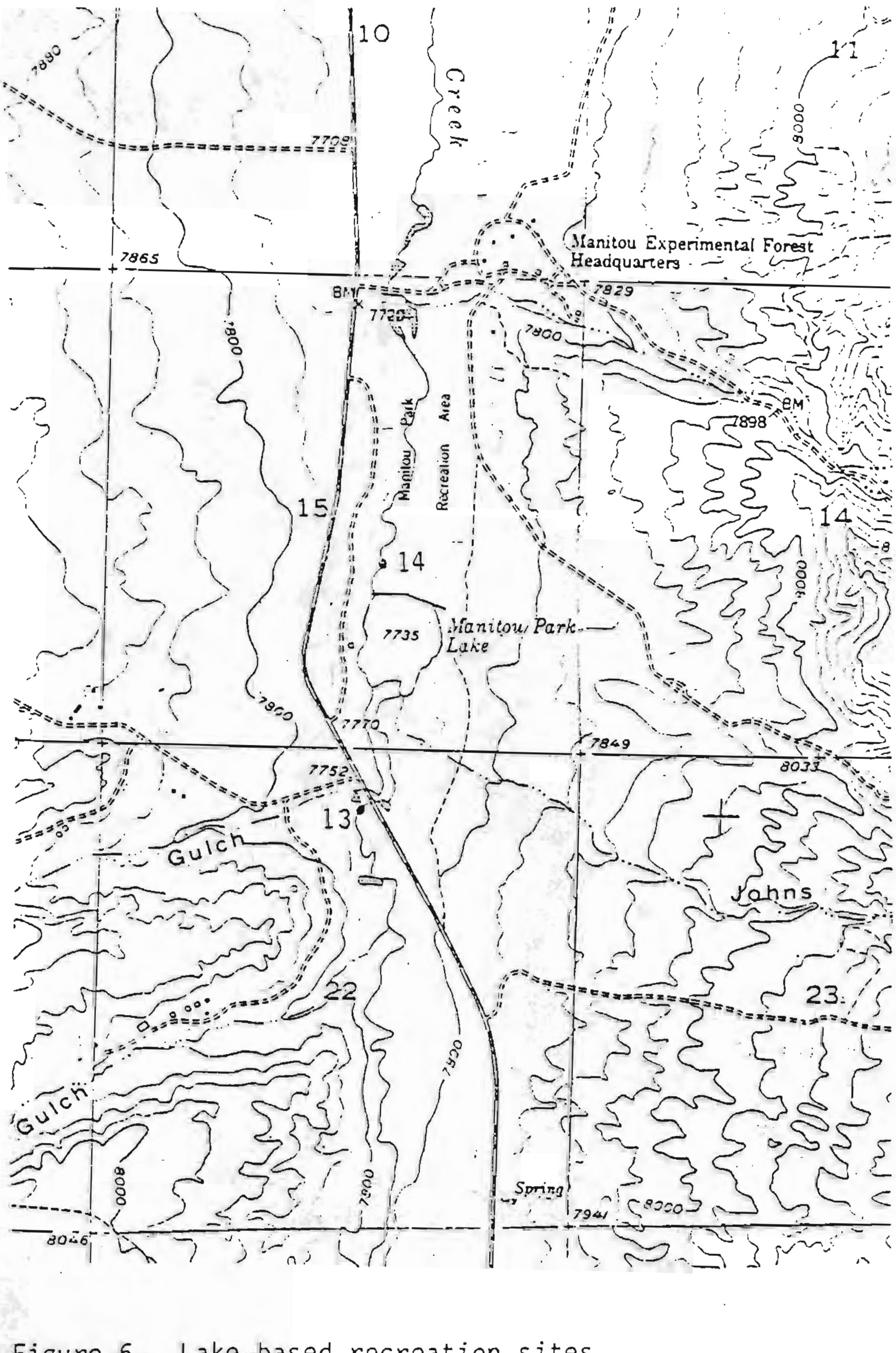

Figure 6. Lake-based recreation sites.

Table 5. 1979 Summary statistics for lake sites (Stations 13, 14)

	Discharge l/sec	Suspended Solids mg/l	Specific Conductance mhos/cm @ 25°C	Total Dissolved Solids	Fecal Coliform colonies/100 ml	Fecal Streptococcus colonies/100 ml
Station (13)						
Mean	56	1.8	260	170	33	350
Medium	8	0.9	270	170	24	240
Std. Dev.	93	1.8	41	25	29	380
Range	1-340	0-5.6	200-345	120-200	2-100	27-1700
n	18	11	17	16	32	33
Station (14)						
Mean	64	8.6	260	160	190	3900
Median	22	7.2	270	160	150	2400
Std. Dev.	89	8.2	36	20	240	4400
Range	11-330	2-32	190-325	110-200	0-980	16-19000
n	17	11	19	17	34	34

into the lake. A conversation with a Forest Service recreation ranger in August 1979 revealed that the primary reason why the Forest Service prohibits swimming in the lake is the dramatic temperature fluctuations apparently caused by spring discharges. In the past, several drownings have been attributed to unsuspecting swimmers debilitated while swimming into the cold water.

Results of paired t-tests on log transformed data (Table 6) reveals significant differences in discharge, suspended solids, temperature, total dissolved solids and fecal streptococcal bacteria. The range of values of suspended solids is fairly low. Although the difference is statistically significant, the actual impact on water quality is low. What difference there is can be attributed to the reach between the dam outlet and the station. This area is heavily used by recreationists. Trails are ubiquitous and substantial vegetation has been trampled to death. Children were frequently observed wading and playing in the stream in this section.

Specific conductance was unchanged between the two sites. Although the total dissolved solids revealed a significant decrease between the two sites, the mean difference between the two sites was only 10 mg/l which is less than 6% of the mean. The difference observed is well within the noise of the analytical procedure and the differences in total dissolved solids concentrations is not considered important.

Table 6. Paired t-tests for lake sites (Stations 13, 14) using log transformed data.

Variable	Number of Samples	$\mu_1-\mu_2$	$s\mu_1-\mu_2$	t	Significant at α = 0.1
Discharge	13	-0.22	0.35	-2.33	*
Suspended Solids	8	-0.67	0.30	-6.38	***
Temperature	15	-0.03	.03	-3.34	**
Specific Conductance	14	0.00	0.04	0.02	N.S.
Total Dissolved Solids	14	0.03	0.04	2.94	*
Fecal Coliform	13	0.07	0.56	0.45	N.S.
Fecal Streptococci	16	-0.39	0.73	-2.15	*

N.S. Not significant

* Significant

** Very significant

*** Very highly significant

Fecal coliform bacteria densities showed no significant change between the two stations while fecal streptococcal densities did. The area where the bacteria are introduced to the system appears again to be the reach between the dam outlet and the station located 50 meters downstream. To confirm previous results reported by Ponce and Gary (1979), several bacteria samples were collected at the top of the dam in August 1979. These were paired with samples collected at the regular lower lake station. The results are presented in Table 7. Fecal coliform densities at the dam outlet were consistent with the findings of Ponce and Gary (1979). Dramatic increases in both fecal coliform and fecal streptococci densities were observed between the dam outlet and the station 50 meters downstream. According to the FC/FS ratio, the fecal contamination cannot be attributed to human sources as the ratio in all cases is much less than 0.7. Numerous bird nests were observed in the escarpment on the west bank of the creek below the dam. Birds might explain the dramatic increase in fecal streptococcal and fecal coliform bacteria in the area. It should be noted that fecal coliform densities at the lower site were similar to those upstream of the lake but fecal streptococci densities were significantly higher.

The overall effect of the lake based recreation on the water quality of Trout Creek in the immediate area of Manitou Lake is minor. No real effects were observed with specific conductance

Table 7. Comparison of bacteria densities between lower lake sub-stations.

Fecal Coliform colonies/100 ml		Fecal Streptococci colonies/100 ml	
Top of Dam	50 Meters Downstream of Dam	Top of Dam	50 Meters Downstream of Dam
4	525	80	4500
3	48	23	2600
1	48	22	3500
15	6		
0	2		

or total dissolved solids. Nitrate and phosphate concentrations were consistently below detectable limits. Suspended solids concentrations significantly increased in a statistical sense but the magnitude of the increase has little water quality importance. Fecal coliform and fecal streptococci bacteria densities were also unaffected by recreational use of the area.

Sewage Lagoon

The sewage lagoon treatment study was broken into two parts. The first portion of the study involved weekly monitoring of four sites during each of the two field seasons to evaluate the effects of the sewage treatment lagoons on the water quality of Trout Creek in the immediate vicinity. The second portion of the study looked at the longitudinal nitrate profile of Trout Creek from a point approximately 1 km upstream of the sewage treatment lagoons downstream to the Manitou Experimental Forest Headquarters to determine the extent of the impact the sewage lagoons had on the nitrate levels of Trout Creek.

Stations considered in the first portion of the study included Trout Creek stations above and below the sewage lagoons (stations 10 and 11 respectively), one station sampling the lagoon discharge into Trout Creek upstream of station 11 (station 31) and a site west of the middle lagoon where seepage from the lagoons reached the ground surface (station 12) (Fig. 7). Summary statistics are presented in Table 8.

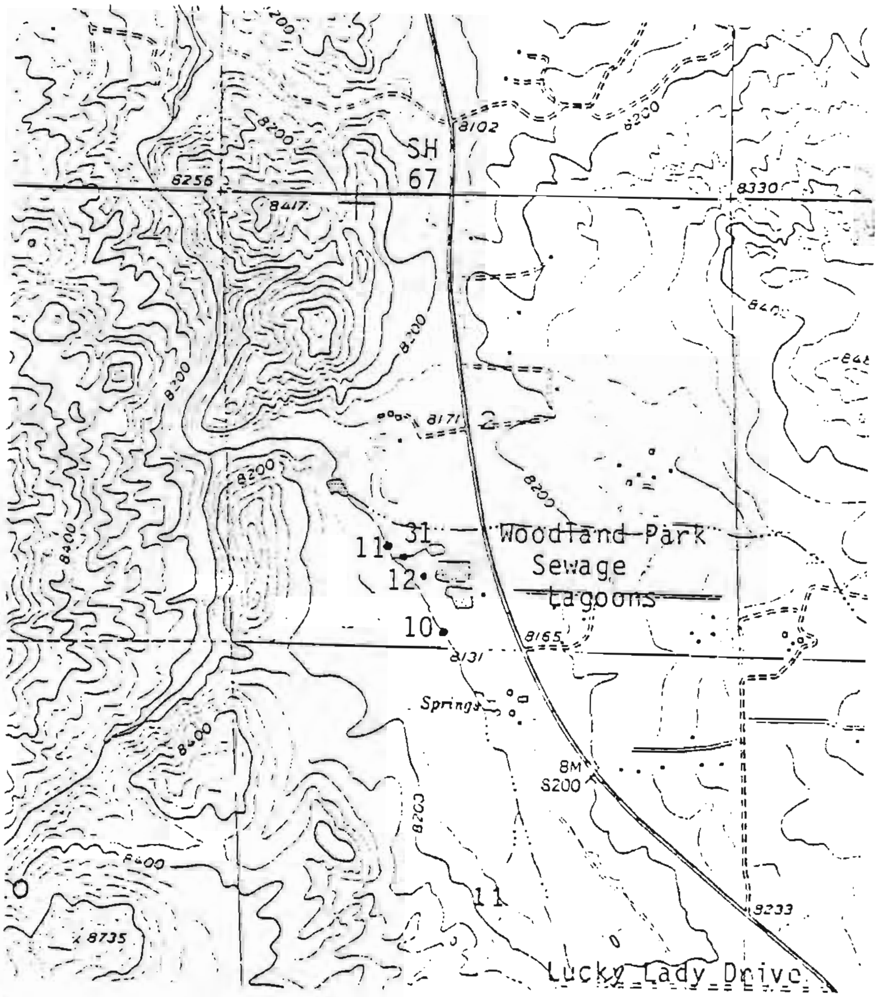

Figure 7. Sewage lagoon station locations. (Stations 10, 11, 12, 31)

Table 8. 1979 and 1980 Summary statistics for lagoon sites (stations 10, 11, 12, 31).

	Discharge (l/sec)	Suspended Solids mg/l	Specific Conductance µmhos/cm @ 25°C	Total Dissolved Solids mg/l	Nitrate mg/l	Nitrate mg/l	Chloride mg/l	Fecal Coliform colonies /100 ml	Fecal Streptococci colonies /100 ml
Station (10)									
Mean	30	6.6	210	140	0.82	8.0	5.8	79	340
Median	27	3.8	210	140	0.59	8.3	6.0	35	260
Std. Dev.	30	11.9	21	31	0.34	1.1	1.6	120	270
Range	7-190	0-52	140-280	61-220	.39-1.55	5.4-9.0	2-8	0-500	98-1600
n	38	18	29	23	24	11	12	37	39
Station (11)									
Mean	33	50	280	170	0.74	7.2	9.6	130	500
Median	31	10	280	170	.68	7.2	10.	53	400
Std. Dev.	28	97	40	29	0.46	1.3	4	180	330
Range	8-180	0.4-350	160-350	98-220	0.45-2.65	5.0-10	2-15	2-960	180-1600
n	38	20	29	24		11	13	37	39
Station (12)									
Mean	-	-	740	410	*	1.3	33	760	3600
Median	-	-	760	410	*	1.2	34	160	2200
Std. Dev.	-	-	87	22		.5	2.8	1400	7200
Range	-	-	900	360-450		.4-2.4	30-37.5	13-6700	165-47000
n	-	-	29	22		11	11	37	39
Station (31)									
Mean	2.2	-	650	350	-	2.9	38	250	370
Median	2.1	-	700	340	-	1.8	39	50	260
Std. Dev.	0.9	-	100	67	-	2.5	4.4	370	320
Range	1-4	-	480-760	210-430	-	.3-8.9	30-45	0-1000	0-1100
n	10	-	13	12	-	10	12	12	13

*Less than detectable limit.

Since heavy livestock grazing occurred at the site during 1979 but not 1980, unpaired t-tests were run at each station on all variables to determine if any variables changed between years (Table 9). Few changes were observed. Discharge increased at both station 10 and 11 following the same trend observed throughout the watershed. Fecal streptococci densities decreased significantly at station 11. This is likely a direct result of the absence of livestock during 1980 and unrelated to the sewage treatment. Suspended solids significantly increased at station 11, which was an obvious result of the lagoon effluent discharge to Trout Creek. During 1979 there was no direct discharge from the lagoons to Trout Creek until an intense storm caused a failure of the downstream wall of the finishing lagoon causing nearly the entire contents of the lagoon to empty into Trout Creek in late August 1979. Throughout 1980, the third lagoon had a discharge that flowed approximately 100 meters from its outfall culvert over unconsolidated alluvium eventually discharging into Trout Creek. The effluent continuously eroded its channel and formed a gulley reaching a depth of over four meters at times. The effect of this discharge of suspended solids concentration of Trout Creek was observed as far downstream as the confluence of Trout Creek and Rule Creek. A single measurement of suspended solids was made on this effluent on August 12, 1980 with a result of approximately 8400 mg/l. Additional measurements were not made due to the impossibility of distinguishing between suspended load and bedload in the effluent which averaged around 2 liters per second.

Table 9. T-tests between years at lagoon sites (stations 10, 11, 12) using log transformation data.

(1980-1979)	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Fecal Coliform	Fecal Strepto-cocci	FC/FS (Untrans-formed)
Station (10)							
Significant @ α = 0.1	**	N.S.	N.S.	N.S.	N.S.	N.S.	*
T-statistic	3.69	0.58	-0.74	0.18	-0.61	-0.05	-2.11
Degree of Freedom	26	16	26	21	25	27	24
p-value	0.001	0.568	0.463	0.860	0.544	0.963	0.045
Station (11)							
Significant @ α = 0.1	**	*	N.S.	N.S.	N.S.	*	N.S.
T-statistic	3.77	2.20	-0.38	0.54	-1.03	-2.26	-1.14
Degree of Freedom	26	18	26	22	26	27	26
p-value	0.001	0.041	0.710	0.597	0.313	0.032	0.265
Station (12)							
Significant at α = 0.1	-	-	N.S.	N.S.	N.S.	N.S.	N.S.
T-statistic			-1.57	-1.24	-0.27	-0.62	-0.50
Degree of Freedom			26	19	26	27	26
p-value			0.128	0.231	0.792	0.542	0.623

N.S. No significant

* Significant

** Very significant

Performing paired t-tests using both years data revealed significant differences in discharge, suspended solids, specific conductance total dissolved solids and chloride, between stations 10 and 11 (Table 10). Significant differences were also observed with fecal coliform and fecal streptococcal bacteria, but these comparisons would have to be made on separate years due to the grazing influence of 1979 and not 1980.

Discharge and total dissolved solids increased between stations 10 and 11 considering each year separately or combined (Tables 11 and 12). The increase is due to the lagoon effluent reaching Trout Creek. A mass balance calculation on total dissolved solids for stations 10, 31 and 11 reveals a difference of only 20 mg between the sum of station 10 and the lagoon runoff, and the measured mass at station 11. The closeness of this mass balance clearly indicates that the source of the increase in total dissolved solids between stations 10 and 11 is from the lagoon effluent.

Caution must be taken in assuming that all of the discharge gain between stations 10 and 11 is accounted for by the direct lagoon runoff. No measurable surface water enters Trout Creek between stations 10 and 11 although a small immeasurable amount of discharge occurs at station 12, as a result of seepage from the lagoons. The seepage that does enter is fairly close in total dissolved solids to that of the lagoon effluent. A chloride mass

Table 10. Paired t-tests for lagoon sites using log transformations on 1979 and 1980 data.

	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Fecal Coliform	Fecal Strepto-cocci	FC/FS (Untrans-formed)
(10, 11)								
Significant α = 0.1	***	**	***	***	*	*	**	N.S.
N of cases	28	10	28	23	13	27	29	26
Difference	-0.08	-0.67	-0.11	-0.09	-0.21	-0.23	-0.16	0.93
Std. Dev.	0.07	0.77	0.06	0.07	0.25	0.58	-0.27	4.96
t-statistic	-5.77	-3.68	-9.72	-6.69	-3.01	-2.04	-3.23	0.96
p-Value	0.000	0.002	0.000	0.000	0.011	0.05	0.003	0.346
(10, 12)								
Significant α =0.1			***	***	***	***	***	N.S.
N of cases			28	21	11	27	29	26
Difference			-0.52	- .47	-0.73	-0.92	-0.93	-1.62
Std. Dev.			0.09	0.08	0.16	0.74	0.51	15.6
t-statistic			-20.85	-28.31	-14.74	-6.51	-9.82	-0.53
p-Value			0.000	0.000	0.000	0.000	0.000	0.00
(11, 12)								
Significant α = 0.1			***	***	***	***	***	N.S.
N of cases			28	21	11	28	29	28
Difference			-0.41	-0.39	-0.59	-0.70	-0.77	-2.89
Std. Dev.			0.09	0.06	0.22	0.56	0.45	12.87
t-statistic			-25.39	-28.25	-7.75	-6.62	-9.28	-1.19
p-value			0.000	0.000	0.000	0.000	0.000	0.24

N.S. Not significant
* Significant
** Very significant
*** Very highly significant

Table 11. Paired t-tests for lagoon sites using log transformations on 1979 data.

Pairs		Discharge	Suspended Solids	Nitrate	Fecal Streptococci
	Significant α=0.1	**	*		**
10, 11	N of cases	15	7	15	16
	Difference	- 0.09	-0.44	0.02	-0.25
	Std. Dev.	0.04	0.45	0.08	0.30
	t-statistic	- 3.98	-2.59	0.80	-3.38
	p-Value	0.001	0.041	0.435	0.004
	Significant α=0.1			***	
10, 12	N of cases			7	
	Difference			0.22	
	Std. Dev.			0.08	
	t-statistic			7.04	
	p-Value			0.000	
	Significant α=0.1			**	
11, 12	N of cases			7	
	Difference			0.21	
	Std. Dev.			0.10	
	t-statistic			5.33	
	p-value			0.002	

N.S. Not significant
* Significant
** Very significant
*** Very highly significant

Table 12. Paired t-tests for lagoon sites using log transformations on 1980 data.

	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Nitrate	Fecal Coliform	Fecal Streptococci
10, 11								
Significant $\alpha = 0.1$	***	*	***	**	*	*	N.S.	N.S.
N of cases	13	11	13	12	13	11	12	13
Difference	-0.07	-0.82	-0.11	-0.10	-0.21	0.04	-0.19	-0.04
Std. Dev.	0.05	0.91	0.06	0.08	0.25	0.04	0.78	0.16
t-statistic	-4.74	-2.97	-6.44	-4.33	-3.01	2.92	-0.83	-0.97
p-value	0.000	0.014	0.000	0.001	0.011	0.02	0.424	0.350
10, 31								
Significant $\alpha = 0.1$	***		***	***	***	***	N.S.	N.S.
N of cases	10		13	12	12	10	11	13
Difference	1.07		-0.49	-0.40	-0.79	0.45	-0.30	0.10
Std. Dev.	0.27		0.06	0.13	0.17	0.25	1.27	0.61
t-statistic	12.57		-32.03	-10.64	-15.83	5.72	-0.79	0.58
p-value	0.000		0.000	0.000	0.000	0.000	0.448	0.570
11, 31								
Significant $\alpha = 0.1$	***		***	***	***	***	N.S.	N.S.
N of cases	10		13	12	12	10	12	13
Difference	1.14		-0.38	-0.30	-0.58	0.41	0.02	0.14
Std. Dev.	0.25		0.05	0.09	0.16	0.23	1.19	0.58
t-statistic	14.76		-25.37	-11.42	-12.14	5.67	0.05	0.87
p-value	0.000		0.00	0.000	0.000	0.000	0.457	0.40
12, 31								
Significant $\alpha = 0.1$			N.S.	*	**	N.S.	*	**
N of cases			13	11	11	10	12	13
Difference			0.00	0.08	-0.06	-0.16	0.74	0.96
Std. Dev.			0.13	0.08	0.06	0.31	1.34	0.79
t-statistic			0.12	3.03	-3.34	-1.64	1.92	4.40
p-value			0.94	0.013	0.007	.135	0.081	0.001

N.S. Not significant
* Significant
** Very significant
*** Very highly significant

balance indicates that the mass of chloride at station 10 and the lagoon effluent accounts for 82% of the chloride mass at station 11. While the discrepancy of 18% is not large, it does suggest the possibility that additional chloride is entering the creek between station 10 and 11 other than the lagoon effluent. The small but not measurable discharge entering the creek at station 12 is an obvious source of additional chloride.

Nitrate levels show a significant decrease between stations 10 and 11 but this will be discussed in further detail in the second portion of the lagoon treatment study.

To evaluate the impact of the sewage lagoons on fecal coliform and fecal streptococcal bacteria the grazing influence must be separated. Consideration will only be given to 1980 data when no grazing occurred. Neither fecal coliform nor fecal streptococci changed significantly between stations 10 and 11. At the same time, there was no significant difference between the lagoon effluent and either station 10 or 11. Clearly the sewage lagoons had no effect on Trout Creek fecal coliform or fecal streptococcal bacteria densities.

The second portion of the sewage lagoon treatment study considered the longitudinal profile of nitrates from a road crossing of Trout Creek approximately 1 km upstream of the lagoon area to the Manitou Experimental Forest Headquarters (Figure 8). On three occasions during the 1980 field season, nitrate and chloride grab samples were collected and analyzed over the 12 km distance described above (Table 13).

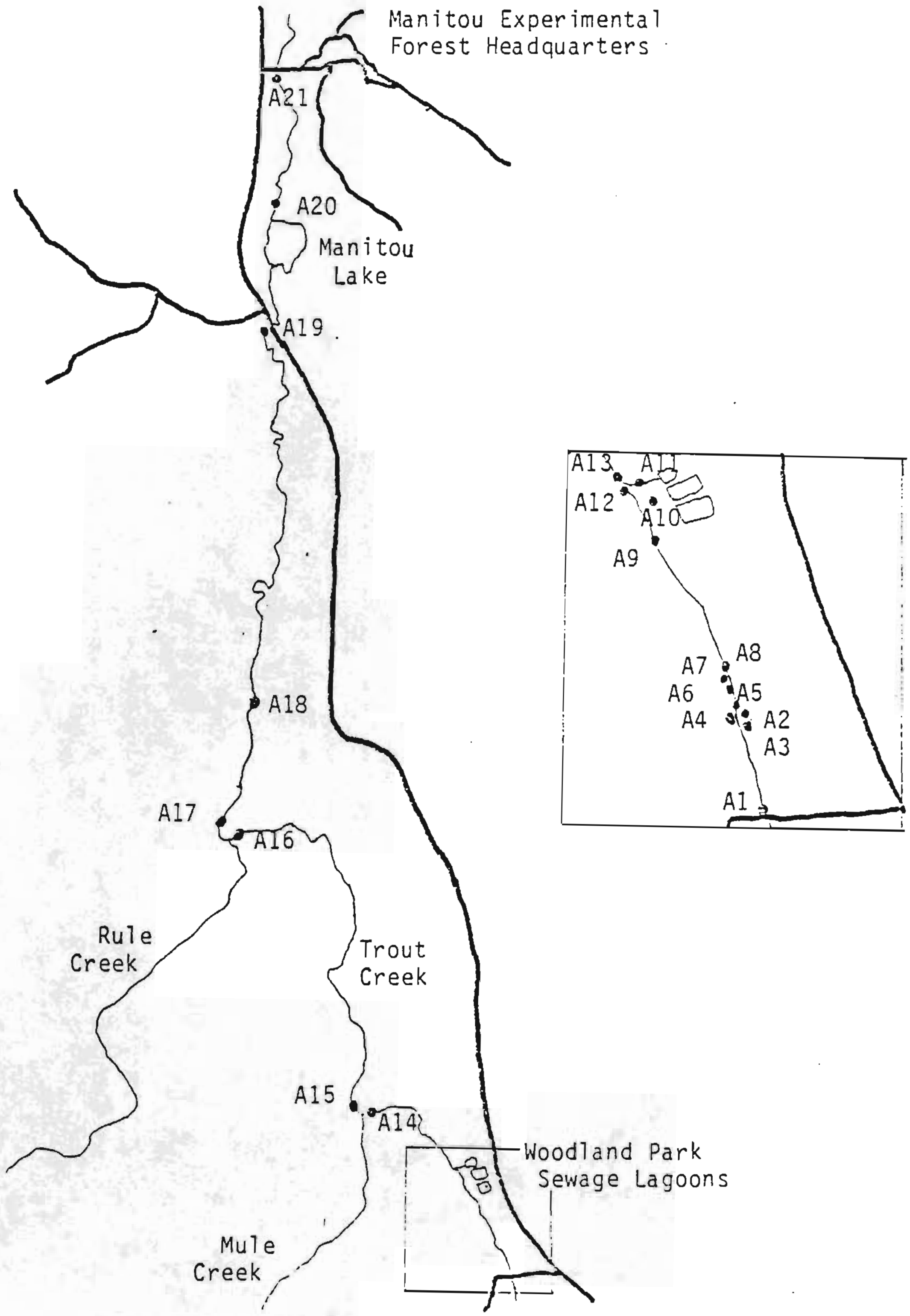

Figure 8. Nitrate profile stations locations.

Table 13. Longitudinal nitrate profile data.

Station Name	Station Number	Distance From Trout at Lucky Lady KM	Nitrates mg/l as NO_3 7/7/80	Nitrates mg/l as NO_3 8/12/80	Nitrates mg/l as NO_3 8/18/80	Nitrate Mean
Trout at Lucky Lady Road	A-1	0	0.11	0.02	0.01	.05
Northeast Tributary	A-2	.5	8.6	8.3	7.7	8.2
Southeast Tributary	A-3	.5	8.1	8.6	7.1	7.9
Southwest Tributary	A-4	.5	3.6	0.05	2.1	1.9
Below 3 Tributaries	A-5	.5	8.4	7.4	6.2	7.4
West Spring	A-6	.6	0.15	3.0	0.13	1.1
Northwest Tributary	A-7	.6	9.7	10.0	9.6	9.7
North Tributary	A-8	.6	9.6	10.	7.2	9.0
Station 10 (L2)	A-9	.9	9.0	8.2	7.7	8.3
Station 12 (L4)	A-10	1.2	1.0	1.2	1.5	1.3
Station 31 (DLR)	A-11	1.4	3.3	.28	.75	1.6
Trout Above DLR	A-12	1.4	8.7	7.6	6.0	7.8
Station 11 (L3)	A-13	1.4	8.4	7.0	7.2	7.6
Station 16 (TAM)	A-14	2.0	7.2	9.2	6.0	7.5
Station 18 (TBM)	A-15	2.0	5.1	7.5	6.0	6.2
Station 19 (TAR)	A-16	5.0	4.7	7.5	6.6	6.1
Station 21 (TBR)	A-17	5.1	2.2	4.4	2.2	3.0
Trout at South Meadows Campground	A-18	6.8	1.5	3.5	1.2	2.1
Station 13 (UL)	A-19	10	0.6	0.3	0.28	0.40
Station 14 (LL)	A-20	11	0.001	0.001	0.32	0.11
Trout at Manitou Experimental Forest Headquarters	A-21	12	0.07	0.14	0.38	0.2?

Nitrogen transformations in lakes have been studied in considerable detail and summarized by Kenney (1973), but published reports on such processes in natural streams are few (Sain, et al., 1977). Kaushik and Robinson (1976) demonstrated substantial loss of NO_3-N of a 2-km long spring-fed stream in Ontario with a mean flow of 3 liters/sec. Denitrification was proposed as the process by which the nitrate concentrations were reduced. Laboratory observations on stream sediment-water columns (Sain, et al., 1977) indicated that denitrification could explain the nitrate loss observed on the small Ontario stream reported by Kaushik, et al (1975). While the researchers on the Ontario stream observed significant decreases in nitrate which they attributed to denitrification, Johnson, et al., (1976) observed increases in nitrate fluxes on a central New York stream downstream from a sewage treatment plant and concluded that denitrification in the stream was not an important process in the overall nitrogen cycle in the watershed. While the role of denitrification has not been specifically studied with respect to the Trout Creek data, the following discussion at leasts suggests that it may play a role.

The Trout Creek channel disappears at a point 100 meters downstream of its crossing Lucky Lady Drive. At this point, some flow recharges groundwater, but the remainder flows across the meadow in undefined channels. Approximately 0.5 km downstream of the road crossing, several indistinct water paths converge creating a head cut, reforming a distinct Trout Creek channel. Seven springs or sub-channels in this area were sampled. Further downstream, samples were collected at the permanent lagoon sites and at Trout Creek immediately upstream of where the lagoon effluent enters. Other samples were collected on Trout Creek immediately above and below Mule Creek and Rule Creek, Trout Creek at South Meadows Campground,upper and lower lake sites (stations 13 and 14) and near the headquarters of the Manitou Experimental Forest.

Of the seven convergent sites upstream of the lagoons four (A-2, A-3, A-4 and A-8) are essentially the same with respect to nitrate according to a one-way analysis of variance on untransformed data. One site had significantly higher nitrate concentrations (Site A-9). Of the two sites that had lower nitrate levels, one (A-6) was a true spring with a constant flow and temperature while the other (A-4) was a very slow moving stream of water with a lush algal growth. Comparing the four similar sites with those sites adjacent to the lagoons (sites A-9, A-12 and A-13) revealed no significant difference between any of the stations at the 10% level (Table 14). Extending the comparison to include Trout Creek above and below Mule Creek, still no significant differences between stations were found despite a general decreasing trend from a point upstream of the permanent station 10 site. A significant difference was observed when the Trout Creek stations above and below Rule Creek were considered with those upstream sites previously mentioned (Table 14).

Table 14. One way analysis of variance for nitrate profile data.

Sites	Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical F-value
A-2, A-3	Factor	4.14	3	1.38	1.23	2.92
A-5, A-8	Error	9.00	8	1.12		
	Total	13.13	11			
A-2, A-3, A-5	Factor	5.29	6	0.88	0.79	2.24
A-8, A-9, A-12	Error	15.67	14	1.12		
A-13	Total	20.96	20			
A-2, A-3, A-5	Factor	14.03	8	1.75	1.33	2.04
A-8, A-9, A-12	Error	23.72	18	1.32		
A-13, A-14, A-15	Total	37.75	26			
A-2, A-3, A-5, A-8	Factor	80.01	10	8.00	5.29	1.9
A-9, A-12, A-13, A-14	Error	33.25	22	1.51		
A-15, A-16, A-17	Total	113.26	32			
A-1, A-2, A-3, A-5, A-7,	Factor	598.45	16	37.40	34.6	2.85
A-8, A-9, A-12, A-13, A-14	Error	36.60	34	1.08		
A-15, A-16, A-17, A-18,	Total	635.05	50			
A-19, A-20, A-21						

Of particular interest is the dramatic increase in nitrate levels from Trout at Lucky Lady Road to convergent surface water sites about 0.5 km downstream. From these several sites to Trout Creek below Mule Creek, the nitrate levels are more than 10 times those found in the remainder of the Trout Creek system, and substantially greater than the lagoon effluent. There is no reason to believe that this is due to natural causes. The lagoon effluent is not a factor in the nitrate increase as the dramatic increase in nitrate levels occurs several hundred meters upstream, and the effluent has a lower nitrate level than Trout Creek. This is a likely result of the treatment process where considerable algal growth can be observed in all three sewage lagcons. Although the lagoon effluent is not a factor, the lagoon treatment system must still be considered a point source, as if it were not present, the nitrate levels would likely be comparable to those found in the remainder of the watershed. Preliminary evidence at least suggests the possibility of a leak in the interceptor, a short distance upstream of the first lagoon, as the source for the increased nitrate concentration in Trout Creek.

The longitudinal profile of mean nitrate concentration versus distance from Lucky Lady Drive is presented in Figure 9. Highest nitrate levels were observed a short distance above the sewage lagoons. Nitrate levels continuously decrease until the outlet of Manitou Lake where the nitrate concentration is similar to that

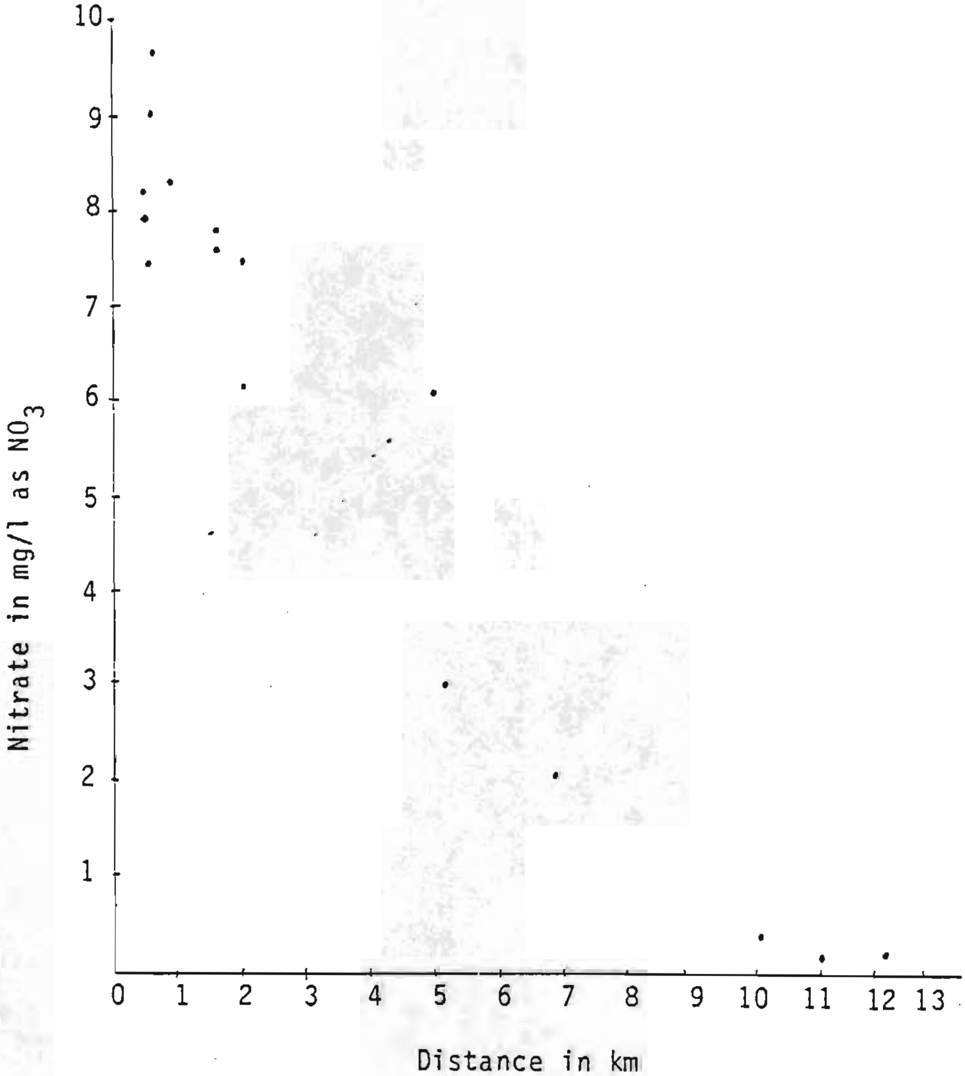

Figure 9. Longitudinal nitrate profile of Trout Creek from Lucky Lady Drive to Manitou Experimental Forest.

found in areas in the watershed unaffected by the sewage lagoons. Regressing the nitrate concentration versus distance, results in strong linear regressionwith an R^2 = 93% (nitrate (mg/l) = 8.7 - 0.8* Distance (km)). The decreasing trend with distance is clear and a one-way analysis of variance on all of the sites of the profile confirms that there are differences between the sites. Dilution from tributaries, denitrification and plant uptake are all likely factors in explaining the decrease of nitrates with increasing distance downstream.

In summary, the sewage treatment lagoons have several effects on Trout Creek. Specific conductance significantly increased between stations 10 and 11. Total dissolved solids and chloride concentrations also increased in Trout Creek as a result of the lagoon treatment. Fecal coliform and fecal streptococcal bacteria densities were uneffected by the lagoon treatment. Nitrate levels in the general area were found to be more than 10 times those found elsewhere in the watershed. High nitrate concentrations were observed several hundred meters upstream from the lagoons and were found to decrease according to a strong linear relationship with distance. Nitrate effects on Trout Creek from the sewage lagoons were no longer detectable by the time the water left Manitou Lake.

Composite Land Use Impacts on Water Quality

Investigations into composite land use impacts on water quality have taken several approaches. Asmusen, Sheridan and Allison (1975) sought to identify differences in water quality of streamflow and alluvial groundwater between four categories of watersheds in a predominately agrictultural area of the Georgia coastal plain. Their land-use categories were described as 1) rural-agricultural, 2) rural-agricultural with some urban influence, 3) rural-agricultural with definite urban influence, and 4) urban-suburban. They found that population densities less than 400 per square mile had little effect on water quality. Above that level increases were observed in specific conductance, chloride, total nitrogen and total phosphorous. Looking at the relationship between land use and nutrient outputs of eighteen rural watersheds of the Cayuga Lake Basin of Western New York, Gates and Haith (1975) could not establish quantitative relationships between land use and nonpoint sources of nitrogen and phosphorous. White (1976) observed different land use-water quality impacts based on geologic formations. He found that construction of access mining roads in west-central New Mexico had the greatest effect on suspended and dissolved solids on streams draining sedimentary formations as compared to basalt formations. Local grazing and irrigation for orchards had no significant effect on water quality for either type of geologic formation. Using Nationa Eutrophication Survey data from 473 nonpoint source-type drainages in the eastern United States, Omernik (1976) found that nutrient concentrations were generally proportional to the percent of agricultural land. Mean total phosphorous concentrations were nearly ten times greater and mean total nitrogen concentrations five times greater in streams draining agricultural areas compared to forested areas.

The approach taken with the Trout Creek data was to use cluster analysis to determine if the data had any structure which could be related to land use. Once the link between land use and water quality was established in defining clusters, further comparisons were made to determine if differences in land use between clusters had any effect on water quality.

Cluster Analysis

Cluster analyses was a major interpretive tool employed in evaluating the composite land use-water quality relationships in the Trout Creek watershed. The procedure is a quasi-statistical technique which groups data on the basis of similarities between specified variables thereby illustrating the underlying structure of a data set. Cluster analysis was applied to the Trout Creek data to identify those sites with similar water quality and to objectively determine if differences between cluster groupings might be explained by land use. The cluster program used in this study was developed by Veldman (1967).

A necessary requirement for interpreting the program results is an understanding of how it operates. Means of each water quality constitutent serve as program input. Variations within each constituent are scaled to an equal range, with the lowest value equated to 0 and the highest equated to 100. Each input variable is given equal weight with respect to all others. The program then determines which stations are most similar and produces a dendrogram which illustrates the relative degree of similarity between stations.

Several different clustering runs were made specifying different combinations of constituents each time. Cluster groupings were the same regardless of the combinations of constituents run with only minor exception. When suspended solids were omitted from the analysis, station 11 was grouped with stations 10, 16 and 19. With all other runs it fell into a cluster by itself. It should be noted that suspended solids were not monitored at the two spring sites (stations 3 and 4). When the cluster routine was run without suspended solids, these sites fell in a cluster with stations 2 and 8, regardless of all other variable combinations that were run.

The final cluster grouping run included suspended solids, specific conductance, total dissolved solids, nitrate, chloride, fecal coliform and fecal streptococci (Figure 10). In order to include the spring sites in the analysis, mean suspended solids concentrations of 2 mg/l were assigned to them. The 2 mg/l value was used as a reasonable estimate of their mean suspended solids concentration based on two years of observation and comparison with measured values throughout the watershed. While this estimation of suspended solids for the spring sites may appear arbitrary, it has only a minor influence on the shape of the final cluster dendrogram, and no effect on the final cluster groupings. The cluster

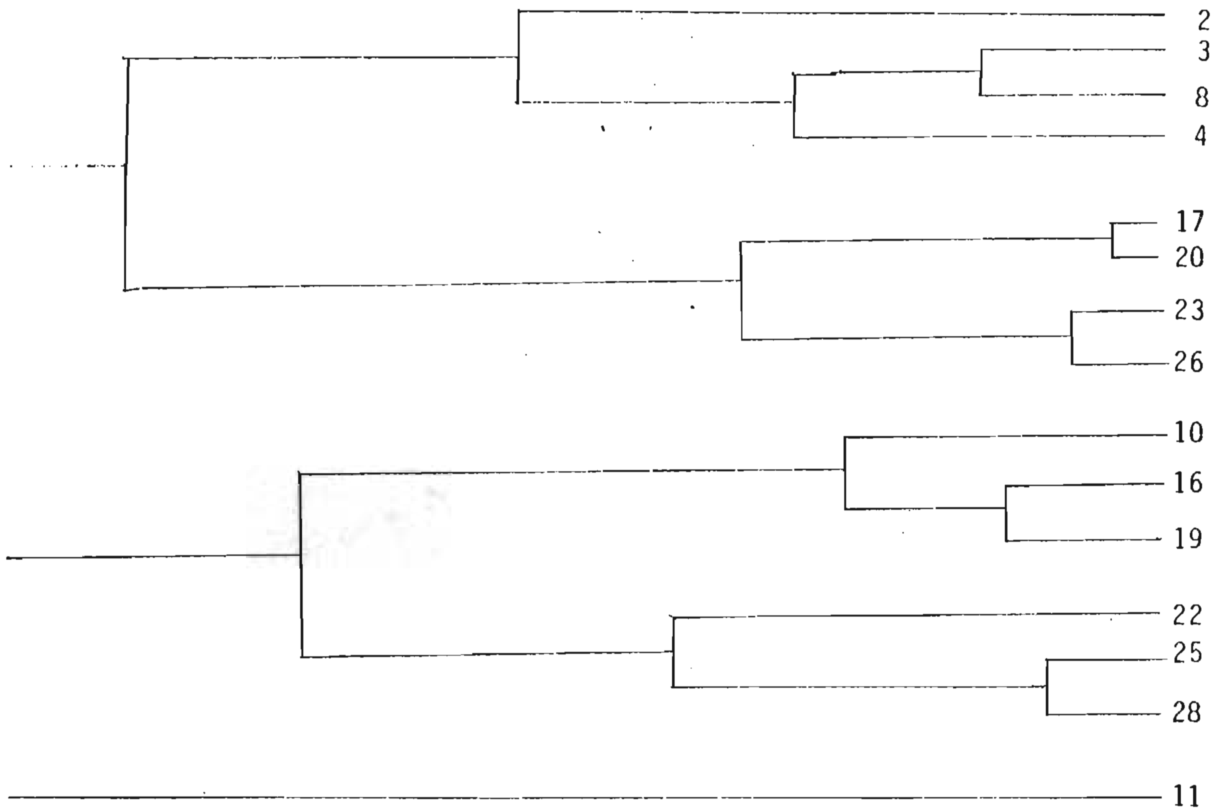

Figure 10. Cluster dendrogram by stations (Arabic numerals)

groupings are the main concern and since they were the same regardless of the combination of variables considered in the analysis, inclusion of the spring sites in this manner appears justified.

Assessment of Composite Land Use Effects

Table 15 displays the cluster groupings with their mean values. Cluster one (stations 2, 3, 4, and 8) represents the upper Trout Creek sub-basin. This area is primarily rural with moderate grazing activity throughout. Residential development is scattered throughout the area but is generally located along the drainage divides. While the four stations comprising the cluster have similar characteristics as compared to remaining stations in the watershed, there are numerous significant differences between them. Summary statistics for cluster one stations are presented in Table 16. Analysis of variance reveals that there are significant differences. between the stations with all constituents except for fecal streptococcal bacteria (Appendix E). Paired t-tests between station pairs reveal the precise differences in water quality variables between stations (Appendix F). The moderate grazing activity observed in this sub-basin is its most common bond between the stations and explains why the cluster has the highest fecal streptococcal bacteria densities in the watershed.

Cluster two (stations 17, 20, 23 and 26) includes all four tributaries to Trout Creek. Summary statistics are presented in Table 17. Mule Creek, Missouri Gulch and Fern Creek represent watersheds essentially in their pristine condition. While Rule

Table 15. Cluster groupings with mean values.

Cluster	Station	Suspended Solids (mg/l)	Specific Conductance mhos/cm at 25°C	Total Dissolved Solids (mg/l)	Nitrate mg/l as NO_3	Chloride (mg/l)	Fecal Coliform colonies/ 100 ml	Fecal Streptococcus colonies/ 100 ml
1	2	6.5	200	150	0.3	0.3	73	1100
	3		170	150	1.3	1.2	27	430
	8	8.2	200	140	0.1	1.5	42	740
	4		150	120	1.3	0.9	100	290
2	17	1.8	130	100	0.0	0.3	9	550
	20	3.1	150	100	0.1	0.1	18	700
	23	4.4	140	100	0.1	0.3	10	100
	26	2.6	120	80	0.1	0.6	11	300
3	10	6.6	210	140	8.0	5.8	79	340
	16	21	270	160	5.9	7.2	110	360
	19	12	250	160	4.3	6.4	86	240
4	22	20	240	160	0.1	2.8	190	400
	25	10	270	160	0.1	2.8	83	480
	28	13	250	150	0.0	5.6	58	500
	11	50	280	170	7.3	9.7	130	150

Table 16. Summary statistics for cluster one (Stations 2, 3, 4 and 8).

Station	Discharge l/sec.	Suspended Solids (mg/l)	Specific Conductance mhos/cm at 25°C	Total Dissolved Solids (mg/l)	Chloride (mg/l)	Nitrate mg/l as NO_3	Fecal Coliform colonies/ 100 ml	Fecal Streptococcus colonies/ 100 ml
2								
Mean	14	6.5	200	150	0.3	0.3	73	1000
Median	5	4.0	210	140	0.1	0.3	24	480
Std. Dev.	34	6.5	47	27	0.6	0.2	110	1600
Range	1-192	0-22	80-260	85-190	0-2	0-0.6	0-540	26-6700
N	38	21	27	34	12	10	32	32
3								
Mean			170	150	1.2	1.3	27	430
Median			170	140	1.1	1.3	23	310
Std. Dev.			15	34	0.4	0.2	28	420
Range			130-190	110-270	0.5-2	1.1-1.6	0-97	2-1500
N			17	16	12	10	19	19
4								
Mean			150	120	0.9	1.3	100	290
Median			150	120	0.5	1.4	24	340
Std. Dev.			9.4	17	1.3	0.3		270
Range			130-170	81-160	0-4	0.8-1.6	0-620	2-1200
N			17	16	12	10	19	19
8								
Mean	50	8.2	200	140	1.5	0.1	42	740
Median	7	5.2	200	140	1.8	0.1	11	270
Std. Dev.	120	10.2	31	31	1.3	0.2	110	1900
Range	1-520	0.8-61	100-240	60-240	0-4	0.0-0.7	0-620	28-12000
N	59	42	36	49	12	10	37	37
Cluster as whole								
Mean	36	7.7	190	140	1.0	0.76	60	710
Median	7	4.6	190	140	0.6	0.71	18	310
Std. Dev.	95	9.1	37	30	1.1	0.59	110	1500
Range	1-524	0-61	81-260	60-270	0-4	0.02-1.59	0-620	2-12000
N	97	63	97	116	48	40	107	107

Table 17. Summary statistics for cluster two (Stations 17, 20, 23 and 26).

Station	Discharge 1/sec	Suspended Solids (mg/1)	Specific Conductance µmhos/cm at 25°C	Total Dissolved Solids (mg/1)	Chloride (mg/1	Nitrate mg/1 as NO_3	Fecal Coliform colonies/ 100 ml	Fecal Streptococci colonies/ 100 ml
17								
Mean	22	1.9	130	100	0.3	0.04	9	550
Median	9	1.7	130	100	0.1	0.04	2	120
Std. Dev.	33	1.6	14	33	0.3	0.01	18	690
Range	1-130	0-5.6	90-150	71-220	0-0.8	0.01-0.04	0-75	13-2200
N	19	14	19	17	13	11	9	19
20								
Mean	98	3.1	150	100	0.1	0.14	19	700
Median	37	1.7	150	100	0.0	0.10	10	280
Std. Dev.	170	3.6	18	16	0.2	0.14	21	1300
Range	6-780	0-12	110-180	45-120	0-0.5	0.02-0.49	0-68	4-4900
N	23	8	22	21	13	10	23	23
23								
Mean	30	4.4	140	100	0.3	0.05	10	99
Median	12	3.1	120	100	0.2	0.04	3	69
Std. Dev.	56	3.8	49	26	0.5	0.04	15	88
Range	0-205	0.3-11	80-120	65-150	0-10	0.01-0.11	0-47	13-320
N	14	7	10	11	7	5	11	11
26								
Mean	41	2.7	120	80	0.6	0.08	11	11
Median	27	1.1	120	80	0.2	0.08	11	300
Std. Dev.	47	4.3	18	13	1.0	0.02	17	360
Range	4-160	0-17	65-140	60-110	0-30	0.05-0.12	0-74	22-1500
N	23	17	21	21	12	10	21	22
Cluster s Whole								
Mean	51	2.8	130	93	0.3	0.08	13	450
Median	19	1.7	130	93	0.1	0.06	5	140
Std. Dev.	100	3.5	27	24	0.6	0.09	13	820
Range	0-780	0-17	65-220	0-3	0.01-9.49	0-95	4-4800	
N	79	56	72	70	45	36	74	75

Creek is larger than the other three and slightly more developed, it is considerably less influenced by urbanization than Trout Creek. The lowest values of all constituents are found in this cluster. One way analysis of variance reveals no significant difference between the cluster stations with respect to suspended solids, chloride and fecal coliform bacteria (Appendix G). Specific differences between station pairs within the cluster have been made using paired t-tests. Their results are presented in Appendix H.

Cluster three includes the stations of the middle Trout Creek sub-basin (stations 10, 16, 19). This is the area most effected by the urbanization centered around Woodland Park. The dominant feature on water quality in this sub-basin is the Woodland Park sewage treatment lagoons. It should be noted, however, that station 11, located immediately downstream of the sewage lagoon effluent discharge is not included in this cluster, Its water quality is so substantially different from the other stations, that it warranted a separate cluster by itself. Summary statistics for the cluster are presented in Table 18. Except for station 11, the highest nitrate and chloride concentrations in the watershed are found in this cluster. Specific conductance and total dissolved solids concentrations are also among the highest in the watershed, a distinction also shared with cluster four. One way analysis of variance reveals that chloride and fecal streptococcal bacteria are the only constituents that are not significantly different between

Table 18. Summary statistics for cluster three (Stations 10, 16 and 19)

Station	Discharge l/sec	Suspended Solids (mg/l)	Specific Cunductance µmhos/cm at 25°C	Total Dissolved Solids (mg/l)	Chloride mg/l	Nitrate mg/l as NO_3	Fecal Coliform colonies/ 100 ml	Fecal Streptococci colonies/ 100 ml
10								
Mean	30	6.6	210	140	5.8	8.0	79	340
Median	27	3.8	210	140	6.0	8.3	35	260
Std. Dev.	30	12	21	31	1.6	1.1	120	270
Range	7-190	0-52	140-280	61-220	2-8	5.5-9.0	0-500	98-1600
N	38	18	29	23	12	11	37	39
16								
Mean	86	21	270	160	7.2	5.9	110	360
Median	33	12	290	160	7.4	6.1	100	300
Std. Dev.	160	23	50	28	3.6	2.6	80	240
Range	12-740	2.4-98	150-320	77-220	2-13	1.2-9.2	4-330	54-970
N	23	20	23	21	13	11	23	23
19								
Mean	97	12	240	160	6.4	4.3	87	240
Median	35	11	260	160	6.9	4.5	72	240
Std. Dev.	160	7.8	45	24	3.1	2.0	87	110
Range	7-700	1.9-33	130-300	110-220	2-12	1.1-7.5	0-310	56-450
N	23	19	22	21	13	11	23	23
Cluster as Whole								
Mean	64	13	240	150	6.3	6.1	89	320
Median	31	8.4	230	150	6.1	6.6	62	250
Std. Dev.	120	17	47	29	3.0	2.5	100	230
Range	7-740	0-97	130-320	61-220	1-13	1.1-9.2	0-500	54-1600
N	84	57	74	65	39	33	83	85

stations of the cluster (Appendix I). Comparisons between specific stations within the cluster with all variables have been made using paired t-tests with the results reported in Appendix J.

Cluster four (stations 22, 25 and 28) represents the lower Trout Creek sub-basin. Land uses represented by these sites are not dominated by any single use. Grazing and forest lands are most common with only minor residential development in the sub-basin. These stations integrate all upstream land uses and reflect the composite effects of land use on water quality throughout the Trout Creek drainage system. Summary statistics for the cluster are presented in Table 19. Nitrate levels are low and are similar to those found in the tributary watersheds. Specific conductance and total dissolved solids are similar to those of cluster three and together are the highest in the watershed. Chloride concentrations are higher than any other cluster except for the area near the sewage lagoons. Suspended solids concentrations were higher than any other site except for station 11. Highest fecal coliform bacteria densities of the watershed were found in this cluster.

One way analysis of variance reveals that there are no significant differences between the cluster stations with respect to suspended solids, specific conductance, total dissolved solids, nitrate, fecal colfiorm and fecal streptococcal bacteria (Appendix K). Paired t-tests were made on specific station pairs and their results are reported in Appendix L.

Table 19. Summary statistics for cluster four (Stations 22, 25 and 28).

Station	Discharge l/sec	Suspended Solids mg/l	Specific Conductance µmhos/cm at 25°C	Total Dissolved Solids mg/l	Chloride mg/l	Nitrate mg/l as NO_3	Fecal Coliform colonies/ 100 ml	Fecal Streptococci colonies/ 100 ml
22								
Mean	238	20	240	160	2.8	0.10	190	400
Median	93	9.4	250	160	3.0	0.05	49	390
Std. Dev.	390	2.8	53	42	1.0	0.12	390	520
Range	2-1600	0-100	140-370	110-310	1.5-4.5	0.02-0.40	4-1500	21-2500
N	22	17	21	21	12	10	21	22
25								
Mean	250	10	270	160	2.8	0.06	83	480
Median	83	3.4	260	170	2.8	0.04	47	280
Std. Dev.	480	14	65	34	1.1	0.06	100	630
Range	1-2200	0-49	140-380	90-210	1.0-4.5	0.01-0.18	0-470	62-2700
N	23	17	21	21	12	10	22	22
28								
Mean	510	13	250	150	5.6	0.03	58	500
Median	250	4.1	250	150	5.1	0.03	28	380
Std. Dev.	710	20	46	26	3.0	0.01	76	410
Range	20-2500	0.4-65	150-350	110-200	2.0-10	0.01-0.04	2-270	28-1300
N	23	17	20	21	12	10	22	21
Cluster as Whole								
Mean	340	14	250	160	3.7	0.06	110	460
Median	120	4.6	250	160	3.1	0.03	37	300
Std. Dev.	550	215	56	34	2	0.08	240	520
Range	1-2500	0-100	140-380	90-310	1-10	0.01-0.4	0-1500	21-2700
N	68	51	62	63	36	30	65	65

Cluster five consists of station 11. Located immediately downstream from the sewage effluent discharge, this station is sufficiently different from all other sites so as to form a separate cluster by itself. (Summary statistics can be found in Table 8.)

Comparisons between clusters were made using unpaired t-tests on log transformed variables. All observations for each variable at each station in the cluster were aggregated and tested against similar values of another cluster (Table 20). Both years of data were used with the exception of nitrate where only 1980 data were considered due to the differences in the analytical technique employed.

Suspended sediment concentrations did not vary significantly between any of the clusters on Trout Creek. The tributary cluster, however, varied significantly with each of the Trout Creek clusters. The explanation of this goes beyond land use. Development along the tributaries is nearly non-existant as most of the land is slightly managed forest. Trout Creek lands by contrast are more developed with road systems, urbanization and grazing. Another important factor is the nature of the respective watersheds. Trout Creek generally flows through a thick and very mobile alluvial fill deposit. The tributaries flow through narrow "V-shaped" valleys nearly devoid of extensive alluvial fill deposits. The increased suspended sediment in Trout Creek as compared to the tributaries is likely the composite effect of the mobile alluvial fill deposit through which it flows, livestock grazing in the riparian

Table 20. T-tests for cluster pairs.

Cluster Pairs	Suspended Solids	Specific Conductance	Total Dissolved Solids	Nitrate	Chloride	Fecal Coliform	Fecal Streptococcus
1,2							
Significant at α=0.1	***	***	***	***	***	***	***
t-statistic	5.94	9.52	13.18	7.05	4.14	5.31	2.70
Deg. of freedom	99	158	155	75	91	166	177
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1,3							
Significant at α=0.1	N.S.	***	N.S.	***	***	**	N.S.
t-statistic	1.09	-7.60	-1.07	-12.71	-12.92	-3.41	0.13
Deg. of freedom	100	160	150	75	85	165	174
p-value	0.278	0.000	0.285	0.000	0.000	0.001	0.900
1,4							
Significant at α=0.1	N.S.	***	**	***	***	*	N.S.
t-statistic	0.19	-8.37	-2.78	6.53	-8.75	-2.28	0.07
Deg. of freedom	93	148	148	69	82	156	167
p-value	0.853	0.000	0.006	0.000	0.000	0.024	0.944
2,3							
Significant at α=0.1	***	***	***	***	***	***	**
t-statistic	-6.96	-17.08	-12.57	19.46	-19.59	-8.30	-3.29
Deg. of freedom	111	144	133	70	82	147	153
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.001
2,4							
Significant at α=0.1	***	***	***	N.S.	***	***	*
t-statistic	-4.89	-16.96	-14.12	0.53	-14.99	-7.10	-2.61
Deg. of freedom	104	132	131	64	79	138	146
p-value	0.000	0.000	0.000	0.598	0.000	0.000	0.010
3,4							
Significant at α=0.1	N.S.	N.S.	N.S.	***	***	N.S.	N.S.
t-statistic	1.17	-1.46	-1.50	17.86	4.22	1.01	-0.04
Deg. of freedom	105	134	126	64	73	137	143
p-value	0.245	0.148	0.136	0.000	0.000	0.314	0.964

N.S. - Not significant; * Significant; ** Very Significant; *** Very Highly Significant zone, and the construction and periodic failure of numerous beaver dams. It should be noted, however, that although the differences are statistically significant, the concentrations do not represent any threat to any beneficial uses for which the water may be used.

Specific conductance and total dissolved solids vary significantly throughout the watershed. Each cluster is significantly different from the others with the exception of cluster pairs three and four for both specific conductance and total dissolved solids and cluster pairs one and three for total dissolved solids (Table 20). Lowest values are found in cluster two which represents the Trout Creek tributaries. On Trout Creek, both variables are lowest in the upper region and gradually increase with increasing distance downstream. The primary mechanism by which specific conductance and total dissolved solids increase is dissolution of soluble minerals with increasing hydraulic residence time. In the grazing treatment discussed previously, increases in specific conductance and total dissolved solids were not attributed to grazing but rather to the flood irrigation process. The lake based recreation treatment revealed no discernable impacts on either specific conductance or total dissolved solids concentration. The sewage treatment was the only specific treatment considered that had any significant effect on specific conductance and total dissolved solids concentrations. While the lagoon effluent resulted in a significant increase within the treatment area, its composite effect on the lower portion of

Trout Creek is minor. Differences between clusters 3 and 4 are not significant. Differences between the upper and lower Trout Creek clusters though statistically significant, are small. The increase in specific conductance between the two clusters is only from 190 to 250 μmhos/cm at 25°C while the increase in total dissolved solids concentrations is only from 140 mg/l to 160 mg/l.

Nitrate levels in the watershed are strongly influenced by the Woodland Park sewage treatment lagoons. Nitrate concentrations for surface waters outside of cluster three average 0.1 mg/l as NO_3. Mean nitrate concentration for cluster three is 6.2 mg/l as NO_3, more than 60 times that found in surface waters for the remainder of the watershed. Cluster three nitrate concentrations are significantly different from all other clusters due to the nitrate influence exerted by the sewage treatment. Cluster one nitrate concentration are also significantly different from all other clusters. By examining the mean nitrate levels for the cluster (Table 15) it is clear that the two spring sites (stations 3 and 4) are the primary cause for the difference between this cluster and clusters 2 and 4. Station 2 is also higher than most other surface water stations outside cluster three. This is a likely effect of the nitrate fertilization by the landowner of the meadow immediately upstream of the station during the 1980 field season. Nitrate levels of cluster 2 and 4 are essentially the same (Table 20).

Although nitrate levels increase dramatically in the region of the Woodland Park sewage lagoons, they gradually decrease with distance downstream until the outlet of Manitou Lake. At this point nitrate levels are similar to those found throughout the remainder of the watershed uneffected by the lagoons.

Another illustration of nitrate decreasing fairly rapidly with distance was observed with a small study conducted in the vicinity of station 3 on the Glen Johnston ranch. On three occasions nitrate samples were collected at the spring egress, the inlet to the small stock pond approximately 100 meters from the spring, the pond itself, the pond outlet and a site approximately 50 meters downstream of the pond (Figure 11). The raw data is presented in Table 21. One way analysis of variance indicates no significant difference in observations by date ($F = 0.4$ compared to a critical value of 2.81 for 2 and 12 degrees of freedom). Significant drops in nitrate concentrations occurred between sites one and two only 100 meters apart, as well as between sites two and sites three and four (Table 22). No differences were found between the pond and the outlet, but a significant increase was observed between the outlet and the site 50 meters downstream. Two concurrent processes appear to be occurring. Based on the laboratory observations of Sain, et al., (1975) denitrification is likely occurring at the interface of the bottom sediments and pond water and possibly between the spring egress and the pond inlet. Extensive algae growth was observed in the pond and substantial nitrate is presumed to be assimilated in the living biomass. The increase of nitrate downstream of the pond outlet is likely the result

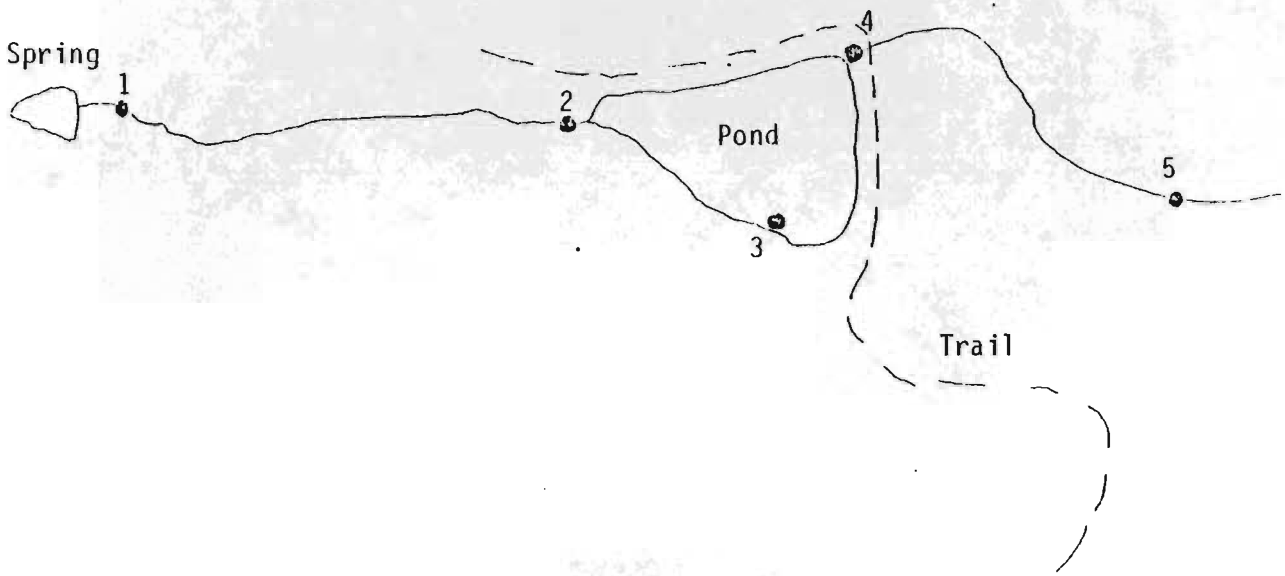

Figure 11. Spring-pond nitrate observations site locations.

Table 21. Raw data for spring-pond nitrate observations.

Date	Spring (1)	Inlet (2)	Pond (3)	Outlet (4)	50m Downstream of Outlet (5)
	Nitrate Concentration in mg/l as NO_3				
7/28/80	1.6	0.36	0.005	0.00	0.08
8/4/80	1.4	0.98	0.01	0.00	0.24
8/18/80	1.3	0.90	0.01	0.01	0.18
Mean	1.4	0.75	0.008	0.003	0.17
Std. Dev.	0.15	0.34	0.003	0.006	0.08

Table 22. T-tests for spring-pond nitrate observations.

Stations	Significant at $\alpha = 0.1$	t-statistic	Degrees of Freedom	p-value
1,2	*	3.12	2	0.085
3,2	*	3.792	2	0.063
3.4	N.S.	1.342	2	0.312
3,5	*	-3.391	2	0.077
4,5	*	-3.491	2	0.073

N.S. Not significant

* Significant

of the outlet water being mixed with additional groundwater with a higher nitrate level. It would appear from these observations and those of the nitrate profile study at the lagoon area that available nitrate in Trout Creek is either fairly rapidly lost to denitrification or converted into biomass.

Chloride concentrations vary considerably between cluster groups. Highest chloride concentrations are found in the area of the sewage lagoons. The obvious source is the domestic wastewater whose treatment process has little effect on chloride concentrations. One set of observations were made on the two large lagoons and the lagoon effluent on July 7, 1980 and the chloride concentrations were all the same (40 mg/l). Lowest chloride concentrations are found in the tributaries (Cluster 2) where concentrations are barely detectable. Concentrations in the upper region of Trout Creek are also fairly low with an increasing trend downstream. Significant differences between cluster pairs occur between all cluster combinations (Table 20).

Chloride concentrations in the Trout Creek watershed are low. Igneous geology plays a major role. Locally important sources in the watershed include domestic wastewater from the sewage treatment lagoons and septic tank leachate. Another potential local source might include salt blocks used for livestock. Natural geologic sources cannot be dismissed when talking about such low concentrations. Unlike nitrate, chloride is a conservative substance which does not interact in the aquatic environment. Once in the stream it will remain. The reason why the highest chloride concentrations are found in cluster three and not cluster four, is dilution from the several tributaries from the lagoons to the lower end of the watershed. However, the contribution of the lagoons to the overall chloride mass at Trout Creek near the confluence with West Creek is not particularly great. Mean chloride mass flux at station 11 is only 320 mg/sec. At station 28 the mass flux is 2900 mg/sec. The mass at station 11 represents approximately 11% of the total mass at station 28. While important additional sources likely include natural geology, septic tank leachate and livestock salt blocks, it should be kept in mind, however, that the chloride levels observed throughout most of Trout Creek are low and have no appreciable impact on water quality.

Fecal coliform bacteria densities vary considerably throughout the entire watershed. Variations within each station outside the tributary cluster range across three orders of magnitude. Lowest fecal coliform bacteria densities are found in cluster two. Densities from this cluster are significantly lower than any other cluster. Along Trout Creek, the lowest fecal coliform densities are in the upper portion of the watershed. A significant increase occurs between this cluster and the lagoon cluster, but no significant change occurs between the lagoon cluster and the lower watershed cluster. Land use clearly plays a major role in determining why the tributaries have the lowest fecal coliform densities. They are relatively pristine and there are few fecal sources. The upper region of Trout Creek is the only Trout Creek sub-basin which doesn't have an appreciable amount of residential development either within the area or upstream. This might explain the statistically significant lower fecal coliform bacteria densities in the upper portion of the watershed as compared to the rest of Trout Creek. Comparing the mean fecal coliform densities of cluster one with those of the remaining Trout Creek clusters indicates that although there are statistically significant differences between clusters, the differences are generally within the range of the standard deviation for the mean at each station and have few water quality implications.

Fecal streptococcal bacteria exhibits a slightly different pattern than fecal coliform bacteria. Although the lowest fecal streptococci densities are again found in the tributaries, the highest densities are found in the upper Trout Creek sub-basin. Significant differences exist between the tributary cluster and all others. This is expected, due to the undeveloped nature of the tributary watersheds. Despite the fact that the highest fecal streptococcal bacteria densities are found in the upper Trout Creek sub-basins, there is no significant difference in fecal streptococci densities between the Trout Creek clusters. Although the grazing treatment demonstrated that grazing can increase fecal streptococci densities in a specific local area, assessment of composite effect reveals that land use does not play a significant role on the fecal streptococcal bacteria densities along the Trout Creek mainstream. Land use does play a major role in explaining dfiferences between Trout Creek and its tributaries.

SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate composite land use impacts on water quality of Trout Creek, a tributary to the South Platte River in Colorado. Four specific treatment areas were considered for their local impacts on water quality before assessing basin-wide composite effects. Composite effects were evaluated by employing cluster analysis. This quasi-statistical technique groups stations on the basis of similarities of input variables.

Summary

The findings of the study are as follows:

1. The only observed effect of the grazing treatment was with fecal streptococcal bacteria. Specific conductance and total dissolved solids increased through the study area, but this was due to flood irrigation and independent of grazing. Nitrate and phosphate were consistently below detection limits for the analytical procedure employed. Fecal coliform levels were uneffected. A statistically significant increase in fecal streptococci was detected along with increase in variability.
2. The road treatment area was observed to serve as a source area for suspended solids during runoff events. Summer convective storms supply the energy which can deliver substantial quantities of sediment to the stream, but their

specific inputs are difficult to monitor due to their unpredictable and sporadic nature. Base flow conditions result in very little sediment transported through the hydrologic system.

3. Lake-based recreation was shown to have very little effect on Trout Creek in the area of the Manitou Lake recreation area. A minor but statistically significant increase in suspended solids concentration was observed. Nitrate and phosphate levels were below detectable limits. Specific conductance, total dissolved solids, fecal coliform and fecal streptococcal bacteria densities were uneffected by the recreational use of the area.

4. Sewage treatment lagoons had several effects on Trout Creek. Specific conductance, total dissolved solids, and chloride all significantly increased in the immediate area. Nitrate levels for the cluster were more than 10 times those found elsewhere in the watershed with highest nitrate concentrations more than 60 times the mean for surface water stations outside of the lagoon dominated cluster. High nitrate concentrations were observed several hundred meters upstream of the lagoons and were found to decrease according to a strong linear relationship with distance. Nitrate effects from the lagoons on Trout Creek were no longer detectable by the time the water left Manitou Lake.

5. Cluster analysis proved to be a very effective tool in interpreting water quality of Trout Creek. Cluster groupings followed a marked spatial pattern, distinguishing between upper, middle and lower sub-basins of Trout Creek, Trout Creek tributaries and a single station immediately downstream of the sewage lagoon effluent discharge.
6. Suspended solids concentrations showed significant differences between the tributary cluster and all Trout Creek clusters, but no significant differences were observed between Trout Creek clusters. Differences in land uses between the tributaries and Trout Creek, do not explain the entire difference as physical characteristics of the watershed also play an important role.
7. Specific conductance and total dissolved solids vary statistically significantly throughout the watershed. Values are lowest in the tributaries. The lowest values on Trout Creek were observed in the upper sub-basin. Only the sewage lagoon treatment had any significant local effect on specific conductance and total dissolved solids. Although statistically significant differences were detected beween the upper and lower Trout Creek sub-basins, the magnitude of the difference was small and had little water quality importance.

8. Nitrate levels were dramatically effected by the sewage treatment. Concentrations decreased linearly with distance and were no longer detectable at the outlet of Manitou Lake. Any nitrate introduced to the aquatic system appears to be lost to denitrification or rapidly converted into biomass.
9. Chloride concentrations vary considerably between cluster groups. The sewage treatment area is a locally important chloride source but its overall contribution to the total chloride mass at the mouth of the watershed is about 10%. Natural geology, septic tank leachate and livestock salt blocks are likely important chloride sources for the basin, but the overall chloride concentrations are quite low.
10. Fecal coliform densities between the tributary cluster and all Trout Creek sub-basins are significantly different. Land use is a prime factor as there are few fecal sources in the tributaries. Although differences between the upper Trout Creek sub-basin and the remainder of Trout Creek are statistically significant, the differences have little water quality importance. Land use differences have little impact on fecal coliform bacteria densities on the main stream of Trout Creek.
11. Fecal streptococcal bacteria densities exhibit the same relationship between the Trout Creek tributaries and the main stream as fecal coliform. The grazing treatment

demonstrated a locally significant increase in fecal streptococci densities, but the composite effect of all land uses on the Trout Creek main stem fecal streptococci densities is insignificant. Land use differences play a major role in explaining significant differences between Trout Creek and its tributaries.

Conclusions

Composite land use impacts on water quality within the Trout Creek watershed are only discernible when comparing the tributaries with mainstream clusters. Sewage treatment has a significant local impact on nitrate water quality of Trout Creek but its impact was no longer detectable approximately 10 km downstream. Other constituents were uneffected by composite land uses along the Trout Creek mainstream. Differences in land uses between the tributaries and the main stem of Trout Creek effected suspended solids, nitrate, chloride, fecal coliform and fecal streptococci concentrations. Differences in specific conductance and total dissolved solids cannot be attributed to land use.

In general, the water quality of the Trout Creek watershed is good. None of the constituents considered in this study were present in concentrations which represented a threat to existing beneficial uses.

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Appendix A. ANOVA for suspended solids analytical procedure.

Station	Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical F-value
5	Factor	1.50	2	0.75	0.62	3.46
	Error	7.31	6	1.22		
	Total	8.81	8			
6	Factor	54.57	2	27.78	0.67	3.46
	Error	243.65	6	40.61		
	Total	298.22	8			
7	Factor	0.33	2	0.16	0.08	3.46
	Error	11.63	6	1.94		
	Total	11.96	8			
8	Factor	1.10	2	0.55	0.17	3.46
	Error	19.07	6	3.18		
	Total	20.17	8			

Appendix B. ANOVA for total dissolved solids analytical procedure.

Station	Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical F-value
1	Factor	86.72	2	43.36	0.89	3.46
	Error	292.32	6	48.72		
	Total	379.04	8			
2	Factor	112.39	2	56.19	0.59	3.46
	Error	566.83	6	94.47		
	Total	679.22	8			
8	Factor	70.17	2	35.08	0.61	3.46
	Error	347.33	6	57.89		
	Total	417.5	8			

APPENDIX C. ANOVA for fecal coliform and fecal streptococcal bacteria analytical procedures.

Station	Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Critical F-value
		FECAL COLIFORM BACTERIA				
9	Factor	0.67	2	0.33	0.6	3.46
	Error	3.33	6	0.56		
	Total	4.0	8			
10	Factor	24.89	2	12.44	1.10	3.46
	Error	68.00	6	11.33		
	Total	92.89	8			
11	Factor	64.67	2	32.33	0.74	3.46
	Error	263.33	6	43.89		
	Total	328	8			
12	Factor	308.22	2	154.11	0.53	3.46
	Error	1760.67	6	293.44		
	Total	2068.89	8			
		FECAL STREPTOCOCCAL BACTERIA				
9	Factor	9205	2	4602	0.36	3.46
	Error	75950	6	12658		
	Total	85155	8			
10	Factor	19062	2	9531	1.42	3.46
	Error	40250	6	6708		
	Total	59312	8			
11	Factor	2314	2	1157	0.09	3.46
	Error	78133	6	13022		
	Total	80448	8			
12	Factor	1601666	2	800833	1.09	3.46
	Error	4428333	6	738055		
	Total	6030000	8			

APPENDIX D. Diurnal paired t-tests.

Station	Number of Cases	Mean	Standard Deviation of Mean	t-Statistic	Significant @ $\alpha = 0.1$
		SPECIFIC CONDUCTANCE			
Road 1(5)	8	0.0	11.0	0.00	N.S.
Road 2(6)	9	-.11	89.0	-0.037	N.S.
Road 3(7)	8	-.38	5.04	-.21	N.S.
Road 4(8)	8	.125	5.94	0.06	N.S.
		TOTAL DISSOLVED SOLIDS			
Road 1(5)	7	-.43	10.8	-.105	N.S.
Road 2(6)	8	-.25	11.7	-0.061	N.S.
Road 3(7)	9	.22	12.1	0.055	N.S.
Road 4(8)	8	.38	3.34	.318	N.S.
		FECAL COLIFORM BACTERIA			
Upper Lake (13)	11	.27	28.2	.032	N.S.
Upper Lake (13)	7	-.29	24.4	-0.031	N.S.
Lower Lake (14)	8	.13	291	0.001	N.S.
		FECAL STREPTOCOCCAL BACTERIA			
Upper Lake (13)	11	.36	444	0.003	N.S.
Upper Lake (13)	8	.63	446	0.004	N.S.

N.S. Not significant

APPENDIX E. ANOVA on cluster one using log transformed data (Stations 2, 3, 4 and 8)

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
		DISCHARGE			
Between Stations	1	2.4	2.4	6.68	0.01
Within Stations	58	20.8	0.36		
Total	59	23.2			
		SUSPENDED SOLIDS			
Beween Stations	1	.77	0.77	5.29	0.03
Within Stations	43	6.23	.15		
Total	44	7.00			
		CHLORIDE			
Between Stations	3	.58	0.19	5.41	0.00
Within Stations	44	1.58	0.04		
Total	47	2.16			
		SPECIFIC CONDUCTANCE			
Between Stations	3	.14	0.05	6.14	0.00
Within Stations	84	.66	0.01		
Total	87	.80			
		TOTAL DISSOLVED SOLIDS			
Between Stations	3	0.09	0.039	4.55	0.01
Within Stations	83	0.52	0.006		
Total	86				
		NITRATE			
Between Stations	3	.84	.278	64.38	0
Within Stations	37	.16	0.064		
Total	40	1.00			
		FECAL COLIFORM BACTERIA			
Between Stations	3	2.96	0.988	2.33	.08
Within Stations	89	37.81	0.425		
Total	92				
		FECAL STREPTOCOCCAL BACTERIA			
Between Stations	3	2.10	0.698	1.40	.25
Within Stations	96	47.97	0.500		
Total	99				

Appendix F. Paired t-tests on cluster one using log transformed data.

Pairs	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Nitrate	Fecal Coliform	Fecal Streptococci
2,3								
Significant at α=0.1			N.S.	N.S.	***	***	**	*
N of cases			17	15	12	10	19	19
Difference			0.05	0.04	-0.26	-0.26	0.53	0.30
Std. Dev.			0.125	0.102	0.14	0.06	0.69	0.69
t-statistic			1.66	1.68	-6.29	-12.98	3.32	1.91
p-value			0.166	0.115	0.000	0.000	0.004	0.072
2,4								
Significant at α=0.1			*	***	*	***	N.S.	**
N of cases			17	15	12	10	19	19
Differences			0.09	0.10	-0.15	-0.25	0.14	0.46
Std. Dev.			0.14	0.08	0.26	0.06	0.64	0.55
t-statistic			2.83	5.17	-2.02	-13.89	0.93	3.66
p-value			0.012	0.000	0.068	0.000	0.362	0.002
2,8								
Significant at α=0.1	***	*	N.S.	*	**	N.S.	*	*
N of cases	27	21	25	24	12	10	25	28
Difference	-0.33	-0.23	-0.01	-0.02	-0.28	0.06	0.38	0.26
Std. Dev.	0.23	0.53	0.06	0.06	0.27	0.12	0.79	0.52
t-statistic	-7.47	-0.99	-0.74	2.14	-3.53	1.44	2.39	2.66
p-value	0.000	0.061	0.466	0.043	0.005	0.183	0.025	0.013
3,4								
Significant at α=0.1			***	***	N.S.	N.S.	*	*
N of cases			17	15	12	10	19	19
Difference			0.04	0.03	0.11	0.01	-0.39	0.15
Std. Dev.			0.04	0.03	0.23	0.03	0.72	0.37
t-statistic			4.86	4.52	1.63	1.37	-2.35	1.79
p-value			0.000	0.000	0.132	0.205	0.030	0.090
3,8								
Significant at α=0.1			*	***	N.S.	***	N.S.	N.S.
N of cases			17	15	12	10	18	19
Difference			-0.06	0.03	-0.02	0.32	0.01	-0.04
Std. Dev.			0.10	0.03	0.25	0.09	0.68	0.54
t-statistic			-2.67	4.52	-0.28	11.35	0.06	-0.36
p-value			0.017	0.000	0.787	0.000	0.956	0.721
4,8								
Significant at α= 0.1			**	**	N.S.	***	*	N.S.
N of cases			17	16	12	10	18	19
Difference			-0.11	-0.06	-0.13	0.31	0.40	-0.20
Std. Dev.			0.10	0.07	0.42	0.11	0.71	0.53
t-statistic			-4.28	-3.37	-1.05	8.49	2.37	-1.63
p-value			0.001	0.004	0.315	0.000	0.030	0.120

N.S. Not Significant; * Significant; ** Very Significant; *** Very Highly Significant

APPENDIX G. ANOVA on cluster two using log transformed data (Stations 17, 20, 23 and 26).

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
			DISCHARGE		
Between Stations	3	5.80	1.93	6.26	0.001
Within Stations	75	23.17	0.31		
Total	78				
			SUSPENDED SOLIDS		
Between Stations	3	0.53	0.176	1.43	0.24
Within Stations	52	6.39	0.123		
Total	55				
			CHLORIDE		
Between Stations	3	0.08	0.026	1.33	0.28
Within Stations	41	0.81	0.620		
Total	44	0.89			
			SPECIFIC CONDUCTANCE		
Between Stations	3	0.15	0.050	8.11	0.000
Within Stations	68	0.42	0.006		
Total	71				
			TOTAL DISSOLVED SOLIDS		
Between Stations	3	0.09	0.029	3.29	0.026
Within Stations	66	0.57	0.009		
Total	69	0.66			
			NITRATE		
Between Stations	3	0.607	0.002	2.81	0.055
Within Stations	32	0.026	0.0608		
Total	35				
			FECAL COLIFORM BACTERIA		
Between Stations	3	1.99	0.664	1.340	0.268
Within Stations	71	35.20	0.496		
Total	74				
			FECAL STREPTOCCAL BACTERIA		
Between Stations	3	4.53	1.51	3.78	0.014
Within Stations	75	30.01	0.40		
Total	78	34.54			

Appendix H. Paired t-tests on cluster two using log transformed data.

Pairs	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Nitrate	Fecal Coliform	Fecal Streptococci
17,20								
Significant at α =0.1	***	*	***	N.S.	*	*	*	N.S.
N of cases	18	13	18	17	13	10	18	18
Difference	-0.71	-0.25	0.06	-0.01	0.06	-0.03	-0.47	-0.10
Std. Dev.	0.18	0.34	0.04	0.09	0.11	0.05	0.45	0.34
t-statistic	-17.08	-2.62	-6.37	-0.[illegible]	1.80	-2.31	-4.49	-1.19
p-value	0.000	0.022	0.000	0.5[illegible]3	0.097	0.046	0.000	0.251
17,23								
Significant at α =0.1	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.
N of cases	12	6	10	11	7	5	11	12
Difference	0.15	-0.4	-0.05	-0.02	-0.00	-0.01	-0.42	0.19
Std. Dev.	0.37	0.26	0.11	0.13	0.12	0.02	0.61	0.59
t-statistic	1.39	-1.05	-1.37	-0.59	-0.06	-1.00	-2.29	1.12
p-value	0.192	0.344	0.205	0.571	0.953	0.374	0.045	0.286
17,26								
Significant at α =0.1	***	N.S.	**	*	N.S.	*	N.S.	N.S.
N of cases	18	12	17	17	12	10	18	18
Difference	-0.49	-0.06	0.05	0.07	-0.05	-0.01	-0.45	0.15
Std. Dev.	0.25	0.28	0.05	0.12	0.18	0.02	1.10	0.67
t-statistic	-8.31	-0.75	4.29	2.43	-0.92	-1.96	-1.67	0.43
p-value	0.000	0.466	0.001	0.027	0.379	0.081	0.115	0.364
20,23								
Significant at α =0.1	***	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*
N of cases	13	7	10	11	7	5	11	13
Difference	0.87	0.12	0.01	-0.0[illegible]	-0.09	0.03	0.19	0.40
Std. Dev.	0.29	0.51	0.11	0.09	0.15	0.07	0.60	0.59
t-statistic	10.84	0.62	0.42	-0.07	-1.55	1.00	1.00	2.46
p-value	0.000	0.559	0.683	0.9[illegible]7	0.172	0.374	0.314	0.030
20,26								
Significant at α =0.1	***	N.S.	***	*	N.S.	N.S.	N.S.	N.S.
N of cases	21	15	19	20	12	9	20	21
Difference	0.20	0.11	0.12	0.06	-0.11	0.03	0.00	0.19
Std. Dev.	0.18	0.40	0.04	0.11	0.24	0.06	0.91	0.72
t-statistic	5.04	1.06	11.46	2.67	-1.63	1.33	0.02	1.24
p-value	0.000	0.309	0.000	0.015	0.132	0.219	0.986	0.229
23,26								
Significant at α =0.1	***	N.S.	**	**	N.S.	N.S.	N.S.	**
N of cases	14	7	10	11	7	5	11	14
Difference	-0.62	0.00	0.12	0.12	-0.10	-0.01	-0.40	-0.43
Std. Dev.	0.36	0.45	0.09	0.09	0.27	0.02	0.89	0.52
t-statistic	-6.48	0.01	4.36	4.82	-1.01	-1.00	-1.49	-3.12
p-value	0.000	0.995	0.002	0.001	0.351	0.374	0.168	0.008

N.S. Not Significant; * Significant; ** Very Significant; *** Very Highly Significant

APPENDIX I. ANOVA on cluster three using log transformed data (Stations 10, 16 and 19).

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
		DISCHARGE			
Between Stations	2	1.53	0.763	4.52	0.014
Within Stations	72	12.14	0.169		
Total	74	13.67			
		SUSPENDED SOLIDS			
Between Stations	2	3.35	1.67	10.45	0.000
Within Stations	54	8.65	0.60		
Total	56	12.00			
		CHLORIDE			
Between Stations	2	0.05	0.0025	0.61	0.550
Within Stations	36	1.50	0.042		
Total	38	1.55			
		SPECIFIC CONDUCTANCE			
Between Stations	2	0.14	0.069	10.84	0.000
Within Stations	71	0.45	0.006		
Total	73	0.59			
		TOTAL DISSOLVED SOLIDS			
Between Stations	2	0.06	0.032	4.07	0.022
Within Stations	62	0.49	0.007		
Total	64	0.55			
		NITRATE			
Between Stations	2	0.34	0.171	3.68	0.036
Within Stations	33	1.53	0.046		
Total	35	1.87			
		FECAL COLIFORM BACTERIA			
Between Stations	2	0.63	0.314	0.80	0.455
Within Stations	71	27.94	0.393		
Total	73	28.57			
		FECAL STREPTOCOCCAL BACTERIA			
Between Stations	2	.37	0.185	2.58	0.083
Within Stations	73	5.24	0.072		
Total	75	5.61			

Appendix J. Paired t-tests on cluster three using log transformed data.

Pairs	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Nitrate	Fecal Coliform	Fecal Streptococi
10,16								
Significant at α 0.1	***	**	***	*	N.S.	*	N.S.	N.S.
N of cases	22	14	18	18	13	11	21	22
Difference	-0.23	-0.58	-0.10	-0.07	-0.09	0.16	-0.16	-0.02
Std. Dev.	0.19	0.61	0.71	0.11	0.26	0.19	0.51	0.33
t-statistic	-5.59	-3.54	-6.67	-2.67	-1.21	2.73	-1.48	-0.29
p-value	0.000	0.004	0.000	0.016	0.251	0.021	0.153	0.775
10,19								
Significant at α 0.1	***	*	**	*	N.S.	***	N.S.	*
N of cases	21	13	20	17	13	11	20	21
Difference	-0.30	-0.44	-0.05	-0.05	-0.05	-0.27	0.08	-0.14
Std. Dev.	0.22	0.53	0.08	0.09	0.25	0.17	0.56	0.36
t-statistic	-6.22	-2.97	-2.94	-2.34	-0.67	5.10	-0.66	1.86
p-value	0.000	0.012	0.008	0.033	0.513	0.000	0.516	0.078
16,19								
Significant at α 0.1	**	**	***	N.S.	N.S.	**	N.S.	**
N of cases	21	18	20	20	13	11	2 1	21
Difference	-0.06	0.20	0.05	0.00	0.04	0.11	0.09	0.16
Std. Dev.	0.08	0.25	0.03	0.09	0.08	0.08	0.30	0.24
t-statistic	-3.57	3.46	6.87	0.12	1.76	4.45	1.40	3.05
p-value	0.002	0.003	0.000	0.904	0.103	0.001	0.177	0.006

N.S. Not significant

* Significant

** Very Significant

*** Very highly signficant

APPENDIX K. ANOVA on cluster four using log transformed data (Stations 22, 25 and 28)

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Probability
		DISCHARGE			
Between Stations	2	3.09	1.545	3.66	0.031
Within Stations	64	27.01	0.422		
Total	66	30.10			
		SUSPENDED SOLIDS			
Between Stations	2	0.60	0.298	1.04	0.362
Within Stations	47	13.49	0.287		
Total	49	14.09			
		CHLORIDE			
Between Stations	2	0.36	0.179	6.75	0.004
Within Stations	33	0.88	0.027		
Total	35				
		SPECIFIC CONDUCTANCE			
Between Stations	2	0.02	0.010	1.00	0.373
Within Stations	59	0.58	0.010		
Total	61	0.60			
		TOTAL DISSOLVED SOLIDS			
Between Stations	2	0.005	0.002	0.27	0.766
Within Stations	60	0.504	0.008		
Total	62	0.509			
		NITRATE			
Between Stations	2	0.003	0.0013	1.63	0.215
Within Stations	27	0.022	0.008		
Total	29	0.025			
		FECAL COLIFORM BACTERIA			
Between Stations	2	0.92	0.459	1.22	0.303
Within Stations	62	23.39	0.377		
Total	64	24.31			
		FECAL STREPTOCOCCAL BACTERIA			
Between Stations	2	0.48	0.243	0.67	0.518
Within Stations	66	24.08	0.365		
Total	68	24.56			

Appendix L. Paired t-tests for cluster four using log transformed data.

Pairs	Discharge	Suspended Solids	Specific Conductance	Total Dissolved Solids	Chloride	Nitrate	Fecal Coliform	Fecal Streptococci
22,25								
Significant at α 0.1	*	**	*	N.S.	N.S.	N.S.	N.S.	N.S.
No. of cases	22	16	20	21	12	5	21	23
Difference	0.10	0.20	-0.04	-0.01	0.00	0.001	0.14	-0.07
Std. Dev.	0.25	0.25	0.06	0.07	0.13	0.02	0.67	0.35
t-statistic	1.87	3.09	-2.88	-0.46	0.13	1.00	0.94	-0.98
p-value	0.076	0.007	0.010	0.652	0.899	0.374	0.358	0.337
22,28								
Significant at α 0.1	***	**	N.S.	N.S.	***	N.S.	N.S.	N.S.
No. of cases	22	16	20	21	12	10	21	22
Difference	-0.39	0.24	-0.01	0.01	-0.21	0.02	0.24	-0.10
Std. Dev.	0.27	0.29	0.05	0.07	-0.21	0.02	0.24	-0.10
t-statistic	-6.63	3.27	0.85	0.85	5.02	1.55	1.56	-1.06
p-value	0.000	0.005	0.407	0.406	0.000	0.155	0.135	0.302
25,28								
Significant at α 0.1	***	N.S.	**	N.S.	**	N.S.	N.S.	N.S.
No. of cases	22	15	19	21	12	10	21	22
Difference	-0.49	0.01	0.03	0.02	-0.21	0.01	0.10	-0.02
Std. Dev.	0.37	0.28	0.04	0.06	0.20	0.02	0.56	0.48
t-statistic	-6.15	0.18	3.39	1.45	-3.78	1.50	0.86	-0.15
p-value	0.000	0.857	0.003	0.162	0.003	0.168	0.401	0.882

N.S. Not significant

* Significant

** Very significant

*** Very highly significant