THESIS

PHYSICAL-CHEMICAL AND RADIATION PROPERTIES OF MOUNTAIN STREAMS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STUART RICHARDSON ENTITLED PHYSICAL-CHEMICAL AND RADIATION PROPERTIES OF MOUNTAIN STREAMS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT

PHYSICAL-CHEMICAL AND RADIATION PROPERTIES OF MOUNTAIN STREAMS

Studies of bacterial fluctuation in mountain streams indicate pronounced seasonal and diurnal variations. This study attempt to determine seasonal and diurnal variation in (1) physical and chemical stream properties, and (2) solar radiation attenuation within the stream. Physical-chemical parameters measured included ammonium nitrogen, nitrate, nitrite, ortho-phosphate, meta phosphate, total dissolved solids, specific conductance, pH, dissolved oxygen, turbidity and temperature.

Study sites were two natural high altitude streams in the Colorado Rocky Mountains. Sampling stations were located above and below two grazed areas which were known sources of bacterial contamination. Sampling and testing techniques were conducted using standard physical-chemical and radiational testing procedures. The above parameters were then compared to the previous biological samplings and findings of Kunkle and Meiman (1967, 1968) investigating the same stream sections.

Results and conclusions are:

1. The small concentrations of physical-chemical parameters together with the accuracy and precision of the testing procedures would not allow a rigorous statistical analysis.
2. No daily or seasonal correlation was observed between the physical-chemical parameters measured and the findings of Kunkle and Meiman (1967, 1968).
3. The extinction of radiation within the stream followed the radiation decay law $I = Ioe^{-bx}$. The beta coefficients, b, are determined by the equation $b = -.31988 + .0952352 \frac{1}{x}, + .28591\ x,$ (x = wavelength, x_1 = depth cm).
4. The intensity of ultraviolet energy in the sample streams was sufficient to cause a diurnal cycling pattern in bacteria concentration.
5. Variations in the measured physical-chemical parameters were not sufficient to account for the increase in bacterial concentrations below a grazed irrigated area. This suggests that bacteria were directly introduced into the stream, rather than increasing due to a more favorable nutrient environment.

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CHAPTER I

INTRODUCTION

Introduction

This investigation is a continuation of a series of water quality studies. These studies are made to determine the factors controlling the growth patterns of aquatic microorganisms and the manner in which grazing affects the bacterial pollution of high mountain streams. Prior to this investigation, biological studies of coliforms, fecal coliforms and fecal streptococci by Kunkle and Meiman (1967, 1968) and Morrison and Fair (1966) statistically established a seasonal and diurnal cycling of bacterial populations, and increased biological pollution below a grazed area.

Accepting their findings this study divorced itself from monitoring the biological parameters and concentrated on sampling the physical-chemical and radiational parameters. In this manner the findings of this investigation could then be implied or correlated with the biological fluctuations determined in these earlier investigations.

Objectives

The objectives of the study are to determine:

1. Whether the low bacteria concentration during the day and high concentrations at night are correlated with physical-chemical parameters, and/or the radiational components.
2. Whether the grazing increased the downstream bacterial pollution by adding bacteria to the stream, and/or adding nutrients to increase the natural population of the stream.
3. The relation between seasonal trends of physical-chemical parameters and the seasonal changes in bacterial concentrations.
4. The amount of energy in selected wavelengths reaching the aquatic organisms.
5. The amount of radiation reflected from the stream's surface and bottom.

CHAPTER II

RESEARCH OF LITERATURE

The dynamics of bacterial growth are one of the most variable growth patterns found in nature. This phenomena occurs due to the rapid growth and death rates of the microorganisms responding to environmental influences. Many investigators have made studies of bacterial growth in laboratory environments, but no studies were found relating the major factors controlling natural stream bacterial dynamics. The studies to date have primarily monitored bacterial populations and then attempted to correlate population dynamics with natural influences after the conclusion of the investigation.

There are many factors affecting the dynamics of natural bacterial populations, however these can be classified into two major categories: physical-chemical and radiational influences. Physical-chemical parameters in the aquasphere consist of temperature, pH, chemical constituents, turbidity and total dissolved solids. Measurement of these factors is standardized and precise results are obtainable. The cycling of some of these factors and their consequent effects on bacteria have been investigated by a number of researchers

(Morrison and Fair, 1966; Kunkle and Meiman, 1967, 1968; Teller, 1965).

The second major influence is the radiation component. This area has received very little study in the natural environment even though the germicidal action of ultraviolet radiation has been recognized since 1877, (Koller, 1965). To understand the complex role of ultraviolet radiation in stream dynamics, the following factors must be recognized:

1. Solar emittance
2. Atmospheric attenuation
3. Aquatic attenuation
4. Germicidal effects

The above factors must all be known and analyzed in continuum to realize their full effects.

Solar Emittance

Radiation from the sun originates from nuclear reactions, H → He, within the gaseous interior of the sun, (Koller, 1965). Energy is radiated from this gaseous core and is modified by the photosphere and atmospheric gases surrounding the sun, (Valley, 1965).

The photosphere, the apparent solar surface, radiates a continuous spectrum near 6000° K. Radiation from this layer is then modified as it passes through the three layers of the solar atmosphere. Innermost is the reversing layer, which selectively absorbs the continuous radiation by Fraunhofer absorption of selective atoms. It has been estimated that 30% of the ultraviolet radiated by the photosphere is absorbed in this layer, (Hollaender, 1956; Valley, 1965).

The outer two layers, the chromosphere and corona, show very little absorption or transmission losses in the ultraviolet and visible bands. Solar energy reaching the top of the earth's atmosphere is not constant, but varies slightly with earth's rotation around the sun and with the solar activity. The variation of energy due to orbital characteristics changes from -3.27% during the aphelion, December 22 and June 21 to 3.42% at the perihelion, March 21 and September 23, (Valley, 1965; Reifsnyder and Lull, 1965). Energy radiated from the sun also varies with an eleven year cycling of solar activity. This activity has been correlated to biological dynamics of cod, mackerel, and several animal species, (Koller, 1965).

Solar intensity reaching the top of the earth's atmosphere is 2.002 g.cal./cm^2 per minute (.1390 watts per cm^2, or 1390 watts per meter^2). The distribution of solar energy in the ultraviolet region is approximately 8.1% of the total energy, (Valley, 1965; Johnson, 1954). This may seem small, but if this amount could reach the earth's surface it would be lethal to all life forms.

Atmospheric Modification and Attenuation

Solar ultraviolet radiation reaching the earth's surface is a function of:

1. Time of day
2. Time of year
3. Latitude
4. Elevation above sea level
5. Atmospheric turbidity
6. Thickness of the ozone layer, (Koller, 1965).

Modification of intensity and spectral quality of the solar spectrum as it passes through the earth's atmosphere is governed by the exponential decay law:

$$I = Io\ e^{-(a\chi + b^{Y})\ \delta \text{ secant } z}$$

where

Io = Energy flux of one band at the top of the atmosphere

I = Energy flux of one band at the earth's surface, (Figure 1).

a = Absorption coefficient of one band per centimeter of ozone, (Figure 1).

χ = Thickness of ozone in centimeters at STP, (Figure 2).

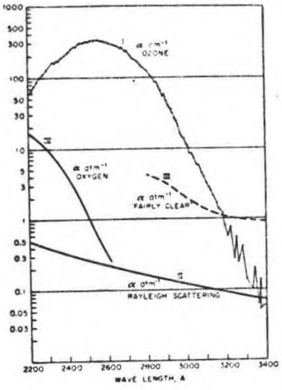
b = Absorption coefficient per kilometer of atmosphere below the ozone layer, (Figure 3).

y = Kilometers of atmosphere below the ozone layer

z = Zenith angle of the sun, (Hollaender, 1956).

The intensity of ultraviolet radiation is primarily absorbed in photochemical reactions with ozone. Absorption of wavelength smaller than .24 μ occurs by the following reaction (Graig, 1950).

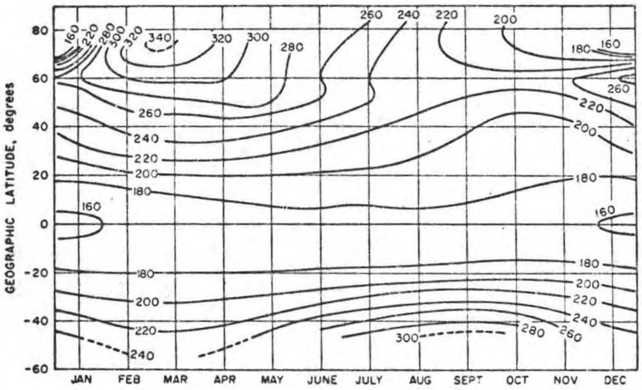
Figure 1



From Hollaender (1956)

Ozone Absorption Coefficients
of Ultraviolet Radiation

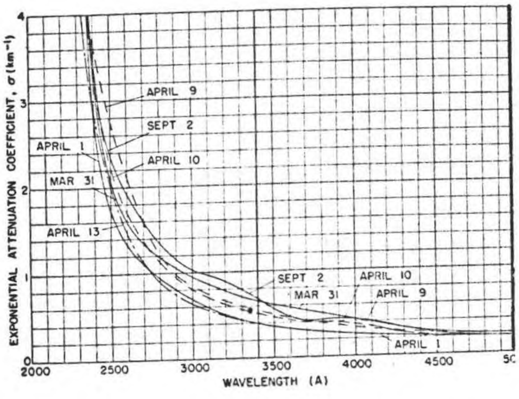
Figure 2



From Hollaender (1956)

Depth of Ozone in the Atmosphere

Figure 3



From Baum and Dunkleman (1955)

Atmospheric Attenuation of
Ultraviolet Radiation

$$h\lambda + O_2 + O + m \rightarrow O_3 + m$$

in which $h\lambda$ = photon energy of solar radiation at $\lambda < .24\ \mu$, and m = third atom or molecule. Three body collisions are necessary for the conservation of energy and momentum (Graig, 1956; Green, 1966). Once the ozone has been created it then becomes a critical absorbing agent for longer wavelengths, .22 μ - .31 μ, in the Hartley continuum. Wavelengths .31 μ - .34 μ are also selectively absorbed in the Huggins band by ozone in a complex temperature controlled reaction. Wavelengths greater than .34 μ into the visible region undergo Rayleigh scattering which linearly decreases the solar intensity (Hollaender, 1956; Stair, 1952a,b). After passing through the variable ozone layer concentrated between altitudes of 15 and 40 km the radiation must then undergo selective attenuation in the variable lower atmosphere (Koller, 1965; Green, 1966).

The attenuation coefficients greatly decrease incoming radiation in the lower three kilometers due to dust, smoke, pollution and atmospheric moisture concentrations (Stair, 1952; Sitnikova, 1965; Baum and Dunkleman, 1949). Investigations (Figure 3) by Baum and Dunkleman (1949), illustrate the selective manner in which the lower atmosphere absorbs and alters the spectral quality of the ultraviolet and visible radiation having passed through the higher ozone layer. At higher elevations the increases in ultraviolet radiation may increase to 100% above those of lower elevations or metropolitan areas due to the absorption in the bottom of the atmosphere (Stair, 1952; Sitnikova, 1965).

The depths of atmosphere, ozone layer and lower layer through which the radiation passes affects the spectral intensity and quality of the radiation reaching the earth's surface. Path lengths subtended by the incoming radiation are variable according to the daily hour and date. These variations greatly affect the energy fluxes reaching the ground (Hollaender, 1956; Bener, 1962; Koller, 1966).

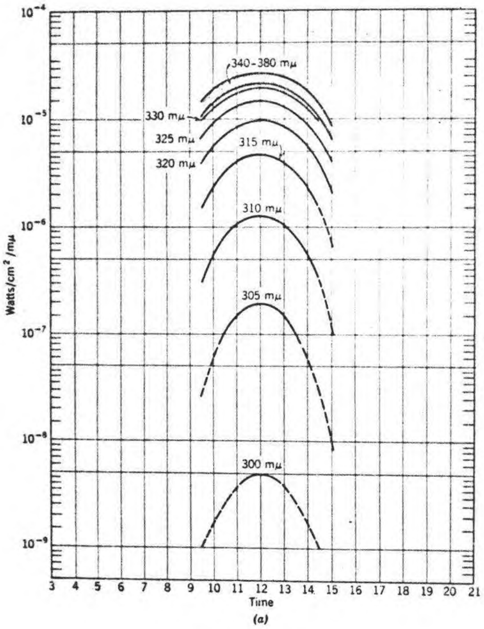
Investigations made in Russia reveal 90% of the annual ultraviolet flux occurs in the spring and summer, 8% in the fall and 2% in the winter (Amirkanova, 1961). Changes in the solar angle not only change the intensity, but also the spectral quality by absorbing more of the shorter wavelengths as the path length increases. Bener's investigations (Figure 4) clearly show the effect of daily and seasonal changes in the intensity and spectral quality of radiation incident upon the earth's surface.

Aquatic Attenuation

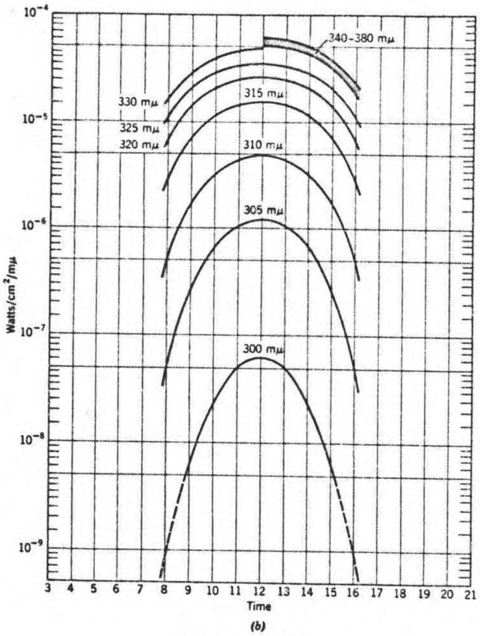
The spectral intensity of radiation reaching a point underwater is a function of:

1. The amount and spectral quality of the incident radiation
2. The amount of reflected radiation at the surface
3. The amount absorbed and scattered between the surface and the point

Figure 4

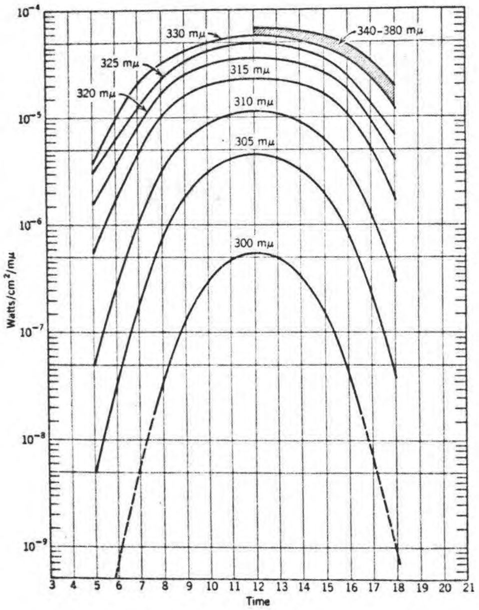


December

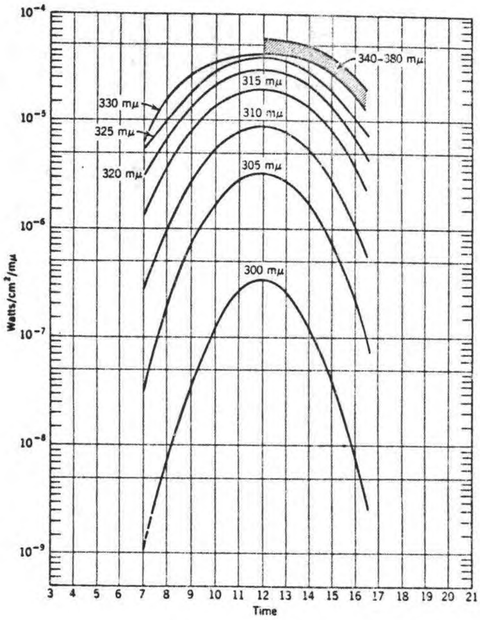


March

Seasonal and Daily Changes
of Ultraviolet Intensity



June



September

From Bener (1962)

4. Amount reflected from greater depths and off the bottom (Davis, 1941).

Davis (1941) shows that the reflected and backscattered radiation are dependent on the angle of incident radiation, nature of the media for backscatter and surface roughness. Backscatter and reflected losses at the surface comprise approximately four per cent at zenith angles of 0 - 40 degrees and increases to 17 per cent at a zenith angle of 75%. Backscatter comprises three per cent of this energy loss at maximum; therefore the primary loss of incident radiation at the air-water interface is due to the reflection component (Davis, 1941).

After light penetrates the surface it interacts with the media and is transformed into non-radiant energy, and ultimately heat. The selective influence of the water medium is due to the differences in absorption coefficients for the various wavelengths and secondly the lengthening of the path lengths due to scattering (Westlake, 1965). Extinction of radiation is then defined as the diminution of radiant energy. The radiation reaching a point underwater can be explained by the logarithmic extinction law of Bouger and Beer:

$$Ix = Io\ e^{-b\chi}$$

where

Io = The incident energy from a given waveband minus the reflected and backscattered components.

Ix = The amount of energy received in this waveband χ distance below the surface.

b = Attenuation (reduction) coefficient for the given waveband per increment of depth.

χ = Depth, any distance increments, (Ruttner, 1953).

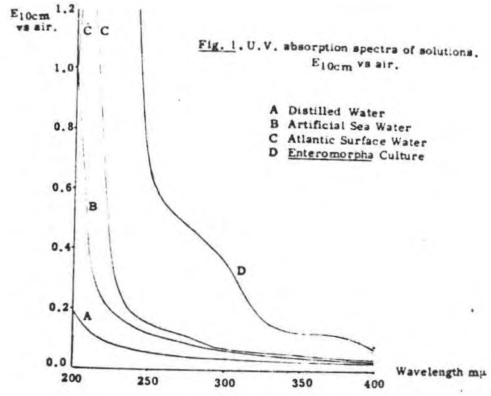
Differences in attenuation coefficients for different wavebands modify the atmospheric radiation pattern reaching a submerged point (Westlake, 1965; Birge, 1938; Ruttner, 1953). These differences are due to water molecules, suspended material and organic matter (Armstrong, 1961). Ultraviolet radiation reaching a given depth is very critical dependent on the concentrations of water suspensoids (Figure 5). This is due to the strong absorption by nitrates, organic matter, bromides and molecular water (Okura, 1964). These factors lead to the intensity of light at the lower depths being very monochromatic in the Green region (Westlake, 1965; Bainbridge, 1966).

Germicidal Action of Ultraviolet Radiation

After the radiation is passed through the atmosphere and water column, its effect on the aquatic bacteria within the water column and bottom sediment must be determined. In order to determine the bactericidal effects of the ultraviolet radiation a complex integration of the following factors must be made:

1. Intrinsic and extrinsic susceptibility of the bacteria.

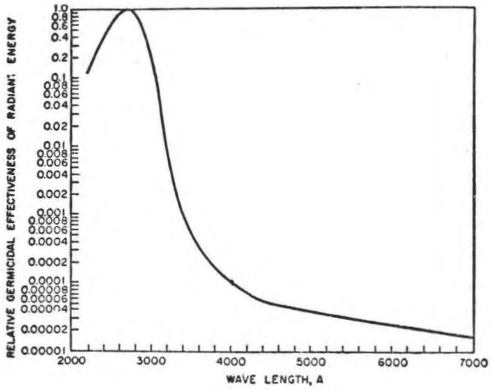
Figure 5



From Armstrong and Boulch (1961)

Changes in the Aquatic Attenuation of Ultraviolet Radiation

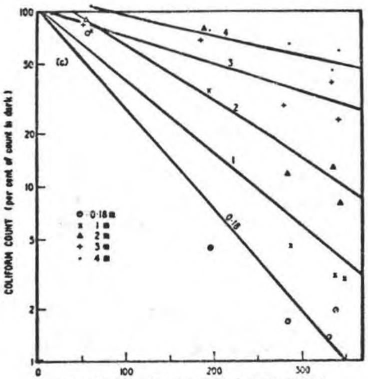
Figure 6



From Hollaender (1956)

Germicidal Effectiveness of Ultraviolet Radiation

Figure 7



From Gameson and Saxon (1967)

Die-off of Aquatic Bacteria by Solar Radiation

2. Germicidal effectiveness of the wavelength.
3. Exposure rate (intensity-time).

Intrinsic susceptibility or sensitivity between different kinds of bacteria varies with a magnitude from 1-3 (Koller, 1965). Spore forming bacteria require 5-10 times the exposure rate for bacteria, whereas fungi only require 1/10-1/100 for a comparable kill-off ratios (Hollaender, 1956). The extrinsic susceptibility is determined by age and varies with a range of 1-3 normal exposure rates. The second extrinsic factor is the climate of the organism. In a humid climate it takes four times the exposure for comparable die-off of dry <u>Escherichia</u> <u>coli</u>. <u>E</u>. <u>coli</u> living in distilled water require 8-10 times the exposure of the dry bacteria even after the absorption of the medium is taken into consideration (Hollaender, 1956). Luckeish and Holliday have determined that it requires 150-200 $\mu w/cm^2$ -minutes for a 99% kill of bacteria. During their irradiation experiments they found that temperatures ranging from 5-37°C had very little effect on the die-off rate (Luckeish and Holliday, 1944).

The relative germicidal action of a given wavelength is not constant but varies from an optimum of one at .26 μ and decreasing its effectiveness with longer wavelengths, (Figure 6) (Hollaender, 1956). The energy dose to kill 50% of an <u>E</u>. <u>coli</u> population then increases from 1 at .26 μ to 25 at .30 μ and 250 at .31 μ. For all practical purposes the germicidal action stops at .36 μ and wavelengths longer than this may even induce photoreactivation of bacteria (Buchbinder, 1941; Kelner, 1948).

Ultraviolet radiation may not kill the organism but render it inactive or unable to reproduce and therefore recoverable in some cases. Mechanisms of inactivation are not very clearly understood, and recent thinking indicates that radiation prevents normal multiplication. Therefore, normal die-off occurs before multiplication.

Recent studies made by Gameson (1967), Kunkle and Meiman (1968) both noted the diurnal cycling of bacterial populations. As a result of these observations Gameson (1967) submerged a series of two bottles of equal bacterial concentrations to depths of .18m, 1, 2, 3, 4. From his results, Figure 7, he concluded that:

1. The logarithm of the coliform count decreased regularly with increases in solar radiation.
2. There is no difference in the mortality rate of various species of coliform bacteria.
3. With advancing season and increased depth more surface energy was required to produce 90% die-off.

The results from Kunkle and Meiman's (1968) study using exposed and shaded containers confirm the trend of rapid die-off in the exposed containers.

CHAPTER III

RESEARCH AREA

Study Area

The study area is located on the eastern slope of the Colorado Rocky Mountains. The two streams sampled are the headwaters of the Little South Fork of the Cache La Poudre River and a tributary to this stream, Pennock Creek (Figure 8). The climate is typical of a mountainous region with 50% of the average precipitation of 20 inches being deposited in the form of snow (Meyers, 1968). Melting of this snowpack results in a "flushing action" that results in 40-60% of the annual runoff occurring between May and Mid-July (Johnson, 1962; Kunkle and Meiman, 1968).

The Pennock Creek watershed ranges in altitude from 8,200 feet to 12,148 feet (Figure 8). Grazing within this area is confined to the lower portion of the watershed. The upper 33% of the watershed is managed as a wild area by the Rocky Mountain National Park Service. The middle third is controlled in the same manner by the Roosevelt National Forest. The lowest third has cattle grazed on it by the Lazy D Ranch. Throughout the entire summer to late September approximately 100 cattle were grazed in the lower third of the watershed. Pennock Creek which traverses this grazed

Little South Fork Cache La Poudre River Watershed

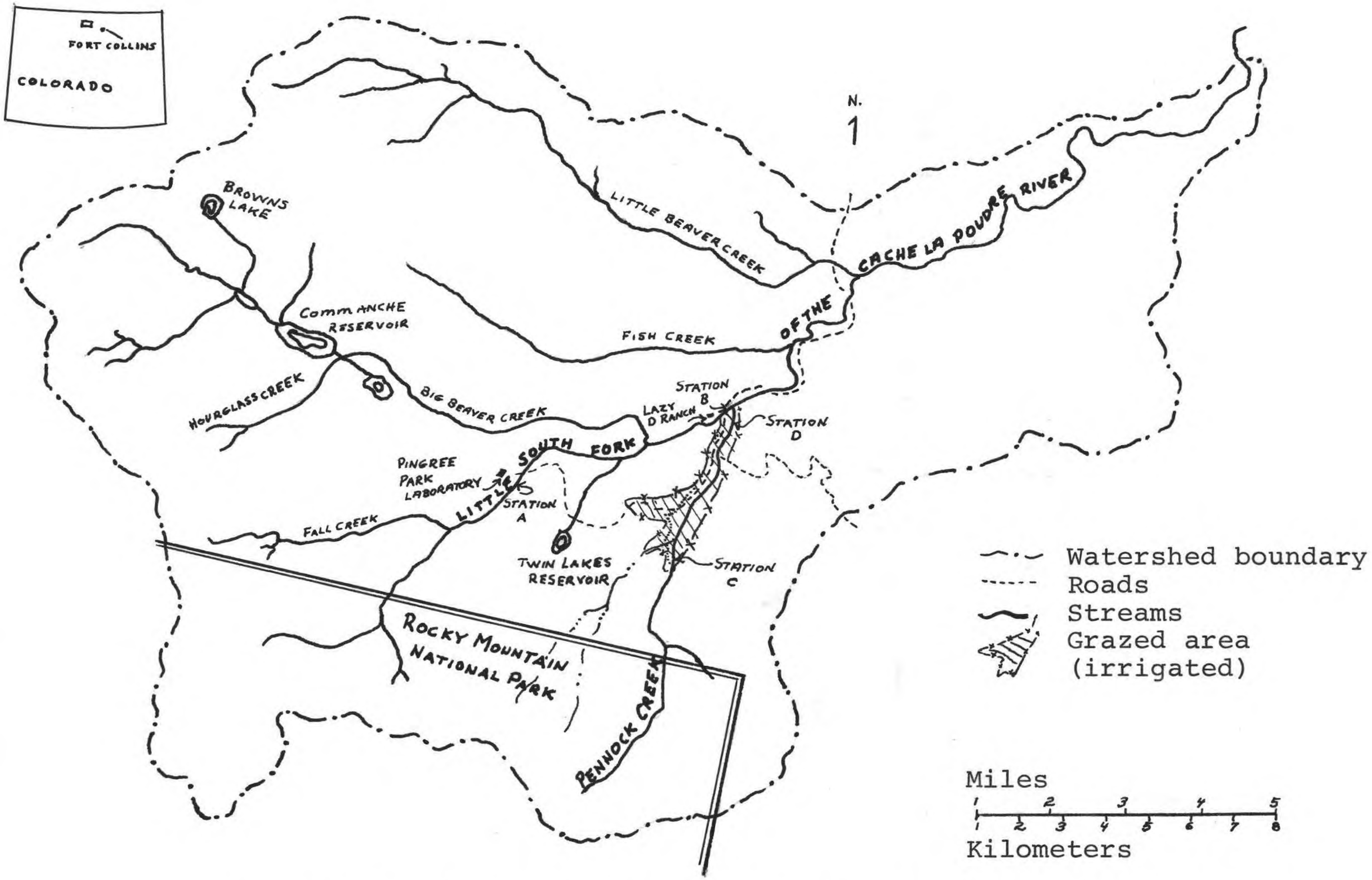


Figure 8. Study Area Showing Sampling Stations

area is polluted with coliform bacteria (Kunkle and Meiman, 1967 and 1968).

The second area is the headwater region of the Little South Fork above the confluence of the Little South and Pennock Creek (Figure 8). This area is almost completely controlled by the Roosevelt National Forest with minor holdings by the Rocky Mountain National Park Service and private ownership. Grazing within this area is light with about six horses pastured for the entire summer and 4,400 sheep grazed in the alpine area of the Little South Watershed from August to late September.

Within both watersheds there are several other potential pollution sites. These include:

1. Colorado State University Summer Camp facilities housing approximately 180 students and faculty during June and July (Figure 8).
2. Tom Bennett Campground providing facilities for a variable number of users.
3. Sky Ranch Summer Camp with approximately 60 campers and counselors from June through early September.
4. Several ranch houses and private homes.
5. One mile of gravel road traversing along Pennock Creek.
6. Regulation and release of water from the Twin Lakes, Commanche and Hourglass Reservoir.

Sampling Sites

The sampling sites were chosen to monitor the physical changes occurring in a stream as it passes through a settled or grazed area where biological pollution is being added. The upper sites were chosen for accessibility and the lack of contamination in the headwater reaches. Sampling Station A, the Pingree Park sampling station (Figure 8) did not meet these requirements due to habitation above the sampling point.

The second headwater station Sampling Station C is located above the diversion of the Lazy D irrigation system on Pennock Creek. The stream above this point was unaffected by grazing or habitation.

Sampling Station B (Figure 8) is located downstream from Station A on the Little South. This sampling point is located on the abutment of the bridge crossing the Little South at the Lazy D Ranch. The second lower station, Sampling Station D, was located 500 feet upstream on the Pennock Creek from its confluence with the Little South.

The area between Stations C and D, on the Pennock Creek is very unique from a pollution standpoint. Between these two stations the stream passes entirely within a heavily grazed pasture containing approximately 100 cattle. The pasture is surface irrigated via a diversion below Sampling Station C. Water from this small diversion channel is released along its course and flows in a laminar layer downslope over the pasture, and into the Pennock Creek. The return water then becomes a major source of biological pollution (Kunkle and Meiman, 1967 and 1968). The proportion of water diverted from the stream is small during snowmelt runoff but as the discharge decreases the proportion diverted increases. In mid-July more water is diverted and used for irrigation than is allowed to flow naturally through the channel.

Two continuously recording 31 day Foxboro air-water thermographs were installed in Pennock Creek to monitor the change in water temperature going downstream and the diurnal temperature cycling. The upper temperature station was located 300 feet upstream from Sampling Point C. The second Foxboro was located at Sampling Station D.

CHAPTER IV

RESEARCH METHOD AND TECHNIQUES

Sampling Schedule

Data was collected during the summer and fall of 1968. Samples were taken to show the changes in the reach, diurnal cycling and monthly changes. During the first day of sampling (Table 1), samples were taken at four sampling times. Due to time limitation, equipment, and results these were then decreased to three samples per day and to two per day in late fall.

Sampling schedules were based on the temperature fluctuation of the water. It was hypothesized that pH, dissolved oxygen, specific conductivity, total dissolved solids, turbidity and the chemical parameters would change with the diurnal and seasonal changes in water temperature. This is an important assumption in the study because from the statement of the problem we assume that the bacterial populations do cycle on a temperature related diurnal basis. Therefore any concurrent cycling of physical and chemical parameters would manifest themselves with some temperature relationship in a positive or negative manner. From the thermograph records, the minimum, maximum and mean temperatures were determined, and the sampling schedule was set to coincide

Table 1

Sampling Schedule

Month	July			August		September		October	
Date	7/23	7/24	7/25	8/15	8/16	9/10	9/11	10/17	10/18
Hour of Sampling	8 AM	8 AM	6 AM	8 AM	7 AM	7 AM	7 AM		7 AM
	12 AM		1 PM			12 AM	12 PM	12 AM	12 AM
	4 PM			3 PM	4 PM	4 PM	4 PM	4 PM	
	8 PM	8 PM	8 PM	8 PM	8 PM				
Number of Samples Collected	16	8	12	12	12	12	12	8	8

with these time periods. Later in the season day length changed the timing, however samples collected were still within ±1°C of the minimum and maximum temperature.

Sampling Procedures and Techniques

The sampling of all four stations required one and a half hours. Stations were always sampled in the same order, A., C., D. and B. The temperature change during the sampling run never exceeded 0.5°C, thus giving essentially simultaneous sampling in relation to the experimental design. Once at the individual station the following tests were made on site:

1. Temperature was recorded with a Yellow Springs Thermistor. (accuracy ±0.5°C)
2. A dissolved oxygen sample was taken and Hach reagents were added to fix it for later laboratory determinations.
3. Determination of the specific conductance was made with a Beckman conductance meter.
4. A water sample was collected in a plastic bottle for later laboratory determination of pH, turbidity, total dissolved solids and chemical constituents.

Laboratory Procedures and Techniques

The samples were transported immediately back to the laboratory at Pingree Park (Station A). This was done as to not allow the temperature of the samples to rise and change the chemical concentrations.

In the laboratory, the testing sequence of all four samples proceeded simultaneously in the following order and manner:

1. PH. determinations were made with a Beckman Model N pH Meter. Calibration proceeded each series of four measurements and immediately afterward. If the deviation was greater than .05 units the series (four samples) was rerun. (accuracy ±.05 pH units)
2. Turbidity measurements were determined with a Hellige Turdimeter. Three readings were taken on each sample and the average used. If the range was greater than two adjustment units, more readings were used until three concurrent readings had a range less than two. The average of these three measurements was then used.
3. Total dissolved solids were determined gravimetrically for each sample by weighing the residue of 100 ml water sample on an analytical balance to the nearest 0.1 mg. The samples were evaporated in a Napco forced hot air oven kept at 85°C.
4. The labeled samples were then placed in a refrigerator, maintained at 4.5°C, for later chemical analysis. This procedure was followed because the chemical analysis required more time than the sampling schedule allowed. After the series of sample

days had been completed all of the samples were removed and allowed to reach ambiant room temperature for the necessary chemical tests.

5. Dissolved oxygen determinations were made with the Hach modified Winkler method established in *Standard Methods for the Examination of Water and Wastewater*, 1960, eleventh edition. Accuracy of this method is ±0.1 ppm dissolved oxygen.

Laboratory Chemical Analysis

All chemical analyses were made in accordance with the procedures published in *Hach Procedures for Water and Sewage analysis using the B & L Spectromic 20 Colorimeter* and the commercial reagents were supplied for these determinations by the Hach Chemical Company. The chemical parameters tested were: ammonium nitrogen, nitrate, nitrite, ortho phosphate, meta phosphate and poly phosphate. The precision of these analyses were:

1. ammonium nitrogen ±0.2 ppm
2. nitrate ±0.01 ppm
3. nitrite ±0.3 - 0.5 ppm
4. ortho phosphate ±0.5 ppm
5. poly phosphate ±0.5 ppm
6. meta phosphate ±0.5 ppm

A Baush and Lomb Spectromic 20 Colorimeter was used in spectographic determination of chemical concentrations.

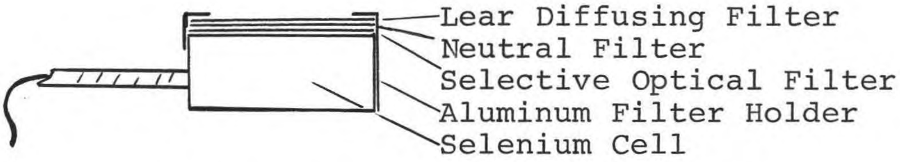
Radiation Investigation

The second major portion of the investigation was the measurement of ultraviolet light intensities reaching the aquatic microorganisms. Measurements of the underwater radiation were made with a selenium photocell. The selenium photocell is a standard limnological tool developed by F. Sauberer and a close associate, Miss Inge Dirmhirn. The particular cell used in this investigation was fabricated under the directions of Miss Dirmhirn at the Colorado State University's Department of Atmospheric Sciences Workshop. Spectral analysis of under water radiation was made with glass filters with selective transmittance ranges. Recording the millivolt output a self-contained Cole Parmer Mark VII chart was used.

Selenium Cell

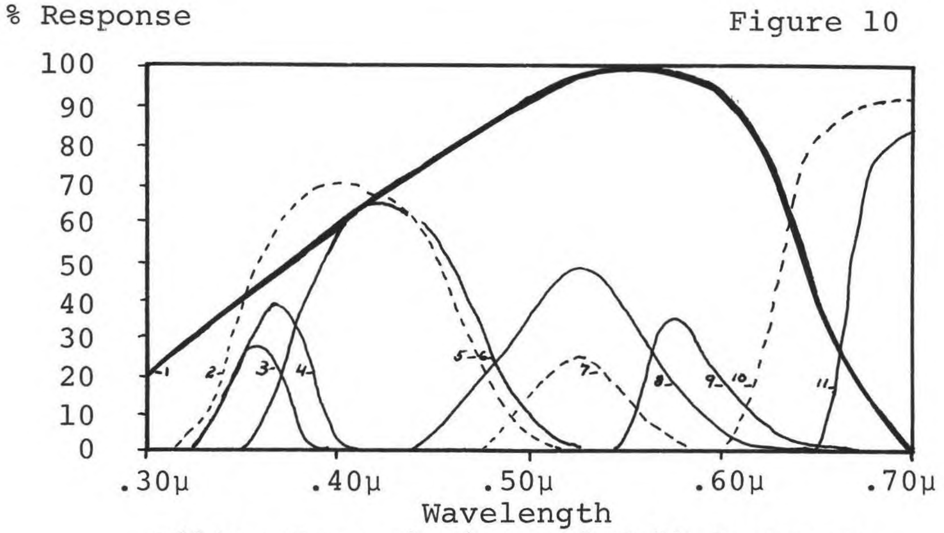
The selenium cell (Figure 9) was designed especially for the commercial Schott Filters used in the spectral investigation. The spectral response of the cell (Figure 10) shows its efficiency over the wavelengths used in this investigation. Output from the cell alone without the dark neutral filter or a selective filter was approximately 1.5 volts under normal room flourescent lighting. Thus to adapt the cell to the Cole Parmer recorder with a maximum range of 200 millivolts an in-line variable resistor was used. This was installed across the output terminals of the cell to make recording possible. The major difficulty encountered

Figure 9



Selenium Cell and Filter Placement

Figure 10



Filter Transmission and Cell Response

1 Selenium Cell
2 Schott Blue
3 Corning Ultraviolet
4 Schott Ultraviolet
5 Schott Blue
6 Corning Blue
7 Corning Green
8 Schott Green
9 Schott Yellow
10 Schott Light Red
11 Schott Dark Red

with the use of the variable resistor was that absolute measurements of output voltage of the cell could not be determined, therefore causing the use of relative units.

When in operation, the cell was first covered with the selective filter, and then a dark neutral filter and finally clear diffusing plastic filter. The dark neutral filter was used to cut down the intensity of the radiation incident upon the cell. This was necessary to protect the cell from large radiation fluxes. The diffusing filter was necessary to negate the influence of the angle of incidence upon the neutral filter and selective filters. Covered in this manner the reflection from the filter surfaces was illuminated due to the completely diffused light passing through the various filters (Figure 9). When the Corning filters were used they were laid on the top of the selenium cell covered with the diffusing filter and held in place with a plastic holder. Operating the cell with this filter combination didn't allow for albedo or reflectance measurements.

Filter Specifications

The filters used for the investigation were commercial Schott filters manufactured in Germany. During the earlier portion of the experiment Corning filters were used until the Schott filters arrived.

Optical transmissions of the Schott filters (Figures 10 and 11; Appendix A) were determined on Colorado State University's Department of Chemistry's Bausch and Lomb

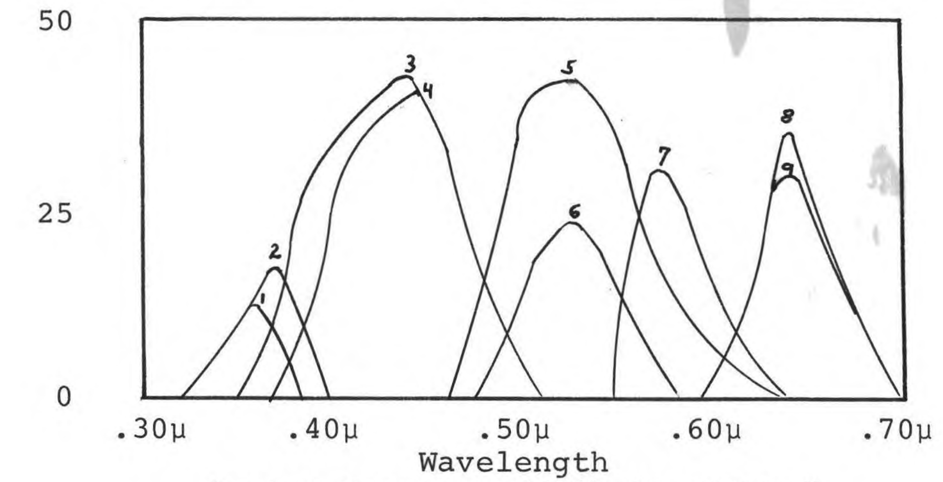
Spectronic 600 coupled with a Sargeant Model SRL-6 Strip recorder. Transmission characteristics of the Corning filters were obtained from the manufacturers catalog. The curves show the wide range of wavelengths used in the experiment. The primary filter used for the determination of the germicidal wavelengths is the ultraviolet and blue combination. The other combinations were used to check the spectral quality of the water and to compare it with laboratory and field tests already made by other investigators.

Radiation Sampling Techniques and Procedures

All under water radiation studies were performed immediately above sampling station A at Pingree Park. The study site was a calm, clear pool below a small dam on the Little South Fork of the Cache La Poudre River. This area afforded testing from 7:00 A.M.-6:00 P.M. in mid-August and shorter time intervals later on due to shading.

The apparatus (Figure 12) used for taking under water measurements consisted of a pipe driven into the bottom and a side arm which could be pivoted around the pipe and moved vertically up and down. The arm was connected to a T junction made of pipe with a slightly larger inside diameter than the outside diameter of the main supporting pipe thus affording vertical and pivoted movement. A clamp was secured on the other end of the arm to secure the radiometer and a calibrated stick to show the depth of the radiometer. The apparatus allowed the operator to move the radiometer up and

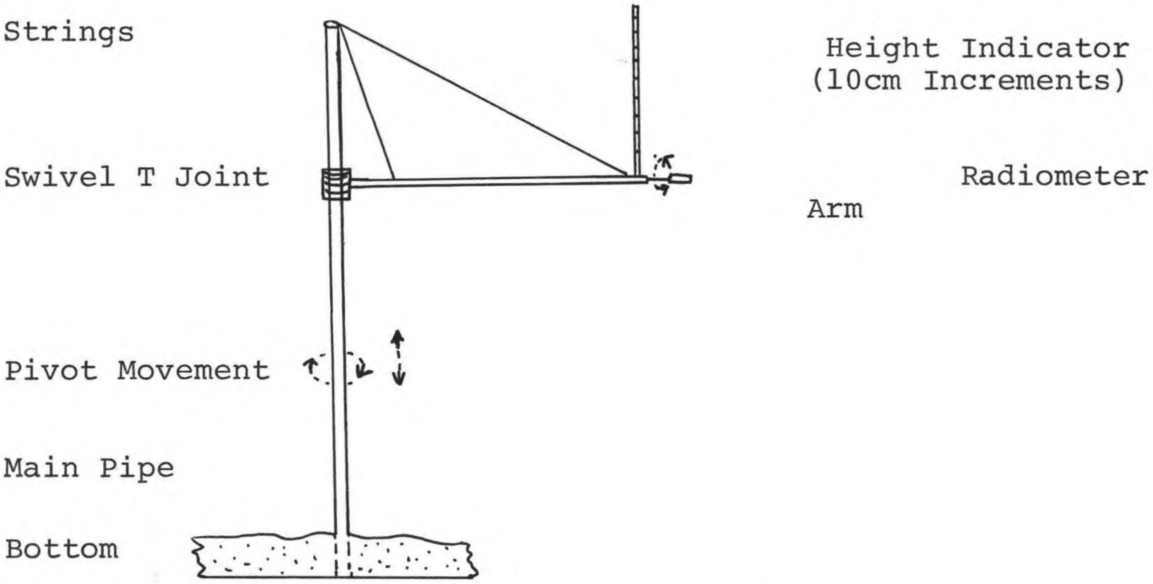
Figure 11



System Response (Cell Response X Filter Transmission)

1 Corning Ultraviolet
2 Schott Ultraviolet
3 Corning Blue
4 Schott Blue
5 Corning Green
6 Schott Green
7 Schott Yellow
8 Corning Red
9 Schott Red

Figure 12



Underwater sensing apparatus

down and pivot it around to change the filter configuration. Once the required position was achieved with the strings, the overhanging weight on the T junction would hold the radiometer in this one position. Thus the operator could use both hands for changing filters and recording data. Another advantage was that this apparatus allowed sampling at the same exact depth and position time after time.

The entire system when placed in a stream consisted of:

1. Apparatus and support for the radiometer (Figure 12).
2. Stand for the Cole Parmer recorder and a work bench for drying the filters and string the clipboard to record the measurements.
3. A metal crate to stand on so as not to disturb the bottom sediment during the run.

The procedure for measuring the downward spectral transmission consisted the following steps:

1. The selected filters were placed on the radiometer and secured in place with an aluminum holder (Figure 9).
2. Pivot the radiometer arm around to the opposite side of the main pipe to prevent operator shadowing or interference.
3. Adjust the variable resistor and span of the Cole Parmer until the intensity of the signal

is adjusted to 100, i.e. full scale of millivolt recorder.

4. Lower the radiometer until 5 cm is indicated on the height indicator stick and record the measured signal.
5. Lower the radiometer to 10 cm depth and record and repeat for 10 cm intervals until 80 cm depth is reached.
6. Bring the head up above the surface again and if the reading is less than 98 or off the scale recalibrate to 100 and repeat the run.
7. If the reading was 100 and albedo measurements are to be made rotate the head 180° so that it is now sensing the surface of the water and record the results as a ratio x/100.
8. Adjust the scale back to 100 relative units with the head still in the inverted position and lower the same increments as before.

The major problem encountered during the study was the variability of cloud cover. During late August and early September there were only several days which were cloud free for the entire day. Due to the use of the variable resistor and thus relative units a standard was established by using only cloud free incident radiation.

The second problem encountered was the variability of surface conditions of the pool. On a day with moderate mountain winds ripples would form, characteristic of a mountain stream, and cause the measurements to vary five units around the mean. To establish the mean of the varying signal would require a thirty-second interval at the one depth and six minutes for the entire run. While this was being done a cloud could obscure the sun and the entire run would have to be repeated, after the cloud had passed. Only runs in which the sun did not vary the intensity at the surface from 98 to off the scale, for the entire run interval, were considered in the analysis of spectral characteristics.

CHAPTER V

RESULTS AND DISCUSSION

The primary experimental design divided the investigation into two separate parts: 1) the physical-chemical parameters, and 2) the radiational components. The results and discussions will be presented separately for greater clarity.

1. Physical-Chemical Parameters

Due to the extremely low concentrations and variation of the physical-chemical parameters, a rigorous mathematical and statistical analysis was not possible. An additional factor was the precision and accuracy of the testing procedures together with the small to nonexistant cycling of the particular physical-chemical parameters recorded. Data were analyzed for: 1) monthly variations or trends and the way these correlated with seasonal bacterial fluctuations, 2) diurnal fluctuations of the parameters and how these varied in relation to the bacterial fluctuations, and 3) the mechanics of stream pollution, i.e. were bacteria injected into the stream from a source or was a more suitable environment created for their growth by the water passing through a grazed area.

The monthly means of all data collected were used to analyze for monthly trends. Monthly means were calculated for each station by averaging all of the data collected in one month at that station regardless of the daily time interval when the sample was collected. The analysis of this data is given in the upper figure of the following plate pages.

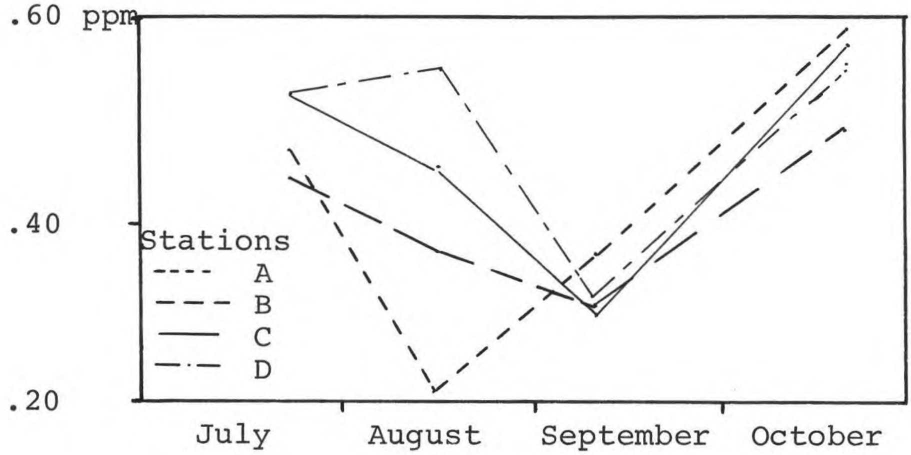
Diurnal variation was determined by using the means of data gathered at that particular station during the morning, afternoon and evening intervals. The intervals consisted of: 1) morning, 7:00 A.M. - 11: A.M., 2) afternoon, 12:00 A.M. - 3:00 P.M., and 3) evening, 4:00 P.M. - 8:00 P.M. The daily variation of the physical-chemical parameters are given in the lower figure of the following plate pages.

Ammonium Nitrogen

Figure 13 shows the variation in station monthly means. Although the variation was not large a low concentration occurred during September with an increase in October. The probable reasons for this trend are the low water stages in October coupled with the bacterial decomposition of organic matter.

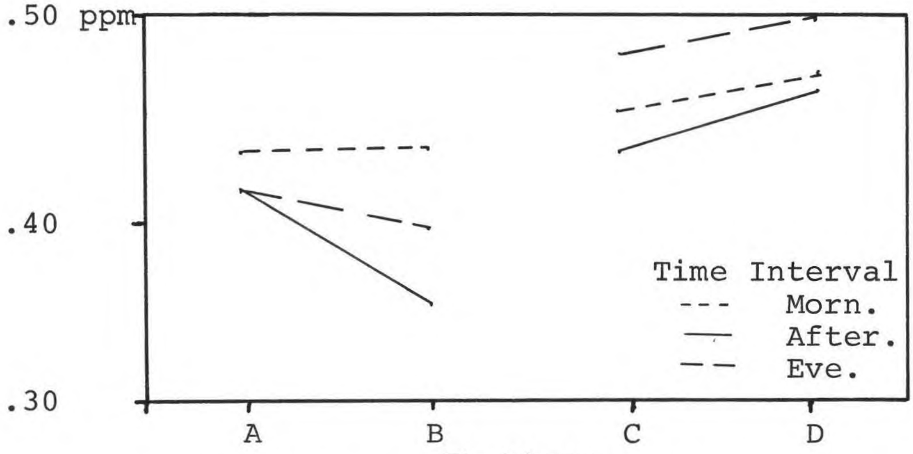
The plot of daily variation (Figure 14) indicates that there are no consistant changes in ammonium nitrogen occurring on a daily basis. The trends shown by stations C and D were consistant but statistically insignificant. Over the entire summer there are no distinct increases in total

Figure 13



Mean Monthly Concentrations of
Ammonium Nitrogen

Figure 14



Diurnal Cycling of Ammonium Nitrogen

ammonium nitrogen concentrations at the downstream stations. Concentrations of ammonium nitrogen didn't exhibit any pattern which could be correlated with the seasonal and diurnal fluctuations of bacterial fluctuations.

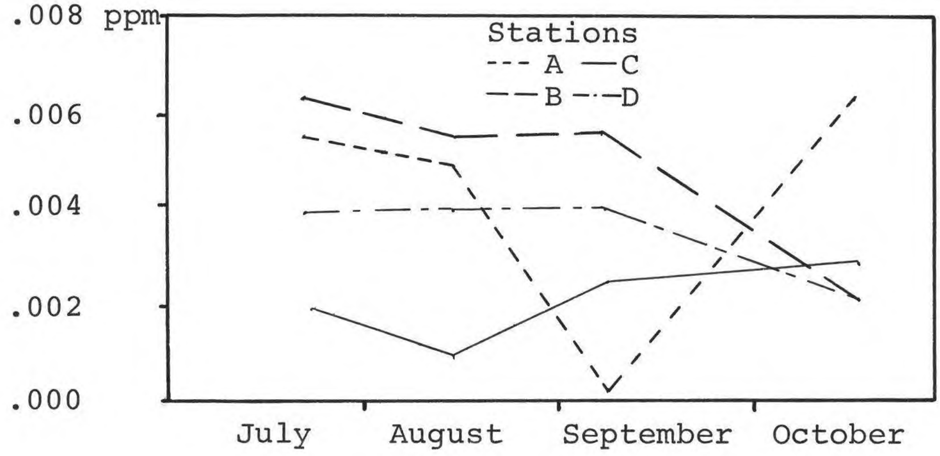
Nitrite

There was a lack of any seasonal trend in nitrite levels as well as any large increases in concentrations at the downstream stations (Figure 15). Diurnal variations in nitrite are also inconsistant (Figure 16). Since there is no consistant trend in nitrite fluctuation no indication of its effect on bacteria could be determined. A slight increase in nitrite occurs as the water proceeds downstream but is not large enough to account for the magnitude of the bacteria increase given by Kunkle and Meiman (1967, 1968).

Nitrate

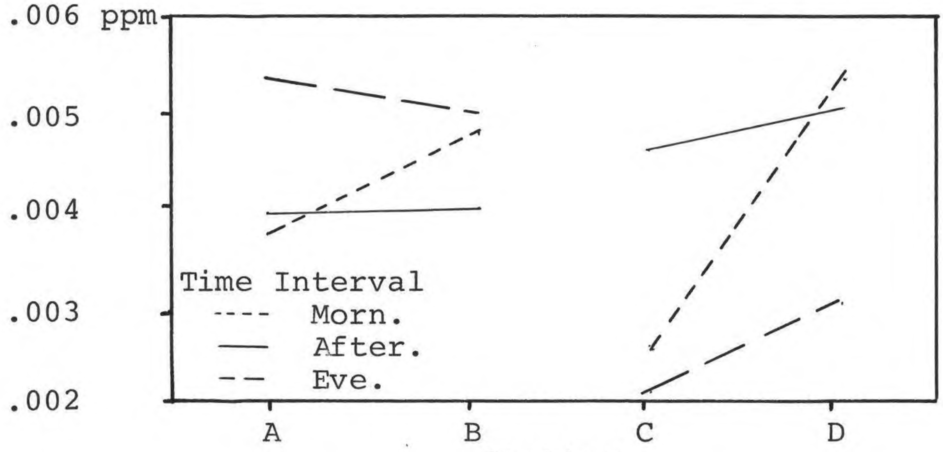
Nitrate in both streams was only present in trace concentrations. The variation of mean monthly (Figure 17) and daily concentrations (Figure 18) was small. Although the diurnal variation isn't statistically significant due to sampling and testing errors, the trend shows constancy on a station to station and a month to month basis at any given station. The nitrate concentrations did not increase as the stream became biologically polluted. Nitrate is used, by coliform bacteria, by reducing it to nitrite and then using nitrite for growth (Dean and Hazelwood, 1966). Kunkle and Meiman (1968) found significantly lower bacteria counts

Figure 15



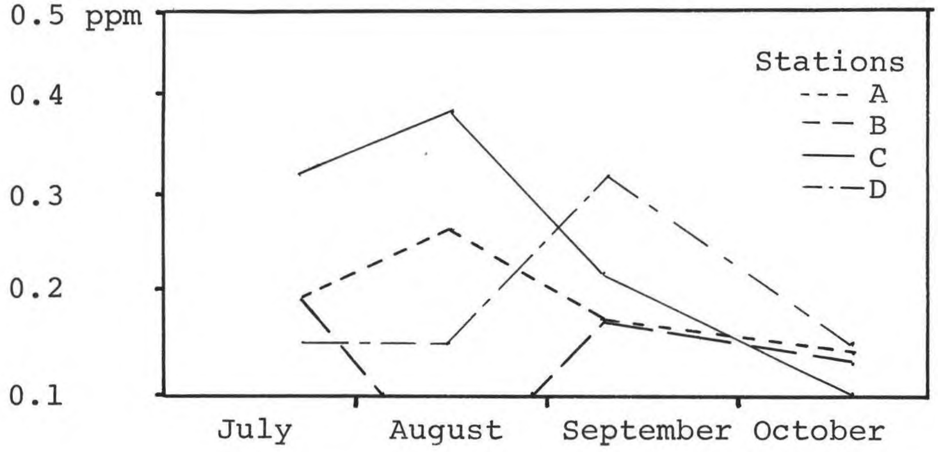
Mean Monthly Nitrite Concentrations

Figure 16



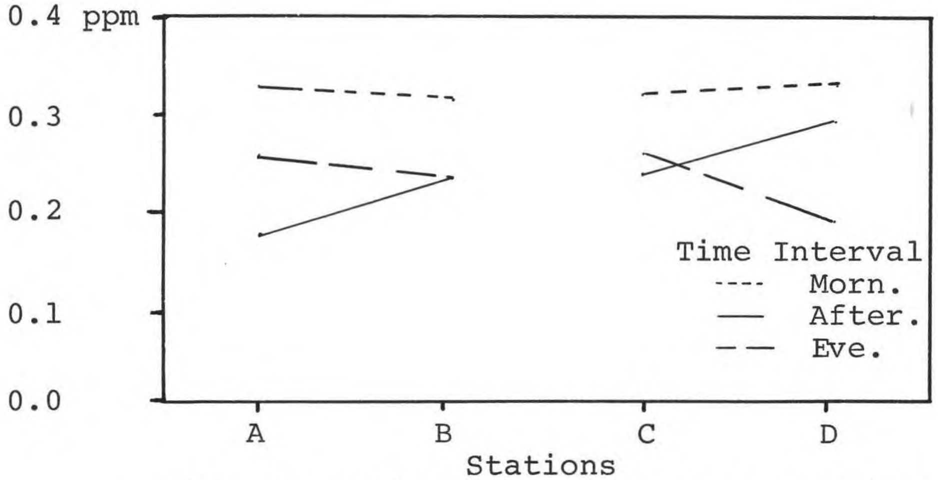
Diurnal Variation of Nitrite Concentrations

Figure 17



Mean Monthly Nitrate Concentrations

Figure 18



Diurnal Cycling of Nitrate Concentrations during the morning hours than during the evening period. Nitrate concentrations tended to be higher during the low bacteria counts and lower during the high bacteria counts. For this reason it does not seem plausible that nitrate concentrations have any controlling affect on the bacteria populations.

Phosphates

The Hach testing procedures proved very unreliable for providing any meaningful data at the extremely low concentrations of ortho and meta phosphate. The encountered results frequently would indicate a larger concentration of ortho phosphate when tested alone than another test made for both ortho and meta phosphate. For this reason the results from these tests are erroneous and not subject to analysis.

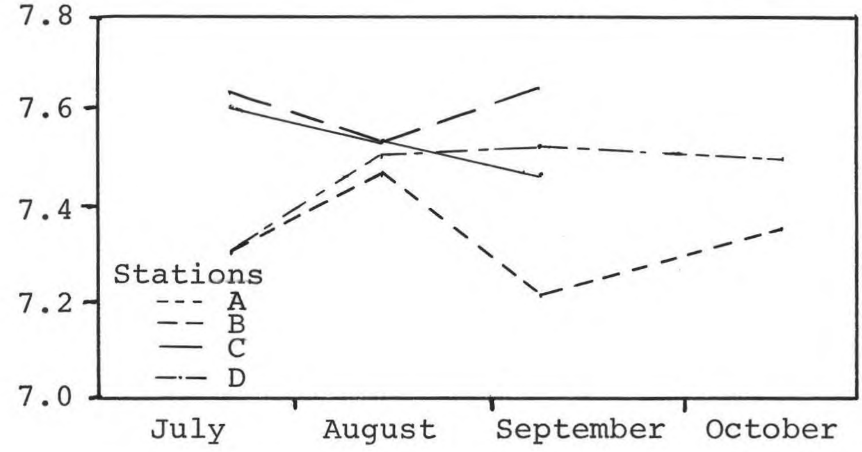
pH

The variability of pH was small but inconsistant on a daily (Figure 19), monthly (Figure 20), and station analysis. The only apparent trend which was consistant was the increase in pH from station A to station B. This same trend on the Pennock Creek stations C and D was inconsistant. Since there is no definite trend it is doubtful that pH could influence the bacteria fluctuations on a daily or monthly basis.

Specific Conductivity

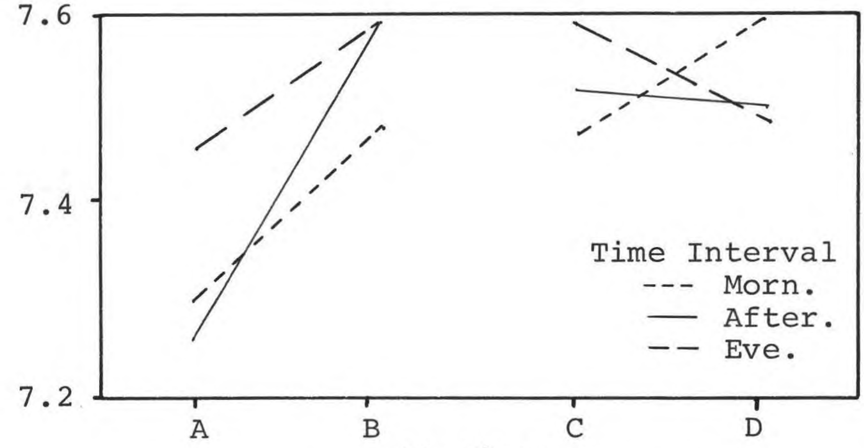
The specific conductance (Figure 21) increased from low summer lows to higher conductances in the late fall. The

Figure 19



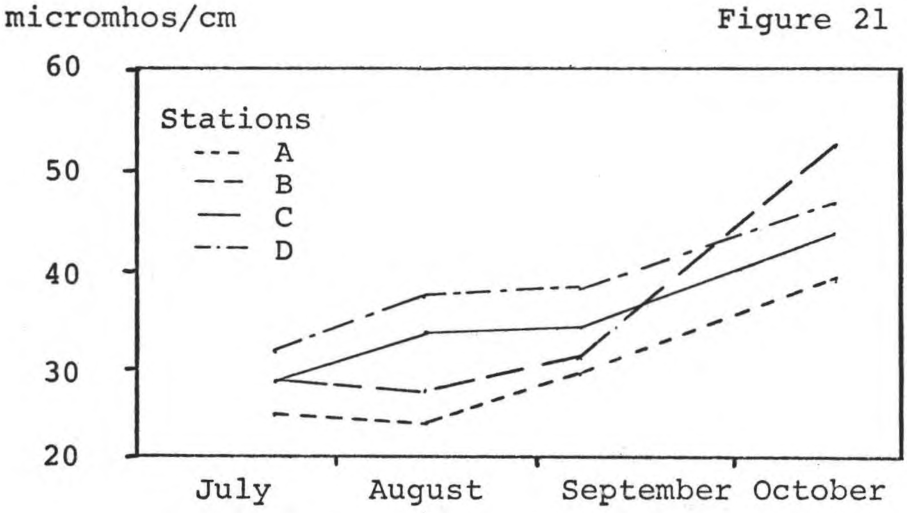
Mean Monthly pH

Figure 20



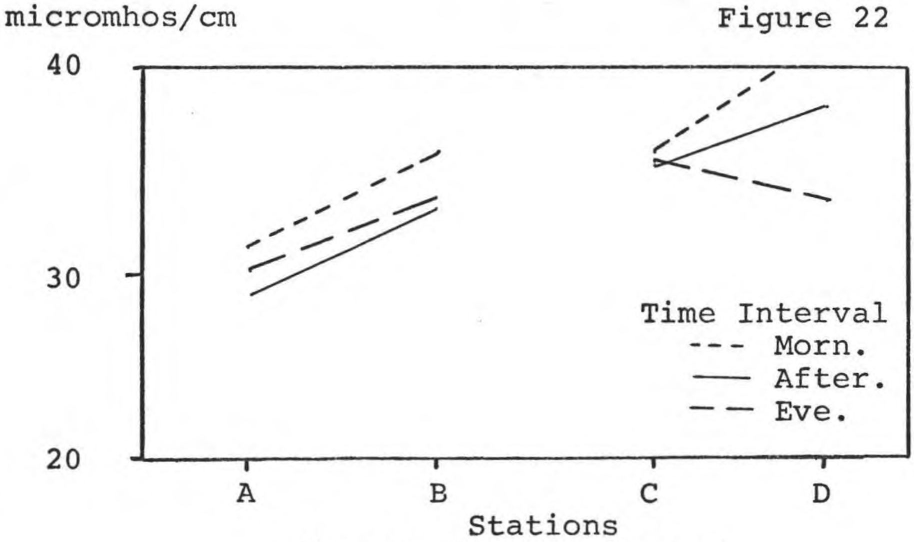
Diurnal Fluctuation of pH

Figure 21



Mean Monthly Specific Conductance

Figure 22

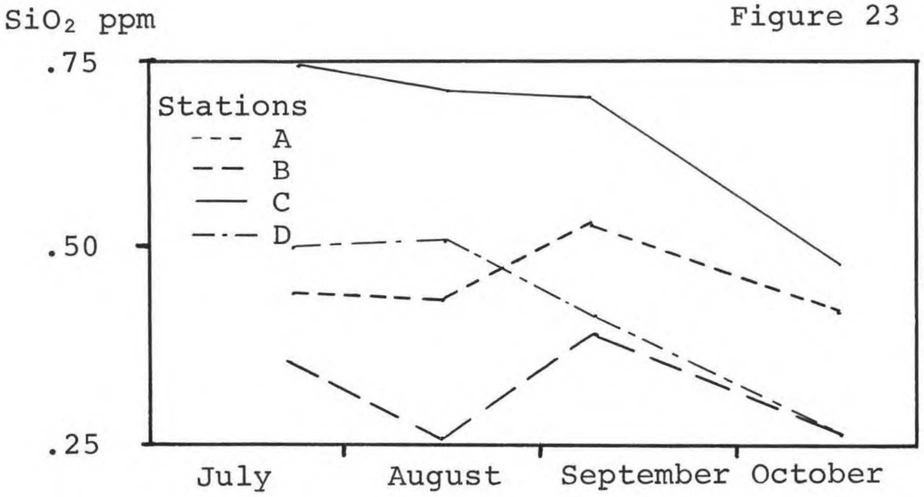


Diurnal Fluctuations of Specific Conductance increase in downstream conductances was expected and shows no effect of cattle grazing. This is evident by the same differential between stations C and D with the cattle and without the cattle in the October analysis. No constant diurnal cycling of specific conductance was detected (Figure 22) although morning readings were generally higher than afternoon or evening readings. This could be due to several factors: 1) the activity of the stream habitants during the night, 2) the small increase in stream stage peaking in the early morning and "flushing" material into stream, and 3) a machine error caused by the internal resistance of the Beckman conductance meter. The variation of specific conductance was not correlated with the measurements of total dissolved solids as normally expected. A correlation of mean monthly specific conductances (Figure 21), and dissolved and suspended solids indicated an inverse relationship. This is due to the change in constituents of the total dissolved solids during the mid-summer measurements. The summer runoff originated from snowmelt and carried a larger percentage of turbid material. Later in the fall the water came from ground water storage and carried a larger percentage of mineral elements. Therefore, the specific conductance increased even though the total dissolved solids decreased.

Turbidity

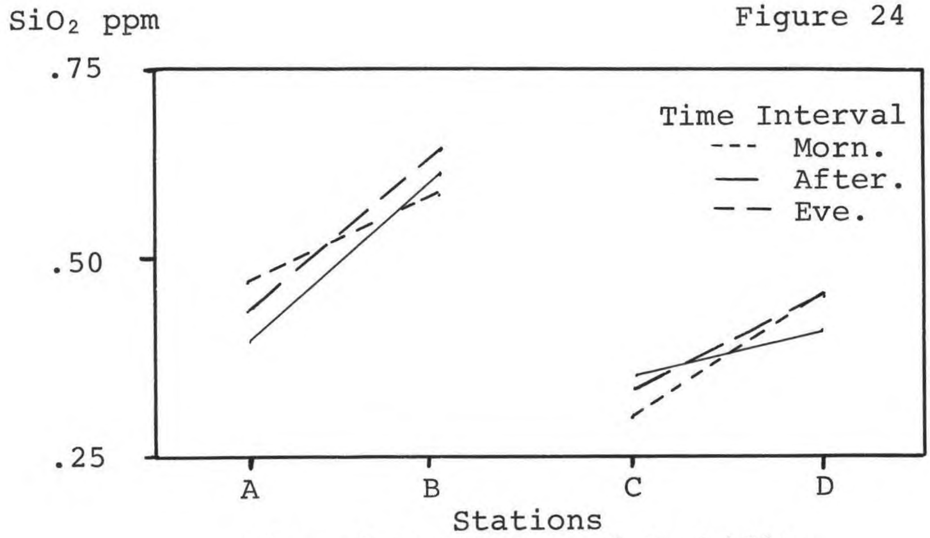
The seasonal trend of turbidity decreased during late summer flow conditions extending into the fall (Figure 23).

Figure 23



Mean Monthly Turbidity Measurements

Figure 24



Diurnal Variation of Turbidity

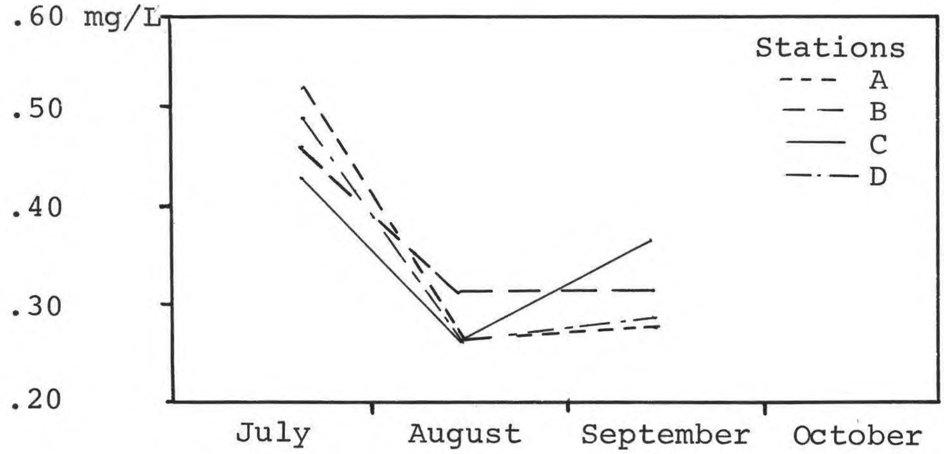
The lack of daily (Figure 24) and monthly cycling suggests that the turbidity conditions occurring during this study had no influences on bacteria populations. The increase in turbidity resulting from cattle grazing between stations C and D was negligible even when the cattle were observed in the stream immediately above station D. This is due to the coarse bottom comprised of rock, gravel and sand. Any material stirred into suspension settled out immediately and was not detected by downstream sampling. A second factor which accounted for the small increases in turbidity was the well vegetated pasture and the stable stream banks. The third factor for the low turbidity measurements during the study was the absence of any large storms that would normally deposit material into the channel and increase turbidity measurements.

Total Solids

The total solids load carried by the stream decreased during the summer and fall (Figure 25). The small increase in September is not significant. Diurnal cycling (Figure 26) reached a maximum during the evening interval at all stations except D. This is due to one extremely high value and without this measurement it would follow the other trends of higher measurements during the evening interval.

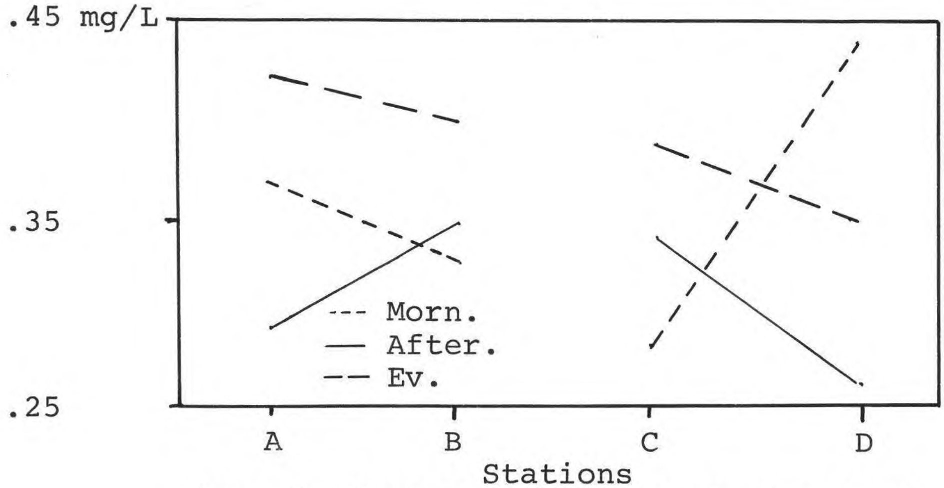
Increases in total solids are positively correlated with the increase in stage during the late afternoon. As the stream starts to increase in stage it would tend to pick

Figure 25



Mean Monthly Concentrations of Total Dissolved and Suspended Solids

Figure 26



Diurnal Fluctuations of Total Dissolved and Suspended Solids up material along the stream channel and carry it downstream. Total dissolved solids were comprised of a greater percentage of turbidity during the summer months. Later in the fall, the percentage of turbidity decreased and the percentage of dissolved minerals increased, thereby, changing the constituents making up the total dissolved solids.

Dissolved Oxygen Percentage

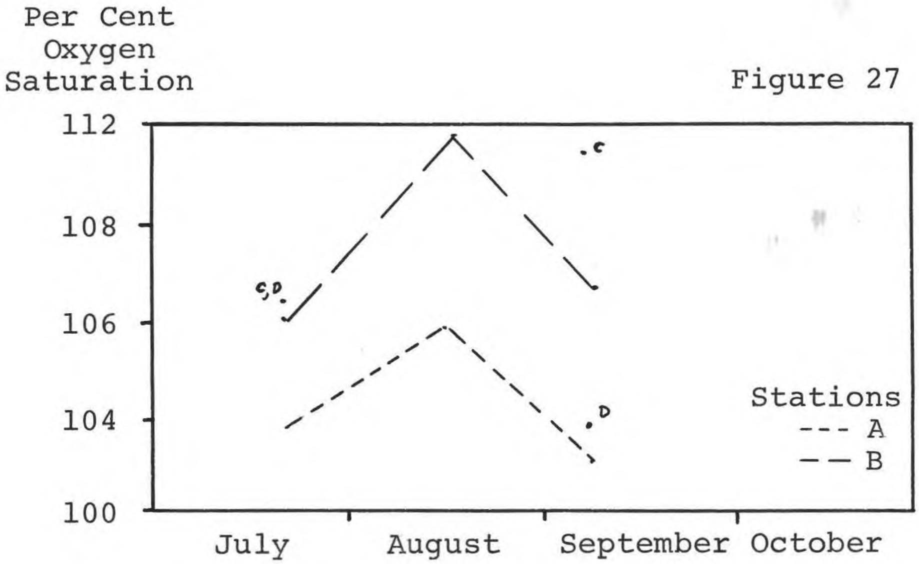
A lack of continuous oxygen determinations limits the analysis of monthly trends. The monthly trends (Figure 27) indicates a maximum level of oxygen saturation during the month of August. This was the result of the abundance of photosynthesizing aquatic plants. It is important to note that the mean oxygen content was always above saturation.

The diurnal variation of oxygen saturation suggests the same photosynthetic influences. Figure 28 indicates a maximum oxygen content during the afternoon interval where the photosynthesizing aquatic plants are most active. Due to the saturated concentrations of the streams it was improbable that this could affect the bacterial fluctuations in any manner.

Temperature

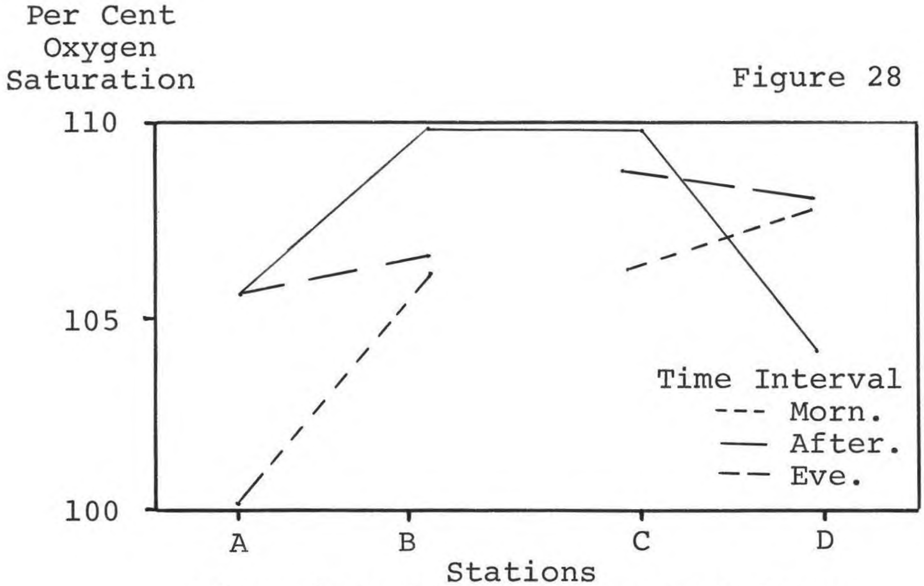
The temperature of Pennock Creek was closely correlated to the air temperature. Heat storage in the stream was small due to high amount of exposure to the atmosphere. Thus the control of air temperature on water temperature was

Figure 27



Mean Monthly Dissolved Oxygen Per Cent

Figure 28



Diurnal Cycling of Dissolved Oxygen

greater than in a deeper more shaded stream. The control of temperature showed more variability of the mean maximum temperature than the mean minimum temperature (Figure 29). This is due to the larger variability of the air temperature during the day than temperatures at night.

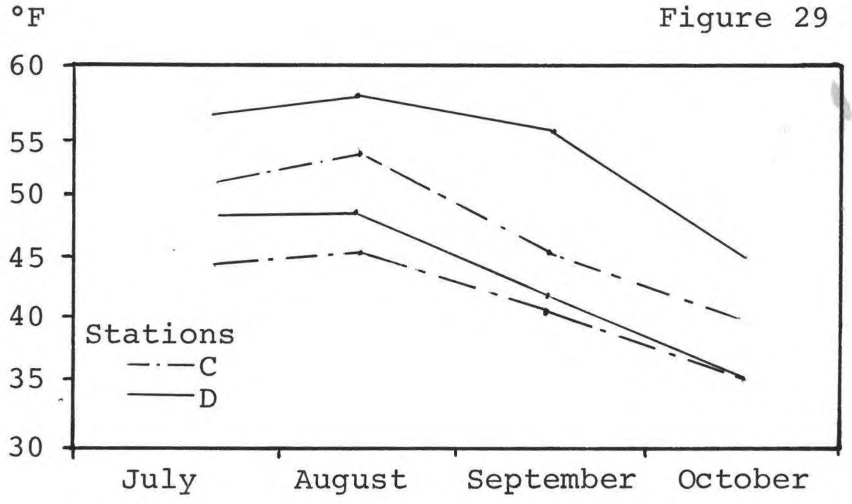
Increases in daily downstream temperature ranges (Figure 29 and 30) are due to two factors:

1. larger unshaded areas of stream as the stream passes through the grazed meadow
2. higher daily air temperatures at the lower stream section.

The increase in downstream temperatures are not constant but vary according to the month (Figure 30). Reasons for this are the variation of daily temperatures at the two sites and the amount of shading.

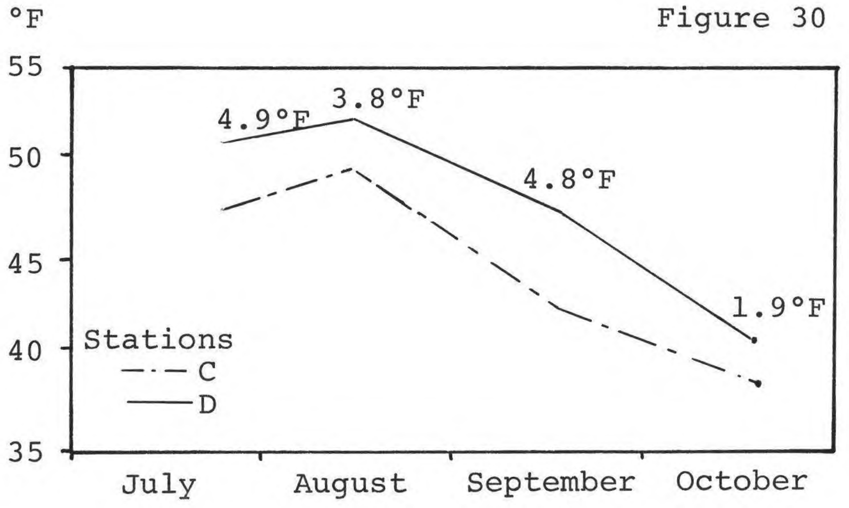
The variation of stream temperature and bacterial fluctuations have a negative correlation. Thus when the stream temperature is high the bacteria concentrations are lower. Kunkle and Meiman (1968) found more statistical differences between the morning, afternoon and night bacteria concentrations at their lower site than at their upper site. Their upper site was just above station C of this study and their lower station was mid-way between stations C and D. The changes of maximum stream temperatures downstream indicate the amount of changes to be expected in the bacteria fluctuations. This is due to the amount of shaded area along the stream. When the stream is shaded the increase in downstream

Figure 29



Mean Monthly Minimum and Maximum Water Temperatures of Pennock Creek

Figure 30



Mean Monthly Water Temperatures of Pennock Creek temperatures would be less, and the daily variation would be smaller, than in an unshaded stream. Consequently, when the stream becomes open to incident solar radiation the downstream temperatures and the daily temperature variations increase.

Concurrent with the increase of mean and maximum temperatures is the increased probability that the diurnal fluctuation of bacteria will also rise. The increase in bacterial fluxtuation is then correlated to the amount of ultraviolet and visible radiation incident on the stream and is reflected in the stream temperature increases and variability. The low turbidity conditions and high input of radiant energy allow high energy levels to be high at deeper depths. These high energy levels are reflected in the increased dissolved oxygen concentrations during the August afternoons and the concurrent die-off of bacteria (Kunkle and Meiman, 1968).

2. Radiation Component

The amount of spectral radiant energy reaching an aquatic organism is a function of:

1. The amount and spectral quality of the incident radiation
2. The albedo of the surface
3. The amount of absorption between the surface and the organism
4. The amount of energy reflected off the bottom strata

Determination of components 2, 3, and 4 was the experimental objective of this investigation.

Albedo

The mean recorded albedo of the different wavebands listed was 6.25%. This was well within the limits of most published data. Albedos of the various wavebands are given in Table 2.

Table 2. Recorded Albedos of Various Wavebands Within the Time Interval 8:00 A.M. - 5:00 P.M.

	Ultra Violet	Blue	Green	Light Green + Orange	Light Red	Dark Red
Mean	6.0%	6.6%	6.0%	6.6%	5.7%	6.6%
Num. OBS	11	11	11	10	10	10
Range	5-8%	2-12%	2-11%	2-13%	2-8%	4-11%

No specific trend of lowered albedo measurement was recorded, around mid-day or any statistical differences in the albedos of different wavebands. The probable reason for the angle of incidence not recording any variation of albedo with the different times of day was relatively high during the time interval 8:00 A.M. - 5:00 P.M. Therefore, the angle of incidence did not effectively change the albedo significantly. Increases would be expected at times earlier or later than the time interval used in this investigation.

Absorption

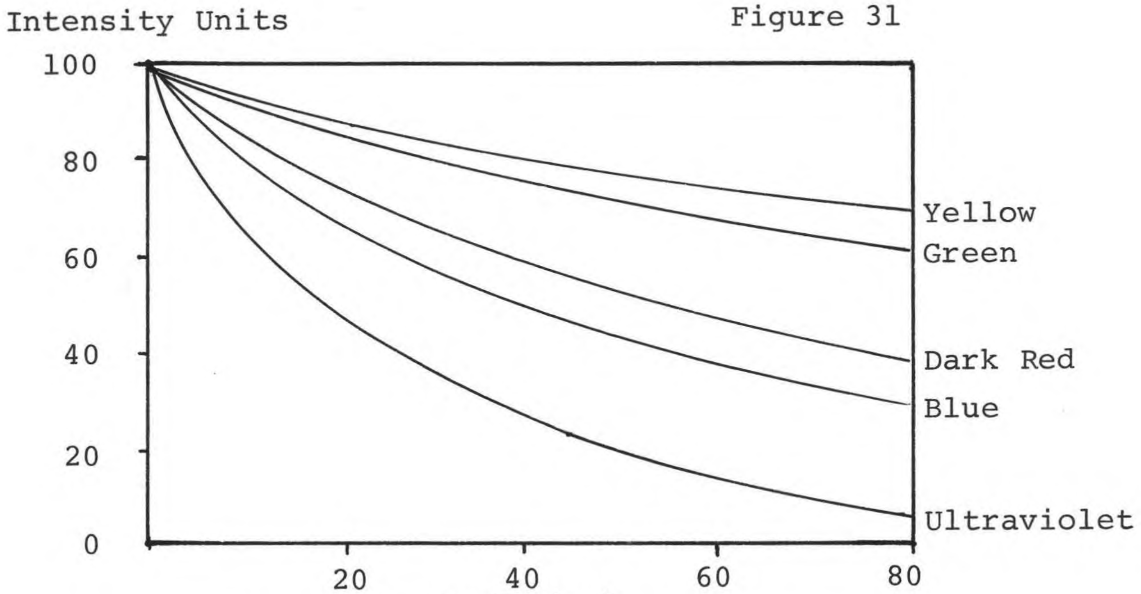
The extinction of light energy in water undergoes a constant logarithmic diminution described by the mathematical law $I = Ioe^{-bx}$. Beta coefficients (b) are variable dependent upon the particular wavelength band and the optical properties of the water media. Coefficients were determined without the complicated calculation of actual pathlengths, but merely taking the depth as a constant not varying as it does by using effective pathlengths.

Table 3 gives the calculated beta coefficients for the observed data. The principal wavelength given for the beta coefficients are the optical centers of the different filter-cell systems, care must be taken to realize the limitations of the beta coefficients. They represent a statistical average of the changes in wavelength betas for a given depth rather than the pathlength subtended by the direct incident radiation. Thus at any one instant the beta value for the

Table 3. Calculated Beta Coefficients for Time Intervals Between 8:00 A.M. - 5:00 P.M.

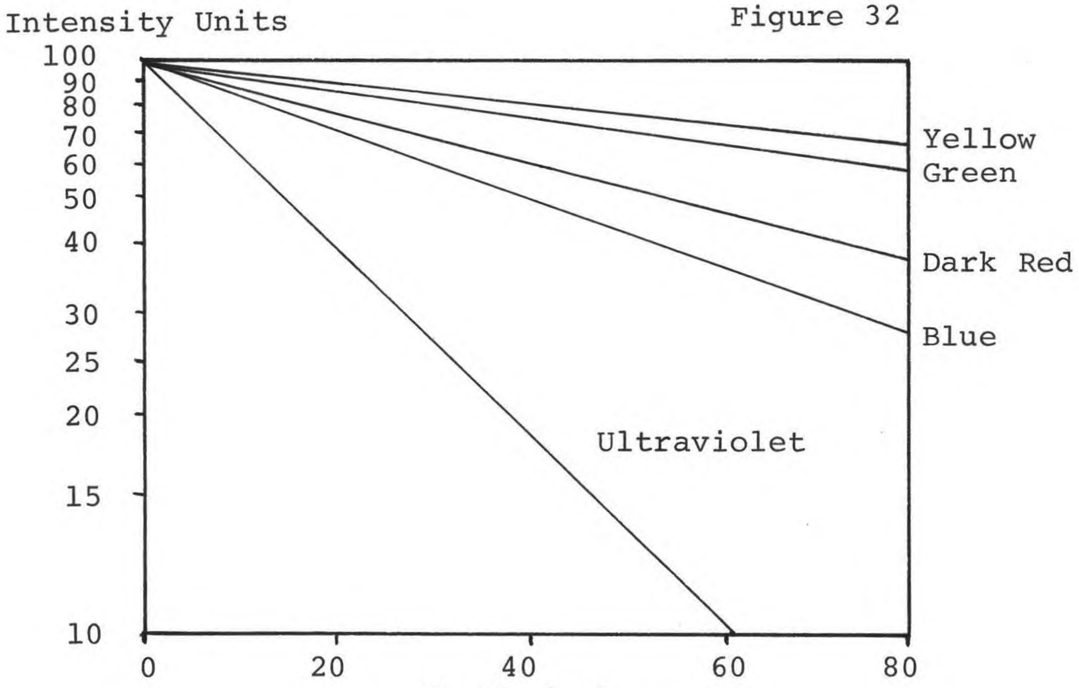
Optical Center of System	Color	Manufacturer of Filter	Beta Coefficient	r^2	Number of Observations	Standard Error of Estimate (Units of Intensity)
.36 μ	Ultraviolet	Corning	.040225	96.49	49	1.2
.37 μ	Ultraviolet	Schott	.0349749	97.95	72	1.2
.43	Blue	Corning	.018517	94.00	44	1.1
.44	Blue	Schott	.014318	93.43	80	1.1
.5250	Green	Schott	.0058750	93.09	79	1.0
.5260	Green	Corning	.0079018	96.24	54	1.0
.5750	Yellow	Schott	.0049719	88.87	63	1.1
.64	Red	Corning	.0073413	94.70	45	1.0
.64	Red	Schott	.0072099	94.64	61	1.1
.70	Red	Schott	.012226	97.58	59	1.1
.36-.70	Visible	Corning	.0053667	94.62	61	1.0

Figure 31



Depth (cm)
Observed Attenuation of Radiation Energy in the Little South Fork of the Cache La Poudre River

Figure 32



Depth (cm)
Logarithmic Decrease of Radiant Energy in Figure 31

equation $I = Ioe^{-bx}$, will not be the same as given in Table 3, but, over the time interval between 8:00 A.M. - 5:00 P.M. the beta value to use is a statistical average as found in Table 3.

The actual attenuated energy at different depths is plotted in Figure 31. These same data points plotted on logarithmic paper form straight lines (Figure 32) of the mathematical relation $I = Ioe^{-bx}$. The absolute deviations from the model of attenuation increase as the depth increases. This is due to increased scattering of radiation at the greater depths and the longer pathlength at lower angles of incidence.

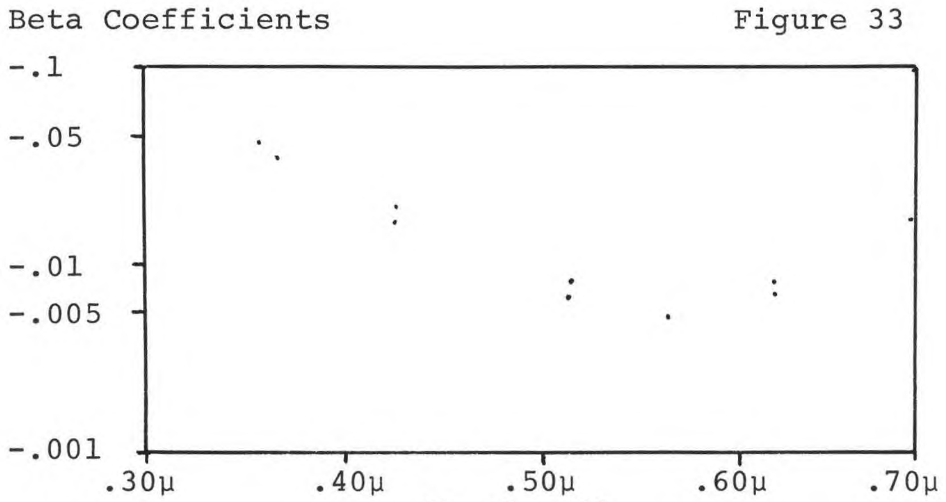
A plot made of the beta coefficients (Figure 33) shows the hyperbolic curve of the beta coefficients. The smaller beta values are wavebands which transmit more energy. This may be expressed as a mathematical relationship:

$$b = -.31988 + .092352\,\frac{1}{x} + .285891X \qquad (1)$$

where b is the beta coefficient, x equals the wavelength, r^2 equals .9958, standard error of estimate equals .00092 and the limits are .36 μ - .70 μ

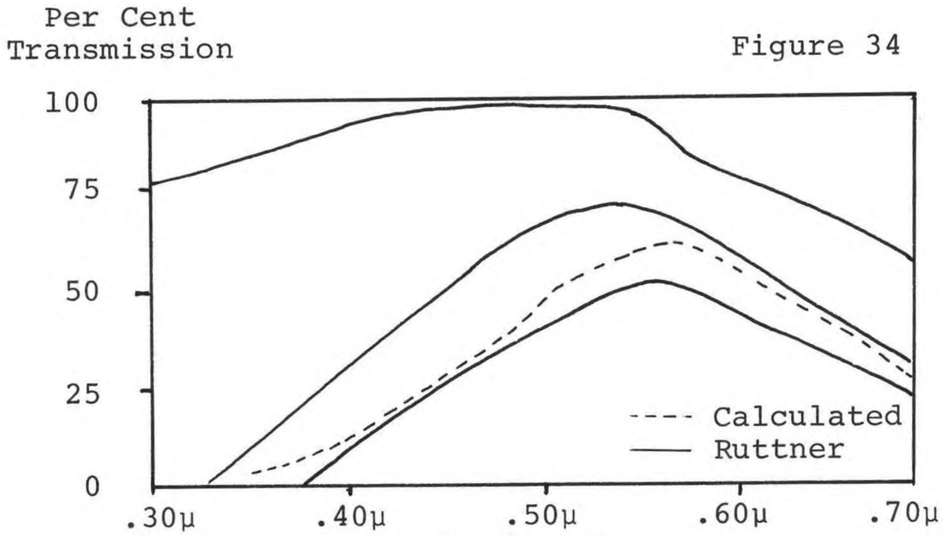
Once the beta values have been calculated the amount of energy reaching any depth can be calculated by the equation $I = Ioe^{-bx}$. The only other parameter which is needed is the amount of incident energy in a given waveband less the amount lost in reflection (Table 2). Equation 1 predicted the beta coefficient of .36 μ ultraviolet i -.03783. If the

Figure 33



Observed Beta Coefficients of the Little South Fork of the Cache La Poudre River

Figure 34



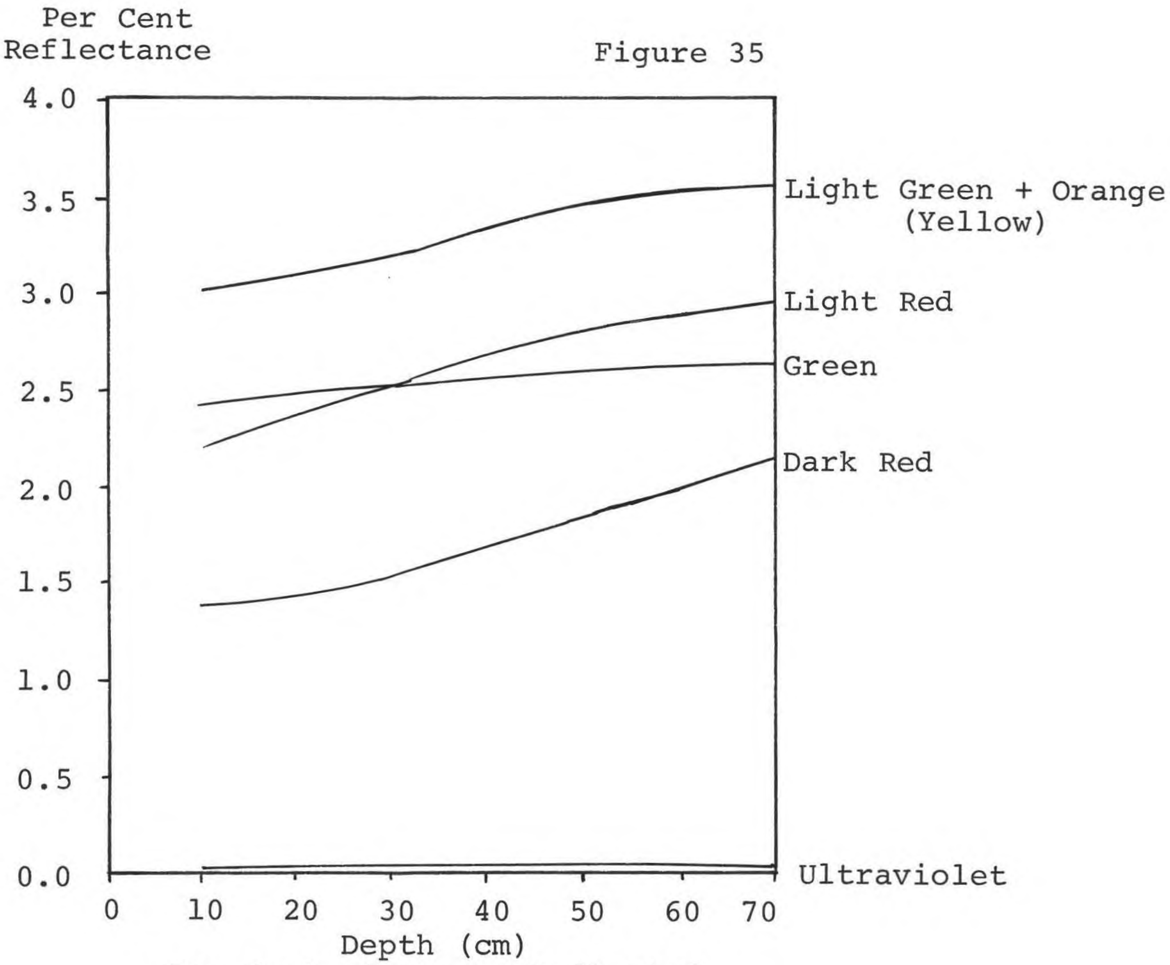
Calculated Transparency of Little South From Ruttner (1953) incident solar radiation is 100 units of energy then 75 units will remain at 8 cm depth, 50 units at 18 cm, 25 units at 36 cm and 10 units at 60 cm. Thus at 60 cm the water had reduced the original 100 units to 10 units. Gameson's (1967) work with bacteria suspended in the ocean clearly shows that die-off can occur solely due to radiation exposure.

The results from this study are within the range of values made with similar testing procedures. Figure 34 shows a plot of the generated results of this experiment in comparison to former investigations found on page 14 of Ruttner's (1966) standard text Fundamentals of Limnology. This analysis is made by a generation of beta coefficients using equation 1 and a calculation of the relative intensity at one meter. In this manner the results from this investigation are then comparative to previous findings.

Reflected Energy

Once the radiant energy has passed through the water column it strikes the bottom and is absorbed or reflected. The amount of energy reflected off the bottom are given in Figure 35. Results expressed in this figure have been adjusted to the original 100 units of incident radiation. The energy reflected off the bottom in the ultraviolet waveband is less than one per cent of the incident radiation. Thus the germicidal action of ultraviolet radiation is solely due to the downward incident component.

Figure 35



Per Cent of Energy Reflected from the Bottom

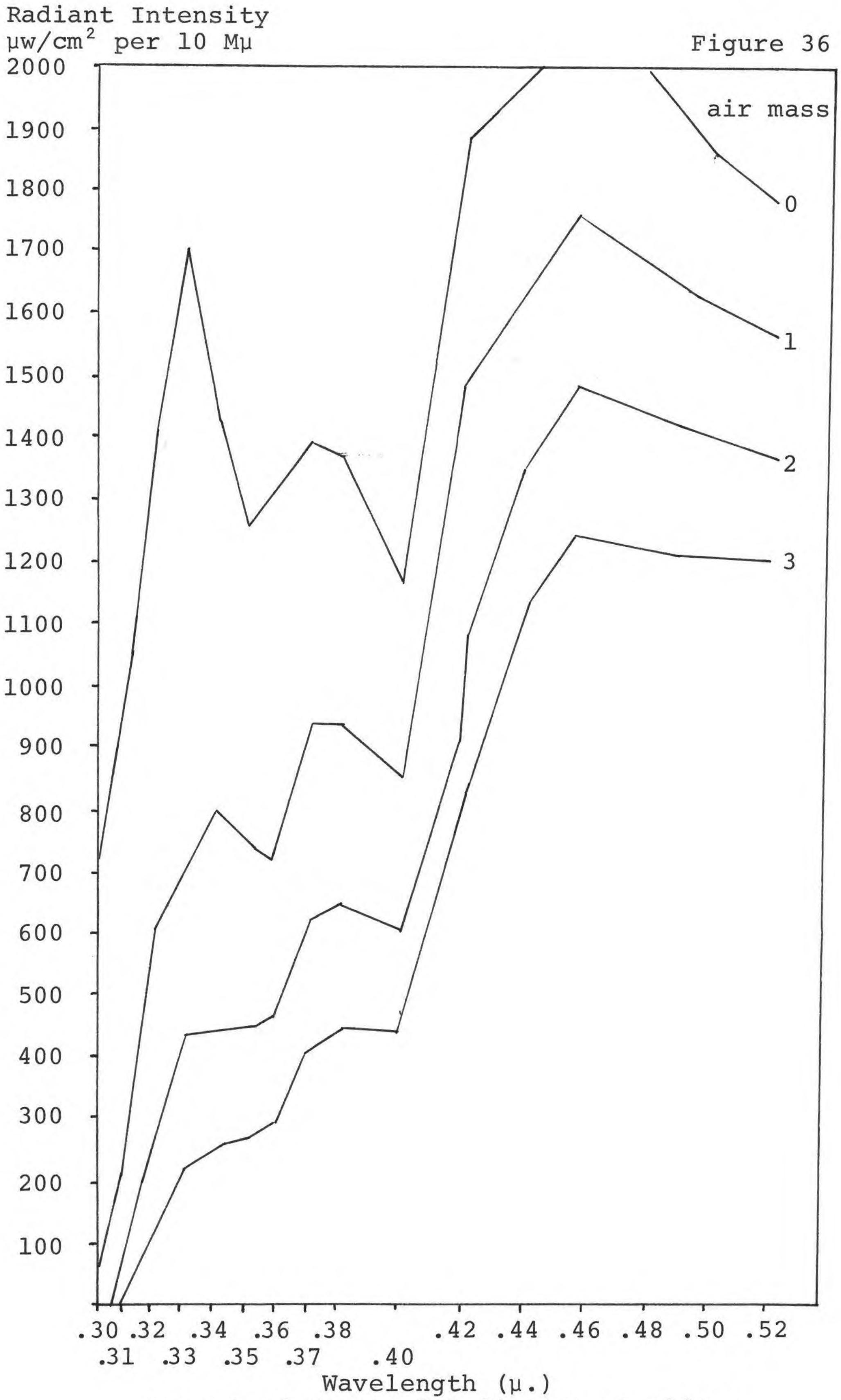
Radiant Energy Reaching an Organism

The amount of ultraviolet energy reaching an aquatic microorganism is greater in high altitude streams and lakes than at lower elevations. This is due primarily to two factors: 1) more incident ultraviolet radiation at the higher elevations, and 2) clear mountain water which transmits larger amounts of ultraviolet radiation than lower elevations and streams with generally larger concentrations of turbid material.

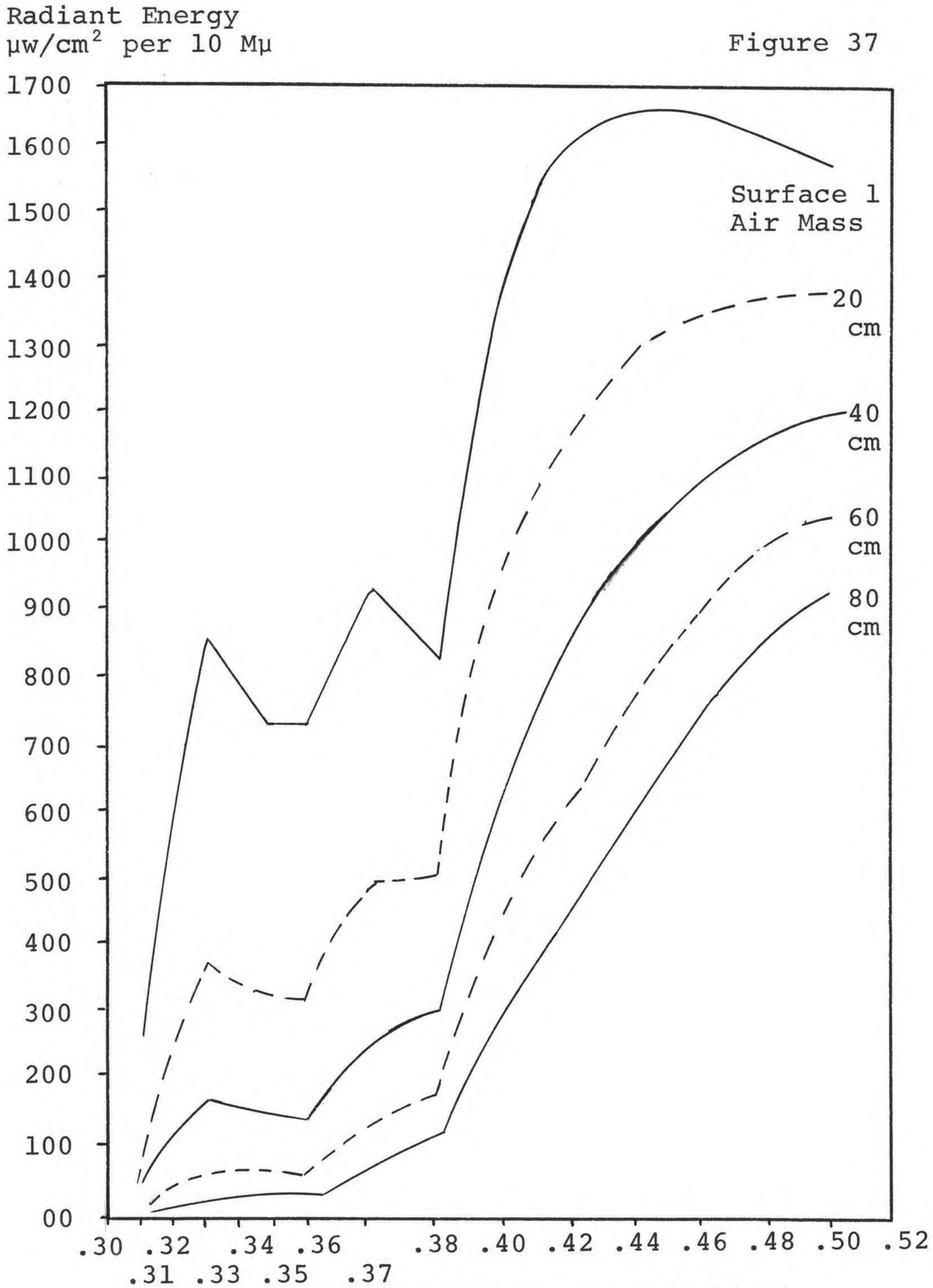
To look at the complete system of air and water attenuation of ultraviolet radiation the incoming spectral composition of radiation and its attenuation in water must be known. This study concentrated on the attenuation of energy in water, thus the atmospheric parameters must be taken from other sources. Stair (1952) studied the incoming clear sky spectral radiation at Climax, Colorado during September, 1951. The altitude (11,200 ft.) at Climax is close to the Pingree elevation of 9,000 feet with only 80 miles separating both points. The data at both can be considered analogous.

A plot of Stair's data (Figure 36) indicates the variability of ultraviolet energy as the pathlength (air mass) changes. Attenuation of Stair's (1952) data (Io) for one air mass (Figure 37) through the water column to depths of 20, 40, 60 and 80 cm by the equation $I = Ioe^{-bx}$ reveals the small amounts of ultraviolet radiation reaching the lower depths. The losses due to reflection of the surface are not considered in Figure 37. Beta coefficients for wavelengths

Figure 36



Amount of Spectral Radiation at Climax
(Stair, 1952) during early September



Underwater Attenuation of Atmospheric Radiation less than .36 μ are taken as .36 based on Armstrong's study (1961, Figure 5). The major variation in ultraviolet radiation reaching an organism is due to the atmospheric attenuation (Figure 36).

Once the radiation reaches the surface it undergoes constant diminution. Thus, the amount of energy incident on the water is the most critical factor along with the depth of the organism and turbidity of the stream.

Bacteria in clear-shallow mountain streams are near the surface some of the time due to the constant mixing. During the mid-day when the bacteria are in an unshaded stream section the energy flux would be the greatest and able to cause bacteria die-off. The die-off of bacteria then causes the significant bacterial variations sampled by Kunkle and Meiman (1967 and 1968).

CHAPTER VI

CONCLUSIONS

Concentrations of coliform, fecal coliform and fecal streptococcus bacteria in mountain streams have been observed to follow pronounced seasonal and diurnal cycles (Kunkle and Meiman, 1967, 1968). The seasonal patterns established include high concentration during early summer snowmelt runoff, a decline during the mid-summer and an increase in late summer and fall. Superimposed upon the seasonal variation is a daily variation. In this study it was assumed that the observed variation could be explained by natural variations of physical-chemical and radiation properties of mountain streams.

In order for a natural physical-chemical parameter to influence bacterial growth it must: 1) vary in a positive or negative manner with the seasonal and daily variations of the bacteria, and 2) place a physiological limitation on the growth of the individual organism. This study was conducted to determine the first of the above factors. However, under the conditions of this study, no attempt was made to determine physiological limitations of the various parameters.

The physical-chemical parameters measured included ammonium nitrogen, nitrite, nitrate, pH, specific conductance, total solids, and dissolved oxygen with the exception of turbidity and temperature. These parameters did not exhibit a seasonal or diurnal variation which could be related to the variation of bacteria concentrations. Although all parameters exhibited some variation, no relationship with previously established bacterial variations could be determined. The only physical-chemical parameters which related to bacteria variations were turbidity and water temperature.

The effect of turbidity on bacteria concentrations is an indirect one. When high runoff (storm or snowmelt) occurs turbidities and bacteria concentration increase simultaneously. Once the stream becomes turbid the light penetration decreases and the controlling effects of ultraviolet radiation are lost. Thus, measured bacteria concentrations may be explained by (1) direct flushing into the stream and (2) lack of ultraviolet control.

The range of the daily mean and maximum water temperatures is an indication of the amount of radiant energy incident upon the stream's surface. Since daily temperature variation is an index of radiation flux, it is also an indication of the intensity of ultraviolet incident upon an organism.

No increases in the chemical parameters were measured in the stream below the grazed area. It is therefore, concluded that the increases in bacteria concentrations result from direct injection of bacteria by grazing animals or increased flow over the grazed area by irrigation or storm runoff, rather than a more favorable nutrient environment.

The major factor controlling bacterial growth patterns appear to be the cumulative amount of ultraviolet radiation reaching the aquatic microorganism. The amount of ultraviolet energy under the optimum atmospheric conditions (clear sky with one air mass) and aquatic attenuation is only a very small amount. Thus any changes in these factors drastically reduces the ultraviolet energy flux. Attenuation of radiation follows the decay law $I = Ioe^{-bx_1}$. Beta coefficients can be determined by the equation $b = .31988 + .092352 \frac{1}{x} + .285891 x$ where x_1 = cm depth, x = wavelength . μ.

The mechanism for the control of bacteria by ultraviolet radiation may occur by one of the following:

1. Actual killing of the bacteria.
2. Inhibit reproduction and allow normal die-off to occur.
3. Change the chemical structure of complex organic amino-acids so as to render them useless for metabolism.

These mechanisms involve physiological changes of the bacteria. Therefore, no further conclusions can be made from this investigation.

This study suggests that the complex bacterial growth patterns when placed in a bio-physical system are dependent on three factors: 1) turbidity, 2) amount of ultraviolet energy incident upon the streams surface and the amount of energy attenuated by the water, and 3) water temperature. The three-phase cycle of seasonal bacterial variation: 1) high concentrations in early summer, 2) low concentrations in mid-summer, and 3) higher concentrations during late summer; and the two-phase diurnal cycle: 1) low afternoon concentrations, and 2) high evening concentrations can be explained by integrating the above three factors.

The high concentrations during early summer snowmelt runoff are caused by the interaction of the following parameters. Large concentrations of bacteria are flushed into the stream. Along with these bacteria, suspended material is also introduced which effectively reduces the transmittance of ultraviolet radiation which reduces the germicidal control of the ultraviolet. Thus the diurnal die-off does not occur.

Once the stream has receded to low levels the low bacteria concentrations of mid-summer occur. This is due to the decreased supply of bacteria and suspended material in the stream. The diurnal fluctuation in stream temperature during this period has greater variability indicating a lack of snowmelt water and large fluxes of incoming radiation in the unshaded area. Due to these large fluxes of incoming radiation and the shallow clear nature of the warm water incident ultraviolet can effectively control the bacteria. The lower seasonal concentrations of bacteria are due to the population being reduced during the afternoon periods by ultraviolet caused die-off. The subsequent increase during night continues only to be reduced again by radiation die-off the following day. The stream during this interval is able to dynamically adjust and purify itself, thus keeping the bacteria concentrations at low levels.

The same conditions exist in the late summer-fall interval as in the mid-summer but with a decreased solar flux. The stream still has warm water but the cumulative ultraviolet intensities are smaller and the stream becomes unable to purify itself by the daily die-off of bacteria. The result of these interactions is an increase in the concentrations of bacteria.

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Appendix Table A

Per Cent Transmission of Schott Filters

Wavelength	Blue + Ultraviolet (Ultraviolet) %	Blue %	Dark Green %	Light Green + Orange (Yellow) %	Light Red %	Dark Red %
.32 µ	0.0	0.0				
.33	3.0	6.0				
.34	12.0	21.0				
.35	24.0	37.0				
.36	34.0	50.0				
.37	38.0	59.0				
.38	32.5	65.0				
.39	24.0	69.0				
.40	2.5	70.5				
.41	0.0	70.5				
.42		70.0				
.43		67.0				
.44		63.0	0.0			
.45		56.0	1.8			
.46		47.5	5.0			
.47		33.0	11.0			
.48		18.0	19.0			
.49		7.0	28.0			
.50		2.2	36.5			
.51		0.0	43.5			
.52			47.0			

Appendix Table A (Continued)

Per Cent Transmission of Schott Filters

Wavelength	Blue + Ultraviolet (Ultraviolet) %	Blue %	Dark Green %	Light Green + Orange (Yellow) %	Light Red %	Dark Red %
.53			47.5			
.54			44.0			
.55			38.0	0.0		
.56			30.0	17.0		
.57			22.0	34.0		
.58			17.0	34.0		
.59			12.0	28.0		
.60			8.0	20.0	0.0	
.61			5.0	13.5	1.0	
.62			4.0	8.5	26.0	
.63			3.0	4.5	64.0	
.64			2.0	2.5	80.5	0.0
.65			2.0	2.0	86.0	2.0
.66			2.0	0.5	88.0	24.0
.67				0.0	89.0	62.0
.68					89.5	78.0
.69					88.5	82.0
.70					87.0	82.5
.71					85.5	81.5
.72					82.0	78.0
.73					75.0	72.5
.74					64.0	62.0