AN ABSTRACT OF THE THESIS OF

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Title: A Model to Predict the Bacterial Quality of a Rangeland Stream

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Grazing cattle usually have access to streams as a source of drinking water. A model was developed for the personal computer to predict the bacterial quality of these streams. The model estimates the number of organisms that enter the stream by the direct deposit of feces and by runoff from rainfall or melting snow. The model also predicts the fate of these organisms upon entering the stream. The stream discharge rates can be calculated by the model or input by the user. The bacterial water quality is determined by the number of organisms suspended in the stream per volume of discharge.

The model results were compared with bacterial levels measured in four different research projects and found to be within an order of magnitude in most cases. These results demonstrate that the model can predict bacterial concentrations with sufficient accuracy to make management decisions to insure a predetermined level of water quality. These results also demonstrate that the model is a better predictive tool for stream bacterial counts than traditional water sampling programs due to the model's ability to predict bacterial levels given a wide variety of grazing and hydrologic conditions.

The model was developed and tested using the most current research in rangeland water quality. As with any model, the accuracy of the results depend upon the accuracy of the input data. Future research can improve the usefulness of the model to better predict the bacterial counts in extended stream reaches.

A Model to Predict the Bacterial Quality of a Rangeland Stream

by

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I. INTRODUCTION

Cattle grazing is a major land use in the United States. According to the United States Department of Agriculture (1977) livestock grazing uses over one-third (300×10^6 ha) of the land area of the continental United States and this land receives 50% of all livestock wastes. The Public Land Law Commission (1970) estimates that nearly one-half of the 273 million acres of public rangeland in eleven western states is grazed at some time by domestic livestock.

Many studies have shown a direct relationship between the presence of grazing cattle and the increased bacterial levels in streams where cattle have access (Doran and Linn, 1979; Gary et al., 1983; Kunkle, 1970b; and Darling, 1973). Cattle grazing under poor management can also affect physical aspects of the stream. Platts (1981) found that streams altered by cattle overuse are more shallow, wider, warmer, have less overhead cover, and have more fine sediment as compared with streams not used by cattle.

In most grazing operations cattle have access to streams to provide a source of drinking water. Much debate centers over the effect of these grazing animals on the bacterial water quality of the streams. The Environmental Protection Agency considers livestock grazing on public lands as a potential non-point pollution problem (Van Haveren et al., 1985). An understanding of this issue is important in order to determine if any actions should be taken by livestock operators to reduce the impact of grazing on the stream water quality.

II. OBJECTIVE

The objective of this thesis project is to develop a computer model which is able to estimate the influence cattle grazing has on the bacterial water quality of a rangeland stream. The model estimates the fecal coliform (FC) and fecal streptococcus (FS) concentrations of the stream.

The model is based on the results of many research papers on the effects of livestock grazing on the bacterial water quality of rangeland streams. Many research papers on this subject report on the results of a bacterial process such as the release of organisms from fecal deposits into runoff water, the die-off of organisms in the bottom sediment, and the concentration of organisms in runoff water running through a rangeland. These papers make no attempt to estimate the influence that these individual processes have on the daily water quality of the stream.

Other papers simply report the results of a water sampling program before and after cattle grazing to estimate the influence of the cattle on the bacterial water quality of the stream. These papers do not estimate how the water quality of the stream would vary under different grazing and environmental conditions. Thus, the model was developed to predict how the bacterial water quality values change when the grazing and environmental conditions change. The model can estimate bacterial concentrations for cattle grazing under runoff and non-runoff conditions.

The model can be used by range managers to plan cattle grazing schedules that minimize the addition of bacterial organisms to the stream. If the rangeland stream is used as a source for drinking water or recreational purposes, the model can be used to determine the frequency that FC and FS concentrations in the stream exceed recommended limits established by the U.S. Environmental Protection Agency, shown in Table 2 on page 17 (USEPA, 1976). The user can also determine how rainfall or snowmelt runoff events affect the FC and FS levels of the stream.

III. MODEL OVERVIEW

Not all cattle manure generated and deposited on rangeland constitutes a water pollution potential. During dry weather, only manure deposited directly into the stream, lake or pond will impact water quality. The model attempts to integrate the bacterial processes resulting from cattle grazing to predict the bacterial concentrations of a rangeland stream. These processes are shown in Figure 1. A brief flow chart summarizing the model operations and the data to be input into the model is shown in Figures 2a and 2b. The relationship between animal behavior and bacterial quality of a rangeland stream is identified and discussed in the following sections.

Number of Cattle

The number of cattle with access to a stream determines the bacterial input to the stream and thus is a key factor in predicting the bacterial water quality of a rangeland stream. As the number of grazing cattle increases, the number of fecal deposits directly entering the stream increases, creating a higher pollution load.

Defecation Pattern of Cattle

Many rangeland operations depend on streams to provide drinking water for the cattle. While cattle are in the stream drinking, any feces voided will land in or adjacent to the stream. The riparian areas adjacent to the stream provide lush grass and cool shaded areas for the cattle. This results in the cattle spending a greater amount of their time in these areas rather than in upland regions during the summer. In the winter, the cooler riparian zones are less desirable to the cattle.

Figure 1. Diagram of bacterial processes from cattle grazing near a rangeland stream.

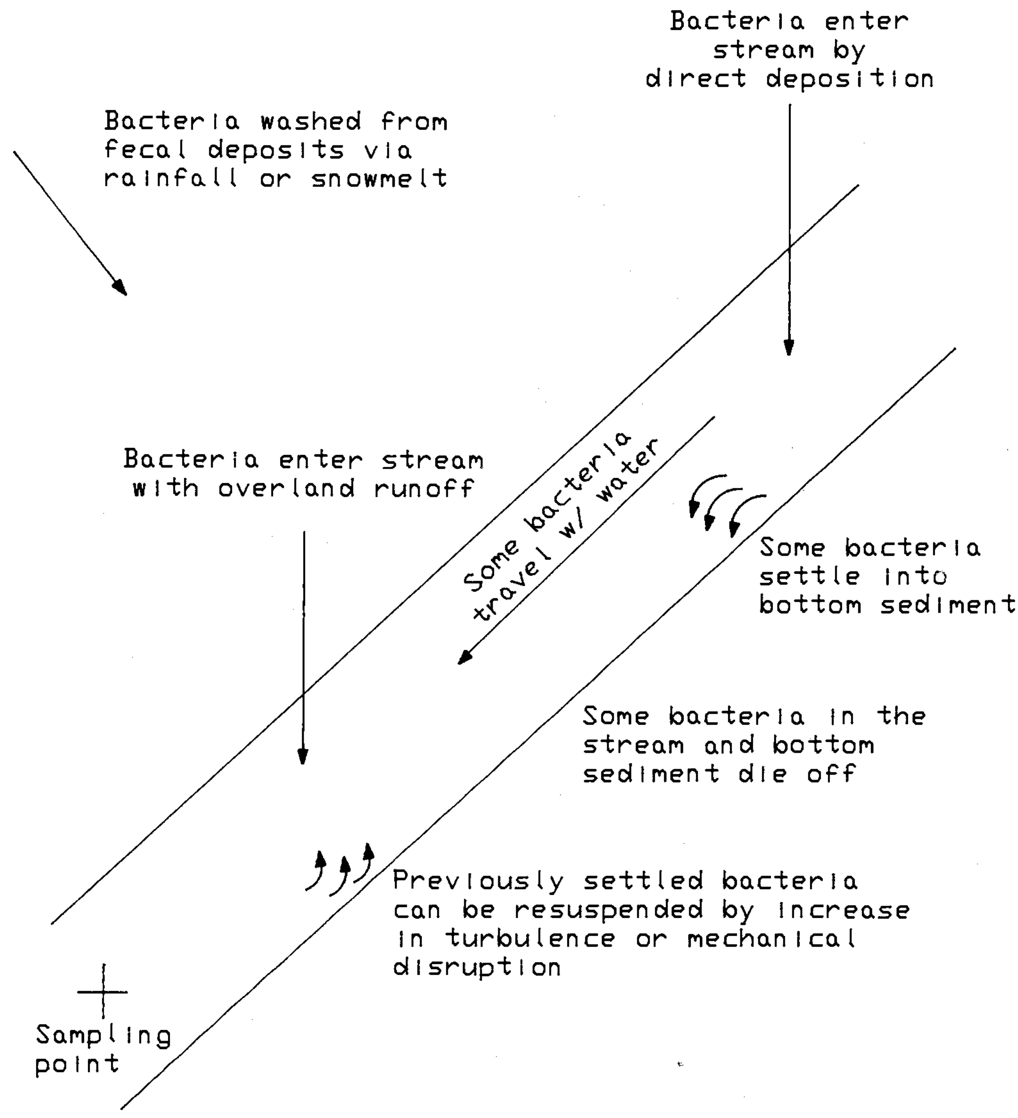


Figure 2. Flow chart summarizing the model operations and the data to be input into the model.

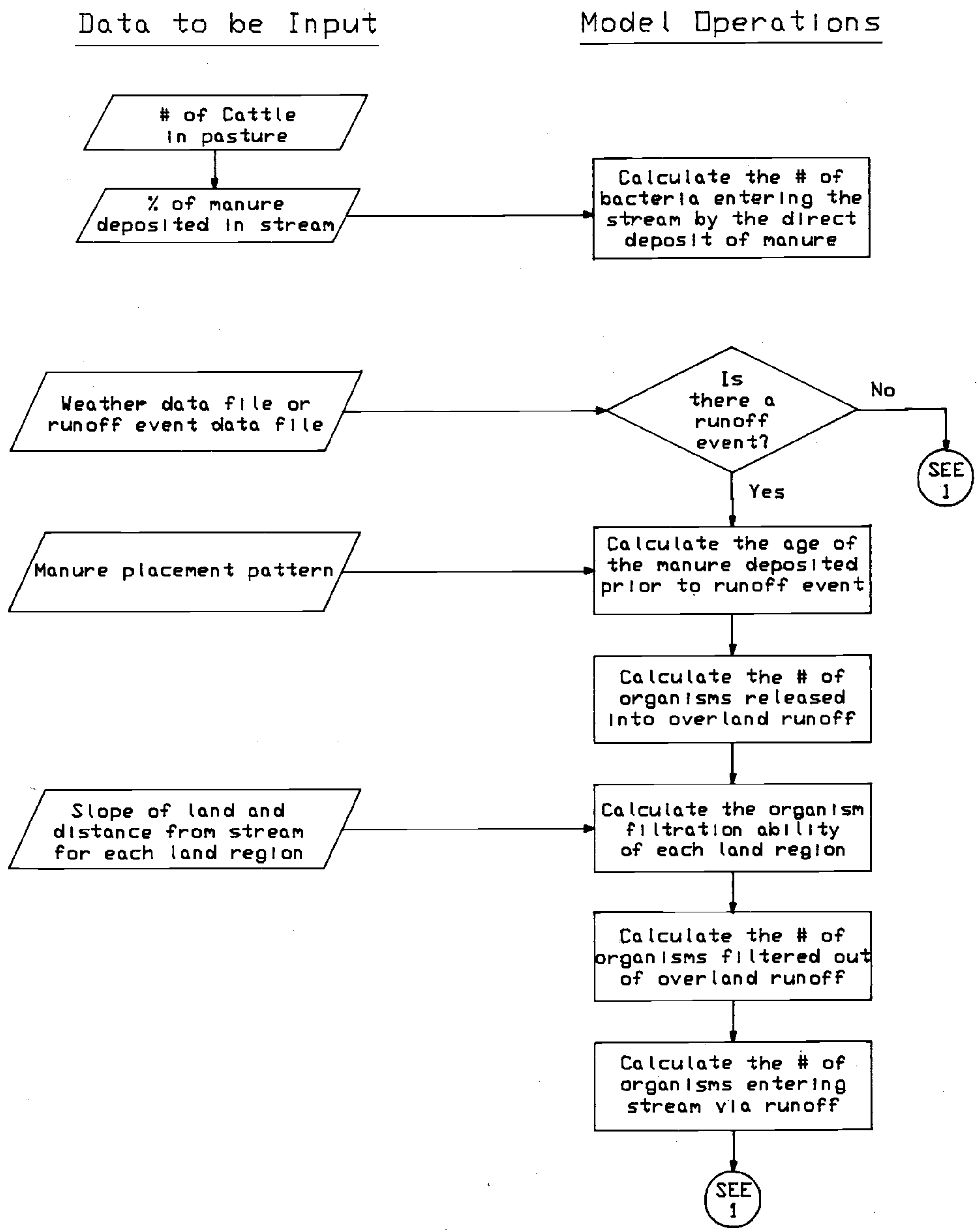
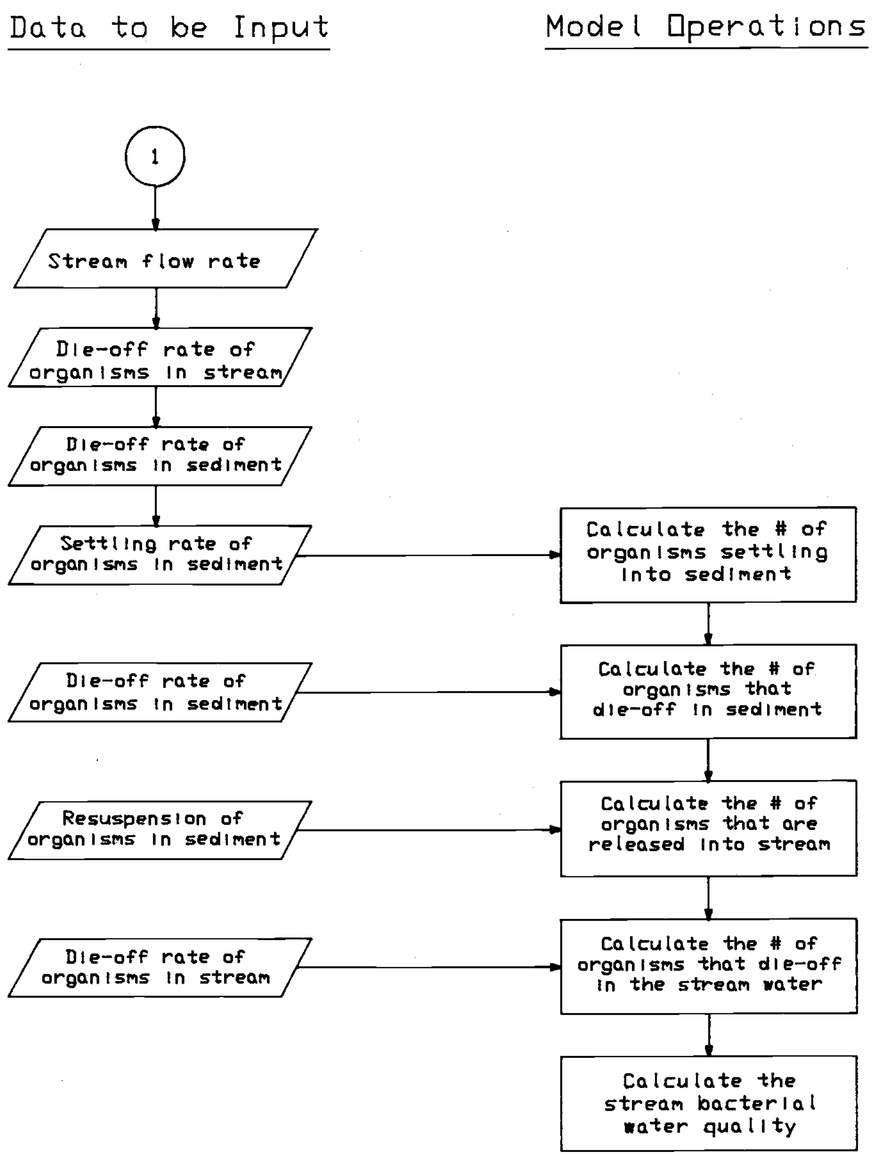


Figure 2. Flow chart summarizing the model operations and the data to be input into the model. (Continued)



Because of the time spent in and along the streams, some feces are deposited directly into the stream. During non-runoff conditions, the direct deposit of feces into the stream is the only input of bacterial organisms into the stream. Since many rangelands are in semi-arid regions with few runoff events occurring each year, it is important to estimate the amount of fecal material directly deposited into the stream.

During non-runoff conditions, the bacterial organisms remain in the fecal matter deposited away from the stream and do not contribute to the bacterial pollution of the stream. Moore et al. (1988b) showed that the fecal deposit distribution pattern (percentage of the deposits in the stream, the riparian zone, or the upland region) varies with the season of the year. The model accounts for the seasonal changes of the defecation patterns of the cattle since these changes vary the bacterial concentrations of the receiving stream.

Runoff Events

A runoff event in a rangeland drainage basin affects the stream bacterial concentrations in two ways: 1) by transporting organisms from fecal deposits on the land into the stream and 2) by increasing streamflow velocities which resuspend organisms attached to or mixed with the bottom sediment. It is important to predict the quantity of runoff and the change of stream velocity to predict the influence of the runoff event on the bacterial water quality of the stream. The quantity of runoff together with the number of cattle grazing determines the number of organisms carried to the stream by runoff and the stream velocity influences the number of organisms that are resuspended from the bottom sediment. The model predicts the amount of runoff and streamflow resulting from runoff events created by rainfall, snowmelt due to rainfall, and snowmelt due to temperature changes.

Release of Organisms from Fecal Deposits into Runoff

The runoff transports bacteria into the stream by flowing across and through fecal deposits on the land and releasing the bacteria contained in the deposits. The model estimates the number of organisms released into the runoff as a function of the depth of runoff and the age of the fecal deposits. As the depth of runoff increases, the number of organisms released from the fecal deposit increases. The age of the fecal deposit is important because with time the natural die-off reduces the number of organisms in the feces available to be released.

Filtering of Organisms from Runoff

The process of overland flow filters bacteria from the runoff water. The filtration capacity of the soil/plant system needs to be estimated to evaluate how many organisms are left in the runoff and enter the stream. The model combines the defecation patterns of the cattle with the filtration capacity of the land to determine the number of organisms removed from the runoff water. The filtration ability of the land is a function of the average distance of the fecal deposits to the stream and the average slope of land from the fecal deposits to the stream. A single value was ascribed to the effectiveness of vegetative cover to filter bacteria from runoff. The filtration is expressed as a percentage of organisms removed from the runoff water. The number of organisms entering the stream from the runoff event is calculated as the number of organisms released into the runoff minus the number filtered from the runoff.

Behavior of Organisms in Stream

After the organisms enter the stream, the behavior of the organisms determine the bacterial concentrations of the stream. The bacteria either settle into the bottom sediment, die in the stream water, or remain suspended and are transported downstream. The organisms that settle into the bottom sediment either die or are resuspended. Bacteria may be resuspended by higher flow rates or physical disturbance of the sediment layer by animal activity.

Settling of Organisms into Bottom Sediment

Most bacteria that enter the stream by the direct deposit of manure settle into the bottom sediment. Sediments are known to bind organic nutrients and prolong the survival of fecal bacteria (Hendricks and Morrison, 1967; Hendricks, 1971; McFeters et al., 1978). As the flow velocity increases the percentage of organisms settling into the bottom sediment would be expected to decrease. The model estimates the number of organisms that settle into the bottom sediment based upon the flow rate of the stream. As the streamflow increases, the model calculates that fewer organisms will settle to the bottom and be incorporated in the sediment.

Resuspension of Organisms from the Bottom Sediment

Since the bottom sediment harbors many bacteria, the resuspension of the bottom sediment releases many bacteria into the stream (Sherer, et al., 1988a). Organisms are released into the stream when the bottom sediment is resuspended due to higher stream flows or a physical disturbance of the sediment layer by animal activity. The number of bacteria in the bottom sediment is dependent on the number of animals grazing and having access to the stream. Moore et al. (1988b) and McDonald et al. (1982) conducted studies where streamflows were artificially increased by releasing water from a reservoir. There was no rainfall or snowmelt to contribute to the increased flow, so the simultaneous increase in bacterial concentrations with the increased flow was attributed to the resuspension of organisms from the bottom sediment. The equation used in the model calculates the number of organisms resuspended as a function of the streamflow based on the results of Moore et al. (1988b). As the streamflow increases, stream velocities increase which will resuspend a higher percentage of the organisms in the bottom sediment.

Die-off of Organisms

The concentration of enteric organisms in a stream is continually decreasing because of the hostile environment. The die-off process occurs in both the stream water and bottom sediment. Although the die-off rates are dependent upon water and sediment temperatures, the model assumes an average die-off rate for the bottom sediment and the stream water since these temperatures are constantly changing. An average daily die-off rate is about 20% of the organisms in the bottom sediment (Sherer et al., 1988b) and the 40% of the organisms in the water (Geldreich and Kenner, 1969).

Water Quality Estimation

The model estimates the bacterial concentrations of the stream on an average daily basis. While Kunkle and Meiman (1968) showed that concentrations can vary during the day, the model makes no attempt to estimate this variation. The model determines the number of organisms input into the stream by runoff events and the direct deposit of feces. The model then estimates the behavior of the organisms once they are input into the stream. The daily bacterial concentrations are calculated by dividing the number of surviving bacteria that are suspended in the streamflow by the daily volume of water flowing in the stream to obtain concentrations in number of organisms per 100 ml.

The model enables the user to predict the bacterial concentrations of the stream under runoff and non-runoff conditions based on the number of cattle grazing and their manure placement patterns. With the knowledge of how the bacterial concentrations of the stream are influenced by the grazing cattle, the rangeland manager can estimate how many cattle can graze in a pasture without violating given water quality standards of the stream. The model can also be used to estimate how many organisms are transported from a rangeland stream into a reservoir or lake to determine when undesirable numbers of organisms are transported into these bodies of water and the frequency of these events. A greater understanding of the transport of bacteria in rangeland streams will enable ranchers and recreational users to better understand actual conditions and how changes may be made in water quality.

IV. LITERATURE REVIEW

Cattle Grazing Operations

To determine the potential influence cattle grazing can have on the water quality of the streams, it is important to understand the nature of these grazing operations. Dixon et al. (1981b) gave a description of a typical cow-calf operation in the western United States:

> "The majority of these ranches semi-confine their cattle during the winter and graze them from late spring to early fall. At the end of the grazing period, the animals are gathered and the calves weaned. The animals not marketed are transferred to the wintering area. The length of time the mature cows are kept in the semi-confinement areas varies from three to five months depending upon climatic conditions and grazing allotments. Lot size and cattle density vary from ranch to ranch, as influenced by the size of the herd and physical limitations. During the grazing season, most of the semi-confinement areas are irrigated and used for hay crops. The major winter cattle feed is baled alfalfa or mixed species hay. This is generally fed from trucks or wagons and scattered on the ground. The water source is often a stream running through the semi-confinement area. Many ranchers plan for calving the cows while they are still in the wintering areas."

The above practice shows the high potential for a wintering operation to lower the stream water quality due to the increased cattle concentrations resulting from the confinement of livestock. Milne (1976) studied a cattle wintering operation and found very little change in the chemical analysis of the creek due to the confinement of the cattle. However, there was a significant change in the bacterial concentrations following the confinement of livestock in the wintering operation. There were 1200 sheep, 350 calving cows, 50 heifers, a 200 head feedlot and 85 hogs in the wintering operation (Milne, 1976). The indicator concentrations in different animal manures is listed in a literature review by Crane (1983).

Monitoring Bacterial Water Quality

Health Concerns

The bacterial water quality is of concern in determining potential health hazards. Diesch (1970) reported that many diseases can be transmitted from warm blooded animals to humans via water. Two diseases resulting from contamination of water supplies from cattle are salmonellosis and leptospirosis. The bacterial contamination of stream water originates with the livestock manure.

Indicator Organisms

Monitoring the actual pathogenic bacteria is very complex, expensive and all the methods for identifications have not been standardized. Thus an indicator organism is commonly used to monitor the water quality of the streams. Moore et al. (1982) describes the characteristics of an ideal indicator organism:

1) They should exist in large numbers in the contributing source and at levels far greater than pathogens associated with the waste.

2) The die-off or regrowth of the indicator organism in the environment should parallel that of the fecal pathogen.

3) The indicator organism should only be found in association with the particular waste source making its presence a positive indication of contamination.

The indicator organisms must be easy to quantify with testing methods applicable to a wide variety of samples from different sources. It should also be simple enough to carry out on a routine basis in the laboratory. These testing methods should be reliable enough to eliminate false positive results from possible interfering flora.

Of the many organisms proposed in the past, those that best fit these requirements are total coliform, fecal coliform and fecal streptococcus. Several studies have shown that agricultural runoff contains high levels of total coliform and fecal streptococci regardless of the contamination of the land with animal fecal materials (Doran and Linn, 1979; Harms et al., 1975; Schepers and Doran, 1980; Kunkle, 1979). Geldreich et al. (1964) states that fecal streptococci are present in substantial numbers on vegetation and insects, and fecal coliform are either not observed on vegetation or only on those insects that may spend part of their life cycle in contact with fecal wastes. This is why many research projects selected fecal coliform for their indicator organism.

Kunkle and Meiman (1967) in a study on mountain watersheds determined indicator ratios in a creek downstream of 350 head of cattle grazing compared with another creek free of animal grazing. These ratios are shown in Table 1. The FC organisms showed the greatest sensitivity in detecting the presence of grazing cattle. These results are expected since the production of FC occurs only in the intestines of warm blooded animals. Harms et al. (1975), Kunkle (1970a), and the ORSANCO Water Users Committee (1971) all report that FC organisms are the most reliable indicator of the fecal pollution of water but note that FC does not identify the source of pollution.

Table 1. Effect of cattle grazing on bacterial counts in creeks. (Kunkle and Meiman, 1967)

Indicator Organism	Grazed to Not Grazed Ratio
Total Coliform	3.2
Fecal Coliform	16.1
Fecal Streptococcus	1.7

Water Quality Standards

The U.S. Environmental Protection Agency (USEPA, 1976) developed some recommended limits of bacterial indicator concentrations in surface waters and are shown in Table 2. Jawson et al. (1982) points out that these bacterial water quality standards were developed for point sources and may not be applicable to nonpoint-source situations. Burt (1976) demonstrated that in water quality planning in Mississippi involving non-point pollution sources, FC is the most difficult water quality standard to attain.

Table 2. Recommended bacterial levels for surface waters. (USEPA, 1976)

All counts in number of organisms per 100 ml.

Beneficial Use	Total Coliform	Fecal Coliform
Public Water Supply (minimal treatment)	50	-
Public Water Supply (conventional treatment)	10,000	2,000
Recreation (limited contact)	1,000	200
Recreation (primary contact)	240	-
Irrigation	5,000	1,000

Pathogenic Organisms

When the levels of the indicator organisms in the stream are known, an estimate of the bacterial pathogen levels can be made. Once the pathogen levels are estimated, the corresponding health hazards can be assessed. Perhaps the bacterial pathogens in cattle feces of greatest interest from the human health standpoint are those of the genus *Salmonella*. Reasoner (1974) obtained more *Salmonella* isolations (220) from cattle than from any other animal in the United States during 1972. In clinically healthy cattle, about 13% were infected with *Salmonella* (Prost and Riemann, 1967). During a water quality survey on Toughannock Creek in New York state, detection of *Salmonellae* occurred in a small tributary stream on a cattle feedlot location (Dondero et al., 1977).

Salmonella can survive in water for lengths of time similar to those reported for fecal coliforms in water (McFeters et al., 1974). Geldreich (1970) correlated *Salmonella* detection with fecal coliform densities in fresh water. The results are shown in Table 3.

Table 3. Detection of *Salmonella* with fecal coliform organisms. (Geldreich, 1970)

Fecal Coliform Density per 100 ml	Number of Examinations	*Salmonella* Occurrences: Number	*Salmonella* Occurrences: Percentage
1-200	29	8	27.6
201-2,000	27	19	85.2
over 2,000	54	53	98.1

Table 3 shows the high correlation between fecal coliform (the indicator) levels and *Salmonella* (the pathogen) levels. Warm-blooded animal fecal contamination was the source of the organisms. As fecal coliform levels increase, the Salmonella levels increase, creating a greater chance of infection upon contact with the water source.

Cattle Grazing Patterns

Cattle grazing patterns are important to observe in relation to water quality because these grazing patterns help determine the defecation patterns of the cattle. These defecation patterns can be used to compare the percentage of defecations deposited directly into the stream, near the stream and at distances far away from the stream. A summary of the three factors found in the literature that exert a major influence on grazing behavior is shown below:

1) Vegetation quality & microclimate of grazing area.
2) Cattle access to a drinking water source.
3) Type of grazing system used.

Vegetation Quality & Microclimate of Grazing Area

Roath and Krueger (1982) in a study in Northeastern Oregon calculated that the riparian zone accounted for 81% of the total herbaceous vegetation removed by livestock. The high percentage of vegetation removal resulted from the restriction of livestock movement, caused by steep slopes and erratic distribution of watering areas away from the creek. They did not estimate the actual percentage of time spent in the riparian zone, although it must have been high.

Senft (1985) discovered that cattle preferred the riparian zone throughout the year. Platts and Nelson (1985) found that in 23 of 25 cases on study areas in

Idaho, Utah, and Nevada, cattle use of riparian vegetation was twice as heavy as use of upland vegetation.

In a study in the Blue Mountains of Northeastern Oregon, Gillen et al. (1985) found that 78% of all cattle occupation of riparian meadows occurred after 12:00 noon. The riparian zone in this study had 2440 kg/ha available herbage at the onset of grazing compared with 200-500 kg/ha on the adjacent uplands, making the riparian zone the preferred grazing region.

Bryant (1982) also had a research project in the Blue Mountains. He showed that cows and yearlings preferred the riparian zone over the upland regions from mid-July to mid-August, had no preference in mid-August to mid-September, and preferred the upland region from mid-September to mid-October. The cattle in the study preferred slopes less than 35% throughout the grazing season. Marlow and Pogacnik (1986) in a study in Southwestern Montana had seemingly opposite results, showing that the cattle grazed the upland regions more than the riparian zone from June through mid-August, after which the riparian zone was increasingly grazed until the end of grazing in early October.

The differences between the two studies can be reconciled when vegetative quality and relative humidity effects are taken into account. In the study by Bryant (1982) the cows and yearlings preferred zones where the relative mean humidity was 60-70% regardless of temperature. From mid-July to mid-August the riparian microclimate was cooler and the forage quantity and quality was more desirable than in the upland zone. Heavy grazing of the riparian zone from mid-July to mid-August, together with two thundershowers producing a total of 6.1 cm of precipitation led to increasingly better forage quality in the upland zone. Also, the relative humidity levels increased in the riparian zone from the preferred level of 60-70% to 80-90%, while the upland zone increased from 40-50% to the 60-70% level. These two aspects led to the increasing amount of grazing of the upland zone over the riparian zone as the grazing season progressed. They also noted that neither salt placement nor another water location away from the riparian zone appreciably influenced livestock distribution.

In Marlow and Pogacnik's study (1986), the forage quality was roughly the same in the riparian zone and the upland zone due to a late June rainfall in 1982. The cattle preferred the upland region over the riparian zone since the particular paddock's riparian zone in the study lacked extensive grass and sedge communities needed to meet daily intake requirements. In 1983 there was no rainfall during late June and the vegetation quality of the upland zone was not as good as the riparian zone in early July. With the reduction in vegetation quality, the cattle did not graze the upland zone as much in 1983. They did not mention the effects of relative humidity.

From the results of the two studies the predominant factor influencing the grazing patterns of cattle is the forage quality of the different pasture areas. Senft (1985) discovered that during times of snow the cattle would graze areas of tall vegetation.

Maynard and Loosli (1969) described digestible energy requirements as 2640 kcal/kg for cows and 2310 kcal/kg for yearlings, while lactating cows have additional energy expenditures. These differing energy requirements led to the cows selecting more productive plant communities, which led to the cows having a greater distribution over the pasture than the yearlings. Holechek et al. (1978)

found that during mid-July to mid-September cattle weight gains in predominantly forested pastures were 0.13 kg/day greater than on predominantly grassland pastures. The gains were attributed to a higher nutritional quality of the forested pastures and a cooler microclimate which allowed the cattle to graze longer each day.

Cattle Access to a Drinking Water Source

Roath and Krueger (1982) found that water appeared to be the central point of distribution, with all the animals returning to a watering area at least once per day. Cook (1966) determined that as the distance from water increased, the use of the area decreased. Hodder and Low (1978) confirmed Cook's results in their research.

Johnson et al. (1978) found that cattle grazing on a floodplain roughly 400 m from the stream spent considerably less than 1% of the day in the stream drinking or resting. Dwyer (1961) also found that cattle spend less than 1% of the day in the stream drinking or resting and the resulting elimination of body waste into the stream was low.

Hull et al. (1960) in a continuous 24 hour study of four steers found the average time spent drinking to be 0.14 hours (8.4 minutes) per day. Cully (1938) had an estimate of 10 minutes per day drinking time for each animal. Wagnon (1963) found that beef cows on a California range spent an average of 3 minutes drinking from a stream or a water trough. If the water source was very shallow or muddy, the average time spent drinking went up to 5-6 minutes. Of the 48 drinking visits observed, 20 cows immediately left the vicinity of the stream after drinking. In two visits the cows spent 11 and 15 minutes standing in or near the stream. In the remaining 26 visits the cows idled anywhere from less than a minute up to four minutes. Sneva (1969) found that yearling steers drank an average of 1.75 times per day with a duration of no longer than 17 minutes during any drinking event.

Larsen et al. (1988) in a study in Central Oregon, found that cattle spent 0.80% of their time in the stream in August and 0.49% of their time in the stream in November. There seemed to be a correlation of the time spent in the stream with the air and water temperatures. August 1987 maximum and minimum air temperatures were 31 ^{o}C and 7 ^{o}C, while November 1987 maximum and minimum air temperatures were 14 ^{o}C and -3 ^{o}C. The maximum and minimum water temperatures in August 1987 were 23 ^{o}C and 13 ^{o}C, while the November water temperatures were 14 ^{o}C and 11^{o}C.

Type of Grazing System Used

Walker et al. (1985) found that cattle on a short duration grazing system tended to walk farther and had a greater variability in their travel distance than with animals on a continuous grazing system. Thus the short duration grazing system will also have a greater variability in the distribution of manure than the continuous grazing system.

Platts (1981) considers continuous season grazing to be a detrimental management technique for riparian meadows. This is because the cattle prefer the lush vegetation of the riparian zone and tend to overgraze it under a continuous season grazing system.

Tiedemann et al. (1987) performed a study on the responses of fecal coliform concentrations in the stream to four different grazing strategies. The four strategies were:

Strategy A: Control - No Grazing.
Strategy B: Grazing with no attempt to attain uniform livestock distribution throughout a pasture.
Strategy C: Management of grazing to attain uniform livestock distribution throughout a pasture by using fences and water developments.
Strategy D: Management of intensive grazing to maximize livestock production with multiple-use considerations. Includes practices to attain uniform livestock distribution and to improve forage production by using such cultural practices as seeding, fertilizing, and forest thinning.

The relationship of the mean fecal coliform concentrations for each of the grazing strategies was A < C ~ B < D, strategy C was slightly smaller than strategy B.

The literature on cattle grazing patterns demonstrate the importance of having accurate information about the four factors used to estimate cattle grazing patterns, since these factors are interdependent. When the cattle grazing pattern is known the manure distribution pattern can be estimated. The manure distribution pattern can also be estimated by the counting of cattle fecal deposits on the land, as Larsen (1989) demonstrated. Hafez et al. (1962) stated that cattle drop their dung haphazardly and Petersen et al. (1956) showed a concentration around water troughs, gates, fences, shade and shelterbelts.

Manure Production Rates

The manure production rates of cattle are estimated in many papers. A summary of the estimates obtained from the literature are shown in Table 4. Kronberg et al. (1986) found some slight differences in fecal output rates between lactating and non-lactating cows as estimated by the chromic oxide technique. These results are shown in Table 5.

Table 4. Manure production rates of cattle.

Reference:	Daily no. of Defecations	Daily Output of Manure, kg	Class of Cattle
(62)	11.75	20.8	Beef Cows
(1)	-	8.9-26.8	Beef Cows
(2)	-	13.4	Beef Cows
(64)	11.4	-	Beef Cows
(28)	12.2	-	Hereford Cows
(78)	11.6	-	Dairy Cows
(135)	16.2	-	Dairy Cows
(94)	10.9	-	Dairy Cows
(12)	11.5	-	Dairy Cows
(46)	11.9	-	Dairy Cows
(47)	12.2	-	Dairy Cows
(40)	12.0	-	Dairy Cows
(45)	7-9	-	Dairy Cows
(132)	10-11	25.0-27.5	Dairy Cows
(100)	12.0	-	Dairy Cows
(30)	17.0	40.0	Holstein Cows
(30)	18.0	27.7	Jersey Cows
(58)	-	25.0	Jersey Cows
(42)	-	31.3	Friesian Cows
(42)	-	28.6	Ayrshire Cows
(43)	-	25.0	Friesian Cows
(43)	-	25.0	Ayrshire Cows

Waite et al. (1951) states that the manure production rate for dairy cows does not change throughout the grazing season. Wagnon (1963) found that the daily number of defecations decreased from the range of 11-18 on the green

Table 5. Manure production rates of non-lactating vs. lactating cows. (Kronberg et al., 1986)

All Rates in kg of dry matter/day

	------Non-lactating-----		-------Lactating--------	
Month	Hereford	75% Simmental & 25% Hereford	Hereford	75% Simmental & 25% Hereford
June	2.62	3.55	3.46	5.08
July	3.87	3.80	3.66	5.01
August	3.98	4.63	4.27	4.69
Sept.	4.05	4.01	3.80	5.27
Average	3.89	3.83	3.68	5.16

forage in the early part of the grazing season down to 8 on the dry forage at the end of the season. The degree of grazing resulted in differing defecation rates, with 12.1 defecations per 24 hour period in a lightly grazed pasture compared with 9.2 for the closely grazed pasture. There was no difference in defecation rates between cows who had their diet supplemented and those who did not. The two studies may be reconciled since the observations of Waite et al. (1951) were made on dairy cows that had the same amount of available forage throughout the season. This resulted in the lack of variation in the defecation frequencies.

Kress and Gifford (1984) weighed 100 different cattle dung piles and found the average to be 1.24 kg. Beef cows in rangeland grazing conditions are likely to produce manure at rates similar to 11.75 defecations per day and 20.8 kg of manure per day as listed in Johnstone-Wallace and Kennedy (1944).

Bacterial Organisms in Cattle Waste

Table 6 lists the values for manure production rates of livestock under various confinement systems from Overcash et al. (1983). Other bacterial concentrations in cattle manure obtained from the literature are shown in Table 7. These organism concentrations in the manure can be combined with the manure production rates to estimate the numbers of organisms contained in the manure deposited on the land and in the stream.

Table 6. Livestock manure production rates. (Overcash et al., 1983)

	Daily Generated Waste, $ft.^3$	FC* x 10^9 per $ft.^3$ waste	FS* x 10^9 per $ft.^3$ waste
Beef:			
Cow/Calf	0.85	34.5	59.6
Feeder	0.61	34.5	59.6
Finisher	0.81	34.5	59.6

* Organism abbreviations: FC = fecal coliform
FS = fecal streptococcus

Effect of Runoff Events on Bacterial Water Quality

Bacterial Concentrations in Stream After a Runoff Event

Morrison and Fair (1966) identified runoff from summer rainstorms as the most important aspect regulating bacterial counts in a stream. Doran and Linn (1979) calculated that 95% of rainfall runoff samples from a control area that was not grazed exceeded the recommended standard of 200 FC/100 ml for primary contact recreation (USEPA, 1976). Robbins et al. (1972) reported yearly mean

FC counts of 10,000 organisms per 100 ml in runoff from watersheds that were not grazed in North Carolina.

Table 7. Bacterial concentrations in cattle waste.

(All concentrations are in numbers of organisms per gram.)

Source:	FC*	FS*	Reference
Cow (f.w.)	2.3×10^5	-	(33)
Cow (f.w.)	-	1.3×10^6	(66)
Dairy Cow (r.w.)	8.5×10^5	-	(84)
Cattle	6.0×10^5	3.1×10^5	(79)
Cattle	$3.2\text{-}5.3 \times 10^5$	$3.5\text{-}17 \times 10^6$	(137)
Beef Cattle (d.s.)	1.1×10^7	1.9×10^7	(117)

Abbreviations

FC: fecal coliform organisms.

FS: fecal streptococcus organisms.

f.w.: fresh waste as defecated.

r.w.: raw waste as collected, may include a short storage period of less than 24 hours.

d.s.: counts expressed per gram of dry solids.

Kunkle and Meiman (1967) found that the fecal coliform levels in the streams increased with increasing stream flow. The trends identified in the article were: (1) increasing FC counts in the spring caused by a "flushing effect" of organisms due to increasing stream stages, (2) a "post-flush lull" in counts, after the hydrograph peak, and (3) a July-August peak in bacterial concentrations during the low streamflow period. The study was performed on mountain watersheds in Colorado so it is assumed that the rising stream stages in the spring were from snowmelt runoff.

In another study of the same area Kunkle and Meiman (1968) found that the concentrations of total coliforms, fecal coliforms, and fecal streptococci were highest in the evening and lowest in the afternoon. This apparently was caused by rising stream levels in the early evening that flushed the banks holding the bacteria. The highest FC concentrations in cattle contaminated sites occurred during the peak runoff periods in the spring, while the highest FS concentrations happened during mid-summer low flows. The bacterial concentrations for all three groups increased during summer storm flows.

Jawson et al. (1982) found that FC numbers in runoff exceeded 200/100 ml in many samples for more than one year after removal of animals from the watershed. They also discovered a wide distribution of the sources of indicator bacteria after the initial runoff events. This makes the present FC recommendations developed for point-sources not applicable to grazed land in semi-arid regions.

Bragg (1987) monitored the indicator bacteria levels in the DeGray reservoir and its major tributaries for several years. Storms were primarily responsible for loading bacteria into the reservoir. The maximum densities of bacteria were associated with the storm plumes.

Runoff Water Quality from Grazed Land

Hanks et al. (1981) observed that on western United States rangelands, high intensity-short duration storms produce conditions which lower infiltration and increase the volume of runoff available to transport bacteria.

Schepers and Doran (1980) sampled runoff from grazed pastures, pastures that have not been grazed for one year prior to sampling and control areas that have never been grazed. Their results are shown in Table 8. The fecal coliform counts increased in the grazed pasture, while the fecal streptococcus counts did not reveal the presence of fecal contamination.

Table 8. Bacterial counts from runoff water. (Schepers and Doran, 1980)

Organism*	Grazed Pasture	Pasture Not Grazed For 1 Year	Control Area
FC	1.21×10^5	-	1.10×10^4
FS	3.60×10^5	-	1.06×10^7
FC	-	1.16×10^3	1.39×10^3
FS	-	4.90×10^4	7.90×10^5

* Organism abbreviations: FC = fecal coliform
FS = fecal streptococcus

Dixon et al. (1977) obtained the runoff levels shown in Table 9 from three lots with different cattle concentrations. The fecal coliform had the greatest sensitivity in response to the different stocking rates, while the total coliform counts increased with decreasing cattle concentrations. Moore et al. (1982) states that in systems involving land areas and runoff, many coliform organisms of natural origin (non-enteric) can be introduced, making the total coliform test ineffective as a true sign of fecal contamination.

Table 9. Bacterial concentrations in runoff under different stocking rates. (Dixon et al., 1977)

	Stocking Rate		
Organism*	40 Head/ha	10 Head/ha	0 Head/ha
FC	2.98×10^3	1.28×10^3	5.80×10^1
FS	2.57×10^4	1.60×10^4	1.45×10^3
TC	7.27×10^3	7.96×10^3	1.27×10^4

* Organism abbreviations: FC = fecal coliform
FS = fecal streptococcus
TC = total coliform

Harms et al. (1975) compared two land uses by observing the percentage of time the runoff concentrations exceeded 1000 organisms per 100 ml, as shown in Table 10. The concentration of organisms in the runoff water depends on the number of organisms in the fecal deposits and the release rates of those organisms from the fecal deposits.

Table 10. Percentage of time runoff concentrations exceed 1000 organisms per 100 ml. (Harms et al., 1975)

Land Use	Organism*	Snow Melt Runoff	Rainfall Runoff
Pasture Areas	FC	50%	50%
	FS	75%	100%
	TC	95%	100%
Cultivated Areas	FC	50%	20%
	FS	100%	90%
	TC	100%	90%

* Organism abbreviations: FC = fecal coliform
FS = fecal streptococcus
TC = total coliform

Chick (1908) developed a model that estimates the decay rate of bacterial organisms known as Chick's Law, which is also the model of a simple first-order reaction in chemical kinetics:

$$\frac{N_t}{N_o} = 10^{-kt}$$

<u>Where:</u> N_t = number of bacteria at time t.
N_o = number of bacteria at time o.
t = time in days from time o to time t.
k = die-off rate constant.

Jones (1971) obtained the die-off rate of bacterial organisms in cattle fecal deposits. The die-off rates are listed in Table 11, being derived using Chick's Law (Chick, 1908).

Table 11. Die-off rates of organisms in manure piles. (Jones, 1971)

Organism*	Die-off Rate, K ($days^{-1}$)
Manure Pile, Uncovered	
TC	0.022
FC	0.029
Manure Pile, Covered from Rain	
TC	0.007
FC	0.012

* Organism abbreviations: TC = total coliform
FC = fecal coliform

The number of FC released per 100 ml of runoff was obtained from a study performed by Thelin and Gifford (1983). In their study fecal deposits of differing ages were exposed to simulated rainfall of 5, 10, and 15 minute durations. The simulated rainfall rate was 61 mm per hour or about one mm per minute. Thus the 5, 10, and 15 minute simulated rainfall durations are equivalent to 5, 10, and 15 mm of rainfall runoff.

The fecal deposits were formed into 203 mm diameter deposits using a pie pan with 900 grams of fresh cattle manure for each deposit. These "standard cowpies" were formed to obtain the concentration of FC in the runoff water solely as a function of fecal deposit age. The fecal deposits were left outside under a plastic tarp to protect from natural rainfall for 3 to 30 days before the experiment began. The FC release rate was obtained by placing the fecal deposit on an impervious plywood platform, adjacent to the drain collection pipe. The resulting equations for the various rainfall durations on the deposits were:

5 minute duration: $\log(y) = 7.041 - 3.199 \log(x)$

10 minute duration: $\log(y) = 8.179 - 2.526 \log(x)$

15 minute duration: $\log(y) = 7.956 - 2.306 \log(x)$

10 & 15 minute durations combined:

$$\log(y) = 8.068 - 2.416 \log(x)$$

<u>Where:</u>

y is the average most probable number of fecal coliform released per 100 ml.

x is the number of days that the manure has not been rained on.

Since the fecal deposits were placed on the impervious platform, all the simulated rainfall translated into runoff water. Release patterns from rainfall occurring on pasture conditions should be lower than the above equation due to the infiltration of the water into the soil and the buffering effect of the field vegetation on the runoff water. However, the release rate obtained above can be used as a function of the runoff depth.

Kress and Gifford (1984) expanded this work to include fecal deposits from 2 to 100 days old. They solved for the same variables as Thelin and Gifford (1983) and obtained the equation:

$$\log(y) = 7.57 - 1.97 \log(x)$$

The correlation coefficient was 0.923 and all the data points fell within the 95% confidence interval. The only difference in the procedure for this study was that the fecal deposits were placed on a very thin layer of sand which covered a soil layer of unknown thickness which covered the same water collection platform.

Glenne (1984) showed that the land has the ability to filter out bacterial organisms from runoff. The filtration capacity of the land was estimated to be a function of the distance of the bacterial source to the stream and the average slope of the land between the bacterial source and the stream.

Moore et al. (1983) in a study on microorganism movement from land-spread manure found no difference in microorganism counts in the runoff from the first simulated rainfall and a second simulated rainfall. This was despite one drying day between the rainfall events.

Buckhouse and Gifford (1976) found that unless the deposition of feces occurred in or adjacent to a streambed, there was little danger of significant bacterial contamination of semiarid watersheds. The cattle density in their experiment was 2 ha/AUM. Kunkle (1970b) concurs with these results, finding that only a minor fraction of the total available live bovine fecal organisms ever washed into the stream.

Sweeten and Reddell (1978) state that when there are cattle spacings of 9 to 45 m^2 per head as in a cattle feedlot, most runoff comes into direct contact with manure covered land surfaces. When cattle spacings are greater than 3.7 ha per head (37,000 m^2 per head), less than 1% of the land is covered with feces. The spacings of 3.7 ha per head are considered to be typical of normal rangeland operations and would not be expected to contribute measurable quantities of bacteria into the runoff water.

Dixon et al. (1981a) gave the average winter stocking rate for ranches in Owyhee County, Idaho to be 0.1 ha per head. They revealed that ground cover mixtures of alfalfa with brome, fescue, and orchard grass showed no significant difference in the retention of pollutants. Young et al. (1980) performed a study of the success of different vegetative buffer strips in controlling pollution from feedlot runoff. They found that every vegetative strip reduced FC & TC counts by an average of 69%, and FS counts by an average of 70%. The length of the buffer strips varied from 14 m to 27 m long.

Three components are needed to estimate the number of bacterial organisms that enter the stream from a runoff event:

1) The total number of organisms contained in the manure deposited on the land.
2) The number of organisms released from the manure into the runoff.

3) The number of organisms that are filtered out of the runoff by vegetation.

These three components must take into account the various ages of the manure deposits to obtain an accurate estimation of the number of organisms that are input into the stream from a runoff event.

Survival of Bacteria in Bottom Sediment

Bottom sediments are apparently a significant reservoir for fecal coliforms which may be dislodged by streamflow or animal disturbance (Kunkle, 1970b; VanDonsel and Geldreich, 1971; Stephenson and Rychert, 1982). Stream and lake sediments are known to bind organic nutrients and prolong the growth and survival of fecal bacteria (Hendricks and Morrison, 1967; Hendricks, 1971b; McFeters et al., 1978).

Van Donsel and Geldreich (1971) reported that FC and FS concentrations were 100 to 1000 times greater in the mud-water interface of the stream than in water above the mud. Tunnicliff and Brickler (1984) also found FC concentrations to be 10 to 1000 times greater in the sediment, even in streams that had extended periods of non-storm flow. These results agree with the suggestion made by Hendricks (1971a) that FC in river and tributary sediments were able to persist for extended periods, whereas their densities increased by slow and steady addition from the overlying water. Matson et al. (1978) compared indicator organism concentrations in river sediment with that of the river water and obtained the results shown in Table 12.

Table 12. Bacterial concentrations in river sediment and river water. (Matson et al., 1978)

	TC*	FC*	FS*
No. of Colonies per cm^2 of Sediment	69,000	3050	500
No. of Colonies per cm^3 of Water	570	26	11
Ratio of Sediment to Water	121	117	45

* Organism abbreviations: TC = total coliform
FC = fecal coliform
FS = fecal streptococcus

Sherer et al. (1988a) performed a study in which a one square meter area of stream bottom sediment was resuspended by raking. On sites that had no cattle in the vicinity for at least sixty days, the average numbers of organisms resuspended were 13.8 million FC and 228 million FS from one square meter of sediment. On a site just downstream from a feedlot which contained 150 cattle, the numbers resuspended were 330 million FC and 5610 million FS. Later in the year the same site had an average of 250 cattle in the feedlot, and the number of resuspended organisms equaled 760 million FC and 1320 million FS. The average FC/FS ratio of the bacteria from the sediment that had no recent cattle activity was 0.06, while fresh cattle manure has an FC/FS ratio of 0.2 to 0.6 (Geldreich et al., 1962; Slanetz and Bartley, 1957; and Kenner et al., 1960).

Schillinger and Gannon (1985) performed a study of urban storm runoff. They found that FC had a mean retention rate on screens of 15.9% and a sedimentation rate of 16.8%, while a large group of Gram negative bacteria had an average retention rate of 37.3% and a sedimentation rate of 46.7%. Sherer et al. (1988a) used the results of Schillinger and Gannon (1985) to explain the higher values of FS that settled out into the sediment.

Gary and Adams (1985) found that the disruption of the bottom sediment of a stream increased the mean concentration of fecal coliforms 1.7 times and fecal streptococci 2.7 times. Samples were obtained in stream moss beds and bottom sediment immediately following passage of a band of 1000 sheep in mid-August, 1980, at one and two month intervals. No sheep were near this site after the passage in mid-August. Their results are shown in Table 13.

Table 13. Bacterial counts in stream bottom sediment and moss. (Gary and Adams, 1985)

All samples are in units of fecal coliform per gram of wet weight.

Sample	August	September	October
Moss	2500	5.0	25
Sediment	570	0.3	4

Research was done to determine the die-off rate of the organisms attached to stream bottom sediment. The "K" values obtained for the die-off rates of organisms in sediment are shown in Table 14. They were calculated from Chick's law.

Table 14. Bacterial die-off rates in sediment.

Org. Type*	Sediment Type & Storage Temp.	Day 1-3 Die-off Rate, k ($days^{-1}$)	Day 4-10 Die-off Rate, k ($days^{-1}$)	Day 11-40 Die-off Rate, k ($days^{-1}$)	Reference
TC	Mud, 20 °C	0.003	0.15	-	(129)
FC	Mud, 20 °C	0.13	0.14	-	(129)
FS	Mud, 20 °C	0.06	0.06	-	(129)
Sa	Mud, 20 °C	0.14	0.14	-	(129)
FC	Sand, 5 °C	-0.333	0.154	0.035	(115)
FC	Silt, 5 °C	-0.410	0.180	0.010	(115)
FC	Sand, 15 °C	-0.350	0.109	0.028	(115)
FC	Silt, 15 °C	-0.160	0.049	0.043	(115)
FS	Sand, 5 °C	-0.175	-0.009	0.035	(115)
FS	Silt, 5 °C	-0.197	0.092	0.028	(115)
FS	Sand, 15 °C	-0.159	0.054	0.025	(115)
FS	Silt, 15 °C	-0.124	0.113	0.049	(115)

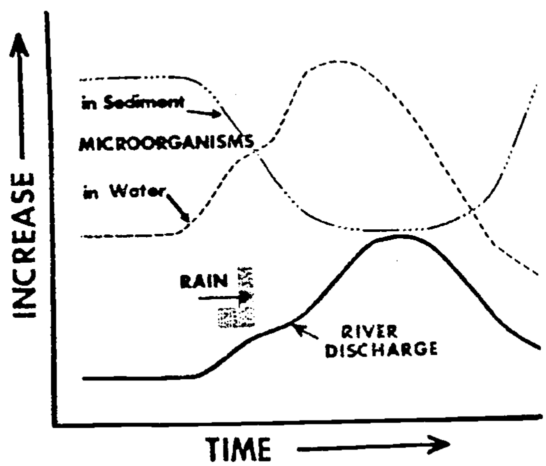
* Organism abbreviations: TC = total coliform
FC = fecal coliform
FS = fecal streptococcus
Sa = Salmonella

Bottom Sediment Organism Release from Increased Flow Rates

McDonald et al. (1982) conducted a series of experiments that created an artificial increase in the stream discharge by releasing water from a reservoir. They discovered that the additional flow increased the total coliform and *Escherichia coli* concentrations increased as well. Note that the bacterial concentrations increased despite the increasing discharge rate. There were no storm events during the augmentation of the stream discharge, thus the increase in bacterial counts were due to release from storage in the stream bottom sediment or the stream banks. Moore et al. (1988b) performed the same experiment in Central Oregon and found increases in FC and FS counts as the flow rate increased.

Matson et al. (1978) also found that the river sediment served as a reservoir for indicator organisms that were resuspended under higher river discharge rates. They developed the diagram in Figure 3 to demonstrate the correlation between higher bacterial counts with the increasing stream discharge.

Figure 3. Model of the effect of changing river discharge rates on bacterial numbers in the water and bottom sediment. (Matson et al., 1978).



Survival of Bacterial Organisms in the Stream

Crane and Moore (1985) reviewed the literature on enteric bacteria die-off models and the many adjustments made to Chick's law to account for bacterial regrowth and differing rates of die-off over time. They state that the first order model appears to accurately describe the die-off of bacteria under all conditions, however, the die-off rate coefficient is a highly variable parameter spanning several orders of magnitude for any given bacterial type.

Biskie et al. (1988) studied the effects of a direct deposit of a fresh cattle manure slurry into the stream. They found that approximately 95% of the FC and FS organisms of a manure slurry settled out of the flow within 50 meters of the point of deposition. It was some time before the background concentrations returned to normal, indicating low levels of bacterial movement in the stream.

The survival of fecal coliforms depends upon the physical and chemical composition of the water (McFeters and Stuart, 1972). According to Davenport et al. (1976) water temperature exerts a major influence on the survival of enteric bacteria, revealing an inverse relationship between bacterial survival and water temperature below 15 ^{o}C. This relationship yields the highest bacterial survival time in 0 ^{o}C water under an ice cover. Bigger (1937) revealed that coliform organisms are able to reproduce in river water, with the optimum temperature for growth at 22 ^{o}C.

Mack (1974) found that coliform bacteria can persist and even multiply in natural waters. The multiplication of the bacteria was greater at 35 ^{o}C than at lower temperatures. Hendricks and Morrison (1967) reported that bacteria have the ability to multiply and regrow in cold mountain streams. They suggest that self-purification mechanisms help restrain the unlimited growth of these organisms.

Studies have been performed to estimate the die-off rates of bacterial organisms in water. The die-off rates were determined from Chick's Law; a summary of the results from these studies are shown in Table 15.

Table 15. Bacterial die-off rates in aquatic environments.

(Reference) & Aquatic System Description	Organism Type*	pH	Water Temp. °C	Length of Study	Die-off Rate ($days^{-1}$)
(87) Well Water Inoculated with Pure Cultures.	Coliforms	7.48	10-12	4 days	0.123
	Coliforms	7.48			0.120
	Enterococci	7.48			0.096
	Streptococci	7.48			0.108
(35) Storm Water Runoff.	FC	-	20	14 days	0.630
	FC	-	10	14 days	0.107
(36) Storm Water Runoff.	FC	-	20	14 days	0.099
	FC	-	10	14 days	0.282

* Organism abbreviation: FC = fecal coliform

In articles on the fate of bacteria in soil, temperature, pH, moisture and nutrient supplies have the greatest effect on enteric bacterial survival. Lower temperatures appear to increase survival time as noted by McFeters and Stuart (1972) and Kibbey et al. (1978).

It is important to measure the background bacterial concentrations of the stream to determine the impact of the grazing cattle on the stream bacterial concentrations. Many studies show that background bacteria levels can be appreciable in areas where there is no livestock grazing (Bates, 1963; Walter and Bottman, 1967; Bissonette et al., 1970; Goodrich et al., 1970; Stuart et al., 1971). Each study attributes the high background counts to indigenous wildlife populations.

Modeling Research

To develop a model that estimates the bacterial water quality of a rangeland stream, many interactive processes must be understood. This section is a summary of the modeling efforts in hydrology, cattle movement, and the behavior of bacterial indicator organisms produced in the fecal deposits of cattle.

Modeling of Rangeland Hydrology

Many hydrologic models can be used to estimate the amount of surface runoff on a rangeland watershed. Some models developed are the Stanford Watershed Model IV (Crawford and Linsley, 1966), the HEC-1 model (U.S. Army Corps of Engineers, 1985), the USDAHL model (Holton et al., 1975), the surface water hydrology component of the CREAMS model (Smith and Williams, 1980), and the hydrology component of the USDA SPUR model (Renard et al., 1983 and Cooley et al., 1983).

Heydarpour et al. (1988) discussed the applicability of these models to rangeland watersheds and found that they required an extensive number of input parameters such as precipitation distribution, basin morphology, land slopes and types, soil characteristics, vegetation cover, snowpack and snowmelt factors, evapotranspiration, and groundwater flow. The conclusion was that such extensive information was generally not available for most rangeland watersheds and so they developed a simpler model to predict runoff in semiarid rangeland watersheds. Inputs to the model were maximum and minimum temperature data, the base flow rate of the stream, the precipitation data, and the snowpack data. Variables used to calibrate the model to different watersheds are the upper and lower limits of temperature (to generate the percentage of precipitation that falls as snow), a snowmelt factor, the number of days for flow recession, the snowmelt retention parameter for snowmelt runoff, and a maximum retention parameter for rainfall runoff. The model was able to adjust these variables to each watershed by linear regression analysis of previous precipitation data, snowpack data, and stream discharge data given for the watersheds.

Modeling of Cattle Grazing Patterns

The modeling of cattle grazing patterns is important in the estimation of the amount of cattle manure deposited directly into the stream. Kunkle (1970b) discovered that grazing near a stream had a significant effect on the bacterial concentrations of the stream, while grazing some distance away from the stream did not significantly change the bacterial concentrations.

Cook (1966) performed a linear regression analysis on many different variables that could affect the amount of grazing utilization at each site. One equation developed to estimate the % utilization at a site was:

$$Y = 20.7 - .308\ X_1 - .405\ X_3 + .218\ X_9 + .164\ X_{18} + .216\ X_{19}$$

Where:

Y = % grazing utilization at a site

X_1 = % slope at site

X_3 = % slope from site to water

X_9 = % palatable plants on site

X_{18} = % use of slope adjacent to bottom

X_{19} = % use on bottom below

The standard error of the estimate was 10.3 and no correlation coefficient was given. They stated that it was impractical to calculate the utilization a particular mountain slope by livestock because of the wide confidence interval of predictability.

Roath and Krueger (1982) developed multiple linear regression models to estimate cattle behavior on a forested range in the Blue Mountains of Oregon. The models developed for different variables are shown in Table 16.

Table 16. Regression models to predict cattle behavior. (Roath and Krueger, 1982)

Activity	Dependent Variable	Independent Variables in Order of Importance	Variability Accounted For	Level of Sig.
Bottoms				
Morning Grazing	Time after sunrise	X_3	0.78	0.037
		X_8	0.98	0.002
Regression Model: $Y = 0.26\ X_3 + 0.15\ X_8 - 4.23$				
Morning Bedding	Time after sunrise	X_7	0.78	0.039
		X_{10}	0.86	0.064
		X_3	0.92	0.101
Regression Model: $Y = -0.26\ X_7 + 0.58\ X_{10} - 0.60\ X_3 + 11.70$				
Afternoon Grazing	Time after sunrise	X_1	0.97	0.016
Regression Model: $Y = -1.68\ X_1 + 1085.6$				
Uplands				
Morning Grazing	Time after sunrise	X_8	0.78	0.037
		X_4	0.98	0.002
Regression Model: $Y = 0.18\ X_8 - 0.18\ X_4 - 0.42$				
Morning Bedding	Time after sunrise	X_8	0.78	0.039
		X_{10}	0.86	0.064
		X_3	0.92	0.101
		X_7		
Regression Model: $Y = 0.69\ X_8 - 0.92\ X_{10} - 0.56\ X_3 + 0.15\ X_7 + 4.88$				

Independent Variables Considered:

X_1	Barometric pressure	X_7	Temperature change
X_2	Temperature °C	X_8	Relative humidity maximum
X_3	Relative humidity	X_9	Relative humidity minimum
X_4	Thermal hum. index	X_{10}	Relative humidity change
X_5	Temperature minimum	X_{11}	Thermal humidity index maximum
X_6	Temperature maximum		

Note: Variables $X_1 - X_4$ were at the time the activity was observed.

Senft et al. (1983) used regression models to predict spatial patterns of cattle behavior. Validation of the models using the spatial patterns of fecal depositions yielded a close fit between the observed and estimated values. Senft (1984) modeled the dietary preferences of range cattle as a function of relative crude protein and obtained the following equations:

Grasses:

$RP_{ic} = e^{k(RCP_{ic} - 1)}$

$r^2 = 0.742$ at $k = 7.339$.

Where:

RP_{ic} is the relative preference for plant species i from plant community c.

RCP_{ic} is the relative crude protein for plant species i from plant community c.

k is the regression coefficient.

r^2 is the correlation coefficient.

Forbs and Shrubs:

$D_{ic} = e^{k(b_{ic} - 1)}$

$r^2 = 0.808$ at $k = 3.153$.

Where:

D_{ic} is the proportion of plant species i selected from plant community c.

b_{ic} is the proportion of plant species i in the herbage of plant community c.

r^2 is the correlation coefficient.

Modeling of Indicator Organisms

Canale (1973) modeled the total coliform concentrations of the Grand Traverse Bay in Michigan. The major source of contamination was from two cherry processing plants located near the bay. The model assumed the cherry waste loadings to be point sources. Kelch and Lee (1978) developed statistical models to estimate fecal coliform levels of the Tillamook Bay in Oregon. The fecal coliform levels of the four rivers that discharged into the bay were used in developing the model.

The Texas Water Development Board (1970) developed a water quality model which they named DOSAG I. DOSAG I was designed to simulate the spatial and temporal variations of biochemical oxygen demand (BOD) and dissolved oxygen (DO) under varying stream conditions. Environmental Dynamics (1973) modified DOSAG I to include additional water quality parameters not considered in DOSAG I. The modified version of DOSAG I was named DOSAG II. Besides the estimation of DO and BOD levels, DOSAG II also estimates the following components of water quality: nitrate, nitrite, phosphorus, total coliform, organic nitrogen, fecal coliform, ammonia, total dissolved solids, and total nitrogen. DOSAG II was applied on the Truckee and Carson River Basins in the Lake Tahoe - Reno, Nevada region. Fecal coliform estimates were made in the model by using a simple mass balance approach:

$$\frac{d(COL)}{dt} = -K_{COL}(COL)$$

Where:

$\frac{d(COL)}{dt}$ is the change in coliform concentration over time, (MPN per 100 ml) / day.

K_{COL} is the coliform die-off rate constant ($days^{-1}$).

COL is the coliform concentration (MPN / 100 ml).

The model also included point source or sink to estimate the addition of other water quality constituents, but did not include this term in the determination of coliform levels since there was no point source or sink of coliforms in the stream. Since the addition of coliform organisms to the stream is not accounted for, the model depends upon two assumptions to be accurate:

1) Accurate estimation of the coliform concentrations at the upstream site of the study area.

2) No input of coliform organisms in the study area by overland flow or direct deposit of animal feces.

Under rangeland grazing situations overland flow carried fecal coliform and fecal streptococcus organisms from cattle manure into the stream (Moore et al., 1988b). They found that the cattle deposited manure into the stream at a rate varying from 0.17 to 0.41 defecations/cow/day. Thus assumption 2) does not apply under rangeland grazing conditions, making the accurate estimation of FC and FS water quality difficult to obtain with the DOSAG II model.

White and Dracup (1977) also used DOSAG II to estimate the water quality of Bishop Creek, located on the eastern side of the Sierra Nevada mountain range near Bishop, California. In the model's estimation of fecal coliform levels they found that the accuracy of the model depended solely on the initial headwater values input into the model. The results were acceptable until there were heavy rainstorms which carried fecal coliform organisms from the domestic and wild animal fecal deposits on the land into the stream via the overland flow.

Jenkins et al. (1984) developed a model which estimates the fecal bacterial levels in upland catchments in Leeds, U.K. The basic equations forming the model were:

$$C_W = I + W - S - D$$
$$N_S = S - D - W$$

<u>Where:</u>

C_W is the bacterial concentration in water.

N_S is the bacterial numbers in sediment.

I is the fecal input.

S is the settlement of bacteria into the sediment.

W is the washout of bacteria due to increased flow velocity.

D is the die-off of bacteria.

The model took into account the stream bottom sediment's ability to store bacterial organisms which were released upon higher flow rates, a phenomenon termed "washout." A threshold velocity was developed to estimate the process of bacterial entrainment. If discharge fell below the threshold, the washout term became zero. The model estimated the concentration of bacteria in the water and the number of bacteria in the sediment by the following equations:

$$\frac{dC}{dt} = -K_C\, C - pC + \frac{a(Q^2 - Q_T^2)N}{Q} + \frac{(I + JQ)}{Q}$$

$$\frac{dN}{dt} = -K_N\, N + pQC - a(Q^2 - Q_T^2)\, N$$

<u>Where:</u>

C is the concentration of bacteria in water (no. per 100 ml).

N is the number of bacteria in sediment (no. per m stream length).

K_C is the coefficient of bacterial decay in water.

K_N is the coefficient of bacterial decay in sediments.

p is the coefficient of settlement of bacteria.

a is the coefficient related to the rate of washout.

Q is the discharge (cubic meters per second).

Q_T is the threshold discharge (cubic meters per second).

I is the input rate of bacteria at base flow (no. per time).

J is the rate of discharge related bacterial input (no. per time).

t is the unit time.

To estimate the input rate of bacteria into the stream, weekly bacterial concentrations were collected just upstream of the sampling site. To apply the model to a different stream under different grazing conditions the variables listed above must be calibrated by iteration of real data of the bacterial concentrations of the stream to be modeled.

Moore et al. (1988a) developed a computer model called MWASTE, which estimates FC and FS concentrations in runoff from various animal waste management systems. The hydrology component of the CREAMS model (Smith and Williams, 1980) was used to generate the runoff component. MWASTE was designed to determine the contribution of bacterial organisms from overland runoff flowing through animal waste spread on the land surface. MWASTE would not give accurate results in a semi-arid rangeland since it does not account for the direct deposit of manure into the streams. Moore (1988b) stated that the direct deposit of manure and the resuspension of the stream bottom sediment are the only input of bacterial organisms into rangeland streams under non-runoff conditions, which exist for the majority of days each year on semi-arid rangelands.

V. MODEL DEVELOPMENT

The model was developed to estimate the daily FC and FS water quality concentrations of a stream where cattle have access. The FC and FS concentrations are modeled since they are commonly used to estimate the potential health hazards of stream water. The model predicts the stream FC and FS concentrations in number of organisms per 100 ml. The number of organisms that enter into the stream each day is calculated by adding the organisms input from the direct deposit of manure and the organisms carried into the stream by runoff flowing through fecal deposits on the land. Once the organisms enter the stream, the model estimates the number of organisms that settle into the bottom sediment, the number of organisms that die-off in the bottom sediment and in the water, and the number of organisms resuspended from the bottom sediment. The flow chart of the model is shown Appendix D and a listing of the computer program is in Appendix E.

Daily Input of Organisms into Stream

Direct Deposit of Organisms into Stream

The model inputs data files with information on the number of cattle grazing and the fecal placement pattern of the cattle. The file for the fecal placement pattern of the cattle provides information on the distribution patterns in the riparian zone of the pasture, the irrigated meadows, and the upland regions where there is no supplemental irrigation. The riparian zone is the area adjacent to the stream and usually has more lush vegetation than the upland pasture due to the availability of moisture from the stream. The fecal placement file is input by the user and also contains the percentage of feces that are directly deposited into the stream, the average slope, and the distance from the stream for each land region.

Larsen (1989) reported on some research in which a visual inspection of a pasture was made during each season of the year to obtain the fecal distribution pattern in the pasture. These typically include a riparian zone, irrigated meadows, and upland region. The report also listed the average distance from the stream and the average slope for each land region. This data is shown in Tables 22a and 22b in Appendix F. The data was compiled into a file and used in each test run of the model and the file is shown in Tables 23a and 23b in Appendix F.

The program estimates how many organisms enter the stream each day from the direct deposit of manure based on the daily weight of manure deposited into the stream for each animal and the number of organisms per gram of cattle manure. The amount of feces defecated per day on each land region can be estimated by combining the defecation amounts with the pattern of defecations. The model multiplies the number of defecations in the stream per cow per day by the number of cows to obtain the total number of defecations directly deposited in the stream each day. The number of defecations in the stream per animal per day input into the model was obtained from the data of Larsen (1988) under rangeland grazing conditions. The number of defecations entering the stream is multiplied by the number of organisms per defecation resulting in the number of organisms entering into the stream each day by the direct deposit of feces. The number of organisms per defecation was calculated by assuming 1770 grams per defecation using the data of Johnstone-Wallace & Kennedy (1944) for beef cows and requiring the user to input the number of organisms per gram of manure. Suggested input values of 2.3×10^5 FC and 1.3×10^6 FS per gram of manure are given to the user based on the results of Geldreich et al. (1962) and Kenner et al. (1960).

Input of Organisms into Stream from Overland Runoff

The program calculates the number of organisms released from the fecal deposits on the land as a function of the daily runoff depth by modifying an equation obtained by Thelin and Gifford (1983). The equation they developed to estimate the FC concentrations of runoff water from simulated rainfall falling on cattle fecal deposits was:

$$\log(Y) = 8.068 - 2.416 \log(X)$$
$$\longrightarrow Y = 10^{[8.068 - 2.416 \log(X)]}$$

Where:

Y is the average most probable number of fecal coliforms released per 100 ml.

X is the number of days that the manure has not been rained on.

Limits: If $X < 2$ days, set $X = 2$ days.

All the simulated rainfall is assumed to be runoff since the deposits were placed on an impervious wooden platform. These results were then converted into an equation that determines the number of FC released as a function of the age of the deposit in days per kg of manure per mm of rainfall runoff (denoted as variable Z):

$$Z = \frac{2.3 * 10^{[8.068 - 2.416 \log(X)]} \text{ FC}}{\text{kg of manure} * \text{mm of runoff}}$$

Using the input value of 2.3×10^5 FC per gram of manure (2.3×10^8 FC per kg of manure), the percentage of the total number of FC on the land released into the runoff water per mm of runoff as a function of the age of the manure by the equation:

$$z = \frac{1 \times 10^{[8.068 - 2.416 \log(X)]}}{1 \times 10^{8}}$$

<u>Where:</u>

X is the number of days that the manure has not been rained on.

z is the proportion of FC on the land released into the runoff water per mm of runoff.

The fecal streptococci were assumed to have the same release rate as the fecal coliforms. Fecal deposits older than 15 days released less than 0.2% of their organisms into the runoff, so their release rates were not calculated. The number of organisms remaining in the fecal deposits on the land after the runoff event were calculated by subtracting the number of organisms released into the runoff from the number of organisms contained in the fecal deposits on the land for each of the 15 days before the runoff event.

In some rangeland systems organisms will be removed by filtering as the runoff flows through the vegetation on the land. Moore et al. (1988a) developed an equation to determine the percentage reduction of bacteria from overland runoff based on the research of Glenne (1984) shown below:

$$PR = 11.77 + 13.98 * S$$

<u>Where:</u>

PR = % removal of bacteria from overland runoff.

S = Buffer distance to stream in meters divided by the buffer slope, %.

Limits:

$0\% < PR < 75\%$

$0\% <$ Buffer Slope, $\% < 15\%$

3 m < Buffer distance to stream, m

The amount of organisms removed from the runoff by the surface vegetation is estimated as a function of the distance away from the stream and the average slope of the land where the manure is deposited. The program calculates the number of organisms that are input into the stream with the runoff by subtracting the number of organisms removed from the runoff from the number of organisms released by the runoff.

Hydrology Component of Model

Accurate estimates of the daily stream discharges and runoff depths are very important to obtain accurate water quality estimates. The daily stream flow and runoff depth can be estimated by the program or the user can also input these values from another program such as the hydrology component of the CREAMS model (Smith and Williams, 1980) or the hydrology component of the USDA SPUR model (Renard et al., 1983 and Cooley et al., 1983).

Based on information input by the user on the hydrologic characteristics of the drainage basin and weather information, the model calculates the depth of runoff each day in mm. The model estimates the percentage of precipitation that falls as snow and the percentage which falls as rain. The snowmelt runoff is divided into snowmelt from thawing and snowmelt from rainfall. The recession flow is calculated for ten days following each runoff event. The recession flow accounts for the remaining surface runoff, interflow, and groundwater flow. The daily stream flow is then calculated by adding the runoff flow and the recession flow to the base flow of the stream under non-runoff conditions.

The model inputs a weather file which contains daily or monthly information on maximum temperature, minimum temperature, and precipitation. The user also inputs a value for the average rainfall retention upper limit of the soil in the basin. The rainfall retention upper limit values of Heydarpour (1988) ranged from 70 mm to 120 mm. A soil with a rainfall retention upper limit of 70 mm would have a lower infiltration rate than a soil with a rainfall retention upper limit of 120 mm.

Snow/Rain Ratio Of Precipitation

After the weather information and the soil information was input into the model, a daily snow/rain ratio (U) was developed for the precipitation to separate rainfall from snowfall. When U = 1.0, all precipitation falling will be snow, and when U = 0.0 all precipitation will be rain. The equation used was:

$$U = (TH - AVETEMP) / (TH - TL)$$

Where:

U is the snow/rain ratio.

TH is the upper temperature limit for snow/rain ratio in degrees C (assumed to be 6.5 ^{o}C in the model).

TL is the lower temperature limit for snow/rain ratio in degrees C (assumed to be 0 ^{o}C in the model).

AVETEMP is the daily average temperature in degrees C, obtained from averaging the maximum and minimum daily temperatures in degrees C.

Limits: $U = 1.0$ if $AVETEMP < TL$

$U = 0.0$ if $AVETEMP > TH$

Rainfall Runoff Estimation

To estimate how much rainfall would occur as runoff it is necessary to account for the antecedent moisture condition of the soil. The program does this by calculating the retention for rainfall runoff by subtracting the accumulative precipitation of the previous five days from the rainfall retention upper limit. The lower limit of the rainfall retention parameter was calculated as a function of the upper limit. Under completely saturated soil conditions, the rainfall retention parameter would equal the lower limit. The rainfall runoff depth is a function of the precipitation that falls as rain and the antecedent moisture of the soil as calculated by the rainfall retention parameter. The stream discharge due to rainfall runoff was then estimated by multiplying the rainfall runoff depth by the drainage basin area and dividing by the 24 hour time span to obtain a value in m^3/second.

Snowmelt Runoff Estimation

The snowpack was calculated in equivalent mm of water rather than depth in cm since the density of the snow in the snowpack varies. The initial snowpack for day one is input by the user as depth in cm and the equivalent water content in mm is determined based on a 10% water content of the snowpack. The snowpack water content is updated each day by the equation below:

$$SP(i+1) = SP(i) + U*PCP - SM(i)$$

Where:

SP(i) is the snowpack water content in mm for day i.

U is the snow/rain ratio.

PCP is the daily precipitation in mm.

SM(i) is the daily snowmelt in mm of water.

The snowmelt is a function of the temperature and the amount of precipitation. The model calculated the snowmelt due to thawing, which was a function of the average temperature, and the snowmelt due to rainfall, which was a function of the daily rainfall and average temperature. The snowmelt runoff depth is a function of the snow retention parameter of the basin, which the model assigns a default value of 7.5 mm, based on the value for Bear Creek in central Oregon determined by Heydarpour (1988). The stream discharge due to snowmelt runoff was then estimated by multiplying the snowmelt depth by the drainage basin area and dividing by the 24 hour time span to obtain a value in m^3/second.

Runoff, Recession Flow, and Total Discharge Rate Estimates

The total daily runoff depth and discharge is the addition of the corresponding rainfall and snowmelt components. The recession flow component is a simple way to estimate the recession curve following a runoff event. The recession flow is the sum of the remaining surface runoff, interflow, and groundwater flow. The equation to determine recession flow is:

$$RECFLOW(K + J) = RUNOFF(K) * (V^J)$$

Where:

RUNOFF(K) is the total runoff in m^3/sec. for the runoff event of day K.

RECFLOW(K + J) is the recession flow in m^3/sec. J days following the runoff event of day K.

V is the recession flow multiplier, where $0 < V < 1$.

J is the number of days following the runoff event occurring on day K.

Following the daily recession flow calculation, the program calculates the total stream discharge for each day. The total discharge is the sum of the base flow, the runoff flow, and the recession flow.

Fate of Organisms in Stream

After the model calculates the number of organisms input into the stream, it then estimates the fate of the organisms in the stream. The bacterial organism concentrations in the stream and the number of organisms in the bottom sediment are a function of the percentage of organisms entering the stream that settle into the bottom sediment, the die-off rate of the organisms in the bottom sediment, and the percentage of organisms released from the bottom sediment by the stream flow. The total number of organisms released into the stream is the sum of the number of organisms released from those input into the stream by direct deposit of manure and runoff events plus the number of organisms released from the bottom sediment. The number of organisms suspended in the stream flow is estimated by subtracting the number of organisms that die-off in the water from the total number of organisms released into the stream. The equations developed to estimate these bacterial relations are shown in the next sections.

Die-off of Organisms in Stream and Bottom Sediment

The die-off rates in the stream water were calculated from the K values given in McFeters et al. (1974). The K values were 0.123 for FC and 0.108 for FS. The K values for the bottom sediment are input by the user to perform a sensitivity analysis on the K values. The K values determined by Van Donsel and Geldreich (1971) for mud inoculated at 20 ^{o}C were 0.14 for FC and 0.06 for FS. The user is suggested to use K values ranging between 0.10 and 0.20 for FC and between 0.05 and 0.15 for FS. The fraction of FC and FS that die-off each day in the water and the bottom sediment are calculated according to the following equations:

$$FCWDOM = 1 - 10^{-KFC}$$
$$FCBSDOM = 1 - 10^{-KVALFC}$$

Where:

FCWDOM is the stream water die-off multiplier for FC.

KFC is the K value for FC in stream water.

FCBSDOM is the bottom sediment die-off multiplier for FC.

KVALFC is the K value for FC in the bottom sediment.

Resupension of Organisms from the Stream Bottom Sediment

Moore et al. (1988b) did a study where a reservoir was opened to increase the stream flow under non-runoff conditions. They concluded that the cause of the increase in bacterial concentrations of the stream was the disruption of the organisms attached to the bottom sediment from increasing stream velocities. The data obtained from the experiment is shown in Appendix G.

These results were used to develop an equation that would predict the increase in the percentage of organisms released into the stream at flow rates greater than the base flow. The release rate multiplier is a number greater than or equal to 1.0 that is multiplied by the release rate of the base flow to obtain the daily release rate for each corresponding flow rate. The ratio of the increased flow rate to the base flow rate was used so the release rate multiplier would equal 1.0 under base flow conditions. If the percentage of organisms released under base flow conditions was 5% and the release rate multiplier for a particular runoff event was 7.0, the release rate for the runoff event would be 35%. The equation obtained for the release rate multiplier was:

$$RRTEMLT = 1.0 + 1.7*QAUG^{2.8}$$

Where:

RRTEMLT is the daily release rate multiplier.

QAUG is the ratio of the augmented flow under runoff conditions to the base flow.

1.7 and 2.8 are constants determined from the data of Moore et al. (1988b).

Daily Water Quality Estimation

The daily water quality values are estimated by the total number of organisms suspended in the stream each day divided by the total volume of water that is discharged each day by the stream. Kunkle and Meiman (1968) showed that bacterial counts in a mountain stream had some variation, but noted that the variation within a single day was less than the day-to-day variation.

The number of organisms released into the stream water was the release rate multiplied by the sum of the number of organisms in the sediment plus the number of organisms deposited directly into the stream plus the number of organisms entering the stream via overland runoff. The number of organisms that died-off in the bottom sediment was the product of the number of organisms in the bottom sediment and the bottom sediment die-off multiplier. The number of organisms that died-off in the stream water was the product of the number of organisms in the stream water and the stream water die-off multiplier. The number of organisms in the bottom sediment was updated each day by adding the number of organisms settling into the sediment from direct deposit of manure and overland runoff and subtracting the number of organisms released from the sediment and the number that died-off in the bottom sediment. Finally the daily FC and FS water quality values were estimated by dividing the number of organisms that remained suspended in the water after die-off by the total volume of water discharged. The total volume of water discharged was calculated by multiplying the average flow rate of the stream by the 24 hour time span.

VI. COMPARISON OF MODEL PREDICTIONS WITH FIELD EXPERIMENTS

The water quality values estimated by the computer model were tested against the values measured by Johnson et al. (1978), Mullen (1983), and Sherer et al. (1988a) under non-runoff conditions. The model was also tested against the water quality values measured by Moore et al. (1988b) following a runoff event.

The runoff component of the model was tested against the discharge rates for previous runoff events of Bear Creek listed in Moore et al. (1988b). The graphs of the model comparisons are shown in Appendix A.

Model Compared to Johnson et al. (1978)

Johnson et al. (1978) sampled from a stream that 75 cows plus 75 calves had access to. There were no runoff events during the sample dates. The model was run with the input of 100 cattle grazing, under the assumption that the calves produced one-third the amount of manure of the cows. The results are shown in Figures 4a and 4b in Appendix A.

For FC values, the model estimated values that were slightly lower than the measured values. The measured values were never more than twice of those determined by the model. The model estimated FS values that were slightly higher than those measured. Most FS values had close agreement except those of June 6th and 8th, where the model predicted much higher values than the measured values. These high FS values predicted by the model in comparison to the measured values was probably caused by the model using a die-off rate for the FS in the bottom sediment that was too low. If the FS die-off rate in the bottom sediment of the model is lower than the actual die-off rate, the model will estimate a higher number of organisms remaining in the bottom sediment than actual conditions. The high number of FS in the bottom sediment predicted by the model were resuspended by the high stream flows of June 6th and 8th, yielding the higher FS counts estimated by the model.

For both the FC and the FS data, the model predicted gradually decreasing counts from June 6th to June 16th. This was because the streamflow rates decreased from an average of 0.15 m^3/sec. from June 6-10 to 0.07 m^3/sec. on June 16. The model calculated that the higher flow rates at the beginning of the month would resuspend organisms from the bottom sediment at a greater rate than the streamflow increase, leading to the higher bacterial counts. This also accounts for the lower counts estimated by the model for the days following June 10th, because fewer organisms were stored in the bottom sediment since they had been resuspended by the previous higher flow rates. The low bacterial counts predicted by the model after June 14th reflect the removal of cattle from the grazing area on June 14th. The FC data of Johnson et al. (1978) fluctuates every two days. There was no explanation as to why the measured data behaved in this manner.

Model Compared to Mullen (1983)

The comparison of the model's predicted values to the measured values of Mullen (1983) are shown in Figures 5a and 5b. Two hundred fifty cattle divided their time grazing from the pasture sampled and another pasture from August to late September in 1975. Therefore it was assumed that 125 cattle were grazing the pasture that was sampled and this number was input into the model. All of the sampling dates were under non-runoff conditions with the exception of July 29 when it had rained the night before and August 19 when there was a very heavy rainfall two days prior to sampling (the exact amount of precipitation was not given).

Mullen (1983) listed the relative streamstage level in inches and not the actual stream discharge values. In a personal communication with Dr. Pache (Mullen's major professor) in February 1989, the stream was an estimated two to six feet in width with an average velocity of about one foot per second. The assumption was made that the average velocity was one foot per second to calculate the stream discharge rates.

The comparison of the results of the model assuming stream widths of four and six feet with the measured values are shown in Figures 5a and 5b. The model predicted higher values than the measured values for most of the sampling dates. The model results usually differed less than 100 from the measured FC counts and 400 from the measured FS counts. The model gave much higher values than the measured counts of August 19, which was two days after a runoff event. The results of the model were based on the assumption of four mm of runoff for the rainfall event of August 17. Some reasons to explain why the model values are so much higher than the measured values are that there may not have been any runoff from the rainfall event or a higher percentage of organisms were filtered out of the runoff flow by the vegetation than the model estimated.

The stream discharge rates input into the model during non-runoff conditions could have been lower than the actual discharge rates, leading to higher bacterial concentrations predicted by the model. Another possibility to account for the slight differences could be the model's input data of the amount of feces deposited directly into the stream. Mullen (1983) stated that large lush meadows away from the stream were grazed heavily while small meadows and streamside areas were used less frequently. The fecal deposition file of the model was based upon cattle grazing patterns of Moore et al. (1988b). They stated that the cattle frequented the lush riparian areas more often than the upland regions. The cattle in Mullen's study probably spent more time away from the stream than what the model placement file estimated. As the time that cattle spend in close proximity to the stream decreases, the amount of manure deposited directly into the stream would be expected to decrease, so the measured bacterial concentrations of Mullen (1983) would be lower than those calculated by the model.

Model Compared to Sherer et al. (1988a)

Sherer et al. (1988a) listed bacterial counts for three different sites on Bear Creek near Brothers, Oregon. The number of cattle grazing upstream from each of these sites were obtained from Moore et al. (1988b) for the Bear Creek watershed. All of the counts were measured under non-runoff conditions.

Site 1 was a control area that had no access to cattle grazing. As Figures 6a-6b in Appendix A demonstrate, the model's results on the dates of June 2, 1986, September 18, 1986, and June 22, 1987 were nearly identical to the measured values for FC and FS. All of the counts estimated by the model at this site were from cattle grazing at distances of 1 km or greater from the site. These results demonstrate the potential of the model to accurately predict bacterial counts at stations greater than 1 km downstream from cattle grazing.

On the dates of March 25, 1986 and January 6, 1987 the model predicted higher FC and FS counts than those measured. The measured results for these dates are only 1 FC/100 ml, which seems too low when comparing these results to the other sampling dates and that there were cattle grazing upstream from the site. The FS counts predicted by the model on these dates are between 700 and 800 FS/100 ml higher than the measured values. Perhaps the actual die-off rate of the bacteria in the bottom sediment was higher than the model estimated, leading to the higher predicted counts of the model.

Site 2 was located just downstream from pastures where cattle had grazed. The results of the model compared to the measured values are shown in Figures 7a and 7b in Appendix A. These results are very similar to the conditions at Site 1, with the exception of the FC counts of June 2, 1986. On this date the measured FC value was 400 FC/ 100 ml, while the model predicted 71 FC/ 100 ml. Since there were cattle grazing immediately upstream on this date, there could have been a higher amount of feces directly deposited into the stream.

Site 3 was located just downstream from a livestock feedlot that contained up to 333 cattle. Again the results of the model shown in Figures 8a and 8b of Appendix A agree with the measured results for FC and FS on June 2, 1986, September 19, 1986, and June 22, 1987. The measured values for FC and FS were higher than the model predictions on March 25, 1986 and January 6, 1987. Since the rate of the direct deposit of the feces input into the model was based on the open range conditions listed in Moore et al. (1988b), the rate could have been lower than the actual feedlot conditions. This would account for the discrepancies of the FC and FS counts on these dates.

Model Compared to Moore et al. (1988b)

Moore et al. (1988b) sampled two sites during a runoff event that occurred on July 22, 1987. The weather station 9 km away from the project site at Brothers, Oregon measured 1.96 inches of rainfall for the date. The results are shown in Figures 9a, 9b, 10a, and 10b. Both of the sites sampled were downstream from areas that had not been grazed for over 100 days prior to the runoff event. One hundred eighty-nine cattle grazed directly upstream from Site 12 until April 10, 1987, while up to 977 cattle grazed directly upstream from Site 15 until April 10, 1987.

The model predicted that there would be no impact from the runoff event, giving a background FC count of 25 and an FS count of 100 at each of the sites, while the measured counts averaged 920 FC & 2890 FS at Site 12 and 4423 FC & 11,365 FS at Site 15. The model predicted no increase in FC and FS counts since the release rate from manure deposited on land for more than 15 days was determined to be negligible according to the results of Thelin and Gifford (1983).

Either these release rates are much too low for fecal deposits greater than 15 days old or the high measured bacterial counts were from cattle grazing upstream from the project site. Under non-runoff conditions these organisms would settle out into the stream bottom sediment before reaching the sampling stations, but under runoff conditions they would continue to remain in suspension in the stream. No samples were obtained upstream from sites

12 and 15 to determine if there were cattle grazing upstream from the sampling stations.

Another reason for the lower model values was that the model predicted over 90% of the FC organisms in the bottom sediment would die-off in eight days, and over 90% of the FS organisms would die-off in 17 days. If the model is run under the conditions that there was recent cattle grazing in the area, the FC and FS counts estimated by the model are only slightly larger than the measured values. If the model predicted higher die-off rates than actually existed, the number of organisms living in the bottom sediment estimated by the model would be lower than actual conditions. Consequently the number of organisms resuspended from the bottom sediment that is predicted by the model would also be lower than actual conditions. These results demonstrate the importance of accurately estimating the die-off rates in the bottom sediment and the release rates during a runoff event from fecal deposits on the land. It is also important to obtain water samples from areas upstream from the known cattle grazing to determine if there is a significant input of bacteria from wildlife or cattle from other upstream pastures.

The results of the model compared with bacterial counts measured in the research projects listed above show that the model gives very good results, usually within one order of magnitude. The model results for non-runoff conditions were better than the runoff conditions since runoff conditions have many more variables that affect the bacterial counts.

VII. SENSITIVITY ANALYSIS OF MODEL

The sensitivity analysis of the model variables are shown in Tables 17 and 18. Each variable shown in the Tables were decreased by 50% and increased by 50% of the values suggested for use in the model. These values were 5% for the release rate of the organisms from the stream bottom sediment, 0.14 for the die-off "K" value for FC, 0.06 for the die-off "K" value for FS, and 120 mm for the upper limit of the rainfall retention parameter.

Non-runoff Conditions

Table 17 shows that under non-runoff conditions, the model variables that affect the model's calculated bacterial concentrations are the release rate of organisms from the stream bottom sediment and the die-off "K" value of the organisms in the stream bottom sediment. The die-off "K" value was the most sensitive variable under non-runoff conditions, increasing the calculated organism concentrations about 60% when the variable was decreased 50%, and decreasing the calculated organism concentrations about 25% when the variable was increased by 50%. This inverse relationship occurs because as the die-off rate increases, the number of organisms remaining in the stream bottom sediment decreases, and thus the number resuspended from the bottom sediment also decreases.

Changing the upper limit of the rainfall retention parameter had no effect on the calculated concentrations of the model under non-runoff conditions since this variable only affects the runoff depth in runoff conditions.

Runoff Events

Table 18 shows that the bacterial concentrations calculated by the model following a runoff event are not as sensitive to changes in the input variables under runoff conditions as they are under non-runoff conditions. The bacterial counts estimated by the model are most sensitive to the upper limit of the rainfall retention parameter. When the upper limit was increased 50%, the model's FC counts increased 9.2% and the FS counts increased 13.3%. When the upper limit is increased, the depth of runoff decreases and the stream discharge from the runoff event also decreases. Since the runoff depth decreases, the number of organisms entering the stream from the runoff also decreases. When the upper limit was increased 50%, the number of FC entering the stream by runoff decreased 73.5%, the number of FS entering the stream decreased 73.6%, and the stream discharge decreased 71.8%. Since the stream discharge decreased less than the number of organisms entering the stream by runoff, the bacterial counts calculated by the model increased when the upper limit was increased.

The bacterial counts under non-runoff conditions are not very sensitive to either the release rate of organisms from the bottom sediment or the die-off "K" value of the organisms in the bottom sediment. The greatest change for these variables occurred when the "K" value was increased by 50% and the FS counts of the model increased 4.9%.

The sensitivity analysis demonstrates that an accurate estimate of the number of organisms per gram of feces is the most important factor to obtain satisfactory model bacterial concentration estimations in both runoff and non-runoff conditions. An accurate estimate of the die-off "K" value and the release rate of organisms from the bottom sediment is also important to obtain good model results under non-runoff conditions. For accurate estimation of runoff depths and bacterial counts during runoff events, a good estimate of the upper limit of the rainfall retention parameter is needed.

Table 17. Sensitivity analysis of model variables under non-runoff conditions.

	Model Variable		
	Resuspension rate of organisms from bottom sediment	Die-off "K" value for bottom sediment	Upper limit of rainfall retention parameter
Fecal Coliform Counts Calculated by Model			
Decrease of 50%	-47.4%	+62.8%	0.0%
Increase of 50%	+41.0%	-24.4%	0.0%
Fecal Streptococcus Counts Calculated by Model			
Decrease of 50%	-45.6%	+59.9%	0.0%
Increase of 50%	+38.7%	-25.0%	0.0%

Table 18. Sensitivity analysis of model variables under runoff conditions.

	Model Variable		
	Resuspension rate of organisms from bottom sediment	Die-off "K" value for bottom sediment	Upper limit of rainfall retention parameter
FC Counts Calculated by Model			
Decrease of 50%	+0.4%	+4.2%	-3.6%
Increase of 50%	-0.3%	-1.6%	+9.2%
FS Counts Calculated by Model			
Decrease of 50%	+0.7%	+4.9%	-4.9%
Increase of 50%	-0.6%	-2.0%	+13.3%
Number of FC Entering Stream by Runoff			
Decrease of 50%	-	-	+210.0%
Increase of 50%	-	-	-73.5%
Number of FS Entering Stream by Runoff			
Decrease of 50%	-	-	+209.6%
Increase of 50%	-	-	-73.6%
Stream Discharge Calculated by Model			
Decrease of 50%	-	-	+206.8%
Increase of 50%	-	-	-71.8%

VIII. USING THE MODEL TO PREDICT WATER QUALITY VALUES AT BEAR CREEK

The computer model is able to predict water quality trends based upon the weather conditions of the past. The Bear Creek project site in the report of Moore et al. (1988b) was chosen as a test site to run the model with 15 years of data from 1970-1984 to determine:

1) The contribution of the grazing cattle to the background bacterial concentrations of the creek under non-runoff conditions.

2) The number of days that the bacterial concentrations of the creek exceed limits between 200 FC/100 ml and 2000 FC/100 ml.

Non-runoff conditions occur a vast majority of the time in the semi-arid rangelands of the western United States. Table 19 shows that precipitation amounts necessary to create runoff conditions occur very infrequently.

Table 19. Average number of days per year that precipitation exceeds given amounts in 24 hours. Data from 1931 to 1965. (Pac. NW River Basins Commission Meteorology Comm., 1969)

Brothers, OR		Spokane, WA		Twin Falls, ID		Butte, MT	
>0.5"	>1.0"	>0.5"	>1.0"	>0.5"	>1.0"	>0.5"	>1.0"
4.9	0.3	6.3	0.6	2.7	0.3	3.4	0.6

Figure 11 in Appendix B shows the background bacterial concentrations when inputting various numbers of cattle grazing with access to Bear Creek into the model. The background concentrations are highest during the summer and lowest during the winter. Even with 1000 cattle grazing in the Bear Creek watershed, the model predicts that the FC concentrations will not exceed 200 FC/100 ml during non-runoff conditions in any season of the year.

Figures 12a through 12d show the number of days that the predicted concentrations will exceed 200 FC/100 ml with various rainfall retention parameter values input into the model. With a rainfall retention parameter value of 120 mm for Bear Creek (Heydarpour, 1988), the model calculated that in 15 years of data that concentrations of 200 FC/100 ml were exceeded only 29 days with 1000 cattle input into the model. This averages less than two days per year that the above limit was exceeded.

If the rainfall retention parameter of the soil at Bear Creek is not as high as the results of Heydarpour et al. (1988), the number of runoff events per year and the number of days that the concentration exceeds 200 FC/100 ml will increase. Figure 12d shows that if the soil has a rainfall retention parameter of 60 mm at Bear Creek, the number of days that the concentration exceeds 200 FC/100 ml increases to 90 days in 15 years, or an average of six days per year. Regardless of the value used for the rainfall retention parameter input into the model, the model shows that bacterial concentrations at Bear Creek exceed 200 FC/100 ml less than 2% of the days with up to 1000 cattle in the Bear Creek basin.

Figures 13a through 13d show that if the bacterial concentration limits are increased, the number of days these limits are exceeded decreases. With a rainfall retention parameter of 60 mm, the number of days that the concentration of 2000 FC/100 ml is exceeded only 16 days in 15 years, or about one day per year.

The model results for FC counts at Bear Creek with 500 cattle grazing in the 1987 grazing year are shown in Figure 14. The model calculated that there were two runoff events in 1987; a rainfall runoff event on day 203 (7-22-87) from 1.96 inches of rain, and a snowmelt runoff event on day 374 (1-9-88).

The rainfall runoff event of day 203 increased the calculated flow rate from 0.03 to 1.03 m^3/sec., while the estimated concentration was 3514 FC/100 ml. Non-runoff concentrations during the summer were 86 FC/100 ml. The snowmelt runoff event of day 374 increased the calculated flow rate from 0.03 to 0.13 m^3/sec., while the estimated concentration was 1500 FC/100 ml with 500 cattle grazing. The non-runoff concentrations during the winter were 36 FC/100 ml with 500 cattle grazing.

The model does not estimate the actual depth of the snowpack, but instead estimates the amount of precipitation that is stored as snow from the precipitation data combined with the maximum and minimum temperature data. When comparing the actual snowpack data at Brothers, Oregon to verify the model's snowmelt estimations, the model yields good results. On day 374 (1-9-88), the snowpack was five inches and day 375 (1-10-88) the snowpack was one inch. Assuming that all four inches of the snowpack melted and that the snow had a 10% moisture content, a depth of 10.2 mm of water was released from the snowpack. This exceeds the retention capacity of the soil to absorb 7.5 mm of snowmelt water, and thus a runoff condition existed. The model calculated that 8.2 mm of water were melted on this day, which is in very good agreement with the actual snowpack data.

These analyses demonstrate the advantage of using the model over a traditional water sampling program. Under a traditional sampling program, the range manager had no way of knowing if the bacterial counts obtained were typical of the entire year, or how the bacterial counts would change under runoff conditions or various numbers of cattle grazing. The model gives the rangeland manager a better idea of how the bacterial concentrations of a stream are affected by different runoff conditions and numbers of cattle grazing.

When combined with a traditional sampling program, the model variables can be adjusted to calibrate the model to represent the particular grazing application. For example, a sampling program can be done for one day during each season of the year under non-runoff conditions, and immediately following a runoff event. The frequency of the sampling program for each day can be varied, but it is recommended that at least three different samples be collected throughout the day to account for variation of bacterial counts that can occur during the day (Kunkle and Meiman, 1968). An average count from the samples should be taken to calibrate the model. As the model results are compared with traditional sampling counts, discrepancies can be compared to see if the model needs to be calibrated, or to determine if the sampling results are not accurate due to sampling errors.

IX. RELATIONSHIP OF MODEL WATER QUALITY PARAMETERS TO PREDICTED WATER QUALITY VALUES AT BEAR CREEK

Graphs were made to show the relationship of different model parameters calculated from input data and how they correlate with the daily water quality of Bear Creek near Brothers, Oregon. Input data used in the model were a sample file with 500 cattle grazing each day during 1987, a daily weather file for Brothers, Oregon during 1987, and a file of the seasonal fecal deposition patterns of the cattle grazing in the Bear Creek pastures.

The graphs are shown in Figures 15a through 19b in Appendix C. The graphs chart only the FC concentrations and not the FS concentrations, since the FS results follow the same pattern as the FC results. The FS concentrations are higher than the FC concentrations since there are approximately four times more FS organisms in cattle feces than FC organisms.

Organisms Deposited Directly Into the Stream

The fecal deposition patterns input into the model were based on the research of Moore et al. (1988b). In their research they watched grazing cattle in each season of the year and counted the number of times that the cattle deposited feces directly into the stream. They divided the number of fecal deposits directly input into the stream each day by the number of cattle grazing to obtain the number of direct deposits in the stream per cow per day. The rates of manure deposited into the stream were assumed to be constant for each season of the year, with the highest rate occurring in summer and the lowest rate in winter.

Figures 15a and 15b show that as the flow rate increased, the FC counts also increased. This demonstrates that while increased flow rates provide a larger volume of water to transport the bacteria (which would decrease concentrations), the number of bacteria entering the stream via runoff and the increased resuspension of organisms from the bottom sediment caused the increase of bacterial concentrations.

Figures 16a and 16b demonstrate the seasonal pattern of the direct deposit of manure in the stream and how it affects the daily water quality. As the number of organisms deposited directly into the stream increased, the bacterial concentration of the stream increased. In all but the two runoff events of day 203 and day 374, the increases or decreases in the FC water quality are a direct result of the number of organisms entering the stream by the direct deposit of feces.

<u>Number of Organisms in Bottom Sediment</u>

Figure 17a shows that the estimated number of organisms stored in the bottom gradually increases or decreases during non-runoff conditions. These gradual increases and decreases result from the changes in the number of organisms entering the stream by the direct deposit of feces. Figure 17b shows the dramatic decrease of FC stored in the bottom sediment, caused by the increased percentage of organisms resuspended, as Figure 19a demonstrates. The FC concentrations gradually increase from day 204 to day 209 because the flow rate gradually decreases (see Figure 15b) while 100% of the organisms in the stream are resuspended during these days (see Figure 19a).

Number of Organisms in Suspension in Stream

As Figures 18a and 18b demonstrate, the number of FC in suspension in the stream directly affects the FC concentrations. The concentrations of organisms are calculated by dividing the daily number of organisms suspended (after die-off in the water) by the total volume of water transporting the organisms in that day.

Percentage of Organisms Resuspended

Figure 19a shows that the percentage of organisms resuspended from the organisms entering the stream and contained in the bottom sediment ranged from 1% to 100%. Under the non-runoff conditions of days 200-202, the percentage was 1%, while the rate increased to 100% following the runoff event of day 203. The 1% resuspension rate under non-runoff conditions assumes that cattle are grazing within 10 km of the sampling point, and is based on conditions at Bear Creek at a flow rate of 0.03 m^3/sec. with a flow velocity of 0.30 m/sec. As flow velocities or sampling distances away from cattle grazing change, the resuspension rate would also be expected to change.

Organisms Input Into the Stream by Runoff

The input of organisms into the stream by the runoff events on day 203 and day 374 contributed to the sharp increases of bacterial concentrations in the stream as Figure 19b shows. Even though the runoff events increase the stream discharge, the bacterial concentrations increased due to the large number of organisms input from both the runoff and the resuspension of organisms from the stream bottom sediment.

For the rainfall runoff event of day 203, the model calculated that 3.85×10^{12} FC entered the stream via runoff and that 2.96×10^{11} FC were stored in the bottom sediment available for resuspension. Therefore, the model calculated that the runoff contributed over 10 times the number of organisms transported downstream than the organisms resuspended from the bottom sediment.

For the snowmelt runoff event of day 374, the model calculated that 3.38×10^{11} FC entered the stream via runoff and that 1.22×10^{11} FC were contained in the sediment available for resuspension. Thus the model estimated that runoff contributed a little less than 3 times the number of organisms transported downstream than the organisms resuspended from the bottom sediment. The results from Bear Creek show that the organisms entering the stream with the runoff influence the bacterial concentrations of the day of the runoff event more than the organisms stored in the bottom sediment.

X. AREAS OF FURTHER RESEARCH

The accuracy of the results obtained from the model depend upon the accuracy of the input data. The priority of topics that warrant further research effort that will improve the ability to predict are in order as follows:

1) The rate of direct deposit of cattle feces into the stream based on seasonal grazing patterns of the cattle.

2) The release rate of organisms from the stream bottom sediment under different stream flow rates and velocities.

3) The die-off rate of organisms in the stream bottom sediment.

4) The release rate of organisms from cattle fecal deposits from overland runoff.

5) The distance travelled in the stream by resuspended organisms taking into account the settling rate and the die-off rate of the organisms.

6) The filtering of the organisms from overland runoff by the vegetation.

As the knowledge of these six areas increase, the accuracy of the model will also increase. Even with the limited data available in these six areas, the model was still able to predict bacterial counts that were usually within 100 organisms per 100 ml of stream water, which demonstrates that this computer model is a useful and accurate tool in helping understand the impact grazing cattle have on the bacterial water quality of a rangeland stream.

XI. CONCLUSIONS

1. It is possible to develop a model that will predict indicator bacterial concentrations of a rangeland stream with sufficient accuracy to make management decisions that will assure a predetermined level of water quality.

The model can be used to estimate bacterial concentrations and was confirmed in four different field experiments. The data used to confirm the model results was the research available to date that included the number of cattle grazing, the dates of grazing, rainfall information, and stream discharge information. All of this information is needed for the model to make an accurate prediction of stream bacterial levels.

2. The model determined that for up to 1000 cattle grazing in the Bear Creek watershed, the stream bacterial counts exceeded 200 FC / 100 ml only 29 days in 15 years, or fewer than 2 days per year.

The recommended bacterial levels for surface waters determined by the USEPA (1976) are 1000 FC / 100 ml for irrigation, 2000 FC / 100 ml for a public water supply under conventional treatment, and 200 FC / 100 ml for limited contact recreation. Sampling confirmed the model prediction that Bear Creek concentrations exceeded 200 FC / 100 ml only following a runoff event, which occurred only 29 days in 15 years with 1000 cattle grazing in the Bear Creek watershed. The precipitation data of four widely distributed weather stations in the semi-arid western United States show that runoff events have a maximum frequency of 2.5%, or less than 10 days per year. The low frequency of these runoff events suggests that decisions made as to the number of cattle grazing in a semi-arid rangeland may be made based on bacterial counts of the stream under non-runoff conditions.

3. The computer model can be used in management decisions regarding the number of grazing cattle having access to a stream for any given set of climatic conditions.

The predictive ability of the model allows a range manager to evaluate what the bacterial counts of the stream would be when different numbers of cattle are grazing with access to the stream. This is useful in making cattle grazing decisions to meet water quality standards.

4. The model is a better tool to predict bacterial counts of a rangeland stream than traditional sampling programs.

The model is a better predictive tool for stream bacterial counts than a typical random water sampling program because a water sampling program has no way to account for variation in the stream and stream bottom conditions, cattle defecation patterns, and runoff conditions. While the model was verified using only four different research project results, the ability of the model to account for the extreme variations that occur in a rangeland setting give it an advantage over a traditional water sampling program in predicting stream bacterial levels.

5. Future research can improve the usefulness of the model to better predict the bacterial counts in extended stream reaches.

The current model is based upon conventional cattle grazing practices and relatively short stream reaches. The impact of alternate feeding/watering regimes can be incorporated into the framework of this model to guide rangeland managers in selecting alternate grazing strategies that will more effectively utilize the resource while maintaining acceptable levels of water quality.

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APPENDICES

APPENDIX A

GRAPHS OF MODEL VERIFICATION

Figure 4a. Model results compared to FC water quality values listed in Johnson et al. (1978).

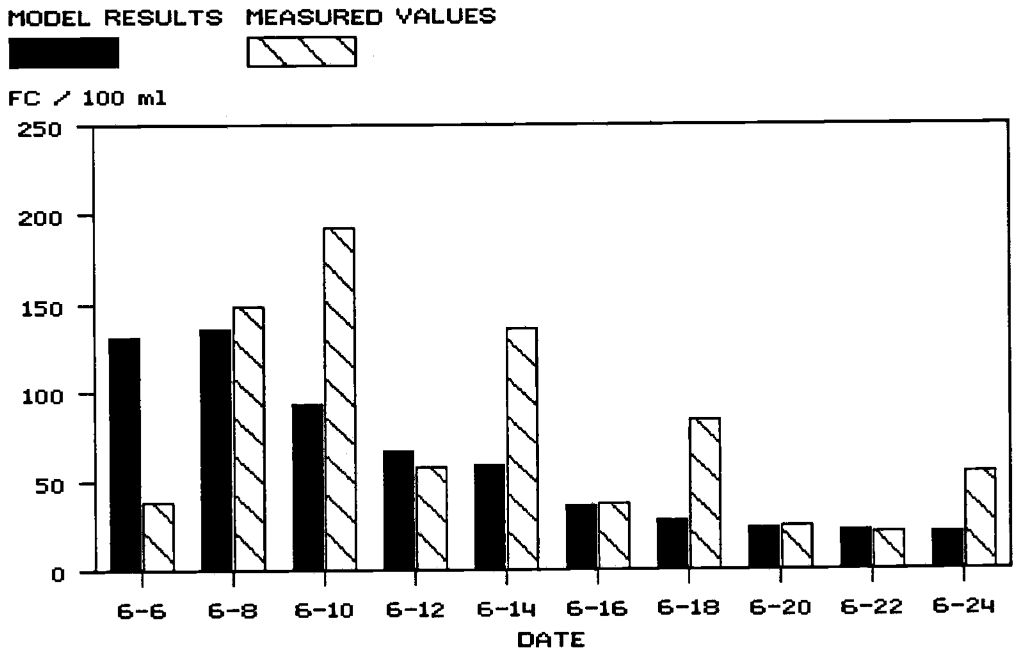


Figure 4b. Model results compared to FS water quality values listed in Johnson et al. (1978).

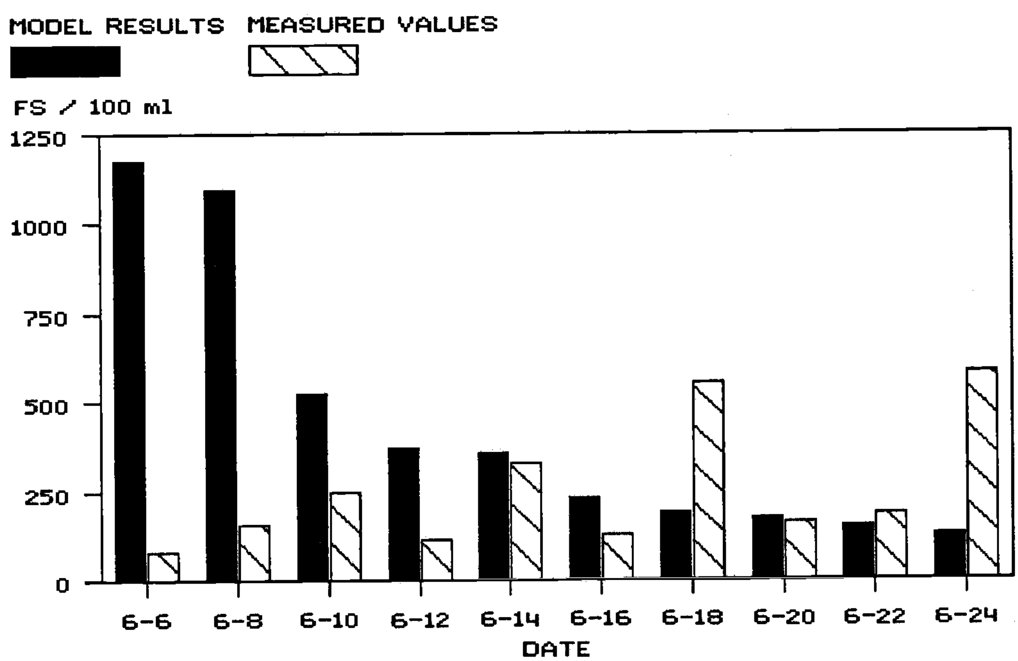


Figure 5a. Model results compared to FC water quality values listed in Mullen (1983).

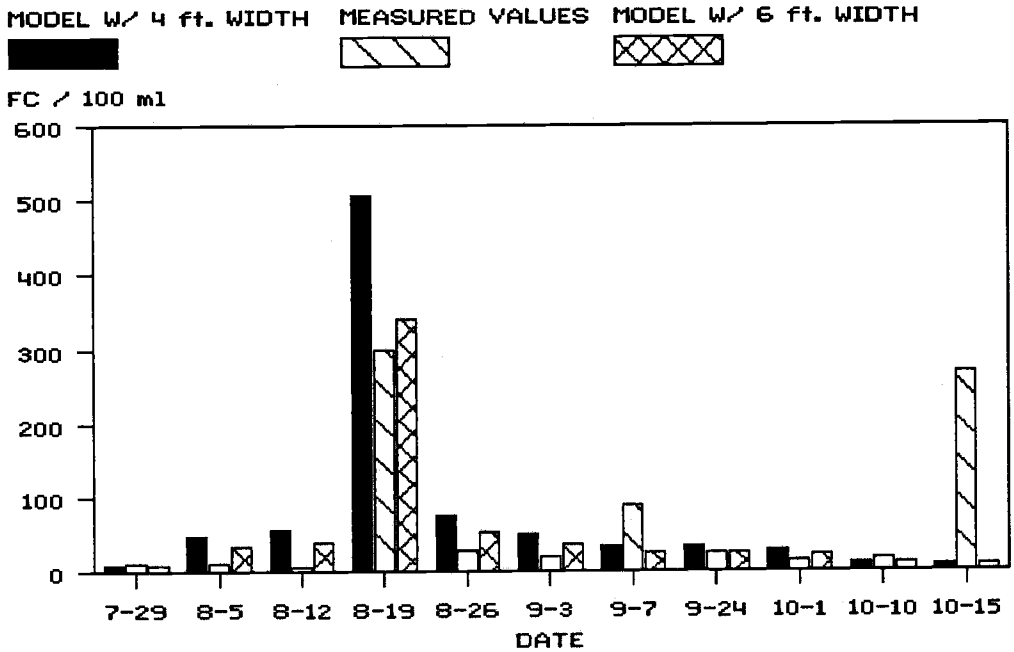


Figure 5b. Model results compared to FS water quality values listed in Mullen (1983).

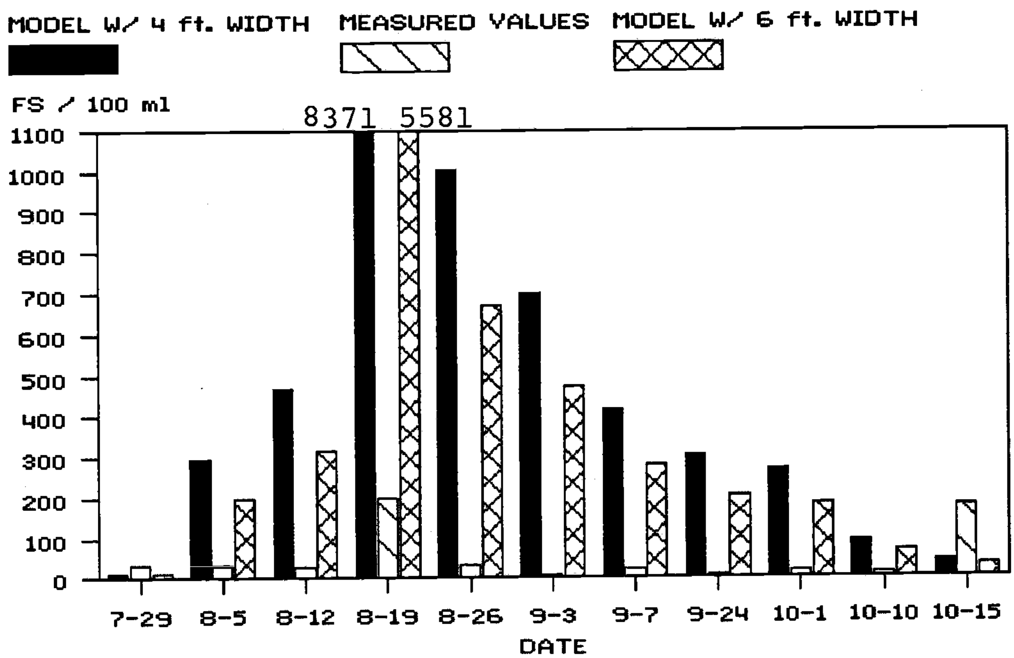


Figure 6a. Model results compared to FC water quality values listed in Sherer et al. (1988a) - site 1.

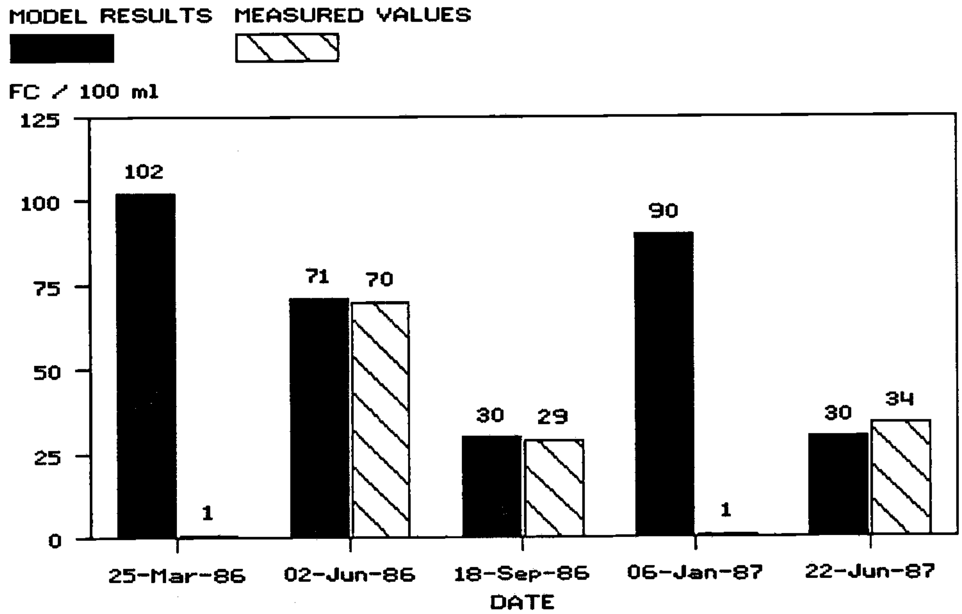


Figure 6b. Model results compared to FS water quality values listed in Sherer et al. (1988a) - site 1.

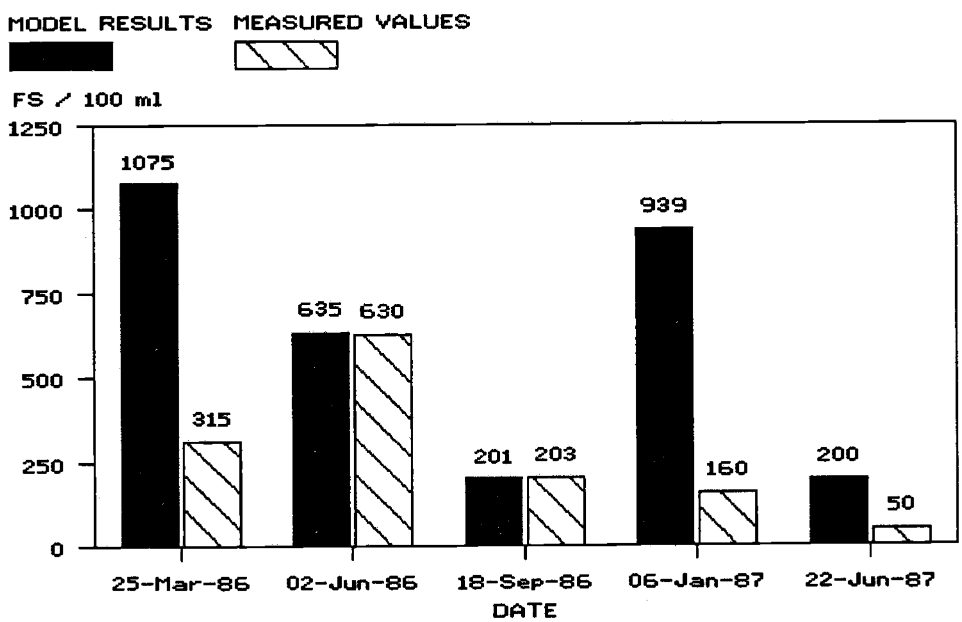


Figure 7a. Model results compared to FC water quality values listed in Sherer et al. (1988a) - site 2.

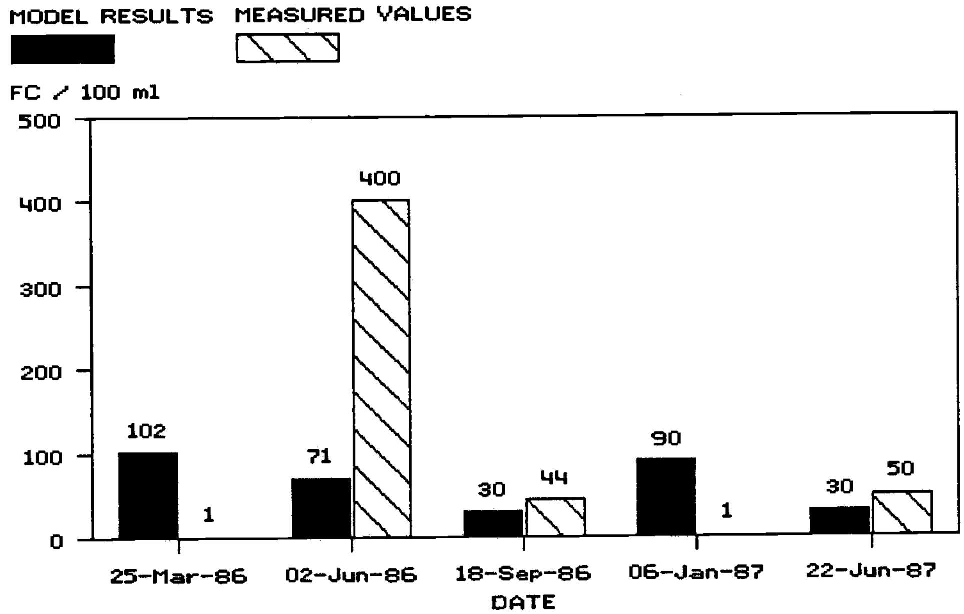


Figure 7b. Model results compared to FS water quality values listed in Sherer et al. (1988a) - site 2.

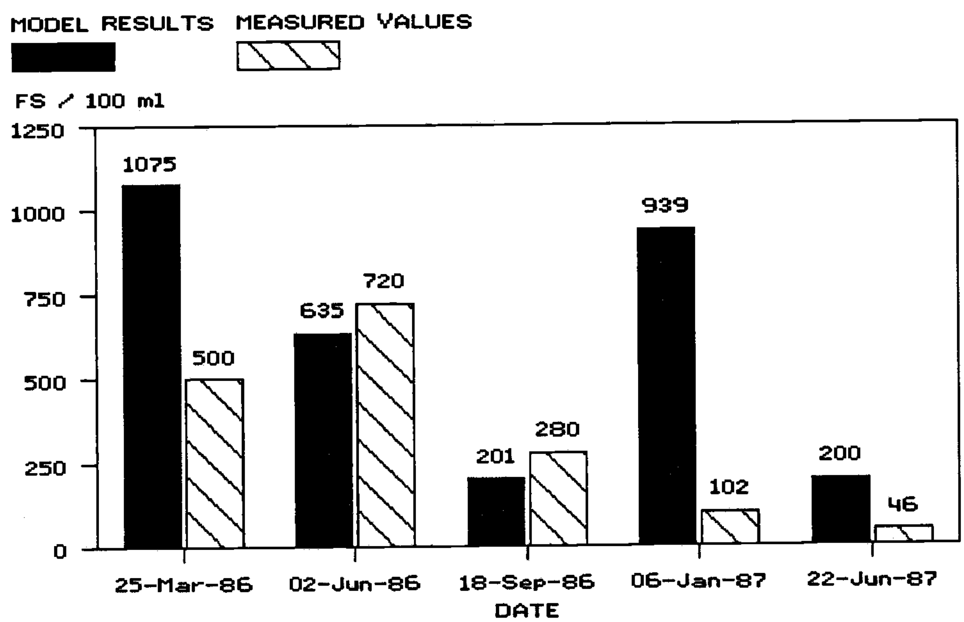


Figure 8a. Model results compared to FC water quality values listed in Sherer et al. (1988a) - site 3.

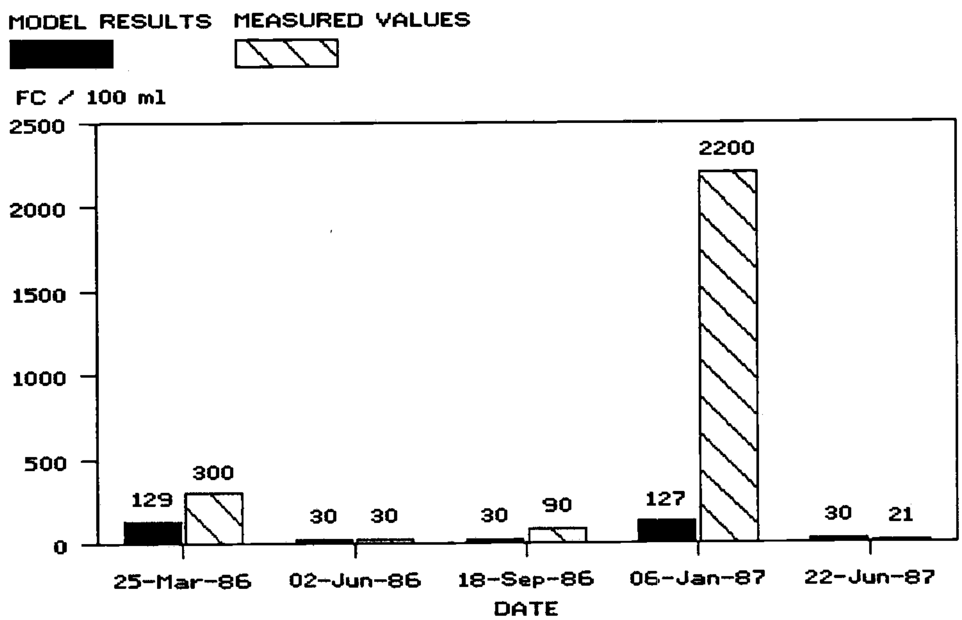


Figure 8b. Model results compared to FS water quality values listed in Sherer et al. (1988a) - site 3.

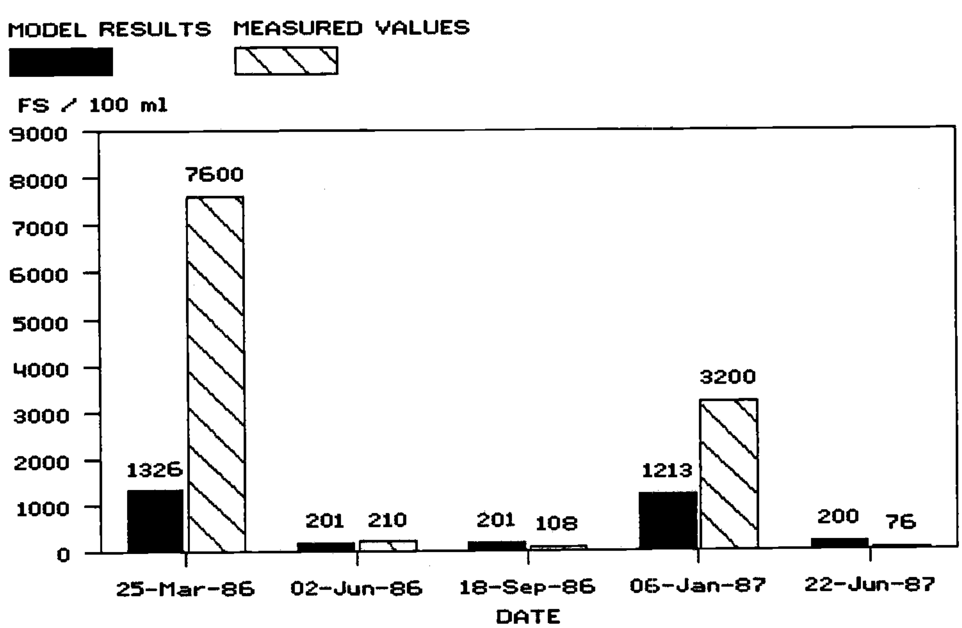


Figure 9a. Model results compared to the FC water quality of a runoff event listed in Moore et al. (1988b) - site 12.

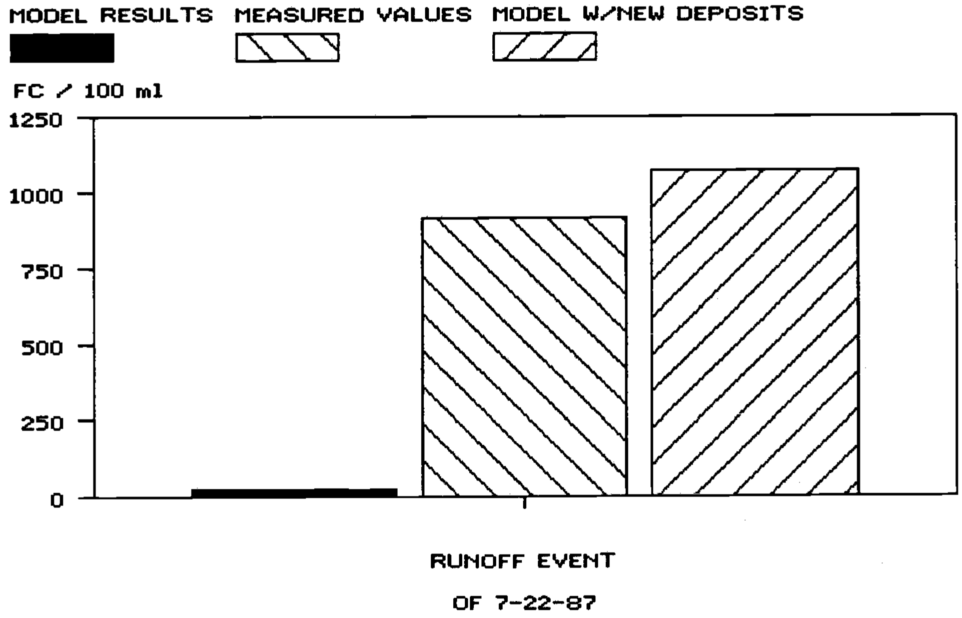


Figure 9b. Model results compared to the FS water quality of a runoff event listed in Moore et al. (1988b) - site 12.

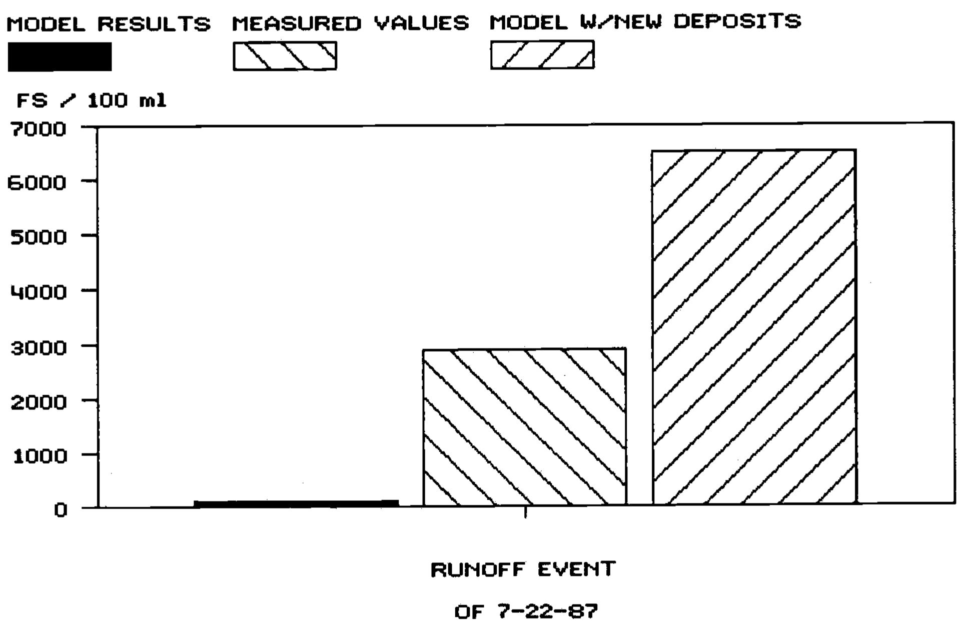


Figure 10a. Model results compared to the FC water quality of a runoff event listed in Moore et al. (1988b) - site 15.

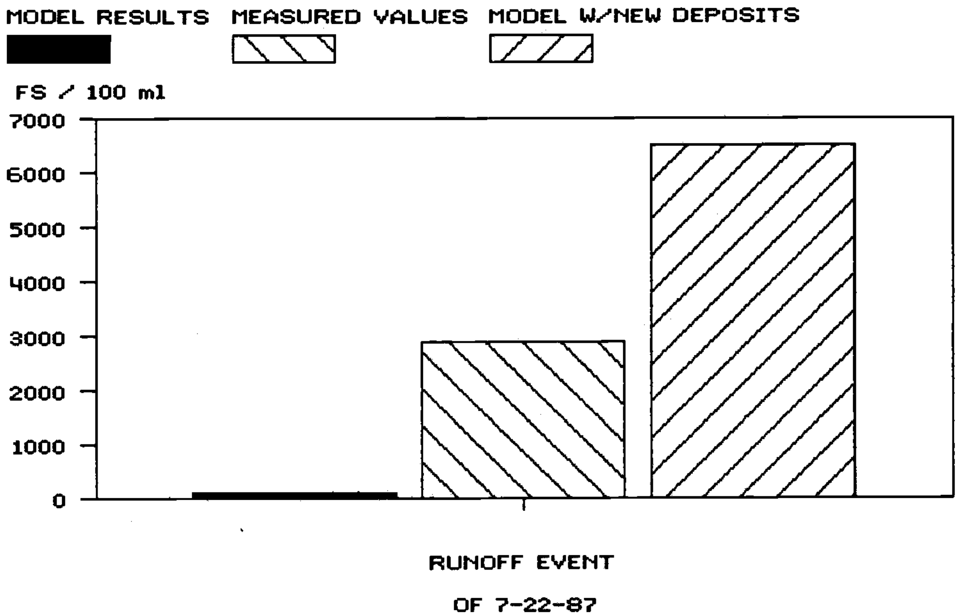
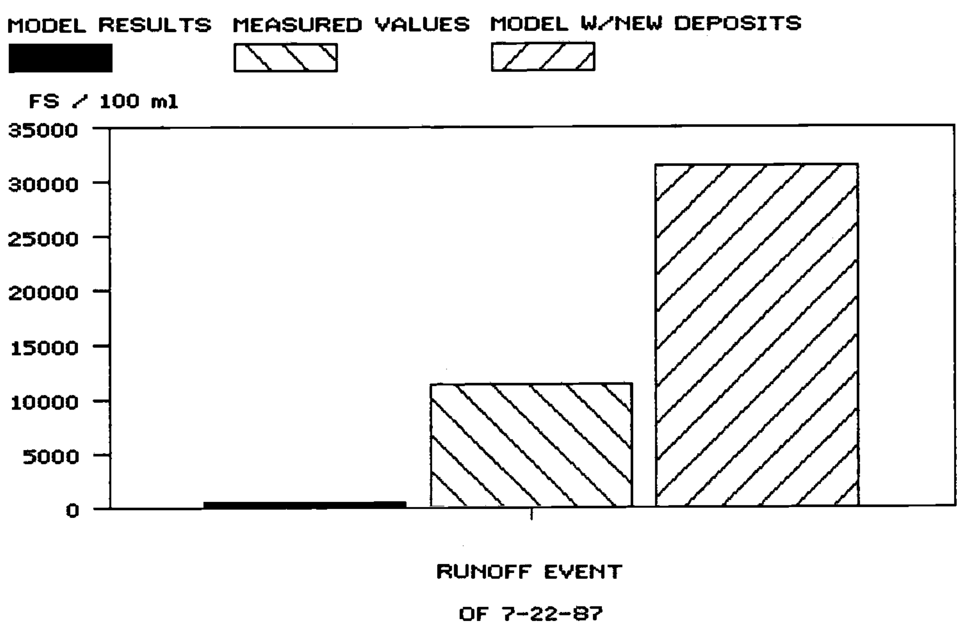


Figure 10b. Model results compared to the FS water quality of a runoff event listed in Moore et al. (1988b) - site 15.



APPENDIX B

GRAPHS OF MODEL PREDICTIONS AT BEAR CREEK

Figure 11. Calculated background concentrations of Bear Creek during the four seasons of the year as a function of the number of cattle grazing with access to the creek.

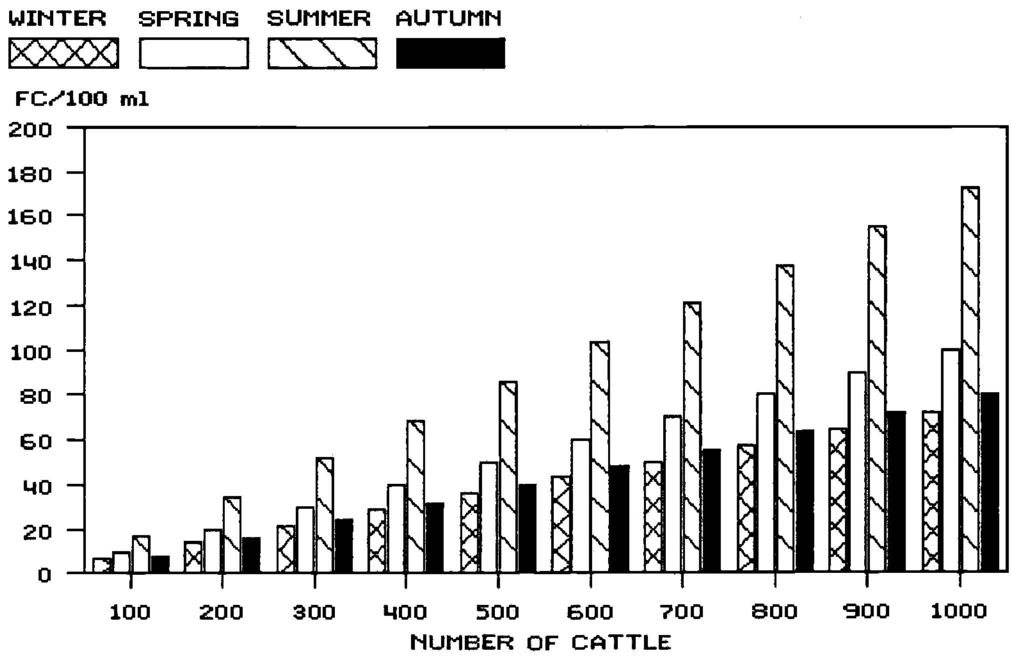


Figure 12a. Calculated number of days in 15 years that FC counts of Bear Creek exceeded 200 FC/100 ml using a rainfall retention parameter of 120 mm.

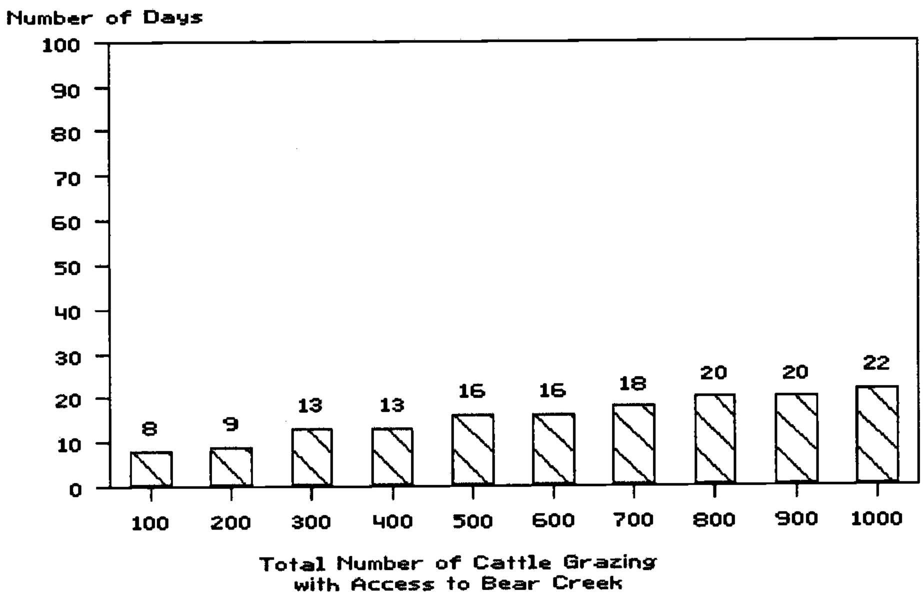


Figure 12b. Calculated number of days in 15 years that FC counts of Bear Creek exceeded 200 FC/100 ml using a rainfall retention parameter of 100 mm.

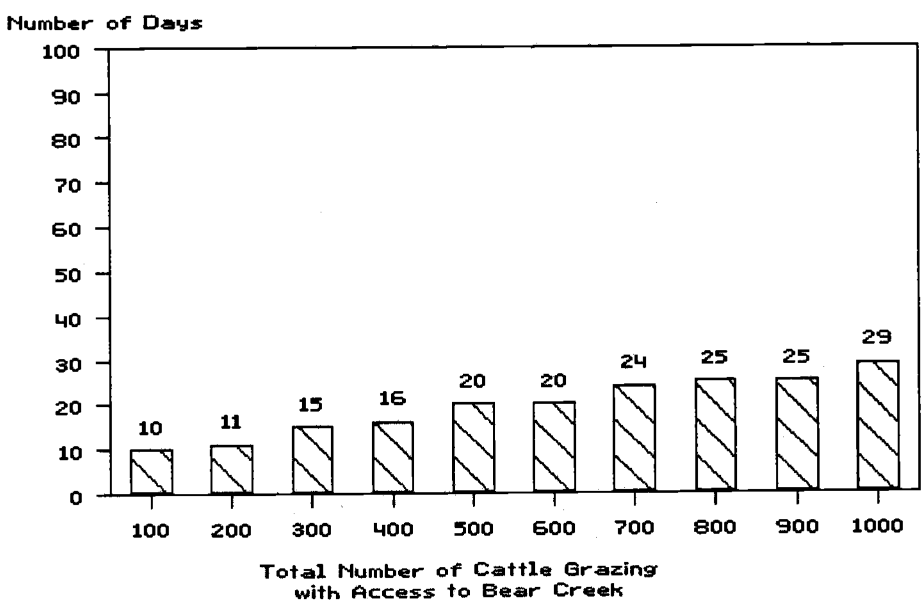


Figure 12c. Calculated number of days in 15 years that FC counts of Bear Creek exceeded 200 FC/100 ml using a rainfall retention parameter of 80 mm.

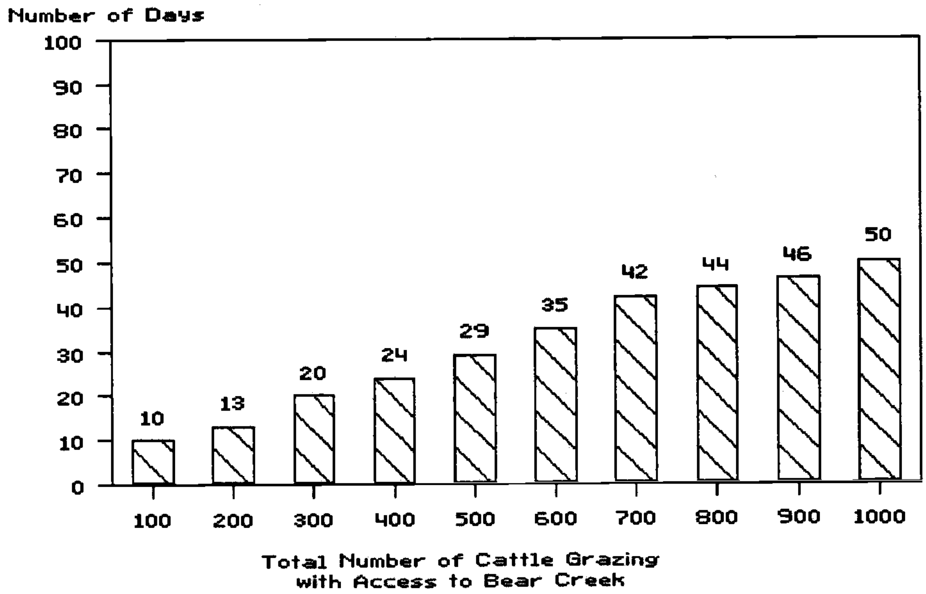


Figure 12d. Calculated number of days in 15 years that FC counts of Bear Creek exceeded 200 FC/100 ml using a rainfall retention parameter of 60 mm.

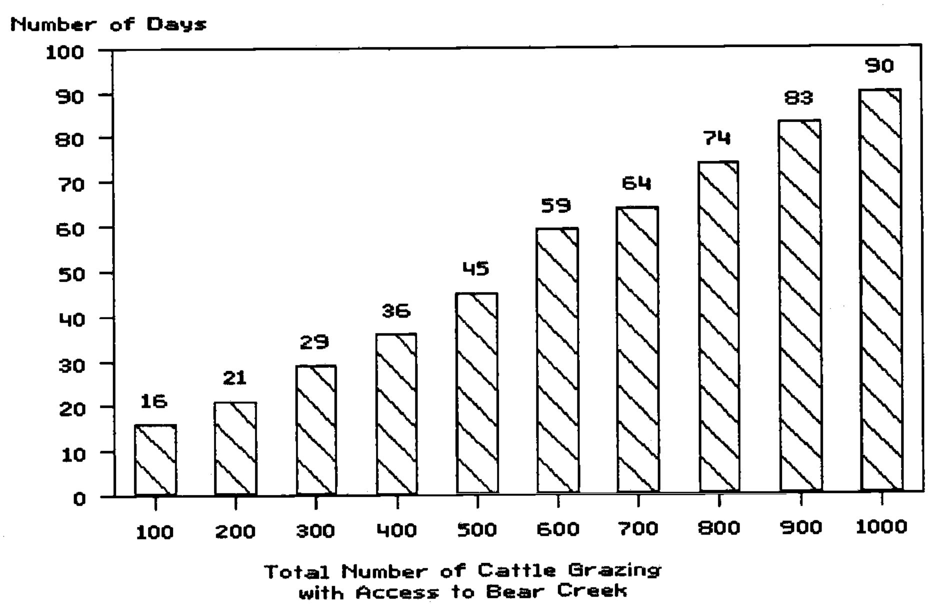


Figure 13a. Calculated number of days in 15 years that Bear Creek FC counts exceeded given limits with 1000 cattle grazing and a rainfall retention parameter of 120 mm.

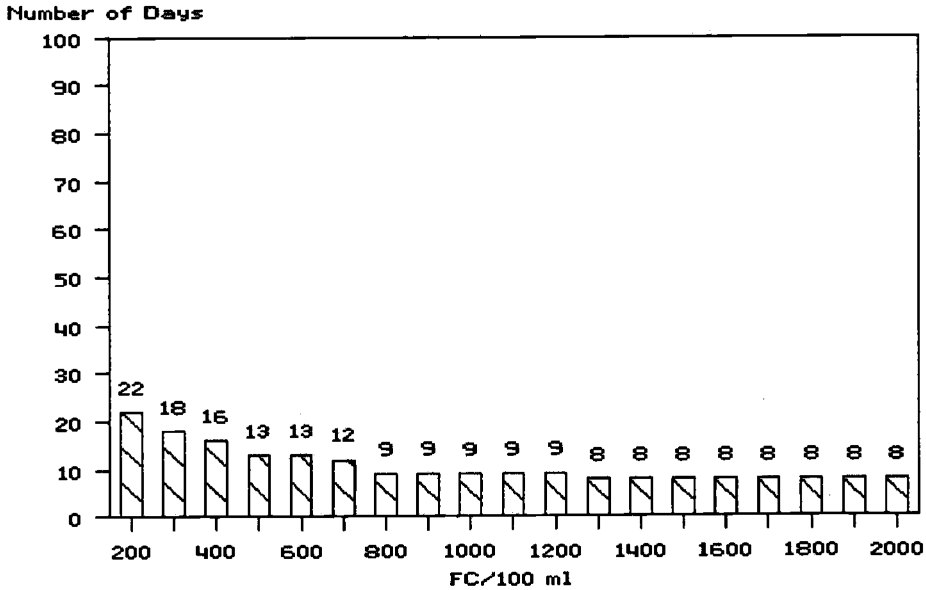


Figure 13b. Calculated number of days in 15 years that Bear Creek FC counts exceeded given limits with 1000 cattle grazing and a rainfall retention parameter of 100 mm.

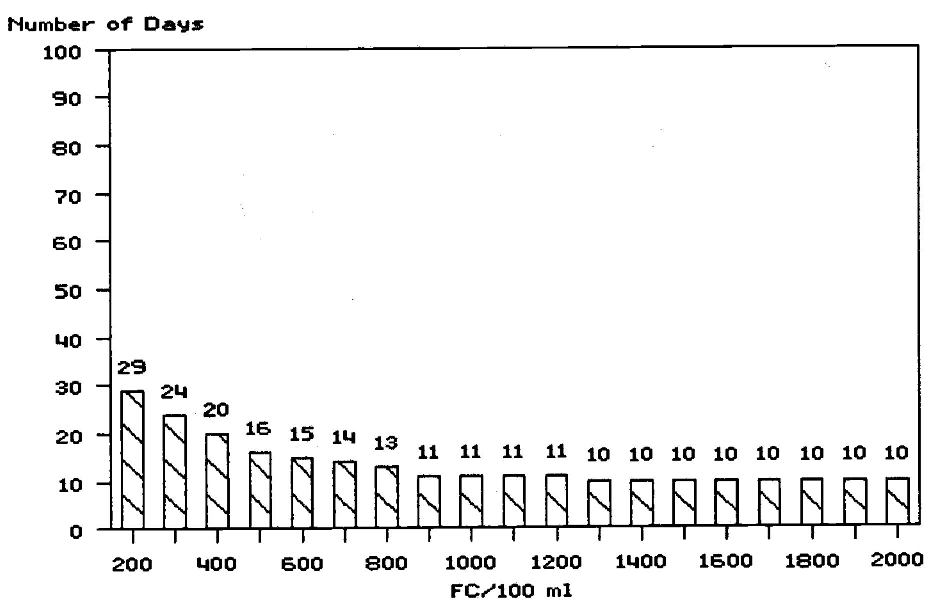


Figure 13c. Calculated number of days in 15 years that Bear Creek FC counts exceeded given limits with 1000 cattle grazing and a rainfall retention parameter of 80 mm.

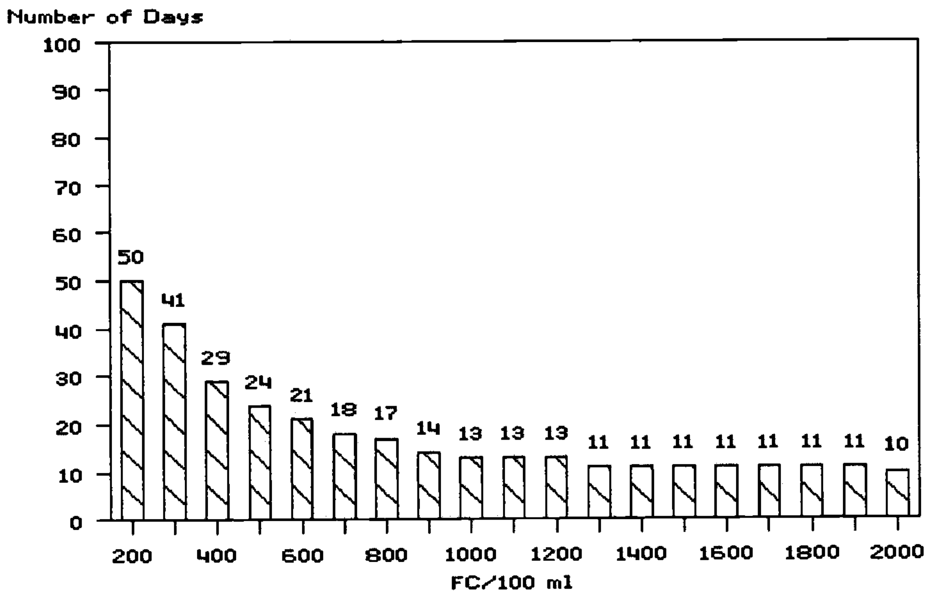
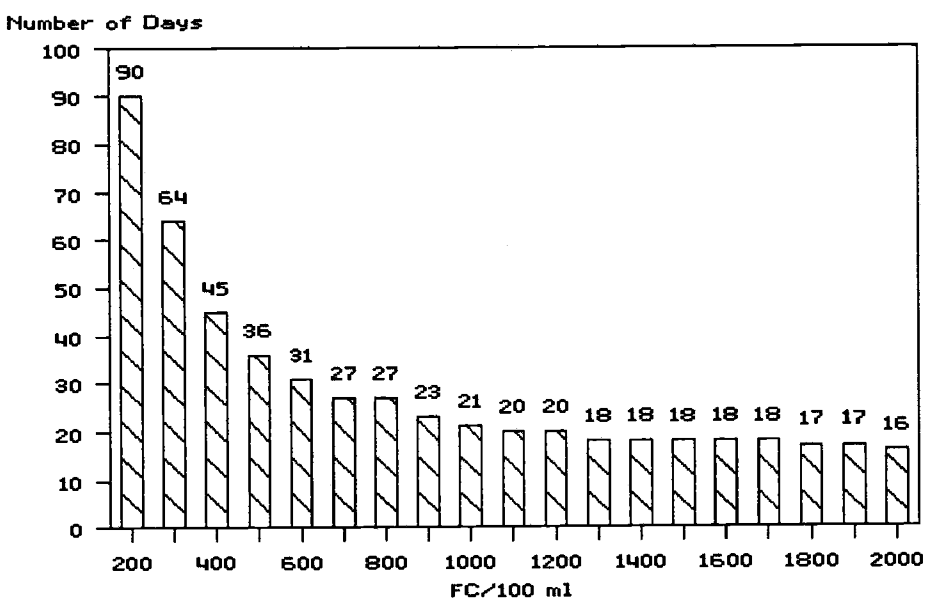


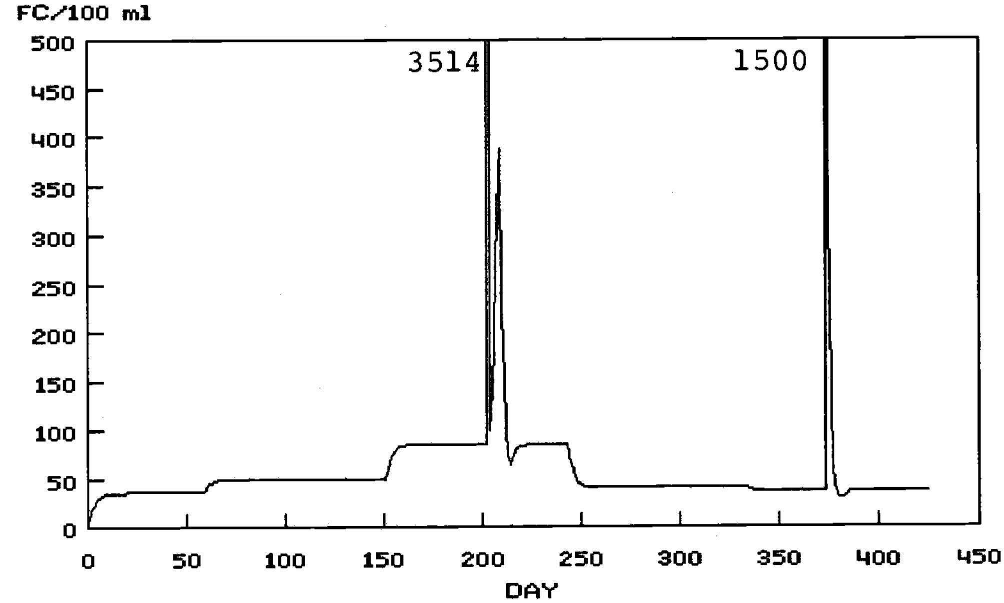
Figure 13d. Calculated number of days in 15 years that Bear Creek FC counts exceeded given limits with 1000 cattle grazing and a rainfall retention parameter of 60 mm.



APPENDIX C

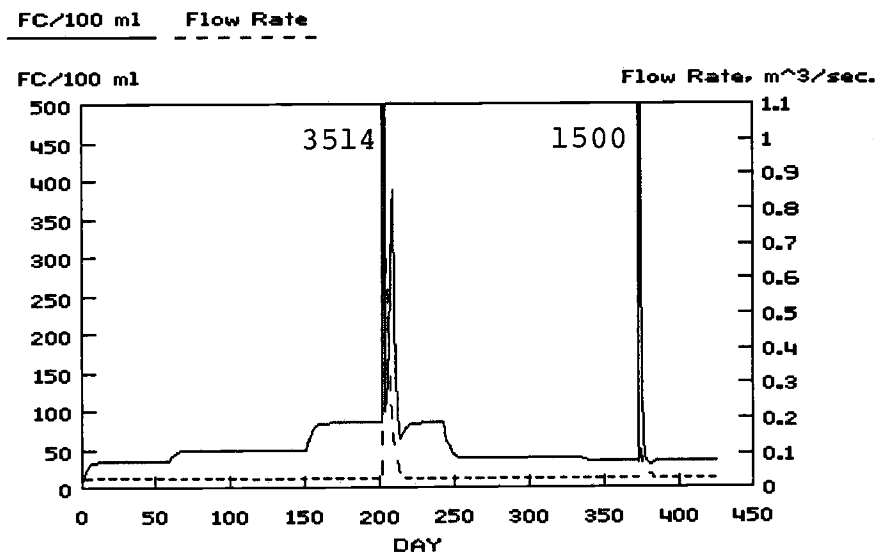
RELATIONSHIP OF MODEL PARAMETERS TO BACTERIAL WATER QUALITY

Figure 14. Model results for FC counts in Bear Creek with 500 cattle grazing during the 1987-88 season.



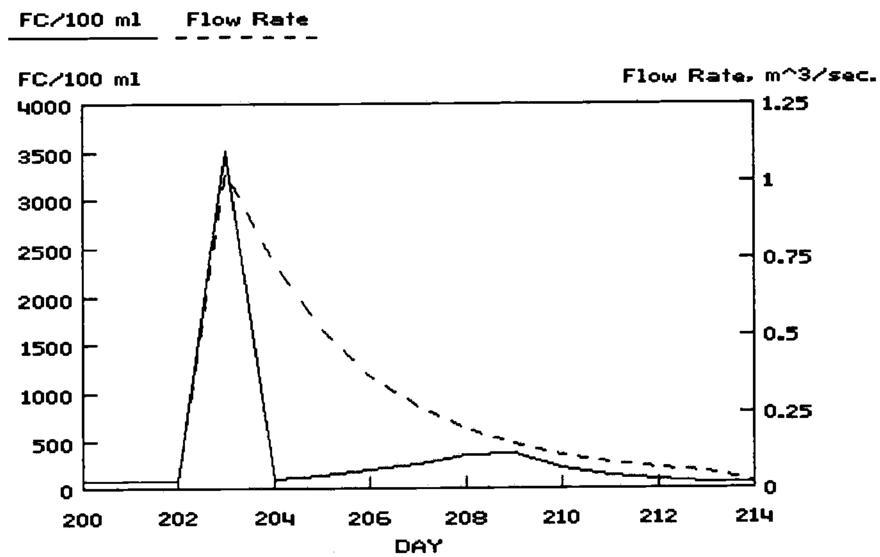
Note: Day 1 is January 1, 1987

Figure 15a. Relationship of the stream flow rate to the calculated daily FC water quality with 500 cattle grazing during 1987-88 at Bear Creek.



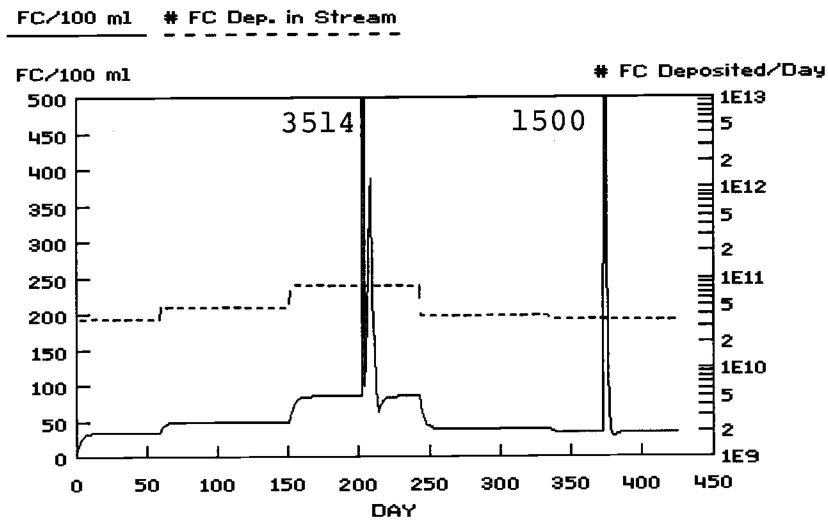
Note: Day 1 is January 1, 1987

Figure 15b. Relationship of the stream flow rate to the calculated daily FC water quality during a rainfall runoff event in 1987 with 500 cattle grazing at Bear Creek.



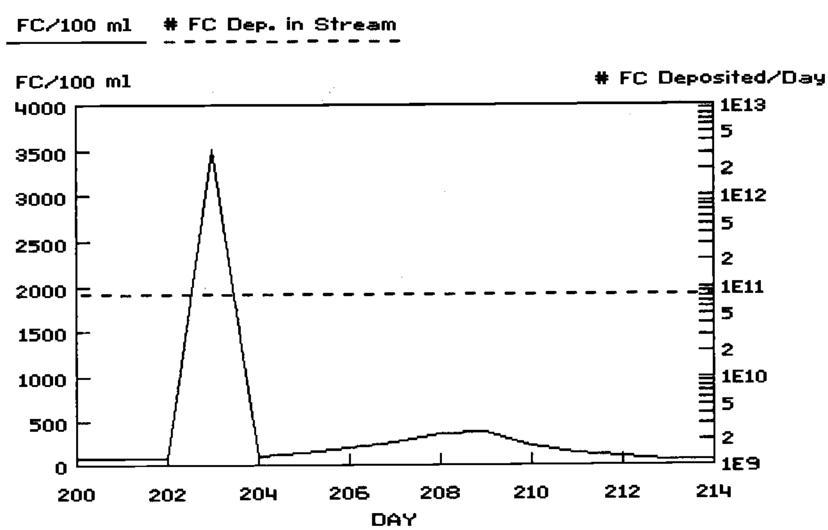
Note: Day 200 is July 19, 1987

Figure 16a. Relationship of the daily no. of FC directly deposited in Bear Creek to the calculated daily FC water quality with 500 cattle grazing during 1987-88.



Note: Day 1 is January 1, 1987

Figure 16b. Relationship of the daily no. of FC directly deposited in Bear Creek to the calculated daily FC water quality during a rainfall runoff event with 500 cattle grazing during 1987.



Note: Day 200 is July 19, 1987

Figure 17a. Relationship of the no. of FC in the bottom sediment to the calculated daily FC water quality for 1987-88 with 500 cattle grazing at Bear Creek.

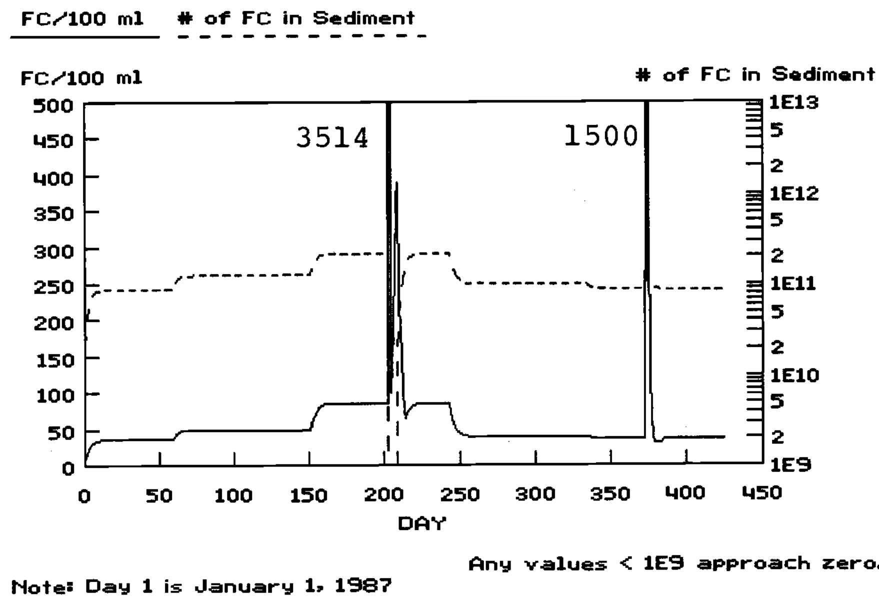


Figure 17b. Relationship of the no. of FC in the bottom sediment to the calculated daily FC water quality during a rainfall runoff event in 1987 with 500 cattle grazing at Bear Creek.

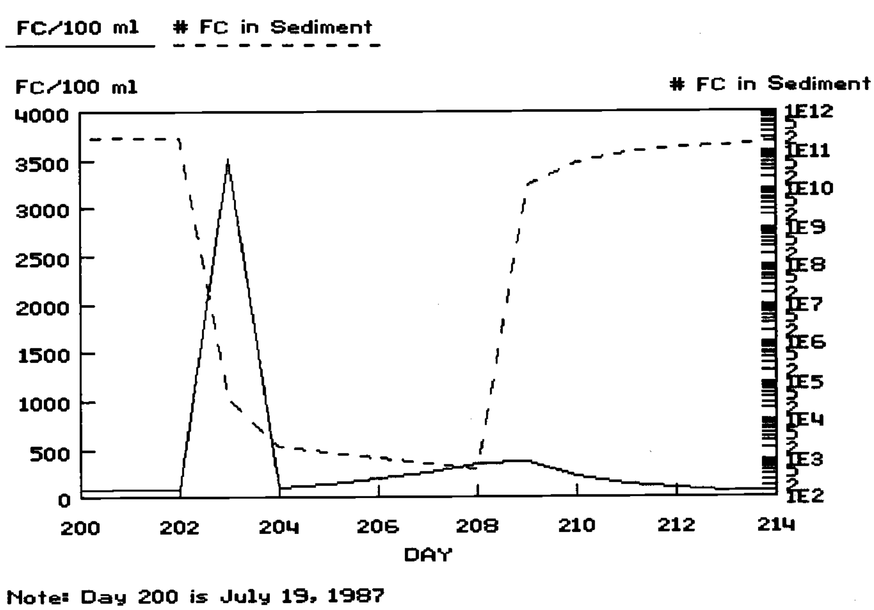
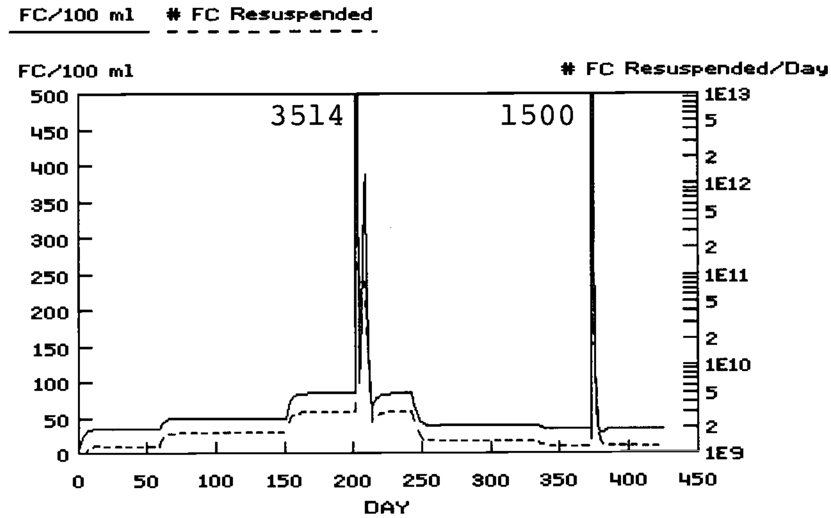
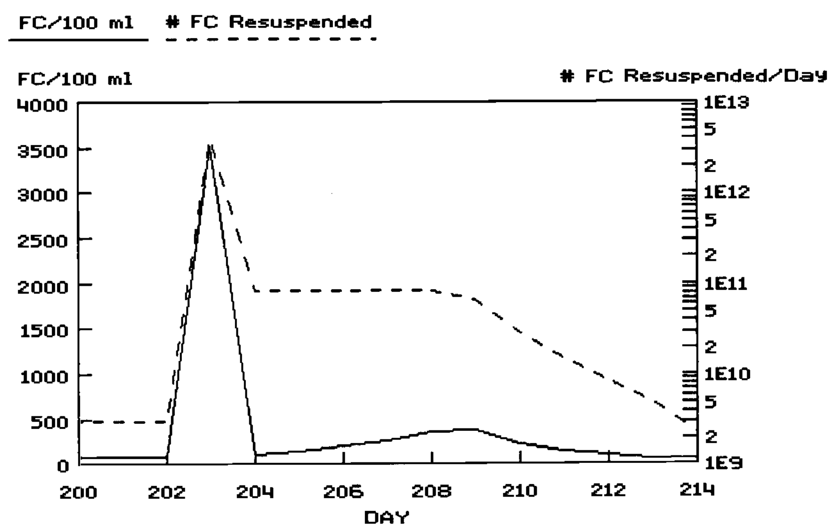


Figure 18a. Relationship of the estimated no. of FC in suspension in Bear Creek to the calculated daily FC water quality with 500 cattle grazing during 1987-88.



Note: Day 1 is January 1, 1987

Figure 18b. Relationship of the estimated no. of FC in suspension in Bear Creek to the calculated daily FC water quality during a rainfall runoff event with 500 cattle grazing during 1987.



Note: Day 200 is July 19, 1987

Figure 19a. Relationship of the estimated daily % of FC resuspended from the bottom sediment to the calculated daily FC water quality during a rainfall runoff event in 1987 with 500 cattle grazing at Bear Creek.

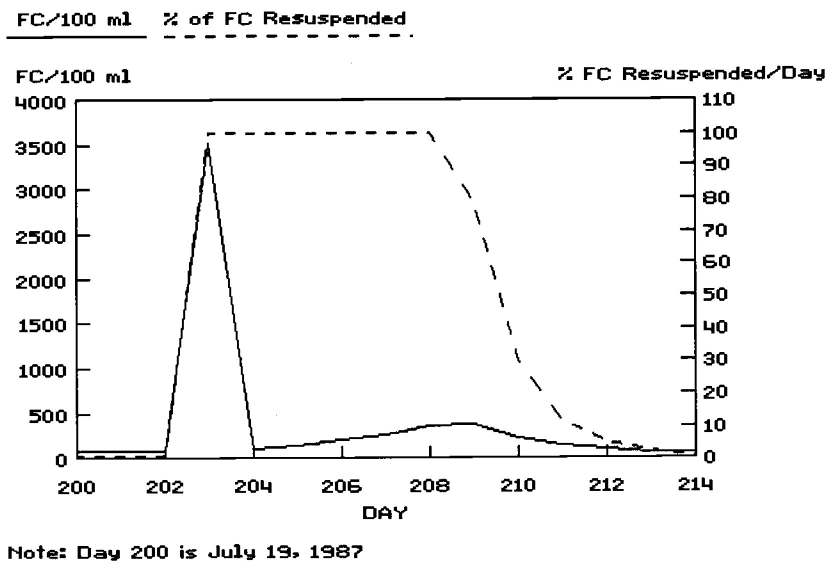
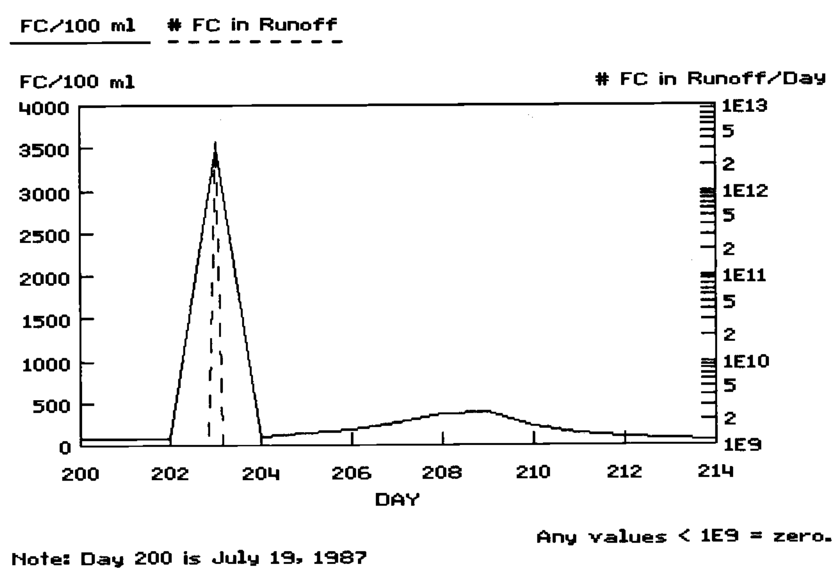
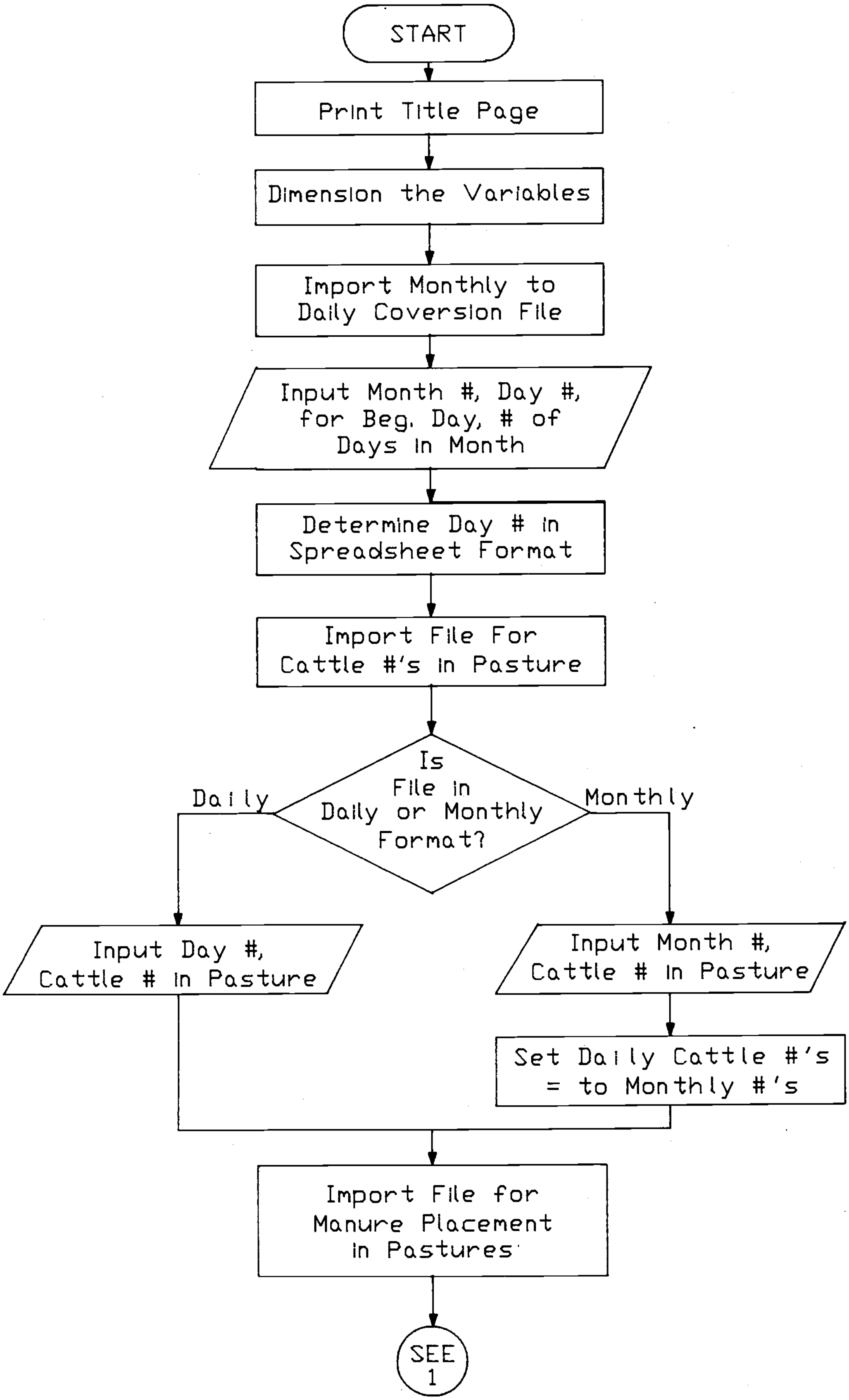


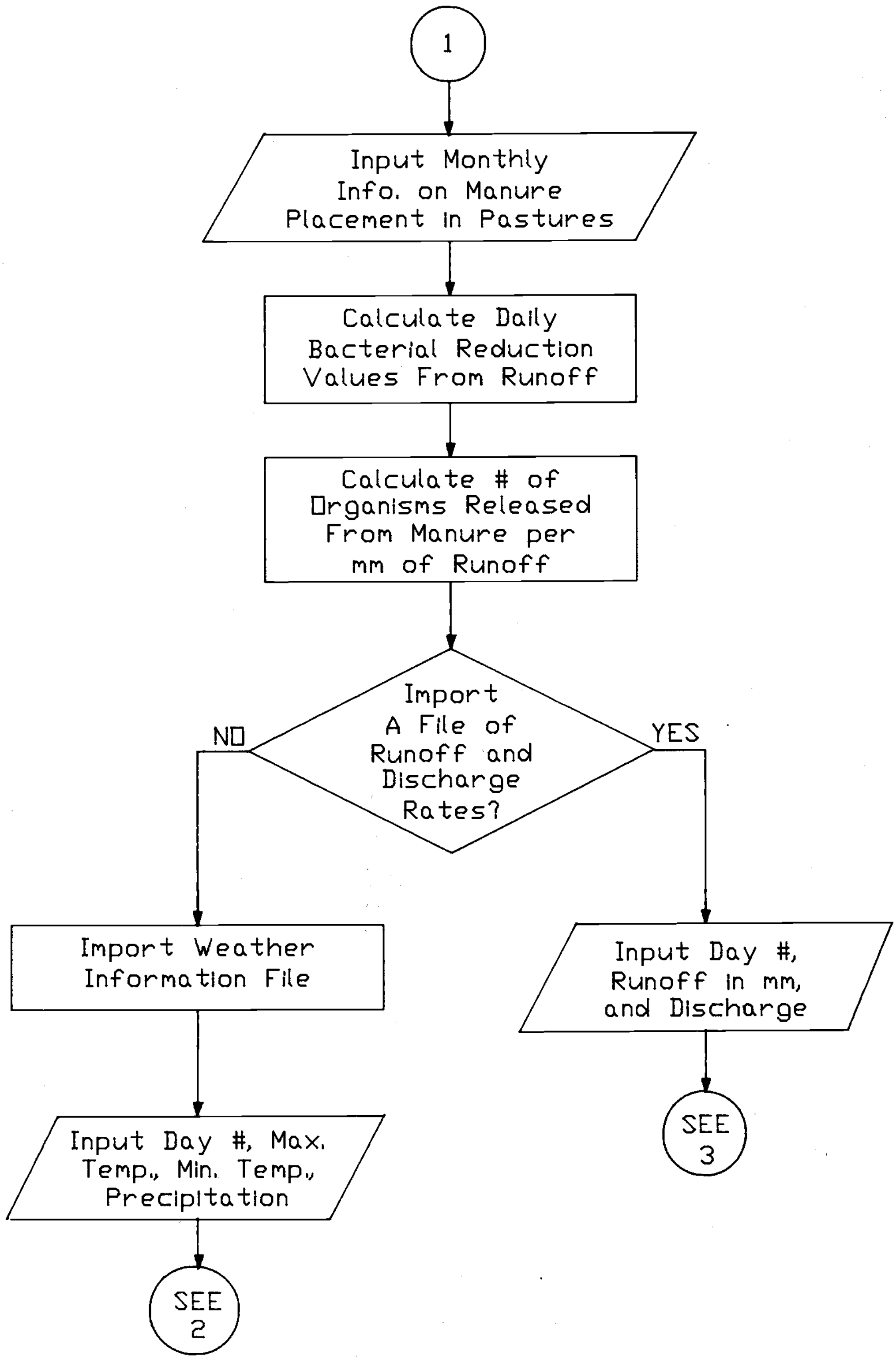
Figure 19b. Relationship of the estimated daily no. of FC entering Bear Creek by runoff to the calculated daily FC water quality during a rainfall runoff event with 500 cattle grazing during 1987.

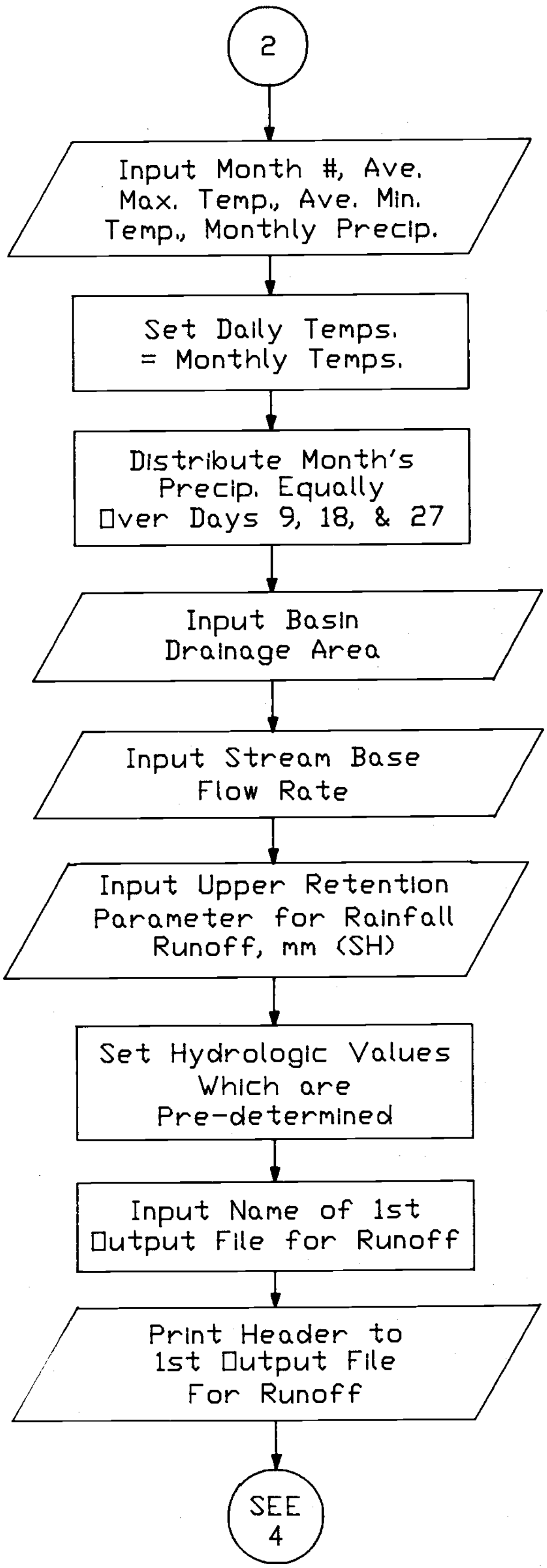


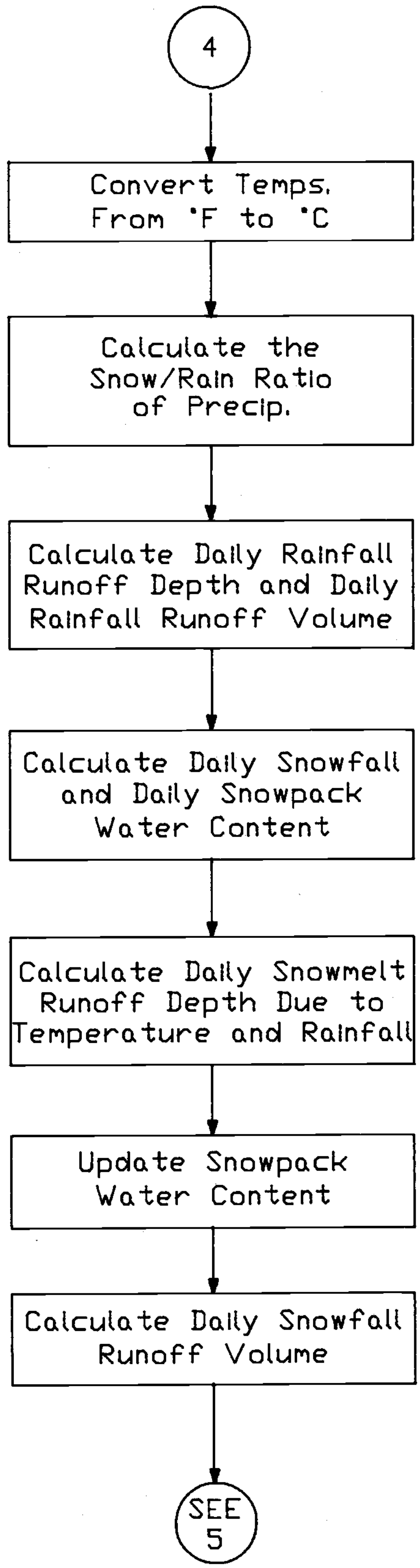
APPENDIX D

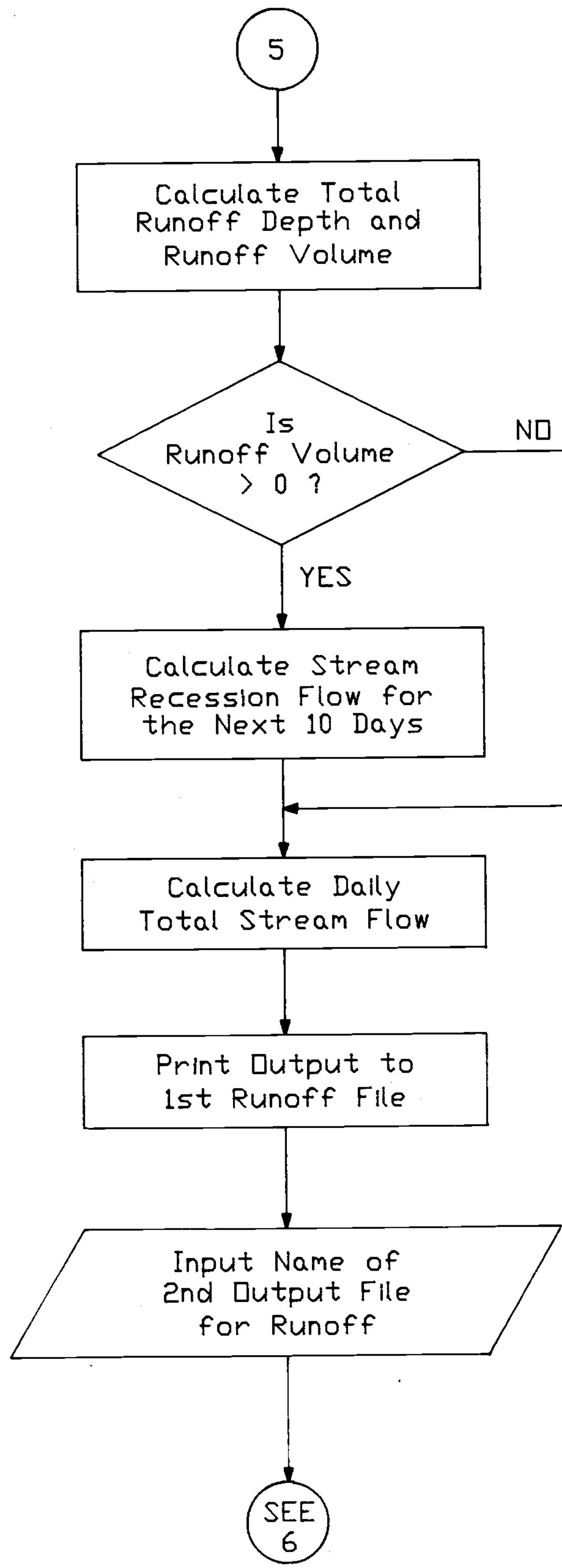
FLOWCHART OF COMPUTER PROGRAM

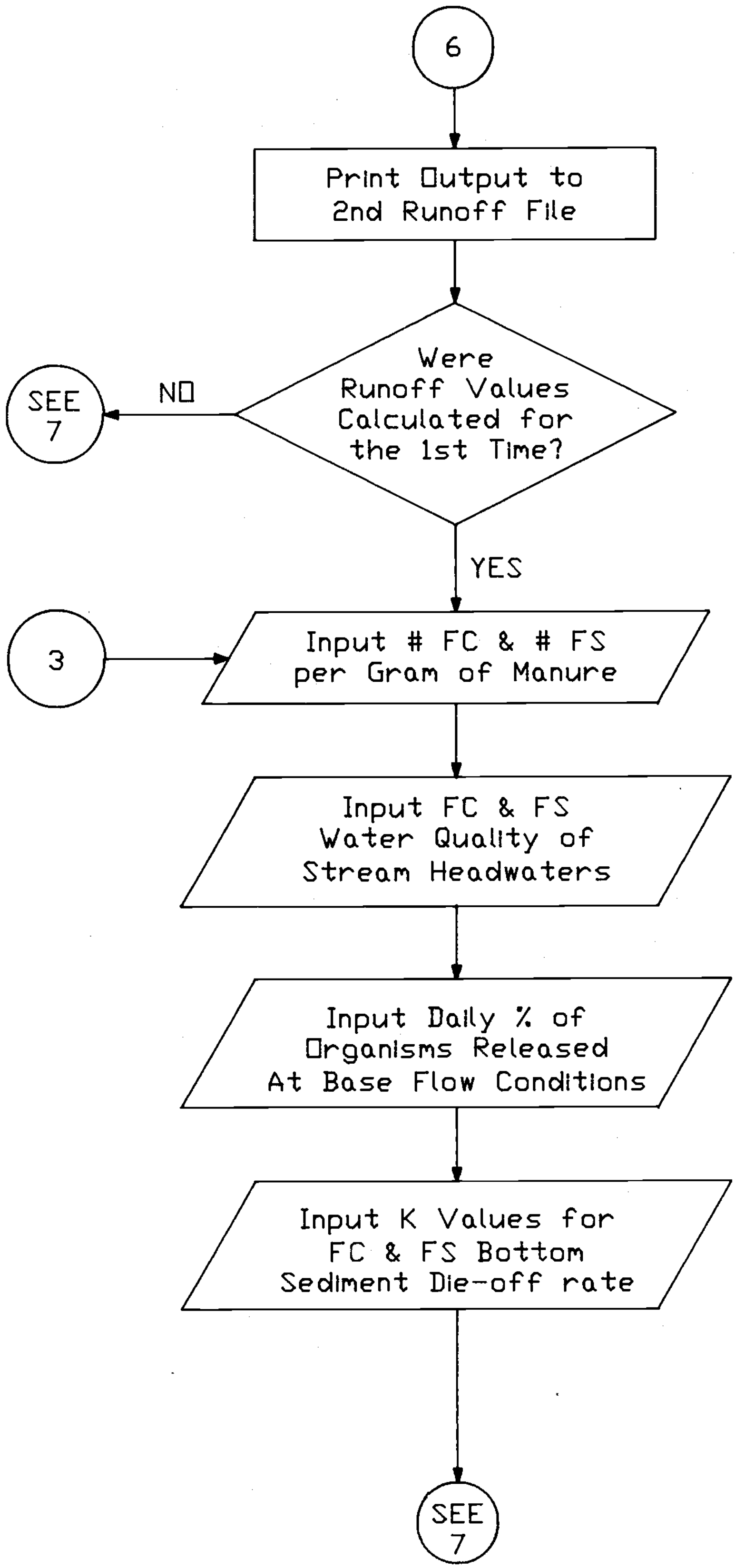

START
Print Title Page
Dimension the Variables
Import Monthly to Daily Coversion File
Input Month #, Day #, for Beg. Day, # of Days in Month
Determine Day # in Spreadsheet Format
Import File For Cattle #'s in Pasture
Is File in Daily or Monthly Format?
Daily
Monthly
Input Day #, Cattle # in Pasture
Input Month #, Cattle # in Pasture
Set Daily Cattle #'s = to Monthly #'s
Import File for Manure Placement in Pastures
SEE 1

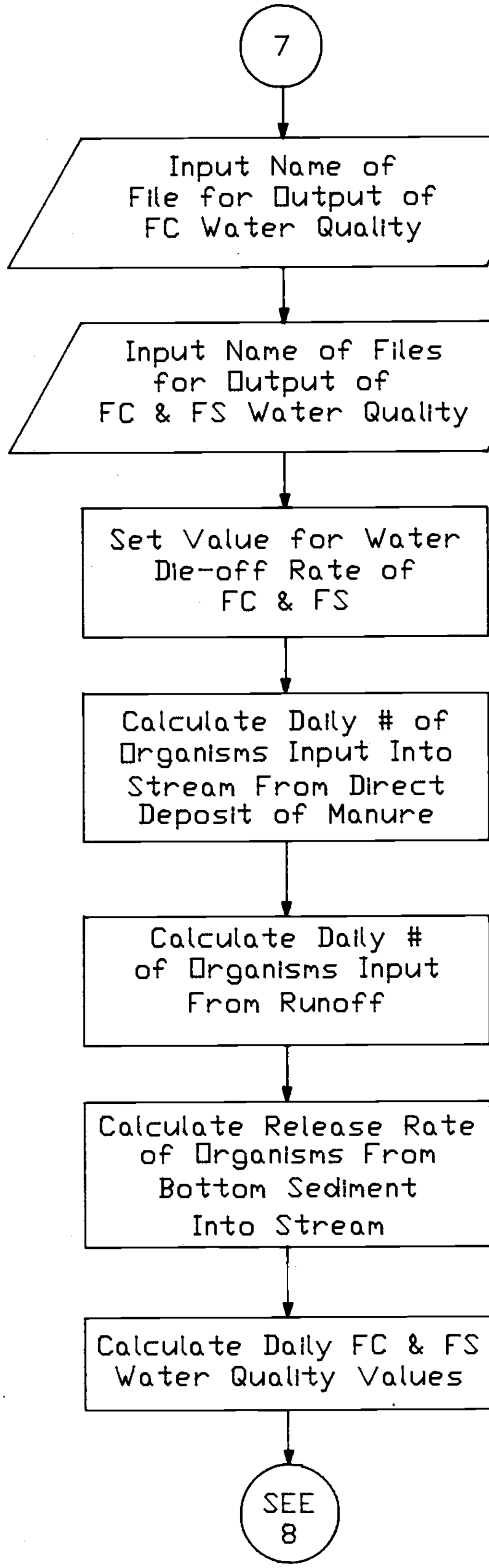

1
Input Monthly Info. on Manure Placement in Pastures
Calculate Daily Bacterial Reduction Values From Runoff
Calculate # of Organisms Released From Manure per mm of Runoff
Import A File of Runoff and Discharge Rates?
NO
YES
Import Weather Information File
Input Day #, Runoff in mm, and Discharge
Input Day #, Max. Temp., Min. Temp., Precipitation
SEE 2
SEE 3

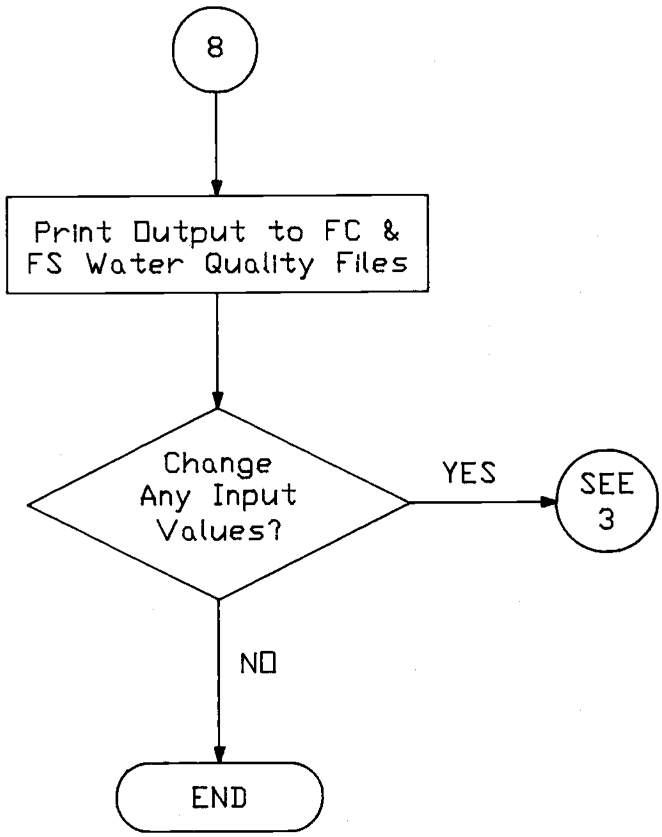

2
Input Month #, Ave. Max. Temp., Ave. Min. Temp., Monthly Precip.
Set Daily Temps. = Monthly Temps.
Distribute Month's Precip. Equally Over Days 9, 18, & 27
Input Basin Drainage Area
Input Stream Base Flow Rate
Input Upper Retention Parameter for Rainfall Runoff, mm (SH)
Set Hydrologic Values Which are Pre-determined
Input Name of 1st Output File for Runoff
Print Header to 1st Output File For Runoff
SEE 4


4
Convert Temps. From °F to °C
Calculate the Snow/Rain Ratio of Precip.
Calculate Daily Rainfall Runoff Depth and Daily Rainfall Runoff Volume
Calculate Daily Snowfall and Daily Snowpack Water Content
Calculate Daily Snowmelt Runoff Depth Due to Temperature and Rainfall
Update Snowpack Water Content
Calculate Daily Snowfall Runoff Volume
SEE 5


5
Calculate Total Runoff Depth and Runoff Volume
Is Runoff Volume > 0 ?
NO
YES
Calculate Stream Recession Flow for the Next 10 Days
Calculate Daily Total Stream Flow
Print Output to 1st Runoff File
Input Name of 2nd Output File for Runoff
SEE 6


6
Print Output to 2nd Runoff File
Were Runoff Values Calculated for the 1st Time?
NO
SEE 7
YES
3
Input # FC & # FS per Gram of Manure
Input FC & FS Water Quality of Stream Headwaters
Input Daily % of Organisms Released At Base Flow Conditions
Input K Values for FC & FS Bottom Sediment Die-off rate
SEE 7


7
Input Name of File for Output of FC Water Quality
Input Name of Files for Output of FC & FS Water Quality
Set Value for Water Die-off Rate of FC & FS
Calculate Daily # of Organisms Input Into Stream From Direct Deposit of Manure
Calculate Daily # of Organisms Input From Runoff
Calculate Release Rate of Organisms From Bottom Sediment Into Stream
Calculate Daily FC & FS Water Quality Values
SEE 8


8
Print Output to FC & FS Water Quality Files
Change Any Input Values?
YES
SEE 3
NO
END

APPENDIX E

LISTING OF COMPUTER PROGRAM

```
'
'  Program Name: GRAZEWQ.BAS
'
'  Written By: Howard Biskie
'
'  For: Partial fulfillment of an M.S. degree in
'       Agricultural Engineering at Oregon State
'       University; Corvallis, Oregon.
'
'
'
'
'   This program estimates the effects of grazing
'   cattle on the water quality of a rangeland
'   stream under runoff and non-runoff conditions.
'   Water quality parameters determined by the program
'   are fecal coliform and fecal streptococcus
'   concentrations in # FC / 100 ml and # FS / 100 ml.
'   The program can estimate stream discharge and
'   runoff rates from a weather data file input by the
'   user.  The user can also import a file of stream
'   discharge and runoff rates either measured or
'   generated from another program and skip the
'   program's estimation of these values.
'
'
DECLARE FUNCTION Log10! (X!)
'   Log10(X) is a function to convert natural logs to
'   common logs.
'
CLS
PRINT : PRINT : PRINT : PRINT : PRINT
PRINT "                                                      "
PRINT "         Program Name: GRAZEWQ                        "
PRINT "                                                      "
PRINT "         Written By: Howard Biskie                    "
PRINT "         Dept. of Agricultural Engineering            "
PRINT "         Oregon State University                      "
PRINT "         Corvallis, OR 97331                          "
PRINT "                                                      "
PRINT "         Press <Return> To Continue                   "
PRINT "                                                      "
PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
INPUT TEST$
IF (TEST$ = "") GOTO 1
'
'   Dimension the variables.  A description of each
'   variable will be given as it is used in the
'   program.
1   DIM DAY123(425), TMAX(425), TMIN(425), PRECIP(-4 TO
425)
DIM RUNOFF(425), RECFLOW(435), RUNDPTH(425), TOTFLOW(425)
```

```
DIM RIPPR(425), RIPDEF(425), STMRATE(425)
DIM MDEF(425), MPR(425), UDEF(425), UPR(425), NUMCAT(425)
DIM FCLAND(425), FSLAND(425)
DIM MONTH(14), DAY123B(14), NUMDAYS(14), NUMCATM(14)
DIM TMAXM(14), TMINM(14), PRECIPM(14)
DIM RIPDEFM(14), RBUFLTH(14), RSLOPE(14)
DIM MDEFM(14), MBUFLTH(14), MSLOPE(14)
DIM UDEFM(14), UBUFLTH(14), USLOPE(14), STMRATM(14)
DIM T(0 TO 18)
'
'
'    ┌──────────────────────────────────────────┐
'    │  Input Monthly To Daily Conversion File. │
'    └──────────────────────────────────────────┘
'
CLS
PRINT "┌──────────────────────────────────────────┐"
PRINT "│  Input Monthly To Daily Conversion File. │"
PRINT "└──────────────────────────────────────────┘"
PRINT
INPUT "Name Of Conversion File"; CONVERT$
OPEN CONVERT$ FOR INPUT AS #22
INPUT #22, N1$, N2$, N3$, N4$, N5$, N6$, N7$, N8$, N9$,
N10$
L = 0
'
'       L is the month number.
'
COUNT = 1
DO UNTIL EOF(22)
     IF L = 15 GOTO 200
     L = L + 1
     INPUT #22, MONTH(L), DAY123B(L), NUMDAYS(L), DAY$
     KBEG = COUNT
     KEND = COUNT + NUMDAYS(L) - 1
     ADDDAY = 0
     FOR K = KBEG TO KEND
          DAY123(K) = DAY123B(L) + ADDDAY
          COUNT = COUNT + 1
          ADDDAY = ADDDAY + 1
     NEXT K
LOOP
CLOSE #22
'
'   NUMDAYS(L) is the no. of days in MONTH(L).
'   DAY123(K) is the day no. in Lotus 123 format.
'   DAY123B(L) is the beginning day of MONTH(L)
'   in 123 format.
'
'
'    ┌──────────────────────────────────────────┐
'    │  Import File For Cattle Numbers in Pastures. │
'    └──────────────────────────────────────────┘
'
'
```

```
CLS
PRINT "┌─────────────────────────────────────────────┐"
PRINT "│ Import File For Cattle Numbers in Pasture.  │"
PRINT "│ ─────────────────────────────────────────── │"
PRINT "│ Enter (D) for Daily Cattle Information.     │"
PRINT "│ Enter (M) for Monthly Cattle Information.   │"
PRINT "└─────────────────────────────────────────────┘"
PRINT
100 INPUT TEST$
IF (TEST$ = "D" OR TEST$ = "d") GOTO 110
IF (TEST$ = "M" OR TEST$ = "m") GOTO 120
PRINT
PRINT "Please Input Either D or M"
PRINT
GOTO 100
'
'    Input Daily Cattle Numbers For Pastures.
'
110 PRINT
PRINT "Name Of File For Cattle Numbers For Pasture?"
PRINT
INPUT CATTLE$
OPEN CATTLE$ FOR INPUT AS #4
INPUT #4, N1$, N2$, N3$, N4$, N5$, N6$, N7$, N8$, N9$
K = 0
'
'       K is the day number.
'
DO UNTIL EOF(4)
     K = K + 1
     IF K = 426 GOTO 200
     INPUT #4, DAY123(K), NUMCAT(K), DAY$
LOOP
CLOSE #4
'
' NUMCAT(K) is the number of cattle in pasture on day K.
' DAY$ is the date.
'
D1COUNT = K
GOTO 130
'
'    Input Monthly Cattle Numbers For Pastures.
'
120 PRINT
PRINT "Name Of File For Cattle Numbers In Pasture?"
PRINT
INPUT CATTLE$
OPEN CATTLE$ FOR INPUT AS #9
INPUT #9, N1$, N2$, N3$, N4$, N5$, N6$, N7$, N8$, N9$
L = 1
'
'       L is the month number.
```

```
'
COUNT = 1
DO UNTIL EOF(9)
     INPUT #9, MONTH(L), NUMCATM(L), DAY$
     IF L = 15 GOTO 200
     '
     '   Set all days in month equal to month's number.
     '   K is the day number.
     '   NUMCATM(L) is the number of cattle in pasture
     '   during MONTH(L).
     '
     KBEG = COUNT
     KEND = COUNT + NUMDAYS(L) - 1
     FOR K = KBEG TO KEND
          NUMCAT(K) = NUMCATM(L)
          COUNT = COUNT + 1
     NEXT K
     L = L + 1
LOOP
'
'
'   | Import File For Manure Placement in Pastures. |
'
'
130 CLS
PRINT "┌─────────────────────────────────────────────┐"
PRINT "│ Input Name of File For Manure Placement.    │"
PRINT "└─────────────────────────────────────────────┘"
PRINT
INPUT MANURE$
OPEN MANURE$ FOR INPUT AS #19
INPUT #19, N1$, N2$, N3$, N4$, N5$, N6$, N7$, N8$, N9$,
N10$, N11$, N12$
L = 0
COUNT = 1
DO UNTIL EOF(19)
IF L = 15 GOTO 200
L = L + 1
INPUT #19, MONTH(L), RIPDEFM(L), RBUFLTH(L), RSLOPE(L),
MDEFM(L), MBUFLTH(L), MSLOPE(L), UDEFM(L), UBUFLTH(L),
USLOPE(L), STMRATM(L)
'   Convert from monthly to daily information.
KBEG = COUNT
KEND = COUNT + NUMDAYS(L) - 1
FOR K = KBEG TO KEND
     RIPDEF(K) = RIPDEFM(L)
     RIPPR(K) = 11.77 + 13.98 * RBUFLTH(L) / SLOPE(L)
     '   Limit % reduction to 75%.
     IF RIPPR(K) > 75 THEN RIPPR(K) = 75
     MDEF(K) = MDEFM(L)
     MPR(K) = 11.77 + 13.98 * MBUFLTH(L) / MSLOPE(L)
     IF MPR(K) > 75 THEN MPR(K) = 75
```

```
     UDEF(K) = UDEFM(L)
     UPR(K) = 11.77 + 13.98 * UBUFLTH(L) / USLOPE(L)
     IF UPR(K) > 75 THEN UPR(K) = 75
     STMRATE(K) = STMRATM(L)
     COUNT = COUNT + 1
NEXT K
LOOP
CLOSE #19
'
'    MONTH(L) is the month number.
'    RIPDEFM(L) is the % of defecations deposited in the
'    riparian zone in MONTH(L).
'    RBUFLTH(L) is the buffer length of the riparian zone
'    in m.
'    RSLOPE(L) is the slope of the riparian zone, %.
'    MDEFM(L) is the % of defecations deposited in the
'    meadows in MONTH(L).
'    MBUFLTH(L) is the average buffer length of the
'    meadows in m.
'    MSLOPE(L) is the average slope of the meadows, %.
'    UDEFM(L) is the % of defecations deposited in the
'    uplands in MONTH(L).
'    UBUFLTH(L) is the average buffer length of the
'    uplands in m.
'    USLOPE(L) is the average slope of the uplands, %.
'    STMRATM(L) is the average daily number of
'    defecations per cow deposited in the stream in
'    MONTH(L).
'    RIPPR(K) is the daily % removal of bacterial
'    organisms from overland flow through riparian manure
'    deposits.
'    MPR(K) is the daily % removal of bacterial organisms
'    from overland flow through meadow manure deposits.
'    UPR(K) is the daily % removal of bacterial organisms
'    from overland flow through upland manure deposits.
'
CLS
PRINT "┌──────────────────────────────────────────────┐"
PRINT "│  Will You Import A File Of Pre-Determined    │"
PRINT "│ Stream Discharge And Runoff Rates? (Y or N)  │"
PRINT "└──────────────────────────────────────────────┘"
PRINT
140 INPUT TESTDIS$
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 190
IF (TESTDIS$ = "N" OR TESTDIS$ = "n") GOTO 150
PRINT
PRINT "Please Input Either Y or N"
PRINT
GOTO 140
'
```

```
'
'        Input Weather Information.
'
'
150 CLS
PRINT "                                                      "
PRINT "     Input Weather Information To Estimate            "
PRINT "       Stream Discharge And Runoff Rates              "
PRINT "    ___________________________________________       "
PRINT "    Enter (D) for Daily Weather Info. File.           "
PRINT "    Enter (M) for Monthly Weather Info. File.         "
PRINT "                                                      "
PRINT
160 INPUT TEST$
IF (TEST$ = "D" OR TEST$ = "d") GOTO 170
IF (TEST$ = "M" OR TEST$ = "m") GOTO 180
PRINT
PRINT "Please Input Either D or M"
PRINT
GOTO 160
'
'       Daily Weather File Input.
'
170 PRINT
INPUT "Name Of Weather File"; WNAME$
OPEN WNAME$ FOR INPUT AS #1
INPUT #1, N1$, N2$, N3$, N4$, N5$, N6$, N7$
K = 0
DO UNTIL EOF(1)
     K = K + 1
     IF K = 426 GOTO 200
     INPUT #1, DAY123(K), TMAX(K), TMIN(K), PRECIP(K),
DTE$
     LOOP
CLOSE #1
D2COUNT = K
'
'   Check to insure that weather file and cattle file
'   have the same number of days.
'
IF D2COUNT <> D1COUNT GOTO 210
'
'   Go to stream discharge and runoff rate
'   estimation subroutine of program.
'
GOTO 220
'
'
'   TMAX(K) is the max. temp. in degrees F for day K.
'   TMIN(K) is the min. temp. in degrees F for day K.
'   PRECIP(K) is the precipitation in inches for day K.
'   SNOW(K) is the snowpack in inches for day K.
```

```
'   DTE$ is the date.
'
'       Monthly Weather File Input.
'
180 PRINT
INPUT "Name Of Weather File"; WNAME$
OPEN WNAME$ FOR INPUT AS #2
INPUT #2, N1$, N2$, N3$, N4$, N5$, N6$
L = 0
COUNT = 1
DO UNTIL EOF(2)
     L = L + 1
     IF L = 15 GOTO 200
     INPUT #2, MONTH(L), TMAXM(L), TMINM(L), PRECIPM(L)
     KBEG = COUNT
     KEND = COUNT + NUMDAYS(L) - 1
     FOR K = KBEG TO KEND
          TMAX(K) = TMAXM(L)
          TMIN(K) = TMINM(L)
          PRECIP(K) = 0
          COUNT = COUNT + 1
     NEXT K
     PRECIP(9) = PRECIPM(L) / 3
     PRECIP(18) = PRECIPM(L) / 3
     PRECIP(27) = PRECIPM(L) / 3
LOOP
'
'   Distribute entire month's precipitation over 3 days.
'   TMAXM(L) is the max. temp. in degrees F for MONTH(L).
'   TMINM(L) is the min. temp. in degrees F for MONTH(L).
'   PRECIPM(L) is the precipitation in inches for
MONTH(L).
'
CLOSE #2
'
'   Go to stream discharge and runoff rate
'   estimation subroutine of program.
'
GOTO 220
'
'
'    +----------------------------------------------------+
'    |   Import File With Discharge And Runoff Rates.     |
'    +----------------------------------------------------+
'
190 PRINT : PRINT
PRINT "+--------------------------------+"
PRINT "|  Name Of Stream Discharge And  |"
PRINT "|  Runoff Rate File To Import?   |"
PRINT "+--------------------------------+"
PRINT
INPUT DISCHRG$
OPEN DISCHRG$ FOR INPUT AS #5
```

```
INPUT #5, N1$, N2$, N3$, N4$, N5$, N6$, N7$
K = 0
DO UNTIL EOF(5)
     K = K + 1
     IF K = 426 GOTO 200
     INPUT #5, DAY123(K), RUNOFF(K), RUNDPTH(K),
TOTFLOW(K)
LOOP
CLOSE #5
PRINT
INPUT "Base Stream Discharge Rate (m^3 / sec.) = "; BFLOW
'
'   Skip stream discharge and runoff rate
'   estimation subroutine of program.
'
GOTO 290
'
'   200 & 210 are error messages due to incorrect file
input.
'
200 CLS
PRINT "  Program Can Only Accept Up To 14 Months Of Daily"
PRINT "  Or Monthly Data.  Please Append Your File."
GOTO 999
'
210 CLS
PRINT "Number Of Days In Cattle File Does Not Equal The "
PRINT "Number Of Days In The Weather File.  Please Revise
File."
GOTO 999
'
'   Stream discharge and runoff rate
'   estimation subroutine of program.
'
220 CLS
PRINT " ┌──────────────────────────────────────┐ "
PRINT " │ Input Basin Drainage Area In km^2.   │ "
PRINT " └──────────────────────────────────────┘ "
PRINT
INPUT DA
'
CLS
PRINT "  ┌───────────────────────────────────────────┐ "
PRINT "  │ Input Stream Base Flow Rate In m^3/sec.   │ "
PRINT "  └───────────────────────────────────────────┘ "
PRINT
INPUT BFLOW
'
'   SHCOUNT is a counter to insure that the user does
'   not have to input variables FCPERGM, FSPERGM, FCWQENT,
'   FSWQENT, RRTEADJ, and KBSDOM a second time.
'
```

```
SHCOUNT = 0
'
230 SHCOUNT = SHCOUNT + 1
CLS
PRINT " ┌──────────────────────────────────────┐ "
PRINT " │ Input Upper Retention Parameter For  │ "
PRINT " │ Rainfall Runoff, SH (60 to 120 mm).  │ "
PRINT " └──────────────────────────────────────┘ "
PRINT
INPUT "SH = "; SH
'
'   Zero out all values for RUNOFF(K), RECFLOW(K) and
PRECIP(-4 TO 0).
'
FOR K = 0 TO D1COUNT
     RUNOFF(K) = 0
     RECFLOW(K) = 0
NEXT K
FOR K = -4 TO 0
     PRECIP(K) = 0
NEXT K
'
'    ┌──────────────────────────────────────────┐
'    │      Determine Daily Runoff Estimates.    │
'    └──────────────────────────────────────────┘
'
CLS
PRINT " ┌──────────────────────────────────────┐ "
PRINT " │ Input Initial Snowpack Depth In cm   │ "
PRINT " └──────────────────────────────────────┘ "
PRINT
INPUT SPI
SP = SPI
'
'   SP is the snowpack water content in mm.
'   SPI is the initial snowpack depth in cm.
'   Initial snowpack water content is approx. 10 %
'   of snowpack depth, and 1 mm is 10 % of 1 cm,
'   therefore SP = SPI.
'
'   Give default values for hydrologic variables.
'
TL = 0
TB = 0
V = .7
RECDAYS = 10
'
'   TL is the lower temperature limit for snow/rain
'   ratio in degrees C.
'   (If any temperature < TL all of the precipitation
'    will be snowfall).
```

```
'   TB is the base temp. for degree-day calculation in
'   degrees C.
'   V is the flow recession rate multiplier.
'   RECDAYS is the number of days for flow recession
'   calculation.
'
'   Give values pre-determined by calibration.
'
TH = 6.5
HK = .0072
HK1 = .0015
RT = 7.5
'
'   TH is the upper temperature limit for snow/rain
'   ratio in degrees C.
'   HK is the snowmelt factor due to temperature.
'   HK1 is the snowmelt factor due to rainfall.
'   RT is the retention parameter for snowmelt runoff in
'   mm.
'
CNH = 1000 / ((SH / 100) + 10)
CNL = SQR(200 * CNH - CNH ^ 2) - 1
SL = 100 * (1000 / CNL - 10)
'
'   CNH is the upper limit of the modified SCS curve
'   number.
'   CNL is the lower limit of the modified SCS curve
'   number.
'   SH is the upper retention parameter for
'   rainfall runoff in mm.
'   SL is the lower retention parameter for
'   rainfall runoff in mm.
'   SA is the actual retention parameter for
'   rainfall runoff in mm.
'
'
'   ┌──────────────────────────────────────────────────┐
'   │          Print Header Output to RUNOFF1$.        │
'   └──────────────────────────────────────────────────┘
'
'
CLS
PRINT "┌───────────────────────────────────────┐"
PRINT "│  Name Of 1st Output File For Runoff?  │"
PRINT "└───────────────────────────────────────┘"
PRINT
INPUT RUNOFF1$
OPEN RUNOFF1$ FOR OUTPUT AS #11
PRINT #11,
PRINT #11, USING "Filename: \          \"; RUNOFF1$
PRINT #11,
PRINT #11, USING "Weather File Used: \          \"; WNAME$
PRINT #11,
PRINT #11, USING "Drainage Area = #### km^2"; DA
```

```
PRINT #11,
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 232
PRINT #11, USING "SH = ### mm"; SH
GOTO 234
232 PRINT #11, USING "Runoff File Used: \          \";
DISCHRG$
234 PRINT #11,
PRINT #11,
PRINT #11, "DAY123 PCP  U   SP   SMT  SMR  SRD  SFLOW  SA
RRD RFLOW RDPTH RUNOFF"
PRINT #11, "-----------------------------------------------
---------------------"
'
FOR K = 1 TO D1COUNT
TMAXC = (TMAX(K) - 32) / 1.8
TMINC = (TMIN(K) - 32) / 1.8
'  Convert TMAX(K) & TMIN(K) from deg. F to deg. C.
'  AVETEMP is the average daily temp. in degrees C.
AVETEMP = (TMAXC + TMINC) / 2
U = (TH - TMAXC) / (TH - TL)
'  U is the snow/rain ratio.
IF TMAXC < TL THEN U = 1
IF TMAXC > TH THEN U = 0
'
'  Calculate Rainfall Runoff.
'
EPCP5 = PRECIP(K - 1) + PRECIP(K - 2) + PRECIP(K - 3) +
PRECIP(K - 4) + PRECIP(K - 5)
'  EPCP5 is the previous 5 days precipitation in inches.
PCP5 = EPCP5 * 25.4
PCP = PRECIP(K) * 25.4
'   Convert EPCP5 & PRECIP(K) from inches to mm.
SA = SH - PCP5
IF SA < SL THEN SA = SL
IF PCP > SL GOTO 240
RRD = 0
RFLOW = 0
GOTO 250
'
'  RRD is the rainfall runoff depth in mm over the
'  entire drainage area (DA).
'  RFLOW is the rainfall runoff volume in m^3 / sec
'  averaged over 24 hr.
'
240     RRD = (((PCP - U * PCP) - .2 * SA) ^ 2) / ((PCP -
U * PCP) + .8 * SA)
IF (PCP - U * PCP) < (.2 * SA) THEN RRD = 0
RFLOW = RRD * DA / 86.4
'
'   Calculate Snowmelt Runoff.
'
250     IF SP > 0 OR U * PCP > 0 THEN GOTO 260
```

```
SMT = 0
SMR = 0
SRD = 0
SFLOW = 0
GOTO 280
260     SP = SP + U * PCP
IF TMAXC < 0 THEN GOTO 270
DGHR85 = 0
T(0) = TMINC
FOR I = 1 TO 17
T(I) = TMAXC - ((TMAXC - TMINC) * (8.5 - I / 2) / 8.5)
TAVE = (T(I) + T(I - 1)) / 2
IF TAVE < 0 THEN TAVE = 0
DGHR85 = DGHR85 + TAVE * .5
NEXT I
TMN = TMINC
IF TMN < 0 THEN TMN = 0
DGDAY = 2 * DGHR85 + 7 * TMN
GOTO 275
270     DGDAY = 0
275     SMT = HK * DGDAY * SP
IF SMT > SP THEN SMT = SP
SMR = HK1 * (PCP - U * PCP) * SP * DGDAY
IF SMR > SP THEN SMR = SP
SM = SMR + SMT
IF SM > SP THEN
     SM = SP
     SMR = SP - SMT
END IF
'   Update snowpack depth.
SP = SP - SM
'   Set snowpack to 0 if depth is < 1 mm.
IF SP < 1 THEN SP = 0
SRD = SM - RT
IF SRD < 0 THEN SRD = 0
SFLOW = SRD * DA / 86.4
'
'   SP is the estimated depth of the snowpack in mm of
'   water.
'   SMT is the snowmelt due to thawing in mm of water.
'   SMR is the snowmelt due to rainfall in mm of water.
'   SM is the total snowmelt in mm of water.
'   SRD is the total snowmelt runoff depth in mm over
'   the entire drainage area (DA).
'   RT is the retention parameter for snowmelt runoff in
'   mm.
'   SFLOW is the total snowmelt runoff flowrate in m^3 /
'   sec. averaged over 24 hr.
'   DGHR85 is the degree-hours in degrees C per 8.5 hrs.
'   DGDAY  is the degree-day in degrees C per day.
'
280 RUNOFF(K) = RFLOW + SFLOW
```

```
RUNDPTH(K) = SRD + RRD
'
'   RUNOFF(K) is the total runoff flowrate in m^3 / sec.
'   averaged over 24 hr.
'   RUNDPTH(K) is the runoff depth in mm averaged
'   over 24 hr.
'
'
'   ┌──────────────────────────────────────────┐
'   │         Print Output to RUNOFF1$.        │
'   └──────────────────────────────────────────┘
'
PRINT #11, USING "#####  ## #.## ###   ##.# ##.# ##.#
###.## ### ##.# ###.## ##.# ###.##"; DAY123(K); PCP; U;
SP; SMT; SMR; SRD; SFLOW; SA; RRD; RFLOW; RUNDPTH(K);
RUNOFF(K)
'
'   Calculate Recession Flow For Ten Days.
'
FOR J = 1 TO RECDAYS
   RECFLOW(K + J) = RECFLOW(K + J) + (RUNOFF(K) * (V ^ J))
NEXT J
NEXT K
CLOSE #11
'
'
'   ┌──────────────────────────────────────────┐
'   │         Print Output to RUNOFF2$.        │
'   └──────────────────────────────────────────┘
'
CLS
PRINT "┌──────────────────────────────────────┐"
PRINT "│ Name Of 2nd Output File For Runoff?  │"
PRINT "└──────────────────────────────────────┘"
PRINT
INPUT RUNOFF2$
OPEN RUNOFF2$ FOR OUTPUT AS #31
PRINT #31,
PRINT #31, USING "Filename: \           \"; RUNOFF2$
PRINT #31,
PRINT #31, USING "Weather File Used: \          \"; WNAME$
PRINT #31,
PRINT #31, USING "Drainage Area = #### km^2 "; DA
PRINT #31,
'   Print different headings dependent upon whether a
'   stream discharge and runoff rate file was input.
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 284
PRINT #31, USING "SH = ### mm"; SH
PRINT #31,
GOTO 286
284 PRINT #31, USING "Runoff File Used: \          \";
DISCHRG$
PRINT #31,
```

```
286 PRINT #31,
PRINT #31, "DAY123    BFLOW      RUNOFF     RECFLOW
TOTFLOW"
PRINT #31, "----------------------------------------------
-----"
'
'
'   ┌──────────────────────────────────────────┐
'   │      Determine Daily Flow Estimates.     │
'   └──────────────────────────────────────────┘
'
FOR K = 1 TO D1COUNT
TOTFLOW(K) = BFLOW + RUNOFF(K) + RECFLOW(K)
PRINT #31, USING " #####     #.##      ###.##      ###.##
###.##"; DAY123(K); BFLOW; RUNOFF(K); RECFLOW(K);
TOTFLOW(K)
NEXT K
'
'   TOTFLOW(K) is the total flow rate in m^3 / sec.
'   for day K.
'   BFLOW is the base flow rate in m^3 / sec.
'   RUNOFF(K) is the runoff flow rate in m^3 / sec.
'   RECFLOW(K) is the recession from a runoff
'   event flow rate.
'
CLOSE #31
'
IF SHCOUNT > 1 THEN GOTO 330
'
'   SHCOUNT is a counter to insure that the user does
'   not have to input variables FCPERGM, FSPERGM, FCWQENT,
'   FSWQENT, RRTEADJ, and KBSDOM a second time.
'
'   End of stream discharge and runoff rate
'   estimation subroutine of program.
'
'   Input information which can be changed for
'   a sensitivity analysis.
'
290 CLS
PRINT " ┌────────────────────────────────────┐ "
PRINT " │     Input # Of FC Per Gram Of      │ "
PRINT " │  Manure (An Estimate Is 2.3E+05)   │ "
PRINT " └────────────────────────────────────┘ "
PRINT
INPUT FCPERGM
CLS
PRINT " ┌────────────────────────────────────┐ "
PRINT " │     Input # Of FS Per Gram Of      │ "
PRINT " │  Manure (An Estimate Is 1.3E+06)   │ "
PRINT " └────────────────────────────────────┘ "
PRINT
INPUT FSPERGM
```

```
CLS
PRINT "┌──────────────────────────────────────┐"
PRINT "│      Input FC Water Quality Of       │"
PRINT "│ Stream Headwaters (# FC / 100 ml)    │"
PRINT "└──────────────────────────────────────┘"
PRINT
INPUT FCWQENT
CLS
PRINT "┌──────────────────────────────────────┐"
PRINT "│      Input FS Water Quality Of       │"
PRINT "│ Stream Headwaters (# FS / 100 ml)    │"
PRINT "└──────────────────────────────────────┘"
PRINT
INPUT FSWQENT
CLS
PRINT "┌──────────────────────────────────────────────┐"
PRINT "│   Input Organism Release Rate Percentage     │"
PRINT "│ Under Base Flow Conditions (0.1% to 100%)    │"
PRINT "└──────────────────────────────────────────────┘"
PRINT
INPUT RRTEPCT
CLS
PRINT "┌───────────────────────────────────────┐"
PRINT "│ Input K Value For Bottom Sediment     │"
PRINT "│ Die-off Rate For FC (0.10 to 0.20)    │"
PRINT "└───────────────────────────────────────┘"
PRINT
INPUT KVALFC
CLS
PRINT "┌───────────────────────────────────────┐"
PRINT "│ Input K Value For Bottom Sediment     │"
PRINT "│ Die-off Rate For FS (0.05 to 0.15)    │"
PRINT "└───────────────────────────────────────┘"
PRINT
INPUT KVALFS
'   Convert from K values to daily die-off multiplier
'   values.
FCBSDOM = 1 - (10 ^ (-KVALFC))
FSBSDOM = 1 - (10 ^ (-KVALFS))
GOTO 330
'
'   The inputs below give the option of trying
'   different values for FCPERGM, FSPERGMG, RRATE,
'   and BSDOM for a sensitivity analysis.
'
300 CLS
PRINT "┌────────────────────────────────────┐"
PRINT "│     Input # Of FC Per Gram Of      │"
PRINT "│ Manure (An Estimate Is 2.3E+05)    │"
PRINT "└────────────────────────────────────┘"
PRINT
INPUT FCPERGM
```

```
CLS
PRINT "┌──────────────────────────────────────┐"
PRINT "│    Input # Of FS Per Gram Of         │"
PRINT "│ Manure (An Estimate Is 1.3E+06)      │"
PRINT "└──────────────────────────────────────┘"
PRINT
INPUT FSPERGM
GOTO 330
'
310 CLS
PRINT "┌───────────────────────────────────────────────┐"
PRINT "│  Input Organism Release Rate Percentage       │"
PRINT "│ Under Base Flow Conditions (0.1% to 100%)     │"
PRINT "└───────────────────────────────────────────────┘"
PRINT
INPUT RRTEPCT
GOTO 330
'
320 CLS
PRINT "┌─────────────────────────────────────────┐"
PRINT "│  Input K Value For Bottom Sediment      │"
PRINT "│  Die-off Rate For FC (0.10 to 0.20)     │"
PRINT "└─────────────────────────────────────────┘"
PRINT
INPUT KVALFC
CLS
PRINT "┌─────────────────────────────────────────┐"
PRINT "│  Input K Value For Bottom Sediment      │"
PRINT "│  Die-off Rate For FS (0.05 to 0.15)     │"
PRINT "└─────────────────────────────────────────┘"
PRINT
INPUT KVALFS
'   Convert from K values to daily die-off multiplier
'   values.
FCBSDOM = 1 - (10 ^ (-KVALFC))
FSBSDOM = 1 - (10 ^ (-KVALFS))
'
'
'        Print Header Output to FCWQ$.
'
330 CLS
PRINT "┌────────────────────────────────────────────────┐"
PRINT "│    Output File For FC Water Quality Info.?     │"
PRINT "└────────────────────────────────────────────────┘"
PRINT
INPUT FCWQ$
OPEN FCWQ$ FOR OUTPUT AS #33
PRINT #33,
PRINT #33, USING "Filename: \           \"; FCWQ$
PRINT #33,
PRINT #33, USING "Weather File Used: \          \"; WNAME$
PRINT #33,
```

```
PRINT #33, USING "Cattle File Used: \          \"; CATTLE$
PRINT #33,
PRINT #33, USING "Drainage Area = #### km^2"; DA
PRINT #33,
'   Print different headings dependent upon whether a
'   stream discharge and runoff rate file was input.
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 331
PRINT #33, USING "SH = ### mm"; SH
PRINT #33,
GOTO 332
331 PRINT #33, USING "Runoff File Used: \          \";
DISCHRG$
PRINT #33,
332 PRINT #33, USING "FC Per Gram Of Manure = ##.##^^^^ ";
FCPERGM
PRINT #33,
PRINT #33, USING "Background Water Quality = ### FC / 100
ml "; FCWQENT
PRINT #33,
PRINT #33, USING "Baseflow Rate = ##.## m^3 / sec."; BFLOW
PRINT #33,
PRINT #33, USING "% Of FC Released Under Baseflow
Conditions = ##.# % "; RRTEPCT
PRINT #33,
PRINT #33, USING "FC Bottom Sediment K Value = #.##";
KVALFC
PRINT #33,
PRINT #33,
PRINT #33, "DAY123  TFLOW RRATE  FCSTM     FCRNOFF   FCSED
FCREL     FCSDOFF    FCWQ"
PRINT #33, "-----------------------------------------------
-----------------------------"
'
'
'    ┌─────────────────────────────────────────────┐
'    │        Print Header Output to FSWQ$.        │
'    └─────────────────────────────────────────────┘
'
CLS
PRINT "┌──────────────────────────────────────────┐"
PRINT "│  Output File For FS Water Quality Info.? │"
PRINT "└──────────────────────────────────────────┘"
PRINT
INPUT FSWQ$
OPEN FSWQ$ FOR OUTPUT AS #34
PRINT #34,
PRINT #34, USING "Filename: \          \"; FSWQ$
PRINT #34,
PRINT #34, USING "Weather File Used: \          \"; WNAME$
PRINT #34,
PRINT #34, USING "Cattle File Used: \          \"; CATTLE$
PRINT #34,
PRINT #34, USING "Drainage Area = #### km^2 "; DA
```

```
PRINT #34,
'   Print different headings dependent upon whether a
'   stream discharge and runoff rate file was input.
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 333
PRINT #34, USING "SH = ### mm"; SH
PRINT #34,
GOTO 334
333 PRINT #34, USING "Runoff File Used: \          \";
DISCHRG$
PRINT #34,
334 PRINT #34, USING "FS Per Gram Of Manure = ##.##^^^^ ";
FSPERGM
PRINT #34,
PRINT #34, USING "Background Water Quality = ### FS / 100
ml "; FSWQENT
PRINT #34,
PRINT #34, USING "Baseflow Rate = ##.## m^3 / sec."; BFLOW
PRINT #34,
PRINT #34, USING "% Of FS Released Under Baseflow
Conditions = ##.# % "; RRTEPCT
PRINT #34,
PRINT #34, USING "FS Bottom Sediment K Value = #.##";
KVALFS
PRINT #34,
PRINT #34,
PRINT #34, "DAY123  TFLOW RRATE  FSSTM     FSRNOFF   FSSED
FSREL     FSSDOFF    FSWQ"
PRINT #34, "-----------------------------------------
------------------------------"
'
'   Initialize the # of organisms in the bottom sediment
to zero.
'
FCSED = 0
FSSED = 0
FCWDOM = .247
FSWDOM = .22
'
'   FCSED is the # of organisms in the bottom sediment.
'   FCWDOM is the daily organism die-off
'   multiplier in stream water.
'
'   RRATE is the release rate of organisms from the
'   bottom sediment under various discharge rates.
'   RRTEPCT is the % release rate of organisms from the
'   bottom sediment under base flow conditions.
'   RRTEMLT is the release rate multiplier.
'   QRATIO is the ratio of total flow to base flow.
'   QAUG is the ratio of augmented flow to base flow.
'   The augmented flow is due to runoff and recession
flows.
'
```

```
FOR K = 1 TO D1COUNT
QRATIO = TOTFLOW(K) / BFLOW
QAUG = QRATIO - 1
'   Ensure that QAUG is not less than zero to
'   prevent a data error.
IF QAUG < 0 THEN QAUG = 0
RRTEMLT = 1 + 1.7 * (QAUG ^ 2.8)
RRATE = (RRTEPCT / 100!) * RRTEMLT
'   Maximum release rate is 100 %
IF RRATE > 1! THEN RRATE = 1!
'
'
'      Determine Daily Input Of Organisms
'      Into Stream And On Land.
'
'
338     DFPRCAT = 11.75
GMPERDF = 1770.2
TOTDEF = DFPRCAT * NUMCAT(K)
STMDEF = STMRATE(K) * NUMCAT(K)
LANDDEF = TOTDEF - STMDEF
FCPERDF = FCPERGM * GMPERDF
FSPERDF = FSPERGM * GMPERDF
FCLAND(K) = LANDDEF * FCPERDF
FSLAND(K) = LANDDEF * FSPERDF
FCSTM = STMDEF * FCPERDF
FSSTM = STMDEF * FSPERDF
'
'   TOTDEF is the daily total number of defecations.
'   DFPRCAT is the daily # of defecations per animal.
'   NUMCAT(K) is the number of cattle on day K.
'   STMDEF is the total number of defecations
'   in the stream.
'   STMRATE(K) is the daily number of defecations in the
'   stream per cow.
'   LANDDEF is the total number of defecations
'   on the land.
'   FCPERDF is the # of organisms per defecation.
'   FCPERGM is the # of organisms per gram of manure.
'   GMPERDF is the # of grams of manure per defecation.
'   FCLAND(K) is the number of organisms on the
'   land in manure deposited on day K.
'   FCSTM is the daily number of organisms input
'   into the stream by the direct deposit of manure.
'
IF RUNOFF(K) > 0 GOTO 340
FCRNOFF = 0
FSRNOFF = 0
GOTO 370
'   Zero out FCRNOFF & FSRNOFF to eliminate
'   previous day's values.
340     FCRNOFF = 0
```

```
FSRNOFF = 0
'
'   Loop for runoff event.
'
FOR J = K - 15 TO K - 1
IF J < 2 THEN GOTO 350
TIME = K - J
IF TIME = 1 THEN TIME = 2
PCTFCRL = (10 ^ (8.068 - 2.416 * Log10(TIME))) / 1E+08
FCRLMLT = PCTFCRL * RUNDPTH(K)
'   Assume FSRLMLT = FCRLMLT
FSRLMLT = FCRLMLT
FCRLSUB = FCRLMLT * FCLAND(J)
FSRLSUB = FSRLMLT * FSLAND(J)
FCRIPRO = FCRLSUB * RIPDEF(J) / 100 * (100 - RIPPR(J)) /
100
FSRIPRO = FSRLSUB * RIPDEF(J) / 100 * (100 - RIPPR(J)) /
100
FCMRO = FCRLSUB * MDEF(J) / 100 * (100 - MPR(J)) / 100
FSMRO = FSRLSUB * MDEF(J) / 100 * (100 - MPR(J)) / 100
FCURO = FCRLSUB * UDEF(J) / 100 * (100 - UPR(J)) / 100
FSURO = FSRLSUB * UDEF(J) / 100 * (100 - UPR(J)) / 100
FCROSUB = FCRIPRO + FCMRO + FCURO
FSROSUB = FSRIPRO + FSMRO + FSURO
FCRNOFF = FCRNOFF + FCROSUB
FSRNOFF = FSRNOFF + FSROSUB
'   Update the # of organisms available for
'   future runoff events from manure deposited
'   on land on day J.
FCLAND(J) = FCLAND(J) - FCRLSUB
FSLAND(J) = FSLAND(J) - FSRLSUB
'   Make sure FCLAND(J) & FSLAND(J) are not
'   negative due to round off errors on large
'   numbers.
IF FCLAND(J) < 0 THEN FCLAND(J) = 0
IF FSLAND(J) < 0 THEN FSLAND(J) = 0
350     NEXT J
'
'   J is a day that is from 1 to 15 days prior to
'   the runoff event.
'   PCTFCRL is the % of organisms / 100 released
'   per mm of runoff per kg of manure deposited on
'   land I days prior to the runoff event of day K.
'   FCRLMLT is the % of organisms / 100 released
'   from runoff event on day K per kg of manure
'   deposited on land I days prior.
'   (PCTFCRL & FCRLMLT range from 0.0 to 1.0).
'   RUNDPTH(K) is the runoff depth in mm averaged
'   over 24 hr.
'   FCRLSUB is the # of organisms released into
'   the runoff from all fecal deposits on land
'   on day J.
```

```
'   FCRIPRO is the # of organisms reaching the
'   stream from runoff passing through manure
'   deposited on the riparian zone on day J.
'   RIPDEF(J) is the % of defecations on land
'   occurring on the riparian zone on day J.
'   RIPPR(J) is the % reduction of organisms
'   from runoff passing through riparian fecal
'   deposits from day J.
'   FCMRO is the # of organisms reaching the
'   stream from runoff passing through manure
'   deposited on the meadows on day J.
'   MDEF(J) is the % of defecations on land
'   occurring on the meadows on day J.
'   MPR(J) is the % reduction of organisms from
'   runoff passing through meadow fecal
'   deposits from day J.
'   FCURO is the # of organisms reaching the
'   stream from runoff passing through manure
'   deposited on the uplands on day J.
'   UDEF(J) is the % of defecations on land
'   occurring on the uplands on day J.
'   UPR(J) is the % reduction of organisms from
'   runoff passing through upland fecal
'   deposits from day J.
'   FCROSUB is the # of organisms reaching
'   stream from manure deposited on day J.
'   FCRNOFF is the total # of organisms
'   reaching stream from a runoff event from
'   all manure deposited on previous days.
'   FCLAND(J) is the number of organisms on the land
'   from manure deposited on day J.
'
'
'   | Determine Daily FC & FS Water Quality. |
'
'
370    FCREL = (FCSED + FCSTM + FCRNOFF) * RRATE
FSREL = (FSSED + FSSTM + FSRNOFF) * RRATE
FCSDSUB = FCSED + FCSTM + FCRNOFF - FCREL
FSSDSUB = FSSED + FSSTM + FSRNOFF - FSREL
'   Make sure FCSDSUB & FSSDSUB are not negative due
'   to round-off errors on large numbers.
IF FCSDSUB < 0 THEN FCSDSUB = 0
IF FSSDSUB < 0 THEN FSSDSUB = 0
FCSDOFF = FCSDSUB * FCBSDOM
FSSDOFF = FSSDSUB * FSBSDOM
FCSED = FCSDSUB - FCSDOFF
FSSED = FSSDSUB - FSSDOFF
FCWDOFF = FCREL * FCWDOM
FSWDOFF = FSREL * FSWDOM
FCWQ = FCWQENT + (FCREL - FCWDOFF) / (TOTFLOW(K) *
8.64E+08)
```

```
FSWQ = FSWQENT + (FSREL - FSWDOFF) / (TOTFLOW(K) *
8.64E+08)
'
'
'     ┌─────────────────────────────────────────┐
'     │        Print Output to FCWQ$.           │
'     └─────────────────────────────────────────┘
'
PRINT #33, USING "##### ###.## #.### ##.##^^^^ ##.##^^^^
##.##^^^^ ##.##^^^^ ##.##^^^^ #######"; DAY123(K);
TOTFLOW(K); RRATE; FCSTM; FCRNOFF; FCSED; FCREL; FCSDOFF;
FCWQ
'
'
'     ┌─────────────────────────────────────────┐
'     │        Print Output to FSWQ$.           │
'     └─────────────────────────────────────────┘
'
PRINT #34, USING "##### ###.## #.### ##.##^^^^ ##.##^^^^
##.##^^^^ ##.##^^^^ ##.##^^^^ #######"; DAY123(K);
TOTFLOW(K); RRATE; FSSTM; FSRNOFF; FSSED; FSREL; FSSDOFF;
FSWQ
'
NEXT K
CLOSE #33
CLOSE #34
'
'   FCREL is the daily # of organisms released from the
'   bottom sediment.
'   FCSED is the daily # of organisms in the bottom
'   sediment.
'   FCSDOFF is the daily total # of organisms that
'   die-off in the bottom sediment.
'   FCWDOFF is the daily total # of organisms that
'   die-off in the water.
'   FCWQ is the daily water quality in # of organisms
'   per 100 ml.
'
CLS
PRINT " ┌───────────────────────────────────────────────┐ "
PRINT " │          Calculations Are Complete.           │ "
PRINT " └───────────────────────────────────────────────┘ "
PRINT
PRINT " ┌───────────────────────────────────────────────┐ "
PRINT " │ Would You Like To Change The Values For The   │ "
PRINT " │ # Of FC & FS Per Gram Of Manure? (Y or N)     │ "
PRINT " └───────────────────────────────────────────────┘ "
PRINT
380 INPUT TEST$
IF (TEST$ = "Y" OR TEST$ = "y") GOTO 300
IF (TEST$ = "N" OR TEST$ = "n") GOTO 390
PRINT
PRINT "Please Input Either Y or N"
PRINT
```

```
GOTO 380
'
390 CLS
PRINT "┌──────────────────────────────────────────┐"
PRINT "│  Would You Like To Change The Value      │"
PRINT "│  For The % Of Organisms Released Under   │"
PRINT "│  Base Flow Conditions? (Y or N)          │"
PRINT "└──────────────────────────────────────────┘"
PRINT
400 INPUT TEST$
IF (TEST$ = "Y" OR TEST$ = "y") GOTO 310
IF (TEST$ = "N" OR TEST$ = "n") GOTO 410
PRINT
PRINT "Please Input Either Y or N"
PRINT
GOTO 400
410 CLS
PRINT "┌───────────────────────────────────────────────┐"
PRINT "│  Would You Like To Change The K Values For    │"
PRINT "│  The Bottom Sediment Die-Off Rate? (Y or N)   │"
PRINT "└───────────────────────────────────────────────┘"
PRINT
420 INPUT TEST$
IF (TEST$ = "Y" OR TEST$ = "y") GOTO 320
IF (TEST$ = "N" OR TEST$ = "n") GOTO 430
PRINT
PRINT "Please Input Either Y or N"
PRINT
GOTO 420
'
' Skip 430 if runoff & discharge rates were imported
' from a file since SH is used to estimate runoff rates.
'
IF (TESTDIS$ = "Y" OR TESTDIS$ = "y") GOTO 999
'
430 CLS
PRINT "┌───────────────────────────────────────────────┐"
PRINT "│       Change The Value For SH? (Y or N)       │"
PRINT "└───────────────────────────────────────────────┘"
PRINT
440 INPUT TEST$
IF (TEST$ = "Y" OR TEST$ = "y") GOTO 230
IF (TEST$ = "N" OR TEST$ = "n") GOTO 999
PRINT
PRINT "Please Input Either Y or N"
PRINT
GOTO 440
'
999 END
```

```
FUNCTION Log10 (X) STATIC
Log10 = LOG(X) / LOG(10#)
'   # - Designates double precision value for 15 to 16
'   digits of accuracy.
END FUNCTION
```

APPENDIX F

OPERATION OF COMPUTER PROGRAM

OPERATION OF COMPUTER PROGRAM

File Input

The model can determine the daily water quality values for up to fourteen months of data. Fourteen months of data were used to ensure that the water quality estimations will accurately reflect the numbers of organisms in the bottom sediment for at least one year. The initial number of organisms in the bottom sediment was set to zero since prior cattle activity to day one was unknown. Since bottom sediments serve as a reservoir for bacteria (Kunkle, 1970b; Van Donsel and Geldreich, 1971; Stephenson and Rychert, 1982), the assumption of zero organisms in the bottom sediment on day one could be too low. This could yield lower bacterial concentration estimations than those obtained if the initial concentration in the bottom sediment was known. Estimated bottom sediment levels using the assumption of zero organisms on day one need less than two months to equal bottom sediment levels obtained with a known initial concentration.

Since a large amount of data is input, the model lets the user input data from files created with a spreadsheet. The output files can be imported into a spreadsheet for data analysis.

Creation of Input Files

Data files were created using the spreadsheet from Integrated 7, written by Mosaic Software. The Integrated 7 spreadsheet uses the same process to print a data table to a file as Lotus 1-2-3, a spreadsheet written by Lotus Development. Most personal computer spreadsheets have this capability.

Monthly to Daily Conversion File

The program gives the option of importing either monthly or daily data. Since some files may be in the monthly format and others in the daily format, a conversion file was developed to enable the program to assign monthly data to each day of the month. For example, an input of 100 cattle grazing in the pasture during January would be converted to 100 cattle grazing the pasture for each day of January. A conversion file used for data in the 1987 grazing season was named, "87CONVT.PRN." It is shown in Table 20.

Table 20. Input file to convert monthly data to daily data.

File: 87CONVT.PRN

1987 Monthly to Daily
Conversion File
for Grazing Season.

Grazing Month Number	1st Day of Month	Number of Days in Month	Date
1	31778	31	01-Jan-87
********Continuing	Through*********		
14	32174	29	01-Feb-88

The first ten lines are title lines which give information about the file. They are input into the program as ten string variables. The data in the first column is the grazing month number, while the second column shows the corresponding date code for the first day of each month. The variable assigned to column two was DAY123B(L) for each month L in column one. The date code for each date can be obtained by the using the @DATE function. An example for this file would be @DATE(88,02,01) which yields the date's value of 32174 for February 1, 1988. Column three lists the number of days in each month. The variable assigned to it was NUMDAYS(L). Column four copied the date numbers of column two over and then formatted them as a date using the /FR (format a range) command sequence for date identification purposes. Column four was input as a string variable in the program. After input of the variables, the day number in spreadsheet code for each day of the month was calculated by adding the number of days after the first day to the code value for the first day.

File for Cattle Numbers in the Pasture

The file to import for the cattle numbers can be in monthly or daily format. The program prompts the user for the format of the input file. The file listed in Table 21 named "87CATS.PRN" was one of the daily cattle number files used in the program.

Table 21. Input file for numbers of cattle in pasture.

File: 87CATS.PRN

Numbers of Cattle at Bear Creek

Note: Cattle no.'s from prev. 2 months before March are Incl. to calculate bacteria no.'s in stream sediment.

DAY	CATTLE#	DATE
31778	500	01-Jan-87
31779	500	02-Jan-87
Continuing Through		
32201	300	28-Feb-88
32202	300	29-Feb-88

The first nine lines are the title block of the file and are input as a string variable for each line. Column one is the day number that the spreadsheet assigns to that date, column two is the daily number of cattle in the pasture, and the third column is the date. The dates in column three were copied from the date numbers of column one and then formatted into the date format. Columns one and two are input as numeric variables and column three as a string variable. The monthly input file has the same format as the daily input file. The monthly to daily conversion file converts the monthly data to daily values.

File for Fecal Distribution Pattern in Pasture

The data collected for this input file was taken from Larsen et al., 1989. The relative total number of defecations for each zone were calculated by multiplying the manure transects for each zone by the estimated land area in map units. The land area was estimated by plotting the map of Figure 20 onto engineering computation paper (which has 100 squares per square inch), and counting the number of squares in each zone. The percentage of the total number of defecations on land that each zone received was calculated by dividing the number of defecations in the zone by the total number of defecations. Table 22 show a portion of the spreadsheet used to calculate these values. The values from the spreadsheet were then printed to a file named MANURE.PRN. The width of the file is greater than the margins of this paper allow, so it is listed as two sides of the file, which if placed side by side would form the file. The left side of the file is shown in Table 23a, and the right side in Table 23b.

Table 22. Spreadsheet used to estimate winter manure distribution pattern by grazing cattle. (Larsen, 1989)

Winter 1988 Manure Transect Data

Site	Area (squares)	Distance to Water Vert. (m)	Horz. (m)	Total (m)	Slope (%)
Riparian Zones					
2	13	0.5	5	5.0	1.0
6	3	0.5	5	5.0	1.0
7	3	0.5	5	5.0	1.0
8	14	0.5	5	5.0	1.0
	Weighted Averages =			5.0	1.0
Meadow Zones					
1	21	6	120	120.1	3.0
11	8	12	240	240.3	5.0
17	4	6	120	120.1	3.0
35	16	4	120	120.1	3.0
	Weighted Averages =			121.6	3.0
Upland Zones					
3	40	40	1302	1302.6	9.1
4	6	18	198	198.8	10.6
5	46	41	433	434.9	12.5
9	16	21	1271	1271.2	11.4
10	8	15	228	228.5	13.5
12	17	91	1080	1083.8	9.2
13	8	103	624	632.4	3.9
14	7	61	480	483.9	7.5
15	11	97	420	431.1	8.5
16	9	18	222	222.7	6.7
19	16	109	864	870.8	4.0
20	9	193	1068	1085.3	2.0
21	2	73	516	521.1	28.2
22	10	106	762	769.3	6.0
23	2.5	73	552	556.8	31.7
24	4	52	486	488.8	32.6
25	25	40	1593	1593.5	10.7
26	20	180	1081	1095.9	18.0
27	10	106	708	715.9	10.2
29	10	219	1573	1588.2	14.8
30	6	158	1081	1092.5	32.4
31	8	64	468	472.4	30.6
32	3	88	240	255.6	38.0
33	24	256	1321	1345.6	29.0
34	5	158	864	878.3	39.0
36	17	135	1075	1083.4	9.5
	Weighted Averages =			870.3	10.8

Table 22. Manure distribution data (Continued).

Site	W1988 Transect (ave)	W1988 Transect * Area, Chip-Squares per 21 m^2	% Of Total Defecations	Defecations Subtotal
Riparian Zones				
2	3.06	39.8	5.3	
6	5.02	15.1	2.0	
7	8.80	26.4	3.5	
8	6.80	95.2	12.6	
% Of Defecations In Riparian Zone =				23.3 %
Meadow Zones				
1	12.74	267.5	35.4	
11	0.44	3.5	0.5	
17	3.62	14.5	1.9	
35	0.94	15.0	2.0	
% Of Defecations In Meadow Zones =				39.8 %
Upland Zones				
3	2.48	99.2	13.1	
4	2.24	13.4	1.8	
5	2.30	105.8	14.0	
9	1.72	27.5	3.6	
10	0.24	1.9	0.3	
12	0.12	2.0	0.3	
13	0.42	3.4	0.4	
14	0.44	3.1	0.4	
15	0.22	2.4	0.3	
16	0.40	3.6	0.5	
19	0.00	0.0	0.0	
20	0.00	0.0	0.0	
21	0.06	0.1	0.0	
22	0.10	1.0	0.1	
23	0.06	0.2	0.0	
24	0.12	0.5	0.1	
25	0.44	11.0	1.5	
26	0.00	0.0	0.0	
27	0.10	1.0	0.1	
29	0.00	0.0	0.0	
30	0.00	0.0	0.0	
31	0.12	1.0	0.1	
32	0.04	0.1	0.0	
33	0.00	0.0	0.0	
34	0.02	0.1	0.0	
36	0.10	1.7	0.2	
	Sum =	756.0	100.0	
% Of Defecations In Upland Zones =				36.9 %
			Total =	100.0 %

Figure 20. Map of Pasture used to Calculate Percentages of Manure Placement. (Larsen, 1989)

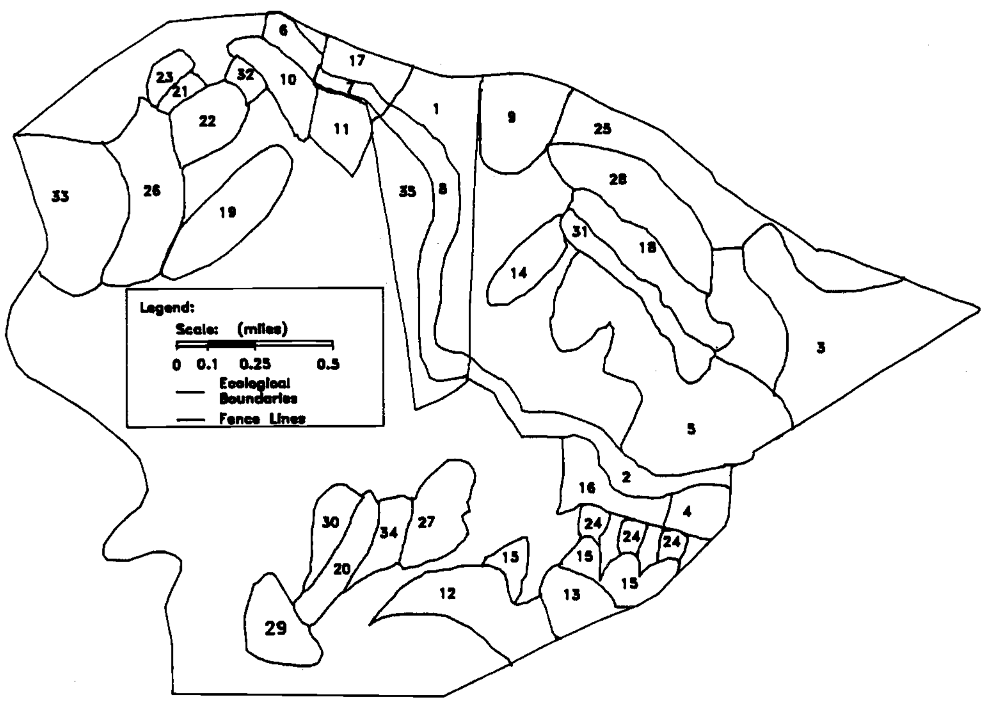


Table 23a. Left side of MANURE.PRN.

File: MANURE.PRN

This file lists manure placement information.

	Riparian Zone			*******Meadows*****		
Month	% of Total Def.	Buffer Strip Dist. From Water	Slope	% of Total Def.	Buffer Strip Dist. From Water	Slope
1	23.3	5.0	2.0	39.8	121.6	3.0
************Continuing Through************						
14	23.3	5.0	2.0	39.8	121.6	3.0

Table 23b. Right side of MANURE.PRN.

****Uplands*****			
% of Total Def.	Buffer Strip Dist. From Water	Slope	Number of Defs. Dep. in Stream Per Cow
36.9	870.3	10.8	0.17
****Continuing Through****			
36.9	870.3	10.8	0.17

The first twelve lines of the file form the title block and are input as a string variable for each line. Column one lists the month number, while column two lists the percentage of total defecations occurring in the riparian zone. Column three lists the average distance from the riparian zone to the stream in meters. Column four shows the average slope of the riparian zone. Columns five through seven list the same variables for the meadow zone as those of the riparian zone. Columns eight through ten list the same variables for the upland region as those of the riparian zone. Column eleven is the monthly average of the number of defecations deposited in the stream per cow per day. Since all the data is in monthly format, the monthly to daily conversion file is used to convert to daily data.

File for Daily Stream Discharge and Runoff Values

Following input of the manure placement file, the program prompts the user to see if they want to input their own file of daily runoff and stream discharge values. The user can create a file from stream data provided by the U.S.G.S., and input daily runoff amounts from a hydrology program. The first seven lines of the data file are for the title block of the data file, thus the numerical data should begin on line number 8. The program will then input the spreadsheet value for each day, the daily runoff depth in mm, and the daily average stream discharge in m^3/sec.

Weather Information File

If the user does not want to import their own data file of daily runoff and stream discharge information, the program can generate its own values. The user will need to import a weather information file for the subroutine that generates daily values for stream discharge and runoff.

The program prompts the user, asking if the weather file is in daily or monthly format. A daily weather file for Brothers, Oregon used with the program is shown in Table 24.

Table 24. Weather input file.

File: WEATH87.PRN

This file contains the weather conditions for
Brothers Oregon from 1-1-87 to 2-29-88.

I7DATE	TMAX	TMIN	PRECIP	DATE
31778	38	27	0.14	01-Jan-87
31779	36	18	0.03	02-Jan-87
**************Continuing Through***************				
32201	62	28	0.00	28-Feb-88
32202	52	22	0.02	29-Feb-88

The program reads in an entire line as a single string variable. In the title block that there is no comma between "Brothers" and "Oregon" since the program interprets any comma as a carriage return. This ensures that the program will read in the seven lines of the title block as seven string variables.

For weather files with daily information, the program inputs the spreadsheet day value, the maximum temperature in degrees F, the minimum temperature in degrees F, and the precipitation in inches. The monthly weather file inputs the spreadsheet day value for the first day of each month. Weather information can be obtained from the climatological data of the nearest weather station to the pasture. The climatological data of each state in the United States is published by the National Weather Service.

Hydrology Component of Model

Input of Variables

Heydarpour, 1988 developed the equations used in the subroutine to calculate daily runoff and stream discharge values. The variables input by the user are the basin drainage area in km^2, the stream base flow in m^3/sec., the upper retention parameter for rainfall runoff in mm, and the depth of the snowpack on day one in cm. The upper retention parameter is the value for rainfall retention under dry antecedent moisture conditions. The program gives a suggested range of 60 to 120 mm as an input value.

The variables held constant in the program are TL, TB, V, RECDAYS, TH, HK, HK1, and RT, with the definitions of these variables shown below:

TL is the lower temperature limit for snow/rain ratio in degrees C. (If any temperature < TL all precipitation will be snowfall).

TB is the base temperature for degree-day calculation in degrees C.

V is the flow recession rate.

RECDAYS is the number of days for flow recession calculation.

TH is the upper temperature limit for snow/rain ratio in degrees C.

HK is the snowmelt factor for thawing of the snowpack.

HK1 is the snowmelt factor for rainfall on the snowpack.

RT is the retention parameter for snowmelt runoff in mm.

Output Files for Runoff Information

The program creates two files for output of the variables used to determine the daily runoff flows and the daily total stream flows. The program prompts the user to input the name for each file.

The first file lists for each day the day number, the precipitation in mm, the snow/rain ratio, the snowpack water content in mm, the snowmelt from thawing in mm of water, the snowmelt from rainfall in mm of water, the snowmelt runoff depth in mm, the snowmelt runoff flow in m^3/sec., the rainfall retention parameter in mm, the rainfall runoff depth in mm, the rainfall runoff flow in m^3/sec., the total runoff depth in mm, and the total runoff flow in m^3/sec. The second file lists for each day the day number, the base flow, the runoff flow, the recession flow, and the total flow; all flows are in m^3/sec.

Calculation of Water Quality Values

Variables Input by the User

The program prompts the user to input variables that can be changed after the program has calculated the water quality values. This allows the user to investigate the sensitivity of the water quality to each of the input variables. The program loops back to the input subroutine without having to import the previous files. These variables are the number of FC and FS per gram of manure, the release rate of the organisms from the stream bottom sediment under base flow conditions, and the K values to determine the die-off rate in the bottom sediment for FC and FS. Variables that remain constant after input into the program are the FC & FS concentrations of the stream entering into the pasture.

Output of Results for Water Quality

The program creates two files for the output of the water quality estimates of the program. The first file is for FC information and the second file is for FS information. The user is prompted to input the name for each output file. Both files are identical except that one is for the FC results and the other is for the FS results. The title block for each output file lists the name of the output file, the names of the input files used, the values of the input variables used, and the header for each value estimated by the program. The values for each day are listed in the following order: The spreadsheet day number, the daily total flow in m^3/sec., the daily release rate of organisms from the bottom sediment, the daily number of organisms input into the stream from direct deposit of manure, the daily number of organisms input into the stream from overland runoff, the daily number of organisms in the stream bottom sediment, the daily number of organisms released from the bottom sediment, the daily number of organisms that died-off in the bottom sediment, and the daily water quality in numbers of organisms per 100 ml.

Prompts to Change Variables for a Sensitivity Analysis

Four different prompts appear at the end of the program which enable the user to test different values for the variables to run a sensitivity analysis. The program is designed so that the user can change only one set of values for each program run. The four variable sets that can be changed are the number of FC & FS per gram of manure, the percentage of FC & FS released from the bottom sediment under base flow conditions, the FC & FS K values for the bottom sediment, and the upper rainfall retention parameter in mm. If the user does not desire to input any new values for the variables, the program ends.

APPENDIX G

DATA FROM RESERVOIR RELEASE STUDY

Table 25. Data from reservoir release study.
(Moore et al., 1988b)

Fecal Coliform Data:

Stream Discharge, l / sec.	Ratio Of Increased Q To Base Flow	FC per 100 ml	Average FC Released per sec.	Ratio Of Increase In FC/sec. To Base Flow
30	0.0	200	6.00×10^4	0.00
75	1.5	500	3.75×10^5	5.25
150	4.0	3180	4.77×10^6	78.50

Fecal Streptococcus Data:

Stream Discharge, l / sec.	Ratio Of Increased Q To Base Flow	FS per 100 ml	Average FS Released per sec.	Ratio Of Increase In FS/sec. To Base Flow
30	0.0	410	1.23×10^5	0.00
75	1.5	1028	7.71×10^5	5.27
150	4.0	7220	1.08×10^7	86.80