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Project 15-1372-3141 – Water Quality Problems of Colorado

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ABSTRACT

HEALTH HAZARDS IN THE DISTRIBUTION OF
TREATED MUNICIPAL WASTEWATER FOR IRRIGATION

The direct and indirect utilization of municipal wastewater effluents for irrigation has been a defacto practice throughout the western United States for over 100 years. Throughout this period there has not been any significant attention given to the problem of a possible public health hazard associated with the practice. Recent federal and state laws, however, have given impetus to a planned practice for reuse of municipal wastewaters by irrigation. Because these laws and regulations constitute public policy, the question of health hazards ought to be ascertained.

This study evaluates, through the use of existing data and field sampling, the potential health risks which may exist in the South Platte River Basin associated with the conveyance of treated municipal wastewater effluents. Fecal coliforms and fecal streptococci were used as indices of pollution relative to health hazards.

It was found that fecal pollution was present in the urban and irrigated areas of the basin. Consistently high densities of indicator organisms were observed in the areas east of the foothills. Over 30 percent of the data from the sampling stations in the South Platte River Basin exceeded the microbiological standards for waters of the State of Colorado.

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1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 Objective

The objective of this study is to evaluate the public health hazard associated with the present practices for distributing and conveying treated municipal sewage effluents through open ditches and streams to agricultural lands. This evaluation was made for the South Platte River Basin located in Colorado, Wyoming, and Nebraska.

1.2 Background

The majority of wastewater treatment plants in Colorado's South Platte River Basin discharge their effluents into surface water courses. These surface waters, comprised primarily of canals and reservoirs, provide irrigation waters to agriculture. This practice of reusing treating sewage effluents without a formal exchange or appropriation being made is termed "indirect reuse." This form of reuse has occurred for many years within the basin.

The need to acquire additional water supplies for future growth both in agricultural and urban areas of Colorado's Front Range has led to the increased and deliberate use of municipal wastewaters for irrigation. Public policy promoted by the U.S. Environmental Protection Agency and Colorado's Water Quality Control Commission, provides incentives for the planned reuse of municipal wastewaters. A significant issue associated with the extensive reuse (planned or indirect) of municipal wastewaters is public health. A potential health risk exists when treated sewage effluents are conveyed through open waterways, i.e., irrigation canals.

Although primarily utilized for irrigation, there exists many opportunities for public contact with canal waters. These waters wind through many municipal areas providing a playground and potential swimming hole for local children. Other opportunities for contact exist in the use of canal waters for the ornamental watering of public lands, and in the recreational use of irrigation storage reservoirs.

Research concerning the health hazard of treated wastewaters conveyed through open waterways is needed in order to determine the degree of such risk to the public. This research is needed now, in light of the recent progress toward planned reuse which is occurring within Colorado's South Platte River Basin.

2.0 STATE OF KNOWLEDGE

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2.1 Introduction

In order to evaluate the health risk associated with the distribution of municipal wastewaters, the term health risk is first defined as the chance of incurring infectious waterborne disease via the water route of transmission. Evidence today shows that this risk is indeed very low. However, in terms of public reaction, no finite risk of disease is acceptable. Todays' public expects that all water is protected and therefore safe for all uses (National Science Foundation, 1978).

By far the best way to evaluate risk is to measure the incidence of a waterborne disease to a population which has been in contact with contaminated water. However, this type of evaluation presents problems in the development of such epidemiological data. For example, it is often very difficult to identify a specific source of a disease. Those diseases which may be waterborne (i.e., transmitted via a water route) may be transmitted via other channels of contact; person to person contact, or through contaminated foods.

Another potential method for the evaluation of disease risk, is to make a comprehensive analysis of the pathogenic organisms present in a water sample. The problem here is that the analytical methods to accomplish this are extremely time consuming, expensive, and imprecise. The data provide only qualitative information, and in no way indicate the virulence of the organisms isolated (National Science Foundation, 1978).

A third method is to measure the degree of fecal contamination in a water body. This is accomplished through the enumeration of the non-pathogenic fecal bacteria in the water. The use of "indicator organisms"

is the method traditionally utilized to evaluate the health risk of waters.

The following sections of this chapter briefly review the current state of knowledge on waterborne disease. Also included are the indicator organisms, and the effectiveness of these organism in forecasting potential health hazards.

2.2 Waterborne Disease

Waterborne disease has been defined as follows:

> Any disease whose etiological agent is shed in the feces, urine, or other excretions of active cases of the disease or by carriers, is washed into the aquatic environment from terestrial niches wherein it multiplies or is part of the aquatic microflora because it multiplies therein (i.e., Aeromonas hydrophila, Pseudomonas aeruginosa) is potentially transmissible by the waterborne route by aerosols generated from the waters or by their application to land (National Science Foundation, 1978).

There is sufficient evidence available to indicate that infectious diesease may be contracted from domestic wastewaters. The majority of outbreaks occuring in the United States associated with waters used for drinking or domestic purposes, has been shown to occur because of inadequacies in water systems and/or deficiences in their operation (Craun and McCabe, 1973). The number and type of enteric infections in the population is reflected in the detection of the infectious organisms in the sewage of that community (Akin, 1977).

The infectious agents orginating in the intestinal discharge of man and animal may be put into three broad categories: bacterial, viral, and parasitic. An excellent review of the infectious agents in wastewaters is given by Robert Cooper (1974). The agents discussed in this review

have been categorized as noted above. The prevalence of their transmission via the water route and the incidence of such transmission has been brought together for presentation in Table 2-1. Cooper indicates that although water is often not a primary route, it does have a significant role in the transmission of disease. If not the only route of transmission, it must certainly play a part in some cycle of disease transmission.

Other routes of transmission have been investigated (National Science Foundation, 1978). Figure 2-1 graphically shows the possible routes of transmission for salmonellosis. It is assumed that 10 to 20 percent of these cases are waterborne; a part of the "unknown" category in the figure (National Science Foundation, 1978).

Figure 2-2 shows the incidence of waterborne disease from 1920 to 1976 (National Science Foundation, 1978). A rapid decline in incidence occurs after the 1931 to 1940 period, to a low of 7 cases per million people per year during 1951 to 1960. The increase that occurs into 1976 may be due to better reporting of these cases (in other words, no real increase in incidence) or the possibility of poorer water quality in terms of health risk. As these questions are unanswered, it becomes impossible to say if in the near future incidence of waterborne disease will in fact increase or actually decrease.

2.3 Indicator Organisms

Fecal indicator organisms provide a measure of fecal pollution to a water body. When detected, they signal the possible presence of pathogenic organisms. In order to be effective to this end, an indicator organism should fulfill the following criteria (Knott, 1976):

TABLE 2-1 Waterborne Diseases

Biological Group	Associated Disease (Specific Agent)	Transmission	Incidence of Waterborne Disease	Comments
Bacterial Agents:				
Salmonella	Salmonellosis:			
	1) Enteric fever (Salmonella typhosa, typhoid fever)	Personal contact, contaminated food and water (water represents less than 2% of total sources)		1900's, Mortality in U.S. was 31.3/ 100,000 persons Today, almost non-existant
	2) Septicemias (S. choleraesuis)			Rare, prediliction for swine
	3) Acute gastroenteritis (S. typhimusium)		1965, Riverside, CA 18,000 people	Most common non-human source is food, e.g., poultry
Shigella	Bacillary Dysentary (Shigella sonnei) (S. flexneri)	Person to person, contaminated food and water	Several cases	Spreads under conditions of over crowding and improper sanitation
Vibrio comma	Cholera	Infected water	Endemic focus is India	No cholera in the U.S. since approximately 1900
			1973 - occurrence in Italy 1973 - occurrence in Lavasca, TX	Man is the only known natural host
Tubercle bacillus	Tuberculosis (Mycobacterium tuberculosis)	Contaminated waters	Yes, to swimmers	

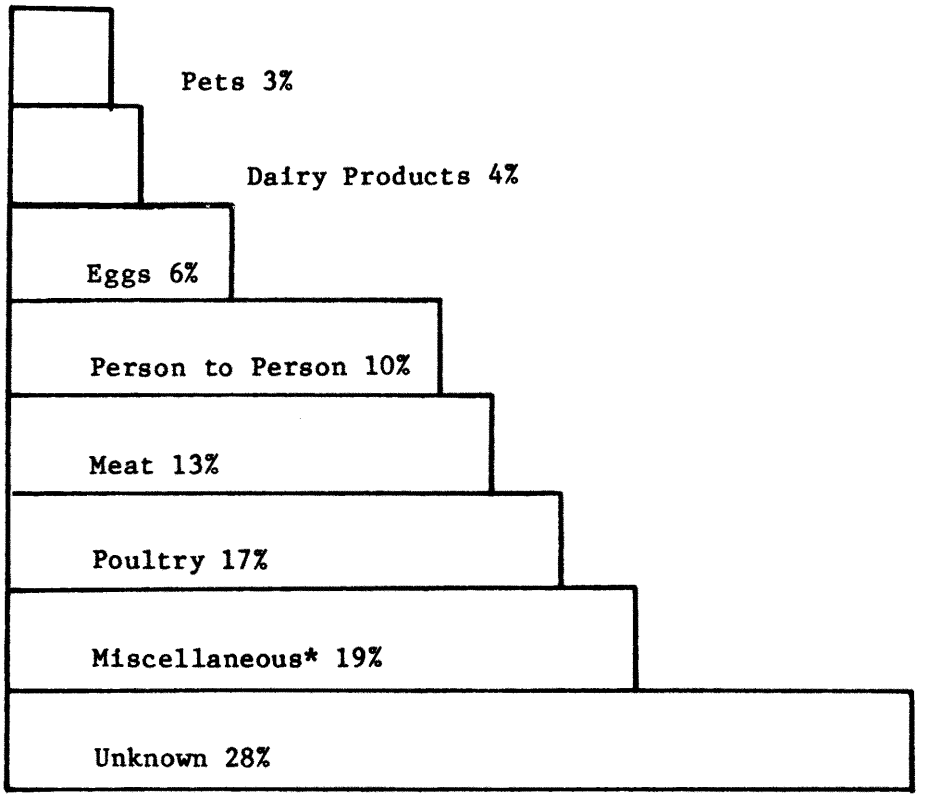
TABLE 2-1 Waterborne Diseases (Continued)

Biological Group	Associated Disease (Specific Agent)	Transmission	Incidence of Waterborne Disease	Comments
Leptospira	Leptospirosis (L. pomona) (L. grypotyphosa)	Water contaminated via animal urine	Yes, to swimmers	Infectious to man and animal
"Non-pathogenic" Bacteria	Gastroenteritis (Entero pathogenic E. coli, strains of Pseudomonas)	Water	Yes	
Viral Agents:				
Agent of Hepatitis A	Infectious hepatitis (hepatitis A)	Contaminated water and food	10 outbreaks are documented in U.S.	Water accounts for less than one percent of outbreaks in U.S.
Enteroviruses	Poliomyetis, aseptic menigitis (Polioviruses)	Person to person Contaminated water	Yes, rare in U.S.	
	Herpangima, aseptic meningitis, exanthem (Coxsackie Virus Group A)	Person to person	Yes	Only one case in 1974, A coxsakie virus was shown to be transmitted to bathers
	Aseptic meningitis, myocarditis, pericarditis (Coxsackie Virus Group B)	Person to person		
	Aseptic meningitis, exanthem, gastroenteritis	Person to person	No	

TABLE 2-1 Waterborne Diseases (Continued)

Biological Group	Associated Disease (Specific Agent)	Transmission	Incidence of Waterborne Disease	Comments
Adenovirus	Upper respiratory illness, pharyngitis, conjuctivitis	Person to person, contaminated water	Yes, swimmers	Based on epidemiologic evidence
Reoviruses	Upper respiratory illness, diarrhea, exanthem	Person to person	No	
Viral	Gastroenteritis and diarrhea	Person to person contaminated water	Yes	No specific causative agent, has been isolated
Parasitic Agents:				
Protozoan	Amoebic Dysentey		Yes	
	Meningoencephalitis (Naeglaria)		Yes, swimmers	
Helminth	Schistosomiasis "Swimmers itch"			Hosts are water fowl, man is infected by cercariae
	Round Worm (Ascaris lumbricoides)			
	Cestodes, tapeworms (Taenia sp.)			

Source: Cooper, 1974



*Fifty vehicles which each cause less than 3% of outbreaks

FIGURE 2-1 Mode of Transmission in 500 Human Salmonellosis Outbreaks, 1966-1975
Source: National Science Foundation, 1978

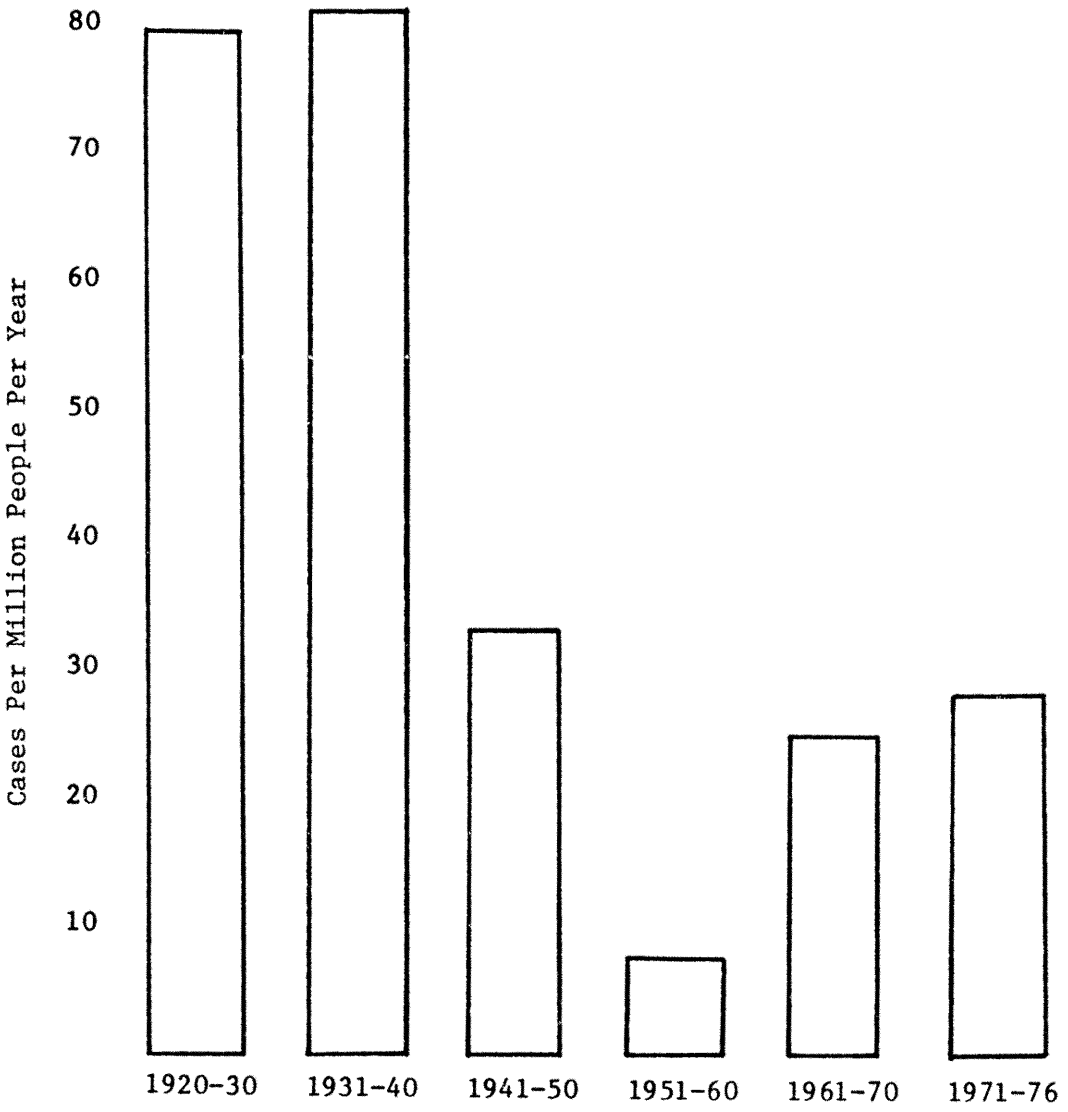


FIGURE 2-2 Incidence of Waterborne Disease 1920-1976
Source: National Science Foundation, 1978

- They should be prevalent in sewage.
- They should be excreted by humans and/or warmblooded animals.
- They should be present in greater abundance than pathogenic organisms and therefore more readily recovered.
- They should be more resistant to disinfectants than the pathogenic organisms.
- Their identification and enumeration should be through easily and quickly carried out laboratory procedures.

A number of organisms have been suggested as possible indicator organisms. Of these, the coliform and fecal streptococci groups will be discussed in more detail. These two indicator groups, especially the coliforms, have been traditionally used in the microbiological analyses of water samples throughout the United States.

2.3.1 The Coliform Group

The total coliform group includes all of the aerobic and facultative anaerobic gram-negative, non-sporeforming, rod-shaped bacteria that ferment lactose in 24 to 48 hours at 35°C. This includes the genera, Escherichia, Citrobacter, Enterobacter, and Klebsiella (U.S. EPA, 1978).

In 1884, Escherich isolated organisms from the stools of a cholera patient which he believed to be the cause of this disease. However, further investigation showed these organisms, Escherichia coli, were present in healthy individuals as well. Ten years after the identification of E. coli, Theobald Smith established the analytical means for isolation of these organisms by the inoculation of fermentation tubes with samples of water (AWWA, 1971). Coliforms have come to be recognized as an inherent characteristic of man's feces, with approximately 200 x 10^9 coliform cells excreted per capita per day (AWWA, 1971).

The total coliform group includes non-fecal as well as fecal bacteria. Non-fecal organisms may originate in the environment, e.g., Citrobacter aerogenes, found in soil.

The total coliform organism has been used in the examination of drinking water for approximately 70 years. The presence of any coliform organism in potable waters suggests inadequate treatment or contamination. This indicator of fecal pollution was first used in the United States in 1914, when it was adopted as a U.S. Public Health Service standard. Although the coliform organism may not always be indicative of fecal pollution, over the past 70 years there has been no significant outbreaks of cholera or typhoid as had been experienced in the past.

2.3.2 Fecal Coliforms

Fecal coliforms are part of the total coliform group. They are defined as gram-negative, non-sporeforming rods that ferment lactose in 24 $\pm$ 2 hours at 44.5 $\pm$ 0.2°C. Gas is produced in the multiple tube test, and acidity and blue colonies result in the membrane filter test (U.S. EPA, 1978).

The major species of this group is Escherichia coli. However, other organisms such as Klebsiella will also give positive results in the fecal coliform test. Knott (1978) states that these false-positive results are unlikely to occur in the majority of water pollution studies.

The fecal coliform indicator is the most widely used indicator of pollution when wastewater contamination is in question. At present, it is utilized as the primary indicator of recreational water hazards.

2.3.3 Fecal Streptococci

The fecal streptococci, when used as an indicator of fecal contamination, includes the serological groups D and Q, as identified in Figure 2-3 (U.S. EPA, 1978).

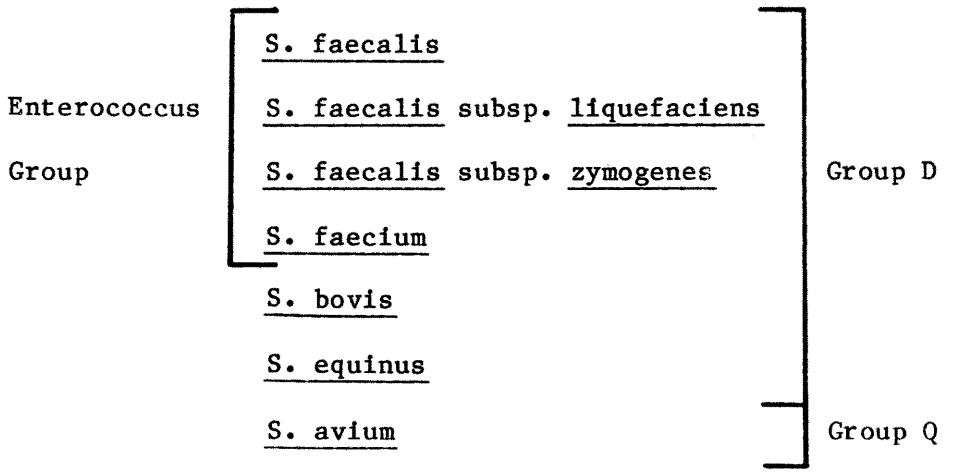


FIGURE 2-3 Fecal Streptococci Serological Groups

The fecal streptococci group are present in the feces of humans and warmblooded animals. They have not been shown to multiply in the environment and are considered non-pathogenic (Clausen, 1978).

This group of organisms has been used to verify the presence of fecal pollution but not as an indicator itself. The reason for this being that two varietes of S. faecalis are associated with vegetation and rarely occur in the feces of warmblooded animals. Therefore, the use of fecal streptococci alone may lead to erroneous indications of fecal contamination. It is suggested that fecal streptococci be tested for in conjunction with the fecal coliform test to confirm the presence of fecal pollution (Geldreich and Kenner, 1968).

2.3.4 Fecal Coliform Fecal Streptococci Ratio

Geldreich and Kenner (1969) proposed the use of a ratio of fecal coliform densities to fecal streptococci densities as a means of identifying the source of fecal contamination to a water body. The ratio of fecal coliform to fecal streptococci densities was found to be greater than 4.0 for man, and less than 0.7 for animals such as cats, dogs, and livestock. Table 2-2 presents some of the data developed by Geldreich and Kenner to demonstrate the application of this ratio to domestic wastewater and stormwater. The domestic wastewaters from various localities all exhibit ratios greater than 4, while stormwater which derives fecal pollution from domestic animals and wildlife, demonstrates ratios well below 0.7.

Survival of E.coli and S. faecalis were shown to demonstrate significant seasonal variations. During summer months fecal coliforms outlived fecal streptococci 3.3 days to 2.7 days. However, during winter months, fecal streptococci survived as long as 20 days, much longer than the fecal coliforms (Clausen, 1978). Evidence of this type suggests caution when using the ratio of these organisms. Geldreich and Kenner (1969) suggest that the use of such a relationship would be valid no longer than 24 hours after the contaminent entered the receiving stream.

2.3.5 Alternative Indicators of Water Contamination

Much of the recent literature is involved with alternative indicators of water contamination. Although the coliform group has served the public well for many years, researchers are looking for more certain indicators of pathogenic organisms. The following compiled by McFeters,

TABLE 2-2 Fecal Streptococci in Domestic Wastewater and Stormwater Runoffs

Water Source	Densities/100 ml* Fecal Coliforms	Fecal Streptococci	Ratio FC/FS
Domestic Wastewater:			
Preston, Ida.	340,000	64,000	5.3
Fargo, N.D.	1,300,000	290,000	4.5
Moorehead, Minn.	1,600,000	330,000	4.9
Cincinnati, Ohio	10,900,000	2,470,000	4.4
Lawrence, Mass.	17,900,000	4,500,000	4.0
Monroe, Mich.	19,200,000	700,000	27.0
Denver, Colo.	49,000,000	2,900,000	16.9
Stormwater:			
Business district	13,000	51,000	0.26
Residential	6,500	150,000	0.04
Rural	2,700	58,000	0.05

*Median values.

Source: Geldreich and Kenner (1969)

et.al. (1978) is a list of potential indicator organisms recently discussed in the literature.

- Clostridium perfringens - This organism was advocated for use as an indicator by Gunner Bonde. It is sporeforming and therefore is persistent in the environment and gives a good indication of the effectiveness of disinfectants. However, this organism is a strict anaerobe and is ubiquitous in nature. Therefore, its usefulness as a sanitary indicator is questioned.

- Klebsiella pneumoniae - This organism has been utilized in Britain as an indicator. It is not considered to be ubiquitous in nature but is found on vegetation. It is, however, capable of growth in the environment and therefore would not be considered a good indicator of fecal contamination. Note this species may be frequently enumerated as a total or fecal coliform.

- Aeromonas species - Several of these species are pathogenic to man and aquatic life. They are considered ubiquitous by some and are capable of long survivals in the water environment. For this reason, they are not considered to be good indicator organisms.

- Psedomonas species - These are opportunistic pathogens, ubiquitous in nature, and capable of enumeration in water. They are a health hazard. Waters containing these species are often lacking coliforms.

- Pathogenic microorganisms - The literature finds that no single pathogen satisfies the criteria of a good indicator.

- Others - Other organisms have been suggested such as coliphage and bifidobacteria. However, little information is available with which to evaluate their value as indicators.

2.4 Indicator Organisms and Their Correlation with Disease

The indicator organism is utilized to measure the degree of fecal contamination of a water body. It is assumed that if water is contaminated with the feces from a large number of people, the variation in the excretion of pathogens and indicators will average out to a ratio of indicators to pathogens. Hence, fecal contamination measured by large

numbers of indicator organisms presumes the presence of pathogenic organisms. In order for disease to result, contact with contaminated waters becomes a function of the dose of pathogens, duration of exposure, and health or resistance of the person making contact. From this discussion, it is evident that a chain of hypotheses exist which correlate the indicator organism with disease (National Science Foundation, 1978). These may be summarized as follows:

- The presence of fecal indicator bacteria suggests fecal contamination in a water body.
- For a given density of these indicator bacteria, pathogenic organisms from fecal materials will be present. (This is a function of the incidence of disease in the contributing population.)
- The greater the density of the pathogens measured by the indicator organism, the greater the risk of disease to the user of the water.

These hypotheses have been generally accepted for many years but have never been verified as such. There have been several attempts at quantifying some of these correlations, however, none successfully relate them directly to disease occurrence.

The bacterial indicator organisms correlate closer to the incidence of bacterial pathogens, as opposed to viral or parasitic pathogens. Geldreich (1970) related the number of fecal coliforms to the isolation of Salmonella in surface waters. Table 2-3 gives these relationships.

TABLE 2-3 Fecal Coliform-Salmonella Relationship in Fresh Water

Fecal Coliform/ 100 ml	Total Samples Examined	Percent Positive for Salmonella
1- 200	29	27.6
201-2,000	27	85.2
> 2,000	54	98.1

Source: Cooper, 1974

These data indicate that when the fecal coliform densities are greater than 200 per 100 ml, the chance for the isolation of salmonella is markedly increased. This relationship forms the basis of the Environmental Protection Agency's water quality criteria for recreational waters.

The correlation of indicator density to pathogen density is also compared based on die-off rates. Table 2-4 presents die-off data for indicator and pathogenic bacteria. Through the use of such data, an indicator might be chosen to describe a specific pathogen based on their comparable die-off rates. The problem with this, however, is that survival rates will differ for different aquatic environments (National Science Foundation, 1978).

With regard to disease whose etiology is viral, a number of studies point out that indicator bacteria have little relation to the presence of enteric virus. Differences between bacteria and viruses in their mode of behavior, replication, stability, and persistence in the environment suggest that a virus indicator would be more desirable to track enteric virus (Kraus, 1978). However, there is also evidence in the literature that there is no normal viral flora in humans or warmblooded animals, and therefore no virus to serve as an indicator. Only that portion of the population that is ill (or subclinically ill) may excrete virus at any given time. In addition, the methods for the cultivation and quantification of some of the important viral pathogens are unavailable (National Science Foundation, 1978). If the source of infectious agent is not fecal, as for example the soil ameoba Naegleria, a fecal indicator is of little value.

TABLE 2-4 COMPARATIVE DIE-OFF RATES OF FECAL INDICATOR BACTERIA AND ENTERIC PATHOGENS

Bacteria	Half-time* (hours)	No. of Strains Analyzed
Indicator bacteria		
Coliform bacteria (avg)	17.0	29
Enterococci (avg)	22.0	36
Coliform from raw sewage	19.5	
Streptococci from raw sewage	19.5	
Streptococcus equinus	10.0	1
S. bovis	4.3	1
Pathogenic bacteria		
Shigella dysenteriae	22.4	1
S. sonnei	24.5	1
S. flexneri	26.8	1
Salmonella enteritidis ser. paratyphi A	16.0	1
S. enteritidis ser. paratyphi D	19.2	1
S. enteritidis ser. typhimurium	16.0	1
S. typhi	6.0	2
Vibrio cholerae	7.2	3
S. enteritidis ser. paratyphi B	2.4	1

*The half-time was determined graphically from the time required for a 50% reduction in the initial population.

Source: National Science Foundation, 1978

Despite the lack of data to support the chain of hypotheses stated above, these relationships comprise a basis for many important public decisions. They have established the need for sewage treatment to realize reduced coliform levels; they are the basis for testing waters to determine suitably for recreation; and they are utilized as the best indicator of the safety of potable waters.

2.5 The Coliform Standard

The decision by adminstrators to protect the public from fecally contaminated waters has resulted in water quality standards, based on indicator organisms. Water quality standards are generally established, fixed, numerical values against which the results of chemical analyses are compared. The use of indicator organisms has resulted in standards which specify a level or density of these organisms which constitute "safe" water for a given use.

Recent literature supports the use of a variety of indicators to be utilized in testing waters for potential health hazards. The choice of these organisms would depend on the use of the waters being examined. Table 2-5 is a list of indicator organisms as well as pathogens that might be isolated when testing waters for a specific use (National Science Foundation, 1978).

Current standards utilize the coliform bacteria as a measure of fecal pollution. As previously mentioned, the coliform standard was first utilized by the U.S. Public Health Service. The development of the U.S. Public Health Service standards for drinking water from 1914 to the 1977 regulations is presented in Table 2-6. It is of interest to note,

TABLE 2-5 Relationship Among Tests for Various Indicators and Pathogens and Water Sources

Indicator/Pathogen	Drinking Water	Effluent Discharge	Swimming Pool	Recreational Beach Waters	Shellfish Waters	Irrigation Waters	Comments
Coliform	****						Still one of the best indicators for drinking water safety, but should be supported by heterotroph plate counts.
Fecal coliform							
E. coli	*(a)	****	**	****	****	****	
Fecal streptococci		*		***	***		Main purposes is to try to establish source of pollution.
Ps. aeruginosa		*	***	***			Simple reliable test-organism man and sewage related.
Clostridium perfringens	*(a)			*(b)	**		Historical pollution.
Bifidobacterium				**	**(c)		New indicator-to establish validity and and specificity.
Coagulase positive staphyloccocci			***	**			
Salmonella	*(a)	*			**(c)	*	

TABLE 2-5 Relationship Among Tests for Various Indicators and Pathogens and Water Sources (Continued)

Indicator/Pathogen	Drinking Water	Effluent Discharge	Swimming Pool	Recreational Beach Waters	Shellfish Waters	Irrigation Waters	Comments
Vibrios					***(c)		*Vibrio parahaemolyticus* emphasized, NAG vibrios considered.
Fecal sterols	*(a)	**		**	**	*	Absolute indicator of fecal material-to establish relationship between this and other indicators.
Candida albicans		*	**	**			Simple reliable test-organism related to human activity.
Fungi				*(b)			To collect data on relationship between occurrence of organism and skin infections.
Viruses	**	*	*	*	***(c)	*	May have greater role in drinking water safety when technology is simplified.

TABLE 2-5 Relationship Among Tests for Various Indicators and Pathogens and Water Sources (Continued)

Indicator/Pathogen	Drinking Water	Effluent Discharge	Swimming Pool	Recreational Beach Waters	Shellfish Waters	Irrigation Waters	Comments
Phage (bacteria)	*(d)	*		*			May be relationship between trophic status/phage. Indication between Enterobacteria and phage.
Heterotrophs	****	*		**			Indicator of productivity of water and therefore deterioration.

Indicator Rating

**** Regularly = daily
*** Routinely = once weekly
** Occasionally = 10 to 20 times per year
* Special problem studies

(a) Well waters or tracing infections
(b) Sediments and/or sands
(c) Shellfish, water, and sediments
(d) Ensuring water main safety after breakdowns

Source: National Science Foundation, 1978

TABLE 2-6 Development of the U.S. Public Health Service Drinking Water Standards

Criterion	1914	1925	1942	1946	1962	1977
			Bacteriological Constituents			
Plate count	Total bacterial count on agar plate not to exceed 100 per ml.					
Coliform bacteria (*B. coli* prior to 1942) a. Dilution technique (five 10-ml portions	Not more than one of the five portions examined from each sample shall show presence of *B. coli* (*B. coli* MPN <2.2 per ml).	1. Not more than 10% of all portions examined shall show presence of *B. coli* (*B. coli* ≤0.9 per 100 ml).	1. Not more than 10% of all portions examined each month shall show presence of coliform bacteria (coliform MPN <1.0 per 100 ml).	Same as 1942	Same as 1942	1. Same as 1942
		2. Not more than 5% of all samples examined shall show presence of *B. coli* in three or more of the five portions examined.	2. No two consecutive samples taken from the same location, and not more than one (or 5%) of all samples examined each month, shall show presence of coliform bacteria in three or more of the five portions.			2. Not more than one (or 5%) of all samples examined each month, shall show presence of coliform bacteria in three or more of the five portions.
b. Dilution technique (five 100-ml portions)			1. Not more than 60% of all portions examined each month shall show presence of coliform bacteria (coliform MPN ≤1.0 per 100 ml).	Same as 1942	Same as 1942	1. Same as 1942

TABLE 2-6 Development of the U.S. Public Health Service Drinking Water Standards (continued)

Criterion	1914	1925	1942	1946	1962	1977
			Bacteriological Constituents			
			2. No two consecutive samples taken from the same location, and not more than one (or 20%) of all samples examined each month, shall show presence of coliform bacterial in all five portions examined.			2. Not more than one (or 20%) of all samples examined each month shall show presence of coliform bacteria in all five portions.
c. MF[1] technique (using 50, 100, 200, or 500 ml)					1. The arithmetic mean coliform count for all samples examined each month shall not exceed one per 100 ml. 2. The coliform count shall not exceed three per 50 ml, four per 100 ml, seven per 200 ml, or thirteen per 500 ml in two consecutive samples taken from the same location, nor in more than one (or 5%) of all samples examined each month.	

TABLE 2-6 Development of the U.S. Public Health Service Drinking Water Standards (continued)

Criterion	1914	1925	1942	1946	1962	1977
			Bacteriological Constituents			
d. MF[1] technique (using 100 ml)						1. The arithmetic mean coliform count for all samples examined each month shall not exceed one per 100 ml. 2. The coliform count shall not exceed four per 100 ml in one sample (for <20 samples) or 5% of all samples when >20 samples are examined per month.

[1]MF = Membrane Filter Technique

Source: AWWA, 1971.

that the only major change in these standards is related to the introduction of the membrane filter techniques; and that the number of permissible organisms has remained relatively the same.

The Environmental Protection Agency (EPA) has established water quality criteria which provide recommended standards, acceptable to the federal government, for use by other regulatory agencies. The Quality Criteria for Water, 1976, cite the fecal coliform indicator organism as important to the protection of bathing waters and shellfish harvesting waters. Pertinent to this study, the bathing waters criteria is as follows:

> Based on a minimum of five samples taken over a 30 day period, the fecal coliform bacterial level should not exceed a log mean of 200 per 100 ml, nor should more than 10 percent of the total samples taken during any 30 day period exceed 400 per 100 ml.

The Colorado Department of Health, Water Quality Control Commission has published regulations establishing basic water quality standards for Colorado state waters, effective July 10, 1979. Waters of the state have been categorized into various use classifications; these are recreation, agriculture, aquatic life, and domestic supply. A brief identification of these classes and the bacteriological standards designated for each use, is presented in Table 2-7. The fecal coliform values presented in this table are utilized by the State Water Quality Control Commission in assigning water quality standards to waters throughout the state. Colorado makes no recommendations on bacteriological parameters with regard to agricultural or aquatic life use classifications. This is consistent with EPA criteria. The 1972 Water Quality Criteria compiled by the National Academy of Sciences and the National Academy of Engineers (1973) devoted several pages of discussion to this topic and developed the following criteria for waters utilized in irrigation:

TABLE 2-7 Colorado State Use Classifications and Standards

Use	Class	Description	Fecal Coliforms per 100 ml
Recreation	1 - Primary Contact	Surface waters suitable or intended to become suitable for prolonged and intimate contact with the body or for recreational activities when the ingestion of small quantities of water is likely to occur.	200
	2 - Secondary Contact	Surface waters suitable or intended to become suitable for recreational uses on or about the water which are not included in the primary contact subcategory.	2,000
Agriculture		Waters suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.	--
Aquatic Life	1 - Cold Water Aquatic Life 1 - Warm Water Aquatic Life 2 - Cold and Warm Water Aquatic Life	Surface waters suitable or intended to become suitable for the protection and maintenance of aquatic life forms as described by classes.	--
Domestic Water Supply	1 - Uncontaminated Groundwaters	Groundwaters which receive a high degree of natural protection and meet, without treatment, all Colorado drinking water regulations and any revision, amendments, or supplements thereto. Colorado drinking water regulations require disinfection of all domestic water supplies regardless of source unless a waiver is obtained.	0
	2 - Waters Requiring Disinfection and/or Standard Treatment	Waters which after receiving approved disinfection such as simple chlorination or its equivalent or which after receiving standard treatment will meet Colorado drinking water regulations and any revisions, amendments, or supplements thereto.	2,000

Source: Colorado Department of Health, 1979.

> Irrigation waters below the fecal coliform density of 1,000/100 ml should contain sufficiently low concentrations of pathogenic microorganisms that no hazards to animals or man result from their use or from consumption of raw crops irrigated with such waters.

The 1972 criteria goes on to state that in the use of wastewater effluents for irrigation, the above density of fecal coliforms bacteria is also recommended.

A contrasting view of adequate coliform densities for agricultural waters utilizing treated municipal wastewaters is presented in the California wastewater reclamation requirements. A brief outline of these standards is given in Figure 2-4. The coliform counts presented are those of total and not fecal coliform densities.

The State of Colorado has not addressed the issue of wastewater reclamation directly, and has omitted it as a potential use category. As this category has no precedent at the federal level, Colorado standards have in essense been consistent with federal policy.

No federal or Colorado state standards exist with fecal streptococci densities as an indicator of fecal pollution. However, these organisms when used in conjunction with fecal coliform bacteria serve to identify a pollution source, i.e., man or animal.

Standards by themselves do not reduce the disease risk attributed to the use of polluted waters. They do provide the levels of achievement necessary for responsible parties to properly maintain and improve our waters (Morrison, 1978). Microbiological standards have had a tremendous impact on the protection of public health. Morrison (1978) exemplified the role of microbiological testing in a graphic representation of typhoid cases in Philadelphia from the 1880's to 1945, as shown in Figure 2-5. Along with the technologies of filtration and chlorination, the

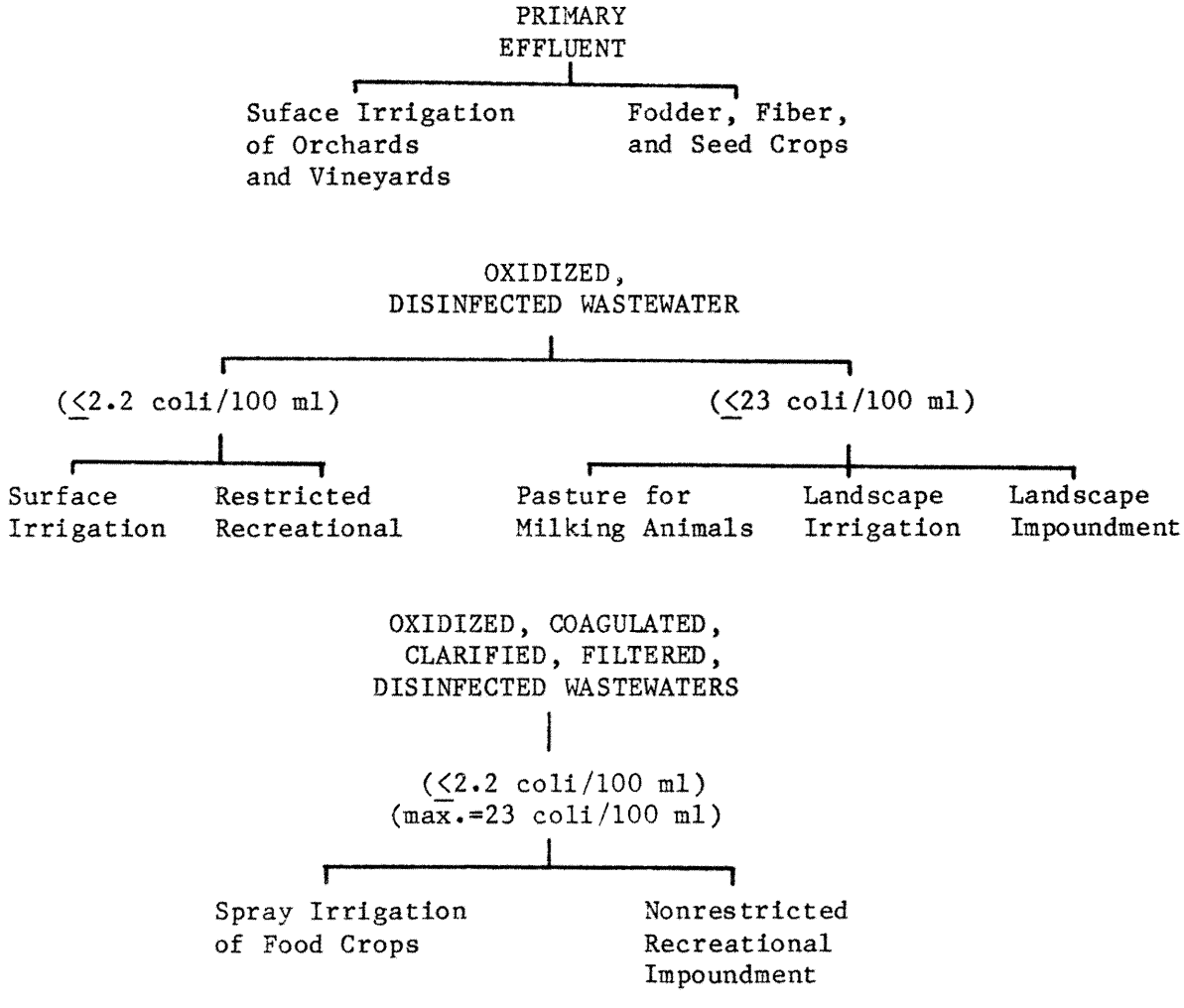


FIGURE 2-4 California Wastewater Reclamation Quality Requirements
Source: Crook, 1978

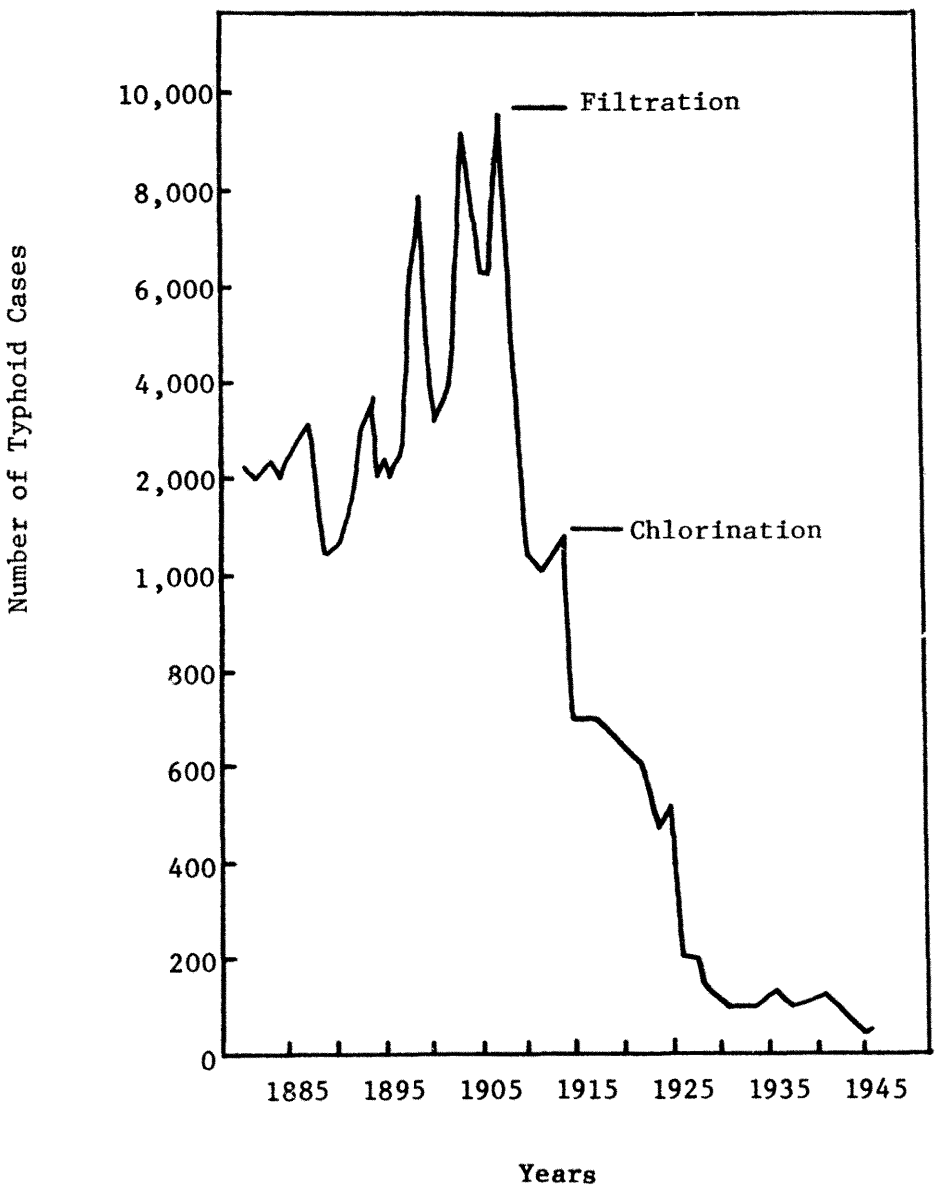


FIGURE 2-5 Reduction of Typhoid Fever in Philadelphia Following Treatment of the Water Supply
Source: Morrison, 1978

major decreases in the outbreaks of this disease also correlate quite well with the publication of the 1905 edition of Standard Methods, (where the first standardized laboratory procedures, including microbiological testing, were established for water quality monitoring) and the 1914 implementation of the U.S. Public Health Drinking Water Standards.

2.6 Treated Wastewater Effluents and Their Association with Waterborne Disease

Many of the examples correlating wastewater with the incidence of waterborne disease have been traced to the contamination of a water supply or water body with raw sewage. Little work has been done in linking disease occurrence to treated municipal wastewater effluents. However, the promotion of the reuse of these waters, especially in the application of wastewaters directly to agricultural lands, has led researchers to investigate the potential health hazards associated with this practice.

Loehr et al., (1979) in an evaluation of land treatment practices states, "no disease transmission has been documented from any planned, properly operated land treatment system in the United States." Therefore, the evaluation of potential health hazards lies in the understanding of the occurrence of pathogens in treated wastewaters, and of their fate in the environment.

The number of pathogens applied to soil when utilizing secondarily treated and chlorinated wastewater effluents is presented in Table 2-8. In this table pathogen density is based on the assumption of an average efficiency of removal by the treatment process.

TABLE 2-8 Estimated Wastewater Pathogens Applied to Soil

Pathogen	Raw Wastewater	Number of Organisms Per Million Gallons Primary Effluent	Secondary Effluent	Disinfection(a)	Organisms Applied Per Acre Per Day(b)
Salmonella	2×10^{10}	1×10^{10} (50%)(c)	5×10^{8} (95%)	5×10^{5}	3.9×10^{3}
Mycobacterium	2×10^{8}	1×10^{8} (50%)	1.5×10^{7} (85%)	1.5×10^{4}	1.2×10^{2}
E. histolytica	1.5×10^{7}	1.3×10^{7} (50%)	1.2×10^{7} (10%)	1.2×10^{4}	9.3×10^{1}
Helminth ova	2.5×10^{8}	2.5×10^{7} (50%)	5×10^{6} (80%)	5×10^{3}	3.9×10^{1}
Virus	4×10^{10}	2×10^{10} (50%)	2×10^{9} (90%)	2×10^{6}	1.6×10^{4}

(a) Conditions sufficient to yield a 99.9% kill
(b) Applied at a rate of 2 inches per week
(c) Estimated pathogen percentage removal efficiency of the treatment
Source: Sagik et al., 1978

Table 2-9 gives the estimated range of concentrations of selected indicator organisms in raw wastewater and after secondary treatment. It has been found that 2 to 6 mg/l of chlorine, if applied for 20 minutes, would effectively kill 99.99 percent of these organisms (SCS Engineers, 1978).

TABLE 2-9 Estimated Number of Indicator Organisms (count/100 ml)

Indicator Organism	Range In Raw Wastewater	Percent Removal After Secondary Treatment*
Total coliforms	1×10^6 to 4.6×10^7	90 to 99
Fecal coliforms	3.4×10^5 to 4.9×10^7	90 to 99
Fecal streptococci	6.4×10^4 to 4.5×10^6	84 to 94

*Activated sludge treatment process
Source: SCS Engineers, 1978

Sagik et al., (1978) points out that many of the data cited for pathogenic removal by chlorination are based on the addition of "free" organisms to the water. In wastewater many organisms are associated with solids or particles. This condition of particle association affects the rate and degree of disinfection. Therefore, much of this type of data may actually overestimate the efficiency of removal by chlorination.

The survival of pathogens in environments outside of the body contributes to the chance of pathogen transfer to another susceptable host. Pathogens have been shown to survive in soil, water, plant, and aerosol environments (Loehr et al., 1979). Data on the survival of pathogens in soil and on vegetation is given in Table 2-10.

TABLE 2-10 Survival of Selected Pathogens

Organisms	Media	Survival Time
Salmonella	Vegetables, fruits	3-49 days
	Grass or clover	12-more than 42 days (and over winter)
	Soil	15-more than 280 days
Salmonella typhi	Soil	1-120 days
Tubercle bacilli	Grass	10-49 days
	Soil	More than 180 days
Entamoeba histolytica cysts	Vegetable	Less than 1-3 days
	Soil	6-8 days
Enteroviruses	Vegetables	8 days
	Soil	8 days
Ascaris ova	Vegetables, fruits	27-35 days
	Soil	Up to 7 years
Hookworm larvae	Soil	42 days

Source: Loehr *et al.*, 1979

Katzenelson and Shuval (1979) reported epidemiological evidence of disease risk associated with wastewater irrigation. Their study compared 77 kibbutzim (in Israel) utilizing wastewater effluent in irrigation, to 130 kibbutzim which did not. The incidence of disease was found to be two to four times as great in the kibbutzim using wastewaters for irrigation. The wastewaters utilized, although partially treated by oxidation ponds, did not receive disinfection and were found to contain a high level of enteric organisms, approaching that of raw sewage.

In a study by Weaver et al., (1978) land application, utilizing treated sewage effluent in San Angelo, Texas, was evaluated for potential health hazards. The only apparent hazard was indicated by a high level of coliform counts in the waters of seepage creeks. These creeks collected the runoff from the applied wastewater effluent. The waters contained total and fecal coliform counts ranging from 1,000 to 100,000 organisms per 100 ml. Salmonella was isolated in the effluent sewage applied to the land, in the soil, and in the seepage creeks. The fecal coliform and fecal streptococci ratios from the soil and creeks indicated the pollution source to be the sewage effluent and not grazing cattle. Human parasites were rarely detected in the effluent and it was felt that the majority of the parasites settled out in the sludge.

Dunlop and Wang (1961), in field studies performed in Colorado, recovered Salmanella, Ascaris ova, and Endamoeba coli cysts from over 50 percent of the irrigation waters they sampled. These waters were contaminated with either raw or primary chlorinated effluents. Today secondary treatment is required by all municipal wastewater treatment

plants in Colorado. According to Table 2-8, this should mean a greater reduction in the number of organisms discharged to the irrigation waters. However, the tremendous population growth in Colorado has resulted in increased municipal discharge to surface waters, therefore, fecal contamination may still be evident.

2.7 Summary

In conclusion, the following points are brought out by the literature:

- Waterborne diseases are indeed transmitted via the water route. They have, in some cases, been linked directly to sewage contamination.
- The chain of assumptions correlating indicator organisms to disease remains unsubstantiated.
- Indicator organisms have been traditionally utilized to indicate potential health risks. They are still utilized today in lieu of concrete epidemiological data.
- Coliforms have been the group most widely utilized in the United States as indicator organisms.
- The choice of indicator organisms should be tied to the type and use of the waters examined.
- It is often best to use more than one indicator organism in determining fecal contamination and/or potential health risk.
- The United States has experienced a low incidence of waterborne disease for the last 70 years. However, the future remains uncertain.
- Effluents subject to treatment, with or without disinfection, may still contain a significant number of pathogenic organisms. These organisms have been found to survive for varying periods of time outside of a host, and in a number of environmental conditions.

3.0 METHODOLOGY

3.0 METHODOLOGY

3.1 Introduction

The conclusions borne out by the literature serve as the basis for the methodology that follows. It has been shown that the use of indicator organisms to identify health hazards is based on a chain of assumptions. Therefore, the proper term for this hazard would be a "presumptive" health hazard. As it is extremely difficult to get a direct relationship between the presence of the indicator organism and the incidence of disease, it is necessary to follow an empirical approach in order to evaluate the presumptive health hazards that may exist in Colorado's South Platte River Basin. The following sections summarize the methodology and discuss the limitations incurred by this approach.

3.2 Research Approach

In order to determine what are the presumptive health hazards associated with the wide spread implementation of ditch and canal systems to convey municipal wastewaters, the research utilized the following approach:

- Indicator organisms were chosen to identify and quantify fecal contamination.
- A basin wide picture, based on available historical data of microbiological parameters, was developed for the South Platte River Basin.
- Confirming field sampling and testing to support historical data, was conducted on a local canal system used to convey municipal wastewaters.

3.2.1 Utilization of Indicator Organisms

The indicator organisms utilized in this study are total coliforms, fecal coliforms, and fecal streptococci. These organisms are the most widely used in the bacterial monitoring of waters and wastewaters in the United States. Their use is consistent with historical practices.

The degree of health risk to the public is evaluated based on the density of these organisms in a water body. The Colorado State, 1979 Basic Standards are utilized as a guideline with which to make this evaluation. These standards have been given in Table 2-7 and are briefly summarized as follows:

- Domestic water supply: Class 1 0 fecal coliforms/100 ml
  Class 2 2,000 fecal coliforms/100 ml
- Recreational waters: Class 1 200 fecal coliforms/100 ml
  Class 2 2,000 fecal coliforms/100 ml
- Agricultural water: No recommendation

In lieu of a "no recommendation" standard for agricultural water use, a standard of 1,000 organisms per 100 ml as developed for irrigation waters by the National Academy of Sciences and the National Academy of Engineers (1973) will be utilized along with the standards outlined above.

3.2.2 Existing Microbiological Field Data

In order to develop a basin wide picture of water quality with respect to microbiological parameters, information on fecal coliform and fecal streptococci densities was gathered through the use of the Environmental Protection Agency's (EPA) STORET program. The STORET computer program acts as a data base for the storage and collection of water quality parameters. It is utilized by a number of federal

agencies. There currently exists over 1,600 sampling stations within the STORET program for the South Platte River Basin. Many of these may have been used only once during the lifetime of the project for which they were created. From these known stations, 99 were chosen to be evaluated in this study. They were chosen on the basis of location, number of samples obtained, and duration of sampling at the site.

Data of the municipal wastewater dischargers within the South Platte River Basin were also collected. Only those municipal treatment plants with effluent discharges greater than 0.1 million gallons per day (MGD) were recorded.

3.2.3 Confirming Field Testing

As historical data for the South Platte River Basin was being compiled, field sampling and testing on a local canal system was conducted. A canal, which received sewage effluent, was sampled and tested for total and fecal coliform counts, and fecal streptococci densities. These results were compared for trends with the historical data.

3.3 Limitations

The paucity of epidemiological data makes it difficult, at best, to correlate public health risk with public contact of contaminated waters. The EPA epidemiologist, Colonel Graig H. Llewellyn states:

> We have increasingly sophisticated techniques for monitoring large amounts of wastewater and biological and chemical agents, and we are able to detect ever lower levels in the samples. We can similarly detect effects from these agents in laboratory animals and in some humans, but under poorly defined conditions. But between these sources of data we simply do not have the methodology to discern, trace, and document these variables which in various areas translate

> the presence of a measurable level of an agent in the environment into a documented health hazard with identifiable human health effects. Epidemiology as a discipline provides strategies for observation. The observations are dependent upon the detection and measurement technology available. This is a critical deficit...Thus epidemiology cannot provide the critical data required for defining health effects and therefore for risk assessment (Llewellyn, 1977).

For this reason, an empirical approach based on the occurrence and density of fecal indicator organisms was utilized to evaluate health risk to the public. This method is not without limitations. The following sections discuss the limitations involved with using STORET data and the absolute values derived from microbiological testing.

3.3.1 Historical Data

The use of the EPA STORET data presents several limitations. These limitations are in the overall data presentation, and sampling and testing information.

The data was collected as a statistically compiled package of arithmetic means and standard deviations of bacteria densities for a given sampling location. The application of arithmetic mean is not desirable as the distribution is usually skewed due to the many low and few extremely high counts. For this reason, a logarithmic transformation is utilized. This may be accomplished through the use of the geometric mean as opposed to the arithmetic mean (EPA, 1978). However, given the arithmetic mean, one cannot convert to the geometric mean. Therefore, the data presented through the utilization of STORET will give means considerably larger than the median.

Different analytical techniques will also lead to misrepresentation of the data. The STORET data does provide for the identification of the

analytical method used in determining density counts, but limits this identification to the membrane filter technique (MF), and the most probable number technique (MPN). Due to recent developments of variations on these techniques, and the materials utilized in them, this is not enough of a distinction. There can be significant differences in coliform recovery due to filter type, organisms tested, and growth mediums utilized (Lin, 1977).

Also missing from the STORET data are river flows at time of sampling, the number of samples taken at any one time, and an indication of the possible impact of precipitation events. All of the above would aid in the development of an understanding of test results as they may greatly influence bacterial counts.

Even with the above limitations, the STORET data provides the largest data base for the collection of microbiological densities within the South Platte River Basin. The number of samples alone should aid in making the data representative.

3.3.2 Analytical Procedures

As brought out in the preceding section, different analytical techniques will lead to different recoveries of coliform densities. The methods utilized in the field study on a local canal may not be comparable with other data collected. Therefore, all data has been evaluated from an order of magnitude perspective. Coliform density counts do not represent absolute numbers, but are representative of a range of densities. Comparisons made on an order of magnitude basis are considered valid for the purposes of this study.

4.0 HISTORICAL BACTERIOLOGICAL DATA FOR THE SOUTH PLATTE RIVER BASIN

4.0 HISTORICAL BACTERIOLOGICAL DATA FOR THE SOUTH PLATTE RIVER BASIN

4.1 Introduction

The South Platte River Basin provides an excellent laboratory in which to evaluate potential health risks to the public. This is due to the extensive use made of surface waters in carrying municipal wastewater effluents to agricultural lands. Historical data of fecal coliform and fecal streptococci counts were compiled to develop a basin wide picture of fecal contamination. Information on total coliform counts was not developed, as these organisms are ubiquitous in nature and are not directly indicative of fecal contamination in surface waters.

Historical data was compiled from the EPA's STORET program. Trends or variations in the indicator organism densities throughout the basin were sought. These densities were compared to the bacteriological standards enforced by the State of Colorado. In addition, a summary of current municipal dischargers was compiled from information made available by the Colorado Department of Health and the environmental agencies of Nebraska and Wyoming. This data was utilized to assess the impact of these dischargers on the observed coliform densities throughout the basin.

The following sections provide a brief background on the South Platte River Basin. In addition, the historical data on indicator organism densities gathered through STORET are presented and analyzed.

4.2 Description of the Study Area

The South Platte River Basin is a part of the Missouri River Basin system as shown in Figure 4-1. It is located in the States of Colorado,

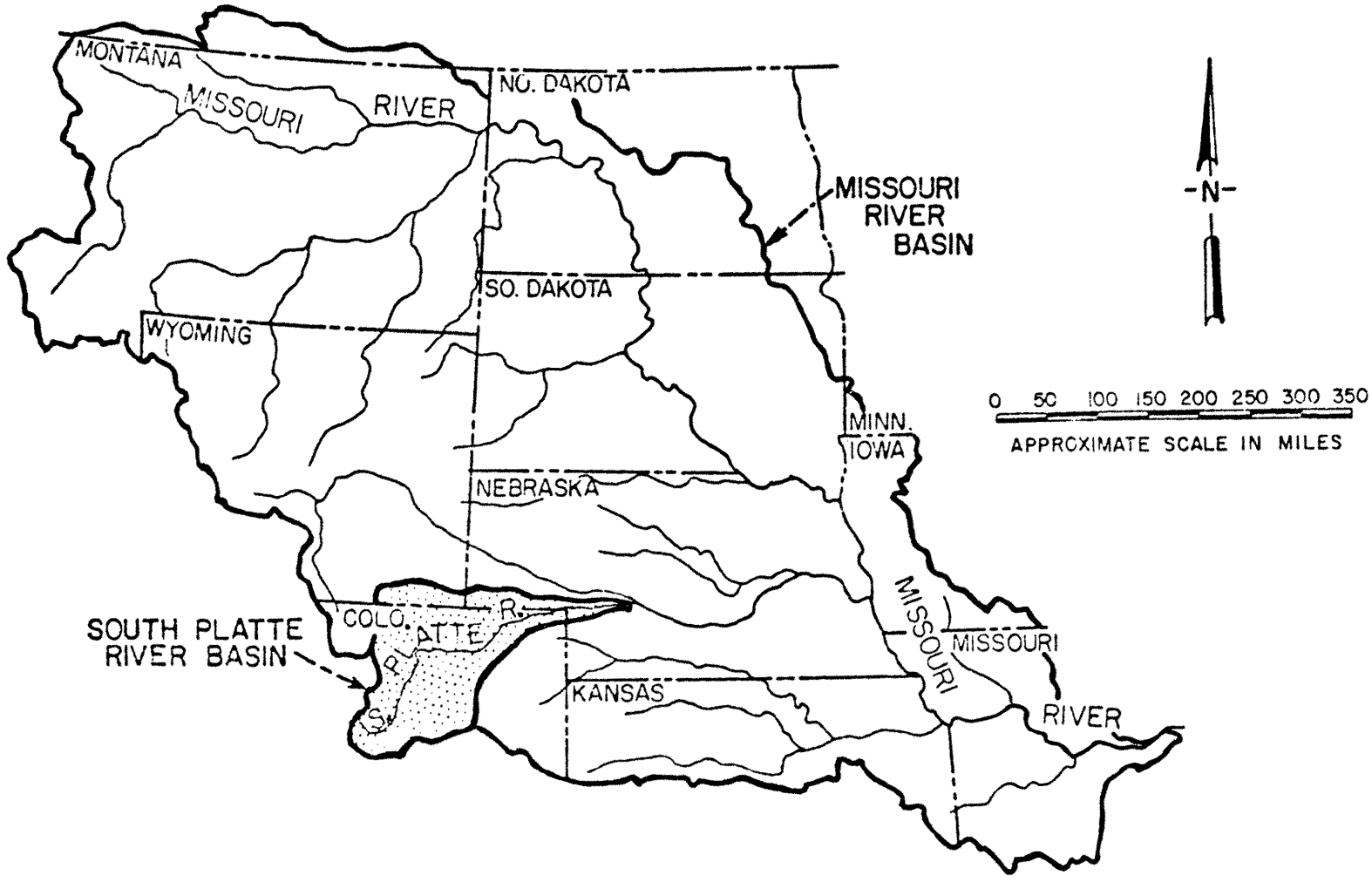


FIGURE 4-1 Location Map-South Platte River Basin

Source: Hendricks et at.,1977

Wyoming, and Nebraska (Figure 4-2). The total basin area is approximately 24,300 square miles, with 19,450 square miles or 80 percent in Colorado (Engineering Consultants, Inc., 1974).

The South Platte River Basin falls within two major geographic areas, the mountain area and the plains area. These vary greatly in topography, climate, and ecology.

Approximately 25 percent of the basin is in the Rocky Mountains (Engineering Consultants, Inc., 1974). The mountains have an abundance of vegetation and a more diverse wildlife than found on the plains. Temperatures are much colder, and roughly 50 inches of moisture equivalent is common along the Continental Divide. Much of this land is utilized for National Parks and Forests (Bluestein and Hendricks, 1975).

The plains area is principally a grassland ecosystem. Today, however, it has been greatly modified by urban, industrial, and agricultural development. The climate is semi-arid with precipitation averaging 14.20 inches a year at Stapleton International Airport in Denver (Bluestein and Hendricks, 1975).

Elevation is important to the vegetation and climate of the basin. Mount Lincoln in Park County is the highest point in elevation at 14,284 feet. This is contrasted to the elevation at the mouth of the South Platte which is 2,795 feet (Engineering Consultants, Inc., 1974).

The South Platte River is approximately 450 miles from source to mouth (U.S. Department of the Interior, 1966). Originating along the eastern slope of the continental divide, it flows south and then east through the mountains. The South Platte River heads north at the outlet of Eleven Mile Canyon Reservoir and emerges from the Rocky Mountains about 15 miles south of Denver. It continues north to Greeley, then

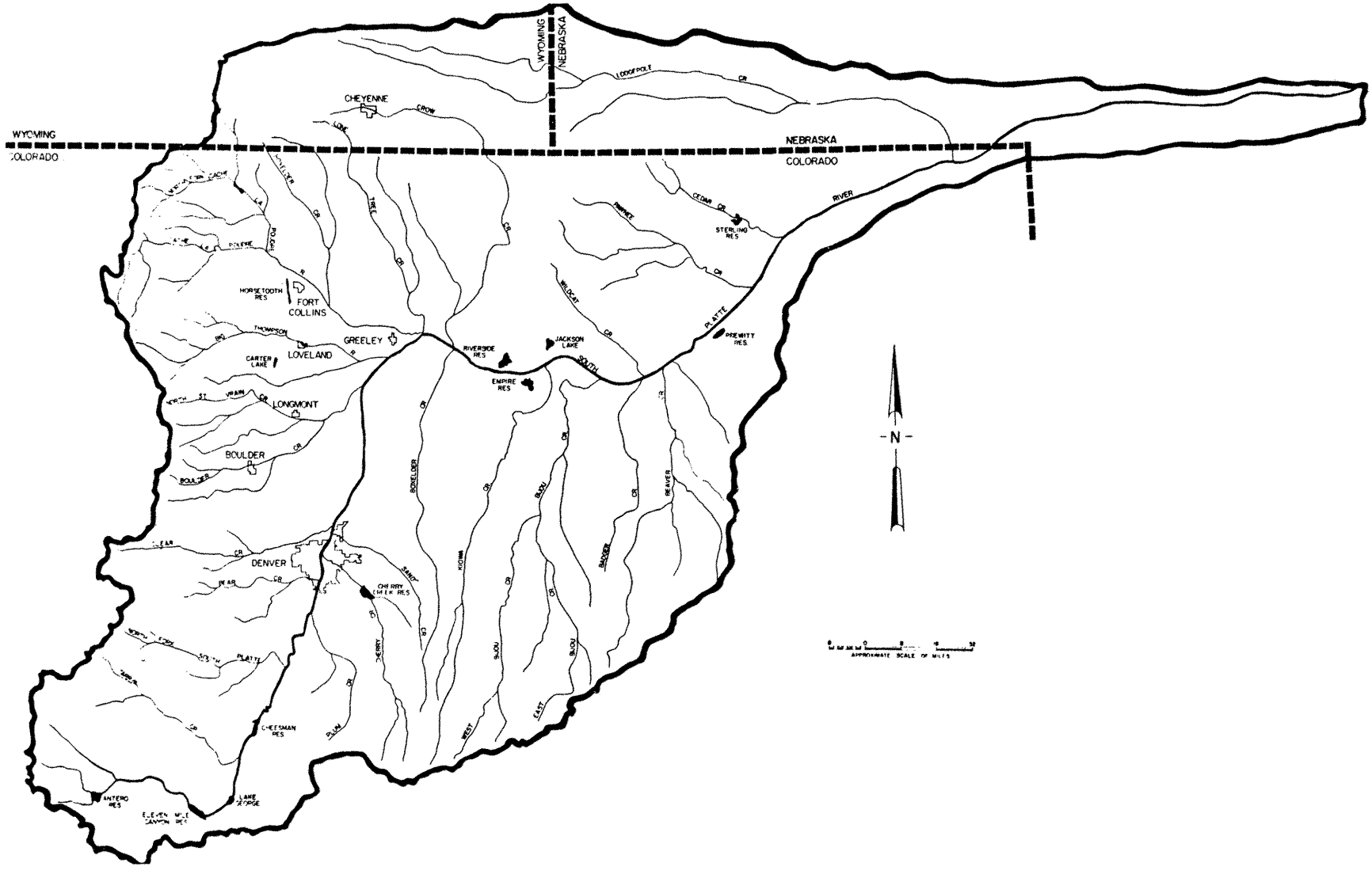


FIGURE 4-2 South Platte River Basin

Source: Hendricks et al., 1977

heads northeast to join the North Platte River at North Platte, Nebraska. At this point, the North Platte and the South Platte form the Platte River, which flows on to the Missouri River.

The major tributaries which join the South Platte River on its route from the Rocky Mountain to Nebraska are given in Table 4-1. Subbasins and their drainage area are provided in Table 4-2.

Water inputs to the South Platte River Basin are comprised of surface runoffs, imported waters, and point and non-point return flows. Bluestein and Hendricks (1975) developed a water account for the South Platte Basin which is presented in Table 4-3. It can be seen that secondary supplies or reuse waters comprise 35.9 percent of the total supplies to the basin. Of these, 44.7 percent are from point sources such as municipal and industrial wastewater discharges.

Settlement within the South Platte River Basin began with the gold rush in Colorado in 1858. Mining flourished, and irrigated agriculture soon developed. Water has always been a major concern in the growth of the basin, and to some extent has dictated development and demography. Table 4-4 presents population data for 1970 and 1980 for those counties located within the South Platte River Basin.

4.3 Results

4.3.1 Introduction

The STORET data on fecal coliform counts have been organized for presentation with the following questions in mind:

- Is there evidence of fecal contamination within the surface waters of the South Platte River Basin?

TABLE 4-1 Major Tributaries to the South Platte River Basin

Description	Miles Upstream from Mouth of the South Platte River
Confluence-North and South Platte River, Nebraska	0.0
Lodgepole Creek	95.2
Crow Creek	241.7
Cache La Poudre River	249.0
Big Thompson River	260.4
St. Vrain Creek	270.0
Big Dry Creek	288.6
Clear Creek	311.1
Sand Creek	312.1
Cherry Creek	317.7
Bear Creek	326.4
North Fork of South Platte River	350.8
Cheeseman Lake	372.4
Tarryall Creek	383.1
Eleven Mile Reservoir	403.7
Middle Fork of South Platte River	426.2
South Fork of South Platte River	426.2

Source: U.S. Department of the Interior, 1966

TABLE 4-2 Subbasins of the South Platte River Basin

Code	Description	Drainage Area (square miles)
01	South Fork Subbasin	1,558
02	North Fork Subbasin	1,803
03	Cherry Creek Subbasin	2,824
04	Clear Creek Subbasin	553
05	St. Vrain Subbasin	974
06	Big Thompson Subbasin	809
07	Cache La Poudre Subbasin	1,851
08	Owl Creek Subbasin	564
09	Crow Creek Subbasin	1,384
10	Plains Subbasin	725
11	Plains Subbasin	1,375
12	Plains Subbasin	2,866
13	Plains Subbasin	1,073
14	Plains Subbasin	726
15	Upper Lodgepole Creek Subbasin	1,096
16	Lower Lodgepole Creek Subbasin	1,340
17	Sidney Draw Subbasin	732
18	Lower South Platte Subbasin	1,384

TABLE 4-3 Water Accounting for the South Platte Basin

Primary Supplies:		
Imports	336,000	
Surface runoff	1,441,000	
Subtotal	1,777,000	
Secondary Supplies:		
Point return flows	445,000	
Nonpoint return flows	550,000	
Subtotal	995,000	
TOTAL		2,772,000
Diversions:		
Surface	2,400,000	
Groundwater[1]	556,000	
Subtotal	2,956,000	
Losses:		
Consumptive uses in basin	1,473,000	
Basin outflow	304,000	
Subtotal	1,777,000	
Diversion - Losses =		1,179,000
Unaccounted for (Diversion - Supplies) =		184,000

[1] Considered as integral part of the stream system.

Note: Water quantities in acre ft/yr.

Source: Bluestein and Hendricks, 1975

TABLE 4-4 Population Data - South Platte Basin

	Counties	1970	1980	Percent Change, 1970-1980
Colorado:				
	Adams	185,789	244,786	31.75
	Arapahoe	162,142	293,606	81.08
	Boulder	131,889	186,988	41.78
	Clear Creek	4,819	7,298	51.44
	Denver	514,678	498,318	(4.93)
	Douglas	8,407	25,138	199.01
	Elbert	3,903	6,818	74.69
	Gilpin	1,272	2,441	91.90
	Jefferson	235,368	371,688	57.92
	Larimer	89,900	147,988	64.61
	Logan	18,852	19,772	4.88
	Morgan	20,105	22,313	10.98
	Park	2,185	5,308	142.93
	Sedgwick	3,405	3,264	(4.14)
	Teller	3,316	8,019	141.83
	Washington	5,550	5,301	(4.49)
	Weld	89,297	122,916	37.65
Wyoming:				
	Laramie	56,360	68,604	21.72
Nebraska:				
	Cheyenne	10,778	10,057	(6.69)
	Deuel	2,717	2,462	(9.39)
	Kieth	8,487	9,364	10.33
	Kimball	6,009	4,882	(19.95)
	Lincoln	29,538	36,455	23.42

Source: U.S. Department of Commerce Bureau of the Census, Preliminary Reports, 1980

- If there is fecal contamination, how extensive is it?
- To what extent is it tied to municipal wastewater?

Ninety-nine stations were selected from the STORET program. Data from these stations were accumulated during the years 1970 through 1980. The station location (verbal description), responsible agency, and hydrologic subbasin are listed in Table A-1 of Appendix A. Included are the total number of samples taken, the duration of sampling, the arithmetic mean, maximum value, and standard deviation of the indicator organism densities.

When using STORET data, fecal pollution was defined by the density of fecal coliform organisms present in a sample. Although fecal streptococci data were collected, ratios of fecal coliform to fecal streptococci data were rarely obtained. In addition, few samples were used to calculate mean values of fecal streptococci organisms as compared to the number of fecal coliform samples obtained for a specific site. For these reasons, fecal streptococci data was not used in the final evaluation of fecal contamination.

Figure 4-3 is a map of the South Platte River Basin with all the sampling stations located. Fecal coliform counts are indicated graphically at each station location point. These points represent order of magnitude densities, and serve to develop a picture of fecal contamination through the basin.

In order to analyze this data, subbasins were looked at in schematic form for evidence of fecal contamination. These schematics are represented in Figures 4-4 through 4-8. The stations are numbered and fecal coliform counts are indicated graphically at each point. The

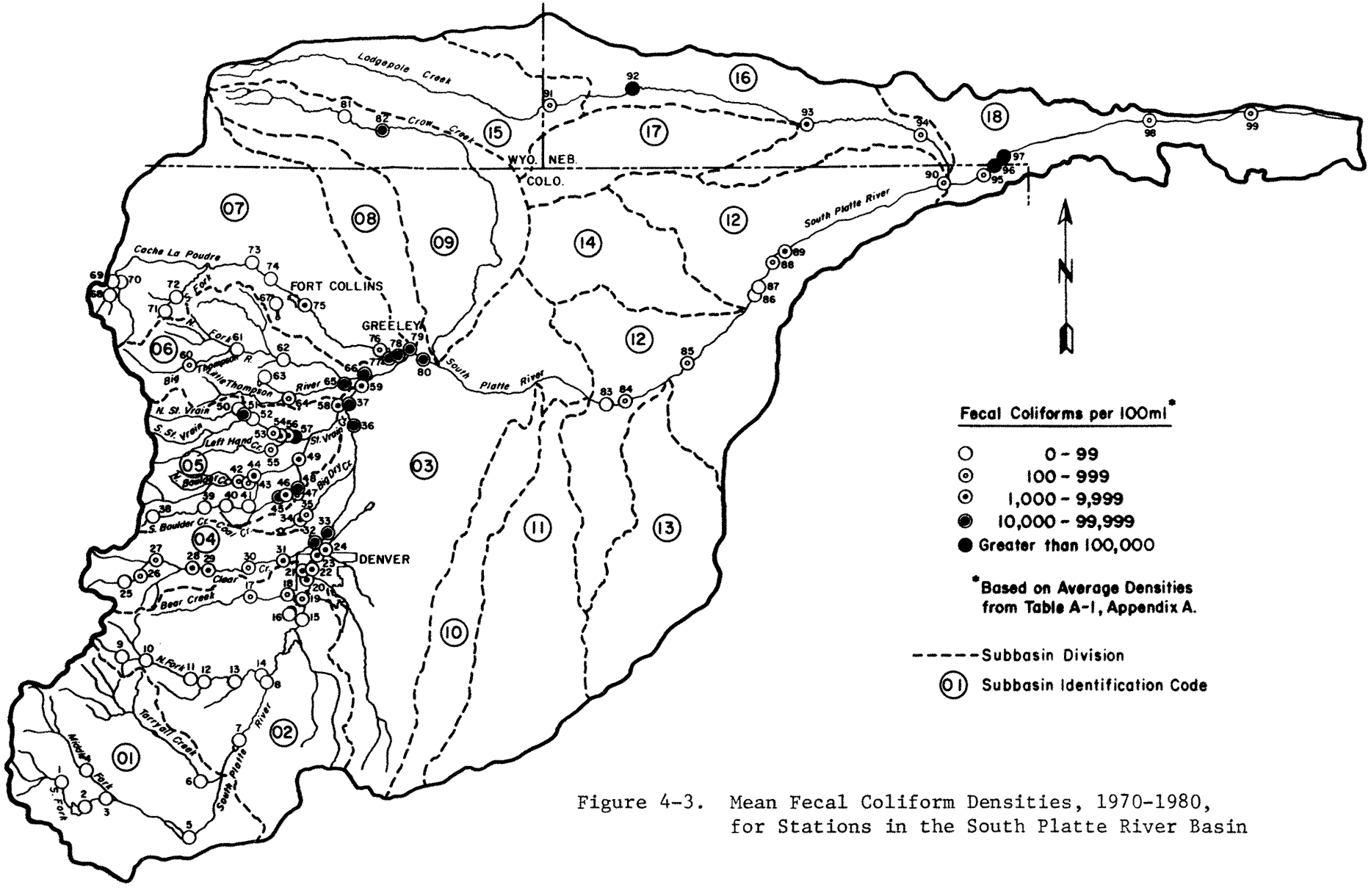


Figure 4-3. Mean Fecal Coliform Densities, 1970-1980, for Stations in the South Platte River Basin

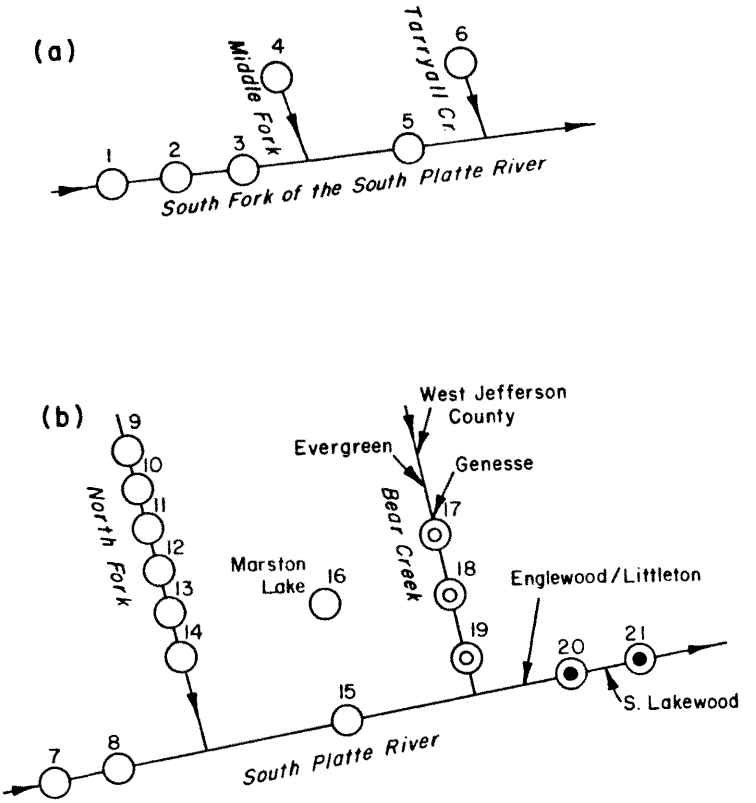


FIGURE 4-4 South Platte River Subbasins--Schematic of Sampling Stations and Mean Coliform Densities for the South Fork and North Fork Subbasins

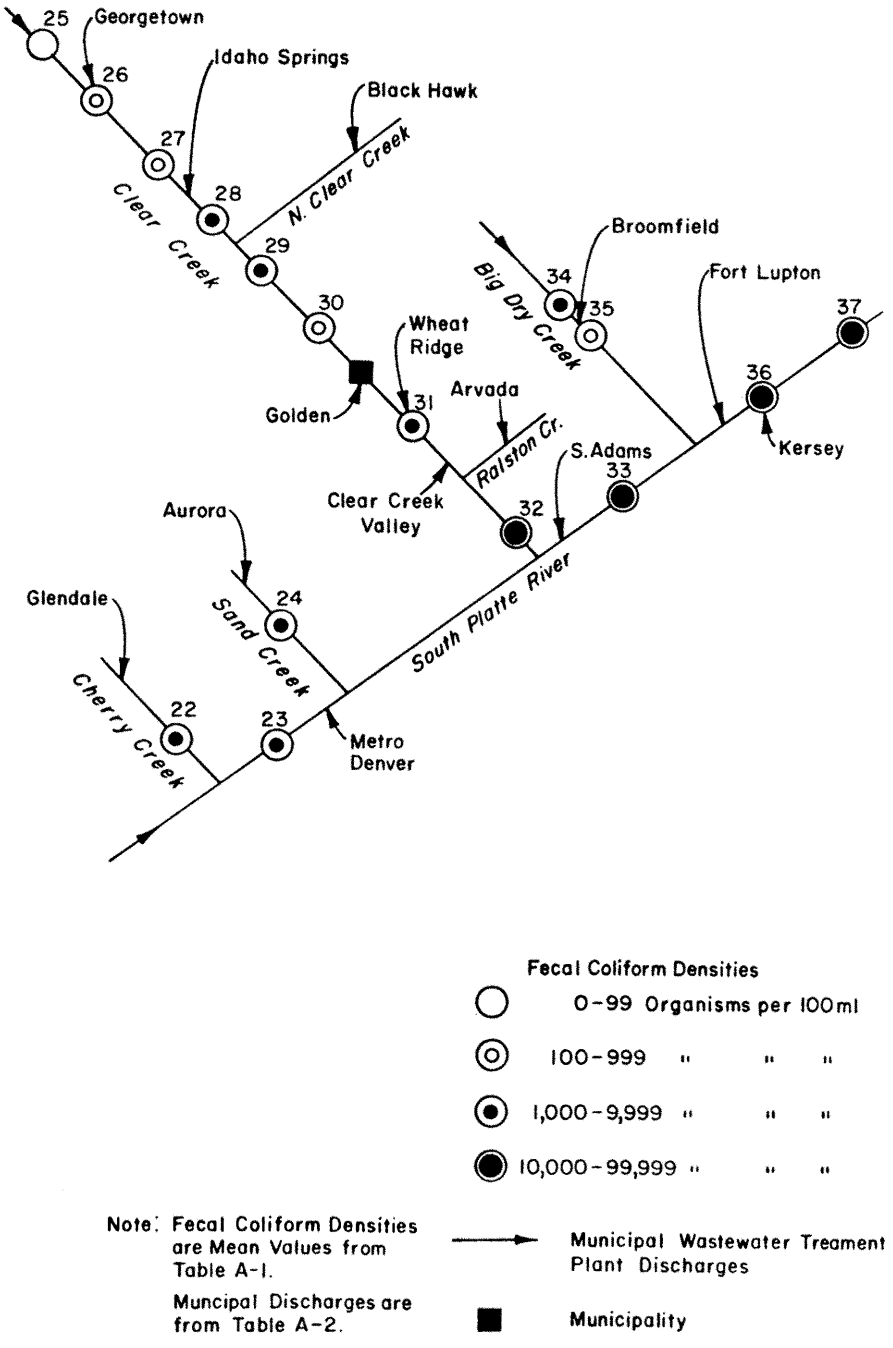
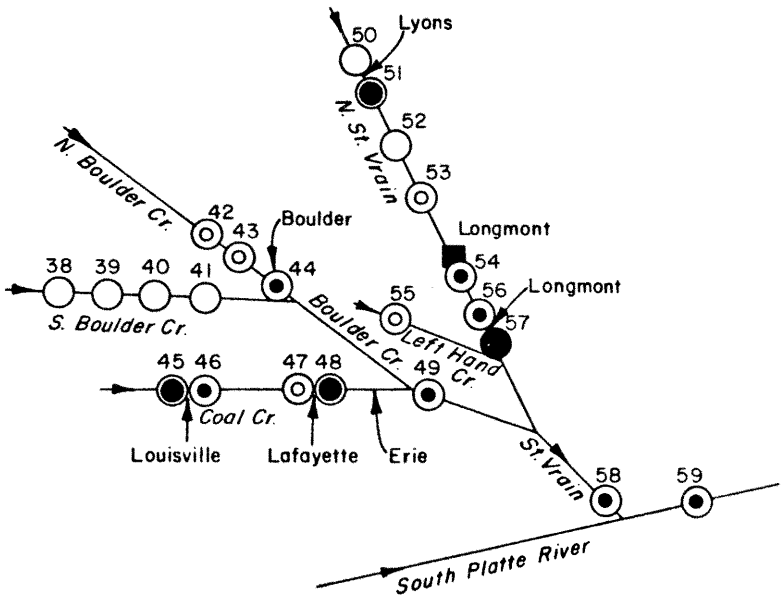


FIGURE 4-5 South Platte River Subbasins--Schematic of Sampling Stations and Mean Coliform Densities for the Cherry Creek and Clear Creek Subbasins



Fecal Coliform Densities

- 0-99 Organisms per 100ml
- 100-999 " " "
- 1,000-9,999 " " "
- 10,000-99,999 " " "
- Greater than 100,000 " "
- Municipal Wastewater Treatment Plant Discharges
- Municipality

Note: Fecal Coliform Densities are Mean Values from Table A-1.

Muncipal Discharges are from Table A-2.

FIGURE 4-6 South Platte River Subbasins--Schematic of Sampling Stations and Mean Coliform Densities for the St. Vrain and Cherry Creek Subbasins

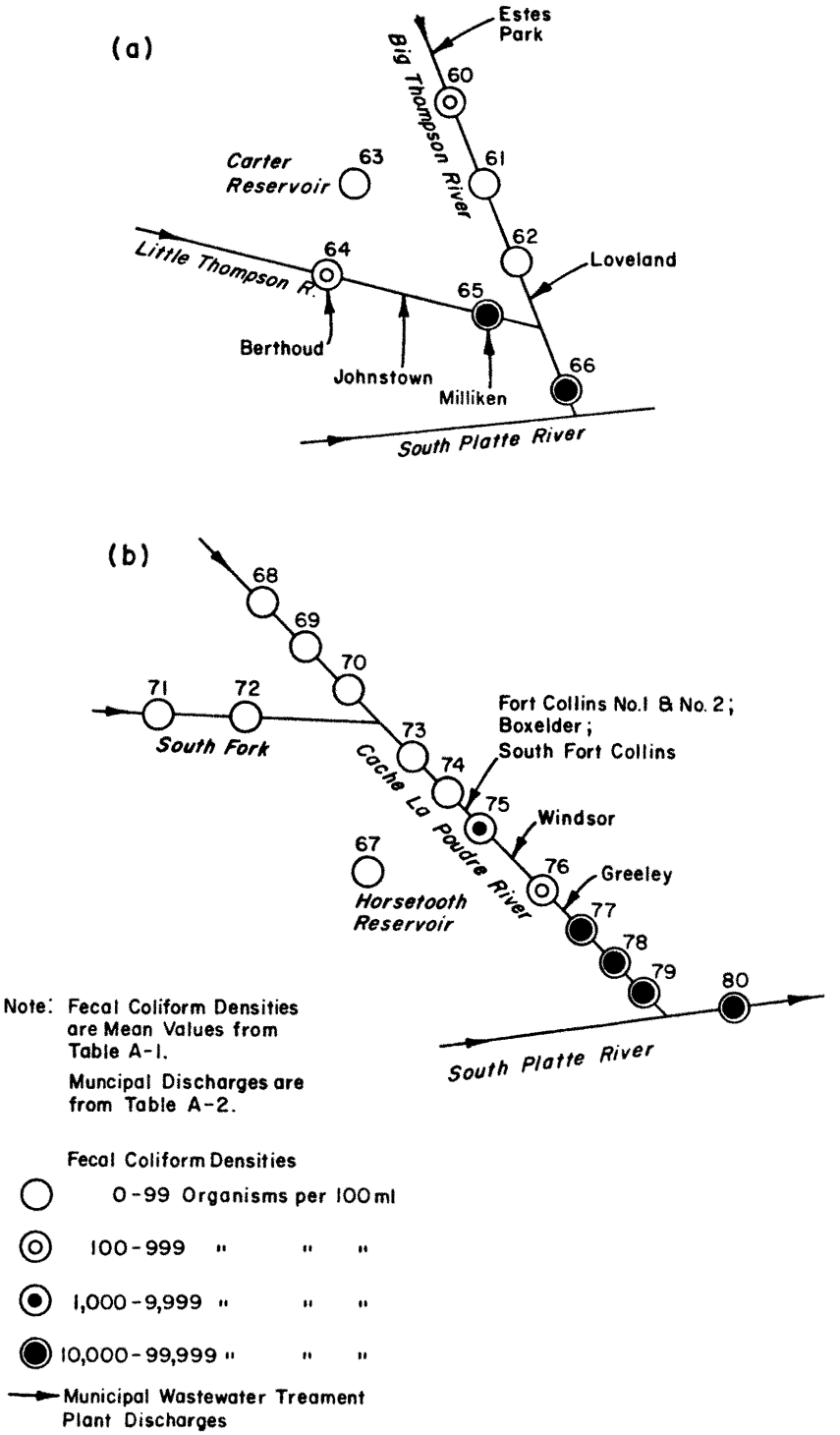


FIGURE 4-7 South Platte River Subbasins--Schematic of Sampling Stations and Mean Coliform Densities for the Big Thompson, Cache La Poudre, and Cherry Creek Subbasins

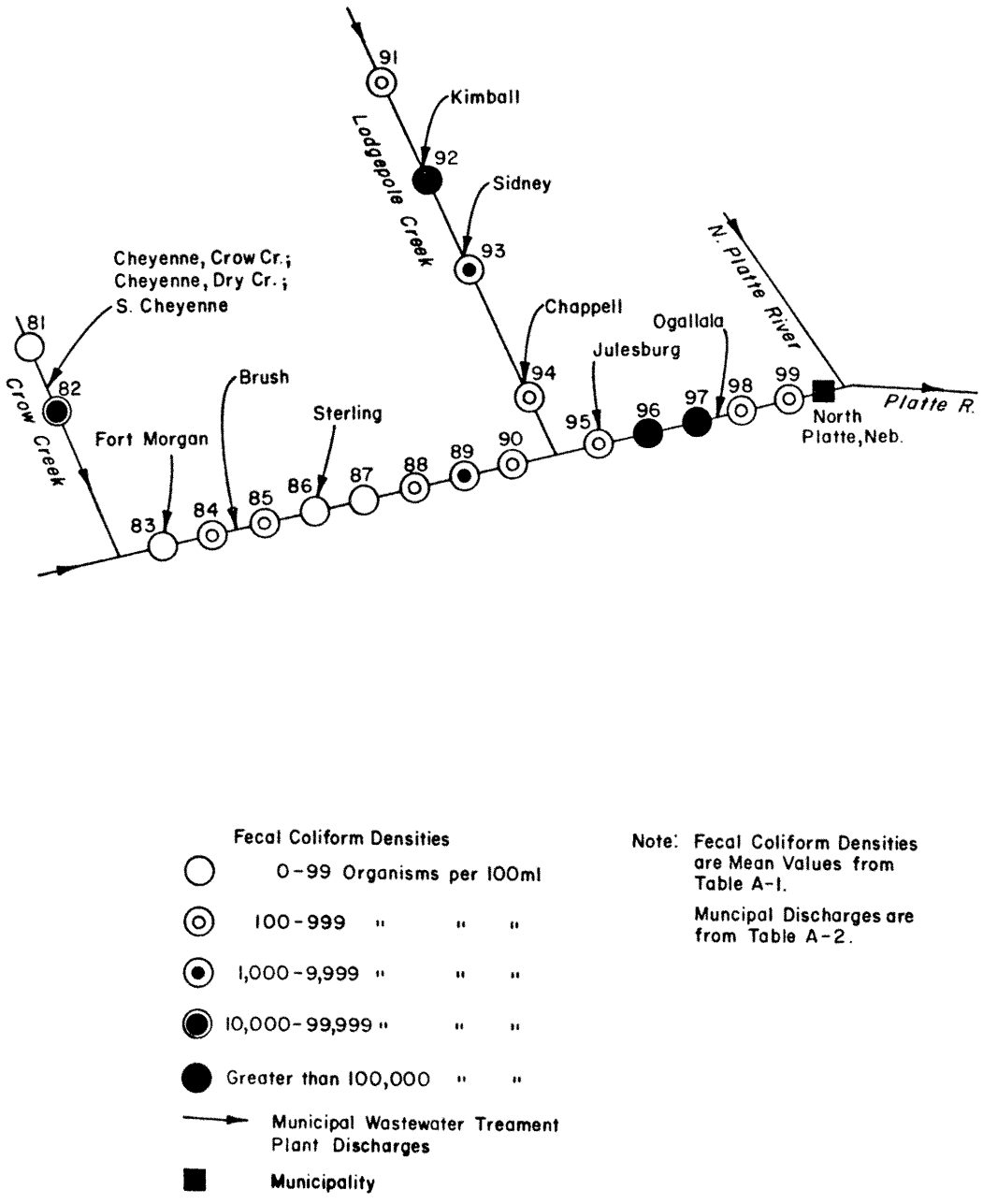


FIGURE 4-8 South Platte River Subbasins--Schematic of Sampling Stations and Mean Coliform Densities for the Crow Creek, South Platte, Upper Lodgepole, Lower Lodgepole and Lower South Platte Subbasins

subbasins and station numbers identified on the schematics correspond to those in Figure 4-3. In addition, urban areas and municipal wastewater inputs located on or near major water courses are identified.

4.3.2 Evidence of Fecal Contamination

From the data presented on Figures 4-4 through 4-8, no evidence of fecal contamination was observed in subbasin 01, (South Fork) and in the headwaters of many of the subbasins sampled. However, average coliform densities in the thousands to hundreds of thousands of organisms per 100 ml are found in all other subbasins. By the water quality standards set for the State of Colorado, this would be an indication of the existence of fecal contamination.

Colorado Water Quality Standards are dependent on water use. If we assume that the surface waters within the South Platte River Basin would be suitable for irrigation, recreation, and as a source of drinking water supply; how do the 99 stations selected meet the standards set for these uses? Table 4-5 identifies the percent of those stations which fail to meet these standards for a given water use. Fecal contamination is implied by the large percentage of stations which fail to meet Colorado State Standards.

TABLE 4-5 Compliance with Colorado State Standards[1]
(Fecal Coliforms per 100 ml)

Use	Standard	Percent of Stations Failing to Comply
Recreation (Class 1)	200	52.5
Irrigation[2]	1,000	37.4
Recreation (Class 2)	2,000	33.3
Drinking water supply (Class 2)	2,000	33.3

1 Colorado Department of Health, 1979
2 NAS and NAE, 1974

4.3.3 Correlation with Land Use

Land use was also examined for a possible correlation with fecal coliform densities. Table 4-6 was developed utilizing the general land use map for the State of Colorado (1974). For the six subbasins investigated, it appears that urban and irrigated land uses are associated with the highest densities of fecal coliforms. Irrigated land uses imply pasture as well as agricultural production. Urban and irrigated land uses that occur high in the watershed have lower indicator organism densities than the urban and irrigated areas occurring at the downstream end of the subbasin. An example of this is subbasin 02, where urban areas (stations 9 and 11) have low densities of organisms compared with urban areas (stations 20 and 21) located at the mouth of the watershed. Irrigated lands in subbasin 05 exhibit relatively low coliform densities at stations 42, 43, 53, and 55, however densities found downstream at station 57 are excessive.

Looking again at Figures 4-4 through 4-8, urban areas seem to have a direct influence on the fecal coliform densities observed in the surface waters. The municipal wastewater treatment plants included on these figures have discharges equal to or greater than 0.1 MGD. (These are cross referenced to Table A-2 of Appendix A.) Those sampling stations located upstream of municipal discharges appear to have low densities of fecal coliform organisms associated with them. However, stations downstream of municipal discharges, in populated or urbanized areas, show much higher densities of fecal coliforms.

The exceptions to this are stations 34, 45, and those stations located in subbasins 12 (South Platte) and 18 (Lower South Platte). Station 34, at Broomfield, shows high fecal coliform densities upstream

TABLE 4-6 Average Fecal Coliform Densities Versus Land Use

	Subbasin	Average Fecal Coliform Densities[1]	Station No.	Land Use[2,3]
02	North Fork		14	Rangeland
			9, 11	Urban
			7, 8, 10, 12, 13, 15	Woodland
			17	Woodland
			18, 19	Urban
			20, 21	Urban
03	Cherry Creek		35	Urban
			22, 23, 24, 33, 34	Urban
			59	Irrigated
			36, 37, 80	Irrigated
04	Clear Creek		25	Woodland
			26, 27, 30	Woodland
			29	Woodland
			28, 31	Urban
			32	Urban
05	St. Vrain		38, 39, 40	Woodland
			41, 50, 52	Rangeland
			42, 43, 53, 55	Irrigated
			47	Urban
			44, 49, 54, 56, 58	Irrigated
			46	Urban
			45, 48, 51	Urban
			57	Irrigated

TABLE 4-6 Average Fecal Coliform Densities Versus Land Use (Continued)

	Subbasin	Average Fecal Coliform Densities[1]	Station No.	Land Use[2,3]
06	Big Thompson	○	61	Woodland
		○	62	Irrigated
		◎	60	Woodland
		◎	64	Irrigated
		◉	65, 66	Irrigated
07	Cache La Poudre	○	68, 69, 70, 71, 72, 73	Woodland
		○	74	Irrigated
		◎	76	Urban
		◉	75	Irrigated
		●	77	Urban
		●	78, 79	Irrigated
09	Crow Creek	○	81	Rangeland
		●	82	Urban
12	South Platte	○	83, 86, 87	Urban
		◎	84	Irrigated and non-irrigated
		◎	88, 90	Irrigated
		◎	85	Urban
		◉	89	Irrigated
15	Upper Lodgepole	◎	91	

TABLE 4-6 Average Fecal Coliform Densities Versus Land Use (Continued)

	Subbasin	Average Fecal Coliform Densities[1]	Station No.	Land Use[2,3]
16	Lower Lodgepole	◎	94	Urban
		◉	93	Urban
		●	92	Urban
18	Lower South Platte	◎	98, 99	Urban

[1] ○ Fecal coliform count 0 to 99 per 100 ml

◎ Fecal coliform count 100 to 999 per 100 ml

◉ Fecal coliform count 1,000 to 9,999 per 100 ml

◉ Fecal coliform count 10,000 to 99,999 per 100 ml

● Fecal coliform count greater than 100,000 per 100 ml

[2]Land Use Map, Colorado Land Use Commission, 1974

[3]Irrigated - irrigated crop and pasture lands

of the municipal treatment plant. The land upstream of this site is urbanized with little irrigated agriculture and no municipal inputs. Station 45, upstream of the Louisville Municipal Wastewater Treatment Plant, is preceded by irrigated lands and sparse urban development.

The high densities of fecal coliforms found at stations 34 and 45 may be a function of upstream land use, however, this correlation does not exist for all cases. In subbasin 12, stations 86 and 87 (located near Sterling) do not reflect an increase in coliform densities from municipal discharges. However, further downstream along the South Platte River, order of magnitude increases in these densities are observed. This also occurs in subbasin 18. Here, a slight increase is observed at Julesburg, and then an increase of two orders of magnitude occurs downstream at stations 96 and 97. While its source appears to be municipal wastewaters, the consistently high densities would indicate additional discharges may be contributing.

4.3.4 Correlation with Municipal Wastewater Inputs

In order to determine what effect wastewater treatment plants have on the densities of indicator organisms in surface waters, six pairs of stations were selected to characterize water quality above and below sewage effluent inputs. Table 4-7 gives the mean fecal coliform densities and maximum densities encountered at these plants. Four of the six pairs of stations show an increase in the level of fecal coliforms by several orders of magnitude downstream of the wastewater discharges. The stations at Broomfield and Louisville, 34, 35, and 45, 46, respectively, show a decrease in coliform densities. This might be the result of higher levels of treatment at these plants; dilution from the plant

TABLE 4-7 STORET Data - Municipal Wastewaters

Station Number	Station Description	Fecal Coliforms[1] Per 100 ml Mean	Maximum
25	Clear Creek, above Silver Plume	7	32
26	Clear Creek, below Georgetown WWTP[2]	120	370
34	Big Dry Creek, 100' above Broomfield WWTP	4,300	24,000
35	Big Dry Creek, 150' below Broomfield WWTP	940	2,800
45	Coal Creek, above Louisville WWTP	24,000	160,000
46	Coal Creek, 200' below Louisville WWTP	9,000	35,000
47	Coal Creek, 50' above Lafayette WWTP	590	2,600
48	Coal Creek, 300' below Lafayette WWTP	26,000	240,000
50	North St. Vrain, 300' above Lyons WWTP	66	170
51	North St. Vrain, 300' below Lyons WWTP	10,000	92,000
56	St. Vrain, 150' above Longmont WWTP	8,400	54,000
57	St. Vrain, below Longmont WWTP	110,000	920,000

1 Data obtained from STORET data, Table A-1
2 WWTP = Wastewater Treatment Plant

effluents may have led to decrease in the already high level of coliforms in the surface waters; or possibly high levels of residual chlorine from the plant effluent may have brought about a decline in fecal coliform numbers. Speculation aside, the densities presented in Table 4-7 are based on relatively few samples obtained over a period of several years. For this reason alone, variations in trends may be observed. The question of whether treated municipal wastewaters impact surface water quality will be looked at in more detail in Chapter 5.

5.0 FIELD SURVEY

5.0 FIELD SURVEY

5.1 Introduction

The field survey was performed to give more resolution into the question of how treated wastewater effluent impacts bacteriological densities in the surface waters of the South Platte River Basin. The information from this portion of the study was utilized to assist in the interpretation of data compiled from the historical records (STORET data) of indicator organism counts within the basin.

The following sections describe the field survey approach. This includes the study area, the field and laboratory procedures utilized, and presentation of results.

5.2 Field Survey Approach

In order to evaluate the impact of municipal wastewater treatment plants on indicator organism counts, an irrigation ditch receiving municipal effluents was monitored for bacteriological densities. The data compiled was compared to densities collected from two other canals, located in the vicinity, which did not receive the same municipal effluent. The study approach included the following:

- Field sampling and laboratory analyses of total coliforms, fecal coliforms, and fecal streptoccoci counts.
- Determination of upstream and downstream indicator densities from municipal inputs.
- Determination of indicator counts in waters not receiving sewage.
- The use of fecal coliform to fecal streptococci ratios to determine the source of fecal pollution.

- Determination of indicator organism densities and chlorine residual levels in municipal wastewater effluences.
- Identification of trends in the data.
- Evaluation of potential public health risks utilizing the Colorado State Biological Standards as guidelines.

5.3 Description of the Study Area

The study area is located in the Cache La Poudre River subbasin, east of the City of Fort Collins. It includes a 13 mile reach of the Cache La Poudre River, three irrigation ditches, and the Fort Collins Wastewater Treatment Plants, Numbers 1 and 2. The study area is shown in Figure 5-1, along with the sampling points utilized in the survey. A schematic representation of this system is given in Figure 5-2.

The Fort Collins Wastewater Treatment Plant No. 1 discharges its effluent directly to the Cache La Poudre River. Approximately 5 miles downstream, Plant No. 2 also has the capability of discharging its effluent to the Cache La Poudre River. However, Plant No. 2 uses an alternative point of discharge, Fossil Creek Ditch. This ditch is used to carry irrigation waters to the Fossil Creek Reservoir for storage. The surface rights of this reservoir are leased during the summer months for recreational use.

The Boxelder Ditch running almost parallel to the Fossil Creek Ditch, diverts water from the Poudre River 0.23 miles upstream of the Fossil Creek Ditch diversion. Since both ditches receive the same water, the Boxelder Ditch was used as a control for the monitoring of indicator

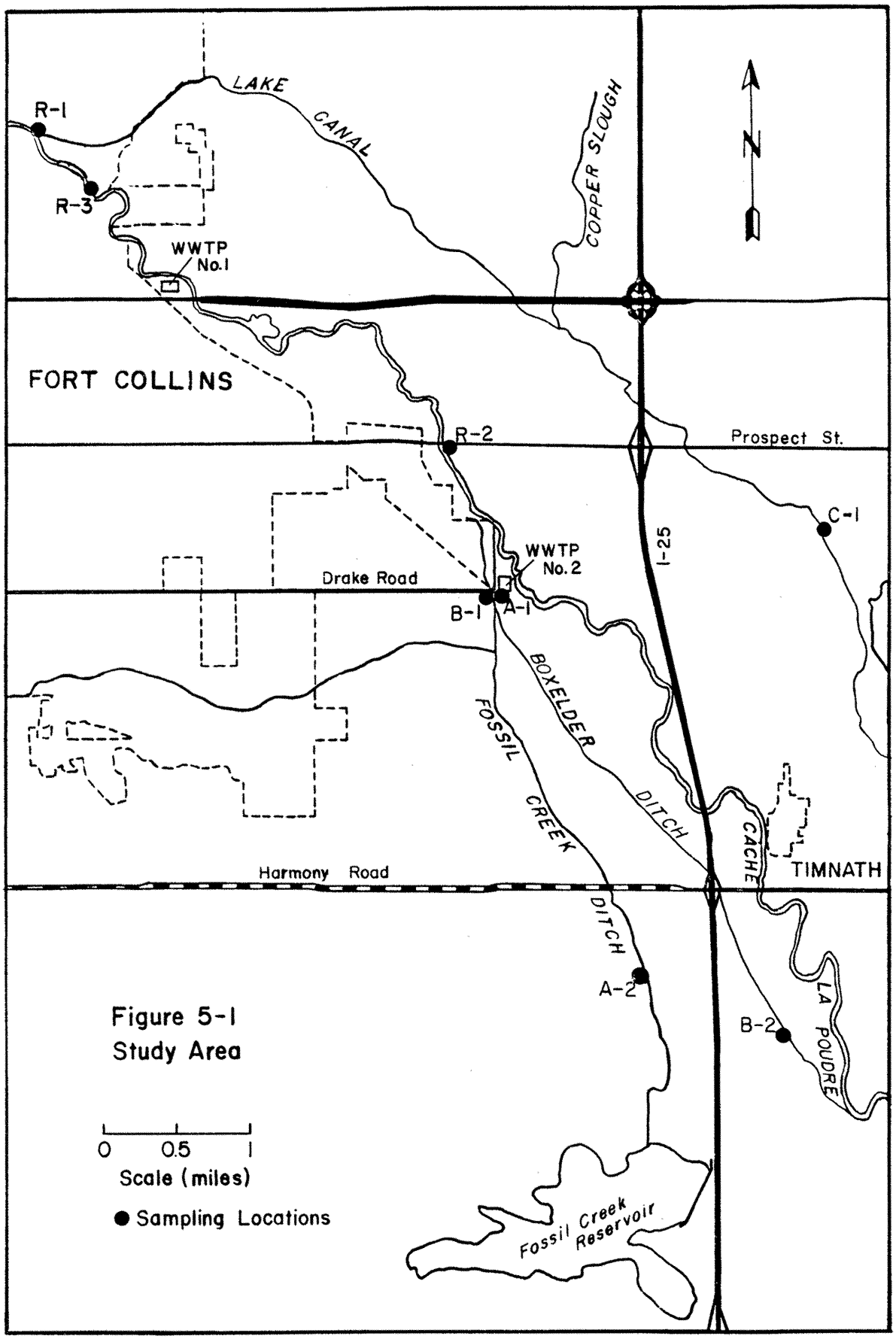


Figure 5-1
Study Area

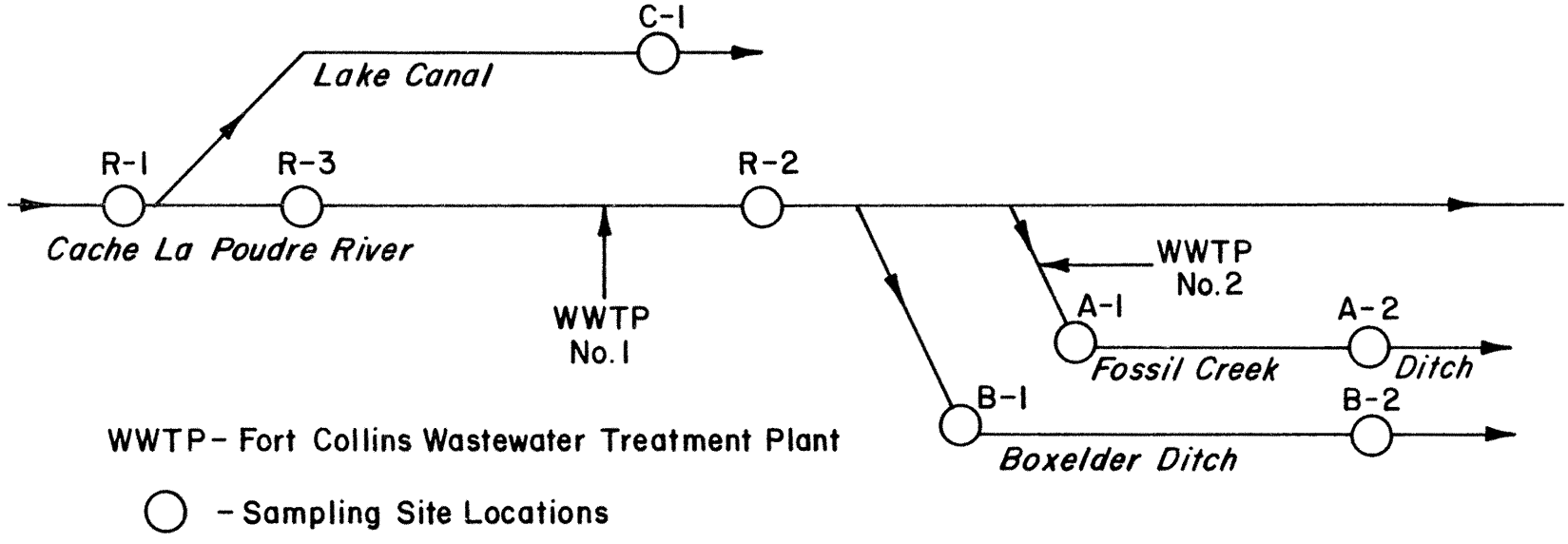


FIGURE 5-2 Schematic of Study Area

organisms. However, both Boxelder Ditch and Fossil Creek Ditch receive effluent from the Fort Collins Wastewater Treatment Plant No. 1. For this reason, a third ditch, Lake Canal, which does not receive municipal wastewater effluent was also monitored. Lake Canal receives its water from the Cache La Poudre River, upstream of Plant No. 1. The Lake Canal diversion is located in the north end of Fort Collins, 0.11 miles west of Route 287. It flows south along the east side of the Cache La Poudre River and eventually discharges into the Greeley No. 2 Canal.

The Fort Collins Wastewater Treatment Plant No. 1 was constructed in 1947, as a trickling filter plant. It has undergone several expansions and today treats a base load of 6 million gallons per day (MGD). This flow drops slightly during the winter months.

The Fort Collins Wastewater Treatment Plant No. 2 was built in 1967. It originally operated as a 4 MGD activated sludge plant. In 1976, the plant was expanded. A new activated sludge plant with much greater treatment capabilities was built. The new No. 2 treats approximately 9 MGD during the summer and 4.5 MGD during the winter. In 1974, a pipeline connecting Plants No. 1 and 2, was constructed. At the present time, it is used to divert peak flows from Plant No. 1 for treatment at Plant No. 2. As mentioned previously, Plant No. 2 has the capability of discharging to either the Cache La Poudre River or Fossil Creek Ditch. During the duration of this study, discharge was to the ditch only.

5.4 Field and Laboratory Procedures

Field samples were obtained at eight sampling sites within the study area. Sampling was conducted during the months of June, July, and August. These months were chosen as the most critical period for the

evaluation of potential health hazards due to the low flows, the high temperatures favorable to bacteria growth, the active reuse of surface waters for agriculatural irrigation, and the high incidence of public contact with surface waters.

The eight sampling sites are located on Figure 5-1. A verbal description of location is provided in Table 5-1. All samples were obtained as grab samples using sterilized polypropylene bottles. A 10 percent dilution of sodium thiosulfate was added to these bottles to neutralize the effects of chlorinated waters on indicator organisms. All samples were immediately put on ice and were analyzed for bacteria counts within 6 hours of obtaining each sample. Sampling and testing procedures were carried out in accordance with the Environmental Protection Agency's Microbiological Methods for Monitoring the Environment, 1978.

Laboratory tests were conducted for the analysis of:

- Total coliforms
- Fecal coliforms
- Fecal streptococci

The membrane filter technique was utilized for all determinations. Samples were pulled through a 0.45 micron pore size membrane filter by an applied vacuum. All equipment was sterilized in an autoclave at 121.6°C for a minimum of 15 minutes prior to use. A summary of the analytical methods, including materials utilized, and sampling and testing procedures and durations, is provided in Appendix B.

Duplicate analyses were run on grab samples obtained throughout the month of August. At this time analyses for total coliform organisms were discontinued in order to provide more time to perform duplicate testing on fecal coliform and fecal streptococci samples. It was also recognized

TABLE 5-1 Field Survey - Sampling Sites

Site Indentification	Water Body Sampled	Location	Miles Upstream from Mouth of Water Body Sampled
A-1	Fossil Creek Ditch	NE bank of railroad crossing off of Drake Rd.	0.6
A-2	Fossil Creek Ditch	Bridge on Rt. 7	4.2
B-1	Boxelder Ditch	NE bank of concrete flume, upstream of siphon, Drake Rd. (and Rt. 9)	0.9
B-2	Boxelder Ditch	NE bank of a small concrete flume on Rt. 36 (north side of the road)	4.5
C-1	Lake Canal	SE bank on Rt. 42, north of Timnath	8.7
R-1	Cache La Poudre River	Upstream of Lake Canal diversion, north bank	45.6
R-2	Cache La Poudre River	East bank, Prospect St.	32.4
R-3	Cache La Poudre River	NW bank, Linden St. bridge	43.5

Note: N = North
E = East
S = South
W = West

that due to high numbers of bacteria present in the waters sampled, the total coliform test was not yielding satisfactory results. This was exhibited by background organism counts (coliform and non-coliform organisms) on the membrane filters that exceeded recommended limits, and total coliform to fecal coliform ratios that were inconsistent.

The data obtained from the duplicate testing showed an average deviation of 26.4 percent between all sets of duplicates in the fecal coliform test, and 31.5 percent in the fecal streptococci test. These data, along with a discussion on the precision and accuracy of bacteriological testing, is presented in Appendix C.

5.5 Results

5.5.1 Introduction

The data presented in this section are data collected from the field survey. These data are given in Appendix D and sampling date, time, and location are included. Geometric means for data collected at each sampling station have been calculated for the duration of the study period. A summary of these data is given in Table 5-2.

The geometric means for the fecal coliform data are graphically shown on a schematic of the study area, Figure 5-3. This graphical representation is intended to distinguish order of magnitude changes as was utilized in Chapter 4.

Grab samples were taken during the daylight hours. In order to determine if one grab sample would be representative of the daily fluctuations in fecal coliform densities for a given sampling site, a 24 hour sampling and testing program was carried out at sites A-1 and B-1.

TABLE 5-2 Field Survey - Data Summary[1]

Water Body	Sampling Point	Geometric Mean Total Coliform	Geometric Mean Fecal Coliform	High Total Coliform	High Fecal Coliform	High FC/FS[2]
Fossil Creek	A-1	2,100	700	>80,000	72,000	4.0
Ditch	A-2	1,600	1,300	79,000	11,000	0.35
Boxelder Ditch	B-1	1,600	1,100	11,000	>6,000	1.24
	B-2	4,200	2,700	>80,000	7,000	1.79
Lake Canal	C-1	140	660	1,000	2,700	0.46
Cache La Poudre	R-1	80	110	100	300	0.21
River	R-2	--	670	--	1,300	0.36

[1] Obtained from Table D-2, Appendix D

[2] FC/FS = Fecal Coliform to Fecal Streptococci Ratio

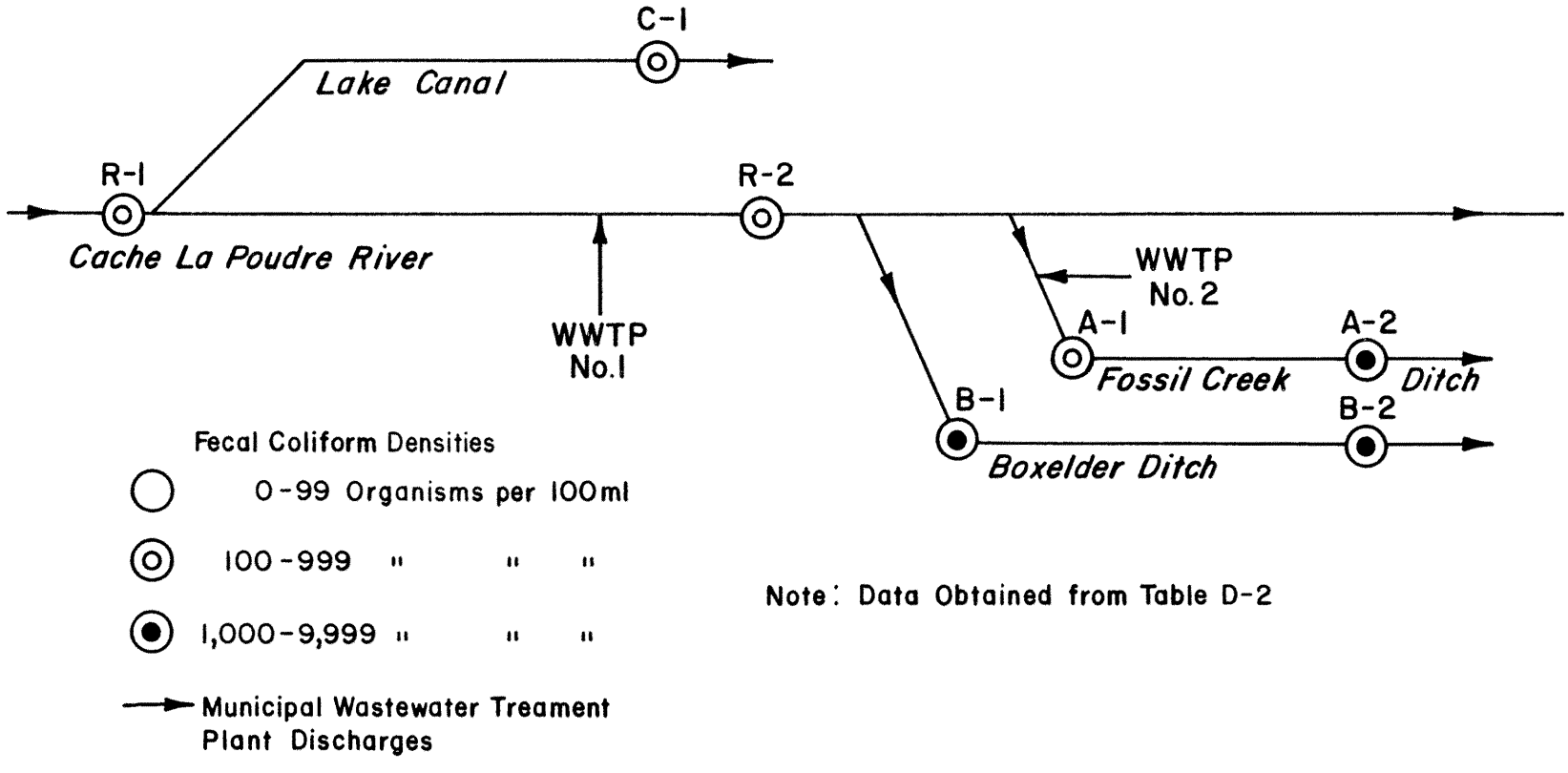


FIGURE 5-3 Mean Fecal Coliform Densities

Table 5-3 presents these results. With the exception of the midnight sample taken at B-1 (Boxelder Ditch), the densities of fecal coliforms showed remarkable similarities. Boxelder Ditch is accessible to cows on the adjacent land. It is believed that these animals may water only once a day, and when they do an increase in coliform organisms would be the result. The fecal coliform to fecal streptococci ratio for these animals has been shown to be 0.2 (U.S. EPA, 1978). Therefore, one might suspect the cows to have been the source of this increased fecal pollution judging by the ratio of 0.22 calculated for the midnight sample at B-1.

5.5.2 Evidence of Fecal Contamination

Utilizing the Colorado State Standards (Colorado Department of Health, 1979) as a guideline, fecal contamination within the study area was observed. The data of geometric means from Table 5-2 showed only sampling station R-1, on the Cache La Poudre River, met the 200 organims per 100 ml limit imposed on recreational waters. Sampling station B-2 was found to be unsatisfactory as a drinking water supply or as Class 2 recreational water (greater than 2,000 organisms per 100 ml). In addition, stations A-2, B-1, and B-2 exceeded the 1,000 organisms per 100 ml criteria on irrigation waters.

This data is compared to the data developed for the South Platte River Basin on Table 5-4. The greatest number of stations in both areas fail to meet the recreational standard. Fecal contamination is evident, and a pattern of decreased compliance with increased levels of quality (i.e., low fecal coliform levels) is observed.

TABLE 5-3 24-Hour Survey, August 19 - 20, 1980

Location	Time	Fecal Coliforms Per 100 ml	Fecal Streptoccoci Per 100 ml	Fecal Coliform Fecal Streptoccoci Ratio
Fossil Creek	1730	300	4,800	0.06
Ditch at	2300	300	5,600	0.05
Drake (A-1)	0610	600 est.	7,000	0.09
	1210	230	5,000	0.05
Boxelder Ditch	1735	950 est.	4,700	0.20
at Drake (B-1)	2310	3,100	14,000	0.22
	0615	950 est.	1,500	0.63
	1215	750 est.	8,500	0.09

TABLE 5-4 Compliance with Colorado State Standards[1]
Study Area Versus Basin

Percent of Sampling Stations	Percent of Stations Failing to Comply	
	Study Area	South Platte River Basin
Greater than 200 organisms per 100 ml (recreation, class 1)	85.7	52.5
Greater than 1,000 organisms per 100 ml (irrigation[2])	42.9	37.4
Greater than 2,000 organisms per 100 ml (drinking water supply, class 2; recreation, class 2)	14.3	33.3

[1] Colorado Department of Health, 1979
[2] NAS and NAE, 1973

Note: Fecal coliform densities for the study area are based on mean densities from Table 5-2.

5.5.3 Correlation with Land use

Figure 5-4 gives the generalized land use pattern within the study area. Lake Canal flows primarily through vacant lands utilized as pasture, and through irrigated agricultural lands. Fecal coliform densities are in the hundreds of organisms per 100 ml, with a slight increase in the mean evidenced from the point of diversion at R-1 to sampling station C-1. The Cache La Poudre River had the lowest mean density of fecal coliforms for the entire study area at R-1. The Poudre River travels through the northwest corner of Fort Collins prior to reaching Wastewater Treatment Plant No. 1. Therefore, the mean fecal coliform levels at R-2 may reflect urban land use as well as municipal wastewater input. In Boxelder Ditch, Station B-1 exhibits a slight increase in mean coliform levels from R-2. Further downstream, an even greater increase is observed at B-2. Mean fecal densities within Fossil Creek Ditch also increases slightly from A-1 to A-2. Both Fossil Creek Ditch and Boxelder Ditch are surrounded by irrigated agriculture and pasture lands. Given the 25 percent variation in the precision of the test results, these increases may not be significant, however, a trend toward higher densities is evident.

Two questions are raised by the data presented in Figure 5-4:

- What impact did the discharges from municipal wastewater treatment Plants No. 1 and No. 2 have on the fecal coliform densities?
- Why are the fecal coliform densities in Fossil Creek Ditch and Boxelder Ditch an order of magnitude above those in Lake Canal?

The impact of wastewater treatment Plants No. 1 and No. 2 appears to have little effect on the level of coliform organisms in the surface waters sampled. Sampling station A-1 at Fossil Creek Ditch shows almost

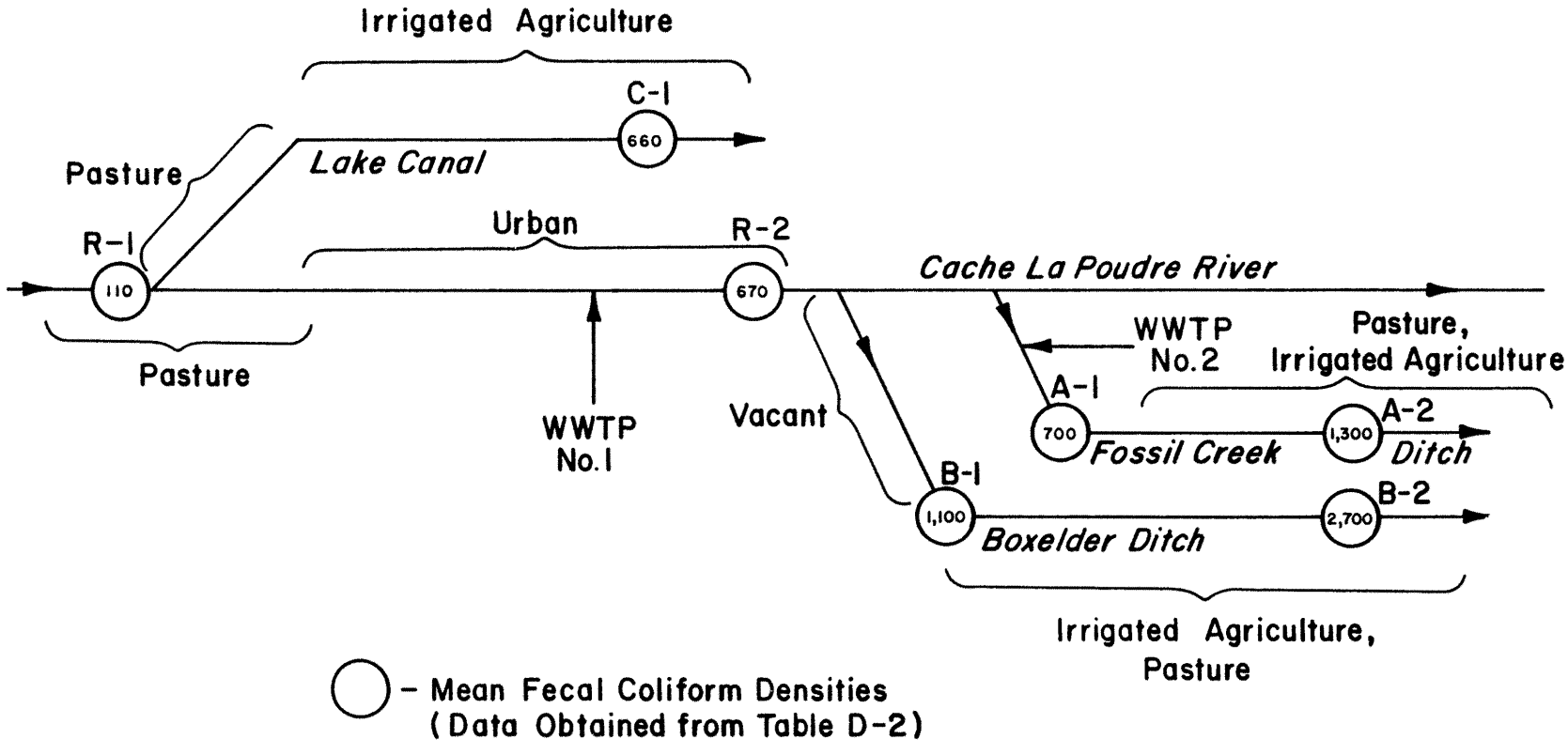


FIGURE 5-4 Land Use Schematic

no effect from No. 1 and No. 2 effluents when compared with Lake Canal at C-1, which receives no sewage at all. The implications of the data with regard to municipal wastewater effluents will be discussed in the following section.

The pattern observed in Chapter 4 of higher fecal coliform densities in irrigated lands downstream of urban areas is also observed in Figure 5-4. Sampling stations A-2 and B-2 appear to have mean fecal densities one order of magnitude greater than mean density observed at C-1. However, the contributions from the treatment plants and urban areas seem to have had little effect.

5.5.4 Municipal Wastewater Effluents

Tables 5-5, 5-6, and 5-7 present data collected from treatment plants No. 1 and No. 2, with corresponding data taken at R-2, B-1, and A-2. Table 5-5 compares fecal coliform densities in the effluent of Plant No. 1, with densities found downstream at R-2. No correlation is apparent from this data. Table 5-6 compares fecal coliform densities found in the effluent of Plant No. 1 with those densities found at B-1, Boxelder Ditch. Again, no correlation seems to exist. The data presented in Table 5-7 are from Plant No. 2 and sampling station A-1 on Fossil Creek Ditch. Although fecal coliform samples are analyzed only once a day at both Plants No. 1 and No. 2, chlorine residual is measured several times during the day at Plant No. 2 to facilitate plant operation. As chlorine is used as a disinfectant, a correlation between the density of fecal coliforms and chlorine residual might exist. Therefore, measurements of residual chlorine in the Plant No. 2 effluent taken at approximately the same time that grab samples were obtained at

TABLE 5-5 Municipal Discharge, Plant No. 1
Versus Poudre River at R-2

	Fort Collins WWTP No. 1, Effluent				Poudre River at Prospect St., R-2		
Date 1980	Average Daily Flow cfs	Sample Time Ts	Fecal Coliforms[1] Per 100 ml at Ts	Total Chlorine Residual, mg/l at Ts	Approximate Time of Sampling T	Flow[2] cfs	Fecal Coliforms Per 100 ml at T
7/16	7.75*	0830	1700	0.14	1230	91	220
7/23	10.80	0825	1550	0.28	0830	31.8	1,300 est.
8/7	9.64	0825	6790	0.28	0830	43.6	900 est.
8/13	11.27	0835	550	0.34	0930	22.3	940 est.
8/20	10.25	0840	1650	0.28	1700	32.3	550

[1] Analytical procedure - membrane filter technique, millipore HC filters

[2] Flow data from Table D-6, Appendix D

* Flows estimated - flow measuring device inoperable

Note: Ts = Time of sampling for effluent samples analyzed by Fort Collins Treatment Plants

T = Time of sampling for samples analysed under Field Survey (data shown on Table D-1)

TABLE 5-6 Municipal Discharge, Plant No. 1
Versus Boxelder Ditch at B-1

	Fort Collins WWTP No. 1, Effluent				Boxelder Ditch at Drake, B-1		
Date 1980	Average Daily Flow cfs	Sample Time Ts	Fecal Coliforms[1] Per 100 ml at Ts	Total Chlorine Residual, mg/l at Ts	Approximate Time of Sampling T	Flow[2] cfs	Fecal Coliforms Per 100 ml at T
6/17	7.75*	8015	130	0.34	1200	22.4	110 est.
6/25	7.75*	0850	1590	0.24	1200	38	250
6/26	7.75*	0825	1300	0.20	0800	41	1,200
7/1	7.75*	0825	160	0.32	0800	41	530
7/3	7.75*	0820	10	0.28	0700	27.5	6,000
7/8	7.75*	0850	720	0.26	0830	26.1	3,400
7/14	7.75*	0840	200	0.14	1030	27	670
7/20	7.75*	0850	500	0.24	1730	31	2,800
7/23	10.80	0825	1550	0.28	0800	26.1	600 est.
7/26	7.61	0820	260	0.28	1000	24.2	2,100
7/31	9.53	0825	1000	0.26	0930	27.5	1,500
8/7	9.64	0825	6790	0.28	0800	31	3,700
8/13	11.27	0835	550	0.34	0900	24	1,300 est.
8/19	10.25	0840	1650	0.28	1730	21.9	950 est.
					2300		3,100
8/20	10.37	0810	2590	0.32	0600	21.5	950 est.
					1200		750 est.

Note: See footnotes and notes on Table 5-5

TABLE 5-7 Municipal Discharge, Plant No. 2
Versus Fossil Creek Ditch, A-1

	Fort Collins WWTP No. 2, Effluent					Fossil Creek Inlet at Drake, A-1		
Date 1980	Average Daily Flow cfs	Sample Time Ts	Fecal Coliforms[1] Per 100 ml at Ts	Total Chlorine Residual, mg/l at Ts	Total Chlorine Residual, mg/l at T	Approximate Time of Sampling T	Flow[2] cfs	Fecal Coliforms Per 100 ml at T
6/17	17.90	0900	55	0.32	0.32	1200	41	630
6/25	18.96	0940	5	0.37	0.29	1200	54	300 est.
6/26	17.98	1045	205	0.39	0.44	0800	54	190 est.
7/1	21.62	0900	35	0.34	0.32	0800	107	120 est.
7/3	26.38	0900	70	0.28	0.33	0700	136	2,200
7/8	22.18	0935	30	0.30	0.32	0830	138	1,900
7/14	18.68	0925	15	0.39	0.43	1030	25	100
7/20	17.98	1320	20	0.34	0.12	1730	101	72,000
7/23	15.48	1045	90	0.36	0.31	0800	16	200 est.
7/26	17.27	1030	35	0.45	0.34	1000	40	300 est.
7/31	14.45	0920	60	0.30	0.29	0930	38	1,300
8/7	13.52	0900	10	0.29	0.25	0800	25	2,400
8/13	13.08	0920	40	0.26	0.26	0900	43	930 est.
8/19	11.94	0940	10	0.38	0.20	1700	46	300
					0.20	2300		300 est.
8/20	12.37	0920	10	0.32	0.32	0600	46	600 est.
					0.29	1200		230

Note: See footnotes and notes on Table 5-5

A-1, and have been included in Table 5-7.

Data of residual chlorine in the plant effluent had been plotted against the fecal coliform densities observed for a given day. Although some correlation appeared to exist, the lack of agreement between chlorine residual data and fecal coliform levels in the plant effluent alone did not lend credibility to this correlation. The only major evidence of fecal coliform increase with chlorine decreases is seen on July 20 when a fecal coliform density of 72,000 organisms per 100 ml was observed and the chlorine residual was 0.12 mg/l, down from the average of 0.3 mg/l. This would suggest that a threshold level of chlorine residual might exist which would prevent such contamination to surface waters. However, Plant No. 1, on July 14, with a chlorine residual of 0.14 mg/l at 8:40 had a level of only 200 fecal coliforms per 100 ml in its effluent. This suggests the threshold value may also vary with other factors such as treatment processes and waste loads.

Flow data has also been given on Tables 5-5, 5-6, and 5-7. These data were analyzed in order to determine what effect relative contributions of water quantities would have on coliform densities. A flow weighted average concentration of fecal coliforms was predicted for site R-2. Flow weighted concentrations are successfully used with conservative parameters which are not lost to or derived from the environment. Coliform organisms in the stream environment are not conservative and approximate a first order rate of die-away (Velz, 1970). Survival for these organisms is also dependent on temperature, pH, nutrient, sedimentation, absorption, and competitive life. A flow weighted approach was utilized to detect a pattern of either death, survival, or growth between two sampling sites.

An example of these results is given on Table 5-8 to show that no pattern was observed. Predicted values of fecal coliform organisms were not found to be consistently above or below actual field observations.

In summary, little direct influence from the Fort Collins Wastewater Treatment Plants was observed. However, on July 20, a high fecal coliform density of 72,000 organisms per 100 ml with a fecal coliform to fecal streptococci ratio of 4.0 was observed at A-1. This clearly indicates the source of this pollution to be from the domestic wastewaters of Plant No. 2. This high ratio was observed only once during the duration of the study.

It appears from these data, that both Plants No. 1 and No. 2 are well operated. But, even these plants are not without operational problems which may result in the same poor treatment as that which occurred on July 20th at Plant No. 2. With this in mind, the increases in fecal coliform densities observed downstream of four treatment plants within the South Platte River Basin in Chapter 4 (Table 4-7) may also be the result of poor plant operation. The STORET data for the municipal treatment plants discharging to the South Platte River Basin was not comprehensive. It covered a short period of time with few samples taken. Therefore, poor plant operation may not have been the specific cause of the observed increases in mean coliform densities. The field survey does point out that occasional poor treatment occurs, and hence is a real concern as a source of fecal contamination within the basin. When looking at the overall picture of the South Platte River Basin with respect to the location of major municipal wastewater discharges (Figures 4-4 through 4-8), their contribution to the fecal contamination in the basin appears to be evident.

TABLE 5-8 Flow Weighted Average[2] To Predict Fecal Coliform Densities at R-2

	WWTP #1		R-1		R-2	
Date-1980	cfs	Fecal Coliforms Per 100 ml	cfs[1]	Fecal Coliforms Per 100 ml	Fecal Coliforms Per 100 ml Calculated	Observed
7/16	7.75	1,700	83.2	40	200	220
7/23	10.8	1,550	21.0	90	590	1,300
8/7	9.64	6,790	34	300	1,700	900
8/13	11.27	550	11	160	360	940
8/20	10.25	1,650	8	230	750	550

[1] Flow reflects cfs at R-1 minus flow to Lake Canal

[2] Flow weighted average $C = \frac{c_1q_1 + c_2q_2}{q_1 + q_2}$

Where:

c = concentration, organisms per 100 ml

q = flow, cfs

5.5.5 Correlation with Rainfall Events

Runoff from rainfall events may be a source of coliforms to streams and ditches. Rainfall events were infrequent during the study period and were in the form of localized showers. Information on rainfall events was obtained from Mountain States Weather Services, Fort Collins. Rainfall data for dates coinciding with sampling events at specific stations has been included in Appendix D, Table D-7. Although increases in coliform counts were observed on days of rain events, increases of the same or greater magnitudes were observed on days of no precipitation. Therefore, for the duration of the field survey, runoff from precipitation was felt to have little effect on the data.

6.0 SUMMARY AND CONCLUSIONS

6.0 SUMMARY AND CONCLUSIONS

The focus of this study was to evaluate the public health hazard posed by the present practices of distributing and conveying treated municipal sewage effluents to agricultural lands. The premises and methods used in this study are enumerated as follows:

- It has been established in the literature that waterborne diseases are transmitted by and are associated with raw and treated municipal wastewaters.

- Indicator organisms are considered an acceptable method of identifying the potential risk of disease transmission. This is true even though fecal contamination has not been directly correlated with incidence of disease.

- The methodology entailed utilization of fecal coliforms and fecal streptococci indicator data to determine the presence of fecal contamination and its source. These data were obtained from the EPA STORET program, for the South Platte River Basin. Confirming field work was performed on an irrigation ditch which received municipal wastewater effluents.

- Limitations to the research approach were found to lie in the lack of well established epidemiological relationships correlating fecally contaminated waters with the incidence of disease. Additional limitations were due to the questionable reliability of the STORET data and the problems inherent to bacteriological testing.

In conclusion, the following points were brought out by the study:

- Fecal contamination is evident throughout portions of the South Platte River Basin. Figure 4-3 shows mean coliform densities ranging well above those indicated as safe by the Colorado State Standards.

- Thirty three percent of the sampling stations failed to comply with the Colorado Standards for Class 2 recreational waters, and for Class 2 drinking waters. These classifications represent the least stringent of the regulations.

- Sampling stations located high in mountain watersheds were found to have low mean fecal coliform densities. Sampling stations located in and around urban and irrigated lands were found to have the highest fecal coliform densities in the basin. This trend which is quite evident on Plate 1 shows the greatest concentration of high coliform densities in surface waters to exist in the plains areas east of the foothills.

- Operational problems that occur in municipal wastewater treatment plants may result in undetected fecal contamination to surface waters. Figures 4-4 through 4-8 indicate a strong relationship exists between the observed high fecal coliform densities and municipal wastewater treatment plant discharges.

- The fecal coliform, fecal streptococci ratio was found to be a reliable indicator of the source of fecal contamination. It was an effective means of monitoring wastewater discharges to detect evidence of fecal contamination during the field survey study.

High fecal coliform counts were found to exist in the urban and irrigated lands of the South Platte River Basin. Over 30 percent of the sampling stations examined failed to pass the least stringent of the Colorado microbiological water quality standards. As these standards have been set by the Colorado State Water Quality Commission to protect the public from the health hazards of contaminated waters, exceeding these regulations suggests a hazard exists. Utilizing this definition of health hazard, the results of this study indicate there is a need to:

- Promote the established microbiological standards for irrigation waters.

- Promote the established microbiological standards for reclaimed wastewaters.

- Implement more reliable controls on municipal wastewater discharges.

- The consistently high coliform densities found in the plains areas strongly suggest the need for more intensive microbiological research to be carried out in the South Platte River Basin.

7.0 REFERENCES

7.0 REFERENCES

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APPENDICES

APPENDIX A

HISTORICAL DATA
SOUTH PLATTE RIVER BASIN

TABLE A-1 STORET Data for the South Platte River Basin

Sampling Station	Hydrologic Code Unit[2]	Agency[3]	Agency Station	Station Name	State	No. of Samples F.C.	Period of Record Began	Period of Record Ended	Fecal Coliforms Average	Fecal Coliforms Maximum	Fecal Coliforms St. Dev.
	10190001										
1		21CODBWC	001101	SO PLAT SO FRK TWN BR ABV ANTERO	CO	12	07/73	10/77	50	210	80
2		21CODBWC	001102	SO PLAT SO FRK ANTERO OUTLET	CO	34	06/70	10/77	1	10	3
3		21CODBWC	001104	SO PLAT SO FRK AT HARTSEL	CO	15	01/73	10/77	15	110	30
4		21CODBWC	001103	SO PLAT SO FRK GARO @ HWY 9	CO	15	01/73	10/77	23	140	37
5		21CODBWC	001106	SO PLAT SO FRK 11 MILE RES OUT	CO	37	02/70	10/77	1	26	5
6		21CODBWC	001107	SO PLAT SO FRK TERRYALL CK	CO	4	02/73	08/74	14	33	13
	10190002										
7		21CODBWC	001109	SO PLAT SO FRK CHEESMAN RES OUTLET	CO	27	04/70	10/77	2	35	7
8		21CODBWC	001112	SO PLAT SO FRK ABV CONF OF N FRK	CO	90	01/70	12/77	4	82	11
9		21CODBWC	001201	SO PLAT NO FRK ABV GRANT & WEBSTER	CO	34	02/70	11/77	2	17	4
10		21CODBWC	001205	N F SP @ GRANT BELOW BENEVA CK	CO	11	02/75	11/77	2	10	3
11		21CODBWC	001202	SO PLAT N FRK BLW BAILEY CROSSING	CO	32	01/70	10/74	88	600	140
12		21CODBWC	001206	N F SP BELOW JUNCTION OF GRAIG CK	CO	11	02/75	11/77	27	180	51
13		21CODBWC	001203	SO PLAT N FRK ABV JCT BUFFALO CK	CO	27	01/70	11/77	18	130	32
14		21CODBWC	001204	SO PLAT N FRK ABV CONF SO FRK	CO	91	01/70	12/77	19	230	37
15		COL001	000024	SO PLAT ABOVE LITTLETON	CO	156	01/70	11/79	70	790	100
16		21CODBWC	001303	SO PLAT AT MARSTON LK	CO	82	01/70	12/77	15	100	25
17		21COL001	0000122	BEAR CK ABV MORRISON	CO	37	12/71	11/79	120	2,200	360
18		21COL001	000036	BEAR CK AT JEFF-DENVER CO LN	CO	156	01/70	11/79	840	43,000	3,600
19		21COL001	SPR17A	BEAR CK AT BRYANT ST	CO	61	07/76	06/77	320	4,500	610
20		21COL001	0699	SOUTH PLATTE R AT ALAMEDA AVE	CO	160	01/70	12/76	1,900	45,000	5,200
21		21COL001	SPR001	SOUTH PLATTE R AT SPEER BLVD	CO	91	07/76	06/77	3,200	34,000	5,500
	10190003										
22		21COL001	SPR010	CHERRY CREEK AT MOUTH	CO	90	07/76	06/77	3,400	80,000	9,300
23		21COL001	SPR005	SOUTH PLATTE R AT YORK ST	CO	88	07/76	06/77	3,200	34,000	5,500
24		21COL001	SPR004	SAND CREEK NEAR MOUTH	CO	89	07/76	06/77	5,100	53,000	10,000
33		21COL001	SPR001	SOUTH PLATTE R AT 104TH AVE	CO	91	07/76	06/77	14,000	190,000	33,000
34		21BCCHD	000430	BIG DRY CK 100' ABV BROOMFIELD STP	CO	8	12/70	11/72	4,300	24,000	8,300
35		21BCCHD	000450	BIG DRY CK 150' BLW BROOMFLD STP	CO	9	12/70	12/72	940	2,800	1,100
36		1110DFID	710163E-24	SO PLAT @ PLATTEVILLE	CO	8	08/71	12/71	67,000	310,000	100,000
37		1110DFID	710112B-1	SO PLAT ABV MOUTH ST. VRAIN	CO	3	09/71	09/71	16,000	32,000	15,000

TABLE A-1 STORET Data for the South Platte River Basin (continued)

Sampling Station[2]	Hydrologic Code Unit	Agency[3]	Agency Station	Station Name	State	No. of Samples F.C.	Period of Record Began	Period of Record Ended	Fecal Coliforms Average	Fecal Coliforms Maximum	Fecal Coliforms St. Dev.
59		1110DFID	7100113B-2	SO PLAT BL ST VRAIN	CO	8	09/71	12/71	5,700	11,000	3,100
80		21COL001	000022	SOUTH PLATTE NR KERSEY	CO	169	01/70	12/79	38,000	5,400,000	420,000
	10190004										
25		21COLSSO	CLCO14	CLEAR CK ABV SILVER PLUME	CO	6	05/76	10/76	7	32	13
26		21COLSSO	CLCO13	CLEAR CK BL GEORGETOWN WWTF	CO	6	05/76	10/76	120	370	150
27		21COLSSO	CLCO12	CLEAR CK @ LAWSON GAGE	CO	6	05/76	10/76	130	800	330
28		21COL001	000132	CLEAR CK BL IDAHO SPRINGS	CO	8	04/79	10/79	2,800	9,300	3,100
29		21COLSSO	CLCO11	CL CK 100 YD BL CONF W N FRK	CO	6	05/76	10/76	1,600	9,300	3,800
30		21COL001	000035	CL CK ABV GOLDEN	CO	156	01/70	10/79	650	24,000	2,300
31		21COL001	000089	CLEAR CK @ WHEATRIDGE	CO	141	11/70	11/79	1,300	43,000	5,200
32		21COL001	000034	CLEAR CK NR MOUTH	CO	162	01/70	11/79	19,000	2,200,000	170,000
	10190005										
38		21CODBWC	003101	MOFFAT BOULDER CK E PTL MOFF TUN	CO	16	02/72	12/77	1	7	2
39		21CODBWC	003102	MOFFAT BOULDER CK SO @ PINE CLIFF	CO	16	02/72	12/77	7	78	20
40		21CODBWC	003103	MOFFAT BOULDER CK GROSS RES OUTL	CO	34	01/71	12/77	1	7	2
41		21BCCHD	000340	S BOULDER CK BLW ELDORADO SPGS	CO	6	06/70	10/72	53	280	110
42		21BCCHD	000160	MDL BOULDER 275' US E PEARL STP	CO	27	02/70	02/73	320	3,500	690
43		21BCCHD	000190	MDL BOULDER VALMONT BRIDGE	CO	29	02/70	02/73	200	2,000	450
44		21BCCHD	000230	BOULDER CK 61ST STREET	CO	34	02/70	02/73	8,000	160,000	31,000
45		21BCCHD	000460	COAL CK ABV LOUISVILLE STP	CO	8	10/70	10/72	24,000	160,000	55,000
46		21BCCHD	000480	COAL CK 200' BLW LOUISVILLE STP	CO	9	03/70	10/72	9,000	35,000	13,000
47		21BCCHD	000500	COAL CK 50' AB LAFAYETTE STP	CO	11	04/70	02/73	590	2,600	800
48		21BCCHD	000520	COAL CK 300' BLW LAFAYETTE STP	CO	10	04/70	12/72	26,000	240,000	24,000
49		21COL001	000033	BOULDER CK AT BOULDER WELD CO LN	CO	169	03/70	12/79	1,800	46,000	4,900
50		21BCCHD	000630	N ST VRAIN 300' US LYONS STP	CO	10	09/70	11/72	66	170	53
51		21BCCHD	000650	N ST VRAIN 300' BLW LYONS STP	CO	9	09/70	11/72	10,000	92,000	31,000
52		112WRD	06724000	ST VRAIN CK AT LYONS CO	CO	7	10/79	06/80	47	205	71
53		1110DFID	710104A-4	ST VRAIN ABOVE LONGMONT	CO	3	09/71	09/71	300	420	100
54		21COL001	000031	ST VRAIN BLW LONGMONT	CO	158	03/70	10/79	4,200	110,000	11,000
55		21COL001	000032	LEFT HAND CK NR NIWOT	CO	42	12/70	11/79	600	4,300	1,000
56		21BCCHD	000680	ST VRAIN 150' ABV LONGMONT STP	CO	12	07/70	01/73	8,400	54,000	17,000
57		21BCCHD	000700	ST VRAIN BLW LONGMONT STP	CO	9	03/71	01/73	110,000	920,000	300,000
58		21COL001	000029	ST VRAIN NEAR MOUTH	CO	55	01/70	11/79	5,800	30,000	9,600

TABLE A-1 STORET Data for the South Platte River Basin (continued)

Sampling Station	Hydrologic Code Unit[2]	Agency[3]	Agency Station	Station Name	State	No. of Samples F.C.	Period of Record Began	Period of Record Ended	Fecal Coliforms Average	Fecal Coliforms Maximum	Fecal Coliforms St. Dev.
	10190006										
60		21COL001	000125	BIG THOMPSON BLW ESTES PK	CO	33	12/71	11/79	530	9,300	1,700
61		112WRD	06736700	BIG THOMPSON R ABV DILLE TUN NR DRAKE	CO	68	09/70	09/79	31	750	105
62		21COL001	000114	BIG THOMPSON NR LOVELAND	CO	37	12/71	09/79	64	430	120
63		112WRD	06742500	CARTER LK NR BERTHOUD CO	CO	147	08/70	09/76	< 1	17	1
64		21COL001	000123	LITTLE THOMPSON NR BERTHOUD	CO	37	12/71	11/79	400	2,300	580
65		21COL001	000124	LITTLE THOMPSON NR MILLIKEN	CO	155	11/71	12/79	59,000	2,200,000	270,000
66		21COL001	000028	BIG THOMPSON NR MOUTH	CO	171	01/70	12/79	11,000	310,000	36,000
	10190007										
67		112WRD	06737500	HORSETOOTH RESV NR FORT COLLINS	CO	146	08/70	05/80	< 1	5	< 1
68		113FORS2	FS021005705031	JOE WRIGHT CR ABV CHAMBERS LK #6	CO	8	06/76	09/76	2	15	5
69		113FORS2	FS0210057450402	JOE WRIGHT @ MOUTH CONFL WITH BIG SO	CO	6	06/76	09/76	< 1	1	< 1
70		113FORS2	FS0210057450401	BIG SOUTH FORK OF SO POUDRE	CO	6	06/76	09/76	1	3	1
71		113FORS2	FS0210059040201	LITTLE SO FRK @ BENNETT CK CAMPGRD	CO	7	01/76	09/76	6	40	15
72		113FORS2	FS0210059040401	LITTLE BEAVER CK #4	CO	7	06/76	09/76	7	21	8
73		113FORS2	FS0210061540101	SOUTH FRK OF POUDRE @ MOUTH #5	CO	10	05/76	09/76	25	210	65
74		21COL001	000026	CACHE LA POUDRE ABV FORT COLLINS	CO	49	01/70	09/79	38	240	58
75		21COL001	000126	CACHE LA POUDRE NR FORT COLLINS	CO	156	11/71	12/79	7,600	930,000	74,000
76		1110DFID	710219CP-4	CACHE LA POUDRE ABV EATON DRAW	CO	5	12/71	12/71	230	690	260
77		1110DFID	710133D-2	CACHE LA POUDRE BLW GREELEY ST	CO	8	09/71	12/71	35,000	150,000	62,000
78		21COL001	000027	CACHE LA POUDRE NR GREELEY	CO	167	01/70	12/79	49,000	2,400,000	260,000
79		1110DFID	710134D-3	CACHE LA POUDRE NR MOUTH	CO	8	09/71	12/71	27,000	100,000	42,000
	10190009										
81		21WYDHSS	000394	CROW CK NORTHWEST OF CHEYENNE	WYO	5	05/74	08/76	23	59	23
82		112WRD	06756000	CROW CK NR CHEYENNE	WYO	46	07/72	08/75	75,000	4,200,000	75,000
	10190012										
83		1110DFID	710212SP-7	SOUTH PLATTE BLW GW FT MORGAN	CO	5	11/71	12/71	72	160	55
84		21COL001	000127	S PLATTE BLW FT MORGAN	CO	36	11/71	11/79	760	7,500	1,600
85		21COL001	000021	SOUTH PLATTE AT BALZAC	CO	54	01/70	11/79	920	13,000	2,300
86		1110DFID	710211SP-6	SOUTH PLATTE ABV STERLING	CO	10	10/71	12/71	53	180	54
87		1110DFID	710210SP-5	SOUTH PLATTE BLW GW STERLING	CO	5	11/71	12/71	75	150	49

TABLE A-1 STORET Data for the South Platte River Basin (continued)

Sampling Station[1]	Hydrologic Code Unit	Agency[3]	Agency Station	Station Name	State	No. of Samples F.C.	Period of Record Began	Period of Record Ended	Fecal Coliforms Average	Fecal Coliforms Maximum	Fecal Coliforms St. Dev.
88		1110DFID	710253	SOUTH PLATTE NR FORD	CO	5	10/71	10/71	550	1,900	760
89		21COL001	000128	SOUTH PLATTE BLW STERLING	CO	37	11/71	11/79	3,900	93,000	16,000
90		1110CFID	710209SP-4	SOUTH PLATTE ABV GW OVID	CO	11	09/71	12/71	190	290	63
	10190015										
91		117TECH	300318	LODGEPOLE @ SR-1104 @ PINE BLUFFS	WYO	2	08/72	08/72	600	780	240
	10190016										
92		112WRD	06762550	LODGEPOLE CK @ KIMBALL	NEB	45	03/73	07/77	110,000	650,000	110,000
93		117TECH	300321	LODGEPOLE CK @ SIDNEY	NEB	2	08/72	08/72	2,900	5,600	3,800
94		117TECH	300322	LODGEPOLE CK @ CHAPPELL	NEB	2	08/72	08/72	750	800	71
	10190018										
95		112WRD	06764000	SO PLATTE R @ JULESBURG	CO	43	02/73	06/80	130	720	190
96		1110DFID	710206SP-1	SO PLATTE AT COLO-NEB BORDER	CO	11	09/71	12/71	120,000	1,000,000	300,000
97		21COL001	000020	SO PLATTE R NR JULESBURG	NEB	53	01/70	12/78	120,000	3,000,000	580,000
98		1117TECH	300326	SO PLATTE R @ ROSCOE	NEB	2	08/72	08/72	180	280	150
99		1117TECH	300327	SO PLATTE R @ SOUTHERLAND	NEB	2	08/72	08/72	130	190	85

[1] Sampling stations located on Plate 1.

[2] Hydrologic Unit Code, last two digits signify subbasin within South Platte River Basin and are indicated on Plate 1.

[3] STORET Agency Codes:
21CODBWC - Denver Board of Water Commissioners
21COL001 - Colorado State Health Department
21CODHDP - Denver County Health Department
21COMETR - Denver Metro Sewer District
21BCCHD - Boulder County Health Department
1110DIFD - EPA Denver Field Investigation
21COLSSO - Special Studies, Colorado
112WRD - United States Geological Survey, Region 8
113FORS2 - Forest Service, Custer
21WYDHSS - State of Wyoming
117TECH

NOTE: F.C. = Fecal Coliform. All fecal coliform densities are organisms per 100 ml.

Source: U.S. EPA, Region 8, Denver, Colorado, 1980.

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
Colorado[3]:								
Adams	Bennett Sanitation District	(2) Aerated Lagoons	0.15 (est.)	0.04	75 (est. @ 0.05 MGD)	Unnamed Draw, Tributary to Kiowo Creek; Unclassified, Effluent Limited	6,000	12,000
	Metro Denver Disposal District		132	137 (140 in 1979)	200,000	South Platte River; Water Quality Limited Segment	1,000	2,000
	So. Adams Water and Sewer District	Trickling Filter	6	2	4,200	South Platte River; Water Quality Limited Segment	6,000	12,000
	Strasburg Water and Sewer District	Lagoons (4)	0.12	0.08	150	Dry ravine to Comanche Creek; Unclassified to Unclassified, Effluent Limited Segment	6,000	12,000
	City of Westminster	Activated Sludge	2.25	1.61	2,700	Big Dry Creek; High Line Canal; Both Unclassified; Effluent Limited	1,000	2,000
Arapahoe	City of Aurora	Activated Sludge	1.0	0.35	600	Sand Creek; Unclassified; Effluent Unlimited	1,000	2,000
	Town of Deer Trail	Lagoon System	0.01 (est.)	0.82	1,500	Bijou Creek; Unclassified; Effluent Limited	1,000	2,000
	City of Littleton/Englewood	Activated Sludge, Pure Oxygen	20	14.4	2,400	South Platte; Water Quality Limited	1,000	2,000
	City of Glendale	Activated Sludge	2.0	0.82	1,500	Cherry Creek	1,000	2,000
Boulder	City of Boulder	Trickling Filter	15.6	12.0	24,000	Boulder Creek; Water Quality Limited	400	800
	City of Broomfield	Activated Sludge and Trickling Filter	3.6	2.2	4,400	Big Dry Creek; Unclassified Effluent Limited	6,000	12,000
	City of Lafayette	Trickling Filter	0.288	0.5	913	Coal Creek; Water Quality Limited	2,000	4,000
	City of Longmont	Trickling Filter, Bio-Disk	8.2	6.3	12,600	St. Vrain Creek; Water Quality Limited	3,000	6,000

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin (continued)

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
	City of Louisville	Oxidation Ditch, Aerated Lagoon	1.0	0.65	1,300	Coal Creek; Water Quality Limited	1,000	2,000
	Town of Lyons	Activated Sludge	0.25	0.10	200	St. Vrain Creek; Effluent Limited Segment	1,000	2,000
	Town of Nederland	Aerated Lagoon	0.088	0.60	120	Boulder Creek; Water Quality Limited	2,000	4,000
	Niwot Sanitation	Aerated Lagoon	0.75	0.40	800	Dry Creek Tributary to St. Vrain Creek; Unclassified, Effluent Limited	1,000	2,000
Clear Creek	Georgetown Valley Water and Sewer District	Activated Sludge	0.25	0.40	210	Clear Creek; Effluent Limited Segment	6,000	12,000
	Town of Idaho Springs	Trickling Filter	0.25	0.40	724	Clear Creek; Effluent Limited Segment	6,000	12,000
Douglas	Town of Castle Rock	Aerated Lagoon	0.312	0.32	536	East Plum Creek	6,000	12,000
Elbert	Town of Simla			0.11	90	Big Dry Creek; Unclassified, Effluent Limited Segment	200	400
Gilpin	Black Hawk - Central City Sanitation District	Activated Sludge	0.05 (winter) 0.5 (summer)	0.06	120	North Clear Creek	200	400
Jefferson	City of Arvada	Trickling Filter	1.0	0.75	150	Ralston Creek	1,000	2,000
	Clear Creek Valley	Trickling Filter, Activated Sludge	2.1	1.65	2,614	Clear Creek; Water Quality Limited Segment	1,000	2,000
	Evergreen	Activated Sludge	1.0	0.32	610	Bear Creek; Water Quality Limited Segment	1,000	2,000
	Genessee Water and Sewer District	Aerated Lagoon	0.20	0.05	100	Unnamed Gulch, Tributary to Bear Creek; Effluent Limited Segment	1,000	2,000

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin (continued)

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
	South Lakewood Sanitation District	Activated Sludge	1.8	1.2	2,400	South Platte River Water Quality Limited Segment	1,000	2,000
	West Jefferson County	Activated Sludge	0.625	0.5	300	Troublesome Creek to Bear Creek; Unclassified to Water Quality Limited Segment	--	--
	Wheatridge Sanitation District	Trickling Filter	3.0	2.2	4,400	Clear Creek Water Quality Limited Segment	3,000	6,000
	Willow Brook Water and Sanitation District	Rotating Bio-Disc	0.25	0.05	100	Unnamed Drainage Gulch Tributary to Turkey Creek; Unclassified to Unclassified	6,000	12,000
Logan	Sterling	Trickling Filter	2.5	2.1	12,000	South Platte River; Effluent Limited Segment	6,000	12,000
	City of Brush	Trickling Filter	1.5	0.75	--	South Platte River; Effluent Limited Segment	6,000	12,000
	Fort Morgan	Trickling Filter	3.6	1.7	--	South Platte River; Effluent Limited Segment	6,000	12,000
Sedgwick	Julesburg	Trickling Filter	--	0.22	--	South Platte River; Effluent Limited Segment	--	5,000
Teller	City of Woodland Park	Aerated Lagoons (north)	0.36	0.045	--	Fountain Creek; Effluent Limited Segment	6,000	12,000
Larimer	Town of Berthoud	Oxidation Ditch	0.9	0.53 - 1.03	650	Unnamed Stream Tributary to Little Thompson River; Effluent Limited Segment	6,000	12,000
	Boxelder Sanitation District	Aerated Lagoons	0.75	0.6	--	Boxelder Creek Tributary to Cache la Poudre River; Unclassifed Tributary to a Water Quality Limited Segment	2,000	4,000

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin (continued)

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
	Estes Park Sanitation District	Activated Sludge	0.75	0.90	--	Big Thompson River; Water Quality Limited Segment	6,000	12,000
	Fort Collins, #1	Trickling Filter, Activated Sludge	22.5	14	--	Cache la Poudre River	1,000	2,000
	Fort Collins, #2	Activated Sludge				Cache la Poudre River; Fossil Creek Reservoir Canal	1,000 6,000	2,000 12,000
	South Fort Collins Sanitation District	Activated Sludge	1.5	0.6	--	Fossil Creek Reservoir to Cache la Poudre River; Effluent Limited Segment	6,000	12,000
	Loveland	Activated Sludge, Trickling Filter	7.7	4.5	--	Big Thompson River; Water Quality Limited Segment	2,000	4,000
	Upper Thompson Sanitation District	Activated Sludge, Sand Filter Ozonation	1.5	0.54	--	Big Thompson River; Effluent Limited Segment	200	400
	Town of Wellington	Aerated Lagoon	0.2	0.175	--	Boxelder Creek; Unclassified Effluent Limited Segment	6,000	12,000
Weld	Delcamino Village	Extended Aeration	0.1	0.05	240	Rural Ditch; Unclassified Effluent Limited Segment	6,000	12,000
	Erie Sanitation District	Aerated Lagoon	0.08	0.12	160	Coal Creek; Water Quality Limited Segment	6,000	12,000
	Town of Eaton	Oxidation Ditch	0.34	0.2	--	Seep Ditch to Cache la Poudre River; Water Quality Limited Segment	1,000	2,000
	Town of Fort Lupton	Aerated Lagoons	1.5	0.45	--	South Platte River; Effluent Limited Segment	6,000	12,000
	Greeley	Trickling Filter, Activated Sludge	9.0	7.5	--	Cache la Poudre River; Water Quality Limited Segment	3,000	6,000

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin (continued)

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
	Hudson Sanitation District	Aerated Lagoon, Polishing Pond	0.197	0.09	394	Beebe Seep Canal; Unclassified; Effluent Limited Segment	6,000	12,000
	Johnstown Sanitation Dis-Trict	Aerated Lagoon, Polishing Pond	0.408	0.35 (est.)	400	Little Thompson River; Effluent Limited Segment	1,000	2,000
	Town of Kersey	Oxidation Ditch	0.25	0.08	--	Unnamed Ditch to South Platte River; Effluent Limited Segment	6,000	12,000
	Town of LaSalle	Aerated Lagoon	0.39	0.185	660	South Platte River; Effluent Limited Segment	6,000	12,000
	Milliken Sanitation District	Extended Aeration	0.095	0.23	--	Little Thompson River; Water Quality Limited Segment	1,000	2,000
	Weld Co. Tri-Area	Aerated Lagoon, Polishing Pond	0.75	0.40	--	Unnamed Ditch Tributary to St. Vrain; Unclassified Effluent Limited Segment	6,000	12,000
	Town of Windsor	Aerated Lagoon, Polishing Pond	0.66	0.60	1,200	Cache la Poudre River; Water Quality Limited Segment	1,000	2,000
Nebraska[4]:								
Kimball	Kimball A	Trickling Filter	0.3	0.3	--	Lodgepole Creek	--	--
	Kimball B	Lagoon	0.3	0.3	--	Lodgepole Creek	--	--
Cheyenne	Sidney	Trickling Filter	1.0	--	--	Lodgepole Creek	--	--
Deuel	Chappell	Activated Sludge with Polishing Lagoons	0.35	--	--	Lodgepole Creek	--	--
Keith	Ogallala No. 1	Trickling Filter	1.0	1:0	--	South Platte River	--	--

TABLE A-2 Municipal Wastewater Treatment Plants, South Platte River Basin (continued)

State: County	Municipal Treatment Plant	Type	Design Capacity MGD	Hydraulic Capacity MGD	Organic Loading[1] lbs. of BOD_5/day	Receiving Water and Classification[2]	NPDES Fecal Coliform Standard Coliforms per 100 ml 30-day ave.	7-day ave.
	Ogallala No. 2	Activated Sludge, Extended Aeration	0.08-0.10	--	--	South Platte River	--	--
Wyoming[5]: Laramie	Cheyenne, Dry Creek	Activated Sludge	4.5	--	--	Dry Creek to Crow Creek	--	--
	Cheyenne, Crow Creek	Trickling Filter	4.0	--	--	Crow Creek	--	--
	South Cheyenne	Extended Aeration	0.4	--	--	Crow Creek	--	--

[1]Organic Loading calculated from hydraulic loading capacity.

[2]Classification: Effluent Limited--where effluent standards applicable to discharges into a segment or portion of State waters are adequate to maintain or attain the assigned stream classification, the effluent standards will not be affected by the classification.

Water Quality Limited--where the effluent standards applicable to the discharges are inadequate to maintain or attain the assigned classification, a degree of treatment which will maintain or attain such classification will be required.

[3]Obtained from Colorado Health Department, Denver, Colorado. Personal communication, August 1980.

[4]Obtained from Department of Environmental Quality, Cheyenne, Wyoming. Personal communication, March 1981.

[5]Obtained from Department of Environmental Control, Lincoln, Nebraska. Personal communication, March 1981.

APPENDIX B

ANALYTICAL METHODS AND MATERIALS FOR THE ENUMERATION OF BACTERIA OF SANITARY SIGNIFICANCE

B.1 Laboratory Preparation

GENERAL:

- Demineralized Water
- Stock Phosphate Buffer Solution
- Stock Magnesium Thiosulfate Solution
- Ten Percent Sodium Thiosulfate Solution
- 0.2 N Sodium Hydroxide (NaOH)
- Rosolic Acid Solution
- Dilution Water
- Laboratory Cleanup

MEDIA PREPARATION:

- M-Endo Broth (Total Coliform Analysis) - Prepared media from Diffco Laboratories, 95 percent non-denatured ethanol, demineralizaed water

- M-FC Broth (Fecal Coliform Analysis) - Prepared media from BBL, rosolic acid solution, demineralized water

- KF-Agar (Fecal Streptococci Analysis) - Prepared media from BBL, TTC solution

STERILIZATION:

- Dry materials - pipets, funnels
- Wet materials - dilution water, rinse water, sample bottles

B.2 Membrane Filter, Single Step Procedure

A. Prepare broth or agar media as directed.

B. Mark petri dishes with sample identities and volume.

C. Place one sterile absorbent pad (for broths) in bottom half of petri dish. Pipet in 1.8 to 2.0 ml of broth onto each pad to saturate. Pour off excess broth.

D. Place sterile membrane filter on filter base, grid side up and attach funnel to base of filter unit.

E. Shake sample bottle vigorously. Select sample volumes (minimum of 3) to produce a specified range of colonies (dependent on colony type). For samples less than 10 ml, add sterile dilution water to filter prior to adding sample.

F. Filter sample and rinse the sides of the funnel with sterile dilution water. Remove funnel from filter base. Aseptically remove the membrane filter and place grid side up the agar or broth soaked pad. Note: reseat membrane if air bubbles occur between filter and pad.

G. Filter samples in order of increasing sample volume.

H. Count colonies.

I. Record as number per 100 ml of sample.

B.3 Counting and Recording Colonies

INDENTIFICATION[1]:

Test	Incubation	Colony Identification
Total Coliform	24 + 2 hrs @ 35 ± 0.5°C approximately 100% humidity	Golden-green metalic sheen colonies
Fecal Coliform	24 + 2 hrs @ 44.5 ± 0.2°C	Blue colonies
Fecal Streptococci	48 + 3 hrs @ 35 ± 0.5°C	Pink to dark red colonies

ACCEPTABLE LIMITS; NUMBER OF COLONIES PER FILTER[1]:

Test	Minimum	Maximum
Total Coliform	20	80
Fecal Coliform	20	60
Fecal Streptococci	20	100

Note: There is a limit of 200 colonies of all types per filter

CALCULATION OF RESULTS[3]:

1. Count per 100 ml = $\frac{\text{Number of Colonies Counted}}{\text{Volume of sample filtered}} \times 100$

2. More than one acceptable count

   a. Replicate plates - Independently carry counts to final reporting units then average arithmetically.

b. More than one dilution - Independently carry counts to final reporting units then average arithmetically.

3. All counts below the lower limit

   a. Non-potable waters - Select the most nearly acceptable count and report as "Estimated."

   b. All counts are 0 - Use the largest volume and a count of one colony. Report as less than the number obtained per 100 ml.

4. All counts above the upper limit

   a. Countable - Use the colony count from the smallest filtered volume. Report as "Estimated."

   b. All counts too numerous to count (TNTC) - Use the upper limit count with the smallest filtered volume. Report as greatern than the number obtained per 100 ml.

5. Counts falling outside the acceptable limits, both above and below.

   a. Select the volumes which come closest to being in the correct range. Counts above and below range and divide sum by the total filtered volume. Report as "Estimated."

[1,2,3] Source: U.S. EPA, 1978.

B.4 Laboratory Materials

MEDIA:

M-FC Broth	BBL, Lot #A2D1QG
M-Endo Broth MF	Difco Laboratories, Lot #669403
Endo Agar	Difco Laboratories, Lot #529182
KF Streptococcal Agar	BBL, Lot #B2D1TM
Bacto Rosolic Acid	Difco Laboratories, Lot #666131
1 Percent TTC Solution	BBL, Lot #12237 (2,3,5 Triphenyl Tetrazolium Chloride)

MATERIALS:

Membrane Filters	Millipore HA 0.45 micron pore size, Lot #C8N7889
Sterile Pads	Millipore Corporation, Lot #C8M76898
Membrane Filters plus Pads	Millipore Corporation, Lot #H9561273C, and Lot # HOB61829A
Filter Holders	Millipore Corporation, Pyrex 47 mm filter holders; Millipore Corporation, Hydrosol Stainless 47 mm
Petridishes	Falcon, 60 x 15 mm, Lot #00021047; Falcon, 50 x 9 mm, Lot #92071004
Sample Bottles	Nalgene, polypropelene, 8 oz
Dilution Bottles	Corning, Pyrex milk dilution bottles, 160 ml
Whirl-Pack Bags	NASCO, 18 oz

B.5 Preparation, Sampling, and Testing Durations

The following briefly outlines the duration of time spent on each aspect of the microbiological testing described in the preceding sections of the appendix.

LABORATORY PREPARATION:

General	4.0 hours
Media Preparation	1.0 hours
Sterilization	4.0 hours
	9.0 hours per sampling expidition

FIELD SAMPLING:

Travel	0.22 hours
Grab Sample	0.08 hours
	0.30 hours per sample

LABORATORY TESTING:

Membrane Filter	
Single Step Procedure[1]	0.75 hours
Counting and Recording	0.05 hours
	0.80 hours per sample

[1]For total coliforms, fecal coliforms, and fecal streptococci

APPENDIX C

BACTERIOLOGICAL TESTING, QUALITY CONTROL, PRECISION, AND ACCURACY

C.1 Quality Control on Routine Analyses

C.2 Analyst Precision

C.3 Accuracy

C.1 Quality Control on Routine Analyses

The following steps were taken during testing periods for each parameter tested.

- Positive Control Samples - one pure culture of known positive reaction was tested during every testing period.
- Negative Control - At least one negative control using buffered water, filter, and each growth medium was included during every testing period.
- Duplicate Analyses - duplicate testing was performed on the samples for each parameter tested (August samples only).

C.2 Analyst Precision

Analyst precision is measured through duplicate sampling procedures. The results of these tests are given below:

Test	Volume Tested (ml)	Number of Sample Pairs		Percent Variation[2]	
		Total	Within Limits[1]	Total	Within Limits[1]
Fecal Coliform	20	2	1	11.4	17.2
	10	17	6	25.8	40.2
	1	15	3	42.1	18.3
				Ave. 26.4	29.3
Fecal Streptococci	3	3	3	20.3	20.3
	1	12	7	19.8	18.7
	0.1	10	3	54.3	17.9
				Ave. 31.5	19.0

[1] Within Limits - Number of organisms per filter were within the acceptable limits indicated for that test (See B.3).

[2] Percent Variation = $\frac{x_1 - x_2}{x_2}$ (100) for $x_2 < x_1$

Where: x_2 and x_1 are duplicate counts per dilution per sample.

The U.S. EPA Microbiological Methods, 1978 states that laboratory personnel should be able to duplicate their colony counts on the same membrane within 5 percent and the counts of other analysts within 10 percent. In an effect to determine why the above levels were not met, duplicates were run on pure cultures in order to determine if interference in the waters sampled, such as turbidity was leading to the wide range in duplicate results. The following results were obtained:

Sample Volume (ml)	Number of Samples of Pure Cultures[1]	Percent Variation[2]
0.1	2	12.90
0.1	2	16.00
0.1	2	38.10
		Ave. 22.33

[1] Pure cultures of E. coli were obtained from the CSU microbiology laboratories

[2] Percent Variation = $\frac{x_1 - x_2}{x_2}$ (100) for $x_2 < x_1$

This would indicate that for the fecal coliform analyses analyst precision, be it in methods, equipment, or media, lead to the observed range in duplicate results.

C.3 Accuracy

Accuracy is a measure of the closeness of observed values to a known true value. In the field of microbioogy the lack of available standards has resulted in methods with limited information as to accuracy.

In order to determine recovery (using this as a measure of accuracy) pure cultures are often utilized as spikes to a sample. Recovery is then defined as the difference between the number of cells obtained with the spike added to the sample, and the number obtained without the spike. The number of cells in the spike must be determined independently using a non-selective medium.

To test the recovery of the membrane filter utilized throughout these anslyses, a suspension of E. coli in laryl sulfate broth was obtained from the CSU microbiology laboratories. Dilutions were examined for recovery of E. coli on M-Endo (Diffco) agar, agar and membrane filters, and M-Endo Broth (Diffco) and membrane filter. The results of this test follow:

Sample	Volume (ml)	Media	Filter	Count (on 2 samples)
E. coli	0.1	M-Endo Agar	No	38, 37
		M-Endo Agar	Yes	123, 124
		M-Endo Broth	Yes	227,202

Prior to performing this test, it was assumed that the best recovery of organisms would be on the Agar alone. However, the reverse was shown to be the case here. Therefore, this test did not add to the knowledge of the recovery of organisms utilizing the membrane filter technique. Problems that have been brought out in the literature regarding this type of analysis are, clumping and the assumption that one organism results in one colony. Clumping may lead to increases or decreases in colony counts which then falsify the assumption mentioned above.

In 1978, the Upper Thompson Sanitation District partook in a testing program utilizing three professional laboratories for microbiological analyses. These laboratories were the Upper Thompson Sanitation District's own Water Quality Laboratory, M&I, Inc. laboratory, and the water quality laboratory of the microbiology department at CSU. Split samples run by these laboratories resulted in deviations of up to 2 logs difference with no pattern of one laboratory being consistently higher or lower than the other. Pure cultures were also put through this test, again, with the same noticeable lack of agreement.

This serves to indicate the difficulty in attempting to develop information on the accuracy of microbiological testing.

APPENDIX D

ORIGINAL DATA FIELD SURVEY

TABLE D-1 Original Data from Field Survey 1980, PJP

Date of Sampling 1980	Time	Sampling Location	Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS[1]	FC/TC[2]	Comments
June 17	1200	Fossil Creek, Drake	1,500	630	950 est.	0.66	0.42	
	1207	Boxelder, Drake	200 est.	110 est.	300	0.37	0.55	
June 25	1215	Fossil Creek, Diversion	240	230	440	0.52	0.96	
	1220	Fossil Creek, Drake	150	300 est.	2,300 est.	0.13	2.00	
	1230	Boxelder, Drake	100 est.	250	500	0.50	2.50	
	1240	Fossil Creek, Rt. 36	50 est.	240	610	0.39	4.80	
	1245	Boxelder, Rt. 36	No result	250 est.	--	--	--	
June 26	0825	Lake Canal, Rt. 42	400 est.	200 est.	--	--	0.50	
	0845	Fossil Creek, Drake	3,300	190 est.	--	--	0.06	
	0850	Boxelder, Drake	6,200	1,200	--	--	0.19	High Water
July 1	0800	Fossil Creek, Drake	180 est.	120 est.	3,100	0.04	0.67	Duplicates
	0805	Boxelder, Drake	160 est.	530	4,100 est.	0.13	3.31	
July 2	0800	Lake Canal, Rt. 42	100 est.	170 est.	2,900	0.06	1.70	
July 3	0735	Boxelder, Drake	> 8,000	> 6,000	>10,000	0.6	0.75	
	0805	Boxelder, Rt. 36	>80,000	> 6,000	>10,000	0.6	0.08	
	0730	Fossil Creek, Drake	No result	2,200	19,000 est.	0.12	--	Background Count >200 for T.C.
	0755	Fossil Creek, Rt. 7 (Bridge)	No result	2,300	>10,000	0.23	--	Background Count >200 for T.C.
July 8	0845	Lake Canal, Rt. 42	<100	130 est.	4,700	0.03	1.30	Recirculation Bath First Used
	0850	Fossil Creek, Drake	14,000 est.	1,900	6,200	0.31	0.14	
	0855	Boxelder, Drake	6,000	3,400	6,800	0.50	0.57	
	0910	Fossil Creek, Rt. 7 (Bridge)	3,000 est.	1,100 est.	10,000 est.	0.11	0.37	
	0920	Boxelder, Rt. 36	8,000 est.	7,000 est.	12,000 est.	0.58	0.88	
July 14	1040	Lake Canal, Rt. 42	100	330 est.	2,200	0.15	3.30	
	1055	Fossil Creek, Drake	2,800	100 est.	3,000	0.03	0.04	
	1100	Boxelder, Drake	1,500 est.	670	1,700	0.39	0.45	
	1110	Fossil Creek, Rt. 7 (Bridge)	400 est.	300 est.	4,600	0.07	0.75	
	1117	Boxelder, Rt. 36	2,000 est.	1,200	3,900	0.31	0.60	

TABLE D-1 Original Data from Field Survey 1980, PJP (continued)

Date of Sampling 1980	Time	Sampling Location	Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS[1]	FC/TC[2]	Comments
July 16	0005	Poudre, S.B., Lake Diversion	--	--	--	--	--	Whirl Pack Bags Utilized
	0030	Poudre, N.B., Lake Diversion	70 est.	40 est.	830	0.05	0.57	
	0045	Lake Canal, Lindenmeir	<30	80 est.	770	0.10	>2.67	
	0055	Poudre, W.B., Linden Street	400 est.	170 est.	1,600	0.11	0.43	
	0110	Poudre, Prospect	<10	220	3,700	0.06	>22.00	
July 20	1740	Fossil Creek, Drake	>80,000	72,000	18,000 est.	4.00	<0.90	Fecal Streptococci samples incubated 48 hrs. ± 3 on 7/20 samples
	1742	Boxelder, Drake	11,000 est.	2,800	4,900 est.	0.57	0.25	
	1750	Fossil Creek, Rt. 7 (Bridge)	100 est.	300 est.	5,500	0.05	3.00	
	1755	Boxelder, Rt. 36	18,000 est.	2,100 est.	9,000	0.23	0.12	
	1810	Lake Canal, Rt. 42	<100	900 est.	3,200	0.28	>9.00	
July 23	0825	Poudre, N.B., Lake Diversion	100 est.	90 est.	2,900	0.03	0.90	
	0835	Poudre, N.W.B., Linden Street	100 est.	680 est.	>3,300	<0.21	6.80	
	0900	Poudre, Prospect	No result	1,300 est.	>3,300	<0.39	--	Background Count >200 for T.C.
	0907	Lake Canal, Rt. 42	No result	1,300 est.	22,000 est.	0.06	--	Background Count >200 for T.C.
	0920	Boxelder, Drake	3,000 est.	600 est.	18,000 est.	0.03	0.20	
	0917	Fossil Creek, Drake	<1,000 est.	200 est.	>10,000	<0.02	0.03	
July 26	1025	Fossil Creek, Drake	1,000 est.	300 est.	7,800	0.04	0.30	
	1027	Boxelder, Drake	1,000 est.	2,100	17,000 est.	0.12	2.10	
	1035	Fossil Creek, Rt. 7 (Bridge)	31,000	10,000 est.	4,600*	2.17*	0.32	*Invalid
	1040	Boxelder, Rt. 36	<30	3,400	9,100	0.37	>113.33	
	1050	Lake Canal, Rt. 42	<30	2,700	5,900	0.46	> 90.00	
July 31	0935	Lake Canal, Rt. 42	1,000 est.	2,200	23,000	0.10	2.20	
	0950	Fossil Creek, Drake	5,000 est.	1,300	38,000	0.03	0.26	
	0955	Boxelder, Drake	4,000 est.	1,500	26,000	0.06	0.38	
	1003	Fossil Creek, Rt. 7 (Bridge)	79,000	11,000 est.	31,000	0.35	0.14	
	1007	Boxelder, Rt. 36	8,000 est.	2,800	23,000	0.12	0.35	

TABLE D-1 Original Data from Field Survey 1980, PJP (continued)

Date of Sampling 1980	Time	Sampling Location	Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS[1]	FC/TC[2]	Comments
Aug. 7	0815	Poudre, above Lake		300	2,200	0.14		Duplicate Testing Began
	0840	Poudre, Prospect		900 est.	2,500	0.36		
	0847	Lake Canal, Rt. 42		1,100 est.	32,000	0.03		
	0900	Fossil Creek, Drake		2,400	25,000	0.10		
	0905	Boxelder, Drake		3,700	23,000	0.16		
Aug. 13	0915	Poudre, above Lake		160	770	0.21		
	0935	Poudre, Prospect		940 est.	>10,000			
	0940	Lake Canal, Rt. 42		460	4,800	0.10		
	1000	Fossil Creek, Drake		930 est.	12,000 est.	0.08		
	1003	Boxelder, Drake		1,300 est.	28,000	0.05		
Aug. 14	1320	Big Thompson, Frontage Rd.		3,100	12,000 est.	0.26		
	1327	Hillsboro Ditch, Frontage Rd.		1,800 est.	9,800	0.18		
	1345	Farmers Canal, E 9		300	4,700	0.06		
	1355	Big Thompson, above WWTP		3,800	>10,000	<0.38		
Aug. 19	1650	Poudre, above Lake		95 est.	2,200	0.04		
	1705	Poudre, Prospect		550	2,800	0.20		
	1714	Lake Canal, Rt. 42		2,000	5,600	0.36		
	1730	Fossil Creek, Drake		300	4,800	0.06		
	1735	Boxelder Creek, Drake		950 est.	4,700	0.20		
Aug. 19	2300	Fossil Creek, Drake		300	5,600	0.05		
	2310	Boxelder, Drake		3,100	14,000 est.	0.22		
Aug. 20	0610	Fossil Creek, Drake		660	7,000 est.	0.09		
	0615	Boxelder, Drake		950 est.	1,500 est.	0.63		
Aug. 20	1210	Fossil Creek, Drake		230	5,000 est.	0.05		
	1215	Boxelder, Drake		750 est.	8,500 est.	0.09		

[1] FC/FS = Fecal Coliform to Fecal Streptococci Ratio

[2] FC/TC = Fecal Coliform to Total Coliform Ratio

TABLE D-2 Fossil Creek Ditch - Microbiological Indicators

Date of Sampling 1980	Time	Drake Rd. (A-1) Total Coliforms per 100 ml	Drake Rd. (A-1) Fecal Coliforms per 100 ml	Drake Rd. (A-1) Fecal Streptococci per 100 ml	Drake Rd. (A-1) FC/FS	Rt. 7 (A-2) Total Coliforms per 100 ml	Rt. 7 (A-2) Fecal Coliforms per 100 ml	Rt. 7 (A-2) Fecal Streptococci per 100 ml	Rt. 7 (A-2) FC/FS
June 17	1200	1,500	630	950 est.	0.66				
June 25	1200	150	300 est.	2,300	0.13	50 est.	240	610	0.39
June 26	0800	3,300	190 est.	No results					
July 1	0800	180 est.	120 est.	3,100	0.04				
July 3	0700	No results	2,200	19,000 est.	0.12	No results	2,300	>10,000	<0.23
July 8	0830	14,000 est.	1,900	6,200	0.31	3,000 est.	1,100 est.	10,000 est.	0.11
July 14	1030	2,800	100	3,000	0.03	400 est.	300 est.	4,600	0.07
July 20	1730	>80,000	72,000	18,000 est.	4.0	100 est.	300 est.	5,500	0.05
July 23	0800	1,000 est.	200 est.	>10,000					
July 26	1000	1,000 est.	300 est.	7,800	0.04	31,000	10,000 est.	--	--
July 31	0930	5,000 est.	1,300	38,000	0.03	79,000	11,000 est.	31,000	0.35
Aug. 7	0800		2,400	25,000	0.10				
Aug. 13	0900		930 est.	12,000	0.08				
Aug. 19	1700		300	4,800	0.06				
Geometric Mean[1]		2,100	700	7,400		1,600	1,300	6,000	
High		>80,000	72,000	38,000	4.0	79,000	11,000 est.	31,000	0.35
Low		150	100	950 est.		50 est.	240	610	
Standard Deviation[2]		29,000	20,000			46,000	6,600		

NOTE: Compiled from original data table.

[1] Geometric Mean = $\sqrt[n]{(x_1)(x_2)\ldots(x_n)}$

[2] Standard Deviation = $\left[\frac{1}{n-1}\ \Sigma(x_i-\bar{x})^2\right]^{1/2}$ where $\bar{x}$ = geometric mean

n = number of samples

TABLE D-3 Boxelder Ditch - Microbiological Indicators

Date of Sampling 1980	Time	Drake Rd. (B-1) Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS	Rt. 36 (B-2) Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS
June 17	1200	200 est.	110 est.	300	0.37				
June 25	1200	100 est.	250	500	0.50	No results	250 est.	--	--
June 26	0800	6,200	1,200	--	--				
July 1	0800	160 est.	530	4,100 est.	0.13				
July 3	0700	>8,000	>6,000	>10,000	0.60	>80,000	>6,000	>10,000	0.60
July 8	0830	6,000 est.	3,400	6,800	0.50	8,000 est.	7,000 est.	12,000 est.	0.58
July 14	1030	1,500 est.	670	1,700	0.39	2,000 est.	7,000	3,900	1.79
July 20	1730	11,000 est.	2,800	4,900 est.	0.57	18,000 est.	2,100 est.	9,000	0.23
July 23	0800	3,000 est.	600 est.	18,000 est.	0.03	--	--	--	
July 26	1000	1,000 est.	2,100	1,700 est.	1.24	<30	2,700	5,900	0.46
July 31	0930	4,000 est.	1,500	26,000	0.06	8,000 est.	2,800	23,000	0.12
Aug. 7	0800		3,700	23,000	0.16				
Aug. 13	0900		1,300 est.	28,000	0.05				
Aug. 19	1700		950 est.	4,700	0.20				
Geometric Mean[1]		1,600	1,100	4,900		4,200	2,700	9,100	
High		11,000 est.	>6,000	28,000	1.24	>80,000	7,000 est.	23,000	1.79
Low		100	110 est.	300		<30	250 est.	3,900	
Standard Deviation[2]		7,500	2,700			41,000	11,000		

NOTE: Compiled from original data table.

[1] Geometric Mean = $\sqrt[n]{(x_1)(x_2)\ldots(x_n)}$

[2] Standard Deviation = $\left[\frac{1}{n-1}\ \Sigma(x_i-\bar{x})^2\right]^{1/2}$ where $\bar{x}$ = geometric mean, n = number of samples

TABLE D-4 Lake Canal - Microbiological Indicators

Date of Sampling 1980	Time	Lindenmeir St. Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS	Rt. 42 (C-1) Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS
June 26	0830					400 est.	200 est.		
July 2	0800					100 est.	170 est.	2,900	0.06
July 8	0830					<100	130 est.	4,700	0.03
July 14	1100					100	330 est.	2,200	0.15
July 16	1230	<30	80 est.	770	0.10				
July 20	1800					<100	900 est.	3,200	0.28
July 23	0900					No results	1,300 est.	22,000 est.	0.06
July 26	1100					<30	2,700	5,900	0.46
July 31	0930					1,000 est.	2,200	23,000	0.10
Aug. 7	0900						1,100	32,000	0.03
Aug. 13	1000						460	4,800	0.10
Aug. 19	1700						2,000	5,600	0.36
Geometric Mean[1]						140	660	6,900	
High						1,000 est.	2,700	32,000	0.46
Low						<30	130 est.	2,200	
Standard Deviation[2]						350	1,300		

NOTE: Compiled from original data table.

[1] Geometric Mean = $\sqrt[n]{(x_1)(x_2)\ldots(x_n)}$

[2] Standard Deviation = $\left[\frac{1}{n-1}\ \Sigma(x_i-\bar{x})^2\right]^{1/2}$ where $\bar{x}$ = geometric mean

n = number of samples

TABLE D-5 Cache la Poudre River - Microbiological Indicators

Date of Sampling 1980	Time	Upstream of Lake Diversion (R-1) Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS	Prospect St. (R-2) Total Coliforms per 100 ml	Fecal Coliforms per 100 ml	Fecal Streptococci per 100 ml	FC/FS
July 16	1230	70 est.	40 est.	830	0.05	<10	220	3,700	0.06
July 23	0830	100 est.	90 est.	2,900	0.03		1,300 est.	>10,000	<0.13
Aug. 7	0830		300	2,200	0.14		900 est.	2,500	0.36
Aug. 13	0930		160	770	0.21		940 est.	>10,000	0.09
Aug. 19	1700		95 est.	2,200	0.04		500	2,800	0.20
Geometric Mean[1]		80	110	1,600			670	4,800	
High		100	300	2,900	0.21		1,300	>10,000	0.36
Low		70	40 est.	770			220	2,500	
Standard Deviation[2]		10	68				260		

NOTE: Compiled from original data table.

[1] Geometric Mean = $\sqrt[n]{(x_1)(x_2)\ldots(x_n)}$

[2] Standard Deviation = $\left[\frac{1}{n-1}\ \Sigma(x_i-\bar{x})^2\right]^{1/2}$ where $\bar{x}$ = geometric mean

n = number of samples

TABLE D-6 Flow Data

(cfs)

Date 1980	Lake Canal	Fossil Creek Ditch at Drake Rd. (A-1)	Boxelder Ditch	Poudre River at R-1
6/17	106	41	22.4	640
6/25	136	54	38	464
6/26	134	54	41	475
7/1	146	107	41	582
7/2	139	236	36	615
7/3	124	136	27.5	646
7/8	123	138	26.1	157
7/14	117	25	27	193
7/16	21.8	57	29.5	105
7/20	0	101	31	24
7/23	54	16	26.1	75
7/26	2.6	40	24.2	22
7/31	29.5	28	27.5	77
8/7	45	25	31	79
8/13	78	43	24	89
8/19	51	46	21.9	73
8/20	43	46	21.5	61

Source: Water Commissioner, Mr. Jack Neutze, Colorado Division 1, District 3, September 1980.

TABLE D-7 Rainfall Data

Date of Sample, 1980	Sampling Site	Rainfall (inches)
July 1	A-1	0.02
	B-1	0.02
July 2	C-1	0.75
July 3	A-1	0.58
	B-1	0.58
	A-2	0.22
	B-2	0.22
July 8	C-1	0.59
	A-1	0.09
	B-1	0.09
	A-2	0.11
	B-2	0.11
July 20	C-1	0.03
	A-1	0.15
	B-1	0.15
	A-2	0.04
	B-2	0.04

Source: Mountain States Weather Service
James F. Wirshborn, Director
Fort Collins, Colorado, March 1981.