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University of Alberta

North Saskatchewan River Dry Weather Contaminant Study

By

Kevin R. McCullum ©

A Thesis
Submitted to the Faculty of Graduate Studies and Research in Partial Fulfillment of the Requirements for the Degree of Master of Science

In

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Department of Civil and Environmental Engineering

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Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **North Saskatchewan River Dry Weather Contaminant Study** submitted by **Kevin R. McCullum** in partial fulfillment of the requirements for the degree of **Master of Science** in Environmental Engineering.

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The North Saskatchewan River head waters start at a glacier, which flows through the heart of the City of Edmonton. The river is the primary source of drinking water for the City of Edmonton and many surrounding communities. There are two water treatment plants built on the rivers banks, the first plant, E.L. Smith draws its raw water upstream of Edmonton's influence. Whereas the second plant, Rossdale, draws its raw water downstream of approximately 85 City storm sewers and 10 creeks. This study entailed a detailed examination of the cause of poorer raw water quality at Rossdale, compared to E.L. Smith. The objective was to study the influence during dry weather, for if the dry weather loading was found, this would account for a continuous source of contaminants to the river, which is evident at Rossdale. Thus during a two week dry period in August of 1996, the river was sampled in 108 pre-selected locations between the two water treatment plants. These locations were broken into ten cross-sections, with nine sampling locations at each cross-section. These samples were taken to the University laboratory and analyzed for ammonia, total and fecal coliforms.

The study also included a detailed sounding of the river bottom, in order to model and more accurately predict the source of contaminant loading to the river. With the sampling results and the soundings, the TRSMIX model was used to predict the contaminant load to the river, in each of the ten pre-selected cross sections. From the results the coliform levels recorded between E.L. Smith and Rossdale was equivalent to Clover Bar's discharge, before UV treatment (Edmonton's wastewater treatment plant) and as a result is a significant source of coliforms to the North Saskatchewan River.

I would like to thank my advisor Steve Stanley for all his help both in the field and the running of the model. I would also like to thank the sponsor of this project, Aqualta, and in particular Audrey Cudrak who gave her assistance when needed.

In the sampling and analysis I would like to thank the City of Edmonton Firefighters (Rossdale Station) for allowing us to load our boat at their emergency launch. My summer students Jeff Davies and Cindy Robinson for collecting samples and assisting me in running the equipment while on the river. In preparing the sample bottles and assisting me during the analysis I would like to specially thank Carla Schumacher for spending the long hours in the lab helping out. I would also like to thank all those who were able to assist in the analysis of the samples; Maria Demeter, Karen Emde, Ahmed Gamal El-Din, Mohamed Gamal El-Din, and Gary Solonynko.

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List of Figures

E_x, E_y, E_z	longitudinal, vertical, and transverse mixing coefficients, m^2/s
β	dimensionless mixing coefficient
l	length scale, m
u^*	shear velocity, m/s
g	gravitational constant, $9.81 m/s^2$
R	hydraulic radius, m
s	channel slope, m/m
w	channel width, m
h	channel depth, m
C	concentration
$C_{o,n}$	initial concentration at station, n
$C_{b,n}$	background concentration at station, n
C_∞	concentration when completely mixed
C'	dimensionless concentration (C/C_∞)
t	time, day
x, y, z	direction components in the river
u_x, u_y, u_z	velocity components in the x, y, z direction, m/s
m_x, m_y, m_z	natural coordinate coefficients, degree of bending in rivers
q	discharge, m^3/s
q_c	cumulative discharge, m^3/s
η	dimensionless transverse location
α	pollutant growth or decay term
β_1	magnitude of source-sink term
n	number of wrong connections (%)
Q_F	average volume of foul sewage passes to sewage works per year
B_F	average BOD concentration of foul sewage
L_F	average BOD load of foul sewage
Q_S	average volume of surface water from impervious area per year
B_S	average BOD concentration of surface water
L_S	average BOD load of surface water
dL	% change in BOD load to watercourse
E	overall removal efficiency at national sewage works, assumed constant
K	volume of surface water per year / volume of foul sewage per year
Q_S	volume of surface water per year
Q_F	volume of foul sewage per year
A	contributing area, ha
C_R	run-off coefficient
I	annual precipitation, mm
P	population
G	dry weather flow, L/(person•d)
N	number of organisms after time t
k	decay coefficient, day^{-1}
N_o	number of organisms at time zero

The Romans were the first to construct large underground drains, able to convey rainfall to the nearest water source. This system eventually expanded throughout Europe and North America and, with the lack of modern treatment methods for sanitary wastes, it was made law to discharge sewage to the storm system (OECD, 1986). Early in the 20th century people in cities began realizing that discharging untreated sewage was degrading their water supplies to a dangerous level. Thus new underground systems were developed for transporting sewage and storm water. For the last fifty years separate sewer systems have been used. One system transports sewage to a treatment system which has greatly reduced concerns about receiving water contamination. However it has been the practice to discharge storm water through the storm sewer system directly to receiving water with no treatment. Since these separate sewer systems have been used concern has been growing, regarding the quality of storm water discharged, which has resulted in numerous studies and new regulations.

Specifically, this study has focused on the storm water inputs to the North Saskatchewan River, in Edmonton, Alberta, Canada (see Figure 1). The primary portion of this study concentrated on a 17.5 km stretch between the two water treatment plants in Edmonton. E.L. Smith Water Treatment Plant (WTP) upstream of the City of Edmonton and Rossdale WTP located in the centre of the city downstream of 85 storm sewer outfalls. There have been a number of studies completed on the Edmonton reach of the North Saskatchewan River over the past 15 years and, each one of them tended to conclude that Rossdale's raw water has consistently been of poorer quality than E.L. Smith's. Previous studies have found a variety of contaminant inputs into the North Saskatchewan River, such as agricultural and illegal dumping, but the most predominant was the storm sewer discharges located between the two water treatment plants. A substantial amount of work has been done to study the contaminants contributed by the storm sewers during wet weather flows, but little has been done for dry weather. Thus a study was proposed to evaluate the water quality between E.L. Smith and Rossdale during dry weather flow.

Figure 1. Location of the North Saskatchewan River

With the water quality at the Rossdale WTP being consistently of poorer quality compared to the E.L. Smith WTP there is a need to identify the reason why. Of interest, is that the difference in water quality occurs year round and is not just associated with runoff events. However, the exact sources of contaminants between the two plants have not been determined. This study was initiated in an attempt to determine the sources of the contaminants. This is the first step in improving raw water quality at the Rossdale WTP which will ultimately reduce the risk associated with drinking water from that facility. Contaminants can enter the storm sewer systems either through runoff or directly through illicit connections with the sanitary sewer system. Contaminants from runoff occur during runoff events while direct sources of contaminants from illicit connections tend to occur on a continuous basis. To date, most studies have focused on runoff or wet weather flow conditions. During wet weather conditions the contributions due to illicit conditions may be relatively small. However, as illicit connections discharge continuously, the overall contribution to contaminant loading in a water body may be significant. Although it has been shown in other communities that illicit connections can be a significant source of contaminants, there was little information available for Edmonton.

Within the City of Edmonton there are 217 separate storm sewer outfalls (not including 22 combined sewer outfalls) which discharge to the North Saskatchewan River. In the reach between E.L. Smith and Rossdale there are a total of 85 outfalls, none of which are combined sewers. A preliminary study by Stanley (1996) found that considering only surface runoff (wet weather flow), storm water contributes 1.7% of the coliform loading on the river. When comparing water qualities at E.L. Smith and Rossdale it was estimated that with a combination of illicit connections, broken pipes, and non-functioning cross connections the storm sewers may contribute as much as 20.6% of the coliform loading. This level of pathogen loading may be equivalent to the treated discharge of the Gold Bar Wastewater Treatment Plant in Edmonton. That work was only preliminary in nature and further investigation was required to confirm these results. Based on that work, combined sewer overflows were recognized as a pollution source during wet weather flow, while sewer cross connections and illicit connections were identified as a major source of pollution during dry weather flow.

In 1988, the Rossdale Water Treatment Plant and the City of Edmonton went through an exercise to relocate their intake upstream to an area of higher water quality. This move would have cost an estimated 85 million dollars which some public leaders and people of Edmonton were opposed to (Reid Crowther, 1990). In turn, they left the intake in its present location and have had to pay other costs resulting from treatment of the raw water to an acceptable level. In 1996, Rossdale underwent the movement of their intake again to a position closer to the center/left bank, downstream of the current intake. Water quality at this location is one area addressed in this study.

1.2 Objectives

The objective of this project was river water quality improvement and determination of the effects on water quality due to storm sewer discharges during dry weather flow. The primary object of this study was to locate the main sources of microbial contaminant entering the North Saskatchewan River upstream of the Rossdale WTP. Two biological indicators were used for analysis, total coliforms and fecal coliforms, as well as conducting ammonia tests on selected areas of the river. The contaminant sources were evaluated so as to determine main outfall problems. The river was sampled at a number of points between E.L. Smith and Rossdale in an attempt to identify the sources of contamination. The TRSMIX model was used to evaluate these effects based on different dry weather river flows.

When cities like Edmonton use the same surface water for discharging effluents and drinking, it is in the best interest of the consumers to locate the raw water intake in an area least effected by the discharges. With the 85 identified storm sewers contributing chemical and biological wastes to the river it is not surprising that Rossdale consistently has poorer introduced or present in the North Saskatchewan River, the water consumers have been made more aware of their drinking water health effects.

By locating the problem sites and potential sources of pathogenic contamination that are directly affecting Rossdale's raw water quality, corrective actions can be initiated which would potentially reduce the flow of contaminants into the North Saskatchewan River. By reducing the amount of pathogens that are entering the North Saskatchewan River, the Rossdale WTP will find better raw water conditions and the water will be better suited for the recreational users of the river. Ice cover samples are currently beyond the scope of this study but the problem may still persist in the iced-up North Saskatchewan River.

1.3 Expected Results

It was believed that one or more outfalls would be found generating a large percentage of the total waste flowing out of the storm sewers upstream of Rossdale. It was also hoped that the study would show the relationship of the Rossdale intake to the dry weather flow plumes of the discharges from the storm water system. The results may identify a main source for there are several places where the bacteria could be originating from during dry weather (illegal dumping, cross-connections, industrial flushing).

2.1 North Saskatchewan River

Flowing easterly, the North Saskatchewan River begins in the Colombia Icefields at the Saskatchewan glacier, which comprises 5% of the winter flow and 50% of the summer flow (see Figure 1). The other main contributors to the North Saskatchewan River are the Clearwater, Brazeau and Nordegg rivers comprising 6%, 36%, and <1% of the winter flow respectively, and 13%, 30%, and 3% of the summer flow respectively (Hrudey, 1986). The glacial melt water is of high quality but the other tributaries flow through muskeg and forested areas, picking up decaying matter and organics. There are two dams located upstream of Edmonton on the North Saskatchewan; Brazeau constructed in 1963 and Big Horn constructed in 1972. Since the construction of these dams, the river flow through Edmonton has been maintained at a rather consistent flow for each season, eliminating the extensive shifts in flow prior to the operation of the dams.

The North Saskatchewan River is the primary source of Edmonton's drinking water supply. The watershed is quite extensive, comprising an area approximately 27000 km^2 upstream of Edmonton. Located in the southwest edge of the city, the E.L. Smith Water Treatment Plant (WTP) is the first of Edmonton's two treatment plants that draw from the river's raw water. At a distance of seventeen and a half kilometres downstream from E.L. Smith the second water treatment plant, Rossdale WTP is found. In this short distance, the water quality, particularly the total coliform levels, has been found to increase by up to two orders of magnitude (Mitchell, 1994a; Toxcon, 1992).

2.1.1 Features of the North Saskatchewan River

The surface of the North Saskatchewan River is frozen over for approximately 4.5 months out of the year, with freeze up beginning in December, and break-up around April. Open channels occur throughout the city due to ice flows jamming on structures and various discharges.

The discharge of the river varies with winter flow ranging from 95 m^3/s to 245 m^3/s, while summer flows average 210 m^3/s. Since operation of the hydroelectric dams, TransAlta Utilities attempts to maintain somewhere between 90 m^3/s and 110 m^3/s flow at Edmonton during the winter months (Ray & Dykema, 1991). Prior to the construction of the dams, the river flow fluctuated quite substantially throughout the seasons.

The river basin is mainly underlain by Paleozoic and Mesozoic strata, with a considerable depth of glacial till on top. This till is very erodable, as noted by the large and steep river valley walls on outside bends of the river. The river bottom is mainly gravel to rubble. Near the banks, the bottom is more sand and mud mix (Paterson & Nursall, 1975; Rutter & Thomson, 1982).

2.2 Storm Water

2.2.1 Storm Water Systems

There are two primary types of sewer and storm systems in use today; separate storm and sanitary systems. There are however components of the two systems, which include combined systems and partially combined systems as part of sanitary systems, and interconnected storm systems as part of the separate storm systems (summarized in Table 1). The separate storm sewers are designed to convey storm water, normally untreated, to the nearest body of water for discharge. The interconnected storm systems are built as relief's to the sanitary system, either intentionally or accidentally (illicit connections). Separate sanitary sewers are designed to convey sewage from households and industry to a wastewater treatment plant where the contaminants are reduced and the effluent discharged to the water body. The combined sewers are designed to carry sanitary sewage to a treatment plant during dry weather and light rains. During heavy rains, the combined sewer tends to mix the sewage quite rapidly with the incoming rain water and this mixture is discharged untreated, through an overflow to the water body.

(Modified from Gore and Storrie Ltd., 1978)

	Combined Sewers	Partially Combined	Interconnected Storm & Sanitary	Separate Storm System	Separate Sanitary System
Flow composition during peak flow	1 part sewage to 50-70 parts storm water	1 part sewage to 10-50 parts storm water	1 part sewage to 5-20 parts storm water	primarily storm water with traces of sewage	primarily sewage with traces of storm water
Flow source identification	Services all storm and sewage drain connections	Storm water mainly from catch basins, collected in separate "street sewers", with sewage flow plus balance of storm water in partially combined sewer	Adjacent separate sewers interconnected intentionally for relief or incidentally such as from major leakage and infiltration	Except the odd incorrect sewage drain connection, storm sewer laterals are connected only, with catch basin connections	Sanitary flow dilution very limited to normal incidence of inflow and infiltration.

The separate storm sewers became popular in the 1950's, with the strong belief at the time that water discharged from storm sewers was of good quality (Harremoës, 1981). The use of separate systems resulted in full treatment of the sanitary sewage and therefore greatly reducing the impact of sanitary sewage on receiving water bodies. However, recently there have been greater concerns with the quality of storm water. Studies have shown storm water may be a significant source of contaminants. Thus any potential improvements in wastewater treatment of the sanitary sewage may not have as big an impact because of the storm water discharges.

2.2.2 Sources of Contaminants

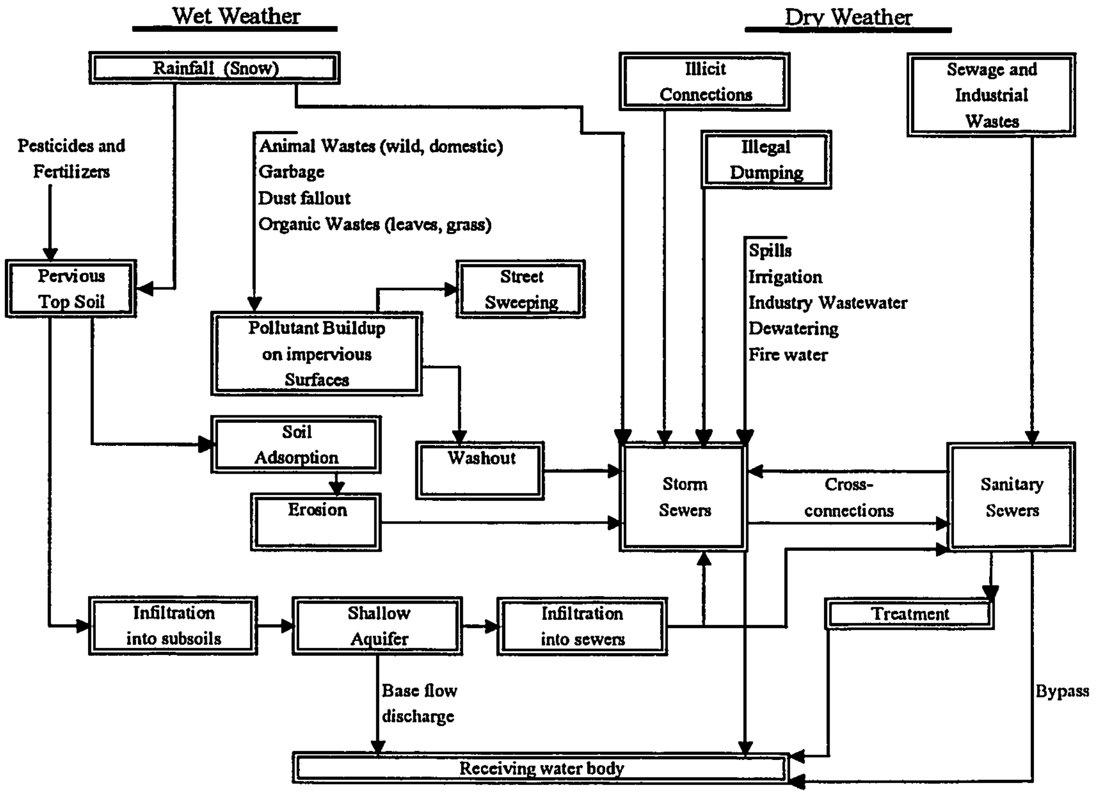
Storm water discharge has the widest range of contaminants due to its dependence on the substances entering the system. The dry weather flow of storm water in particular, can be comprised of a variety of things, including (Lalor, 1993, Nix, 1994);

- sewage sources (raw sanitary sewage, septic tank discharges, animal wastes)
- automobile maintenance (car wash, radiator flushing, engine de-greasing, improper oil disposal)
- irrigation (over-watering runoff, direct spraying of impervious surfaces)
- clean sources (infiltrating groundwater, routed springs/streams, leaking water mains)

- leakage (hazardous waste sites, leachate from landfills, leaking storage tanks)
- sediment (sand, silt, clay)
- others (laundry wastewater, rug cleaning wastewater, wash water from ready mix concrete trucks, dewatering of construction sites, sump pump discharges, non-contact cooling water, metal plating baths, improper disposal of household toxic wastes, spills from roadway and other accidents, fire water and other fire fighting substances)

In certain locations, natural springs or groundwater can infiltrate into the storm sewer with the water entering through infiltration which is generally believed to be clean, initially. The continuous water flow would act to dilute or scour the sediments out of the storm water system, depending upon the flow of the infiltration. Thus this intermittent infiltration can pose a problem for dry weather flows. When the flow path of water during wet and dry weather is examined (see Figure 2), there were numerous pathways found that pollutants can travel, to enter a receiving water system.

Figure 2. Water Flow Path
(modified from Novotny and Olem, 1994)



prevalent, and frequent, even during the driest of times. There are many programs under way in communities across North America to control these entries, or to apply some measure to reduce the load of pollutants that can adversely effect the receiving water body (Novotny and Olem, 1994). Illicit connections are a primary concern for dry weather studies and believed to occur through deliberate means or ignorance, such as sanitary building drains connected to the storm sewers, or fixtures inside a building connected to the storm sewers. This results in the discharge of untreated sewage directly to the storm system during dry weather and eventually is washed out to the receiving water.

2.2.3 Storm Water Quality

The quality of storm water strongly depends upon the type of system involved; combined, separate, or partially combined. The quality also depends upon the amount of sediment present in the system, the nutrient load (primarily phosphorus, and nitrogen), the oxygen demanding material present in the effluent (which can include human and animal wastes, decaying flora, litter, and food wastes), toxic substances present (organic and inorganic), and the pathogenic quality of the effluent. Research has demonstrated that almost all of the phosphorus and nitrogen, half of the biochemical oxygen demand, and many toxic substances are contributed by rural and urban non-point sources, which include storm water systems (Nix, 1994; Niedzialkowska and Athayde, 1985).

The discharge quality of separate storm systems, for organics and nutrients was estimated at one third that of combined systems during wet weather. For fecal coliform concentrations, the separate system was estimated to constitute one eighth that of combined systems also during wet weather (Gehm *et al*, 1976).

When comparing the quality of storm water with combined systems, treated sewage, and untreated sewage, storm water discharge is found to have the widest quality range. This range incorporates inorganic chemicals, organic chemicals, and microbiological summary of urban storm water quality. The abundant loading of contaminants to a river have resulted in serious problems for downstream users for drinking water, due to the increased health risk associated with the introduced pollutants.

Table 2. Urban Microbiological Waste Streams
(modified from Nix, 1994; Makepeace *et al*, 1995)

Discharge Type	BOD_5 (mg/L)	Suspended Solids (mg/L)	Coliforms (cfu/100mL)
Storm water	10 to 250	3 to 11000	10^3 to 10^8
Total coliforms			7 to $1.8\text{x}10^7$
Fecal coliforms			0.2 to $1.9\text{x}10^6$
Combined sewer overflows	60 to 200	100 to 1000	10^5 to 10^7
Untreated sewage	160	235	10^7 to 10^9
Treated sewage effluent	20	20	10^4 to 10^6

2.2.4 Remediation Options

Treatment of storm water is a new concept, but remedial actions are required to improve the runoff quality during wet and dry weather. Dry weather corrections are most important because the concentration of contaminants are quite high, with no rain to dilute the flow. Remedial actions could range from correcting illicit connections to treating the discharge.

For separate storm drainage systems, with notable sewage contamination, an effort should be made to trace and disconnect any illegal connections to eliminate such problems. If the illicit connections are too numerous or too costly to correct, an end-of-pipe treatment could be employed (Field *et al*, 1993).

A trace or system inspection of a storm sewer system should consist of identifying (Ontario Ministry of the Environment (OME), 1980); cracked or broken sewer lines, dislocated joints, root intrusions, cracked or leaking access hole structures, sewer lines with debris or deposits, improper connections, sunken access hole covers, and corroded piping. The larger storm lines can be physically inspected, while the smaller lines can be inspected with remote robotic cameras, with dye or smoke studies which are washed down the sewer lines and watched to see if any is found in the surrounding pipes.

Currently there are four main types of storm water runoff control systems. These include: site controls, system controls, end-of-pipe treatment, and in-river controls (OECD, 1986; Novotny & Chesters, 1981; Herricks, 1995). Site controls can include alternate deicing methods, leaf removal, repair of streets, control of fertilizer and pesticide addition, control of pet litter (feces), proper garbage control, runoff storage, forced infiltration (warmer climates), controlled site grading, and improved street sweeping. Street sweeping is very popular in most areas, for the cleaning results can reduce the sediments and garbage that enter the storm water but not by significant enough levels to warrant extra sweeping.

System controls include preventative maintenance, which includes cleaning catch basins, storm sewers, and drainage channels. From these maintenance activities, problem sites can be found and corrective measures can be taken. A system control can also include storm water storage in super pipes or off-line storage.

End-of-pipe treatment includes a variety of mechanisms such as storage with treatment, sedimentation (with and without chemicals), screening (microstrainers, drum screens, rotary screens, and static screens), swirl and helical concentrators, dissolved air flotation, high gradient magnetic separation (bench scale only), high rate filtration, biological (rotating biological contactors, trickling filters, oxidation ponds, aerated lagoons, and facultative lagoons), disinfection, and pond treatment. The efficiencies of the end-of-pipe treatments vary greatly, from 5% to 98%, depending upon the water quality parameter and method used. The biological processes would only be applicable to Combined Sewer Overflows (CSOs), for the biomass involved is generally very sensitive to the toxic materials commonly present in storm water, and the expense to keep the biomass alive during irregular storm events and dry periods would be too costly (Novotny & Chesters, 1981).

The last control measure would include in-river control methods, which could incorporate such systems as in-stream aeration and off-line lakes or wetlands.

Due to the unpredictability of runoff and the storm events, no known technology can be applied to be a general "fix" for these non-point sources. What can be applied is known as Best Management Practices for Non-point Control, which consists of the afore mentioned controls. There are several types of these control systems in place today which are quite effective, although costly.

2.2.5 Edmonton's Storm Water

Edmonton has a total of 85 storm sewer outfalls located in the seventeen and a half kilometre distance between the E.L. Smith WTP and the Rossdale WTP (2 to 4 hour stream flow time). This distance is not sufficient for the 'natural' water treatment process to make a significant impact. In other words, the assimilative capacity of the river is exceeded for this short reach. With substances like toxic chemicals, BOD, TOC, microbial contaminants, and sediments entering the river and reducing or impeding the natural purification process. This in turn creates an additional treatment requirement at the Rossdale WTP.

The storm sewer system in Edmonton presents a number of indirect routes in which pollutants have the ability to reach the North Saskatchewan River. Past studies of rain events in Edmonton have been found to increase the number of contaminants to the river, including fecal coliforms through storm sewers and combined overflows (Mitchell, 1994a). As for dry weather flow, very little has been done in the Edmonton area. It has only been within the past few years that monitoring programs have begun.

The water quality at Rossdale is largely a function of pollutant loading that enters the river via storm sewer outfalls, upstream of the intake. Thus Rossdale has remained highly vulnerable to accidental spills into the upstream storm sewers. It has been noted that the best protection available for raw water quality at Rossdale is to limit the inputs which may adversely affect the water quality (Smith, 1986; Hrudey, 1986).

2.2.5.1 History of Edmonton's Storm System

Over the past two decades water quality testing of the North Saskatchewan River in Edmonton has continuously demonstrated an increase in the presence of coliforms as the river flows through the city. With the coliform origin unknown, these investigations have believed the cause to be animals or illicit connections to storm sewers. These continuous discharges of sanitary waste have given the Rossdale plant a more difficult job of water treatment (Logsdon, 1986).

The storm water system in Edmonton has gone through several changes in the past (Toxcon, 1992). Prior to 1948 there were only combined sewer systems in which treatment occurred, for dry weather flow. From 1948 to 1958 the combined systems were connected with weeping tile and in some cases eaves of houses and buildings greatly increasing the storm water flow during rain events. From 1950 to 1970 the city switched to a dual system in which storm runoff was conveyed from houses to the front, and sanitary waste from houses was directed to the rear. In the period between 1970 and 1980, the city allowed a common trench for both the storm and sanitary connections from the house, which led to the bulk of the inflow/infiltration problems, illicit connections being made, and cross-connections occurring. From 1990 to present, houses are no longer connected to the storm water system, instead the runoff is routed to a sump which discharges the water on the homeowners property.

2.2.5.2 Edmonton's Current Storm System

There still are designed cross connections in the system which were installed to alleviate the pressure on the sanitary sewage system. This allows discharging to the storm sewers with a hinged lid on the sanitary and an overflow from a pumpwell to a storm water access hole. There are also unintentional cross connections which have been the result of installation mistakes or illegal practices. The extent and impact of sanitary sewage from these sources within Edmonton are unknown, and are revealed on a continual basis with on-going maintenance work.

There were three storm outfalls sampled in this study; Quesnell, Millwoods (30th avenue), and Groat (refer to Figure 4). Of the three outfalls, the Millwoods outfall is by far the largest on the river between E.L. Smith and Rossdale. In 1970-71 construction of the Millwoods storm sewer began. This is a double barreled sewer that was put in on 30th Avenue from 91st street to 99th street. This pipe split at 99th street where the sanitary portion flows north to the sewage treatment plant. The storm water portion continues West to the river (Department of the Environment, 1973). There may be a potential for sanitary input from cracks, leaks, or breaks in the double barreled portion, thus this outfall has been watched on a continuous basis for potential problems.

2.2.5.3 Edmonton Creeks

There are a total of 10 creeks that enter the North Saskatchewan River between E.L. Smith and Rossdale, of which the Whitemud Creek is the largest and the only one that drains on the right bank (left to right convention looking downstream). There are several inputs into Whitemud creek, including;

- eight city storm sewers with a combined capacity of 22.7 m^3/s
- a series of sloughs
- several feed lots (pig farms)
- highway ditches
- storm water from New Sarepta, Nisku (Including the International Airport), and Leduc.

There are also two main bridges over Whitemud Creek that are designated a dangerous goods route, with one on the route to Swan Hills Waste Treatment Centre.

Whitemud Creek would likely not effect the current intake at Rossdale, due to poor transverse mixing, but with the new intake, there may be a potential for contamination. If the pollutant is buoyant it will likely not cause a problem because the intake is a few metres under the surface, but if the pollutant is not buoyant, it may cause a problem.

The remaining nine creeks that drain on the left bank of the river have no known data relating to spills or potential problems associated with their drainage.

2.2.5.4 Spills and Illegal Dumping

In April 1988, restrictions were placed on liquid wastes that enter Clover Bar landfill. This necessitated shipments of these wastes to Swan Hills for disposal. Unfortunately, Swan Hills has not recorded a large increase in shipments since these restrictions came into place, thus it is suspected that the material is being dumped into ditches or storm sewers. This belief is supported by a similar situation that happened almost two decades earlier in Windsor, Ontario in which restrictions were placed on their landfill, resulting in a large increase of illegal dumping in roadside ditches and storm systems (Toxcon, 1992).

It would be very difficult, if not impossible, to put a quantity on the amount of material that is illegally dumped into local storm sewers. Annual Drainage Branch Reports (City of Edmonton, 1989 to 1994), indicate that there are 15 to 22 reported spill incidents per year. From 1985 to 1990, approximately 130 contaminant incidents were recorded, of which over three quarters were downstream of the E.L. Smith WTP, but upstream of the Rossdale WTP. Rossdale WTP has little to no advanced warning of such spills that are discharged from storm sewers. It should be noted that for all of the spills reported, there are likely even more that are never reported. The majority of these spills are upstream of the Rossdale intake, which implies the Rossdale WTP is in a very vulnerable position to any spills, accidental or intentional (Hrudey, 1986). These spills can be noted back to 1979 (Masuda, 1979), in which the Groat outfall discharged a substance that forced shut down for hours while waiting for the plume to travel down stream of the intake (City of Edmonton, 1989 to 1994). Currently, there are no known records of the E.L. Smith WTP having to shut down due to river contaminants.

When illegal dumping does occur it is very difficult to track the source and, if by chance the source is found, it becomes very difficult to lay charges on the persons or company believed responsible. The majority of reported illegal dumpings have been in the area downstream of the Rossdale WTP, likely due to the larger population base. While illegal dumpings in upstream reaches occur, they are infrequently reported due to lower population density available to witness dumping occurring.

2.2.6 Observed Storm Water Problems

There have been several studies performed in urban areas that have demonstrated problems relating to storm water discharges such as illicit connections and illegal dumping. The cases looked at were broken into three areas; Canada, United States, and outside North America. From the following studies reviewed, it becomes apparent that storm water problems go far beyond local limits, and affects most industrialized countries in the world.

2.2.6.1 Canada

In Canada the law does not require monitoring of storm water systems. The possibility or probability of having such a law in the near future has some cities studying their storm systems and making corrections prior to such regulations being enacted.

Sylvan Lake, Alberta (Mitchell, 1988)
Sylvan Lake, Alberta, a popular vacationing site, was found to be contaminated with high fecal coliform counts along the public beach. The town of Sylvan Lake was found to be

with either cross-connections, ground contamination, or campers discharging their sewage directly into the storm sewers. The recommendation was to move or divert the storm water discharge to a treatment facility to avoid the potential of illegal dumping and toxic spills resulting in serious and lasting damage to their beaches.

Prince Albert, Saskatchewan (Saskatchewan Environment, 1984)
An independent study of Prince Albert's storm sewers was done, and some were found to contain both industrial and sanitary sewage. Of particular concern in this survey was the presence of pentachlorophenol from one of the outfalls. The source was unknown but believed to be a former wood preserving facility which caused groundwater and surface drainage to move pentachlorophenol into the storm system, which then discharged untreated to the North Saskatchewan River.

Windsor, Ontario (Sullivan, et al, 1978)
A study in the suburb of Riverside, an area in the City of Windsor, was found to have many illicit connections in its separate storm water system. The sanitary and storm systems share many of the same access holes, which were separated by plates, but investigations found leakage due to improper plate sizes or plates missing.

St. Catharines, Ontario (Sullivan, et al, 1978)
In the City of St. Catharines additional drainage pipes have been built for their separate sewers with low flow dividers built to drain into the combined sewer systems resulting in a substantial pollution increase.

Toronto, Ontario (Pitt et al, 1989; OME, 1980)
In a survey of illicit connections performed on 600 Toronto households, a total of 80 illicit connections where found. In a later more thorough monitoring program, high pesticide concentrations and metal concentrations where found in the storm system draining

of water, solids, chlorides, and bacteria during dry weather flows.

Scarborough, Ontario (Pitt et al, 1989)

The city of Scarborough has an active and ongoing program, to detect and correct illicit connections, which many cities have duplicated.

Humber River, Ontario (Pitt et al, 1989; MacDonald, 1987)

A total of 625 outfalls that discharged to the Humber River were sampled during dry weather and found to have high concentrations of nutrients, phenols, and metals. From their tests, 10% of the outfalls were considered significant pollution sources. Further studies found an apartment building with eight units illegally connected to the storm water system, along with many more sewage cross-connections draining into the storm system.

Huron River, Ontario (Barbé et al, 1993)

A dye-test study was performed on 1067 commercial, industrial, and tax-exempt buildings that are part of the drainage system on the Huron River. One hundred fifty four were found to have improper connections, a majority of which were from car-washes and automobile related businesses.

East York, Ontario (OME, 1980)

An investigation of 1000 houses in East York, found 5% had improper connections to the storm systems. In many cases house owners simply connected their sanitary appliances to the nearest drain which made it very difficult to correct, and collect payment for these errors.

2.2.6.2 United States

In the United States, several studies have been done in compliance with the Non-Point Discharge Elimination System (NPDES) permit procedures.

Houston, Texas (Davis et al, 1995; Glanton et al, 1992)

In 1989 Houston, Texas intensified its efforts to eliminate illicit connections along with other storm related discharges into the Buffalo Bayou. Since the study began, 132 questionable sources of pollution were found. Further studies identified the sources as: 55% broken sewer lines, that were discharging to the storm water system; 30% plugged sewage lines which then overflowed to the storm systems; 10% of illicit connections with private sanitary hookups; and 5% due to incorrect floor drains, illegal dumping, and private sanitary lines overflowing. With corrective actions they were able to obtain approximately 90% improvement in their dry weather flow.

Bellevue, Washington (Pitt et al, 1989; Field and Pitt, 1990)

Fish populations were studied, due to unexpected fish kills occurring in Bellevue urban creeks. The study was conducted to determine illegal discharges in the storm system during dry weather. A complaint phone line was set up and over a three year period 50 complaints were lodged about illegal dumping; a quarter of which were oil discharges. The survey also turned up large amounts of toxic material which would have hampered any tests to determine illicit connections because the toxins would rapidly kill bacteria.

Indianapolis, Indiana (Peterson & Grout, 1992)

Field screening was conducted on 504 outfalls during dry weather and resulted in a total of 162 outfalls with flow, of which the majority had positive indications of illicit connections.

Milwaukee, Wisconsin (Peterson & Grout, 1992)

Field screening in Milwaukee was conducted on 370 outfalls and revealed that 250 of them had flow during dry weather. Of those that flowed, a majority had a positive indication of illicit connections.

Sacramento, California (Barbé et al, 1993; Field, et al, 1994)

A study performed in Sacramento, California indicated that slightly less than half of the discharge from their storm system was not directly related to precipitation, sighting the remaining flow to illicit connections and inappropriate entries.

Washtenau County, Michigan (Barbé et al, 1993)

A dye test was done on 160 businesses from 1984 to 1986, and found 61 of them had improper connections.

2.2.6.3 Outside of North America

Illicit connections and storm water problems are not confined to North America. These ongoing problems happen around the world where there are two separate systems to convey storm and sanitary wastes. In several countries there is only one system in which storm and sanitary is conveyed, untreated to the nearest water body.

London, United Kingdom (Edmonds-Brown and Faulkner, 1995)

Pymme's Brook in North London is an area that was found to have occasional illicit connections with washing machines, or sewer pipes. Thus an *E. coli* survey was conducted to reveal levels over 5 million cfu/100mL which labels this as a "serious sewage contamination" classification. The survey attempted to pinpoint the problem but this was extremely ineffective and costly. They concluded that it would be more cost effective to replace a large or main section of the sanitary sewer system. Larger problems became the focus and the smaller households were left, with or without the necessary connection. In the end this survey recommended sampling infrequently during low-flow periods, which could help to identify any of the smaller sources of pollution.

In the Moldavian region of Russia, the fate of microorganisms was studied, and it was found that the effluent from the wastewater treatment plant was purified by the river in a matter of two days, during dry weather. When wet weather situations happened, they found that the storm water runoff would temporarily block the natural purification process of the river.

Ahmedabad, India (Ruparelia et al, 1987)

Lake Kankaria, in the city of Ahmedabad, has storm water discharge to it which have been found to be high in nutrients, industrial wastes, and raw sewage. The presence of sewage was believed to occur through leakage or illicit connections.

2.2.6.3.1 Illicit Connections Calculation

The Working Party on Storm Sewage in Scotland has demonstrated theoretically that only a small percentage of illicit connections to storm drains could potentially nullify the advantage of adopting the totally separate system (Nicoll, 1988). The following calculations were not used in the model, just illustrated to show how storm water problems have been viewed, outside of North America.

Formulation is as follows:

- Load in sanitary sewer due to sanitary sewage $=L_F(1-n)$
- Load in sanitary sewer due to surface water: $=nL_S$
- Load to sewage treatment plant: $=L_F(1-n) + nL_S$
- Load in effluent from STP: $=(1-E)[L_F(1-n) + nL_S]$

- Load in separate storm system due to surface water: $=L_S(1-n)$
- Load in surface water due to sanitary sewage: $=nL_F$
- Load discharged from storm water system: $=L_S(1-n) + nL_F$

Therefore the total load to the water course: $=(1-E)[L_F(1-n) + nL_S] + L_S(1-n) + nL_F$
$=En(L_F - L_S) + L_F + L_S - EL_F$

With no wrong connections, n=0, the total load would be: $=L_F + L_S - EL_F$
$=(1-E)L_F + L_S$

The percent change in BOD load to water system (dL)

$$= \frac{\left[En\left(L_F - L_S\right)+L_F+L_S-EL_F\right]-\left[(1-E)L_F+L_S\right]}{\left[(1-E)L_F+L_S\right]}$$

by simplifying: $$dL = \frac{}{(1-E)B_F + KB_S}$$

Where K, can be determined by: $$K = \frac{27.4AC_R I}{PG}$$

The percent change in BOD (dL) load to the water system can be determined with respect to the number of known illicit connections. This was done to argue against changing the existing combined system to a separate system. There are advantages and disadvantages in adopting a separate sewer system, but it is not as clear-cut as was assumed in the past. In some areas around the world, planners are contemplating the economic and social impacts of going back to a combined system, with modern techniques for preventing dry weather overflows. It is now being argued that with the number of illicit connections, the separation of storm sewers might not be the best solution after all (Nicoll, 1988).

2.3 Water Quality Regulations

Through recent regulations point sources of pollution have drastically improved, the water quality of the receiving waters have not always followed the same pattern. The initial focus on water pollution control was that of point sources, mainly industrial pollution. However, it has been found that even in the elimination of these point sources, there has not been the desired improvement in water quality that was targeted. This was mainly due to the non-point sources that come from urban and rural areas (Ahern *et al*, 1981). Laws have shifted focus to other possible discharges, and have found that several non-point sources can be as severe or worse than point sources. One such non-point source is the current storm water system. Storm water systems have been found to contain high concentrations of bacteria and other microorganisms that are potentially pathogenic to humans. The sources of these microorganisms are very diverse and to isolate one specific source would be extremely difficult. In answer to this, new regulations are addressing such areas as urban and rural runoff and storm sewers.

In Alberta, the *Environmental Protection and Enhancement Act* (AEPEA, 1992) is used as the main environmental enforcement act, and takes into account several factors of the water systems in the province, such as; Part 4, Release of substances, Division 1, Section 98.1:

> *No person shall knowingly release or permit the release into the environment of a substance in any amount, concentration or level or at a rate of release that causes or may cause a significant adverse effect.*

This applies to only those that release a substance without a permit or regulation, like illegal dumping in the storm sewers. Also part of the AEPEA is the Wastewater and Storm Drainage Regulation (1993), which details who is and who is not entitled to dispose of substances into the storm and wastewater drainage systems.

2.3.2 Canada

In Canada the main environmental enforcement act falls upon the *Canadian Environmental Protection Act* (CEPA, 1988). CEPA would be used as enforcement for toxic materials purposely released into a water body. However, there are no current laws at a federal level that apply to discharge of substances from storm sewers. There is however, the *Fisheries Act* (Fisheries Act, 1991), which, under the Fish Habitat Protection and Pollution Prevention section, part 36.3, states:

> *no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.*

Where a deleterious substance is defined as a substance that upon entering a water system, would alter or degrade the water to affect fish or fish habitats. This may include some substances that are released by storm sewers.

The United States is currently far ahead compared to Canada and the Provinces in enforcing restrictions of storm water and non-point discharges into their water ways. Prior to 1960, storm water concerns focused primarily on floods or drainage. More recently, concerns have shifted to characterizing and quantifying the pollutants which are entering and discharging from storm water systems. In 1972, amendments to the *Clean Water Act* (CWA) prohibited the discharge of pollutants to navigable waters from a point source regulated by a National Pollutant Discharge Elimination System (NPDES) permit. In 1987, amendments to the CWA required the Environmental Protection Agency (EPA) to establish NPDES requirements for storm water discharges. The initial publication of the permit applications appeared on November 16, 1990 (55 FR 47990) and defines the requirements needed to apply for a NPDES permit for storm water discharge. This required all municipalities with a population over 100000 to apply for a permit for discharging storm water under NPDES. The amendments were broken into two phases; Phase I - for municipalities over 100000, and Phase II - for municipalities under 100000.

The final rules published by the USEPA pertaining to the permit rules of Phase I, are broken into two parts (Roesner & Traina, 1994; Diller, 1995; Mumley & Brosseau, 1996):
Part 1 - (i) General Information; (ii) Legal Authority; (iii) Source Identification; (iv) Discharge Characterization; (v) Management Programs; (vi) Fiscal Resources. The Discharge Characterization (iv) section, pertains to the identification and detection of dry weather flows that result from illicit connections or non-storm water discharges to the system. This field screening will become an ongoing program for discovering and controlling any illicit discharges during the life of the permit (Kobylinski & Andrens, 1991). The Management Programs (v) section, has to include a program to identify and remove the illicit connections from the storm system.
Part 2 - (i) Adequate Legal Authority; (ii) Source Identification; (iii) Characterization Data; (iv) Proposed Management Program; (v) Assessment of Controls; (vi) Fiscal Analysis. Under the Source Identification (ii) section, the illicit connections or non-storm

Proposed Management Program (iv) section, the main focus is to write up any source control proposals and control programs for illicit connections in developed areas. Under this program the municipality must also specify the prevention and reduction procedures for problems associated with illicit connections, spills, toxic materials, and leaking/overflowing separate sanitary sewers.

The rules for Phase II were to be released October 1, 1993, but due to delays and feedback from Phase I, those municipalities with a population under 100,000 still do not require a permit under the NPDES storm water discharge regulations

A report written to the United States Congress by EPA in 1985, addressed urban storm water discharge as a major concern in need of control. This report helped prompt the Congress to initiate the 1987 amendments to the CWA. A statement from the report summarized by Jones-Lee and Lee (1994) stated:

> *Based in part on national assessments conducted by the US Environmental Protection Agency it is now recognized that non-point sources and certain diffuse point sources (e.g. Storm water discharges) are responsible for between one-third and two-thirds of existing and threatening impairments of the Nation's waters.*

Presently the CWA Section 402 (NPDES) is the most practical for the control of pollution discharges from storm water systems. In order for these regulations to be enforced, there must be a key program involved that helps to identify the types and location of pollutants that enter the water system. The USEPA also published a draft Combined Sewer Overflow (CSO) Policy in January of 1993, which reiterates the objectives of the 1989 CSO Control Strategy (Roesner & Traina, 1994). One main point of this policy is to ensure that if CSO discharges must occur, they should only occur during storm events, and not dry weather flow.

In examining current water quality regulations, standards, and guidelines, three main parameters were investigated. Raw surface water, treated drinking water, and recreational levels were investigated and summarized with respect to regulatory agency, in Table 3.

2.4.1 Alberta

Alberta has raw surface water guidelines for water to be withdrawn for treatment. The guidelines indicate the total coliform count must be less than 5000 cfu/100mL, and the fecal coliform count must be less than 1000 cfu/100mL. These values are based on at least 90 percent of the samples, with not less than 5 samples taken in any consecutive 30 day period (Alberta Environment, 1993).

2.4.2 Other Provinces and Federal

There are currently no federal regulations on raw water, but Saskatchewan, Manitoba, Ontario, and Quebec do have standards and guidelines listed. Saskatchewan and Alberta have the same guidelines with the total coliform less than 5000 cfu/100mL and the fecal coliform less than 1000 cfu/100mL (CCREM, 1985). Manitoba guidelines for raw water are more stringent. The total coliform must be less than 100 cfu/100mL and the fecal coliform less than 10 cfu/100mL for the 90th percentile of samples (CCREM, 1985). Ontario has set surface water guidelines with total coliforms to be less than 5000 cfu/100mL, and fecal coliforms to be less than 500 cfu/100mL (Ontario Water Resources Commission, 1970). Quebec has three different water quality standards for raw water. The first is raw water to be used without treatment and must have a total coliform count of no more than 10 cfu/100mL, and no fecal coliforms. The second is for raw water only receiving disinfection with the total coliform maximum between 100 to 1000 cfu/100mL, and the fecal coliform between 10 to 100 cfu/100mL. The third is for raw water receiving a full water treatment, allowing the total coliform to be higher than 1000 cfu/100mL and

Table 3. Water Quality Standards and Guidelines

Water Parameters / Quality	Regulatory Agency	Total coliform Count org/100mL		Fecal coliform Count org/100mL		References
Raw Surface Water Requirements - intended for drinking water:						
With simple physical treatment and disinfection	EEC	50		20		Newman, 1988
Normal physical treatment, chemical treatment and disinfection	EEC	5000		2000		Newman, 1988
Intensive physical and chemical treatment, extended treatment and disinfection	EEC	50000		20000		Newman, 1988
Waters to be withdrawn for treatment and distribution as a potable supply	Alberta	5000	a	1000	a	Alberta Environmental Protection, 1993
Waters to be withdrawn for treatment and distribution as a potable supply	Saskatchewan	5000	a	1000	a	CCREM, 1985
Raw water for drinking water supply	Manitoba	100	b	10	b	CCREM, 1985
Surface water quality guidelines	Ontario	5000		500		Ontario Water Resources Commission, 1970
For raw water without treatment	Quebec	10		0		CCREM, 1985
For raw water receiving disinfection only	Quebec	100 to 1000		10 to 100		CCREM, 1985
For raw water receiving complete treatment	Quebec	> 1000		> 100		CCREM, 1985
Treated drinking water Requirments						
Treated water entering distribution system	WHO	0		0		World Health Organization, 1984
Untreated water entering distribution system	WHO	0 to 3	c	0		World Health Organization, 1984
Water in a distribution system	WHO	0 to 3	c	0		World Health Organization, 1984
Unpiped water supplies	WHO	0 to 10	d	0		World Health Organization, 1984
Maximum Acceptable Concentration (MAC) for treated drinking water	Canada	0 to 10	e	0		Health and Welfare Canada, 1989
For treated drinking water	Mexico			0		Mexico General Health Law, 1991
For treated drinking water	Quebec	10	f	0		Quebec Environmental Quality Act, 1992
Maximum Contaminant Level (MCL) - for treated drinking water	EPA	≤ 5%	g	0		USEPA, 1996
Maximum Contaminant Level (MCL) - for treated drinking water	EPA	≤ 1	h	0		USEPA, 1996
Maximum Acceptable Concentration (MAC) - Objective	Saskatchewan	0		0		Saskatchewan Environment, 1991
Definition of unsafe drinking water quality	Ontario	< 5		0		Ontario Ministry of the Environment, 1983
Secondary water requirements - recreation, bathing:						
Quality requirements for bathing water - Guideline	EEC	500		100		Newman, 1988
Quality requirements for bathing water - Mandatory	EEC	10000		2000		Newman, 1988
Recreational water quality - body contact	Ontario	1000	i	200	i	Ontario Water Resources Commission, 1970
Recreational geometric mean density for samples	Manitoba	1000		200		CCREM, 1985
Recreational maximum for individual samples	Manitoba	2000		400		CCREM, 1985
For direct contact recreation	Alberta	1000	a,j	200	a	CCREM, 1985
For direct contact recreation	Saskatchewan	1000	a,j	200	a	CCREM, 1985

(a) at least 90 percent of the samples (not <5 samples in any consecutive 30 day period); (b) 90th percentile of samples; (c) a count of 3 in an occasional sample, but not in consecutive samples; (d) a count of 10 should not be repeatative, if so, corrective action should be taken, or a new source found; (e) no sample may have a count >10 repeadativly; (f) at least 90% of the samples be free of all coliform bacteria, no sample may have a count >10 (where >10 samples are collected in a 30 day period) AND no more than 1 sample may contain colifrom bacteria, in which the count must be <10 (where >10 samples are collected in a 30 day period); (g) for a system which collects >40 samples per month, no more than 5% can be TC positive; (h) for a system which collects <40 samples per month, no more than 1 sample can be TC positive; (i) the geomean of a series consisting of at least 10 samples per month; (j) cannot exceed a count of 2400/100mL on any day

2.4.3 World Wide

At present time the World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) do not have raw water quality guidelines or standards (refer to Table 3). They do however have treated drinking water standards. The European Economic Community, similar to Quebec has three different guidelines for raw water quality with the first entailing simple physical treatment plus disinfection and the total coliform count must be less than 50 cfu/100mL, and the fecal coliform count less than 20 cfu/100mL. The second guideline is for raw water going through normal physical treatment, chemical treatment, and disinfection. The total coliform count must be less than 5000 cfu/100mL and the fecal coliform count less than 2000 cfu/100mL. The third is for raw water going through intensive physical and chemical treatment, extended treatment, and disinfection. The total coliform count must be less than 50000 cfu/100mL, and the fecal coliform count less than 20000 cfu/100mL.

2.5 River Mixing

Mixing of water in a river occurs in three directions; longitudinal, vertical, and transverse (referred to as x, y, and z directions), refer to Figure 3. The transverse gradients of a river is the primary cause of longitudinal mixing. A river mixes vertically though eddies which occur naturally in the channel while transverse mixing occurs due to the slope and roughness of the river bottom. The vertical mixing occurs much more rapidly than longitudinal mixing in the North Saskatchewan River, due to the hydraulic characteristics of being wide and shallow. In a well mixed river, the dimensionless concentration on both sides would be equivalent (good transverse mixing), but in a poor mixed river there would be extreme differences. From previous mixing studies (Beltaos, 1978; Lau, 1985; Luk, 1991; Milne, 1991; and Van Der Vinne, 1992) it was found that the North Saskatchewan River has poor mixing from Edmonton to the Alberta-Saskatchewan border. Thus km downstream of the discharge (Shaw *et al*, 1994).

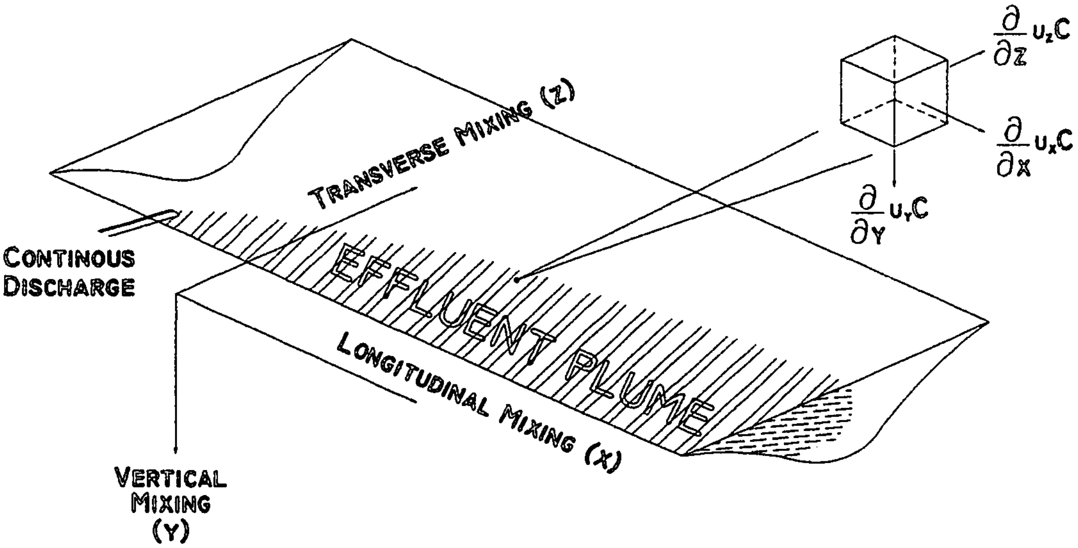


Figure 3. Mixing Process

The physical process of flow, or the 'transport processes' of water in a river, can be summarized in the following (Elhadi *et al*, 1984; Fischer *et al*, 1979):

Advection

Mixing which occurs with direct relation to the river current.

Convection

The vertical transport due to hydrostatic instability (movement from warm to cold)

Molecular Diffusion

The mixing due to random molecular movement, following Fick's law. For a turbulent stream, molecular diffusion is negligible, but for laminar flow it becomes the dominant mixing process.

The random scattering of particles, much like molecular diffusion, incorporates eddy diffusion, which becomes larger than molecular movement.

Shear (or Differential Advection)

This mixing is related to non-uniform velocity gradients in the river. The spread of a pollutant varies in all directions - vertical, horizontal, and longitudinal.

Dispersion

The scattering effect of a pollutant by both the Shear and Transverse Diffusion effects.

Secondary Circulation

This occurs in rivers with noncircular bottoms (cross sections), resulting in secondary currents. These secondary currents demonstrate a dispersive transport on a tracer.

Evaporation

The movement of water through a phase change, from liquid to gaseous.

Radiation

The change in radiant energy of particles, particularly at the water surface

Non-neutral Substances (Particle Settling or Particle Entrainment)

This relates to non-buoyant substances that enter a river and respond to buoyancy flux.

2.5.1 Transverse Mixing Theory

When looking at the mixing process, it begins with a fundamental, three-dimensional mass transport equation. By analyzing a neutral tracer entering a straight channel and using the conservation of mass theory, a three-dimensional mass transport equation can be developed:

$$\frac{\partial C}{\partial t}+u_x\frac{\partial C}{\partial x}+u_y\frac{\partial C}{\partial y}+u_z\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(E_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(E_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(E_z\frac{\partial C}{\partial z}\right) \quad \ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where C is the concentration of a neutral substance, u_x, u_y, u_z are the velocity components in the x, y, z directions and E_x, E_y, E_z are the turbulent mixing coefficients in the x, y, z directions. The derivation for equation (1) has been thoroughly explained in previous

Rutherford, 1994):

Equation (1) can be simplified to a two-dimensional mass transport equation, in a natural channel where the depth is small and width is large. The equation can be reduced to a two-dimensional form by integrating over depth. This is applicable when a tracer concentration over depth becomes uniform much sooner than transverse and longitudinal direction such as the case of the North Saskatchewan River. When the general equation is integrated over depth (h), it can be written as (Holley *et al*, 1972; Somlyódy, 1982):

$$\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(hu_xC)+\frac{\partial}{\partial z}(hu_zC)=\frac{\partial}{\partial x}\left(hE_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial z}\left(hE_z\frac{\partial C}{\partial z}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad(2)$$

In turn, this equation can be rewritten to account for river curvature and variation of width. This has been termed the orthogonal curvilinear coordinate system or the natural coordinate system in which m_x, m_y, m_z are coordinate coefficients (where $m_x=1$ is a straight channel), (Yotsukura and Sayre, 1976; Lau and Krishnappan, 1981):

$$m_xm_z\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(m_zhu_xC)+\frac{\partial}{\partial z}(m_xhu_zC)=\frac{\partial}{\partial x}\left(\frac{m_z}{m_x}hE_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{m_x}{m_z}hE_z\frac{\partial C}{\partial z}\right).\ (3)$$

An area of mixing that has been studied extensively, has been defined as longitudinal dispersion. The area of most recent concern is that located just downstream of pollutant sources where transverse mixing becomes important. This is referred to as the transverse mixing zone (also described as the solute transport equation). By neglecting the longitudinal diffusion portion, and left with the transverse diffusion equation (Yotsukura and Cobb, 1972; Beltaos, 1979; Beltaos and Arora, 1988):

$$\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(hu_xC)=\frac{\partial}{\partial z}\left(hE_z\frac{\partial C}{\partial z}\right);\quad m_xm_z\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(m_zhu_xC)=\frac{\partial}{\partial z}\left(\frac{m_x}{m_z}hE_z\frac{\partial C}{\partial z}\right).\ (4)$$

Also looking at the two-dimensional equation, with a continuous release of a pollutant, and with conditions being steady state, the equations left are:

$$\frac{\partial}{\partial x}(hu_xC)+\frac{\partial}{\partial z}(hu_zC)=\frac{\partial}{\partial z}\left(hE_z\frac{\partial C}{\partial z}\right) \quad \ldots\ldots\ldots\ldots (5)$$

$$\frac{\partial}{\partial x}(m_zhu_xC)+\frac{\partial}{\partial z}(m_xhu_zC)=\frac{\partial}{\partial z}\left(\frac{m_x}{m_z}hE_z\frac{\partial C}{\partial z}\right) \quad \ldots\ldots\ldots\ldots (6)$$

Applying steady state approach to the transverse diffusion equation:

	Yotsukura and Sayre, 1976 Natural Coordinates (7,8,9)	Yotsukura and Cobb, 1972 (10,11,12)
Cumulative discharge function	$q_c=\int_0^z m_zhu_xdz$	$q_c=\int_0^z hu_xdz$
Depth integrated, at steady state	$m_z\frac{\partial}{\partial x}(hu_xC)=\frac{\partial}{\partial z}\left(\frac{m_x}{m_z}hE_z\frac{\partial C}{\partial z}\right)$	$\frac{\partial}{\partial x}(hu_xC)=\frac{\partial}{\partial z}\left(hE_z\frac{\partial C}{\partial z}\right)$
Transformed equation from the above two	$\frac{\partial C}{\partial x}=\frac{\partial}{\partial q_c}\left(u_xh^2m_xE_z\frac{\partial C}{\partial q_c}\right)$	$\frac{\partial C}{\partial x}=\frac{\partial}{\partial q_c}\left(u_xh^2E_z\frac{\partial C}{\partial q_c}\right)$

With the transformed transverse mixing equation, a decay term is added which takes effect in the form of a first order decay coefficient:

$$\frac{\partial C}{\partial x}=\frac{\partial}{\partial q_c}\left(u_xh^2m_xE_z\frac{\partial C}{\partial q_c}\right)-\frac{kC}{u_x} \quad \ldots\ldots\ldots\ldots (13)$$

Where k is the decay term and $m_x=1$, for the straight stretch of river.

By aligning the longitudinal coordinates with the velocity component stream tube equations can be developed with the combination of the transverse mixing equation and the cumulative discharge:

$$\frac{\partial}{\partial t}(hC)+\frac{\partial}{\partial x}(hu_xC)=\frac{\partial}{\partial z}\left(hE_z\frac{\partial C}{\partial z}\right) \quad \text{and} \quad q_c=\int_0^z hu_xdz \quad \ldots\ldots\ldots\ldots (14,15)$$

$$\frac{\partial C'}{\partial x}=\frac{1}{Q^2}\frac{\partial}{\partial \eta}\left(u_x h^2 E_z \frac{\partial C'}{\partial \eta}\right) \qquad (16)$$ (Putz, 1983)

$$\frac{\partial C}{\partial x}=\frac{1}{Q^2}\frac{\partial}{\partial \eta}\left(u_x h^2 m_x E_z \frac{\partial C}{\partial \eta}\right) \qquad (17)$$ (Lau and Krishnappan, 1981)

$$\frac{\partial C}{\partial t}+\frac{u_x}{m_x}\frac{\partial C}{\partial x}=\frac{\partial}{\partial \eta}\left(\frac{u_x^2 h^2 E_z}{Q^2}\frac{\partial C}{\partial \eta}\right)+\alpha C+\beta_1 \qquad (18)$$ (Yotsukura and Sayre, 1976)

2.5.2 Transverse Mixing Length

The mixing length is the distance required for complete transverse mixing of a pollutant or tracer. The following four formulas are used to calculate the transverse mixing length based on prismatic channels, bank discharge, or centre discharge.

Distance for transverse mixing in prismatic channels only (Elhadi *et al*, 1984):

$$Xm=\frac{0.5u\left(\frac{B}{2}\right)^2}{E_z} \qquad (19)$$

Transverse mixing distance for a bank discharge (Rutherford, 1994):

$$L_z=0.536\frac{u_x w^2}{E_z} \qquad (20)$$

Transverse mixing distance for a mid-channel discharge (Rutherford, 1994):

$$L_z=0.134\frac{u_x w^2}{E_z} \qquad (21)$$

Transverse mixing length, a=1/2 river width, R=hydraulic radius (Fischer, 1967b):

$$L=1.8\frac{a^2}{R}\cdot\frac{u}{u*} \qquad (22)$$

2.5.3 Transverse Mixing Coefficients

From flume experiments, Elder (1959) was able to developed the transverse mixing equation:

The length scale, λ, can change to incorporate different lengths like average river depth, width, plume width, half width, half plume width, and hydraulic radius which are a few that have been used in various studies.

From a search of laboratory and field studies on transverse mixing, an average transverse mixing coefficient (E_z) value was found to range from $1(10^{-3})$ to 0.14 m^2/s for field and from $4.5(10^{-5})$ to $3.3(10^{-3})$ m^2/s) for the laboratory (refer to Appendix C).

There were four main length scales used in the various tests studied, depth, width, hydraulic radius, and plume width. This resulted in various dimensionless mixing coefficients ($\beta=E_z/\lambda u^*$) for both field and laboratory studies. When average depth is used for the length scale, the results from the field studies ranged from 0.03 to 6.5 while the laboratory showed a range of 0.07 to 2.4, the average values of β (depth) were 0.56 and 0.34 for field and laboratory respectively. When the width was used as the length scale, the dimensionless coefficient for the field ranged from 0.07 to 2.5, and laboratory from $4.3(10^{-3})$ to 0.12, with the average values of β (width) being 0.01 and 0.02 for field and laboratory respectively. When hydraulic radius was used as the length scale, the field studies had a range of 0.07 to 2.5, and laboratory, from 0.1 to 2.2, with the average β (hydraulic radius) being 0.76 and 0.53 for field and laboratory respectively. The last length scale looked at was for plume width, and only field work was performed using plume width as a length scale, resulting in a β (plume width) range of $6(10^{-3})$ to 0.015, with an average of 0.011.

2.6 Mixing Models

In developing a mixing model to study the behavior of a physical, chemical, or biological substance in a river, specific hydrodynamic laws need to be accounted for. These laws include conservation of mass, momentum, thermal energy, and species concentration (chemical or microbiological) (Rodi, 1984).

A mass balance is performed on a defined volume of water to account for all of the substances that enter and leave the specified volume. The balance accounts for all changes in the substance's mass due to mixing processes, decay, reactions, and transformations. Two approaches can be used to derive the conservation of mass equation, the Eulerian and Lagrangian methods (McCutcheon and French, 1989). The Eulerian method refers to modeling a dynamic process in terms of a fixed point or a fixed volume of fluid. The Lagrangian method also refers to a dynamic process but in terms of a moving reference point.

Conservation of momentum

The conservation of momentum accounts for all the forces acting upon a defined volume of fluid, and the resulting movements associated with these forces (Phan *et al*, 1994). Navier Stokes' equations are commonly used to define the conservation of momentum (Rodi, 1984).

Conservation of thermal energy and species concentration

This takes into account the thermal energy change associated with chemical and biological reactions in a given volume of water which can result in an increase or decrease of species concentration.

2.6.1 Mixing Model Types

There are several different types of mixing models to study the behavior of a physical, chemical, or biological substance in a river, and include:

- one, two, and three-dimensional models;
- near and far-field models;
- steady state, quasi-dynamic, and dynamic models;
- conservative and non-conservative pollutant models;
- point and non-point source models.

Most current mixing models include in whole or in part, the one, two, or three-dimensional formulation.

longitudinal, vertical, and transverse. These models are versatile and can be used for lakes, esturarites, or rivers. They can also be used to describe complex situations in these water bodies, such as jets and temperature stratification. These models generally require extensive amounts of data to run which is both time-consuming and expensive to collect. Some examples include; CTAP, MEXAM, WASTOX, TOXIWASP, and TOXIC (Phan *et al*, 1994).

Two-dimensional models can be broken into two types - longitudinal and transverse or longitudinal and vertical. The longitudinal and transverse models are used primarily in wide, shallow rivers, where the vertical mixing is rapid in comparison to the other mixing directions, thus the model is depth averaged. Examples of this model type is TRSMIX and RIVMIX (Putz, 1983; Phan *et al*, 1994). The longitudinal and vertical models are used in cases where the transverse mixing is assumed uniform. Examples of this type are SERATRA and FETRA (Phan *et al*, 1994).

One-dimensional models are very limited for they assume that changes occurring in two of the three dimensions are uniform. This is the most simplistic approach, thus it can not account for many factors effecting a pollutant in a water body. Some examples of one-dimensional models include; QUAL 2E, WQAM, SLSA, MICHRIV, and WASP 4.1 (Phan *et al*, 1996).

The TRSMIX model was chosen for this project, which was created by Putz (1983). This model is very applicable to the North Saskatchewan River, for it is a shallow, wide river. It has been been used in other studies on this river with good results (Smith, 1986; Milne, 1991).

TRSMIX is based upon an implicit finite-difference approximations of the one-dimensional steady-state advection-diffusion equation (Putz, 1984). The finite-difference approximations were first introduced by Stone and Brian (1963), and were later used by Lau and Krishnappan (1981). Lau and Krishnappan (1981) were able to use this method to examine steady-state transverse diffusion in natural channels, and investigate the sensitivity of different diffusion factor formulations (Putz, 1984). TRSMIX is very similar to the model used by Lau and Krishnappen, but was able to incorporate a first order decay term and used the metric coefficients proposed by Sayre and Chang (1976), with the longitudinal axis following the line of flow (Putz, 1984). Finally, the TRSMIX model is broken into a streamtube formulation in order to account for more natural hydraulics.

The model TRSMIX was used for a mixing simulation of the North Saskatchewan River, with five major outfalls between E.L. Smith and Rossdale as point sources of pollution. Only five of the 85 outfalls were used in this study. This does not say the other 80 outfalls are of no concern, it was just impractical to include all of them in the model (Yaremko and Stanley, 1994). This model was used in two previous studies, one on chlorine decay from the effluent of the water treatment plants (Milne, 1991). The second study was done in Smith's (1986) report on microbial levels between the E.L. Smith WTP and the Rossdale WTP as part of the Water Quality Study by S.E. Hrudey (1986) for the City of Edmonton.

2.7 Microbiology

Biological pollution is one of the most widespread impairments of surface water its sources are normally urban discharges as combined sewer overflows, storm water, and effluents or bypasses of wastewater treatment plants (Marsalek, 1994). Previous studies (Makepeace *et al*, 1995), have shown that bacteria levels found in storm water discharges were close to those of diluted sanitary sewage. During a storm event, an abundance of dry weather, allowing the concentration of pathogens to be much greater.

The primary focus of this study was to monitor and model the microbial levels affecting the Rossdale WTP during dry weather. This included identifying the potential for microbial levels, choosing appropriate indicators, and looking at the fate of the indicators involved.

2.7.1 Indicator Organisms

Before choosing indicators for this study, one had to first understand the intent of indicators and what it means to choose a certain indicator. An indicator is defined as 'something which points out or gives information' (Webster's Encyclopedic Dictionary, 1988). Thus an indicator is used to help identify what is in surface water that can have potential impacts on human health or the environment.

When studying surface water, pathogens should be assumed present, for it is very unlikely to have a natural source of water, one hundred percent pathogen free.

To test for all known pathogens in a water source would be very difficult due to the time, labour, and costs involved in such a task. Therefore a simpler approach is used in which indicator organisms are monitored. The presence of an indicator in the water source would give rise to the possible presence of pathogens related to the indicator.

The following are a criteria list for indicator organisms which *should* be met before they are used to help indicate the presence of pathogens or harmful organisms (McFeters *et al*, 1977):

- the indicator should always be present when the pathogen of concern is present
- the indicator should be absent when the pathogen of concern is absent
- the indicator should respond to natural environmental conditions and to treatment processes in a fashion similar to the pathogen of concern
- the indicator should be easy (and inexpensive) to isolate, identify and enumerate

to allow unambiguous identification of the group/species

- the indicator should be a transient and not permanent occupant of the ecosystem being measured
- the indicator and pathogen should be from the same original source (e.g. gastrointestinal tract).

Unfortunately there are no indicators currently available to match such a strict set of criteria, instead it becomes a matter of using the 'best' indicator, or one that matches most of the criteria. For the North Saskatchewan River the current and most used indicator for raw water is the total coliform group and the fecal coliform group.

The intent of indicators was never meant to index the presence of pathogens but, rather, to identify a potential health risk to the users of the water source. Thus the presence of an indicator in a water source may identify poorer water quality, but does not necessarily indicate the presence of pathogenic bacteria (Cabelli, 1978; Saskatchewan Environment, 1984).

There is current work to move away from the indicator system with the use of gene probes, or Polymerase Chain Reaction (PCR) techniques. This new technology can be used for rapid detection. Unlike the indicator system, this technique could be automated for sampling. The drawbacks of this system are that it is in the early stages of development. It is a new technology and thus is expensive and not fully accepted in industry and government. Until the gene probes can prove their validity there will be a continued use for indicator organisms.

2.7.1.1 Indicator Species

There are several different indicator species which have been used and many more which are being investigated for use as indicator species (see Table 4). Currently there is no global standard indicator for water treatment or waste investigation. The European Community tends to use *Escherichia coli* (which is part of the fecal coliform group) as a fecal indicator (Cabelli, 1978).

With all the different indicators that can be used, the most common in use today is the coliform group. Some indicators, like *E. coli* and enterococci have been found to be a better indicator in relationships between gastrointestinal illnesses (GI) and presence of fecal pollution, compared to the coliform group. In 1986 the USEPA recommended to switch from total coliform to *E. coli* and enterococci as indicators. However, with lack of direction and help, most States have remained using total and fecal coliforms as their main indicators.

Table 4. Microorganisims as Indicators
(modified from Cabelli, 1978)

Indicator	Sources					Indicator Potential					
Coliforms	F	S	I	R	A			S			
Escherichia coli	F	S				P	F	S	A		
Klebsiella sp.		S	I	R	A	P		S			N
Enterobacter sp.		S	I	R	A			S			
Citrobactoer sp.		S	I	R	A			S			
Fecal coliforms	F	S	I	R	A		F[1]	S	A	D	
Enterococci	F	S		[2]			F	S		D	
Clostridium perfringens	F	S		[2]			F	S			
Candida albicans	F	S				P	F	S			
Bifidobacteria	F	S					F	S	A	D	
Enteroviruses	F	S				P					
Salmonella sp.	F	S				P					
Shigella sp.	F	S				P					
Coliphage		S[1]			[2]			S			
Pseudomonas aeruginosa		S	I	R	A	P		S			N
Aeromonas hydrophila		S	I	R	A	P		S			N
Vibrio parahemolyticus					A	P					N

Sources; (F) feces of warm-blooded animal; (S) sewage; (I) industrial waste; (R) runoff from uncontaminated soils; (A) fresh and marine waters.
Indicator Potential; (P) pathogen; (F) fecal; (S) sewage; (A) separation of human and lower animal sources; (D) proximity to fecal source; (N) indicator of nutrient pollution.
[1] Questionable
[2] Require more study

Sampling for various forms of inorganic and organic compounds is becoming faster with more technological advances. Biological sampling however, has been overlooked, mainly due to the high uncertainties involved in sampling techniques. Attempts have also been made to correlate Fecal Coliform (FC) levels during dry weather flow with TSS, VSS, BOD, and TC so as to quantify water conditions faster. These relationships were found to be largely storm sewer dependent as well as seasonally dependent with no real strong correlation (Ashley and Dabrowski, 1995).

A major question associated with monitoring fecal pollution in raw water sources is the pollutant origin. The most common indicators used cannot distinguish the difference between human and animal fecal pollution. Thus recent discoveries of the indicator *Rhodococus coprophilus* are very good for it has been found to be highly specific for animal excreta. While sorbitol-fermenting bifidobacteria, and *Bacteroides fragilis* HSP40 phages have been found to be highly specific for human excreta (Jagals *et al*, 1995). Therefore, it is possible to distinguish between animal and human fecal pollution with indicators, but the cost associated with the distinction is still quite high.

Other less costly attempts were made at detecting specific human-enteric bacteria with the use of indicators or ratios of several common indicators; fecal coliform/fecal streptococci; *P. Aeruginosa*/fecal coliform; *Clostridum perfringes*/fecal coliform; Fecal sterols (eg. *Epicoprostanol* and *coprostanol*); species specific bacteriophages (eg. RNA coliphages, bacteroides fragilis phages); Genus bifidobacteria species (Field *et al*, 1993). These extensive investigations have found that the species and their relationships all have limited, specific use, not a general use which is needed the most.

In a detailed study (Whipple *et al*, 1983) of raw surface water and urban storm sewers four main pathogenic organisms were identified. These pathogens were compared to total coliform, fecal coliform, fecal streptococci, and enterococci in order to identify a pattern of the ratio with enterococci, for it has the lowest ratio with each of the four pathogens found. This would suggest enterococci as a good indicator.

The most popular ratio used with indicators has been the relationship of fecal coliform to fecal streptococci (FC/FS). It was believed to differentiate between human and animal fecal origins, for humans a ratio of four, and animals a ratio of less than one. However, recent studies (Whipple *et al*, 1983), like one in Baltimore, have demonstrated that this ratio is not very reliable for storm water. Fecal coliform tests were performed on 136 storm sewers, of which 123 had levels that exceeded 2000cfu/100mL. From these tests, 94% of the storm sewers had a FC/FS ratio of less than four. In the combined sewers studied, only 15% had a ratio greater than four. Finally raw sewage was tested and found only 50% of the samples had a ratio greater than four. Thus it has been recommended not to use the FC/FS ratio to differentiate between human and animal excreta, for the uncertainty and chance for error runs quite high (Standard Methods, 1995; Smith, 1986).

Table 5. Ratios with Pathogens to Common Indicators
(modified from Whipple, *et al*, 1983)

Species	Ratio
P. aeruginosa to Total Coliform	1:45
P. aeruginosa to Fecal Coliform	1:14
P. aeruginosa to Fecal Streptococci	1:18
P. aeruginosa to Enterococci	1:5
Staphylococus aureus to Total Coliform	1:4780
Staphylococus aureus to Fecal Coliform	1:1410
Staphylococus aureus to Fecal Streptococci	1:2000
Staphylococus aureus to Enterococci	1:630
Salmonella to Total Coliform	1:141000
Salmonella to Fecal Coliform	1:105000
Salmonella to Fecal Streptococci	1:147000
Salmonella to Enterococci	1:45500
Enteric virus to Total Coliform	1:151000
Enteric virus to Fecal Coliform	1:50000
Enteric virus to Fecal Streptococci	1:85500
Enteric virus to Enterococci	1:40700

2.7.1.3 Coliform Group

The coliform group was first discovered more than one hundred years ago, originating in 1880 with Von Fritsch when he described *Klebsiella pneumonia* and *K. rhinoscleromatis* as organisms characteristic of human fecal contamination (Wolf, 1972). Since that time, the coliform group has been used as an indicator of fecal pollution. Several attempts have been made to correlate members of this group more closely with human fecal contamination which is most important for pollutant monitoring and wastewater treatment. This resulted in the development of the fecal coliform indicator test.

Most current water quality standards around the world are written in terms of total and fecal coliforms, despite recent investigations which are questioning their validity as good indicators. The coliform group has been used extensively because they are easily measured in the laboratory and not generally found in unpolluted waters. Their count has been well correlated with fecal pathogenic contamination.

2.7.1.3.1 Total Coliform

Standard Methods (1995) defines total coliforms as all of the "aerobic and facultative anaerobic Gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C, as per the multiple tube fermentation" (Standard Methods, 1995). According to the membrane filtration procedure, members of the coliform group are defined as all organisms which produce a dark colony (generally purplish-green) with a metallic sheen within 24 hours of incubation (on an appropriate medium and at the corresponding temperature for the medium) (Standard Methods, 1995).

Total coliforms are a large group of bacteria that may be found in soil or water and in the feces of warm blooded animals. The following isolates have been identified for total coliform; *Citrobacter* (*C. freindii*, *C. diversus*), *Enterobacter* (*Enter. Aerogenes*, *Enter.*

rhinoscleromatis, *K. oxytoca*, *K. ozaenae*, *K. planticola*, and *K. terrigena*)

High levels of total coliforms are indicative of poor water quality but do not indicate if the water has pathogenic properties. Thus total coliform data alone is not a good indicator for evaluating health risk from storm sewers.

2.7.1.3.2 Fecal Coliform

Fecal coliforms are defined according to the membrane filtration technique as those bacteria that produce a variety of blue colonies on M-FC (an enriched lactose medium) medium, within 24 hours, incubated at 44.5 (±0.2°C) (Standard Methods, 1995).

Fecal coliforms are a group of bacteria that are found primarily in the intestine of warm-blooded animals. Fecal coliforms were believed to be comprised of 95% *E. coli*, and 5% *A. aerogenes* or *E. freundii* species (*Enterobacter - Citrobactor*), (Cabelli, 1978). In reality, *E. coli* has only been found to make up 1/3 to 1/4 of fecal coliforms. The remainder was found to be *Klebsiella*, *Enterobacter*, and *Citrobacter*, of which all three can be readily found in soils and vegetation. It was believed that fecal coliforms will not multiply outside the intestinal tract of warm-blooded animals, but recently the *Klebsilla* sp. has been recovered in a variety of places outside the intestine. They have been found in storm sewer sediment, pulp mills, textile finishing plants, and industrial effluents high in carbohydrates (Cabelli, 1978). These studies have shown growth occurring in nutrient rich storm sewer sediment, in which both fecal coliform and fecal streptococci can survive for up to six days.

Despite these new findings, fecal coliforms have been found to be the "best" indicator for "quickly" identifying polluted water. In their absence the water column may still contain harmful pathogens. However, the presence of fecal coliforms may be a strong indicator of the presence of fecal material in the water or the presence of enteric pathogenic bacteria.

problems in surface water testing.

2.7.1.4 Limitations of Indicators

There are limitations in using indicators to identify the quality of a water source, limitations which must be respected, if not respected, the results can be speculations on incorrect measures. The coliform group has the following limitations:

- They may not be detected when in small numbers in large volumes of water
- If non-coliform bacteria are present, interferences may occur
- With nutrients present, coliforms have the ability to replicate in natural water systems
- Species other than coliforms were able to re-establish after chlorination, and included Achromobacter, Pseudomonas, Vibro, and Moraxella (Andreychuk, 1980)
- In the absence of coliforms, pathogens may still be present in the water
- Fecal coliforms are not specific for enteric bacteria
- Coliforms can not distinguish between human and non-human pathogens
- If there is a failure of growth on the media plate, it does not mean the indicator is absent; it means the cells could not adapt fast enough to grow in laboratory conditions. Also, the injured cells which 'could be' viable, do not necessarily grow in the medium within the time frame set forth by Standard Methods.
- False positives can make a minor problem seem worse than it really is
- A positive test will not identify the transmittance of the pathogenic organisms

The World Health Organization found that bacterial indicators were unsuitable for viruses, encysted protozoa, and helminths. Therefore, if fecal wastes are found and the origin is unknown, viruses and protozoa cysts in the water should be considered possible even if the indicator bacteria identify little to no counts (Payment, 1986; Smith, 1986). The current indicators fail to identify or warn of the total pathogenic potential in water, but there are no indicators to date that have the ability to identify every possible health hazard or potential health hazard.

2.7.2 Storm Water Microbiology

When high concentrations of microbes are found in storm water, there becomes a high priority to identify the origins and any pathogenic properties. Pathogens that enter the *et al*, 1994):

- soil runoff (land wash)
- plants (vegetation)
- domestic pets
- wildlife (birds)
- sanitary line leaks
- cross-connections (or interceptor diversions) with raw sewage
- inefficient solid waste collection and disposal, accumulation of sediment (in sewers), rodents in sewers, and
- growth of bacteria in the nutrient rich storm sewer system.

There are numerous species of infectious agents in the water column, for most water sources. There are four broad groups: bacteria, viruses, protozoa, and helminths (Geldreich, 1996; Geldreich, 1972; Toxcon, 1992; Payment, 1986; Field *et al*, 1993; Andreychuk, 1980). The following is a list of species broken into the four groups that have been found infectious or viable in water sources:

Viruses

- Adenoviruses (31 types)
- Enteroviruses (71 types)
- Hepatitis A
- Norwalk agent
- Reoviruses
- Rotavirus, and
- Coxsackie virus

Bacterium

- *Acinetobacter* (sp.)
- *Aeromonas hydrophila*
- *Alcaligenes* (sp.)
- *Bacillus cereus*
- *Campylobacter coli*
- *Campylobacter jejuni*
- *Citrobacter freundil*
- *Clostridlum perfringens*
- *Enterobacter aerogenes*
- *Enterobacter agglomerans*
- *Enterobacter cloacae*
- *Enteropathogenic E. coli*
- *Escherichia coli*
- *Flavobacterium* (sp.)
- *Hafnia alvei*
- *Klebsiella oxytoca*
- *Klebsiella ozonae*
- *Klebsiella pneumophila*
- *Legionella* (sp.)
- *Legionella pneumophila*
- *Leptospira*
- *Moraxella* (sp.)
- *Mycobacterium avium-intracellulare*
- *Mycobacterium chelonae*
- *Mycobacterium fortuitum*
- *Mycobacterium gordonae*
- *Pasteurella multicida*
- *Proteus* (sp.)
- *Pseudomonas aeruginosa*
- *Pseudomonas cepecia*
- *Pseudomonas fluorescens*
- *Salmonella* (1700 species)
- *Serratia* (sp.)
- *Shigella* (4 species)
- *Staphyloccus aureus*

- *Streptococcus faecalis*
- *Streptococcus fecium*
- *Tularemia*
- *Tuberculosis*
- *Vibrio cholerae* (Cholera)
- *Vibrio fluvalis*
- *Yersinia enterocolitica* (Gastroenteritis)

Protozoa

- *Balantidium coli*
- *Entamoeba histolytica*
- *Giardia lamblia (G. lamblia, G. duodenalis, G. muris, G. Agilis)*
- *Cryptosporidium* (*C. parvum* and *C. Muris*)
- amoebae
- *Naegleria gruberi*

Helminths

- *Ancylostoma duodenale* (Hookworm)
- *Ascaris lumbricoides* (Roundworm)
- Echinococcus ganulosis
- Enterobius vermicularis
- *Necator americanus* (Hookworm)
- *Strongyloides stercoralis* (Threadworm)
- Taenia (species)
- *Trichuris trichiura* (Whipworm)
- *Hymenolepis nana* (Dwarf tapeworm)
- *Taenia saginata* (beef tapeworm)
- *Schistosoma*

An important component in the strategy of controlling waterborne diseases is to avoid the contamination of surface water with feces (Jagals *et al*, 1995). Thus, in densely populated areas with inadequate sanitation (discharging directly to surface water), there could be a primary source of surface and ground water contamination. The contributions of pathogens to surface water via storm outfalls (see Table 6) have been well documented. From these recorded levels, it is evident how wide variations are hard to monitor and control.

(modified from Makepeace *et al*, 1995)

Species	cfu/100mL unless otherwise stated	Properties / Features
Pseudomonas aeruginosa	1.0 to 1.1×10^7	Opportunistic, non-enteric pathogen found in soil and on plants
Escherichia coli	12 to 4.7×10^3	Main component of human feces, but also found in feces absence
Salmonella	4.5×10^3	Domestic animals are the main source, thus if fecal coliforms >2000cfu/100mL, there is a 97.6% chance Salmonella is present
Shigella	Unrecorded	Isolated in wastewater and urban runoff, this is the main source of recreational water pollution
Klebsiella	4.0×10^3 to 1.9×10^5 (in sediment)	Two main components; *K. Pneumoniae* & *K. Aerogenes*, are found to grow in organic rich environments, and give positives for total coliform and fecal coliform tests
Yersinia enterocolitica	Unrecorded	Wild animals are the main source, thus the presence in storm sewers is assumed
Staphylococcus aureus	1.0 to 1.0×10^3	Opportunistic pathogen, can survive for long periods of time in water
Viruses	1.0 to 10^4 /10 L	There are 118 known types of human enteric viruses, of which they are negative for the total and fecal coliform tests
Fungi	6.0×10^2 to 1.2×10^7 organisms/100mL	Could not be identified as invasive, pathogenic, or saprophytic, just present in high levels.

2.7.2.1 Population Effect on Storm Water

With the average human discharging approximately 4 billion fecal coliforms per day (10^4 to $>10^7$ per gram of feces) (Geldreich, 1978) and neglecting die-off, this amount would result in exceeding the standard of 200 fecal coliforms/100mL for over one and a half million litres of water per day. If you assume warm blooded animals can discharge an equivalent (based on weight), the improper disposal of human wastes through overflows or illicit connections and animal discharge entering the storm sewers, can easily degrade the water quality (McCarthy & Mercer, 1995; Gehm *et al*, 1976).

Pathogens present in human wastes (feces) are highly dependent on the health status of the people in the community where the wastes originate. For a healthy person the bacteria present in the feces can contain 1 to 1000 million per gram of; enterobacteria, enterococci, 1996). With such varying concentrations of microorganisms, the fate and die-off are important factors that need to be understood.

2.7.3 Fate and Die-off of Microorganisms

The distance between an upstream discharge and downstream intake is termed a buffer zone. This is an area which should have the ability to remove harmful pollutants without lasting damage to the water column. All water sources have what is called an assimilative capacity, or the ability to handle pollutants and self-purify the water. This is a very complex system, of which bacteria assimilation is a very small part. Bacteria have the ability to adapt, die (decay), or become dormant. Without knowing the exact concentration of the bacteria that requires treating, there becomes an increased health risk involved with the treatment process. The die-off process is of most interest in a water system and there are several processes in which die-off or removal of bacteria can happen (Nemerow, 1991; Geldreich, 1996);

- sedimentation (results in the appearance of a decrease, but microbes can survive longer in sediment, compared to the water column above, thus resuspension can become a problem)
- protozoa (which ingest bacteria)
- nutrient deficiencies (less in the water than on the media plate in the laboratory)
- water temperature (normally lower than optimal growth)
- UV-radiation (has bactericidal properties)
- bacteriophage (destruction occurs when rapid multiplication of bacteria exits)
- industrial toxic waste (results in a rapid die-off)
- dilution effect (appears as less bacteria with more stream flow)
- pH (optimal growth pH can be changed due to pollution)
- salinity (can effect growth mainly in esturaries)

Each method of removal is complex in itself and can be hampered in a variety of ways, such as (Nemerow, 1991; Geldreich, 1996);

- excess nutrients (can provide protection, by hampering the disinfection process in water treatment)
- resuspension (from sedimentation)
- industrial food waste (can provide the excess nutrients needed)

disinfection)

2.7.3.1 Die-off Rate Coefficients

There are two common ways to denote bacteriological die-off; one is through a die-off coefficient (log or natural log); and the other through inactivation time. The die-off coefficient used in the TRSMIX model is based on Chick's Law, defined as a first order die-off equation, and expressed as;

$$N = N_o e^{-kt}$$

The die-off coefficient (k) is commonly reported as an hourly or daily rate constant. The inactivation time, denoted as T_{90} is the time required to obtain 90% mortality of the bacteria population. Inactivation time can be converted to a natural log based die-off rate constant though the equation;

$$T_{90} = 2.303/k_e$$

The inactivation time for coliform bacteria is considerably less in saline water (e.g. estuary, sea, or ocean) than for freshwater (Wolf, 1972). This study recorded ranges of die-off coefficient values, with sea water having a typical die-off coefficient (natural log based) range of 92.12 to 6.91 per day (T_{90} range of 0.6 to 8 hours). The typical die-off coefficients for fresh water (natural log based) were found in the range of 2.76 to 0.48 per day (T_{90} range of 20 to 115 hours). A more detailed search was performed to find other studies reporting die-off coefficients in both laboratory and field studies (refer to Appendix C for complete listing). From this search several die-off coefficients for total coliforms, fecal coliforms, and *E. coli* have been found, reported in studies from around the world (see Table 7).

(Values of coefficients are reported as base *e*, per day)

Species	Water Source	Field	Laboratory
Total coliform	River - fresh	0.39 to 3.32	
	Lake - fresh	0.46 to 11.52	1.14 to 7.2
	Groundwater - fresh	0.021	0.979
	Bay - sea water	0.330 to 230.26	0.322 to 1.176
Fecal coliform	Sediments - fresh	0.004 to 0.012	
	Lake - fresh		0.30 to 1.66
	Runoff - fresh	0.239 to 1.07	
	Estuary - sea water	29.1	
	Bay - sea water		33.8 to 221.05
E. coli	River - fresh	0.8 to 1.796	0.138 to 1.386
	Lake - fresh	0.192 to 0.755	
	Bay - sea water	0.337	0.078 to 3.076

2.7.4 Microbiology of the North Saskatchewan River

Almost fifty years ago the first water quality study was performed on the North Saskatchewan River (1950-51). This report found low dissolved oxygen levels, high bacterial counts, odors, visible garbage, and oil slicks all downstream of Edmonton (Bouthillier, 1984; Reynoldson, 1983). From these early studies, water quality concern focused on the source of biological pollutants which were believed to originate from Gold Bar, Edmonton's Wastewater Treatment Plant (WWTP). More recent investigations (Mitchell, 1994b; Logsdon, 1986), however, have shown that a substantial release of microorganisms from storm sewer discharges occur upstream of the Gold Bar WWTP. Discharges from these storm sewers have been noted to include a multitude of microorganisms including direct and opportunistic pathogens. These previous studies have demonstrated an apparent trend in the biological counts as the river passes through Edmonton (see Table 8).

Table 8. Past Water Quality in the North Saskatchewan River
(Mitchell, 1994b; Logsdon, 1986; Bouthillier, 1984)

Indicator	Median Concentration, cfu/100mL	
	Upstream of Edmonton	Downstream of Edmonton
Fecal Coliforms	<4	160
Total Coliforms	24	1580
	E.L. Smith	Rossdale
Total Coliforms	200	4000

It was found that at the E.L. Smith WTP, the fecal coliform guideline have consistently been met, but at Rossdale there have been several reported excursions over the fecal coliform guideline limit (Toxcon, 1992). Thus the outfalls of most concern are located between these two water treatment plants. In spring and during storm events, there are reported peaks in coliform levels but there also remains a background level of coliforms throughout the year (Coleman *et al*, 1974; Smith, 1986).

2.7.4.1 Health Effects to Potential Users of the River

From different independent health risk assessments of the raw water used at the Rossdale WTP, three main recommendations were made; relocate the intake, upstream watershed management, and storm sewer effluent management (Hrudey, 1986; Toxcon, 1992). Since it is impossible to eliminate all potential health risks from a river, the best thing to do is then reduce the risk to an acceptable level set forth by the consumers of the drinking water supply. With discharges from storm sewers occurring over extended periods, cause and effect relationships are very difficult to observe or understand. With activity in the river increasing, the need to understand the potential risks have likewise increased. Thus epidemiological studies are severely lacking with respect to the pathogen potential of storm water that is discharged from various watershed types (Field *et al*, 1993; Field & Pitt, 1990).

swimming, fishing, or boating. Recreational contact and ingestion of polluted waters can results in:

- Eye infections (pinkeye and conjunctivitis)
- Ear infections (swimmers ear)
- Nasal infections (colds and sinus infections)
- Skin infections (swimmers itch, shicistsoma, gonococcus infection of the eyes)
- Gastrointestinal (*Giardia lamblia*, *Cryptosporidium*, etc.).

2.7.4.2 Treating the Raw Water

Potable water is not sterile, and was never intended to be. Instead two objectives are set, the first being the ability to treat the water so as to reduce the health risk to the lowest extent possible. The second objective is for taste and odor of the treated water to be acceptable by the end consumer (Geldreich, 1996). In order to reduce the health risk, human pathogens must be removed, which can include viruses, bacteria, protozoa, helminths, and fungi. There are a wide range of treatments that can be used to reduce the pathogen level, and these include: sedimentation, coagulation/flocculation, filtration, and disinfection. The disinfection (or treatment) process is of most importance and can include; heating, chlorine (chlorine dioxide), ozone, extreme pH's, iodine, and ultra violet radiation.

A field study undertaken as part of this research consisted of a preliminary survey, a trial sample run, and two full sample runs. The preliminary survey consisted of determining the location of cross sections and river depth soundings. The trial sample run was performed on August 13, 1996 and only samples from the first cross section were collected. This trial was done in order to determine an appropriate dilution range for the samples collected over the entire study area. The full sample runs were performed on August 22 and 28, 1996 (river flows of 118 and 191 m^3/s respectively). These days were chosen based on the prior dry weather record. Prior to August 22, 1996 sample run, there were four days of no precipitation (Appendix H). Prior to August 28, 1996 sample run, there were 10 days of no precipitation (Appendix H).

3.1 Preliminary Survey

Over a period of several weeks, the study reach, which consisted of the North Saskatchewan River from the E.L. Smith WTP to the Rossdale WTP was thoroughly investigated. After examining the inputs of storm water, and structures on the river in this reach, the study area was broken into ten stations which are identified on the drawing of the river reach and aerial photos (refer to Figure 4 and Figure 5). Station ten was located on a transect of the intake at the E.L. Smith WTP and station one was located on a transect of the approximate location of the new intake for the Rossdale WTP.

3.2 Station Investigation and Marking

Sites that were easy to locate were chosen. These sites had several outfalls within their. The stations were all staked with wooden markers and survey tape so that they could be located from the centre of the river. Cross section characteristics were determined with a Raytheon echo sounder (results are recorded in Appendix A). Also, width measurements were taken with a Topofil®, and distance measurements with a

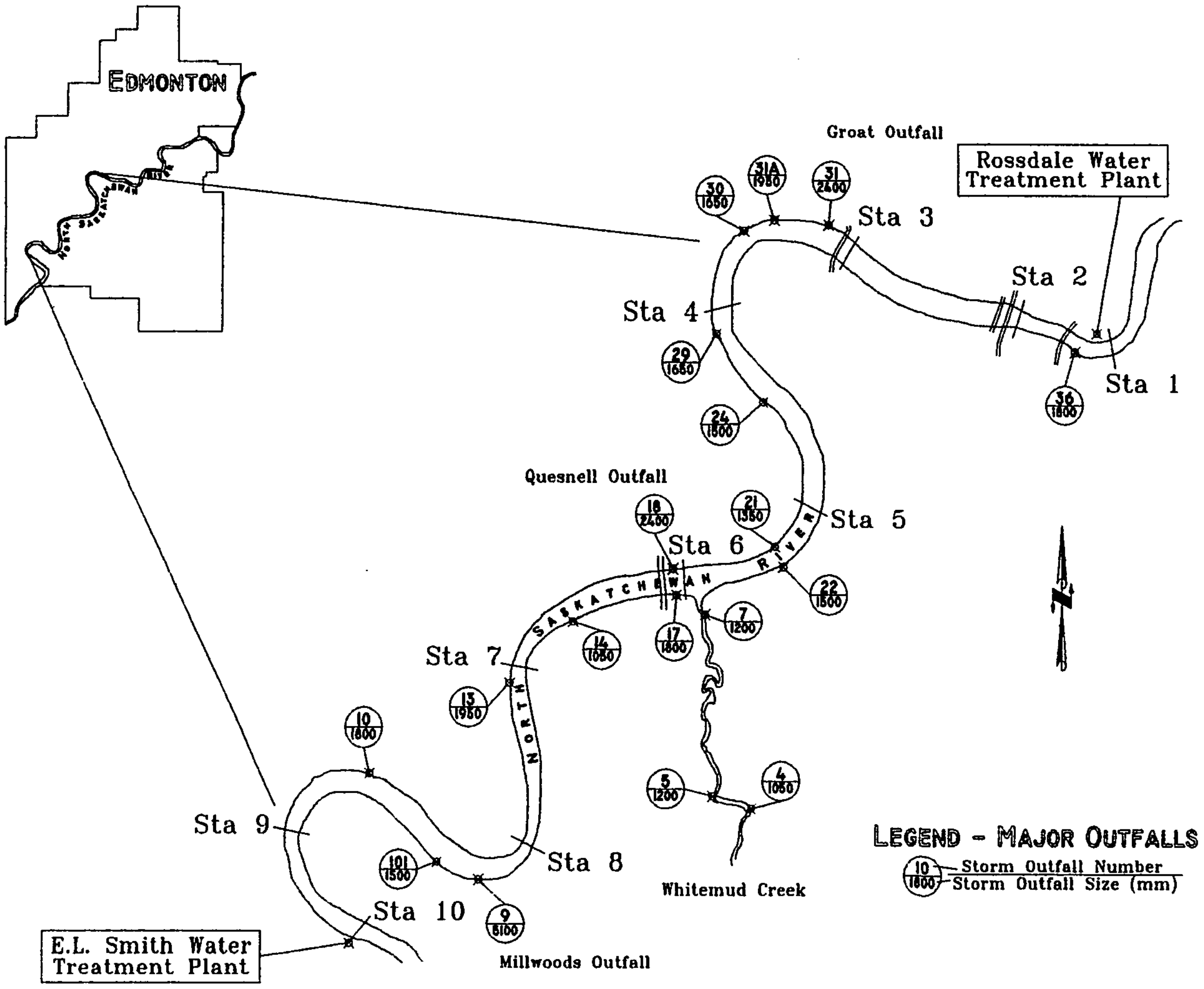


Figure 4. Station and Storm Sewer Locations

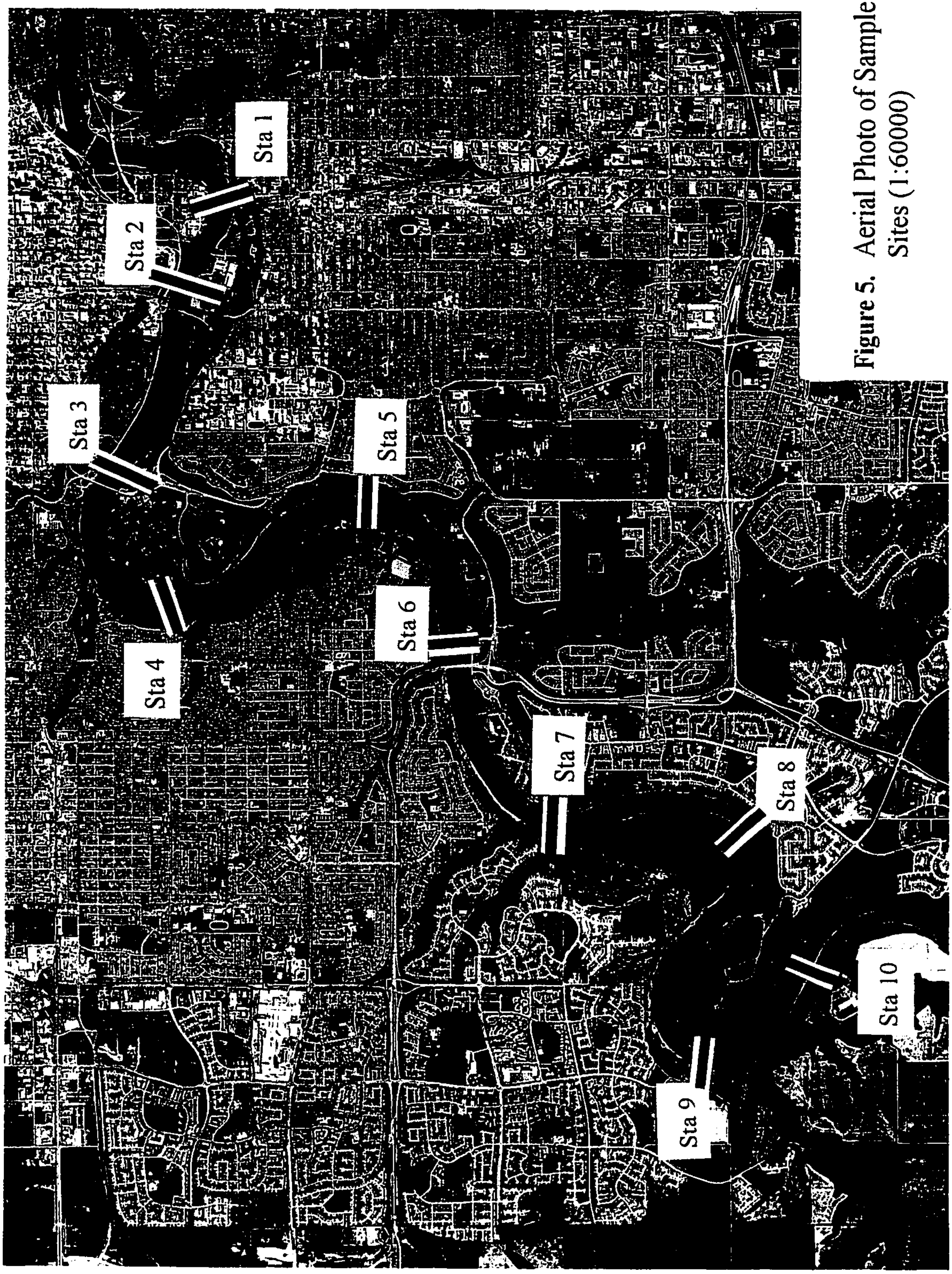


Figure 5. Aerial Photo of Sample Sites (1:60000)

measurements were compared with aerial photos to confirm the distances recorded which gave bank to bank width measures of the river at each of the ten stations (see Table 10). The soundings and distance measurements were used in the TRSFLO portion of the TRSMIX model.

Table 9. Distance and Width of Sample Stations

Station	Width (m)	Distance to Station Downstream (m)
10	125	1333
9	140	3417
8	119	1610
7	134	2111
6	220	1671
5	147	2342
4	156	1944
3	185	1979
2	178	1071
1	120	-

3.3 Sample Procedure

Following the identification and hydraulics of each station recorded, the next stage of the study, consisted of gathering samples for total coliforms, fecal coliforms, and ammonia. Field sampling was performed by following guidelines set forth by Environment Canada in Sampling for Microbial Analysis (Environment Canada, 1983). The handling of collected samples and laboratory procedures were executed according to Standard Methods (1995).

A sixteen foot Lund boat with an outboard motor was used to move from station to station collecting samples. Several coolers were loaded into the boat which contained pre-marked Nalgene bottles and numerous ice packs. The screw top Nalgene bottles were autoclaved prior to sampling with approximately 0.5mL of a 10% sodium thiosulfate solution to eliminate residual chlorine in the water. All samples collected were taken to

Standard Methods (1995).

3.3.1 Sample Locations

At each cross section nine samples were collected at transverse locations (shown in Table 10). At all points the samples were collected once with the exception of station 5 where all of the sample points were collected in triplicate for statistical purposes. All transverse sampling locations were the same for each of the two sample runs (August 22 and 28, 1996).

Table 10. Station Sampling Point Locations
(all distances going from left to right bank looking upstream)
Units are in metres

	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Bank	0	0	0	0	0	0	0	0	0	0
Point 1	12	18	19	16	15	22	13	12	14	13
Point 2	24	36	37	31	29	44	27	24	28	25
Point 3	36	53	56	47	44	66	40	36	42	38
Point 4	48	71	74	62	59	88	54	48	56	50
Point 5	60	89	93	78	74	110	67	60	70	63
Point 6	72	107	111	94	88	132	80	71	84	75
Point 7	84	125	130	109	103	154	94	83	98	88
Point 8	96	142	148	125	118	176	107	95	112	100
Point 9	108	160	167	140	132	198	121	107	126	113
Bank	120	178	185	156	147	220	134	119	140	125

With the use of the boat, samples were collected across the width of the river at the appropriate distance, approximately one third of a metre below the water surface. Closer to the banks, the samples were taken by walking so as not to ground the boat during this low water sampling time. All samples were collected in the moving waters using the sterilized 500 mL Nalgene bottles. The bottles were lowered into the river and at the appropriate depth, the top was unscrewed, allowing water to fill the bottle. Once the bubbles stopped, the cap was screwed back on, allowing the bottle to be withdrawn without contamination from the air or the surface of the river. Upon collection, the bottles were given to a person who transported them to the laboratory where processing began immediately or the sample was refrigerated until analysis could begin. Sample accuracy was maintained by analyzing them within 20 hours after collection.

Additional samples were collected from the Millwoods (30th avenue) outfall, the Quesnell outfall, Whitemud Creek, and the Groat outfall (refer to Figure 4). Millwoods outfall is located just upstream of station eight, on the right bank side (left to right looking downstream). The Quesnell outfall is located just upstream of station six on the left bank side, while Whitemud Creek enters the river just downstream of station six, on the right bank side. Finally, the Groat outfall is located just upstream of station three, on the left bank side of the river. These sample collections were not part of the original sample plan but the results proved interesting enough to justify their collection. The samples from the Quesnell and the Groat outfalls were taken directly from the flow, before entering the River, while the Millwoods outfall was sampled approximately two metres into the confluence. This was done because direct sampling was impractical and unsafe. Whitemud Creek was sampled approximately fifty metres upstream of the confluence with the North Saskatchewan River to avoid any mixing effects with the river.

3.3.2 Sampling Errors

By selecting single locations along this reach of river to sample, a bias is introduced, due to the natural state of bacteria. Unfortunately, there are no current possible methods of continuous measurement of coliform loading. Also, by selecting a single day to sample, it is possible to miss certain sanitary sewage flows and industrial drainage, that can occur on an unpredictable schedule.

All microbial densities were determined using the membrane filtration method as per Standard Methods (1995). Ammonia determination was performed using the phenate method, as defined in Standard Methods (1995). Standard Methods procedures are listed in Table 11.

Table 11. Laboratory Testing

Analysis	Standard Methods
Total Coliforms	Section 9222B Standard Total Coliform Membrane Filter Procedure
Fecal Coliforms	Section 9222D Fecal Coliform Membrane Filter Procedure
Ammonia	Section 4500-NH_3 Nitrogen (Ammonia); 4500-NH_3 F. Phenate Method

4.1 Total Coliform

Using the membrane filtration procedure, the following dilutions were used to determine the concentration in the river and storm sewers sampled; 10^{-2}, 10^{-1}, 1, 10, 25 for run one, and 10^{-2}, 10^{-1}, 1, 10, 50 for run two. The mEndo agar was prepared and used as the media for total coliform incubation according to the manufacture's specifications. The results of the total coliform samples from the river are summarized in Table 12. The data are also summarized in surface charts that demonstrate the trend of total coliforms in the river. For the first sample run (Figure 6) there were low levels of coliforms until station seven, then the counts increased as the river flowed through more stations. The majority of the high concentrations of coliforms were found close to the left bank. For the second sample run (Figure 7) a much different profile was seen, with a small increase at station eight, down past station seven on the right bank. On the left bank it was very apparent that there was a high concentration entering the river just upstream of station six, and this remained apparent down to station one. A flux chart was also prepared (Figure 8) to demonstrate the variability of total coliform number in the flow between each of the stations. From the results of both sampling runs there was an approximate rise of total coliform levels of 6×10^8 total coliforms per second.

		Count, cfu/100 mL			
		Sample Run 1		Sample Run 2	
Station	Point	Total Coliform	Fecal Coliform	Total Coliform	Fecal Coliform
1	1	2245	83	667	211
	2	1967	101	943	135
	3	2041	144	948	90
	4	1433	42	322	140
	5	1167	58	116	134
	6	300	40	166	122
	7	33	1	266	102
	8	33	1	391	125
	9	433	42	473	89
2	1	2253	154	7310	244
	2	1900	78	4084	188
	3	1793	76	739	79
	4	1300	41	349	109
	5	1367	34	159	87
	6	767	33	136	89
	7	567	42	158	67
	8	1433	31	157	89
	9	1666	145	264	141
3	1	2181	938	301	139
	2	1333	590	201	133
	3	3260	417	295	40
	4	1766	372	241	102
	5	1467	99	348	39
	6	1600	580	183	25
	7	1833	197	241	49
	8	1775	155	220	40
	9	1633	224	436	97
4	1	3658	1493	10388	125
	2	1833	956	6280	111
	3	967	27	501	33
	4	767	463	122	106
	5	<1	<1	93	30
	6	1267	340	153	42
	7	1400	525	232	24
	8	1100	142	270	50
	9	1500	195	348	64

Station	Point	Total Coliform	Fecal Coliform	Total Coliform	Fecal Coliform
5.1	1	2310	357	3776	172
	2	445	90	525	158
	3	467	10	182	106
	4	600	45	152	187
	5	45	29	140	139
	6	49	188	145	123
	7	233	52	197	123
	8	700	14	351	109
	9	1200	63	292	228
5.2	1	1300	101	1094	374
	2	323	58	720	205
	3	226	62	222	85
	4	53	13	130	157
	5	53	43	111	88
	6	142	31	144	188
	7	37	34	224	186
	8	336	33	350	227
	9	461	95	410	209
5.3	1	6491	73	707	376
	2	176	74	656	239
	3	85	55	174	170
	4	57	36	136	215
	5	29	37	117	113
	6	65	33	134	252
	7	123	41	213	121
	8	278	43	253	121
	9	384	147	354	123
6	1	2309	7	4320	266
	2	1167	510	150	84
	3	600	374	112	131
	4	1433	2	123	138
	5	1667	3	127	140
	6	1599	343	150	157
	7	4667	299	95	81
	8	1767	471	165	90
	9	1133	440	462	187

Station	Point	Total Coliform	Fecal Coliform	Total Coliform	Fecal Coliform
7	1	1000	445	132	18
	2	1367	449	120	136
	3	967	432	91	106
	4	1233	2	103	79
	5	1000	5	104	88
	6	1567	4	105	185
	7	1567	486	209	84
	8	1767	575	490	172
	9	1300	813	706	203
8	1	76	23	117	35
	2	233	51	109	129
	3	1500	<1	142	27
	4	51	114	147	25
	5	28	151	139	19
	6	233	39	123	51
	7	400	22	101	39
	8	<1	18	108	54
	9	267	56	606	198
9	1	47	17	91	113
	2	85	31	77	131
	3	79	25	83	51
	4	97	36	96	135
	5	72	35	81	116
	6	71	25	75	120
	7	114	49	127	39
	8	59	27	128	61
	9	65	20	106	43
10	1	<1	40	112	138
	2	57	38	105	158
	3	63	32	106	136
	4	367	29	119	53
	5	100	34	112	108
	6	41	41	118	77
	7	200	15	151	102
	8	467	29	114	38
	9	633	2	183	61

Figure 6. Total Coliform Profile from Sample Run One (August 22, 1996)

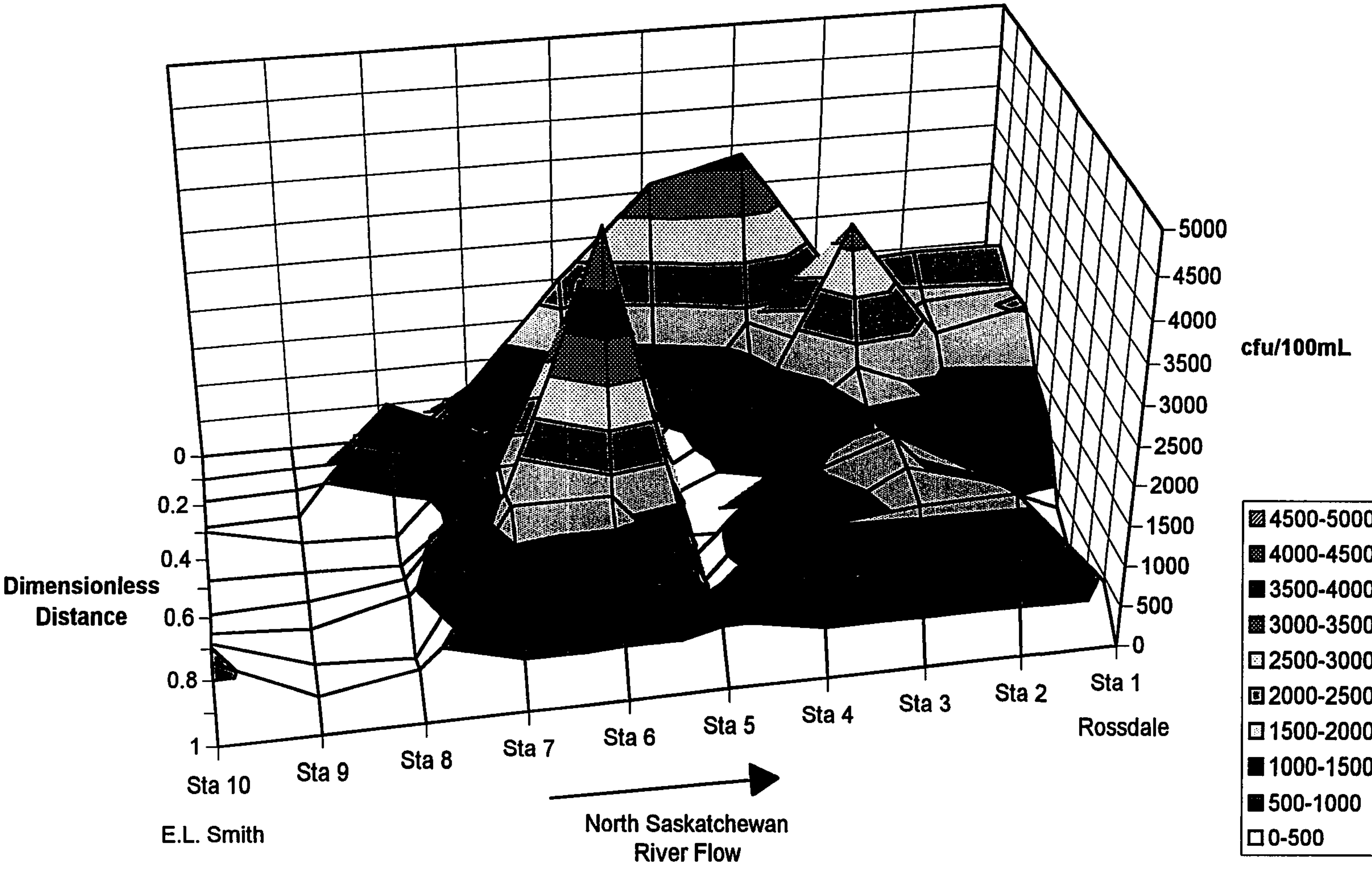


Figure 7. Total Coliform Profile from Sample Run Two (August 28, 1996)

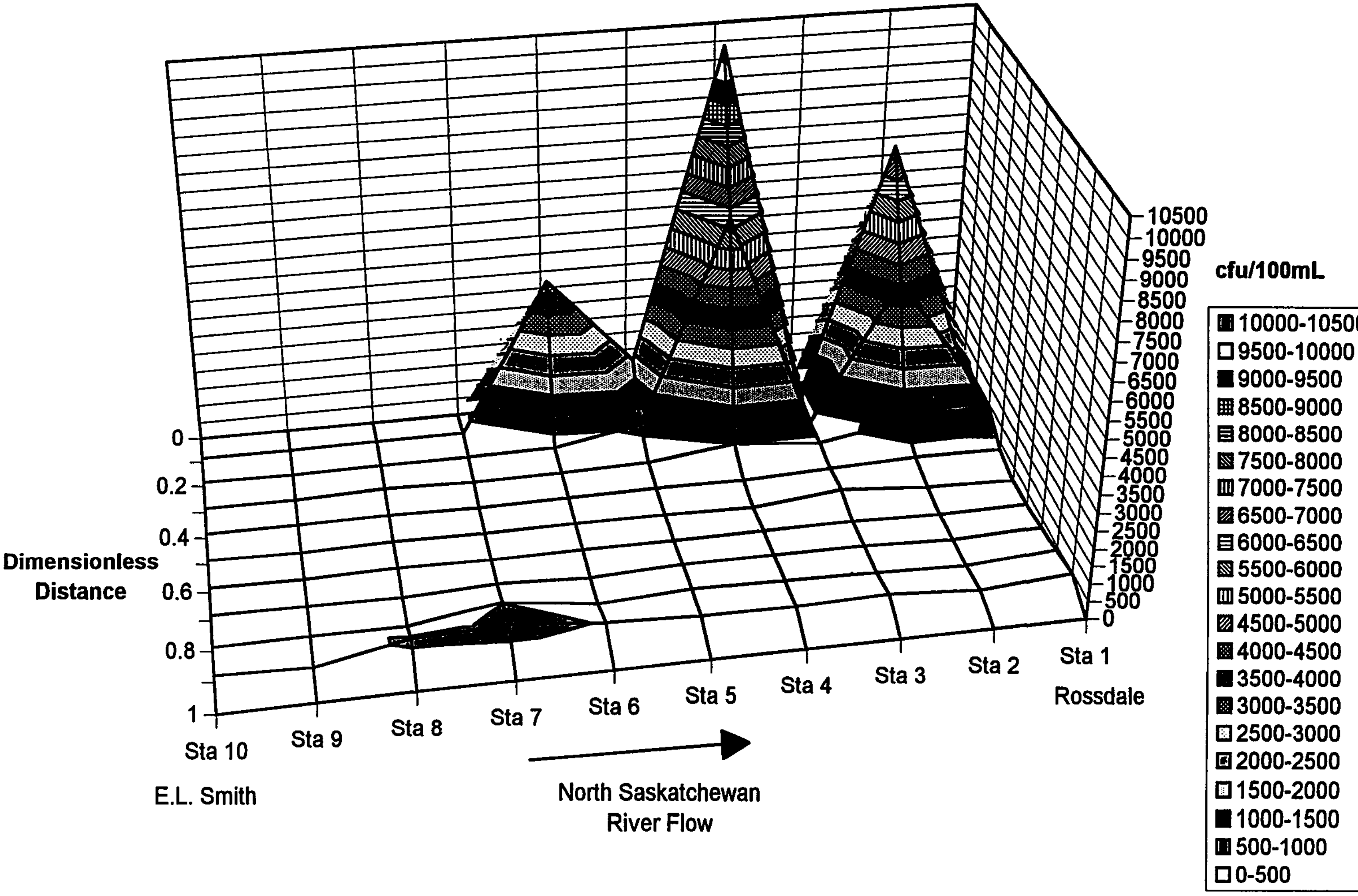
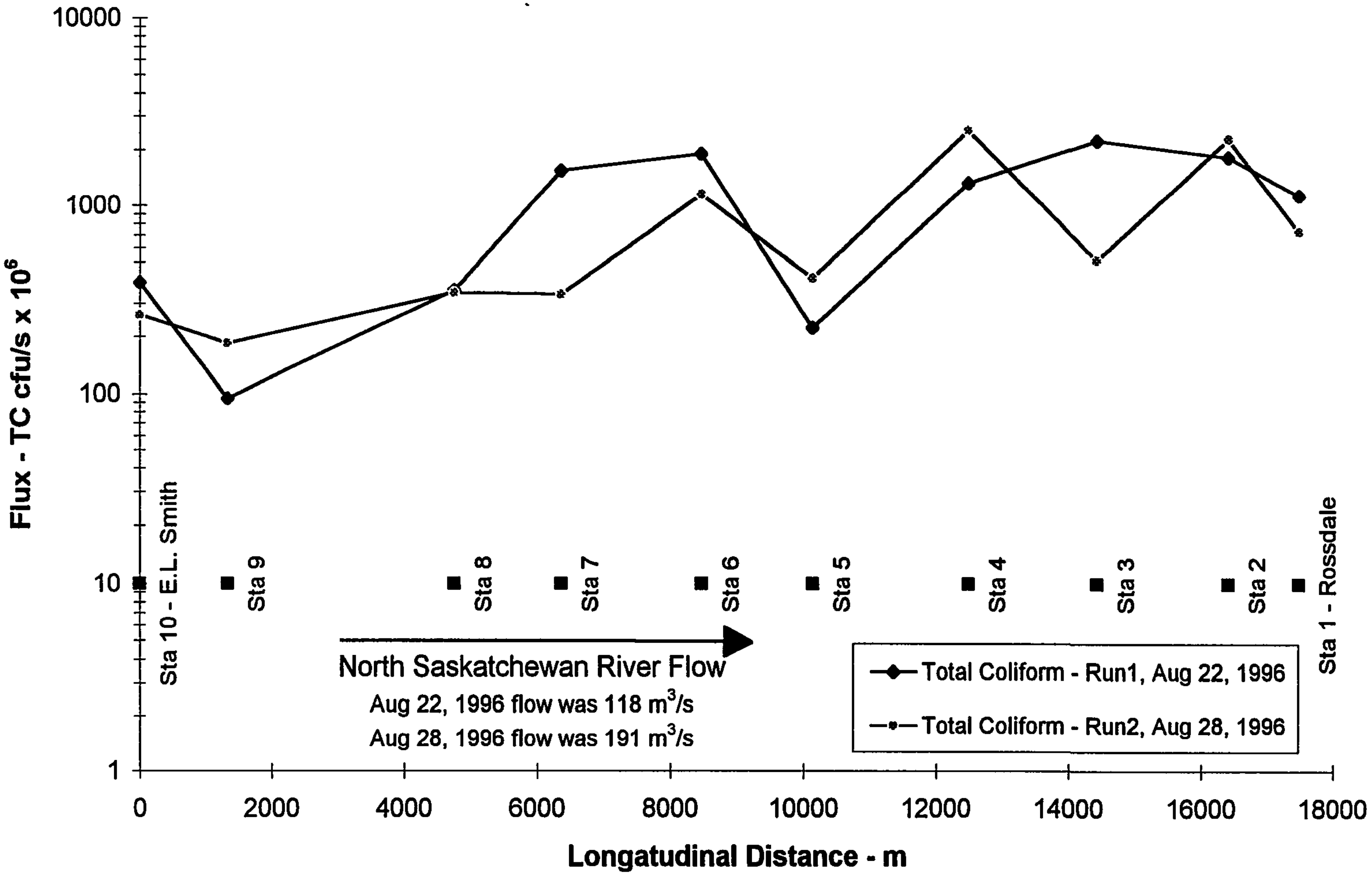


Figure 8. Flux Values for Total Coliform Samples



early 1994 (see Table 13). Two of the three outfalls sampled during this project have historic dry weather sampling results. Total coliform levels discharged at the Quesnell outfall tend to be very steady with the, while those from the Millwoods outfall tend to fluctuate a great amount. From this historic data it would appear that the Quesnell outfall is a cause of a large quantity of total coliforms. For the outfalls sampled in this project (Table 14) it would appear that the Quesnell outfall is a major contributor of total coliforms, in the range of 600000cfu/100mL. The Whitemud creek, which has commonly been blamed for pathogen loading, had the lowest level of total coliforms entering the river, with approximately 2000cfu/100mL.

4.2 Fecal Coliform

Using the membrane filter procedure, the following dilutions were used to determine the fecal coliform load in the river and storm sewers sampled; 10^{-2}, 10^{-1}, 1, 10, 25 for run one, and 10^{-2}, 10^{-1}, 1, 10, 50 for run two. The mFC agar was prepared and used as the media for fecal coliform incubation according to the manufacture's specifications. The results of both fecal coliform sample runs are summarized in Table 12. From this data and from the surface charts for both sample runs (Figure 8 and 9) the concentrations are much lower than the total coliform data. The first sample run showed a trend of increase from station seven down to station three, then the fecal coliform level drops off. For the second sample run a different trend was found, in which fecal coliform levels were rather sporadic throughout the reach. For both sample runs the fecal coliform levels were found highest near the left bank. A flux chart for the fecal sample results (Figure 11) was also prepared. From the results of the sample runs there appeared to be a different pattern, and from the data there was an approximate rise of $6x10^7$ fecal coliforms per second from the E.L. Smith WTP to the Rossdale WTP.

Like the total coliform levels in certain outfalls, the fecal coliform levels have also been reported during dry weather since early 1994 (see Table 13). Much like the total

Date	Outfall	TC	FC
		cfu/100mL	
Mar/09/94	30th Avenue (Millwoods)	>16000	9000
Mar/23/94	30th Avenue (Millwoods)	>16000	>16000
Jun/21/94	30th Avenue (Millwoods)	>160000	>160000
Jul/06/94	30th Avenue (Millwoods)	160000	160000
Jul/20/94	30th Avenue (Millwoods)	160000	92000
Aug/16/94	30th Avenue (Millwoods)	35000	3000
Aug/30/94	30th Avenue (Millwoods)	>160000	>160000
Sep/13/94	30th Avenue (Millwoods)	460000	23000
Sep/21/94	30th Avenue (Millwoods)	>16000	>16000
Oct/05/94	30th Avenue (Millwoods)	>16000	>16000
Oct/11/94	30th Avenue (Millwoods)	460000	240000
Oct/25/94	30th Avenue (Millwoods)	>1100000	210000
Nov/07/94	30th Avenue (Millwoods)	16000	500
Nov/28/94	30th Avenue (Millwoods)	1100	130
Jan/18/95	30th Avenue (Millwoods)	5000	5000
Jan/14/94	Quesnell	>16000	>16000
Jan/28/94	Quesnell	>16000	>16000
Feb/11/94	Quesnell	>16000	>16000
Feb/23/94	Quesnell	>16000	>16000
Mar/14/94	Quesnell	>16000	>16000
Mar/28/94	Quesnell	>16000	16000
May/19/94	Quesnell	>16000	>16000
Jun/20/94	Quesnell	>16000	>16000
Jun/21/94	Quesnell	>16000	5000
Jul/06/94	Quesnell	>160000	35000
Jul/20/94	Quesnell	>16000	>16000
Jul/29/94	Quesnell	>160000	>160000
Aug/16/94	Quesnell	>16000	>16000
Aug/23/94	Quesnell	>16000	16000
Aug/30/94	Quesnell	>16000	16000
Sep/06/94	Quesnell	>16000	>16000
Sep/13/94	Quesnell	460000	9000
Sep/23/94	Quesnell	>1100000	240000
Oct/11/94	Quesnell	>16000	>16000
Oct/25/94	Quesnell	>1100000	460000
Nov/04/94	Quesnell	>16000	>16000
Nov/21/94	Quesnell	>16000	16000
Nov/25/94	Quesnell	>16000	>16000
Dec/07/94	Quesnell	>16000	>16000
Dec/12/94	Quesnell	>16000	>16000
Jan/17/95	Quesnell	>16000	1600

Date	Outfall	TC	FC
		cfu/100mL	
Aug/28/96	30th Avenue (Millwoods)	8707	266
Sep/03/96	30th Avenue (Millwoods)	67911	3947
Sep/03/96	30th Avenue (Millwoods)	54743	5422
Sep/03/96	30th Avenue (Millwoods)	71647	3501
Sep/03/96	Quesnell	715913	39449
Sep/03/96	Quesnell	613048	48053
Sep/03/96	Quesnell	551127	27882
Sep/03/96	Whitemud Creek	2060	33
Sep/03/96	Whitemud Creek	1933	19
Sep/03/96	Whitemud Creek	2033	24
Sep/03/96	Groat	58308	2482
Sep/03/96	Groat	56291	4082
Sep/03/96	Groat	59911	2224

Figure 9. Fecal Coliform Profile from Sample Run One (August 22, 1996)

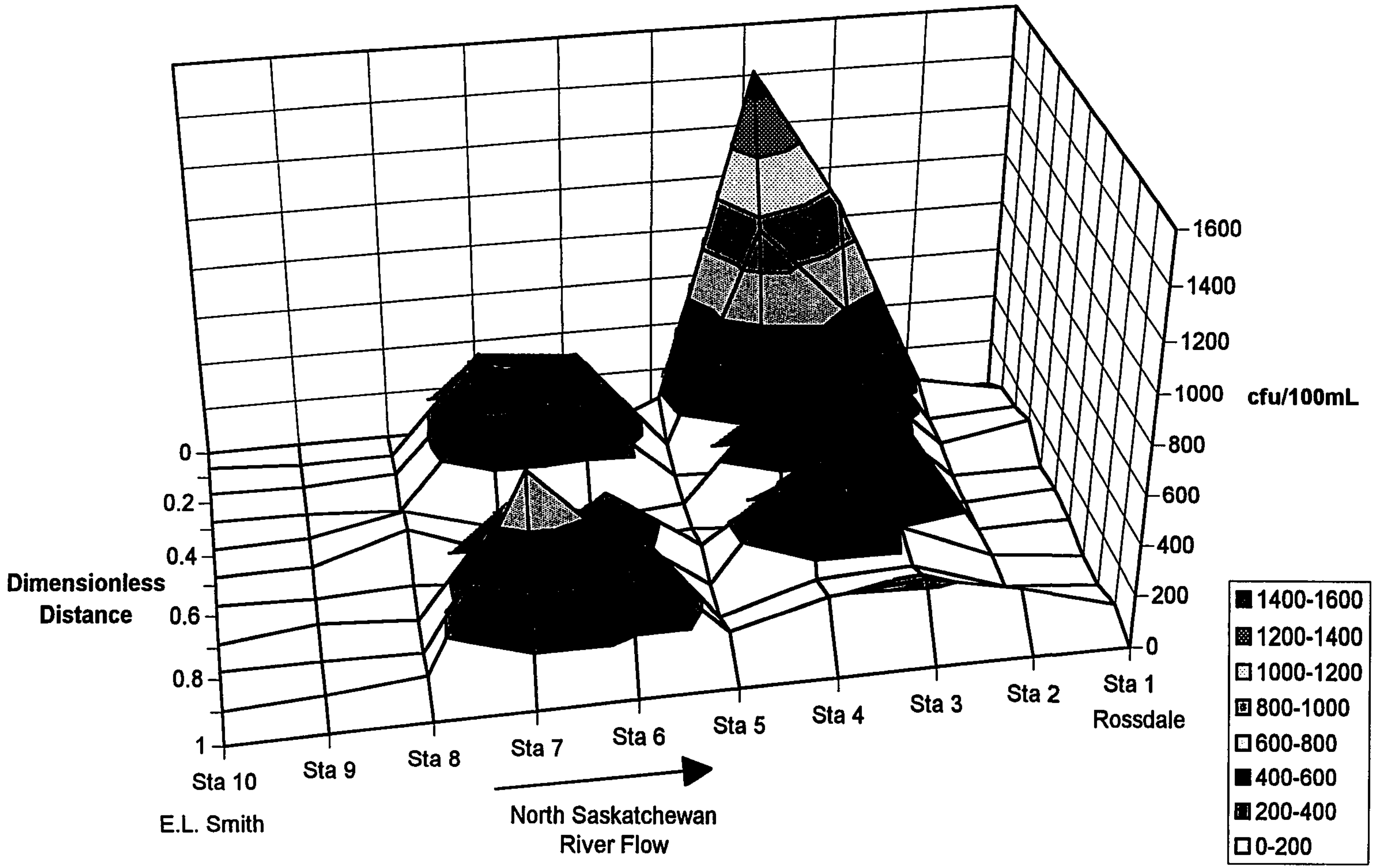


Figure 10. Fecal Coliform Profile from Sample Run Two (August 28, 1996)

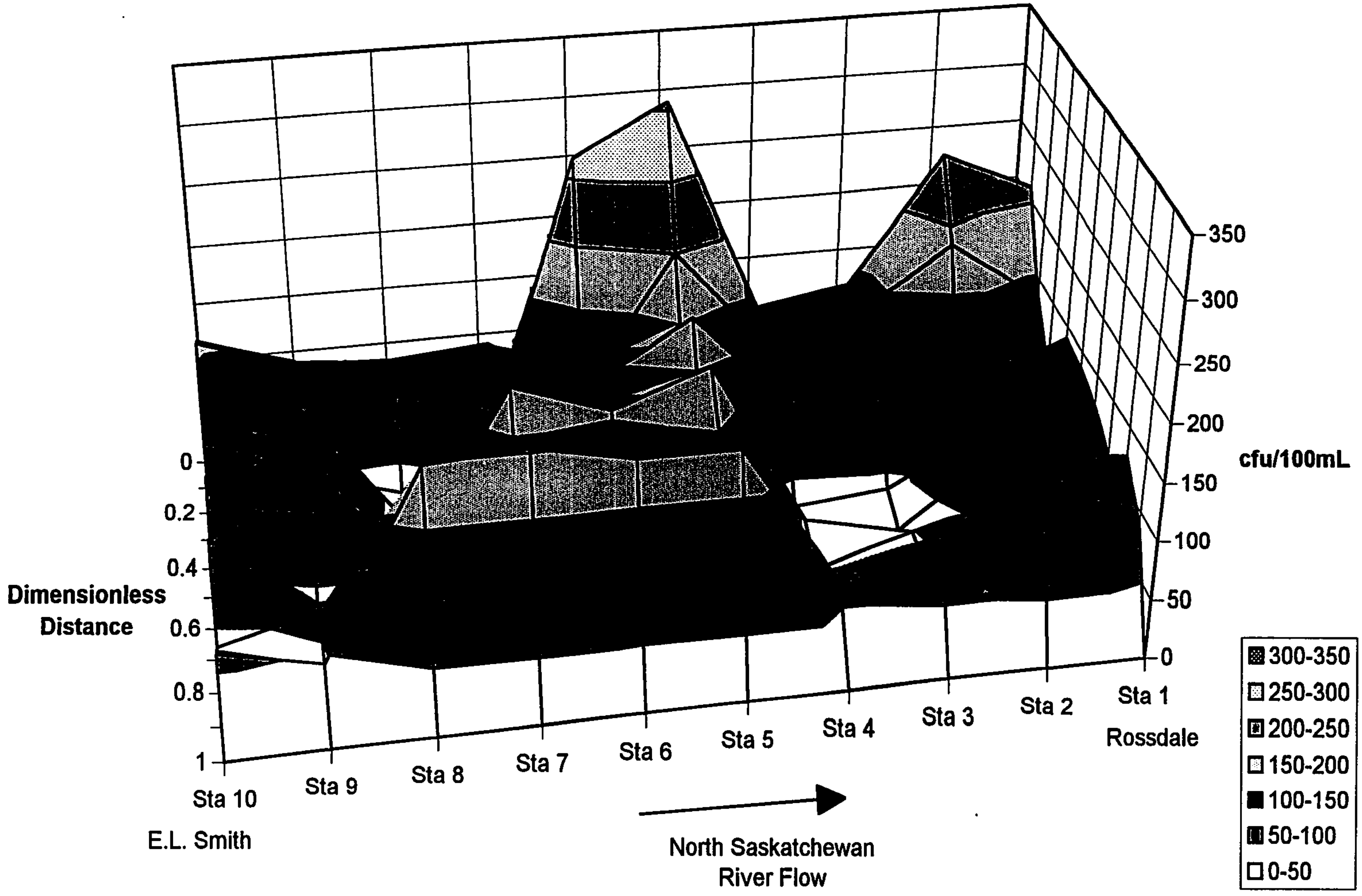
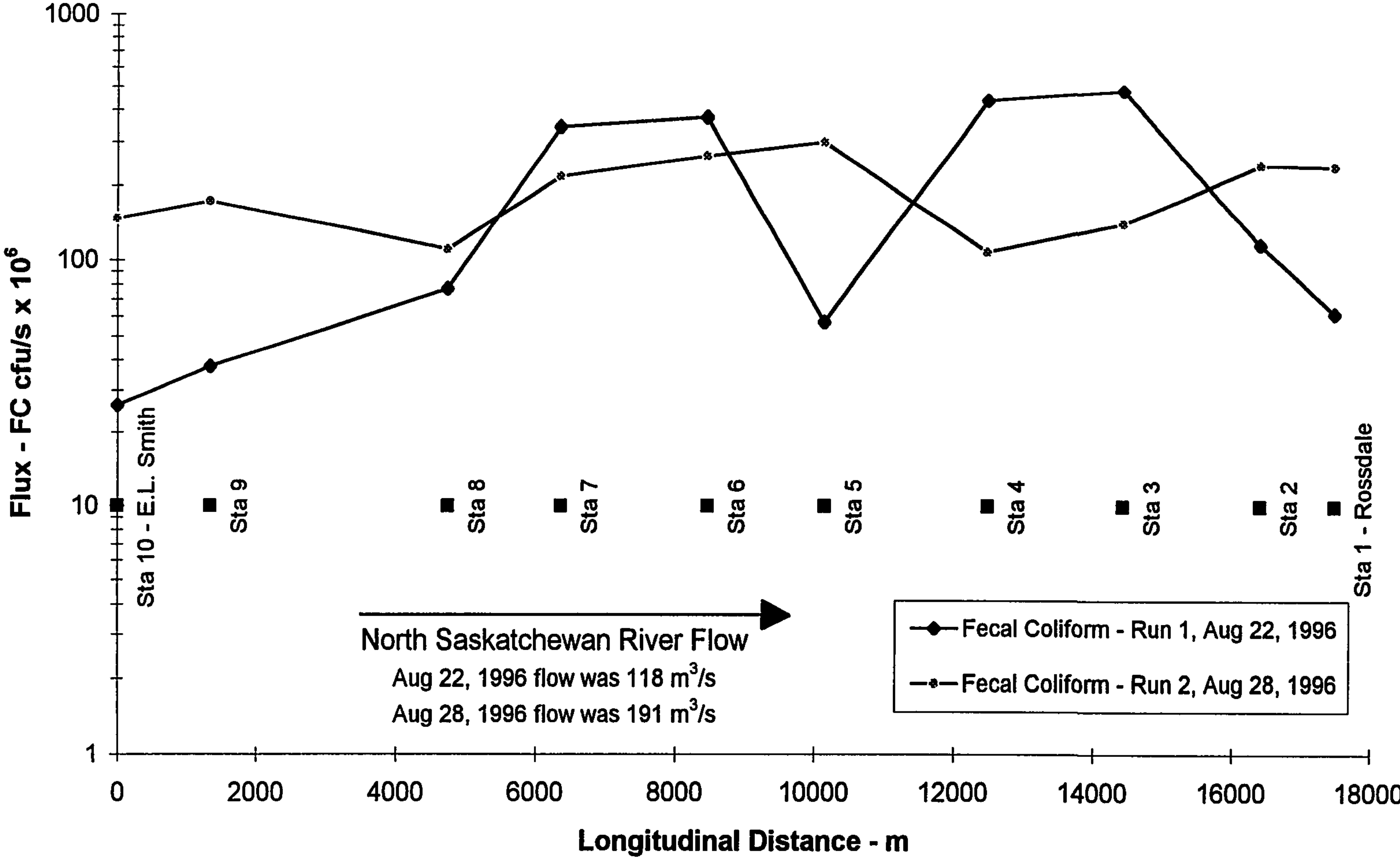


Figure 11. Flux Values for Fecal Coliform Samples



comparison with the Millwoods outfall which fluctuate a great amount. From the result of the outfall sampling (Table 14) the fecal coliform levels were highest at the Quesnell outfall, in the range of 40000 cfu/100 mL. The lowest fecal coliform levels were from Whitemud Creek, in the range of 20 cfu/100 mL.

4.3 Ammonia

The ammonia sampling was performed because nitrogenous organic matter is a good indicator of raw sewage, and if a correlation could be made, automated sampling could be accomplished. It has been noted in other studies that ammonia (NH_3) or the ammonium ion (NH_4^+) can be used as an indicator for sanitary wastewater, and the testing is much faster than microbiology testing (Lalor, 1993).

The ammonia samples gathered were only taken at stations one, five, seven, and ten. For the first sample run, the samples were collected and preserved with concentrated sulfuric acid and stored in a refrigerator at 4°C. Thus, prior to analysis, the samples needed to be neutralized with sodium hydroxide. The samples collected during the second run were analyzed within 24 hours of collection, thus not requiring preservation, only refrigeration until the analysis could be done. Interference was not suspected to be present in the water, therefore, the samples were not distilled, which may have caused some problems in the analysis of the samples. The results of the ammonia sampling (Table 15) demonstrated no real trend which could be recognized or repeated. The levels of ammonia were well within acceptable limits, with one quarter of the data not even having measurable levels. During the first sample run, station one had the highest recorded levels, while the other three stations had very sporadic readings. For sample run two, the levels were fairly consistent at station ten, seven, and four, with station one not having measurable levels.

Table [illegible]: Summary of Ammonia Samples for Both Runs

		mg NH_3-N/L	
Station	Point	Sample Run 1 August 22, 1996	Sample Run 2 August 28, 1996
1	1	4.20	0.81
	2	3.11	-
	3	7.18	-
	4	5.28	-
	5	7.04	-
	6	5.55	-
	7	9.07	-
	8	7.85	-
	9	10.70	-
4	1	-	5.55
	2	-	5.15
	3	2.30	3.79
	4	3.39	4.47
	5	-	8.26
	6	-	3.79
	7	-	2.57
	8	12.86	5.69
	9	17.60	4.20
7	1	-	4.47
	2	-	5.82
	3	-	7.04
	4	-	5.82
	5	-	4.74
	6	-	2.57
	7	-	4.60
	8	-	1.62
	9	-	3.79
10	1	-	11.92
	2	2.84	5.28
	3	0.41	5.42
	4	-	7.58
	5	0.81	4.87
	6	-	7.58
	7	-	5.42
	8	-	3.52
	9	-	5.69

Groat, including Whitemud Creek (Table 16). From the total and fecal coliform results the highest ammonia levels would be expected to be from the Quenell outfall. However, for these results Quenell had the lowest levels of ammonia, with Groat outfall having the highest levels. This did not demonstrate what was expected, and thus further testing for ammonia at the outfalls was suspended.

Table 16. Summary of Outfall Ammonia Samples
All Samples Collected on October 3, 1996

Location	mg NH_3-N/L
The Millwoods outfall	44
The Millwoods outfall	30
The Millwoods outfall	47
The Ouesnell Outfall	21
The Ouesnell Outfall	20
The Ouesnell Outfall	24
Whitemud Creek	67
Whitemud Creek	63
Whitemud Creek	54
The Groat outfall	174
The Groat outfall	220
The Groat outfall	171

5.1 TRSFLO Results

The TRSFLO program is the part of TRSMIX that is used to generate stream tubes using the depth soundings performed on the river. This included taking ten depth sounding profiles that had been performed in the summer of 1996. There were an additional thirty-two sounding profiles used for the model. Those were obtained by Alberta Environment in 1994. The more sounding information used with TRSFLO, the better and more accurate the stream tubes would become, and with no major flood event in 1994 or 1995, all forty two sounding profiles were used for the reach between the E.L Smith WTP and the Rossdale WTP.

Prior to using the data in TRSFLO, all of the soundings performed were adjusted to the flows that corresponded to the two sampling runs (118 m^3/s on Aug 22, 1996 and 191 m^3/s on Aug 28, 1996). This was done by adjusting the respective water elevations for each sounded cross-section in the computer. Thus TRSFLO was run twice, once for each of the sample runs performed, with the flows adjusted accordingly.

The output from TRSFLO is broken into two parts, one is the stream tube hydraulic profile of the river, and the other is the input file for the TRSMIX model. The hydraulic profiles of the ten stations, along with the respective soundings are summarized in Appendix A.

5.2 TRSMIX Results

The TRSMIX model was run four times, using two different flow rates corresponding to the two test conditions, and two different microbial decay rates, resulting in four combinations of results. The following section explains the coefficients used in the TRSMIX model.

In order to run the TRSMIX model, certain coefficients are required to initiate the calculations and to allow for mixing and die-off, the following coefficients were used to complete a model run:

Coefficient	Run One	Run Two
Flow	118 m^3/s	191 m^3/s
Shear Velocity	Varied throughout the sections	
Dimensionless mixing coefficient	0.35	0.35
Length Scale	Average depth, which varied for each section	
Die-off coefficient	2.0 day^{-1} 4.0 day^{-1}	2.0 day^{-1} 4.0 day^{-1}
Diffusion Factor	0.095	0.095

The flow of the river was treated as a constant for the model and was recorded during the day of sampling. The flow rate was determined by Environment Canada via a flow gauge on the low level bridge (between station one and two). The shear velocity was a fluctuating coefficient that changed for each cross section, and was determined using the output generated in TRSFLO. The calculation for shear velocity was based on

$u^* = \sqrt{g^* R^* s}$, where;

g is the gravitational constant, 9.81m/s^2
R is the hydraulic radius that varied according to the river bed profile, m
s is the slope of the river which was calculated at 3.68(10^{-4}) m/m

The dimensionless mixing coefficient was determined using a detailed search of past experiments, including both field and laboratory studies, that pertained to all water bodies around the world. From these results a coefficient of 0.35 was used, for it seemed to best fit with similar river reaches of other studies (refer to Appendix F - Model Coefficients from the search results). The length scale used was based on average depth, which varied for each cross section. The average depth values were given as part of the output from the TRSFLO program. The die-off coefficient that was used, is based on Chick's law, in which 'k' is the coefficient required. In order to determine an appropriate die-off coefficient, a detailed search was done to find similar studies with both laboratory and field work that reported die-off coefficients. From this search a die-off coefficient of 2.0/day was found to be conservative, but another run was used with a die-off coefficient

Coefficients for the search results). The final coefficient used in the model was the diffusion factor, which was also determined from previous studies. This resulted in a coefficient of $0.095m^5/s^2$ used for this model (refer to Appendix F - Model Coefficients for the search results).

The TRSMIX model was run using the output file from TRSFLO and adding the appropriate coefficients where they were required. For each run with the model, eighteen input files were required, this consisted of nine left bank inputs and nine right bank inputs. The first of the files would consist of an input introduced on the left bank just downstream of station ten, and the influence of this load was recorded throughout the nine remaining stations (refer to Figure 12). This input was a computer-generated input that corresponded to observed loading values found in the field sampling. This would continue for all the remaining stations, such that the last file would consist of an input on the left bank just downstream of station two, with the load effect recorded at the remaining station one. This whole set would be run again, but with the input introduced from the right bank.

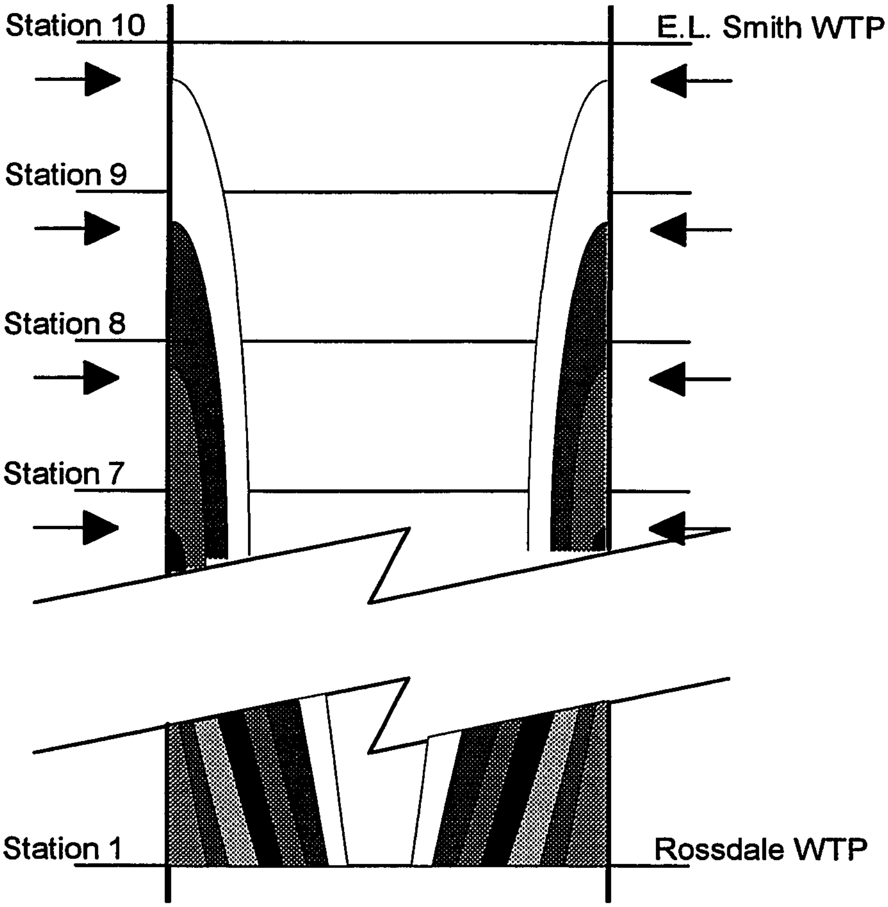
The output from the TRSMIX model was a single file, which was imported into Excel for analysis. The data of concern were at the dimensionless distances 0.1, 0.2, ..., 0.9, the locations where the samples were taken in the transverse location. Using the measured coliform data, the model results, and the decay coefficient, a mass balance approach was used to determine the loading effect at each station.

At station nine the equation was:

$$C=(C_o)_{10}*\left(C/C_o\right)_{10-9}+C_{b,9} \qquad \text{.......(24)}$$

At station five the equation becomes:

$$C=(C_o)_{10}*\left(C/C_o\right)_{10-5}+(C_o)_9*\left(C/C_o\right)_{9-5}+(C_o)_8*\left(C/C_o\right)_{8-5}+(C_o)_7*\left(C/C_o\right)_{7-5}+ \qquad \text{....(25)}$$
$$(C_o)_6*\left(C/C_o\right)_{6-5}+C_{b,5}$$



Finally, at station one the equation becomes:

$$C = (C_o)_{10} * \left(\frac{C}{C_o}\right)_{10-1} + (C_o)_9 * \left(\frac{C}{C_o}\right)_{9-1} + (C_o)_8 * \left(\frac{C}{C_o}\right)_{8-1} + (C_o)_7 * \left(\frac{C}{C_o}\right)_{7-1} + (C_o)_6 * \left(\frac{C}{C_o}\right)_{6-1} + (C_o)_5 * \left(\frac{C}{C_o}\right)_{5-1} + (C_o)_4 * \left(\frac{C}{C_o}\right)_{4-1} + (C_o)_3 * \left(\frac{C}{C_o}\right)_{3-1} + (C_o)_2 * \left(\frac{C}{C_o}\right)_{2-1} + C_{b,1} \qquad \ldots.(26)$$

where; C is determined twice, using the C/C_o at two locations, 0.1 and 0.9

C/C_o is determined from TRSMIX

$Q\left(m^3/s\right)$

Q was the flow of the river during the sample run
m was the mass flux determined by the solver in Excel
$C_{b,n}$ is the background level of coliforms at station n_{10-1}

A spreadsheet was setup in Excel, where the concentrations were determined at the dimensionless distances 0.1 and 0.9, then from these results the concentration at the remaining dimensionless distances were calculated. The calculated (or predicted) values determined were then compared with the measured concentrations and presented on several charts (Figures 13 through 25). The charts demonstrate a fair degree of correlation between the measured and predicted coliform concentrations at each station. From the charts it can be seen that there is a rise at station eight and seven near the right bank (left to right looking downstream), which is most pronounced in sample run two. This rise in coliform levels would correspond with the presence of the Millwoods outfall, just upstream of station eight on the right bank. At station six there is a large shift in concentrations, which show an increase at the left bank, and is present at station five, four, two, and one. Likely this high concentration on the left bank would be due to the presence of the Quesnell outfall, which is located just upstream of station six on the left bank. At station three, the model predicts the higher concentration, but the measured values do not indicate a high concentration on either bank. The high concentration on the left bank at station two could not be accounted for, thus an assumption was made, that there was a sampling error or laboratory error that did not report a higher concentration at station three.

5.2.2 Model Results

From the final results it was found that a die-off coefficient of 4.0/day demonstrated the best correlation between the predicted and measured concentration values. This value was well within the range reported in the literature. In addition, sampling was done during dry weather conditions with bright sunshine. With high UV from the sun, a higher die-off the model versus predicted results are located in Appendix G - Model Results. Selected charts were taken from each run to be explained in more detail. For the total coliform concentration during run one, the charts at station nine, four, and one were used. For run two the charts of station nine, seven, five, and two were used to explain the total coliform concentrations. While for the fecal coliform concentrations, stations eight, five, and one were used.

In Figure 13, the total coliform concentration during run one at station nine demonstrates a lower measured level than predicted, which indicates the background at station ten was higher than at station nine, giving reason to believe there are no major inputs upstream of station nine. In Figure 14, there is a large concentration of total coliforms on the left bank of station five, with moderate concentrations near the right bank. Thus, there is reason to speculate there is a major input of coliforms from the left bank, upstream of station five, which would correspond to the Quesnell outfall. With Whitemud Creek discharging on the right bank upstream of station five, a larger concentration of coliforms would be expected, but this did not occur in any of the tests. It more likely corresponds with low coliform concentration found in Whitemud creek. In Figure 15, which depicts the concentration of total coliforms at station one for run one a movement of concentration was depicted. The higher levels are near the left bank but instead of dropping sharply they taper slowly across the river channel. This would account for a major input upstream, which has had time to diffuse further into the centre channel.

For the fecal coliform concentrations during run one, Figure 16 demonstrates a good correlation between the measured and predicted concentrations at station nine. From this chart it was assumed there are no measurable fecal coliform loads entering the river from either bank. Figure 17 shows the fecal coliform concentrations at station four quite high near the left bank, and not as identifiable on the right bank. With the high concentrations occurring on the left bank, it is assumed the coliform loads are entering from the Quesnell outfall upstream of station four. In Figure 18, the measured fecal coliform concentrations this being the first station sampled during run one or simply a higher die-off rate, higher than anticipated.

The total coliform concentrations in run two, at station nine, depicted in Figure 19 shows little to no influence of coliform inputs upstream of station nine. Whereas in Figure 20 for run two at station seven, a high concentration of coliforms were found near the right bank. This can be accounted for by Millwoods outfall which is located on the right bank just upstream of station eight. When looking further downstream, at Figure 21, which is located at station five, the effect of the right bank was negligible compared to the levels of total coliforms near the left bank. The high concentrations of coliforms near the left bank could be accounted for by the Quesnell outfall which is located just upstream of station six on the left bank. The left bank concentration levels can still be identified at station two, Figure 22, which shows a very low concentration of coliforms on the right bank, with extremely high values for the left bank.

Figure 23 depicts the fecal coliform levels for run two where a small increase in concentration was found near the right bank, but the level differences are not enough to distinguish any major influence. When looking at station five, in Figure 24, there were higher concentrations of fecal coliforms near the left bank more so than the right or centre areas. However, the concentrations are still not high enough to distinguish any major influence aside from the Quesnell outfall. Figure 25 identifies the fecal coliform concentrations for station one, run two, and shows an increase in concentration near the left bank. Similar to the other charts for fecal coliforms, concentration differences are not enough to make any real distinction of a pollutant source other than ones already identified.

Figure 13. Total Coliform Measured vs Predicted
Run One - Station Nine, k_e 4/day

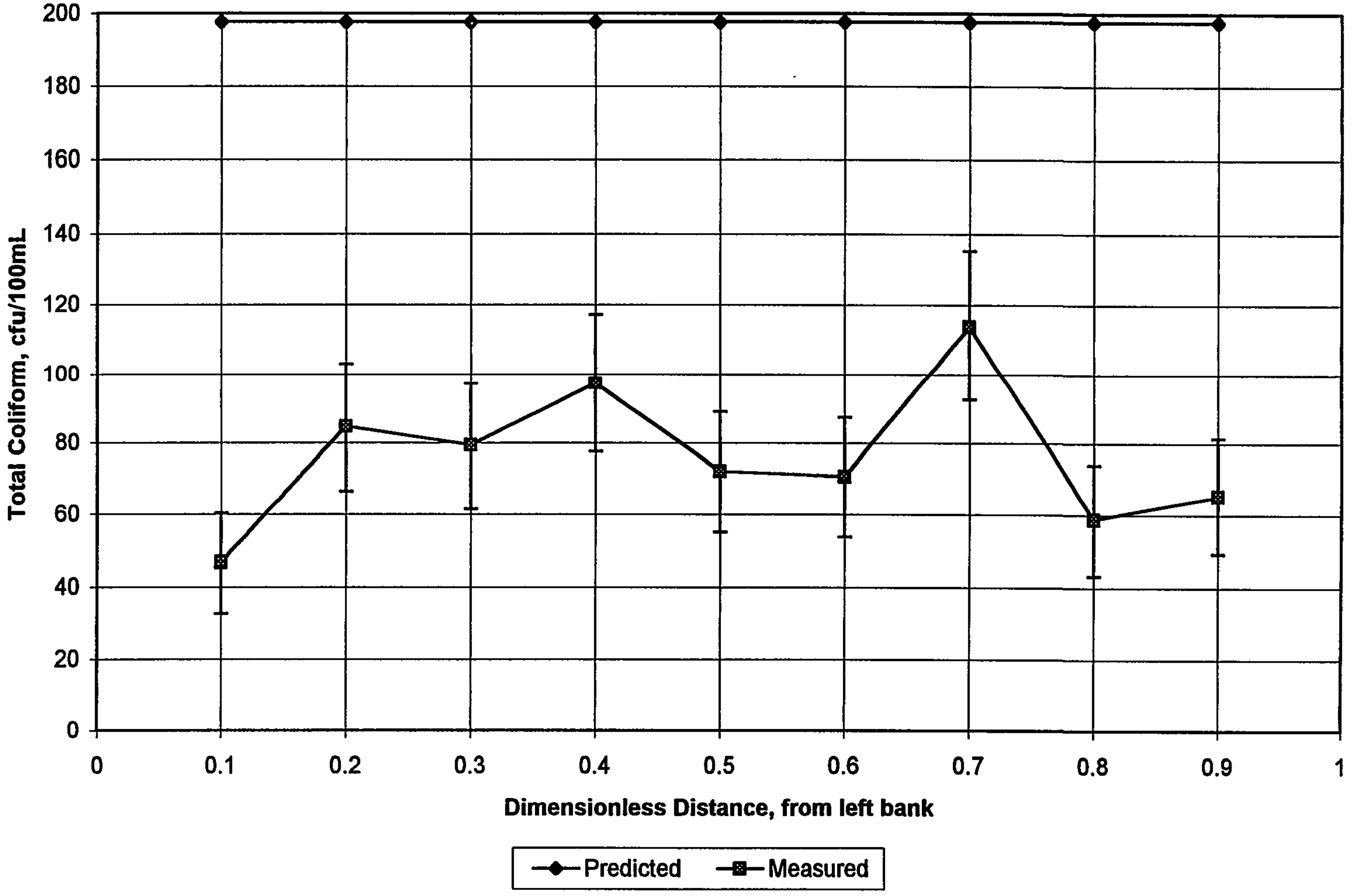


Figure 14. Total Coliform Measured vs Predicted
Run One - Station Five, k_e 4/day

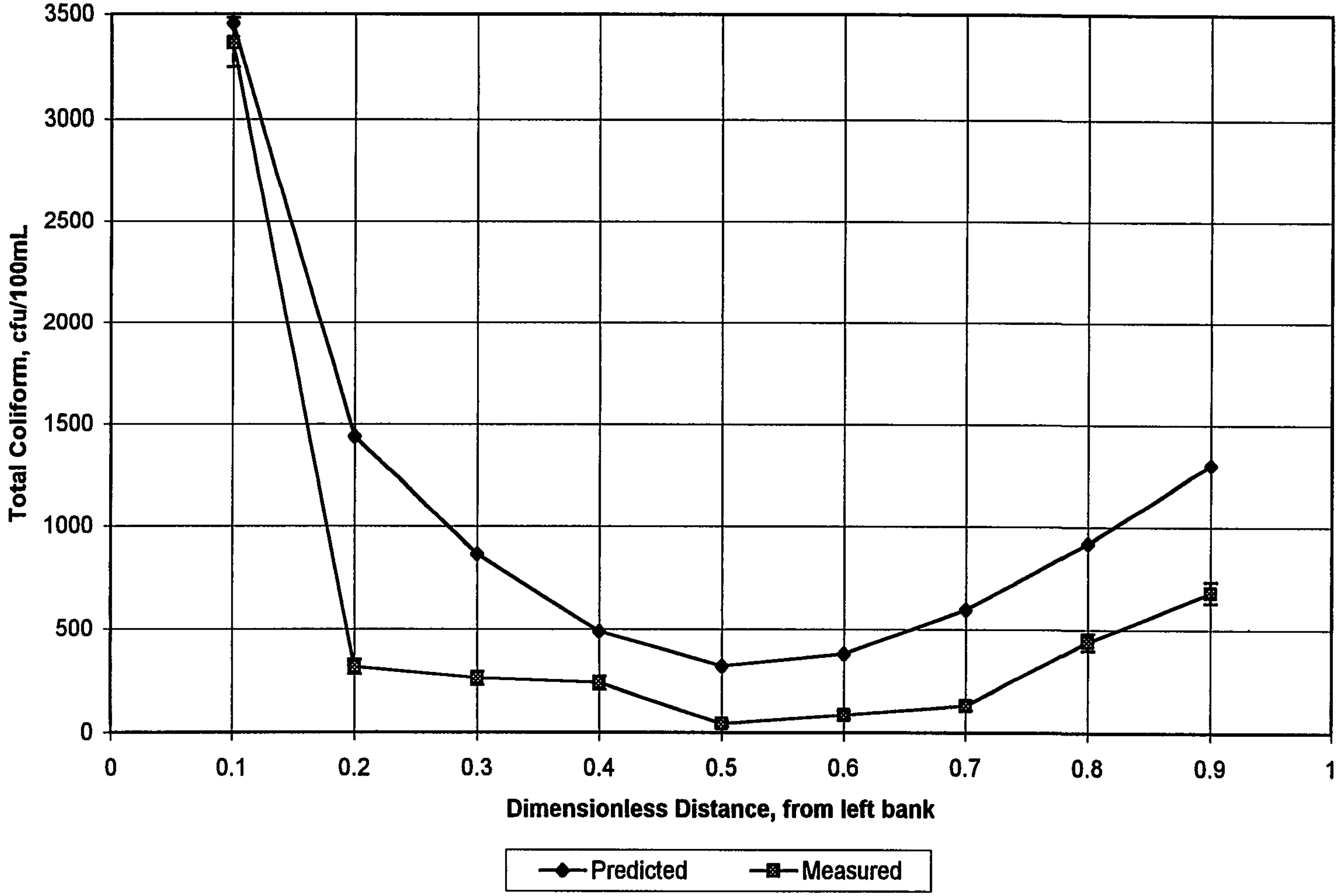


Figure 15. Total Coliform Measured vs Predicted
Run One - Station One, k_e 4/day

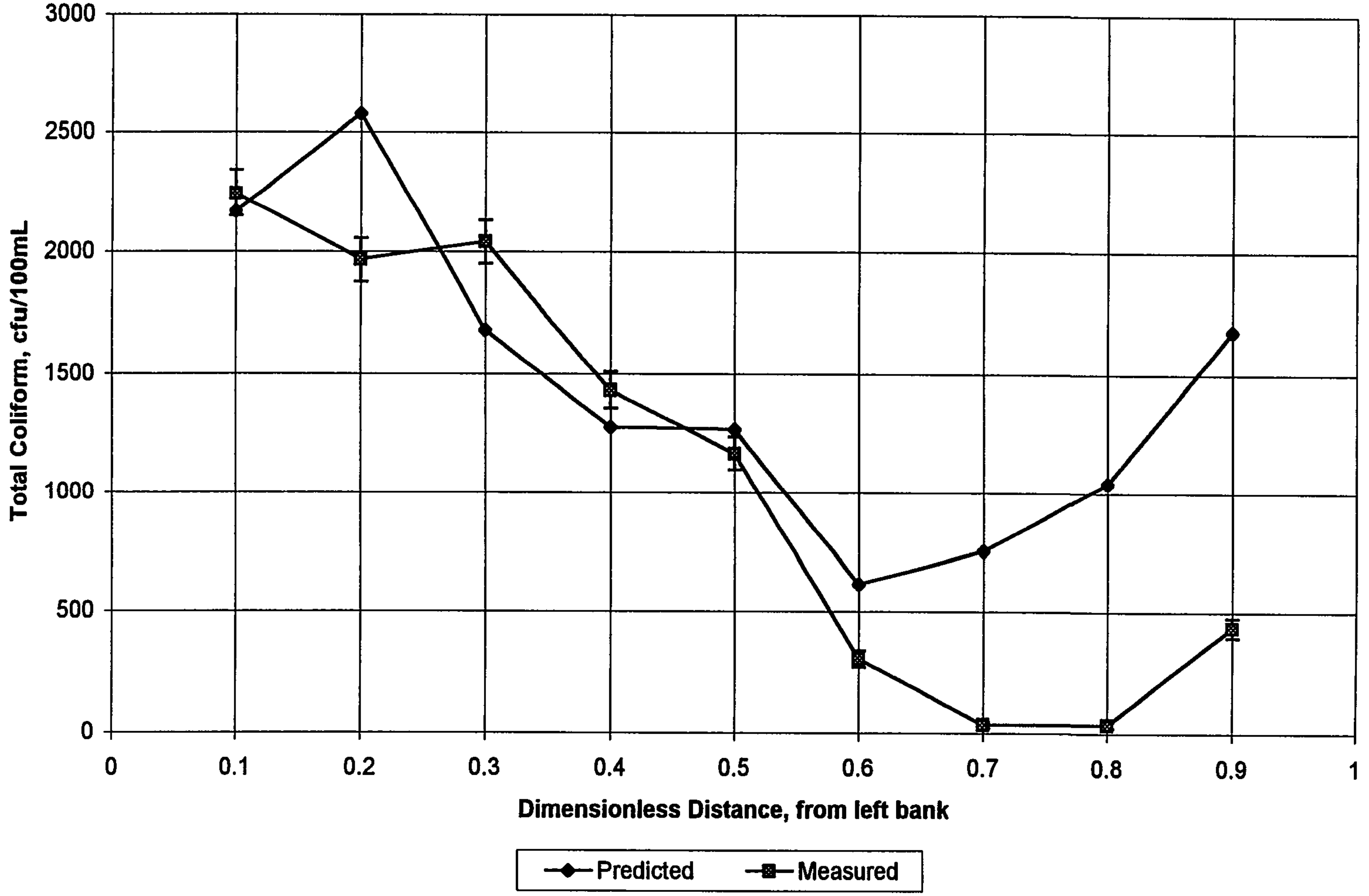


Figure 16. Fecal Coliform Measured vs Predicted
Run One - Station Nine, k_e 4/day

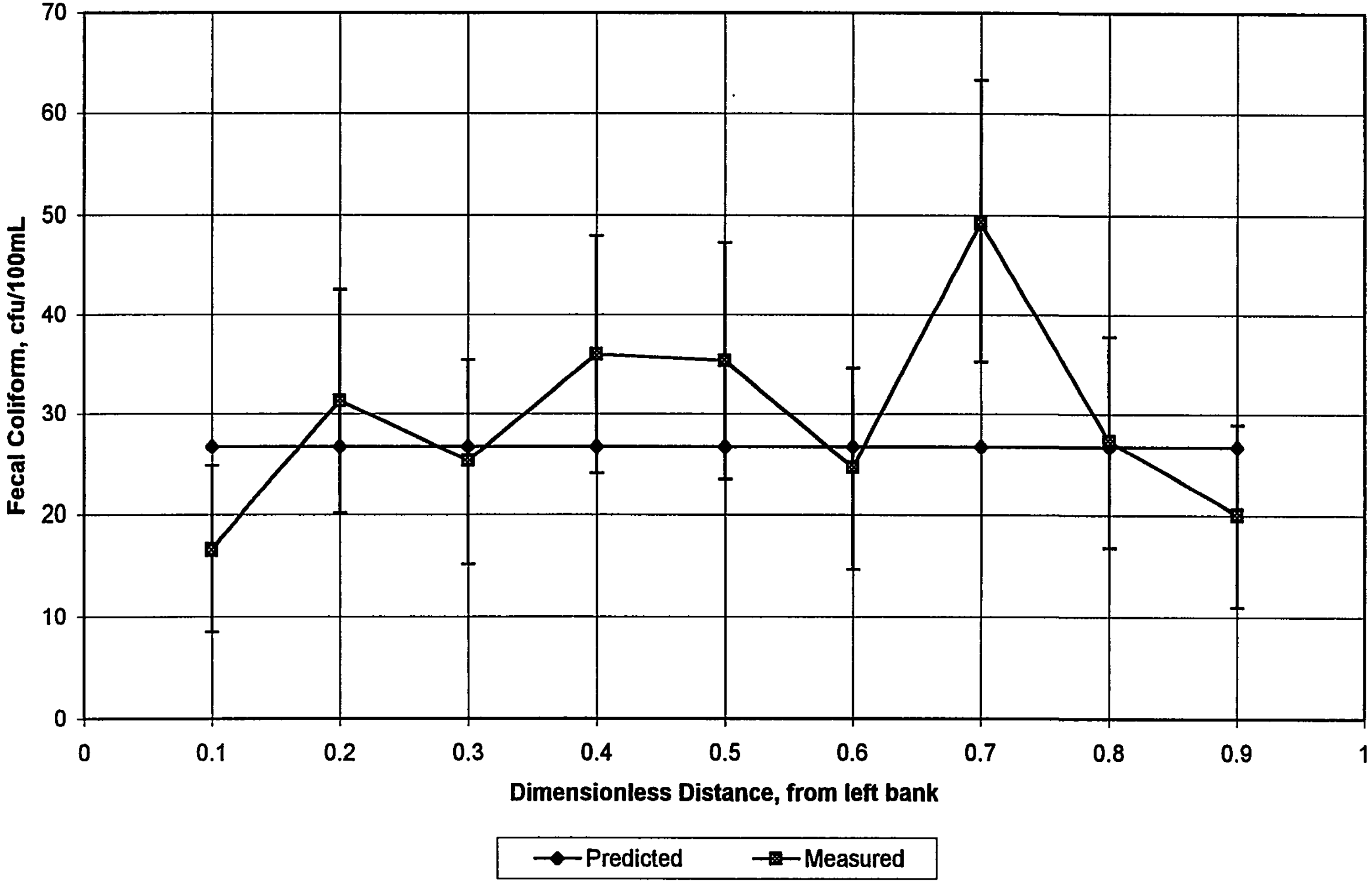


Figure 17. Fecal Coliform Measured vs Predicted
Run One - Station Four, k_e 4/day

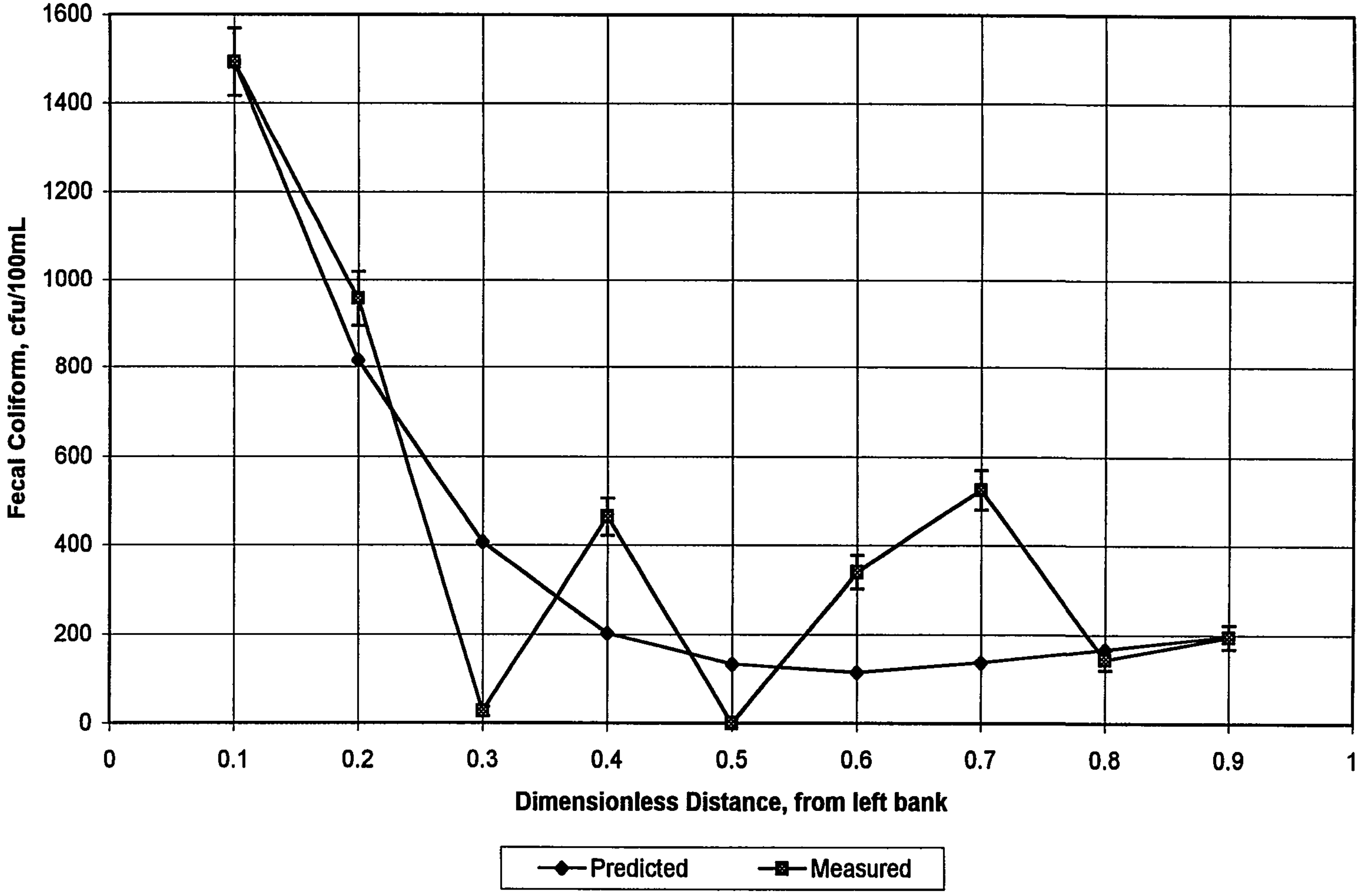


Figure 18. Fecal Coliform Measured vs Predicted
Run One - Station One, k_e 4/day

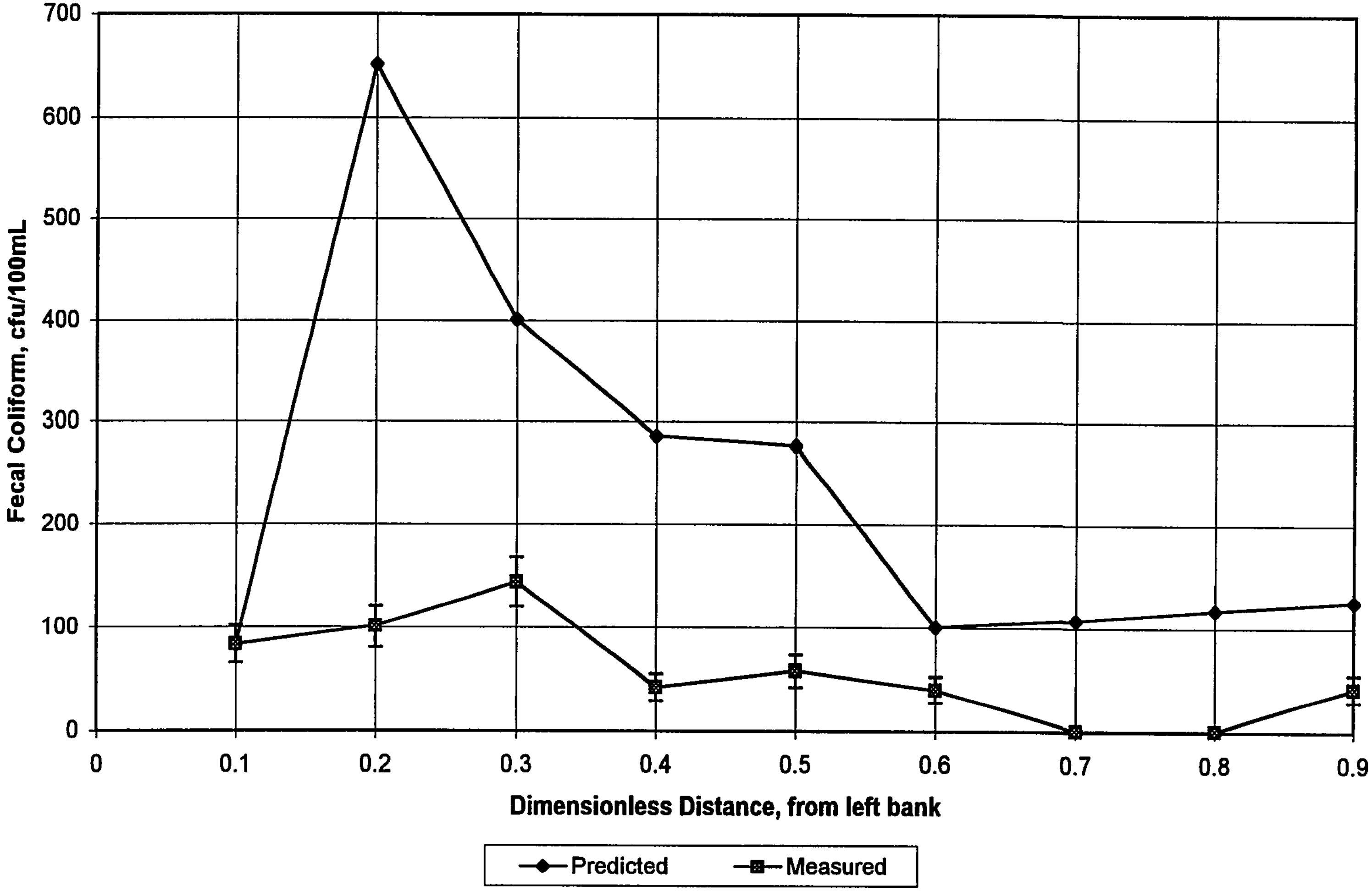


Figure 19. Total Coliform Measured vs Predicted
Run Two - Station Nine, k_e 4/day

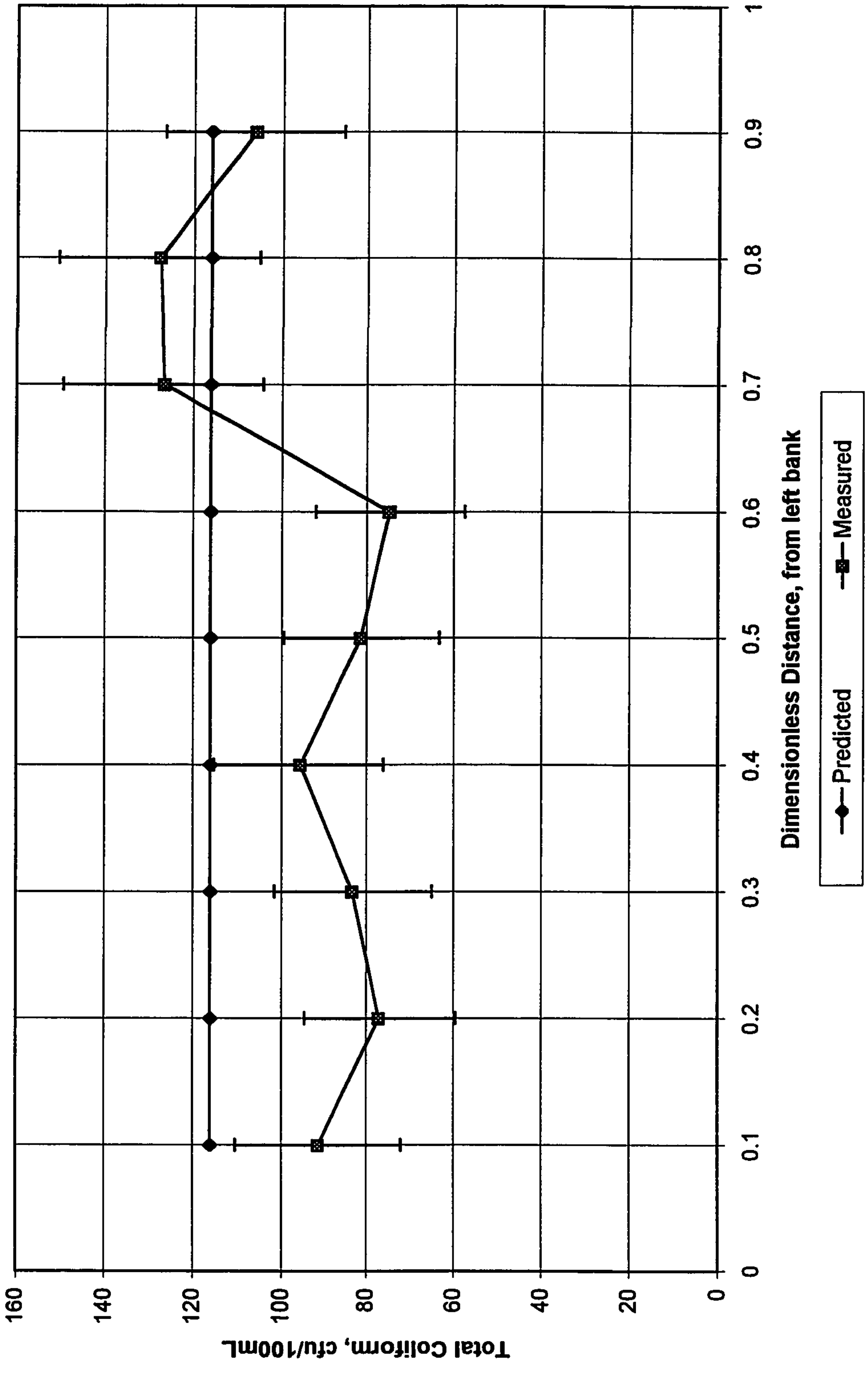


Figure 20. Total Coliform Measured vs Predicted
Run Two - Station Seven, k_e 4/day

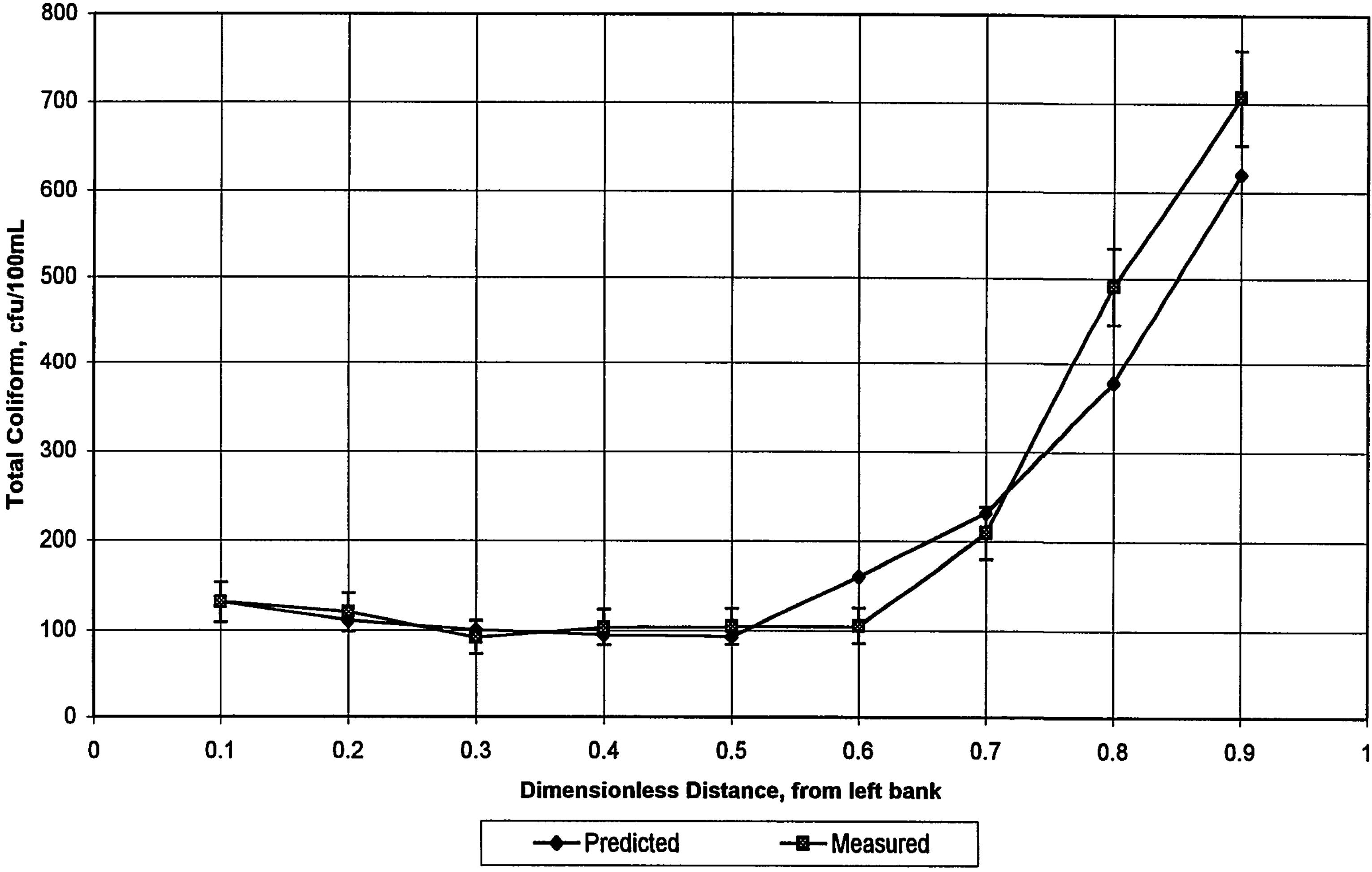


Figure 21. Total Coliform Measured vs Predicted
Run Two - Station Five, k_e 4/day

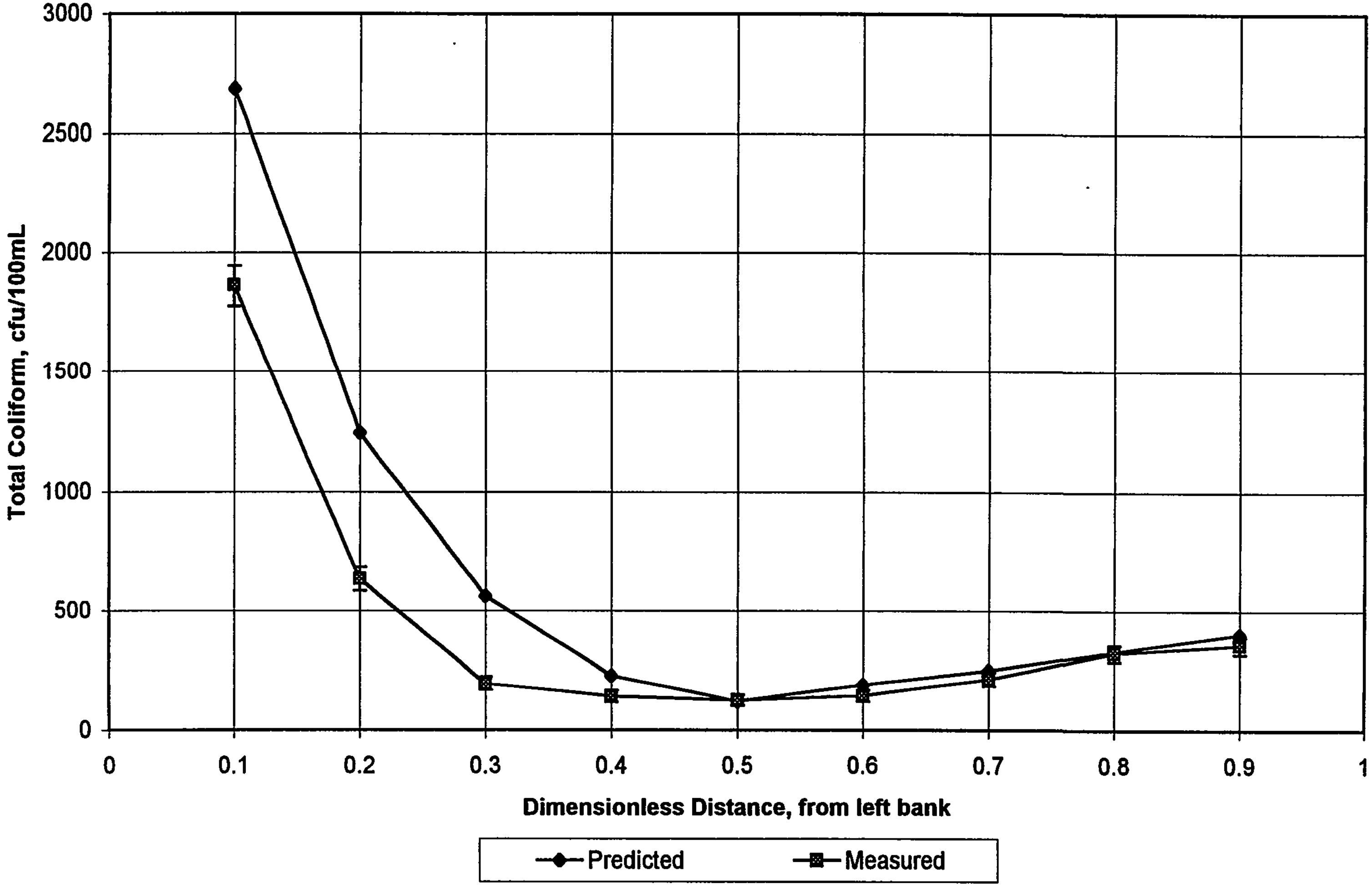


Figure 22. Total Coliform Measured vs Predicted
Run Two - Station Two, k_e 4/day

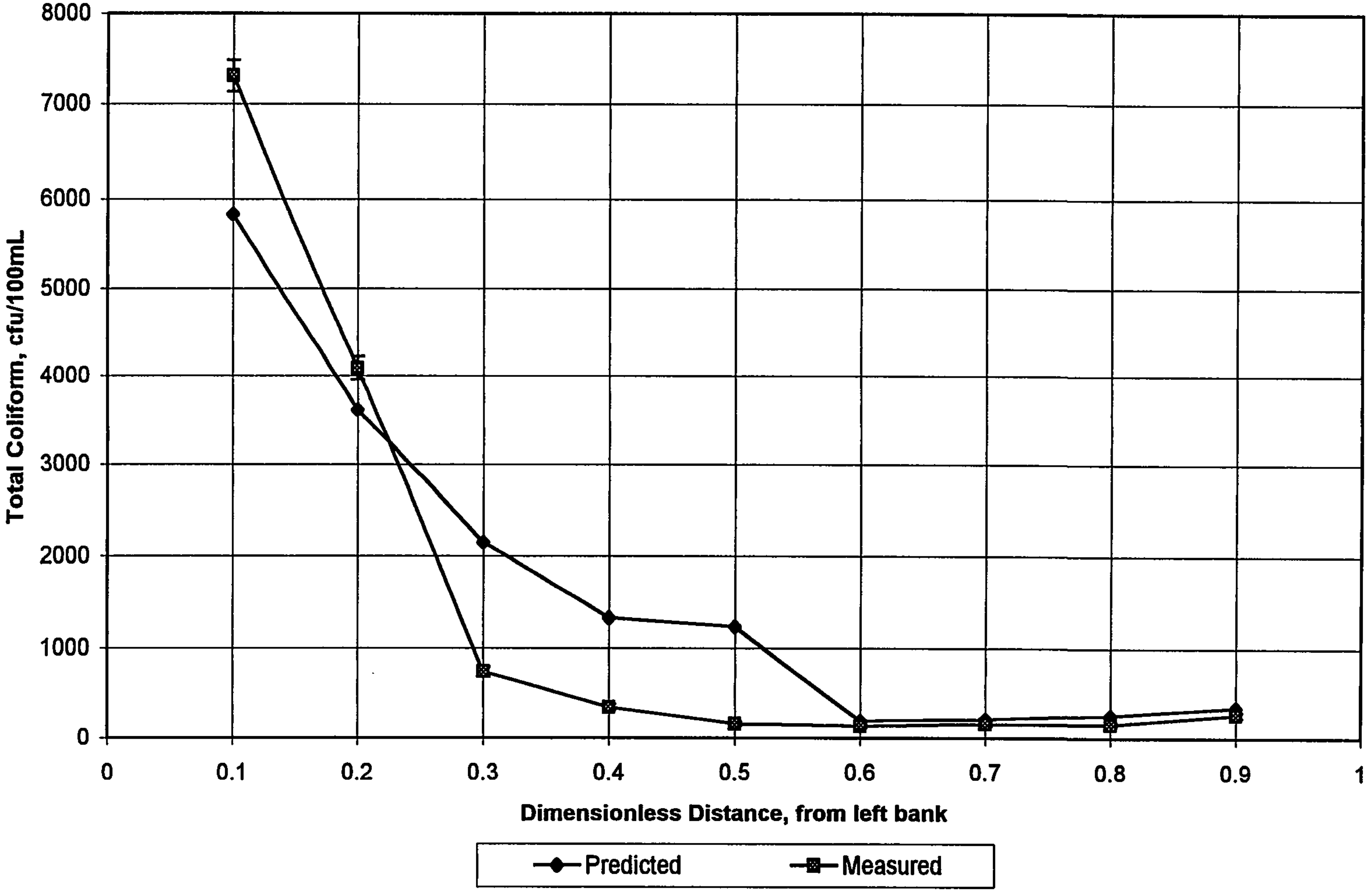


Figure 23. Fecal Coliform Measured vs Predicted
Run Two - Station Eight, k_e 4/day

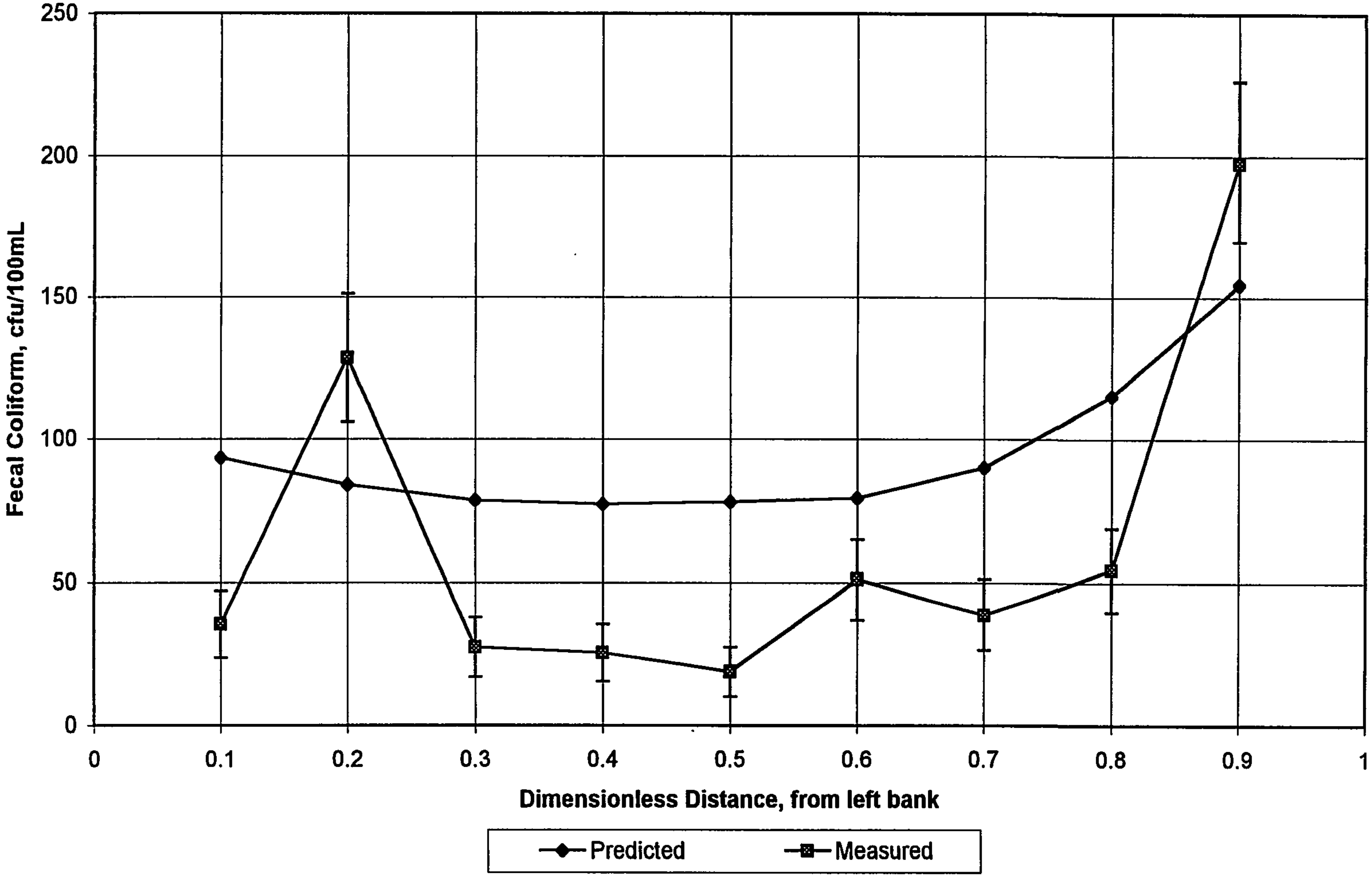


Figure 24. Fecal Coliform Measured vs Predicted
Run Two - Station Five, k_e 4/day

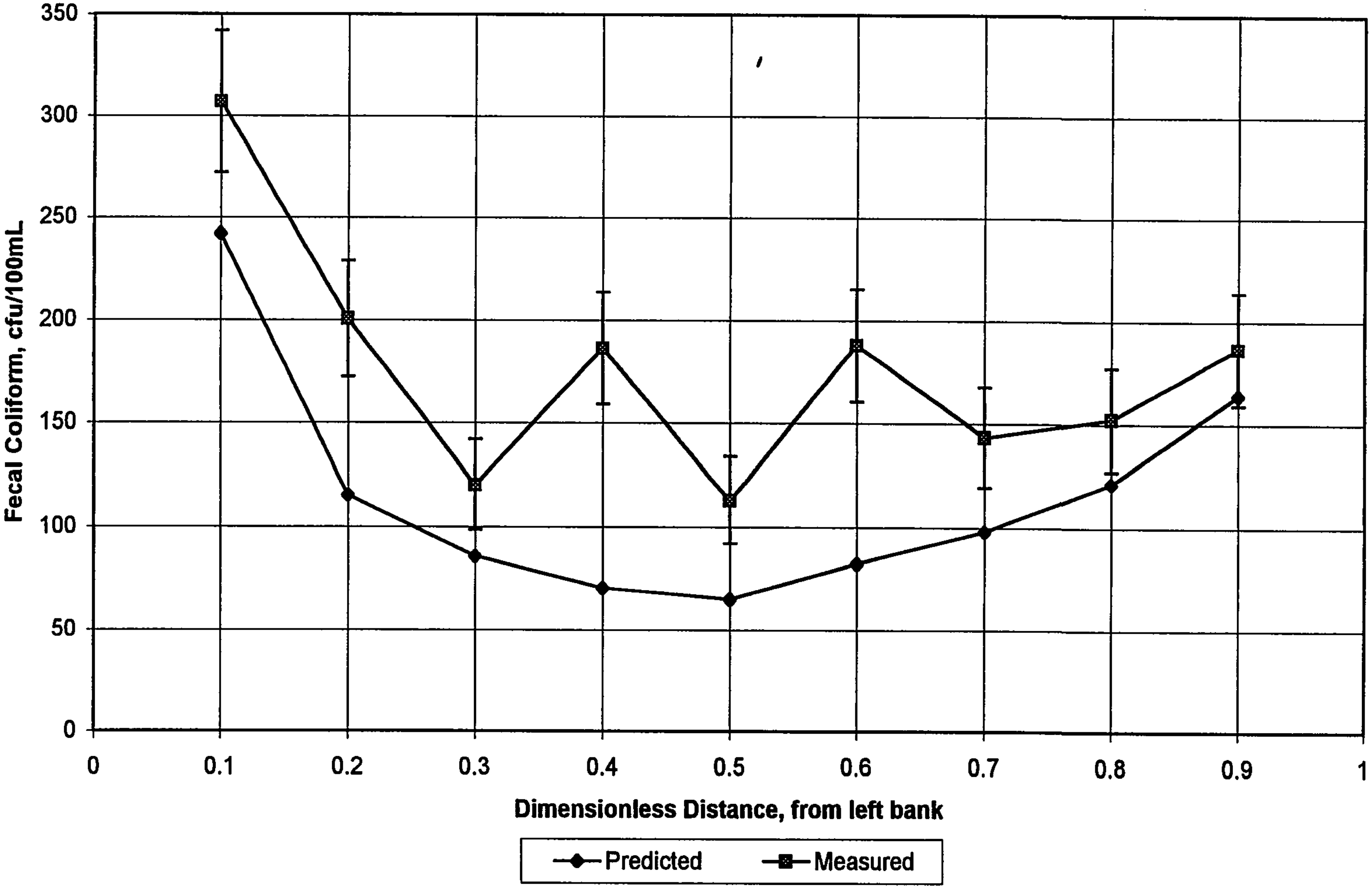
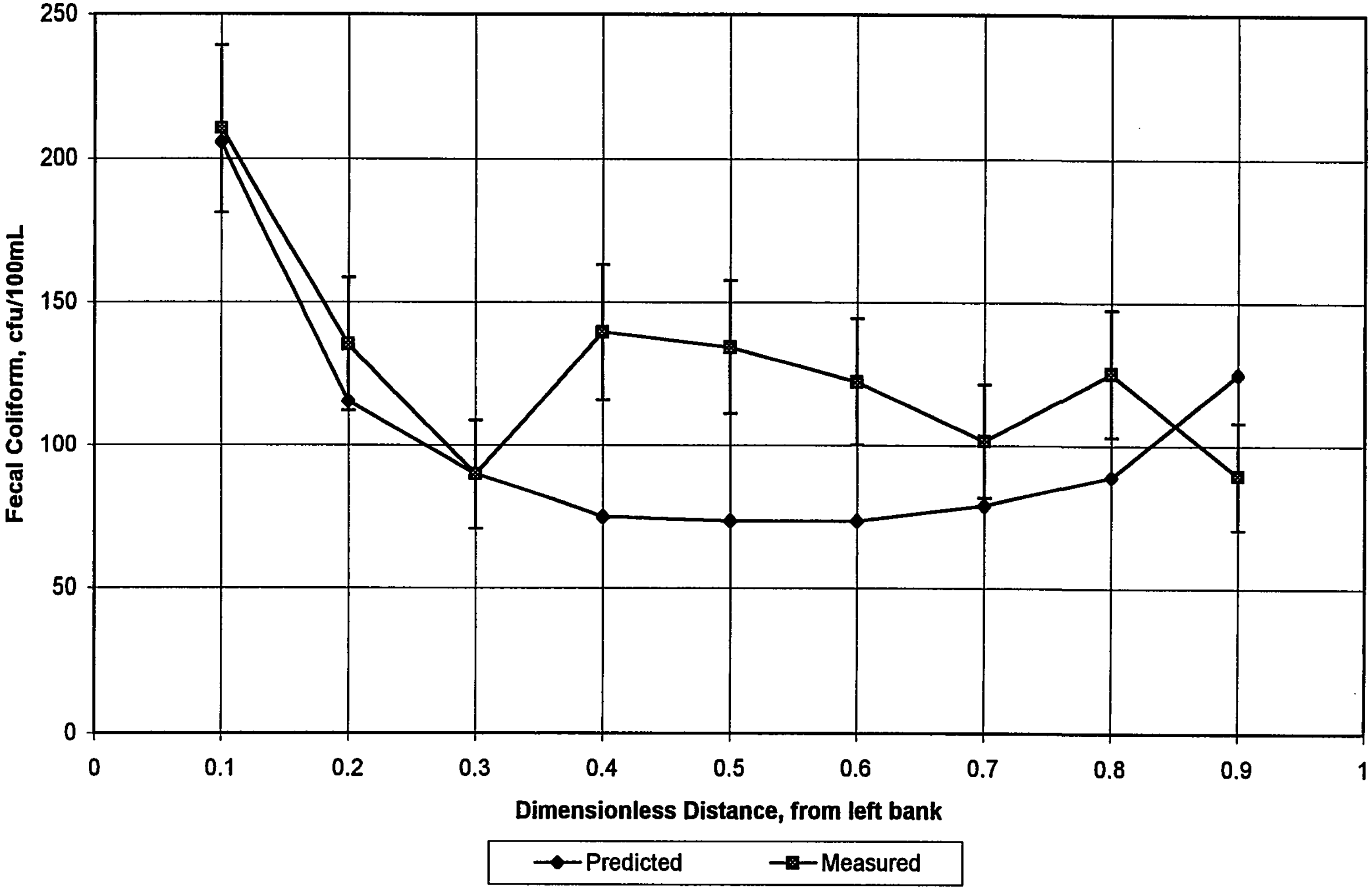


Figure 25. Fecal Coliform Measured vs Predicted
Run Two - Station One, k_e 4/day



to show major loads to the North Saskatchewan River between the E.L. Smith WTP and the Rossdale WTP. This loading was broken into eighteen inputs, nine for each bank and split into inputs between each cross section. From the results, there were consistencies in the loading data such that high concentrations were found just after station six on the left bank which would correspond to the Quesnell outfall input located approximately 50 metres upstream of station six. The right bank was also found to have a high loading value just downstream from station eight which would correspond to the Millwoods outfall. The Millwoods outfall was located approximately 200 metres upstream of station eight. The input loading was found to be consistently higher on the left bank compared to the right bank.

The overall coliform loading results were compared to the discharge levels at the Gold Bar wastewater treatment plant (Table 18). The Gold Bar wastewater treatment plant has recently upgraded to include an Ultra-Violet bacteria reduction unit that is able to substantially reduce the bacteria entering the North Saskatchewan River several kilometres downstream of the Rossdale WTP. When comparing the total coliform levels between the E.L. Smith WTP and the Rossdale WTP to the wastewater treatment plant (prior to UV bacteria reduction) the discharges are in the same order of magnitude 0.6×10^{10} to 1×10^{10} total coliforms per second for the storm sewer loading compared to 1×10^{10} to 1.5×10^{10} total coliforms per second for the wastewater discharge. However, the wastewater now passes through the UV bacteria reduction process before entering the river which reduces the total coliform load to 3×10^7 total coliforms per second. This level of total coliforms is substantially lower than what was entering the river between the water treatment plants. For the fecal coliform loads the levels are also found to be close, 6×10^8 to 2×10^9 fecal coliforms per second, compared to the wastewater discharge (prior to the UV bacteria reduction) of 0.9×10^9 to 1.5×10^9 fecal coliforms per second. With the UV bacteria reduction, however, the levels drop to 1.5×10^6 fecal coliforms per second, which is lower than the loading entering the river between the water treatment plants.

	Run One, at a flow of 118m^3/s and decay of 4.0/day			
Input from	TC (left) Load (cfu/s)	TC (right) Load (cfu/s)	FC (left) Load (cfu/s)	FC (right) oad (cfu/s)
E.L. Smith - 10	0	0	0	0
9	0	3.91E+07	4.81E+05	1.25E+07
8	4.74E+08	4.74E+08	1.43E+08	1.42E+08
7	6.48E+08	1.37E+08	0	0
6	1.78E+09	0	0	0
5	0	3.02E+08	5.50E+08	0
4	0	2.14E+08	0	2.51E+06
3	0	1.18E+08	0	0
2	1.78E+09	0	1.21E+09	0
Rossdale - 1				
Totals, cfu/s	4.67E+09	1.28E+09	1.90E+09	1.57E+08
	5.96E+09		2.06E+09	

	Run Two, at a flow of 191m^3/s and decay of 4.0/day			
Input from	TC (left) Load (cfu/s)	TC (right) Load (cfu/s)	FC (left) Load (cfu/s)	FC (right) oad (cfu/s)
E.L. Smith - 10	0	0	2.45E+07	0
9	2.31E+07	4.77E+08	0	9.54E+07
8	3.21E+07	2.17E+08	0	3.90E+07
7	3.34E+09	0	1.43E+08	3.69E+07
6	0	0	8.98E+07	1.86E+07
5	7.64E+09	0	0	0
4	0	1.67E+08	0	0
3	5.22E+08	0	7.16E+07	3.55E+07
2	0	1.04E+08	0	0
Rossdale - 1				
Totals, cfu/s	1.16E+10	9.65E+08	3.29E+08	2.25E+08
	1.25E+10		5.55E+08	

Loading	Total Coliform and Fecal Coliform Loads
Run One Total Loads- August 22, 1996	5.96×10^9 TC/s 2.06×10^9 FC/s
Run Two Total Loads - August 28, 1996	1.25×10^{10} TC/s 5.55×10^8 FC/s
Gold Bar Loads - prior to disinfection	1×10^{10} to 1.5×10^{10} TC/s 9.0×10^8 to 1.5×10^9 FC/s
After UV disinfection	3.0×10^7 TC/s 1.5×10^6 FC/s

Prior to the UV bacteria reduction of the wastewater at Gold Bar, the discharge was identified as a significant source of microbial contaminants to the North Saskatchewan River. With the disinfection now in operation, levels of contaminants entering the river through Gold Bar has substantially decreased. However the storm sewer discharge was only identified as a minor source of microbial contaminants to the river. From these findings it would appear that the storm sewer discharge of contaminants has now become a significant source of coliforms to the river, and should be responded to as such.

This dry weather study has been able to define a significant difference in coliform concentrations between the E.L. Smith WTP and the Rossdale WTP. This difference has been blamed on illegal dumping, agricultural runoff to creeks, and storm sewer discharges. Thus for this study the river was broken into ten sections, and the sections with major sources of contaminants were identified, and correlated to known outfalls or discharges in that particular section. The definite source of the increase has not be recognized, but the area to do further investigation has been significantly narrowed to certain storm sewers. The storm sewer discharges were of particular focus due to the presence of illicit connections and designed cross connections. The two sample runs (August 22 and 28, 1996) were completed during dry weather so as to ensure the lack of runoff in the storm sewers. Thus the only flow from storm sewers would likely be illicit connections or failing designed cross-connections.

From the sampling and modeling results the coliform loading values were calculated in order to determine the source (or sources) of significant loads to the North Saskatchewan River. The loading to the river, between the water treatment plants was determined to be on the same order of magnitude as Edmonton's wastewater treatment plant before bacteria reduction. With bacteria reduction of the wastewater effluent, the loading due to illicit connections have two to three orders of magnitude higher values. Therefore with the anticipation of more stringent regulations by Alberta Environment, this storm water effluent will have to be delt with in order to reduce the pollutant loading.

Further studies are required during longer periods of dry weather, to better understand where the source of contamination is originating from, and to determine the control measures that need to be taken to control or stop the flow of contaminants into the North Saskatchewan River.

A further study could include a winter sampling program, thus illicit discharges from storm sewers could be more easily determined due to the lack of surface runoff.

Further modeling of the storm water inputs could be done, but with coefficients determined experimentally on the North Saskatchewan River. Thus the modeling would be more accurate due to the fact that all of the unknown coefficients would be based on experiments performed on the river.

A more important study could be made on the storm drainage areas of the outfalls identified as potential problems. The focus can be moved from the river, and closer to the actually source of the contaminants. This study identified reaches in the river which were causing a large increase in coliforms, a closer sampling program at or in the outfalls draining into these sections could be done. With other outfalls that are known problems, flow gauges can be implemented, and an illicit connection program can be initiated to identify and correct any major cross-connections or leaks from sanitary sewage to the storm drainage system.

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Appendix A Cross Sectional Sounding and Flow Distribution Plots

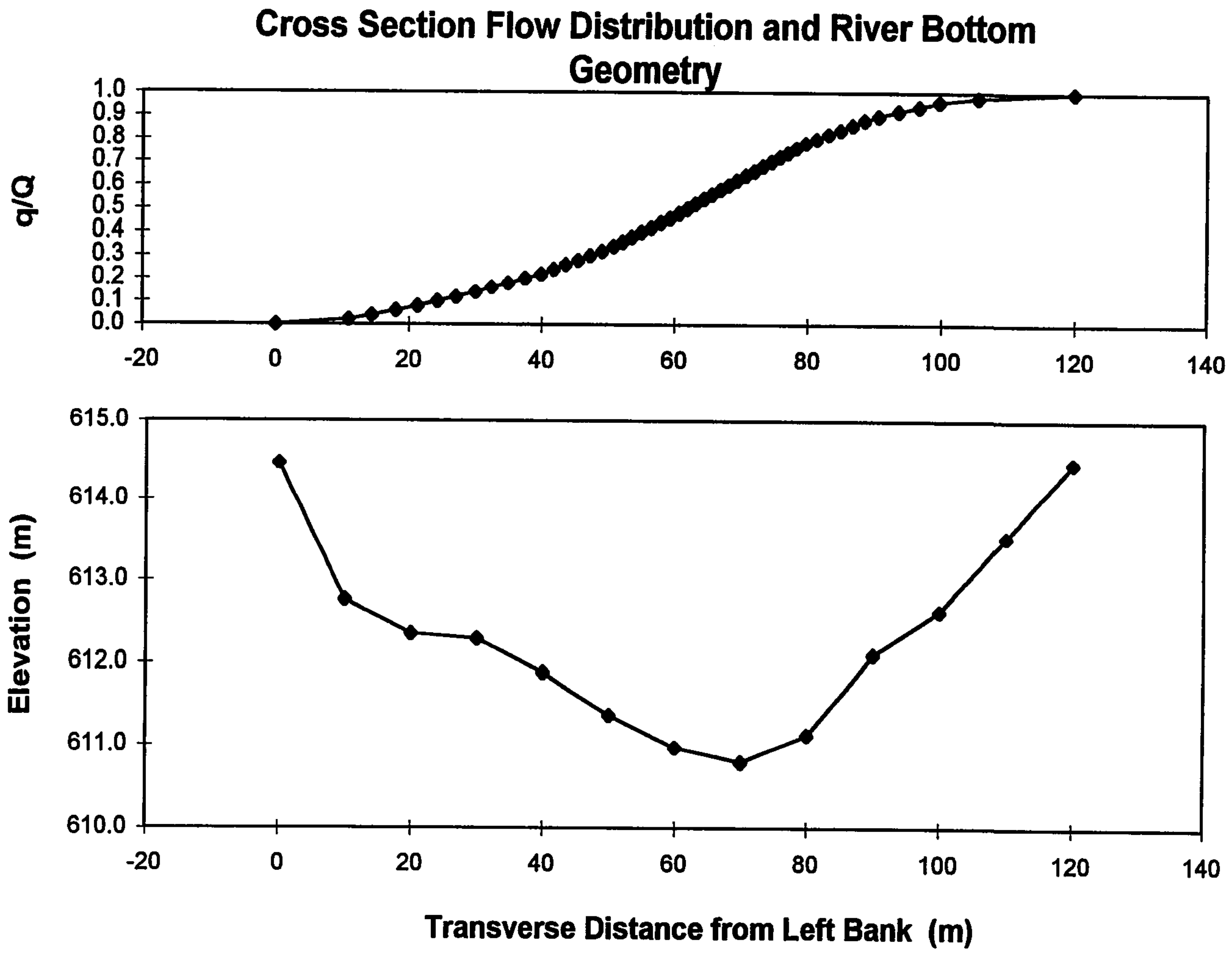


Figure A1. Hydraulic Summary for Station 1

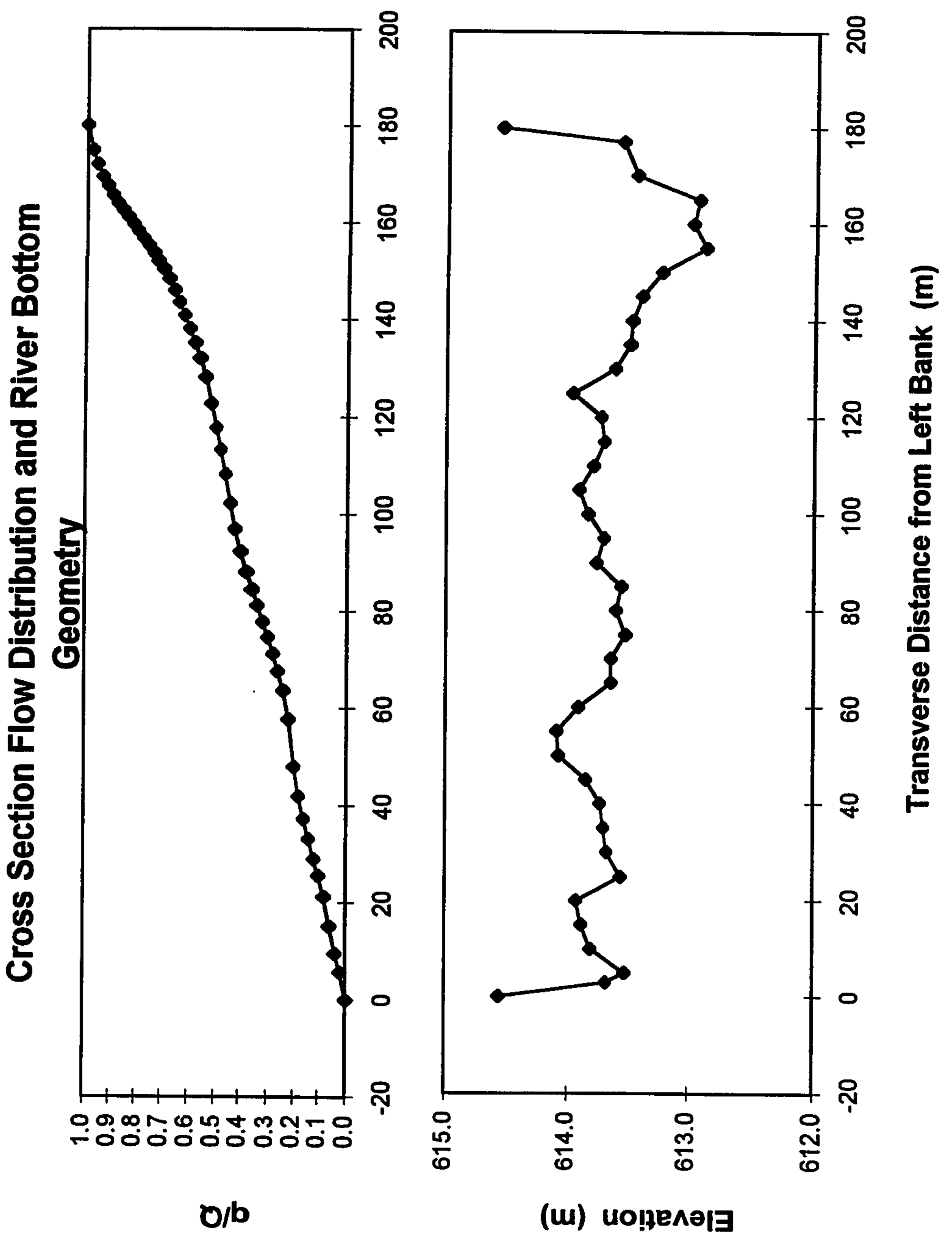


Figure A2. Hydraulic Summary for Station 2

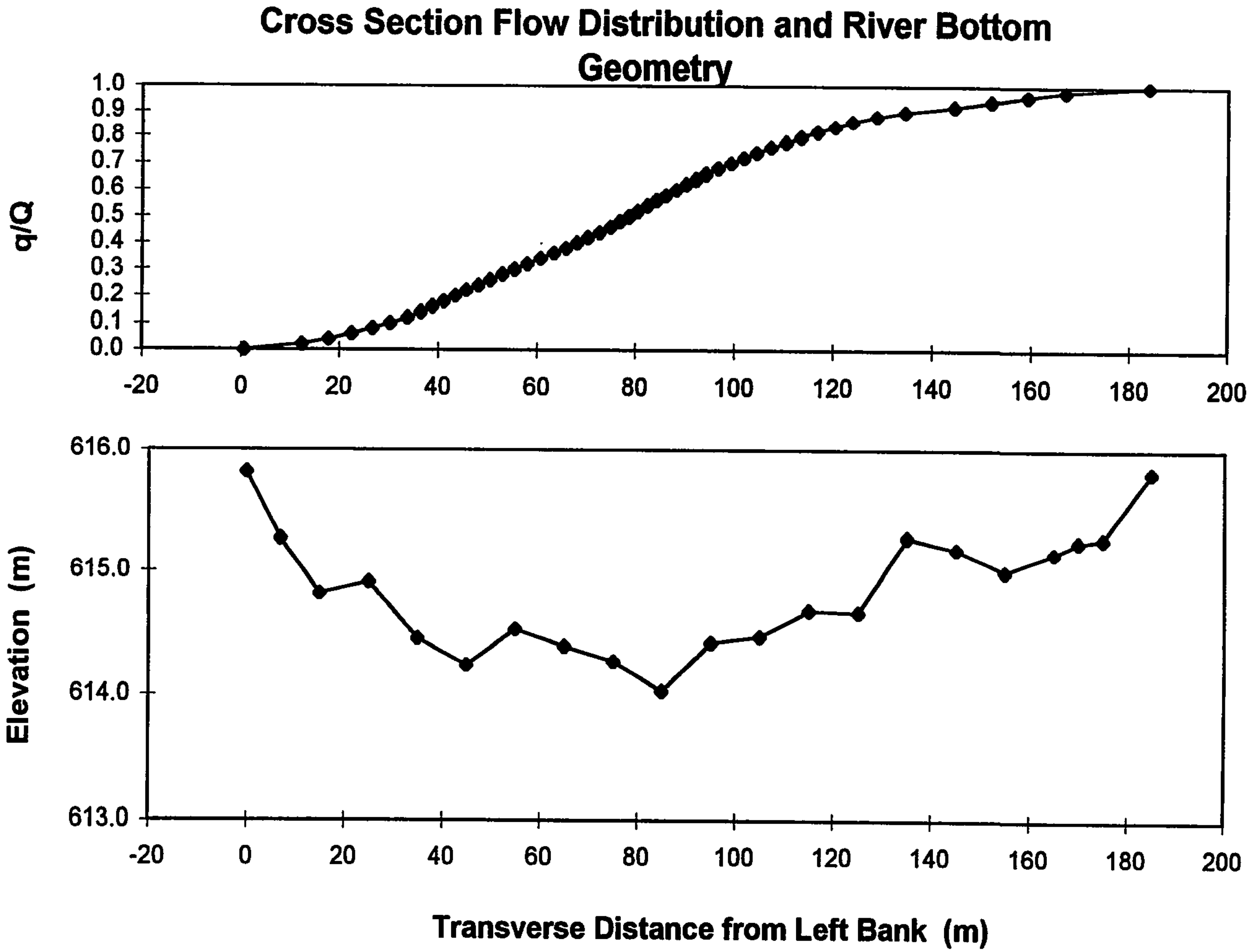


Figure A3. Hydraulic Summary for Station 3

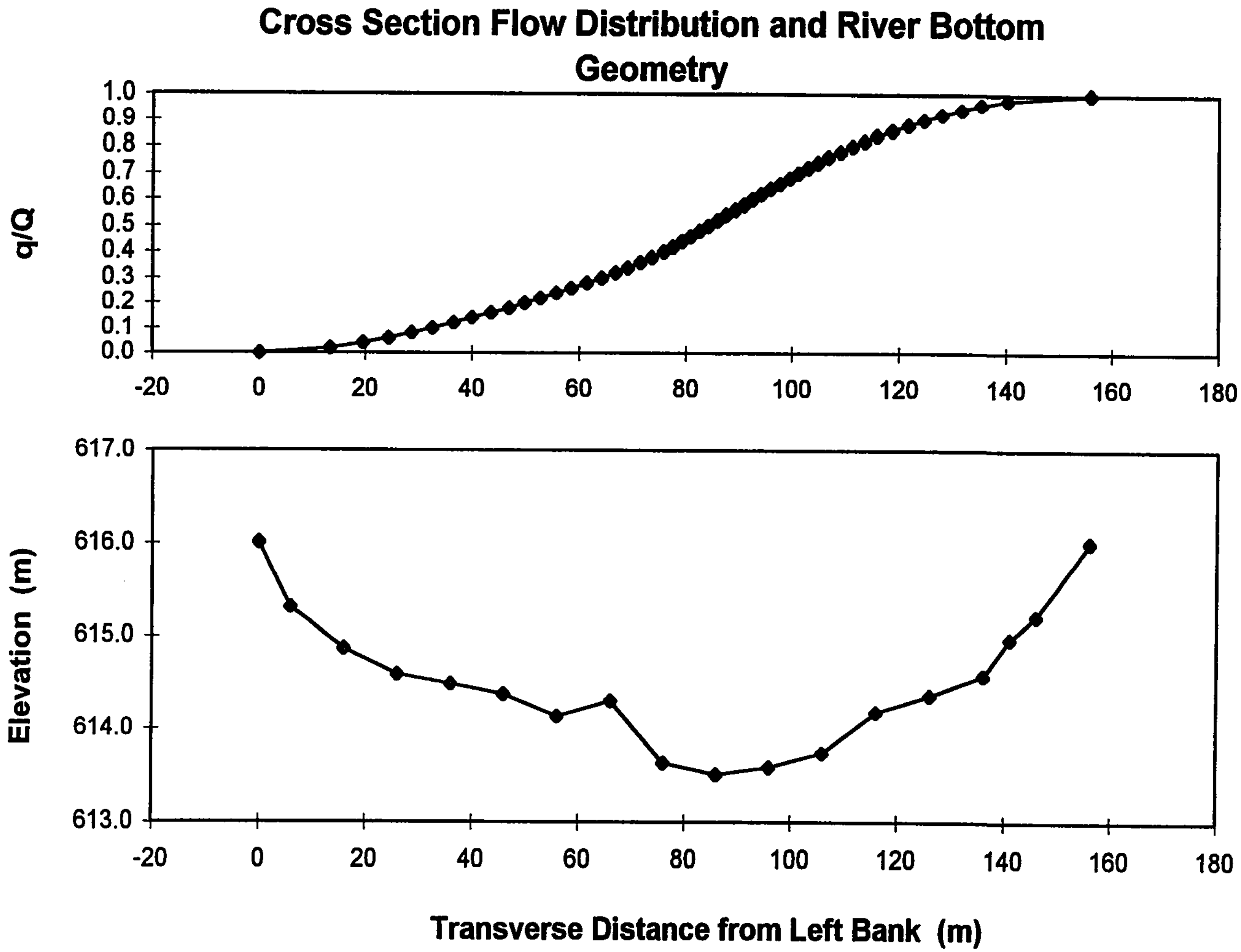


Figure A4. Hydraulic Summary for Station 4

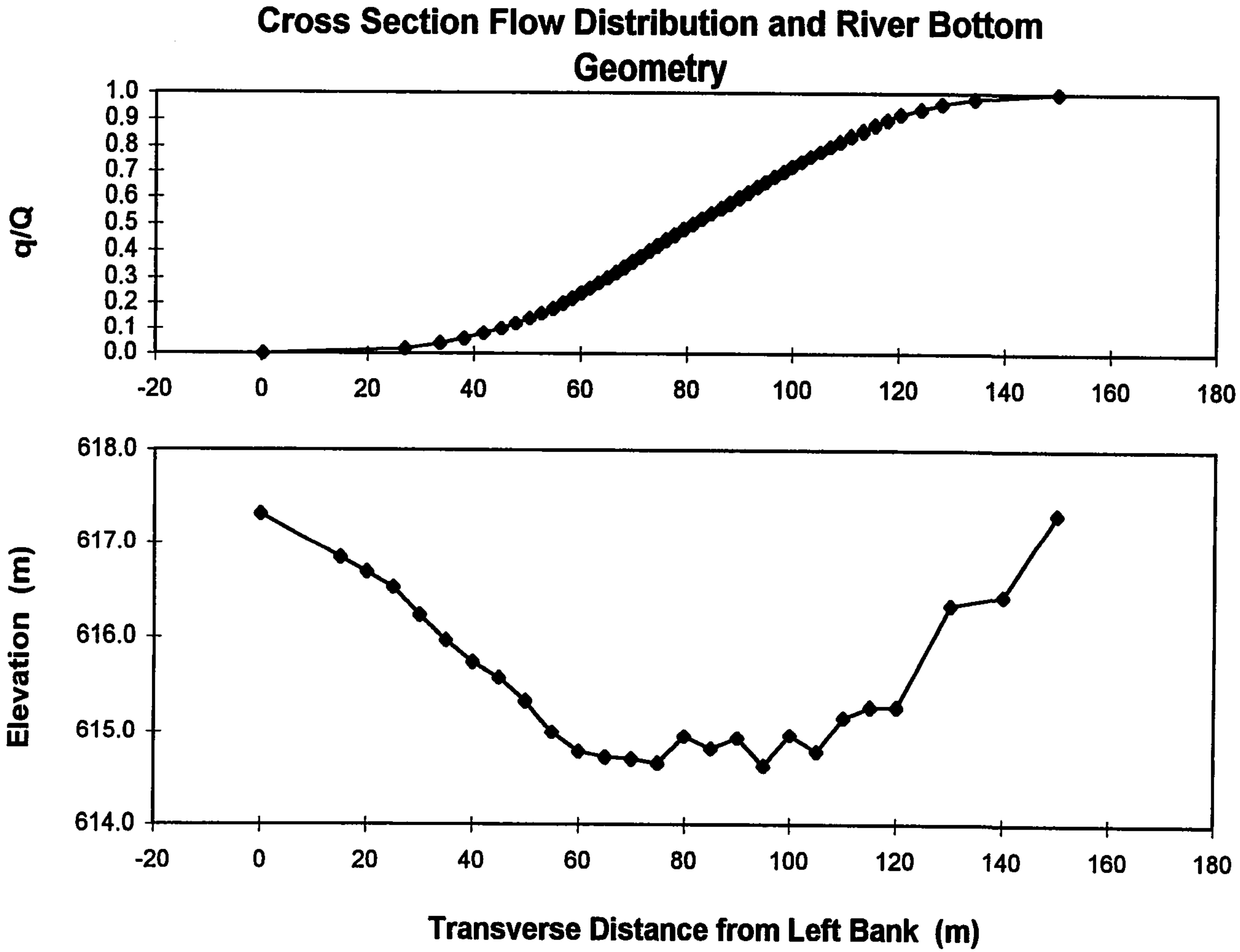


Figure A5. Hydraulic Summary for Station 5

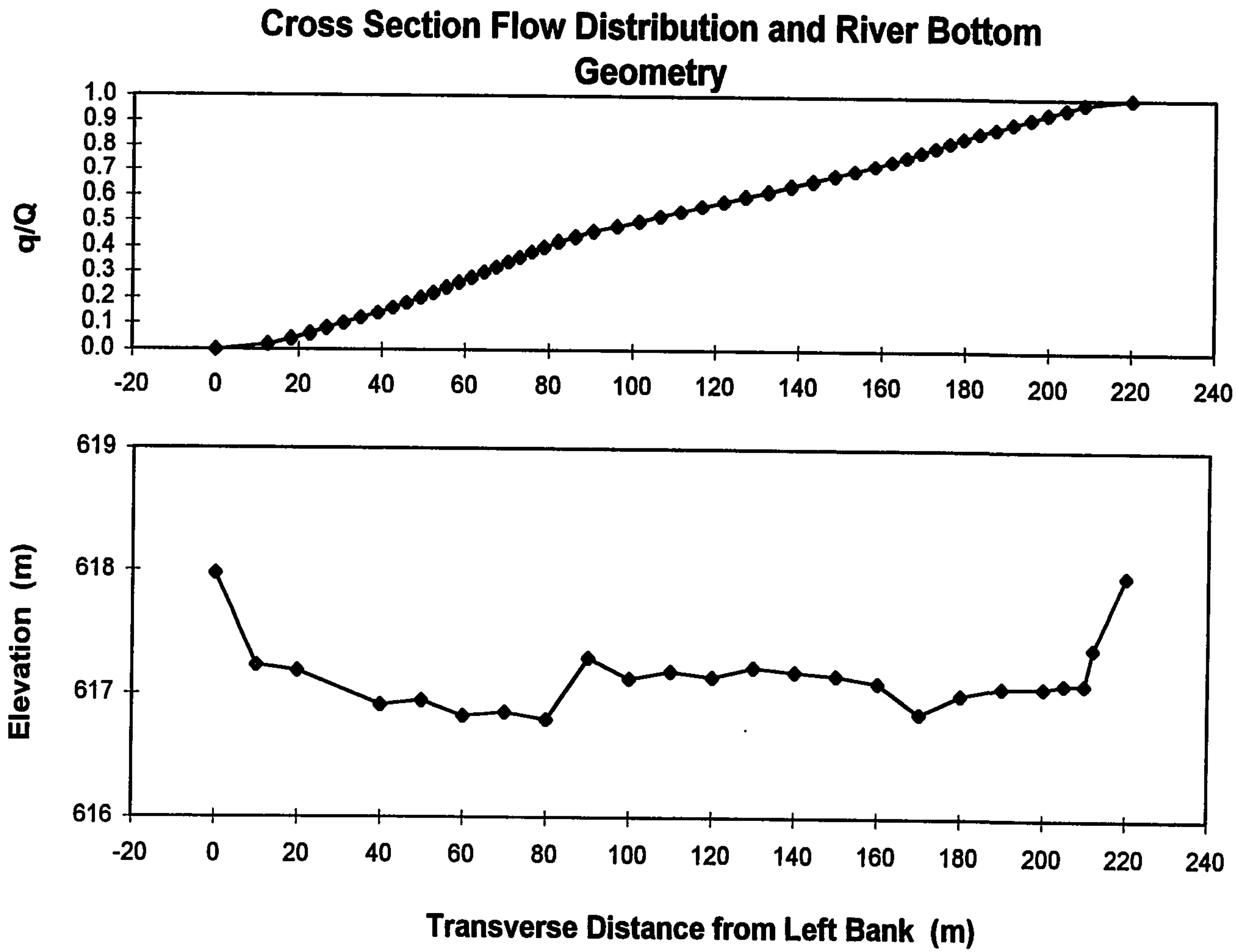


Figure A6. Hydraulic Summary for Station 6

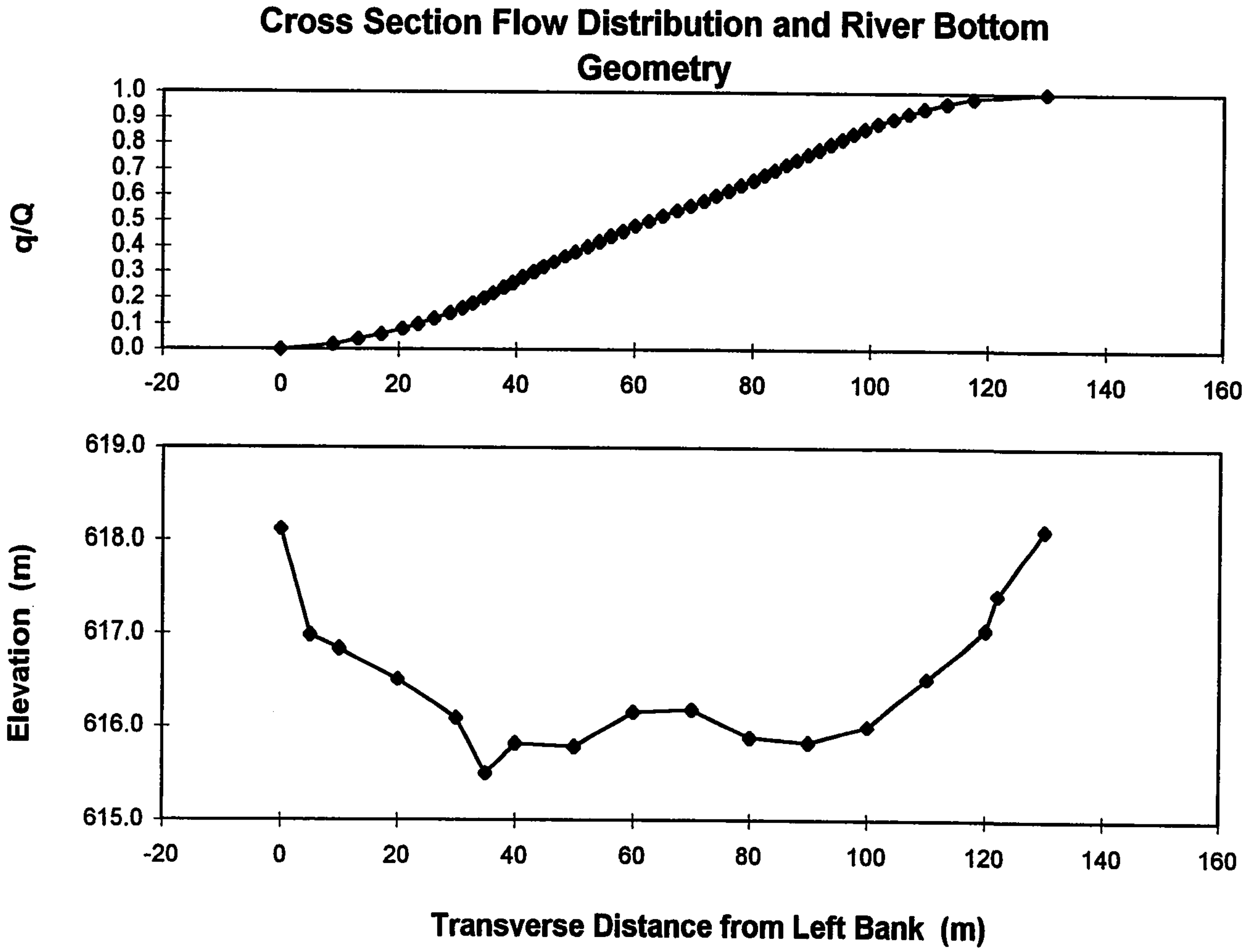


Figure A7. Hydraulic Summary for Station 7

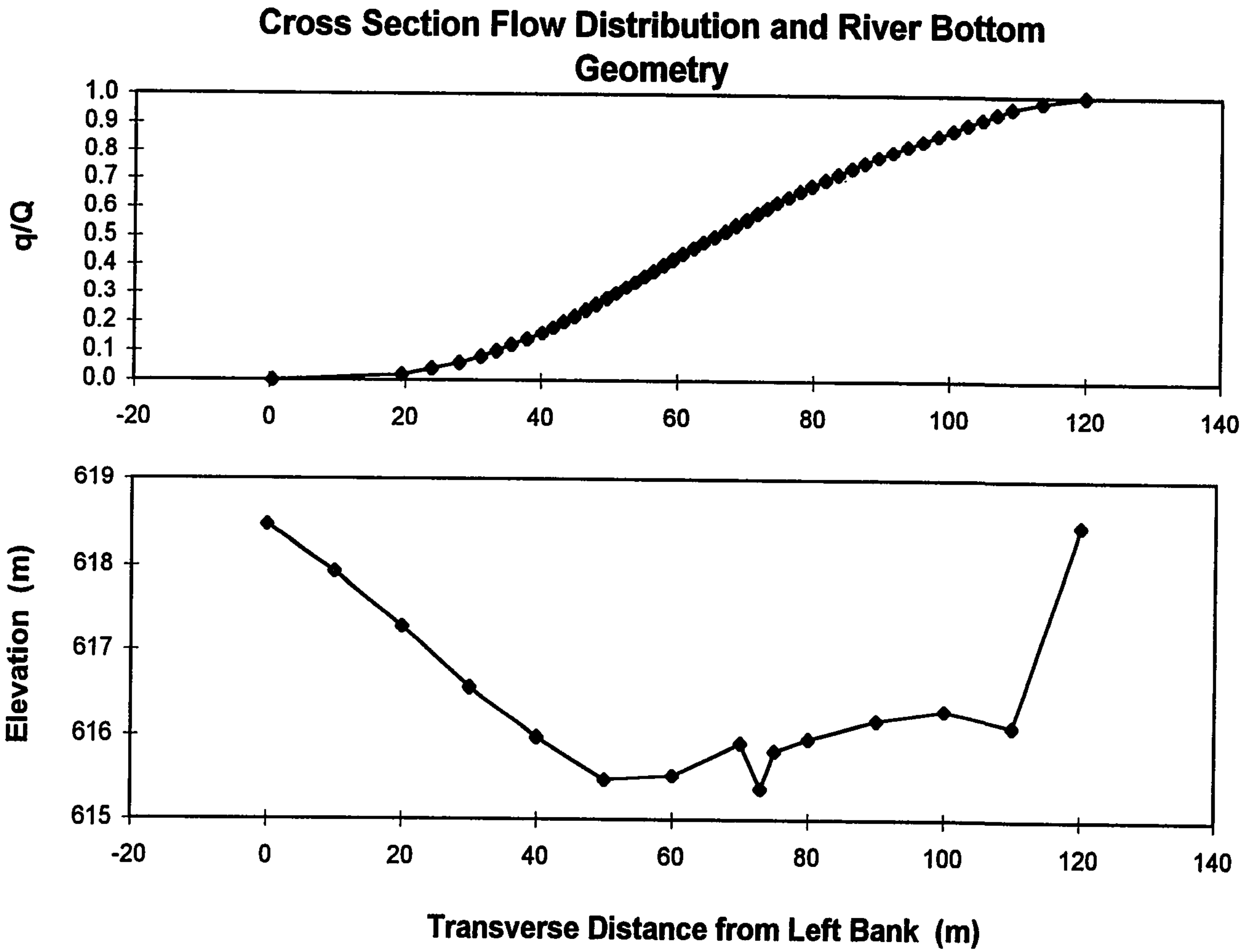


Figure A8. Hydraulic Summary for Station 8

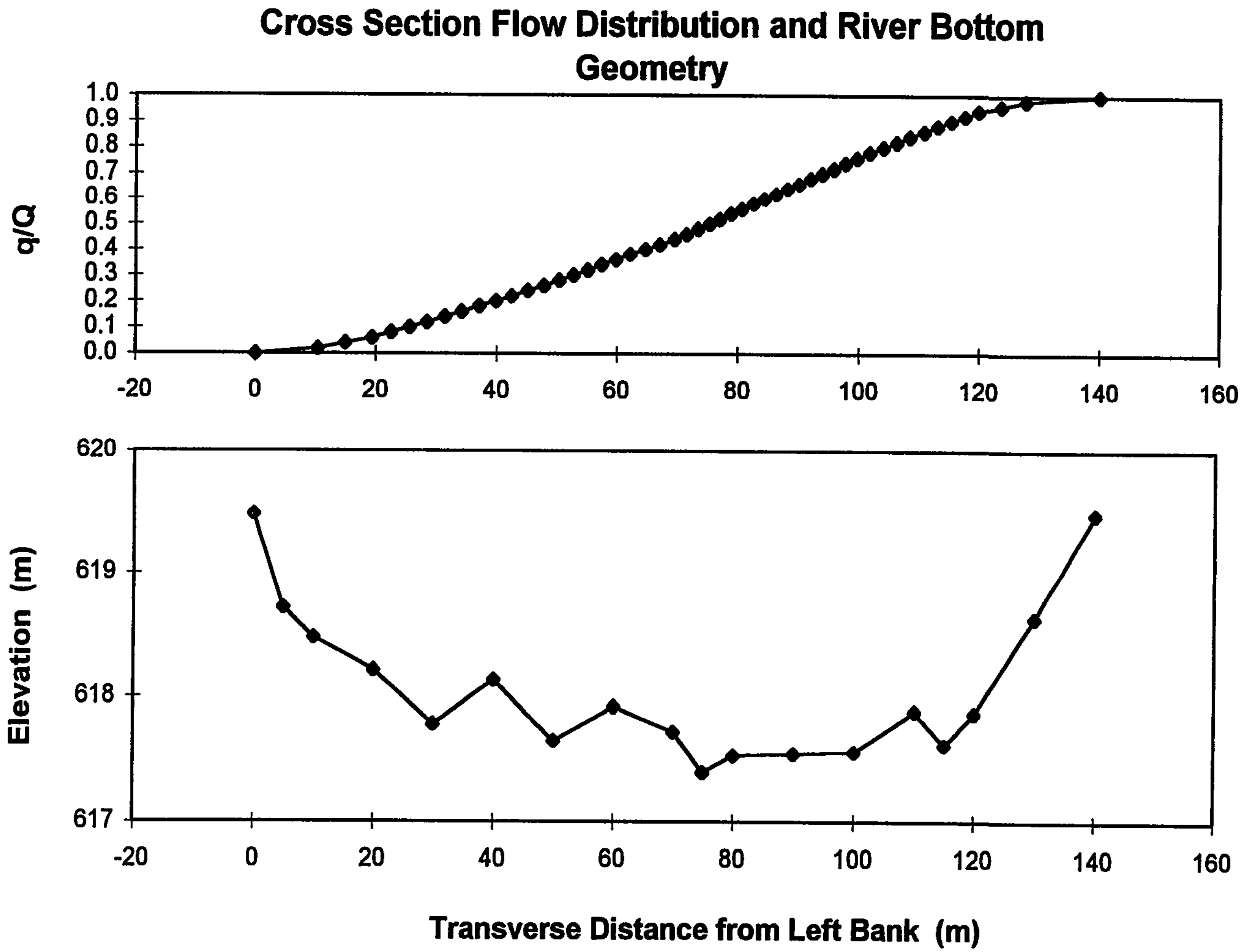


Figure A9. Hydraulic Summary for Station 9

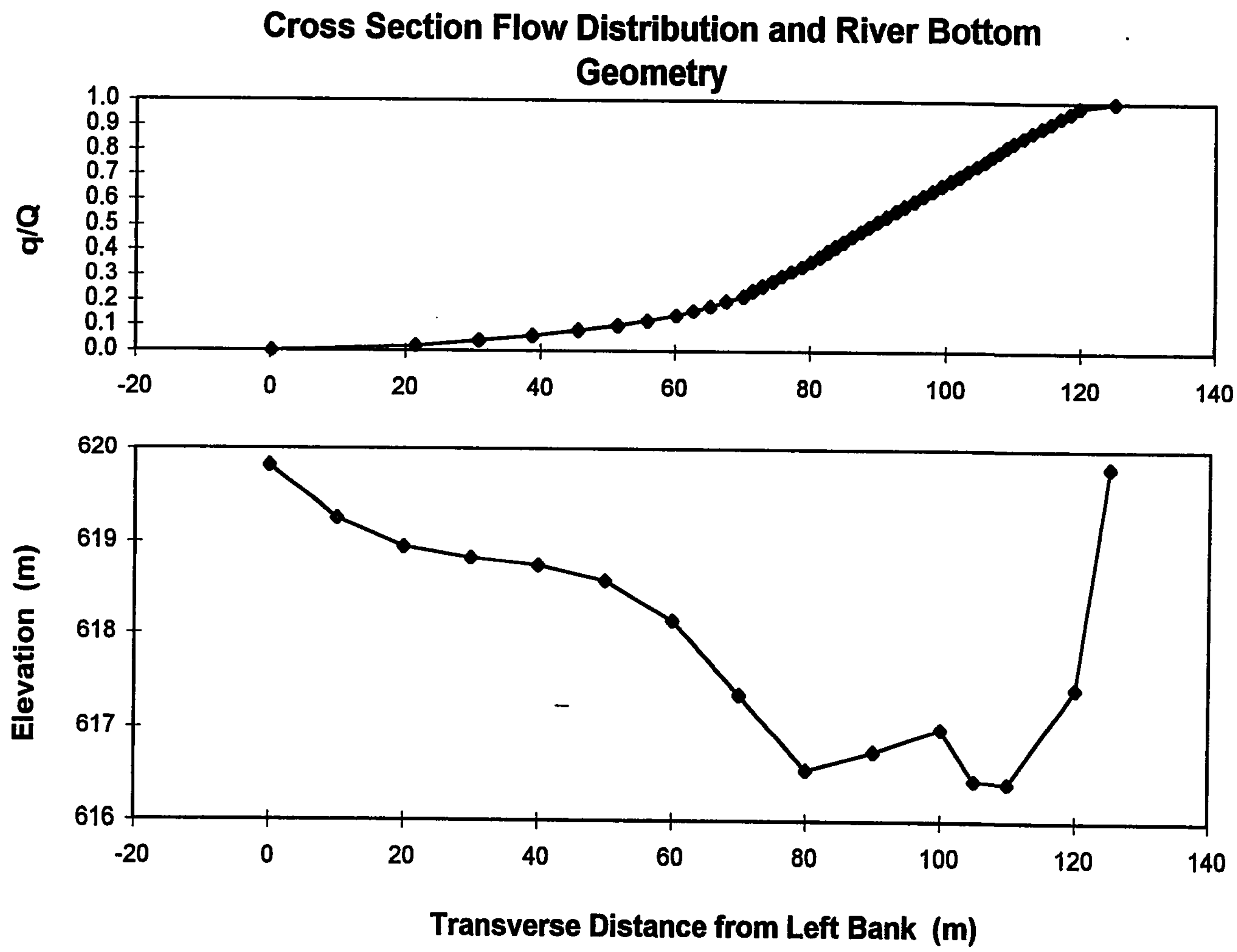
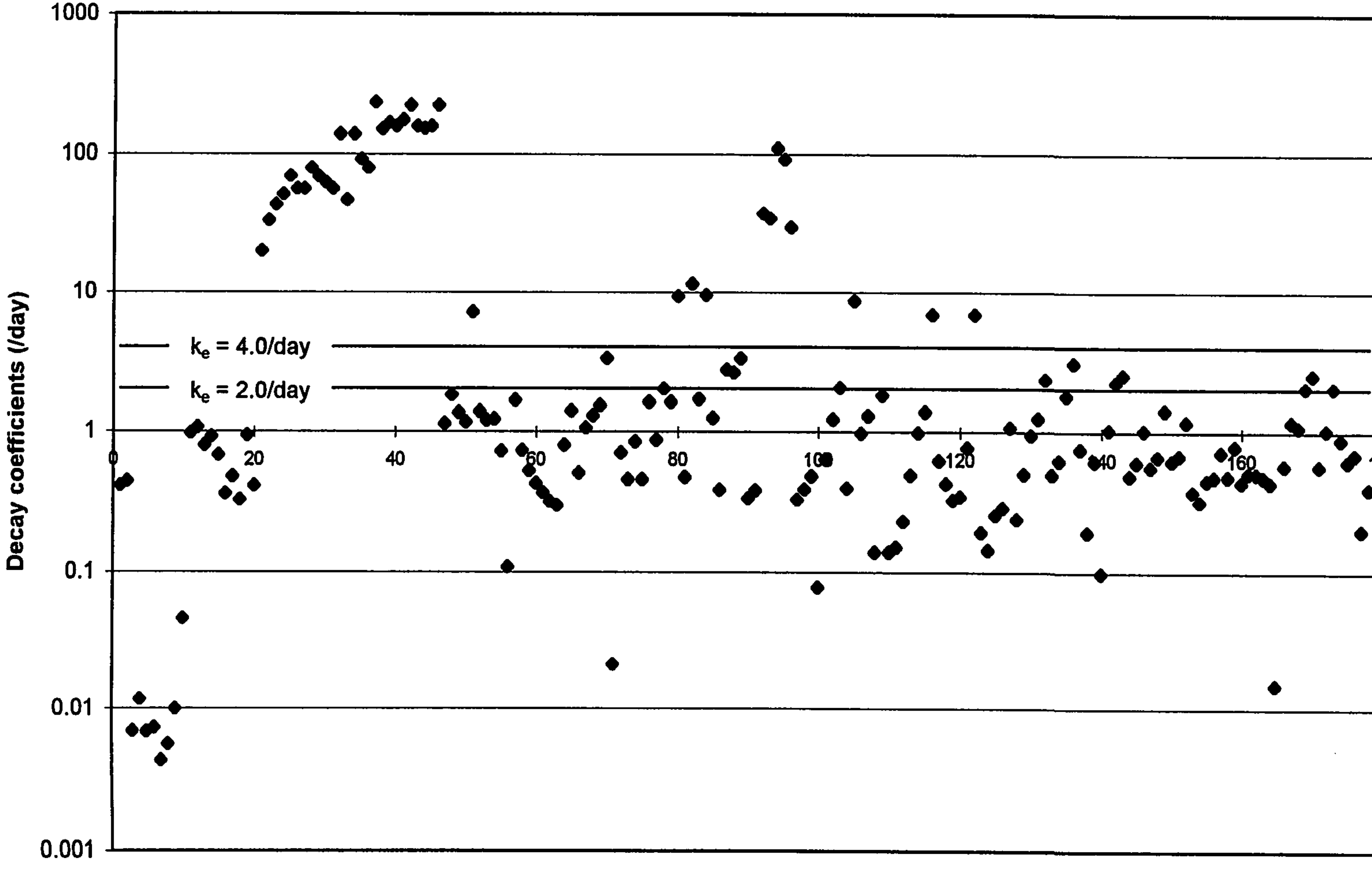


Figure A10. Hydraulic Summary for Station 10

Appendix B Bacteria Die-off Search Results

		°C				k (day-1)	
Sarikaya & Saatçi (1987)	TC	25		Secondary effluent	Laboratory - dark	0.415	0.446
Glenne (1984)	TC	T		soil / groundwater	Field - three canyons, east of Salt Lake City	$k = 0.85e^{-0.092(14-T)}$	
	TC	T		fresh stream water		$k = 2.5e^{-0.092(20-T)}$	
	TC	-10		snow		0.007	
Sherer *et al.* (1992)	FC			sediments	Low FC, fine sediment	0.012	
	FC				Low FC, coarse sediment	0.007	
	FC				Medium FC, fine sediment	0.007	
	FC				Medium FC, coarse sediment	0.004	
	FC				High FC, fine sediment	0.006	
	FC				High FC, coarse sediment	0.010	
	FC				FC in supernatant	0.046	
Steynberg, *et al.* (1995)	*E. coli*			Rietspruit River, South Africa	Winter, upstream	0.975	
	E. coli				Winter, downstream	1.075	
	E. coli				Summer, upstream	0.800	
	E. coli				Summer, downstream	0.925	
Sarikaya & Saatçi (1995)	TC	35		Sea, 100m off the Jeddah coast	dark sea water sample	0.686	
	TC	40			dark sea water sample	0.366	
	TC	30			dark sea water sample	0.483	
	TC	25			dark sea water sample	0.330	
	TC	20			dark sea water sample	0.939	
	TC	35			dark sea water sample	0.414	
	TC				sample exposed to sunlight	19.543	
Aral, *et al.* (1995)	TC			Mediterranean Sea	Istanbul	32.51	69.08
	TC				Marmara Sea, Tracer Technique	42.51	55.26
	TC				Marmara Sea, Polyethylene Bag	50.24	55.26
	TC				Aegean Sea, Tracer Technique	78.95	
	TC				Aegean Sea, Polyethylene Bag	69.08	138.16
	TC				Mediterranean Sea, Tracer	61.40	92.10
	TC				Mediterranean Sea, Bag	55.26	78.95
	TC				Antalya, Tracer Technique	138.16	230.26
	TC				Antalya, Polyethylene Bag	46.05	149.36
Bravo & de Vicente (1992)	TC			Mediterranean Sea - Spain	Aladino outfall	165.79	
	TC				Fuengirola outfall - trail 1	157.89	
	TC				Fuengirola outfall - trail 2	174.51	
	TC				Costa-Cabana outfall	221.05	
	FC				Aladino outfall	157.89	
	FC				Fuengirola outfall - trail 1	150.72	
	FC				Fuengirola outfall - trail 2	157.89	
	FC				Costa-Cabana outfall	221.05	
Qin, *et al.* (1991)	TC	20	8.30	Maturation ponds	Laboratory experiment	1.140	
	TC	20	8.67		Laboratory experiment	1.803	
	TC	24	7.95		Laboratory experiment	1.356	
	TC	24	8.25		Laboratory experiment	1.165	
	TC	28	8.32		Laboratory experiment	7.200	
	TC	28	8.00		Laboratory experiment	1.379	
	TC	32	7.93		Laboratory experiment	1.204	
	TC	32	8.16		Laboratory experiment	1.227	
Auer & Niehaus (1993)	FC	20		Onondago Lake, Syracuse, NY	Laboratory - dark death rate	0.73	
Mayo (1989)	FC			Pilot stabilization ponds, Dar es Salaam, Tanzania	Dar es Salaam, Tanzania - dark	0.108	
	FC				Light - 550 cal/cm^2, depth 0 m	1.66	
	FC				Light - 550 cal/cm^2, depth 0.5 m	0.74	
	FC				Light - 550 cal/cm^2, depth 0.75 m	0.53	
	FC				Light - 550 cal/cm^2, depth 1.0 m	0.43	
	FC				Light - 550 cal/cm^2, depth 1.25 m	0.37	
	FC				Light - 550 cal/cm^2, depth 1.5 m	0.32	
	FC				Light - 550 cal/cm^2, depth 1.75 m	0.3	
Mancini (1978)	TC	20		Fresh water	summary	0.8	
	TC	20		Sea water	summary	1.4	
Kittrell & Furfari (1963)	TC			Missouri River	Winter study	0.51	
	TC			Tennessee River	(Knoxville) - Summer study	1.06	
	TC			Tennessee River	(Chattanooga) - Summer study	1.3	
	TC			Sacramento River	Summer study	1.52	
	TC			Cumberland River	Summer study	3.32	
Wuhramnn (1972)	TC	10		Groundwater Stream		0.021	
Klock (1971)	TC	12.7		Wastewater Lagoon	Field winter study	0.71	
	TC	7.9			Field winter study	0.46	
	TC	17.9			Field spring study	0.85	
	TC	14.4			Field spring study	0.46	
	TC	25.2			Field summer study	1.61	
	TC	25.5			Field summer study	0.87	
Marais (1974)	TC	19		Maturation Ponds	South Africa study location	2	
	TC	19		Maturation Ponds	Calculation	1.6	
	TC			Maturation Ponds	"T" for unknown	$k = 2.6(1.19)^{T-20}$	
Gannon *et al* (1983)	TC			Ford Lake - Ypsilant, Michigan	Normal sunlight - August, dry weather	9.36	11.52
	TC				Low / little sunlight - August, dry weather	0.48	1.68
	TC				Field study - August, dry weather	9.6	
Thornton *ei al* (1980)	TC	15		Caddo river & DeGray Reservoir	October	1.25	

	TC	10			March	0.39	2.61
	TC	20			June	2.74	3.31
Dutka & Kwan (1980)	*E. coli*	18.5		Hamilton bay	depth - 1 m, days - 28, summer study	0.337	
	E. coli	18.7		Lake Ontario	depth - 1 m, days - 28 summer study	0.387	
Pujioka *et al* (1981)	FC			Seawater - Hawaii, Honolulu	Laboratory - exposed to sunlight	36.8	110.5
	FC			Seawater - Hawaii, Honolulu	Simulated field - exposed to sunlight	33.8	92.1
	FC			Freash water - Nuuanu Stream	Field study	29.1	
Anderson *et al* (1979)	*E. coli*			Seawater	Laboratory study, days - 2-8, salinity - 10‰	-0.003	0.078
	E. coli				Laboratory study, days - 2-8, salinity - 15‰	0.331	0.638
	E. coli				Laboratory study, days - 2-8, salinity - 25‰	0.393	1.227
	E. coli				Laboratory study, days - 2-8, salinity - 30‰	0.489	2.037
Mahloch (1974)	TC			Leaf River	Pascagoula river basin - (Mississippi)	0.4	
Zanoni *et al* (1978)	TC	10		Lake Michigan	A deep oligotrophic type lake	8.726	
McFeters *et al* (1974)	TC	9.5-12.5		Well water	Inoculated with pure cultures	0.979	
	TC						
	TC						
McFeters & Stuart (1972)	*E. coli*			Freashwater - Bozeman Creek	Field study - Mystic watershed, Montana	1.289	
	E. coli				Laboratory study	0.138	
	E. coli			Freashwater - Middle Creek	Field study - Hyalite watershed, Montana	1.796	
	E. coli				Laboratory study	0.138	
	E. coli	5	8.1	Freashwater - Middle Creek	Laboratory study	0.151	
	E. coli	10	8.1		Laboratory study	0.231	
	E. coli	15	8.1		Laboratory study	0.495	
	E. coli	20	8.1		Laboratory study	0.99	
	E. coli	25	8.1		Laboratory study	1.386	
	E. coli	10	2.5	Freashwater - distilled	Laboratory study	6.93	
	E. coli	10	4		Laboratory study	0.63	
	E. coli	10	5		Laboratory study	0.433	
	E. coli	10	5.5		Laboratory study	0.33	
	E. coli	10	7.3		Laboratory study	0.347	
	E. coli	10	10		Laboratory study	0.77	
	E. coli	10	12		Laboratory study	6.93	
Mitchell & Starzyk (1975)	*E. coli*	0		Freashwater	Inocoulated river water - Laboratory, 20 day	0.192	
	E. coli	5			Inocoulated river water - Laboratory, 20 day	0.144	
	E. coli	10			Inocoulated river water - Laboratory, 20 day	0.256	
	E. coli	20			Inocoulated river water - Laboratory, 20 day	0.288	
Geldreich & Kenner (1969)	FC	20		Storm water runoff	Summer, 14 day test	1.07	
	FC	10		Storm water runoff	Winter, 14 day test	0.239	
Hanes & Fragola (1967)	TC		6.8	BOD dilution water	Dissolved Oxygen - 7.8 mg/L, 8 day test	0.505	
	TC		7	Seawater - 33%	Dissolved Oxygen - 7.2 mg/L, 8 day test	0.952	
	TC		7.3	Seawater - 67%	Dissolved Oxygen - 6.8 mg/L, 8 day test	1.25	
	TC		7.8	Seawater - 100%	Dissolved Oxygen - 6.5 mg/L, 4 day test	2.341	
	E. coli		6.8	BOD dilution water	Dissolved Oxygen - 7.8 mg/L, 8 day test	0.501	
	E. coli		7	Seawater - 33%	Dissolved Oxygen - 7.2 mg/L, 8 day test	0.631	
	E. coli		7.3	Seawater - 67%	Dissolved Oxygen - 6.8 mg/L, 8 day test	1.781	
	E. coli		7.8	Seawater - 100%	Dissolved Oxygen - 6.5 mg/L, 4 day test	3.067	
Geldreich et al. (1980)	*E. coli*	20		Water supply reservoir	Surface - 0.9 m depth, 9 day test	0.755	
	E. coli	10		Water supply reservoir	6.1 m depth, 24 day test	0.192	
Vasconceles & Swartz (1976)	*E. coli*	8.9		Seawater	Laboratory study - 7 day test	0.625	
	E. coli	9.8			Laboratory study - 7 day test	0.0987	
	E. coli	10.7			Laboratory study - 6 day test	1.036	
	E. coli	12.6			Laboratory study - 6 day test	2.239	
	E. coli	14.5			Laboratory study - 6 day test	2.52	
Slanetz & Bartley (1965)	TC	18	7.2	Seawater - New Hampshire Bay	Sewage effluent, Field, 7 day test	0.491	0.565
	FC	18	7.2		Sewage effluent, Field, 7 day test	0.613	0.669
	E. coli				Pure culture test	1.023	1.417
Orlob (1956)	TC	5		Seawater - Pacific Ocean - (San Francisco Bay)	Laboratory study - May Samples	0.628	
	TC	21			Laboratory study - May Samples	0.686	
	TC	30			Laboratory study - May Samples	1.176	
	TC	6			Laboratory study - March Samples	0.38	
	TC	10.2			Laboratory study - March Samples	0.322	
	TC	15.2			Laboratory study - March Samples	0.456	
	TC	20.4			Laboratory study - March Samples	0.482	
	TC	25.8			Laboratory study - March Samples	0.723	
	TC				Laboratory study - incubated & agitated	0.489	
	TC				Laboratory study - incubated & not agitated	0.793	
	TC	20			Laboratory study - Lactose broth added - 120ppm	0.443	
	TC	20			Laboratory study - Lactose broth added - 60ppm	0.517	
	TC	20			Laboratory study - Lactose broth added - 30ppm	0.509	
	TC	20			Laboratory study - Lactose broth added - 15ppm	0.483	
	TC	20			Laboratory study - Lactose broth added - 7.5ppm	0.438	
	TC	6			Laboratory study - Lactose broth added - 120ppm	0.015	
	TC	20.4			Laboratory study - Lactose broth added - 120ppm	0.583	
	TC	30.4			Laboratory study - Lactose broth added - 120ppm	-0.099	



Die-off Coefficients
(Base e)

Appendix C Transverse Mixing Coefficients Search Results

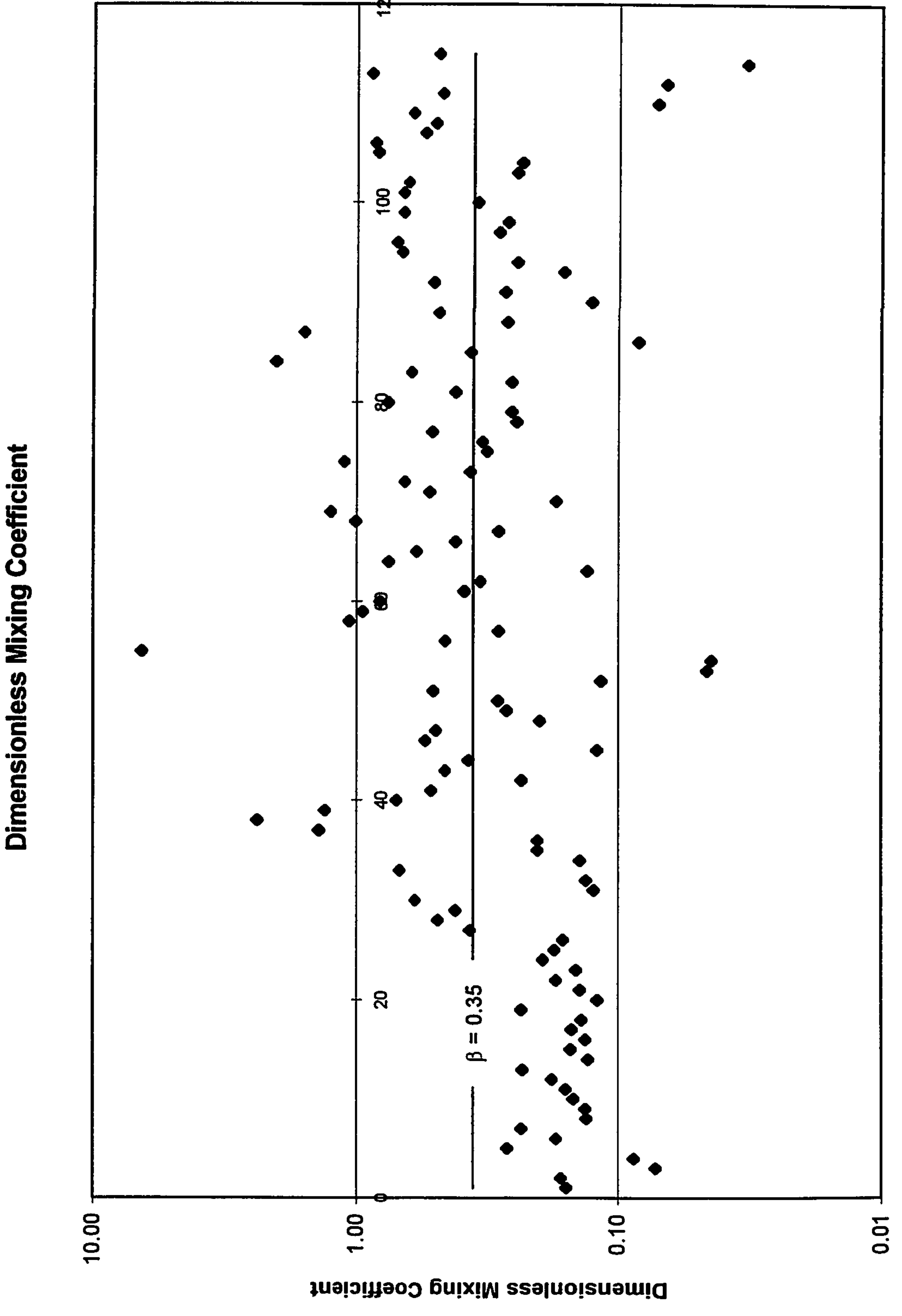
Transverse Coefficients - Laboratory

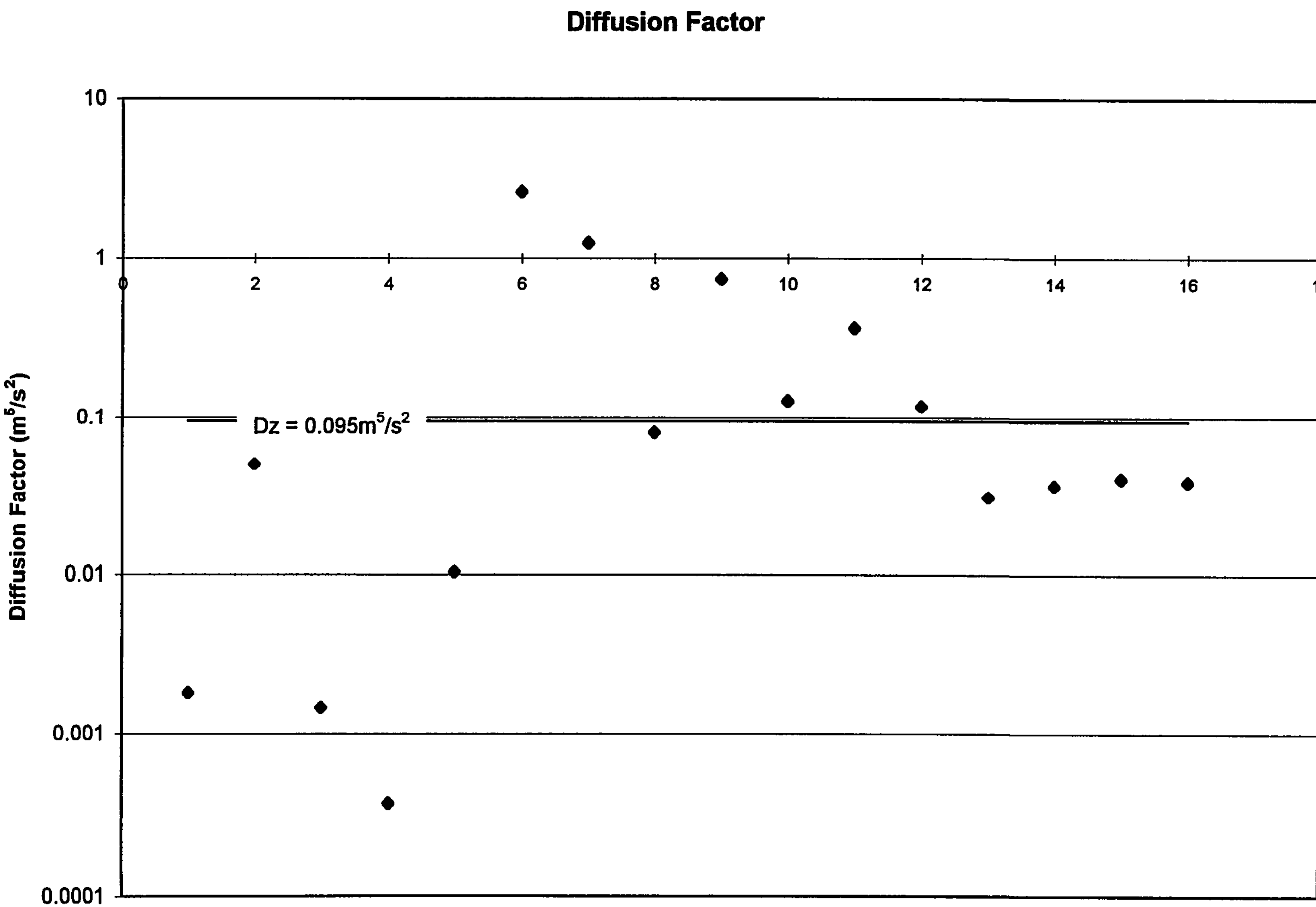
Source	S	u cm/s	u^* cm/s	d cm	w cm	R cm	p cm	Ez (cm^2/s)	Dz (m^3/s^2)	Channel type / Comments	E_z/du^*	E_z/wu^*	E_z/Ru^*	E_z/pu
Engmann (1974)	0.00037	16.0	1.3548	5.61		5.1359		1.203		Straight channel, rough bottom, open	0.156		0.170	
	0.00107	24.6	1.9751	4.01		3.7643		1.282		Straight channel, rough bottom, open	0.163		0.174	
	0.00072	15.7	1.3853	5.73		2.728		0.581		Straight channel, rough bottom, ice cover	0.073		0.153	
	0.00156	25.4	1.9355	3.90		1.8898		0.655		Straight channel, rough bottom, ice cover	0.088		0.181	
	0.00138	29.2	2.3713	5.64		4.8768				Meandering channel, rough bottom, open			2.153	
	0.00042	23.9	1.585	7.16		6.035				Meandering channel, smooth bottom, open			2.000	
	0.00218	29.1	2.286	5.55		2.5603				Meandering channel, rough bottom, ice cover			0.775	
	0.00085	22.9	1.6794	7.47		3.3833				Meandering channel, smooth bottom, ice cover			0.880	
Sayre and Chamberlin (1964)	0.00071	65.8	3.28	17.678	243.84	15.439	0.25	15.1		Straight channel	0.26	0.019	0.298	
Glover (1964)				14.752	242.01			33.45		Laboratory - Rough bottom			0.36	
				13.807	242.01			8.27		Laboratory - Smooth bottom			0.22	
				28.743	121.92			7.15		Laboratory - Smooth bottom			0.14	
Sayre and Chang (1968)	0.001	35.154	4.537	25.461	238.66	20.984		19.64		Laboratory - Coefficients in the fluid flow	0.17	0.018	0.206	
	0.001	35.154	4.537	25.461	238.66	20.984		26.57		Laboratory - Coefficients for the fluid surface	0.23	0.025	0.279	
Somlyody (1982)	0.0003				100	14				Straight rectangular flume			0.10	
										Straight Flume, Bottom - Clips (9 tests)				
Webel and Schatzmann (1984)	0.0004	10.26	1.555	6.33				1.286		Straight Flume, Bottom - Clips - 9 runs	0.1307			
	0.000267	10.369	1.246	6.33				1.04		Straight Flume, Bottom - Gravel - 26 runs	0.1319			
	0.00015	11.017	0.9527	6.33				0.88		Straight Flume, Bottom - Gravel - 8 runs	0.146			
	0.00015	13.067	0.9527	6.33				0.939		Straight Flume, Bottom - Pebbles - 8 runs	0.1557			
	0.00006	10.11	0.6023	6.33				0.672		Straight Flume, Bottom - Smooth - 8 runs	0.1763			
Elder (1959)				1.27						Straight - Smooth flume	0.228			
Okoye (1970)		38.78		6.531	85			1.458		Straight Rectangular channel - Smooth bed	0.1287	0.00871		
		37.26		7.963	110			1.8		Straight Rectangular channel - Smooth bed	0.1494	0.0092		
		38.75		10.725	110			6.265		Straight Rectangular channel - Stone bed	0.132	0.1242		
Prych (1970)		42.2		7.23	110			2.22		Straight Rectangular channel - Smooth bottom	0.1483	0.010027		
		41.6		5.15	110			2.75		Straight Rectangular channel - Metal Lath	0.1365	0.006395		
Miller & Richardson (1974)	0.00954		8.351	12.726	59.74			17.033		Straight Flume	0.23			
Lau & Krishnappan (1977)		20.04	1.82	2.138	60			0.454		Straight rectangular Flume - 0.4mm sand bed	0.119	0.004318		
		19.88	1.67	3.39	45			0.775		Straight rectangular Flume - 0.4mm sand bed	0.138	0.010405		
		20.17	2.127	2.483	30			0.846		Straight rectangular Flume - 2.0mm sand bed	0.17	0.01347		
		20.23	2.275	2.603	60			0.794		Straight rectangular Flume - 2.7mm sand bed	0.143	0.00617		
		19.9	2.248	2.51	45			0.956		Straight rectangular Flume - 2.7mm sand bed	0.191	0.009725		
		25.62	1.505	4.412	60			1.12		Straight rectangular Flume - smooth bed	0.172	0.012702		
Holley and Abraham (1973a)				9.7						Straight rectangular Flume - Smooth, centre injection	0.16			
				9.7						Straight rectangular Flume 50cm groins, centre injection	0.36			
				9.7						Straight rectangular Flume 50cm groins, side injection	0.48			
				9.7						Straight rectangular Flume 15cm groins, side injection	0.41			
				9	122					Laboratory model of the Ijssel River	0.59			
Nokes & Wood (1988)	0.00047	28.1	1.55	6.5	55.9			1.239		Rectangular Flume, smooth bed	0.123	0.014		
	0.00047	23.6	1.4	5	55.9			0.917		Rectangular Flume, smooth bed	0.131	0.012		
Bruno *et al* (1990)		31.17	2.07	21.8	340			30.76		Large recirculating flume - 6 runs	0.682			
Luk *et al* (1990)	0.0035	35		4				2.1		Sinuous channel, with an irregular bottom				
Krishnappan & Lau (1977)		28.1	3.997	6.7		2.939				Sinous channel, bottom - loose ottawa sand - 7 tests	0.138		0.3146	
Djordjevic (1993)	0.0015			10.1	34.45					Straight rectangular channel	0.2			
	0.0015			24.825	68					Straight compound channel	0.2			
Fischer (1969)	0.0023	31.7	2.66	3.02				11.3		Circular Flume test - Run 1	1.407			
	0.001	27	1.7	5.28				21.4		Circular Flume test - Run 2	2.384			
	0.0012	26.8	2.13	3.72				10.6		Circular Flume test - Run 3	1.338			
	0.0012	19	1.37	2.03				1.95		Circular Flume test - Run 4	0.701			
	0.0013	19.7	1.68	2.2				1.88		Circular Flume test - Run 5	0.509			

Transverse Coefficients - Field

Source	S	u	u^*	d	w	R	p	Ez	Dz	Channel type / Comments	E_z/du^*	E_z/wu^*	E_z/Ru^*	E_z/pu^*
		m/s	m/s	m	m	m	m	(m^2/s)	(m^3/s^2)					
Engmann (1974)		0.3758		2.0336	36.06			0.0121		Field Study - Lesser Slave River, Winter - 6 tests			0.404	
		0.6081		2.2822	42.10			0.0399		Field Study - Lesser Slave River, Summer - 4 tests			0.323	
Pospicilik (1972)	0.000345	0.2911	0.0454	0.8894	216	0.475		0.0093		Ft. Saskatchewan - Vinca Bridge, UofA Master Study	0.23			
Luk (1991)	0.00005			1.68				0.0216		NSR - Clover Bar Bridge - Ft. Saskatchewan	0.45			
Smith & Putz (1993)		0.63	0.059	2.74			67	0.0589		MacKenzie River - downstream of Norman Wells, NWT	0.365			0.0149254
		1.24	0.086	5.85			51	0.0602		MacKenzie River - Open	0.120			0.0137255
		0.98	0.073	4.16			211	0.1619		MacKenzie River - Open	0.536			0.0105689
		0.85	0.070	3.87			316	0.1323		MacKenzie River - Open	0.488			0.0060
		0.20			2030			0.016		MacKenzie River - Ice cover, no decay				
Cotton & West (1980)		0.47	0.065	0.11	5.1			0.0014		River Rea - Straight channel	0.196	0.0042		
		0.7	0.072	0.17	6.6			0.0032		River Rea - Straight channel	0.261	0.0067		
		0.73	0.075	0.18	6.7			0.0038		River Rea - Straight channel	0.281	0.0076		
Gowda (1983)									0.0018	Grand River - Meandering channel		0.0011		
Rutherford, *et al* (1980)								0.065		Waikato River - New Zealand	0.5			
Somlyody (1977)	0.00007	1	0.058	5	500	4.9		0.0335		Danube River - Czechoslovakia	0.116			
	0.00007	1	0.058	5	500	4.9		0.0135		Danube River - Czechoslovakia	0.047			
	0.00007	1	0.058	5	500	4.9		0.0130		Danube River - Czechoslovakia	0.045			
Stallard (1987)								0.81		Orinoco River - South America				
								3.01		Orinoco River - South America				
								1.55		Orinoco River - South America				
Meyer (1977)	0.000006	0.3	0.0177	4.9926	429.16			0.576		Mobile River - Fairly stright channel	6.504	0.076		
Sayre (1979)										Missouri River - d/s of Fort Calhoun power station (fall)	0.45			
										Missouri River - d/s of Fort Calhoun power station (winter)	0.28			
										Missouri River - d/s of Cooper power station (winter)	1.07			
										Missouri River - d/s of Cooper power station (winter)	0.95			
										Missouri River - d/s of Cooper power station - bend	0.81			
										Missouri River - d/s of Cooper power station - bend	0.38			
										Missouri River - d/s of Cooper power station - straight	0.33			
										Missouri River - d/s of Cooper power station - straight	0.13			
Beltaos (1978a)		0.95			169.6					Athabasca River - d/s Ft. McMurray - straight, islands, mid channel bars	0.75		0.75	
		0.49			131.3					Athabasca River - d/s Ft. McMurray - straight, islands, mid channel bars - ice cover	0.58		1.16	
		0.86			156					Athabasca River - d/s Athabasca - irregular, islands, bars	0.41		0.41	
		0.4			287.5					Athabasca River - d/s Athabasca - irregular, islands, bars - ice cover	0.28		0.56	
		0.5			44.6					Beaver River - near Beaver Crossing - meanders, point bars, dunes	1.01		1.01	
		0.28			63.5					Beaver River - near Beaver Crossing - meanders, point bars, dunes ice cover	1.27		2.54	
Beltaos & Anderson (1979)	0.000442	0.59	0.0815	1.54				0.0216	0.051	NSR - Clover Bar - Waskatenau Bridge, straight, uniform	0.17			
Jackman & Yotsukura (1977)		0.3838	0.042	1.22	750			0.0278		Potomac River - 29km downstream of the Dickerson Power Plant - March	0.52	0.0009		
										Potomac River - 29km downstream of the Dickerson Power Plant - April	0.65			
Glover (1964)		1.3466	0.0875	6.096	304.8	3.057		0.1923		Columbia River, near Richland, Washington	0.36	0.007	0.72	
Somlyody (1982)	0.00007	0.725		2.5	425	4.0		0.038		Danube River, upstream of Budapest			0.25	
	0.00041				9.75	1.06		0.011		Kis-Rába, Irrigation Canal			0.16	
Yotsukura and Cobb (1972)		0.2438	0.0396	0.3688	18.288			0.0163	0.0014502	South River, Virginia - Test 1	1.117	0.023		
		0.1829	0.0396	0.4389	18.288			0.0054	4E-04	South River, Virginia - Test 2&3	0.310	0.007		
		1.2497	0.0619	0.701	20.117			0.0140	0.010344	Bernado Conveyance channel, New Mexico	0.324	0.011		
		1.7374	0.0732	2.7432	182.88			0.1011	2.6114406	Missouri River	0.504	0.008		
Fischer (1967a)	0.00059	0.634	0.0628	0.683	17.678			0.0102		Atrisco Feeder Canal, New Mexico - Centre injection	0.240	0.009		
	0.00058	0.661	0.0613	0.668	17.069			0.0102		Atrisco Feeder Canal, New Mexico - Side injection	0.25	0.010		

Source	S	u m/s	u* m/s	d m	w m	R m	p m	Ez (m^2/s)	Dz (m^5/s^3)	Channel type / Comments	E_z/du^*	E_z/wu^*	E_z/Ru^*	E_z/pu^*
Beltaos (1980)	0.0011	0.95	0.056	2.2	373			0.093	1.26	Athabasca River - below Ft. McMurray, Straight with bars & islands - Open	0.755	0.0044	0.75	
	0.000144	0.49		1.9	252			0.041		Athabasca River - below Ft. McMurray, Straight with bars & islands - Ice Cover			1.16	
	0.00021	0.5		0.96	42.7			0.043		Beaver River, near Cold Lake, meanders, with point bars & dunes Open			1.01	
	0.0011	0.28		0.61	38.7			0.02		Beaver River, near Cold Lake, meanders, with point bars & dunes Ice Cover			2.54	
	0.00031	0.86	0.079	2.05	320			0.067		Athabasca River - below Athabasca, meanders, bars & islands - Open	0.41	0.0026	0.41	
	0.0011	0.4		0.96	276			0.01		Athabasca River - below Athabasca, meanders, bars & islands - Ice Cover			0.56	
Beltaos (1978b)		0.58	0.08	1.55	213			0.031		North Saskatchewan River, below Edmonton	0.25	0.0018		
		1.05	0.139	1	104			0.085		Bow River, at Calgary	0.61	0.0059		
Demetracopoulos & Stefan (1983)	0.000648		0.081	1	178			0.171		Upper Mississippi River	2.03			
Engmann & Kellerhals (1974)	0.00011	0.589	0.0488	2.296	42.164	2.53		0.0402		Lesser Slave River, meander, no bars - Open	0.359	0.0195	0.33	
	0.000095	0.3719	0.0305	2.025	36.322	0.9815		0.0052		Lesser Slave River, meander, no bars - Ice Cover	0.084	0.0047	0.17	
Holly and Nerat (1984)								0.96		Field test - Straight river, mild bends	1.6			
Lau and Krishnappan (1981)		0.35	0.069	0.506	59.2			0.009		Grand River, below Kitchener, Ontario	0.26	0.0022		
Yotsukura *et al* (1970)		1.74	0.073	2.74				0.0975		Missouri River near Blair, Nebraska	0.475			
Milne (1991)	0.000558	0.8	0.059	1.38	145			0.0531	0.0808989	North Saskatchewan River, Downstream of E.L. Smith WTP	0.126			
	0.00026	0.828	0.064	1.63	158.2			0.339	0.7457706	North Saskatchewan River, Downstream of Rossdale WTP	0.266			
Holley and Abraham (1973b)										Ijssel River, Groins on sides and gentle curvature	0.5			
										Ijssel River, as a Rectangular channel	0.16			
Van Der Vinne (1992)								0.036	0.13	North Saskatchewan River, Quesnell Bridge, u/s Groat Bridge	0.24			
								0.1	0.37	North Saskatchewan River, Quesnell Bridge, u/s Groat Bridge	0.67			
								0.04	0.12	North Saskatchewan River, Millwoods outfall - Quesnell Bridge	0.7			
								0.02	0.031	North Saskatchewan River, Cloverdale Bridge - Ft. Saskatchewan	0.28			
								0.02	0.037	North Saskatchewan River, Cloverdale Bridge - Ft. Saskatchewan	0.26			
								0.033	0.041	North Saskatchewan River, Shandro Bridge - Duvernay Bridge	0.66			
								0.025	0.039	North Saskatchewan River, Shandro Bridge - Duvernay Bridge	0.34			
Lau (1985)		0.16	0.078	0.54	36			0.028		Nith river, Canning, Ontario - Open	0.66	0.0100	0.69	
		0.23	0.051	0.44	37.5			0.014		Nith river, Canning, Ontario - Ice Cover	0.63	0.0073	1.26	
		0.4	0.07	0.41	48			0.007		Grand River, West Montrose, Ontario - Open	0.24	0.0021	0.25	
		0.34	0.043	0.3	50.8			0.003		Grand River, West Montrose, Ontario - Ice Cover	0.23	0.0014	0.46	
		0.04	0.01	0.48	15			0.004		Nith river, Philipsburg, Ontario - Open	0.83	0.0267	0.89	
		0.2	0.007	0.42	14.6			0.0025		Nith river, Philipsburg, Ontario - Ice Cover	0.85	0.0245	1.72	
		0.17	0.055	0.67	18.2			0.02		Nith river, Plattsville, Ontario - Open	0.54	0.0200	0.59	
		0.26	0.037	0.55	18.6			0.01		Nith river, Plattsville, Ontario - Ice Cover	0.49	0.0145	0.98	
Park & Uchrin (1986)		0.3		0.475	14					Passaic River, New Jersey - test 1		0.0169		
		0.37		0.335	14.5					Passaic River, New Jersey - test 2		0.01612		
Patterson & Gloyna (1965)			0.6858					0.0497		Colorado River, near Austin, Texas				
Fischer (1969)		0.28			20			0.012		Green-Duwamish, Washington				
		1.75	0.074	2.7	180			0.12		Missouri River, Nebraska	0.601	0.0090		
Putz (1983)	5.2E-08	0.51	0.034	4.82	787	2.41		0.0119		Slave River, Northwest Territories - March 1980, u/s	0.072	0.0004	0.144	
	2.24E-07	0.55	0.034	4.66	777	2.33		0.0729		Slave River, Northwest Territories - March 1980, d/s	0.463	0.0028	0.926	
	4.4E-08	0.8	0.053	5.36	879	5.36		0.0183		Slave River, Northwest Territories - July 1980, u/s	0.067	0.0004	0.067	
	3.69E-07	0.87	0.051	5.38	864	5.38		0.234		Slave River, Northwest Territories - July 1980, d/s	0.879	0.0055	0.879	
	3.2E-08	0.38	0.035	5.09	836	2.55		0.0059		Slave River, Northwest Territories - March 1981, u/s	0.033	0.0002	0.065	
	2.73E-07	0.43	0.035	4.9	785	2.45		0.0811		Slave River, Northwest Territories - March 1981, u/s	0.477	0.0030	0.954	


Dimensionless Mixing Coefficient
β = 0.35
10.00
1.00
0.10
0.01
Dimensionless Mixing Coefficient
0
20
40
60
80
100
12


Diffusion Factor
Diffusion Factor (m^5/s^2)
10
1
0.1
0.01
0.001
0.0001
0
2
4
6
8
10
12
14
16
Dz = 0.095m^5/s^2

Appendix D Microbiology Sampling Results

Sta	Pt	Dilutions												Count		Count	95% Confidence Limits	
		0.01			0.1			1			25			<20	>20	cfu/100mL	Lower	Upper
1	1	0	0	-	-	4	3	-	24	21					2244.99	2245	2150	2340
	2	0	0	0	1	7	1	14	16	29				1966.67		1967	1878	2055
	3	0	0	0	7	3	7	20	17	25					2040.83	2041	1950	2131
	4	1	0	0	2	7	7	7	23	13				1433.33		1433	1358	1509
	5	1	0	0	0	1	0	10	6	19				1166.67		1167	1098	1235
	6	0	0	0	2	0	1	9	0	0				300.00		300	265	335
	7	0	0	0	0	0	0	1	-	0				33.33		33	22	45
	8	0	0	0	0	0	0	0	0	1				33.33		33	22	45
	9	0	0	0	0	3	0	3	4	6				433.33		433	392	475
2	1	0	1	0	5	5	2	22	20	26					2253.25	2253	2158	2348
	2	1	1	0	3	3	3	22	19	16				1900.00		1900	1813	1987
	3	1	-	0	2	1	0	24	12	20					1792.56	1793	1708	1877
	4	0	0	1	1	0	1	14	13	12				1300.00		1300	1228	1372
	5	1	0	0	1	1	2	18	12	11				1366.67		1367	1293	1441
	6	0	0	0	0	0	2	11	5	7				766.67		767	711	822
	7	0	0	0	0	0	1	1	7	9				566.67		567	519	614
	8	1	0	0	5	0	1	15	12	16				1433.33		1433	1358	1509
	9	1	0	0	9	4	2	20	21	11					1665.51	1666	1584	1747
3	1	0	0	2	3	3	1	19	26	21					2180.97	2181	2088	2274
	2	0	1	1	1	2	3	16	10	14				1333.33		1333	1260	1406
	3	0	0	0	3	3	5	33	42	25					3260.13	3260	3146	3374
	4	-	0	0	0	1	3	-	26	12					1766.35	1766	1682	1850
	5	0	0	0	1	0	0	12	13	19				1466.67		1467	1390	1543
	6	0	0	0	0	-	2	11	24	13				1600.00		1600	1520	1680
	7	1	0	0	0	-	1	17	18	20				1833.33		1833	1748	1919
	8	0	0	0	4	5	7	23	9	27					1774.64	1775	1690	1859
	9	0	0	0	1	2	1	17	15	17				1633.33		1633	1553	1714
4	1	2	1	1	5	9	6	28	46	38					3657.91	3658	3537	3779
	2	1	0	0	3	3	3	13	25	17				1833.33		1833	1748	1919
	3	0	0	0	0	1	1	10	11	8				966.67		967	904	1029
	4	0	0	1	1	2	2	6	4	13				766.67		767	711	822
	5	0	0	0	0	0	0	0	0	0				0.00		0	0	0
	6	0	0	0	0	2	1	13	14	11				1266.67		1267	1195	1338
	7	0	0	0	1	1	0	11	15	16				1400.00		1400	1325	1475
	8	0	0	0	3	3	2	12	17	4				1100.00		1100	1034	1166
	9	2	1	0	3	1	4	14	16	15				1500.00		1500	1423	1577
5	1				5	0	0	29	25	17		TNTC			2309.91	2310	2214	2406
	2				0	2	0	12	9	12	81	124	137		444.91	445	403	487
	3	0	0	0	0	0	0	5	6	3				466.67		467	423	510
	4	0	0	0	0	1	2	6	9	3				600.00		600	551	649
	5				0	0	1	5	3	3	13	14	7	45.33		45	32	59
	6				0	0	1	4	2	4	15	16	6	49.33		49	35	63
	7	0	0	0	0	0	0	3	3	1				233.33		233	203	264
	8	0	0	0	1	1	2	12	6	3				700.00		700	647	753
	9	0	1	0	1	2	1	11	14	11				1200.00		1200	1131	1269
5	1				1	1	1	16	9	14		TNTC		1300.00		1300	1228	1372
	2				1	1	1	24	22	13	111	78	61		323.33	323	287	359
	3				1	0	1	13	8	11	56	73	44		225.80	226	196	256
	4				0	2	1	8	10	14	10	17	13	53.33		53	39	68
	5				0	-	-	-	12	9	20	5	15	53.33		53	39	68
	6				0	0	0	4	4	6	42	41	26		142.04	142	118	166
	7				0	1	0	3	2	6	10	7	11	37.33		37	25	50
	8				1	3	2	8	12	8	86	94	73		335.51	336	299	372
	9				3	9	4	14	11	17	112	116	118		461.22	461	418	504
5	1				8	14	2	53	60	86		TNTC			6490.95	6491	6330	6652
	2				2	0	2	14	18	17	11	109	71		175.96	176	149	202
	3				1	0	0	2	8	1	24	20	20		85.01	85	67	103
	4				1	0	2	4	2	1	17	11	15	57.33		57	42	72
	5				0	0	0	1	2	2	13	8	1	29.33		29	19	40
	6				0	0	0	2	4	5	19	19	11	65.33		65	49	81
	7				0	1	0	5	8	8	36	27	30		123.12	123	101	145
	8				0	2	1	11	16	16	63	83	64		277.71	278	244	311
	9				1	0	0	17	15	8	95	95	98		383.96	384	345	423

6	1	0	0	0	6	6	5	27	19	24					2309.10	2309	2213	2405
	2	0	0	0	1	1	0	2	11	22				1166.67		1167	1098	1235
	3	0	0	0	1	0	4	2	9	7				600.00		600	551	649
	4	0	-	0	4	2	3	18	12	13				1433.33		1433	1358	1509
	5	0	0	1	2	2	1	-	-	9				1666.67		1667	1585	1748
	6	-	0	0	1	2	3	31	6	22					1599.48	1599	1519	1679
	7	0	0	0	0	5	9	-	-	14				4666.67		4667	4530	4803
	8	2	1	1	3	5	3	9	32	12				1766.67		1767	1683	1851
	9	0	1	0	2	-	2	8	14	12				1133.33		1133	1066	1201
7	1	0	0	0	1	2	2	11	11	8				1000.00		1000	937	1063
	2	1	0	0	4	1	1	12	14	15				1366.67		1367	1293	1441
	3	0	0	0	0	0	2	11	9	9				966.67		967	904	1029
	4	0	0	0	3	1	4	5	13	19				1233.33		1233	1163	1304
	5	0	0	0	4	1	3	7	11	12				1000.00		1000	937	1063
	6	1	0	0	3	2	1	11	14	22				1566.67		1567	1488	1646
	7	0	0	0	1	3	3	22	10	15				1566.67		1567	1488	1646
	8	1	0	0	2	4	4	17	26	10				1766.67		1767	1683	1851
	9	1	0	0	1	4	3	12	19	8				1300.00		1300	1228	1372
8	1				0	0	0	0	0	6	17	20	20		75.78	76	58	93
	2	0	0	0	1	0	0	3	3	1				233.33		233	203	264
	3	0	0	0	2	2	4	14	21	10				1500.00		1500	1423	1577
	4				0	-	1	5	3	5	14	11	13	50.67		51	36	65
	5				0	0	0	5	3	5	6	6	9	28.00		28	17	39
	6	0	0	0	0	0	0	5	0	2				233.33		233	203	264
	7	0	0	0	0	1	0	5	6	2				400.00		400	360	440
	8	0	0	0	1	-	0	-	0	0				0.00		0	0	0
	9	-	0	-	1	-	0	3	4	1				266.67		267	234	299
9	1				2	0	0	11	9	14	12	13	10	46.67		47	33	60
	2				0	0	0	4	3	2	22	24	18		84.73	85	66	103
	3				0	0	0	5	2	1	27	32	9		79.25	79	61	97
	4				1	2	1	2	5	8	16	30	30		97.32	97	78	117
	5				0	1	-	-	3	10	16	21	17	72.00		72	55	89
	6				0	1	0	2	4	7	19	19	15	70.67		71	54	87
	7				0	1	2	12	14	7	37	39	16		113.90	114	93	135
	8				0	0	1	-	5	2	-	14	30	58.67		59	43	74
	9				1	1	1	5	8	5	15	27	7	65.33		65	49	81
10	1				0	0	0	0	0	0	0	0	0	0.00		0	0	0
	2				0	0	0	2	1	1	4	27	12	57.33		57	42	72
	3				0	0	0	0	1	1	21	9	17	62.67		63	47	78
	4	0	0	0	0	0	1	3	2	6				366.67		367	328	405
	5	0	0	0	0	0	0	2	0	1				100.00		100	80	120
	6				0	0	0	3	13	1	12	9	10	41.33		41	28	54
	7	0	0	0	1	1	0	2	3	1				200.00		200	172	228
	8	0	0	0	0	1	0	1	7	6				466.67		467	423	510
	9	0	0	0	0	1	0	1	8	10				633.33		633	583	684

Sta	Pt	Dilutions									Count		Count	95% Confidence Limits	
		1			10			25			<20	>20	cfu/100mL	Lower	Upper
1	1	31	54	25	**76**	**60**	**65**	TNTC				666.74	667	615	718
	2	20	25	3	**96**	**108**	**81**	TNTC				943.47	943	882	1005
	3	33	23	18	**103**	**91**	**91**	TNTC				948.36	948	887	1010
	4	4	1	2	**33**	**35**	**29**	TNTC				322.35	322	286	358
	5	1	2	0	18	7	7	**32**	**28**	**27**		115.69	116	94	137
	6	16	12	6	28	27	45	**49**	**35**	**42**		166.43	166	141	192
	7	13	14	5	21	29	18	**71**	**70**	**59**		265.74	266	233	298
	8	18	22	12	**42**	**42**	**34**	73	TNTC			391.43	391	352	431
	9	11	13	14	**51**	**46**	**45**	TNTC				472.62	473	429	516
2	1	**62**	**84**	**75**	TNTC			TNTC				7309.89	7310	7139	7481
	2	**43**	**33**	**48**	TNTC			TNTC				4083.89	4084	3956	4212
	3	13	11	16	**70**	**75**	**77**	TNTC				739.41	739	685	794
	4	16	6	7	73	40	29	**79**	**101**	**83**		348.66	349	311	386
	5	3	4	6	33	35	19	**34**	**43**	**43**		159.05	159	134	184
	6	2	3	6	12	16	8	**34**	**40**	**29**		136.16	136	113	159
	7	6	2	9	15	14	22	**34**	**44**	**41**		157.75	158	133	183
	8	0	2	2	24	31	18	**44**	**37**	**37**		156.80	157	132	182
	9	17	4	20	38	42	37	**67**	**67**	**64**		263.94	264	231	296
3	1	0	1	2	47	30	34	**69**	**77**	**80**		300.75	301	266	335
	2	10	6	3	18	22	19	**50**	**48**	**53**		201.17	201	173	230
	3	0	1	1	**42**	**17**	**36**	28	33	34		295.12	295	261	329
	4	0	0	3	**23**	**17**	**36**	21	30	17		241.45	241	210	273
	5	0	5	0	**53**	**22**	**36**	23	33	18		347.54	348	310	385
	6	10	5	2	22	26	22	**41**	**48**	**49**		183.43	183	156	211
	7	16	6	7	23	16	31	**57**	**64**	**60**		241.06	241	210	272
	8	6	3	1	28	42	26	**53**	**52**	**60**		219.55	220	190	249
	9	6	12	13	**43**	**47**	**41**	TNTC				435.96	436	394	478
4	1	**101**	**100**	**111**	TNTC			TNTC				10388.39	10388	10185	10592
	2	**73**	**64**	**53**	TNTC			TNTC				6279.52	6280	6121	6438
	3	16	12	15	**50**	**45**	**56**	TNTC				501.33	501	457	546
	4	2	1	0	17	19	21	**28**	**32**	**32**		122.43	122	100	145
	5	11	6	2	23	28	27	**23**	**17**	**32**		92.86	93	74	112
	6	5	2	3	30	14	37	**46**	**34**	**36**		153.31	153	129	178
	7	17	5	3	42	48	30	**66**	**53**	**56**		232.31	232	202	263
	8	19	7	13	36	33	45	**76**	**77**	**53**		269.57	270	237	302
	9	33	17	15	0	57	45	**96**	**84**	**82**		348.48	348	311	386
5	1	**39**	**30**	**46**	TNTC			TNTC				3775.56	3776	3653	3898
	2	15	19	10	**51**	**58**	**49**	TNTC				525.29	525	479	571
	3	7	3	3	23	29	17	**47**	**51**	**39**		181.54	182	155	208
	4	3	4	3	24	24	21	**39**	**36**	**39**		151.89	152	127	177
	5	4	9	9	35	21	20	**30**	**45**	**32**		140.35	140	117	164
	6	8	9	4	24	30	27	**38**	**38**	**33**		145.02	145	121	169
	7	11	6	2	38	28	29	**46**	**52**	**50**		197.08	197	169	225
	8	7	14	10	62	-	46	**96**	**66**	**107**		351.39	351	314	389
	9	13	16	15	41	30	27	**78**	**77**	**65**		292.34	292	258	327
5	1	16	22	19	**127**	**103**	**100**	TNTC				1093.65	1094	1028	1160
	2	10	9	11	**73**	**71**	**72**	TNTC				719.95	720	666	774
	3	13	5	4	44	28	32	**52**	**60**	**55**		222.28	222	192	252
	4	5	7	12	20	18	22	**31**	**30**	**37**		130.10	130	107	153
	5	3	2	4	12	15	15	**31**	**21**	**33**		111.20	111	90	132
	6	8	6	3	21	19	19	**30**	**37**	**42**		143.96	144	120	168
	7	9	4	17	36	27	33	**54**	**57**	**57**		223.93	224	194	254
	8	12	8	12	49	39	64	**89**	**92**	**82**		350.26	350	313	388
	9	24	16	15	35	50	38	**117**	**90**	**102**		409.64	410	369	450
5	1	19	27	17	**84**	**81**	**52**	TNTC				707.28	707	654	760
	2	11	17	17	**76**	**58**	**64**	TNTC				655.85	656	605	707
	3	8	7	1	32	23	30	**39**	**50**	**42**		173.71	174	147	200
	4	6	6	8	28	37	29	**29**	**40**	**34**		136.16	136	113	159
	5	7	0	2	22	30	15	**26**	**30**	**32**		116.90	117	95	139
	6	2	7	2	24	22	12	**31**	**30**	**40**		133.53	134	110	157
	7	18	11	9	-	22	29	**45**	**61**	**55**		212.99	213	184	242
	8	6	13	9	32	37	34	**75**	**55**	**61**		252.53	253	221	284
	9	14	8	6	34	27	36	**94**	**84**	**88**		354.29	354	317	392

6	1	**45**	**56**	**32**	TNTC			TNTC				4320.33	4320	4189	4452
	2	3	5	2	17	23	16	**34**	**44**	**35**		149.64	150	125	174
	3	1	4	5	22	20	30	**38**	**23**	**25**		111.83	112	91	133
	4	0	10	3	30	17	25	**32**	**35**	**26**		123.06	123	101	145
	5	12	5	7	1	10	19	**40**	**23**	**35**		127.26	127	105	150
	6	4	7	2	20	20	23	**37**	**35**	**41**		150.34	150	126	175
	7	2	5	6	27	19	23	**34**	**22**	**18**		95.16	95	76	115
	8	7	4	13	24	20	32	**31**	**53**	**43**		165.36	165	140	191
	9	12	7	10	**48**	**42**	**49**	TNTC				462.27	462	419	505
7	1	0	0	10	14	20	16	**40**	**27**	**33**		131.64	132	109	155
	2	4	1	3	10	31	15	**30**	**30**	**30**		120.00	120	98	142
	3	6	6	2	26	22	10	**22**	**18**	**30**		91.27	91	72	110
	4	5	3	2	16	15	16	**29**	**19**	**31**		103.01	103	83	123
	5	14	1	0	15	21	11	**24**	**23**	**32**		104.17	104	84	125
	6	4	7	6	19	19	12	**36**	**24**	**21**		105.11	105	85	126
	7	1	4	6	36	20	22	**55**	**55**	**47**		208.77	209	180	238
	8	20	15	6	**56**	**50**	**42**	TNTC				489.93	490	446	534
	9	14	19	11	**71**	**62**	**80**	TNTC				706.18	706	653	759
8	1	3	2	1	11	24	13	**37**	**20**	**34**		117.21	117	96	139
	2	7	3	7	18	38	22	**28**	**28**	**26**		109.27	109	88	130
	3	2	5	8	17	23	25	**35**	**28**	**46**		142.36	142	118	166
	4	7	3	13	17	21	21	**31**	**40**	**40**		146.97	147	123	171
	5	2	5	7	19	13	19	**25**	**51**	**33**		139.12	139	116	163
	6	2	3	7	14	7	24	**34**	**33**	**26**		123.14	123	101	145
	7	2	3	2	10	22	21	**33**	**21**	**23**		100.67	101	81	121
	8	10	3	6	24	23	16	**22**	**27**	**33**		107.85	108	87	129
	9	0	0	0	0	0	0	**-**	**153**	**150**		605.97	606	557	655
9	1	1	2	1	8	12	8	**22**	**27**	**20**		91.27	91	72	110
	2	0	1	0	6	14	14	**21**	**20**	**17**		77.02	77	59	95
	3	0	3	2	14	11	15	**17**	**23**	**23**		83.18	83	65	101
	4	0	4	2	14	8	10	**25**	**26**	**21**		95.60	96	76	115
	5	3	0	2	17	14	7	**13**	**31**	**17**	81.33		81	63	99
	6	1	1	1	17	9	5	**17**	**20**	**19**	74.67		75	57	92
	7	3	5	2	21	34	25	**26**	**37**	**33**		126.66	127	104	149
	8	4	9	1	34	14	15	**31**	**35**	**30**		127.72	128	105	150
	9	5	9	3	16	26	9	**20**	**31**	**30**		105.98	106	85	127
10	1	0	3	1	36	11	22	**33**	**24**	**28**		112.38	112	91	134
	2	2	0	0	18	18	12	**24**	**28**	**27**		105.11	105	85	126
	3	1	3	1	16	8	7	**32**	**25**	**23**		105.60	106	85	126
	4	0	0	1	30	27	37	**30**	**26**	**34**		119.28	119	97	141
	5	0	5	1	31	39	49	**30**	**28**	**26**		111.81	112	91	133
	6	2	8	1	31	16	27	**26**	**29**	**34**		117.94	118	96	140
	7	3	9	2	15	13	19	**35**	**48**	**32**		150.97	151	126	176
	8	4	2	2	20	29	19	**22**	**31**	**34**		114.06	114	93	135
	9	0	9	2	31	42	48	**41**	**58**	**40**		182.59	183	156	210

Sta	Pt	Dilutions (mL)									Count		Count	95% Confidence Limits	
		1			25			50			<20	>20	cfu/100mL	Lower	Upper
1	1	0	0	0	18	15	17	49	37	40		83.40	83	65	102
	2	0	1	0	25	23	28	28	21	30		101.00	101	81	121
	3	2	1	2	31	41	37	0	66	74		144.38	144	120	168
	4	1	1	0	16	13	10	24	22	18		42.36	42	29	55
	5	2	0	1	13	13	14	29	29	29		58.00	58	43	73
	6	0	0	0	9	9	10	22	17	22		40.38	40	28	53
	7	0	0	0	0	0	0	1	0	0	0.67		1	<1	2
	8	0	0	0	0	0	0	0	1	0	0.67		1	<1	2
	9	0	0	0	6	10	11	20	21	22		41.97	42	29	55
2	1	4	3	2	38	38	35	83	72	76		153.73	154	129	179
	2	2	1	0	20	24	23	42	34	41		77.66	78	60	95
	3	0	1	4	19	18	26	40	37	37		75.95	76	59	93
	4	0	1	2	13	14	17	13	22	30		40.94	41	28	54
	5	2	5	0	4	9	-	21	22	11		34.39	34	23	46
	6	1	1	0	7	2	7	16	18	15	32.67		33	21	44
	7	0	0	0	15	14	19	16	24	24		41.93	42	29	55
	8	0	0	0	8	12	7	8	17	21	30.67		31	20	42
	9	1	4	0	40	40	30	80	78	33		145.37	145	121	169
3	1	9	14	7	228	246	230	TNTC				938.12	938	877	999
	2	4	9	5	168	132	145	TNTC				590.40	590	542	639
	3	1	4	1	93	106	115	TNTC				417.08	417	376	458
	4	1	0	3	74	111	98	TNTC				372.09	372	334	411
	5	4	1	1	24	26	18	55	45	49		99.00	99	79	119
	6	8	8	9	146	149	140	TNTC				579.81	580	532	628
	7	4	1	0	29	38	33	89	111	97		197.18	197	169	225
	8	1	4	3	35	40	41	79	76	77		154.65	155	130	180
	9	3	3	3	64	65	53	117	101	119		224.07	224	194	254
4	1	17	26	30	385	370	365	TNTC				1492.95	1493	1416	1570
	2	18	17	20	190	242	297	TNTC				956.10	956	894	1018
	3	1	1	0	4	3	13	7	11	22	26.67		27	16	37
	4	3	3	13	109	116	123	TNTC				463.44	463	420	506
	5	0	0	0	0	0	0	0	0	0	0.00		0	0	0
	6	6	2	4	65	102	93	TNTC				340.45	340	304	377
	7	6	4	5	135	130	129	TNTC				525.23	525	479	571
	8	4	2	2	40	40	42	58	66	94		142.25	142	118	166
	9	3	1	3	61	56	45	88	108	97		194.65	195	167	223
5	1	4	1	0	75	100	95	TNTC				357.26	357	319	395
	2	1	1	0	28	20	22	51	45	40		90.22	90	71	109
	3	0	0	0	5	4	2	5	5	5	10.00		10	4	16
	4	0	0	0	16	12	10	11	23	44		44.66	45	31	58
	5	0	0	0	2	6	5	16	18	10	29.33		29	19	40
	6	0	0	1	61	60	71	81	98	105		188.22	188	161	216
	7	1	1	0	46	63	49	18	25	38		51.53	52	37	66
	8	0	0	0	8	16	9	8	4	9	14.00		14	7	21
	9	0	0	0	36	43	31	36	27	32		62.90	63	47	79
5	1	0	0	0	26	23	24	52	50	49		100.64	101	81	121
	2	2	0	0	15	22	13	32	27	28		57.84	58	43	73
	3	0	0	0	9	13	13	21	45	31		61.65	62	46	77
	4	0	0	0	4	2	5	5	8	6	12.67		13	6	20
	5	0	0	0	9	13	10		-		42.67		43	30	56
	6	0	0	0	7	10	10	11	22	14	31.33		31	20	43
	7	0	0	0	8	10	12	17	17	17	34.00		34	22	46
	8	0	1	0	9	5	10	13	16	21	33.33		33	22	45
	9	1	2	0	33	30	37	48	50	45		95.24	95	76	115
5	1	1	1	1	22	23	16	31	34	47		73.45	73	56	91
	2	0	0	0	12	20	17	31	35	47		74.17	74	57	91
	3	1	1	0	8	14	15	20	38	28		55.42	55	41	70
	4	2	0	0	15	10	13	23	16	15	36.00		36	24	48
	5	0	0	0	7	11	10	21	16	19	37.33		37	25	50
	6	0	2	0	10	17	17	17	16	17	33.33		33	22	45
	7	0	0	0	11	12	8	21	20	21		41.32	41	28	54
	8	0	0	0	22	17	18	14	22	33		43.32	43	30	56
	9	1	1	0	67	46	40	79	71	71		147.14	147	123	171

6	1	1	1	-	7	7	8	**4**	**3**	**3**	6.67		7	2	12
	2	2	3	4	**93**	**131**	**170**		TNTC			509.87	510	465	555
	3	5	2	3	**75**	**104**	**105**		TNTC			374.24	374	336	413
	4	0	0	0	0	4	1	**3**	**0**	**0**	2.00		2	<1	5
	5	0	0	0	0	0	0	**2**	**3**	**0**	3.33		3	<1	7
	6	1	5	4	**95**	**83**	**80**		TNTC			343.05	343	306	380
	7	1	3	7	**83**	**72**	**70**		TNTC			299.15	299	265	334
	8	3	1	6	**118**	**107**	**129**		TNTC			470.63	471	427	514
	9	4	3	2	**81**	**117**	**140**		TNTC			439.53	440	398	481
7	1	2	2	1	**100**	**119**	**116**		TNTC			445.38	445	403	488
	2	7	4	3	**130**	**96**	**113**		TNTC			448.56	449	406	491
	3	3	4	3	**114**	**120**	**92**		TNTC			431.87	432	390	473
	4	0	0	0	0	0	0	**1**	**1**	**1**	2.00		2	<1	5
	5	0	0	0	1	2	1	**2**	**4**	**1**	4.67		5	<1	9
	6	0	0	0	1	1	0	**2**	**2**	**2**	4.00		4	<1	8
	7	4	2	4	**128**	**121**	**116**		TNTC			486.27	486	442	530
	8	3	4	8	**143**	**165**	**126**		TNTC			575.16	575	527	623
	9	10	15	9	**198**	**212**	**200**		TNTC			812.96	813	756	870
8	1	3	0	0	10	6	4	**5**	**15**	**15**	23.33		23	14	33
	2	0	1	0	6	5	10	**16**	**19**	**41**	50.67		51	36	65
	3	0	0	0	0	0	0	**0**	**0**	**0**	0.00		0	0	0
	4	1	0	0	34	41	37	**58**	**41**	**78**		114.06	114	93	135
	5	0	0	0	48	48	50	**48**	**97**	**92**		150.76	151	126	175
	6	1	0	0	9	12	10	**22**	**16**	**21**		38.96	39	26	51
	7	0	0	0	4	5	3	**11**	**9**	**13**	22.00		22	13	31
	8	0	0	0	1	5	4	**7**	**10**	**10**	18.00		18	10	26
	9	0	0	0	10	15	11	**27**	**25**	**32**		55.70	56	41	71
9	1	0	1	0	5	2	5	**6**	**5**	**14**	16.67		17	9	25
	2	0	0	0	5	10	9	**14**	**17**	**16**	31.33		31	20	43
	3	0	0	0	3	4	2	**7**	**14**	**17**	25.33		25	15	35
	4	0	0	0	12	10	8	**20**	**17**	**17**	36.00		36	24	48
	5	0	2	0	16	11	10	**16**	**20**	**17**	35.33		35	23	47
	6	0	0	0	3	5	4	**18**	**10**	**9**	24.67		25	15	35
	7	1	0	0	12	15	16	**21**	**31**	**23**		49.29	49	35	63
	8	0	0	0	3	2	4	**15**	**11**	**15**	27.33		27	17	38
	9	1	0	0	5	7	10	**13**	**9**	**8**	20.00		20	11	29
10	1	0	0	0	7	12	14	**16**	**22**	**22**		39.57	40	27	52
	2	0	1	0	11	10	11	**12**	**27**	**22**		38.49	38	26	51
	3	0	0	0	13	14	14	**8**	**24**	**16**	32.00		32	21	43
	4	0	0	0	**9**	**6**	**7**	9	-	40	29.33		29	19	40
	5	0	0	0	9	11	7	**13**	**22**	**16**	34.00		34	22	46
	6	0	0	0	9	6	6	**22**	**23**	**17**		40.98	41	28	54
	7	0	0	0	0	1	2	**3**	**11**	**8**	14.67		15	7	22
	8	0	0	0	3	3	12	**16**	**14**	**14**	29.33		29	19	40
	9	0	0	0	0	0	0	**1**	**1**	**1**	2.00		2	<1	5

S SPREADER

Sta	Pt	Dilutions (mL)						Count		Count	95% Confidence Limits	
		25			50			<20	>20	cfu/100mL	Lower	Upper
1	1	**60**	**45**	**64**		TNTC			210.53	211	182	240
	2	35	26	20	**59**	**73**	**72**		135.37	135	112	159
	3	25	36	30	**26**	**58**	**60**		89.79	90	71	109
	4	39	40	33	**67**	**66**	**77**		139.66	140	116	163
	5	35	39	33	**47**	**75**	**86**		134.35	134	111	158
	6	**32**	**28**	**32**	60	74	S		122.43	122	100	145
	7	**34**	**13**	**37**	73	73	S		101.53	102	81	122
	8	27	25	22	**56**	**61**	**72**		125.31	125	103	148
	9	28	22	22	**39**	**44**	**52**		89.37	89	70	108
2	1	**64**	**67**	**53**		TNTC			244.10	244	213	275
	2	**44**	-	**50**		TNTC			187.62	188	160	215
	3	25	14	34	**39**	**48**	**33**		79.06	79	61	97
	4	**30**	**26**	**26**	59	S	S		109.08	109	88	130
	5	23	8	22	**43**	**38**	**50**		86.78	87	68	105
	6	27	20	16	**49**	**51**	**35**		88.78	89	70	108
	7	19	12	9	**43**	**30**	**29**		66.89	67	51	83
	8	**28**	**19**	**21**	S	44	S		89.42	89	71	108
	9	43	32	28	**80**	**63**	**69**		140.64	141	117	164
3	1	**49**	**25**	**34**	66	67	S		138.65	139	115	162
	2	**34**	**32**	**34**		TNTC			133.28	133	110	156
	3	19	11	7	**15**	**26**	**20**		39.66	40	27	52
	4	30	16	15	**52**	**48**	**53**		101.91	102	82	122
	5	15	13	20	**17**	**17**	**24**	38.67		39	26	51
	6	9	8	4	**6**	**19**	**12**	24.67		25	15	35
	7	17	14	13	**15**	**32**	**30**		48.66	49	35	63
	8	10	7	9	**21**	**23**	**16**		39.54	40	27	52
	9	**25**	**34**	**17**	45	54	S		97.43	97	78	117
4	1	**39**	**20**	**39**	63	TNTC	43		124.87	125	103	147
	2	43	32	38	**48**	**78**	**46**		111.27	111	90	132
	3	**9**	**4**	**12**	19	22	-	33.33		33	22	45
	4	**41**	**19**	**24**	S	46	S		106.16	106	86	127
	5	9	11	5	**11**	**25**	**9**	30.00		30	19	41
	6	16	16	13	**21**	**17**	**26**		42.03	42	29	55
	7	4	3	1	**19**	**6**	**12**	24.00		24	14	34
	8	19	12	11	**17**	**29**	**31**		49.63	50	36	64
	9	15	17	9	**31**	**27**	**40**		64.46	64	48	81
5	1	**60**	**38**	**35**		TNTC			172.21	172	146	198
	2	34	32	28	**81**	**86**	**71**		158.17	158	133	183
	3	26	22	6	**66**	**43**	**53**		106.36	106	86	127
	4	**37**	**59**	**47**		TNTC			187.26	187	160	215
	5	42	31	27	**78**	**69**	**62**		138.72	139	115	162
	6	**36**	**34**	**24**	77	60	S		123.42	123	101	146
	7	41	35	40	**80**	**60**	**49**		123.46	123	101	146
	8	30	28	22	**61**	**61**	**43**		108.58	109	88	129
	9	**60**	**56**	**55**		TNTC			227.84	228	198	258
5	1	**112**	**101**	**72**		TNTC			373.55	374	335	412
	2	**61**	**51**	**43**		TNTC			204.57	205	176	233
	3	11	12	9	**46**	**44**	**38**		85.05	85	67	103
	4	40	31	25	**73**	**80**	**83**		157.11	157	132	182
	5	24	33	24	**43**	**56**	**35**		87.69	88	69	106
	6	**52**	**54**	**37**	85	96	S		188.04	188	161	215
	7	**49**	**47**	**44**		TNTC			186.48	186	159	214
	8	**64**	**47**	**61**		TNTC			227.30	227	197	257
	9	**51**	**48**	**58**		TNTC			208.68	209	180	238
5	1	**92**	**98**	**92**		TNTC			375.83	376	337	415
	2	**58**	**75**	**49**		TNTC			238.94	239	208	270
	3	**42**	**40**	**46**	TNTC	S	S		170.38	170	144	196
	4	**63**	**49**	**50**		TNTC			214.57	215	185	244
	5	22	23	23	**63**	**72**	**40**		113.22	113	92	135
	6	**64**	**62**	-	S	-	TNTC		251.97	252	220	284
	7	**30**	**31**	**30**	52	S	S		121.32	121	99	143
	8	36	25	18	**58**	**61**	**63**		121.26	121	99	143
	9	**38**	**33**	**23**	S	108	70		122.67	123	101	145

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		TNTC			266.42	266	234	299
	2	**29**	**17**	**17**	49	30	S	84.00		84	66	102
	3	**36**	**28**	**35**	S	S	71		131.19	131	108	154
	4	**35**	**30**	**39**	S	S	60		137.87	138	114	161
	5	**45**	**28**	**34**		TNTC			139.96	140	116	164
	6	**40**	**42**	**36**	66	83	S		157.01	157	132	182
	7	**25**	**22**	**15**	55	S	S		80.82	81	63	99
	8	**27**	**22**	**19**	45	S	S		89.72	90	71	109
	9	**64**	**48**	**33**	66	100	S		186.51	187	159	214
7	1	3	0	0	**12**	**9**	**6**	18.00		18	10	26
	2	43	31	24	**66**	**65**	**73**		135.82	136	113	159
	3	24	20	11	**54**	**56**	**49**		105.83	106	85	126
	4	**32**	**14**	**17**	50	31	S		78.70	79	61	96
	5	24	21	15	**52**	**37**	**45**		88.48	88	70	107
	6	**46**	**55**	**39**		TNTC			184.84	185	158	212
	7	6	31	25	**50**	**44**	**34**		84.27	84	66	103
	8	**46**	**43**	**40**		TNTC			171.72	172	146	198
	9	**56**	**52**	**45**		TNTC			203.17	203	175	232
8	1	12	16	12	**11**	**19**	**23**	35.33		35	23	47
	2	**28**	**36**	**33**		TNTC			128.64	129	106	151
	3	3	5	3	**9**	**14**	**18**	27.33		27	17	38
	4	2	3	1	**18**	**11**	**9**	25.33		25	15	35
	5	10	1	0	**3**	**14**	**11**	18.67		19	10	27
	6	14	11	11	**26**	**32**	**20**		51.06	51	37	65
	7	9	6	7	**23**	**19**	**16**	38.67		39	26	51
	8	14	18	8	**30**	**23**	**29**		54.30	54	40	69
	9	**53**	**53**	**43**		TNTC			197.73	198	170	226
9	1	34	24	25	**60**	**60**	**50**		112.92	113	92	134
	2	**38**	**30**	**31**	64	73	S		131.26	131	108	154
	3	21	14	9	**20**	**28**	**30**		51.22	51	37	66
	4	37	32	28	**70**	**61**	**72**		134.98	135	112	158
	5	32	23	25	**65**	**51**	**59**		116.09	116	95	138
	6	27	25	27	**60**	**50**	**72**		120.00	120	98	142
	7	10	14	13	**26**	**17**	**16**	39.33		39	27	52
	8	16	15	21	**40**	**35**	**20**		60.73	61	45	76
	9	10	8	11	**21**	**21**	**22**		42.66	43	30	56
10	1	**32**	**37**	**35**	72	S	S		138.42	138	115	162
	2	**40**	**47**	**33**		TNTC			158.35	158	133	184
	3	**37**	**32**	**33**	62	S	57		135.73	136	112	159
	4	14	17	14	**27**	**26**	**27**		53.32	53	39	68
	5	37	25	19	**61**	**55**	**47**		108.05	108	87	129
	6	12	12	4	**37**	**33**	**47**		77.14	77	60	95
	7	21	27	15	**45**	**49**	**61**		102.47	102	82	123
	8	8	13	8	**12**	**21**	**28**		38.36	38	26	51
	9	22	15	22	**38**	**37**	**20**		60.82	61	45	76

Trial Run Number Two Performed on Augest 28, 1996
Run Number Three Perfomed on October 3, 1996
Microbiology Counts for total coliforms
All values are number of coliforms on each plate

Location of Outfall	#	Date of Collection	0.01			0.1			1			Count <20	Count >20	Count cfu/100mL	95% Confidence L Lower	Upp
Millwoods	9	28-Aug	4	4	8	37	55	33	**92**	**92**	**78**		8707.43	8707	8521	88
Millwoods	9	3-Oct														
1/3			15	21	14	**72**	**75**	**58**	TNTC				67911.07	67911	67390	684
2/3			30	31	21	**62**	**54**	**49**	TNTC				54742.82	54743	54275	552
3/3			40	37	22	**70**	**71**	**74**	0	TNTC			71646.67	71647	71111	721
Quesnell	18	3-Oct														
1/3			**71**	**76**	**68**	TNTC			TNTC				715913	715913	714221	717
2/3			**64**	**60**	**60**	TNTC			TNTC				613048	613048	611482	614
3/3			**60**	**45**	**62**	TNTC			TNTC				551127	551127	549642	552
Whitemud Creek		3-Oct														
1/3			0	0	1	0	1	4	**26**	**24**	**14**		2059.54	2060	1969	215
2/3			0	0	0	1	4	2	**14**	**30**	**14**	1933.33		1933	1845	202
3/3			0	0	0	2	6	2	**15**	**15**	**31**	2033.33		2033	1943	212
Groat		3-Oct														
1/3			14	11	12	**56**	**60**	**59**	TNTC				58308.31	58308	57825	587
2/3			18	13	16	**69**	**55**	**47**	TNTC				56290.69	56291	55816	567
3/3			17	22	20	**60**	**64**	**56**	TNTC				59910.98	59911	59421	604

Trial Run Number Two Performed on Augest 28, 1996
Run Number Three Perfomed on October 3, 1996
Microbiology Counts for fecal coliforms
All values are number of coliforms on each plate

Location		Date of	Dilutions									Count		Count	95% Confidence Li	
of Outfall	#	Collection	1			10			25			<20	>20	cfu/100mL	Lower	Upp
Millwoods	9	28-Aug	16	11	5	33	30	19	44	55	TNTC		265.95	266	233	29
Millwoods	9	3-Oct														
1/3			61	36	28		TNTC			TNTC			3946.97	3947	3821	407
2/3			72	54	41		TNTC			TNTC			5422.13	5422	5275	556
3/3			65	30	22		TNTC			TNTC			3500.68	3501	3382	361
Quesnell	10	3-Oct														
1/3			450	429	318		TNTC			TNTC			39448.66	39449	39051	398
2/3			515	447	482		TNTC			TNTC			48053.01	48053	47615	484
3/3			322	347	194		TNTC			TNTC			27882.33	27882	27548	282
Whitemud Creek		3-Oct														
1/3			0	0	0	3	1	4	4	8	13	33.33		33	22	45
2/3			0	0	0	3	2	0	5	4	5	18.67		19	10	27
3/3			0	0	0	5	1	4	4	7	7	24.00		24	14	34
Groat		3-Oct														
1/3			38	29	24	283	239	226		TNTC			2481.79	2482	2382	258
2/3			45	56	27		TNTC			TNTC			4082.46	4082	3955	421
3/3			19	24	31	228	231	209		TNTC			2224.49	2224	2130	231

Appendix E Ammonia Results

Ammonia Analyzed September 20, 1996

Ammonia Results

Samples labeled from left to right bank

Points	Trial of Absorbance 1	Trial of Absorbance 2	Trial of Absorbance 3	Arithmetic Mean
Blank	0.000	0.000	0.000	0.00

Standards	N, µg	NH_3, µg	1	2	3	Absorbance
1	100	122	0.033	0.034	0.034	0.034
2	500	610	0.235	0.233	0.234	0.234
3	1000	1220	0.397	0.400	0.400	0.399
4	2000	2440	0.601	0.602	0.599	0.601
5	3000	3660	0.801	0.801	0.806	0.803
6	4000	4880	1.017	1.015	1.015	1.016
7	5000	6100	1.256	1.260	1.259	1.258

Station	Point	Run	1	2	3	Mean	mg NH_3-N/L
1	1	1- 08/22/96	0.011	0.010	0.010	0.010	4.198
	2	1	0.008	0.008	0.007	0.008	3.114
	3	1	0.017	0.018	0.018	0.018	7.176
	4	1	0.013	0.013	0.013	0.013	5.281
	5	1	0.018	0.017	0.017	0.017	7.041
	6	1	0.014	0.013	0.014	0.014	5.552
	7	1	0.022	0.021	0.024	0.022	9.072
	8	1	0.020	0.019	0.019	0.019	7.853
	9	1	0.027	0.026	0.026	0.026	10.697
4	1	1	-0.005	-0.005	-0.006	-0.005	-
	2	1	-0.004	-0.003	-0.006	-0.004	-
	3	1	0.007	0.006	0.004	0.006	2.302
	4	1	0.008	0.008	0.009	0.008	3.385
	5	1	-0.003	-0.004	-0.004	-0.004	-
	6	1	-0.008	-0.009	-0.008	-0.008	-
	7	1	-0.003	-0.002	-0.003	-0.003	-
	8	1	0.034	0.031	0.030	0.032	12.863
	9	1	0.047	0.042	0.041	0.043	17.603
7	1	1	-0.011	-0.012	-0.011	-0.011	-
	2	1	-0.011	-0.012	-0.011	-0.011	-
	3	1	-0.013	-0.013	-0.012	-0.013	-
	4	1	-0.008	-0.008	-0.008	-0.008	-
	5	1	-0.013	-0.012	-0.013	-0.013	-
	6	1	-0.012	-0.013	-0.012	-0.012	-
	7	1	-0.008	-0.008	-0.008	-0.008	-
	8	1	-0.012	-0.013	-0.012	-0.012	-
	9	1	-0.014	-0.013	-	-0.014	-

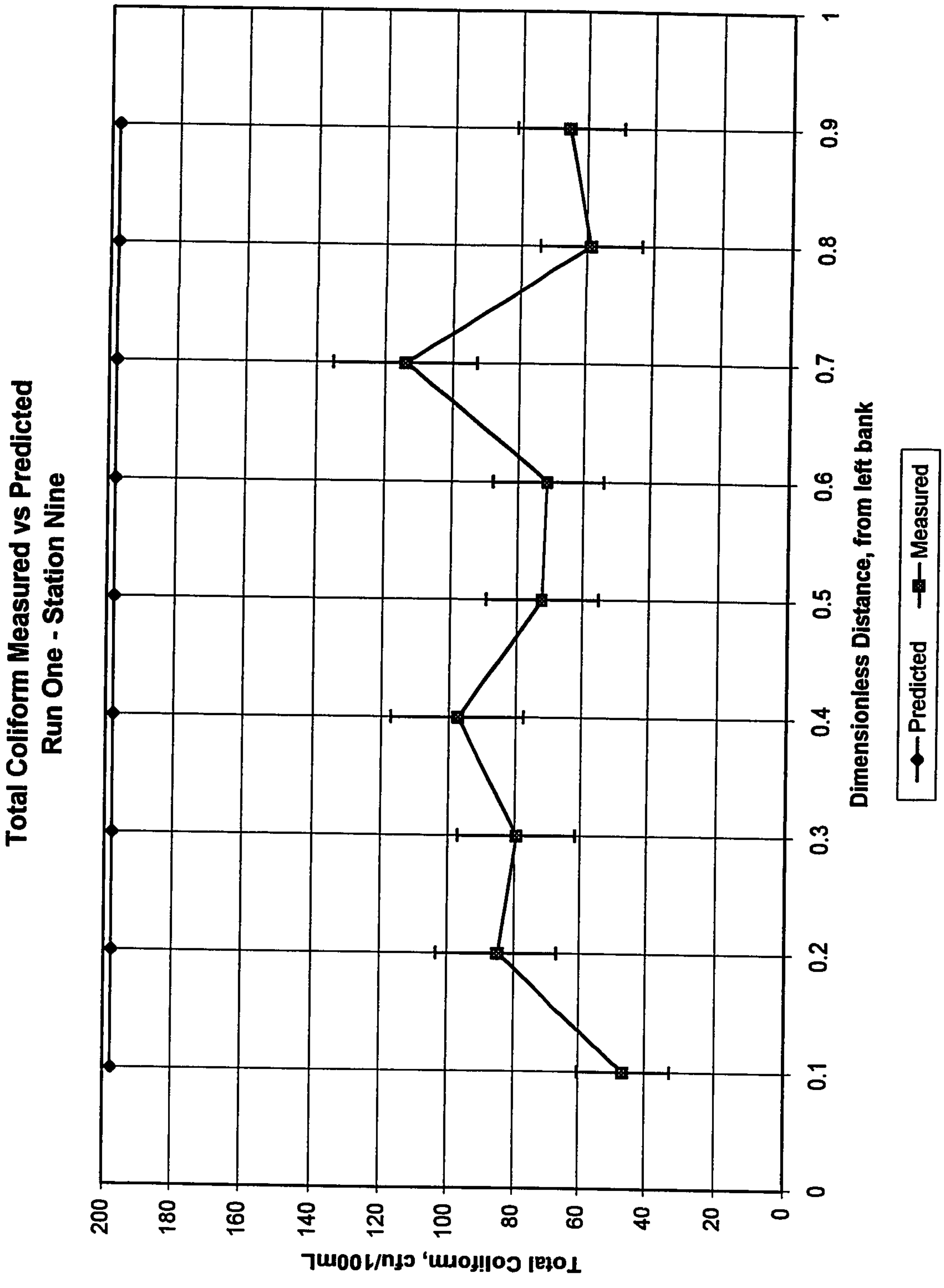
Station	Point	Run					mg NH_3-N/L
10	1	1	-0.004	0.000	-0.002	-0.002	-
	2	1	0.007	0.008	0.006	0.007	2.844
	3	1	-0.002	0.004	0.001	0.001	0.406
	4	1	-0.004	-0.004	-0.004	-0.004	-
	5	1	0.001	0.003	0.002	0.002	0.812
	6	1	-0.002	0.000	-0.002	-0.001	-
	7	1	-0.004	-0.004	-0.004	-0.004	-
	8	1	-0.010	-0.011	-0.011	-0.011	-
	9	1	-0.014	-0.013	-0.013	-0.013	-
1	1	2- 08/28/96	0.003	0.001	0.002	0.002	0.812
	2	2	0.000	0.000	-0.002	-0.001	-
	3	2	-0.014	-0.013	-0.013	-0.013	-
	4	2	-0.013	-0.014	-0.013	-0.013	-
	5	2	-0.010	-0.011	-0.010	-0.010	-
	6	2	-0.002	-0.002	-0.002	-0.002	-
	7	2	-0.011	-0.012	-0.011	-0.011	-
	8	2	-0.012	-0.012	-0.012	-0.012	-
	9	2	-0.013	-0.013	-0.013	-0.013	-
4	1	2	0.013	0.014	0.014	0.014	5.552
	2	2	0.014	0.012	0.012	0.013	5.145
	3	2	0.010	0.009	0.009	0.009	3.791
	4	2	0.012	0.010	0.011	0.011	4.468
	5	2	0.021	0.020	0.020	0.020	8.260
	6	2	0.010	0.009	0.009	0.009	3.791
	7	2	0.007	0.007	0.005	0.006	2.573
	8	2	0.015	0.014	0.013	0.014	5.687
	9	2	0.010	0.011	0.010	0.010	4.198
7	1	2	0.012	0.010	0.011	0.011	4.468
	2	2	0.014	0.014	0.015	0.014	5.822
	3	2	0.018	0.016	0.018	0.017	7.041
	4	2	0.015	0.014	0.014	0.014	5.822
	5	2	0.013	0.010	0.012	0.012	4.739
	6	2	0.006	0.006	0.007	0.006	2.573
	7	2	0.011	0.012	0.011	0.011	4.604
	8	2	0.005	0.004	0.003	0.004	1.625
	9	2	0.011	0.009	0.008	0.009	3.791
10	1	2	0.034	0.025	0.029	0.029	11.916
	2	2	0.013	0.012	0.014	0.013	5.281
	3	2	0.012	0.012	0.016	0.013	5.416
	4	2	0.018	0.019	0.019	0.019	7.583
	5	2	0.012	0.012	0.012	0.012	4.875
	6	2	0.019	0.019	0.018	0.019	7.583
	7	2	0.012	0.013	0.015	0.013	5.416
	8	2	0.009	0.010	0.007	0.009	3.521
	9	2	0.016	0.013	0.013	0.014	5.687

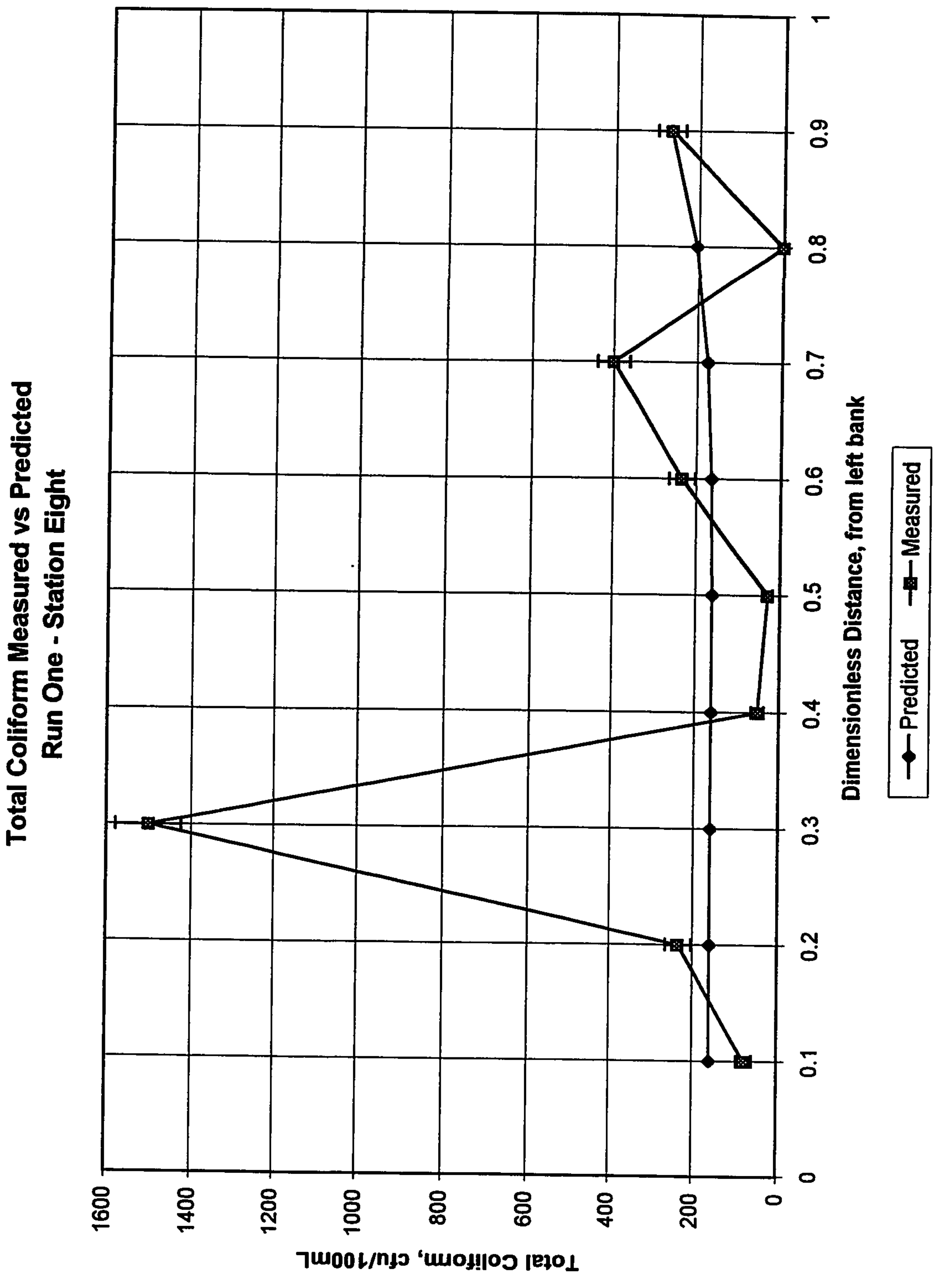
Ammonia Analyzed on October 4, 1996
Ammonia Results

Points			Trial of Absorbance 1	2	3	Arithmetic Mean
Blank			0.000	0.000	0.000	0.00
Standards	N, µg	NH_3, µg				Absorbance
1	50	61	0.018	0.018	0.018	0.018
2	100	122	0.033	0.032	0.034	0.033
3	500	610	0.162	0.162	0.161	0.162
4	1000	1220	0.290	0.290	0.291	0.290
5	3000	3660	0.786	0.783	0.785	0.785
6	5000	6100	1.264	1.265	1.266	1.265

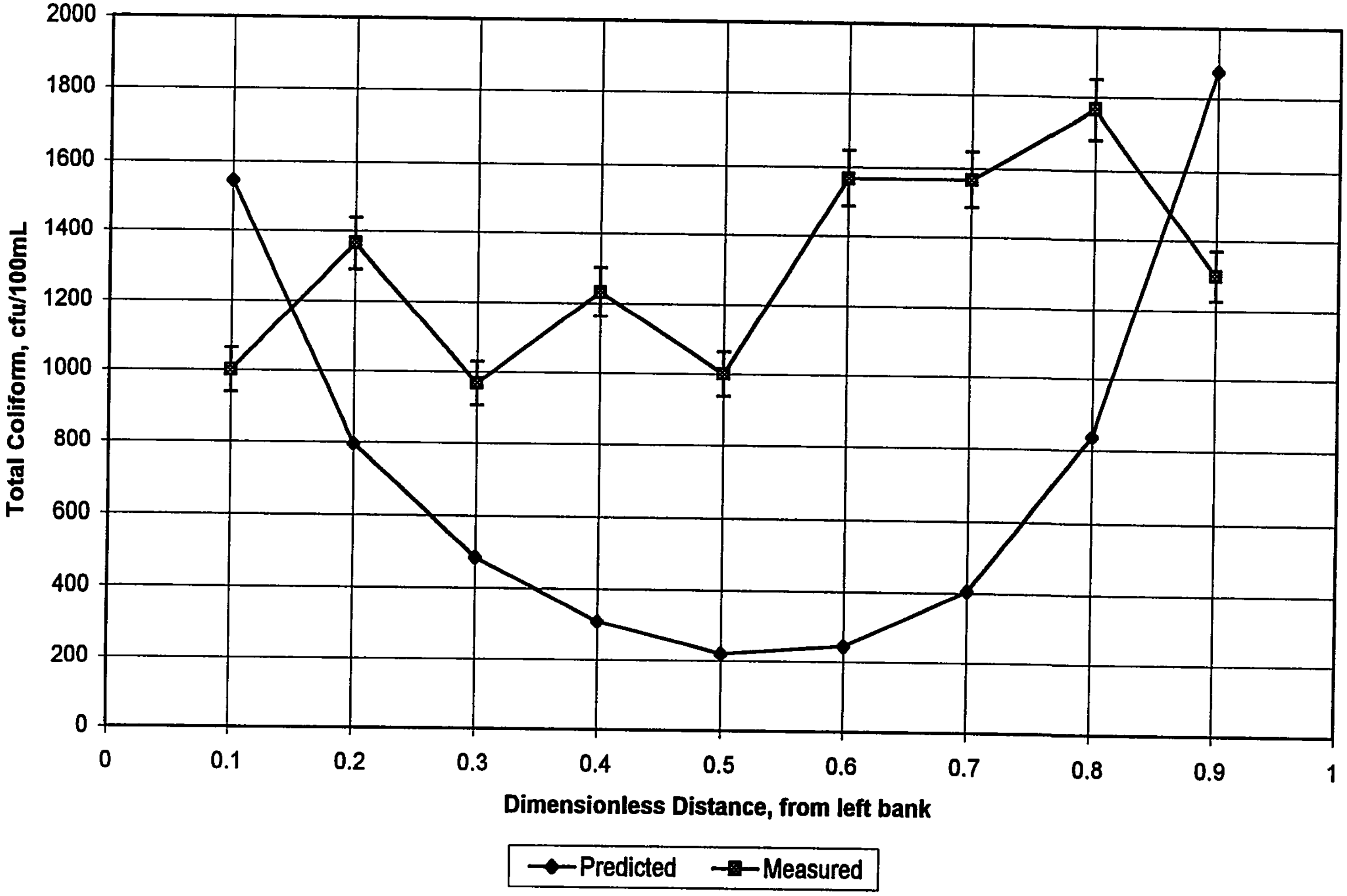
Location	#	Sampled					mg NH_3-N/L
Millwoods	1	3-Oct-96					
1/3			0.103	0.104	0.104	0.104	43.56
2/3			0.072	0.070	0.071	0.071	29.83
3/3			0.116	0.109	0.110	0.112	46.92
Quesnell	2	3-Oct-96					
1/3			0.166	0.186	0.209	0.187	
2/3			0.050	0.050	0.051	0.050	21.15
3/3			0.049	0.048	0.048	0.048	20.31
1/3 Rerun			0.056	0.056	0.056	0.056	23.53
Whitemud Creek	3	3-Oct-96					
1/3			0.171	0.154	0.150	0.158	66.53
2/3			0.159	0.143	0.149	0.150	63.17
3/3			0.132	0.125	0.132	0.130	54.49
Groat	4	3-Oct-96					
1/3			0.609	0.540	0.525	0.558	
2/3			0.373	0.357	0.412	0.381	
3/3			0.804	0.803	0.794	0.800	
1/3 Rerun			0.420	0.410	0.409	0.413	173.55
2/3 Rerun			0.521	0.530	0.517	0.523	219.63
3/3 Rerun			0.408	0.376	0.435	0.406	170.74

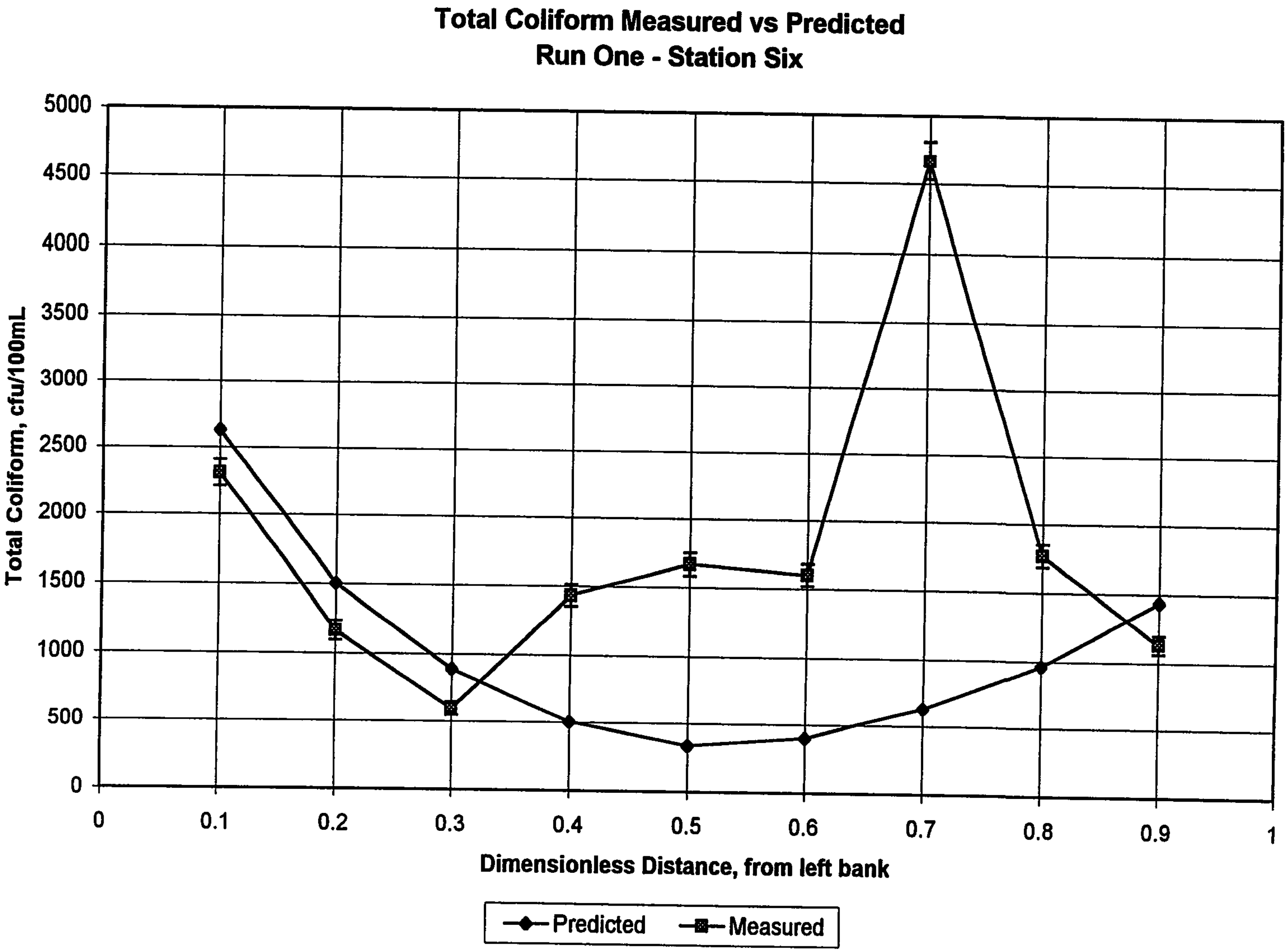
Appendix F Model Results

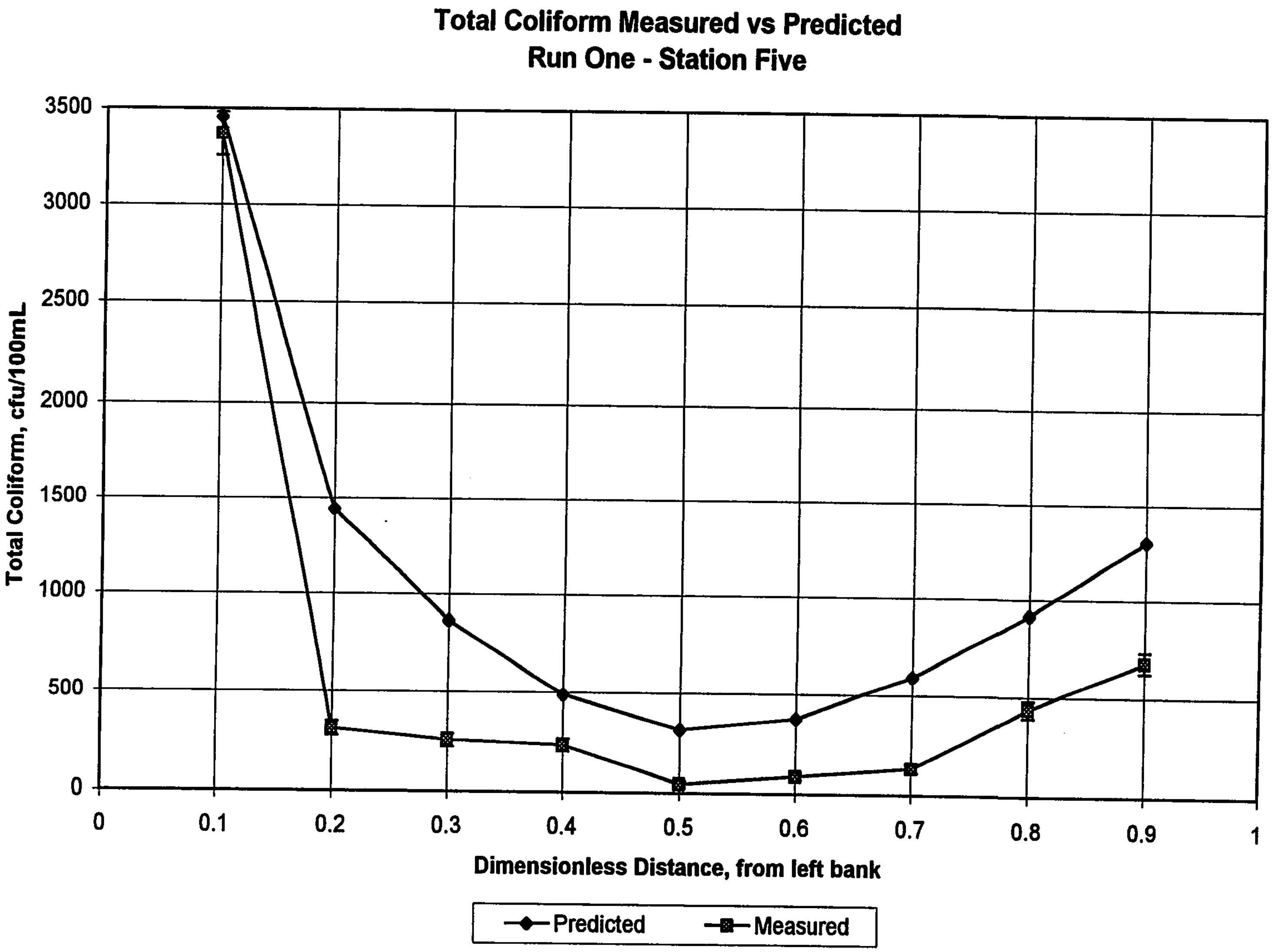

Total Coliform Measured vs Predicted
Run One - Station Nine
Total Coliform, cfu/100mL
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured


Total Coliform Measured vs Predicted
Run One - Station Eight
Total Coliform, cfu/100mL
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

Total Coliform Measured vs Predicted
Run One - Station Seven

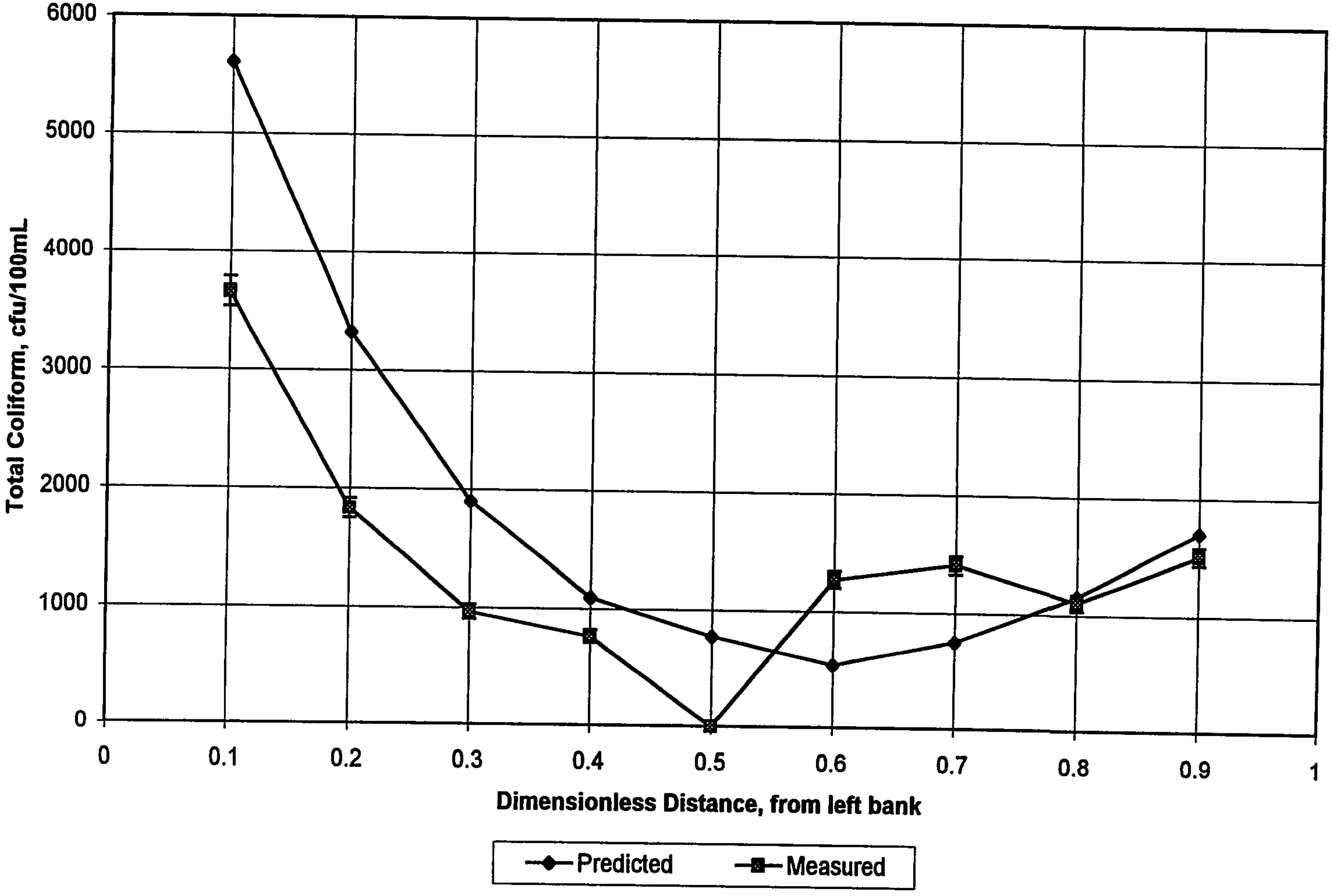



Total Coliform Measured vs Predicted
Run One - Station Six
Total Coliform, cfu/100mL
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

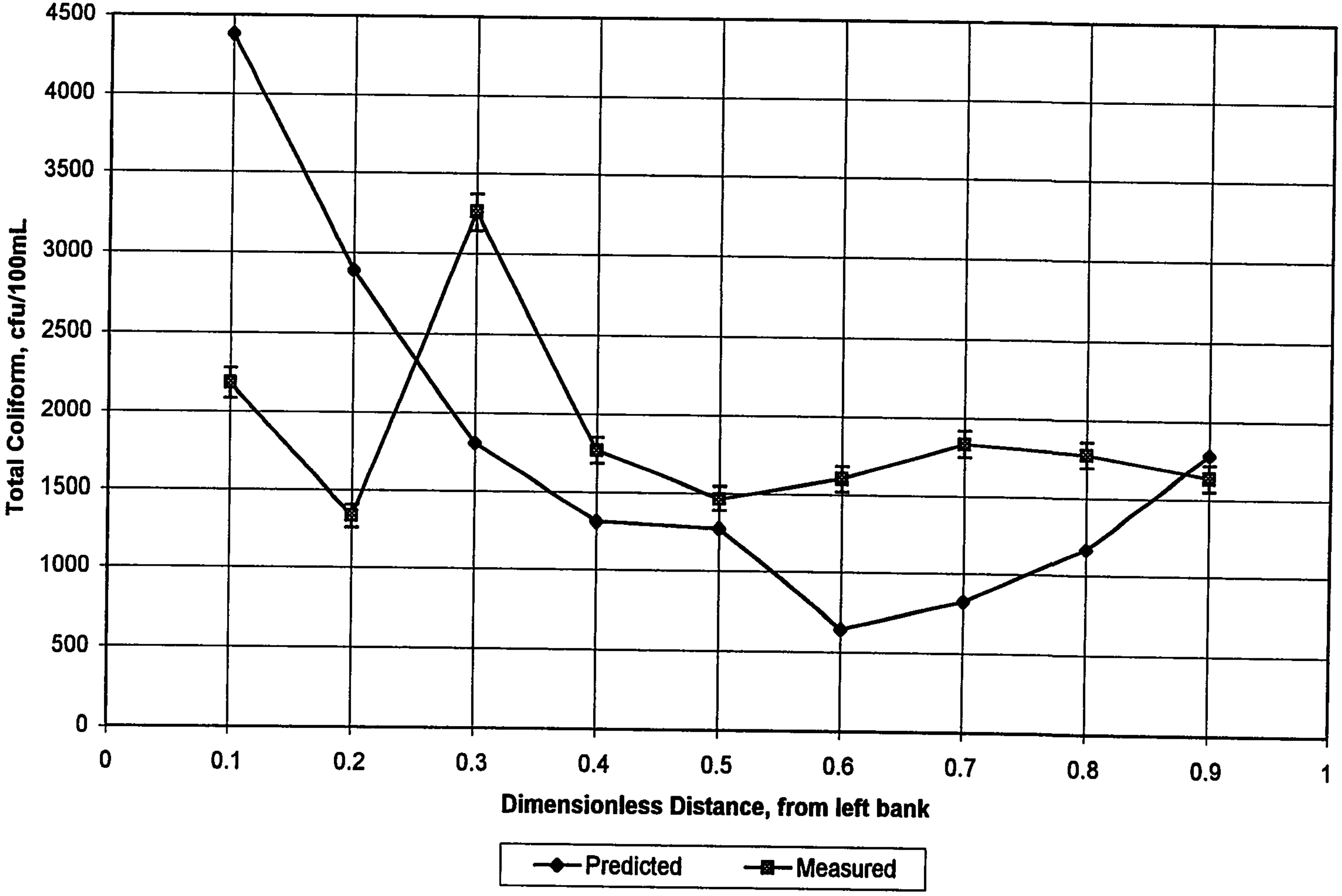


Total Coliform Measured vs Predicted
Run One - Station Five

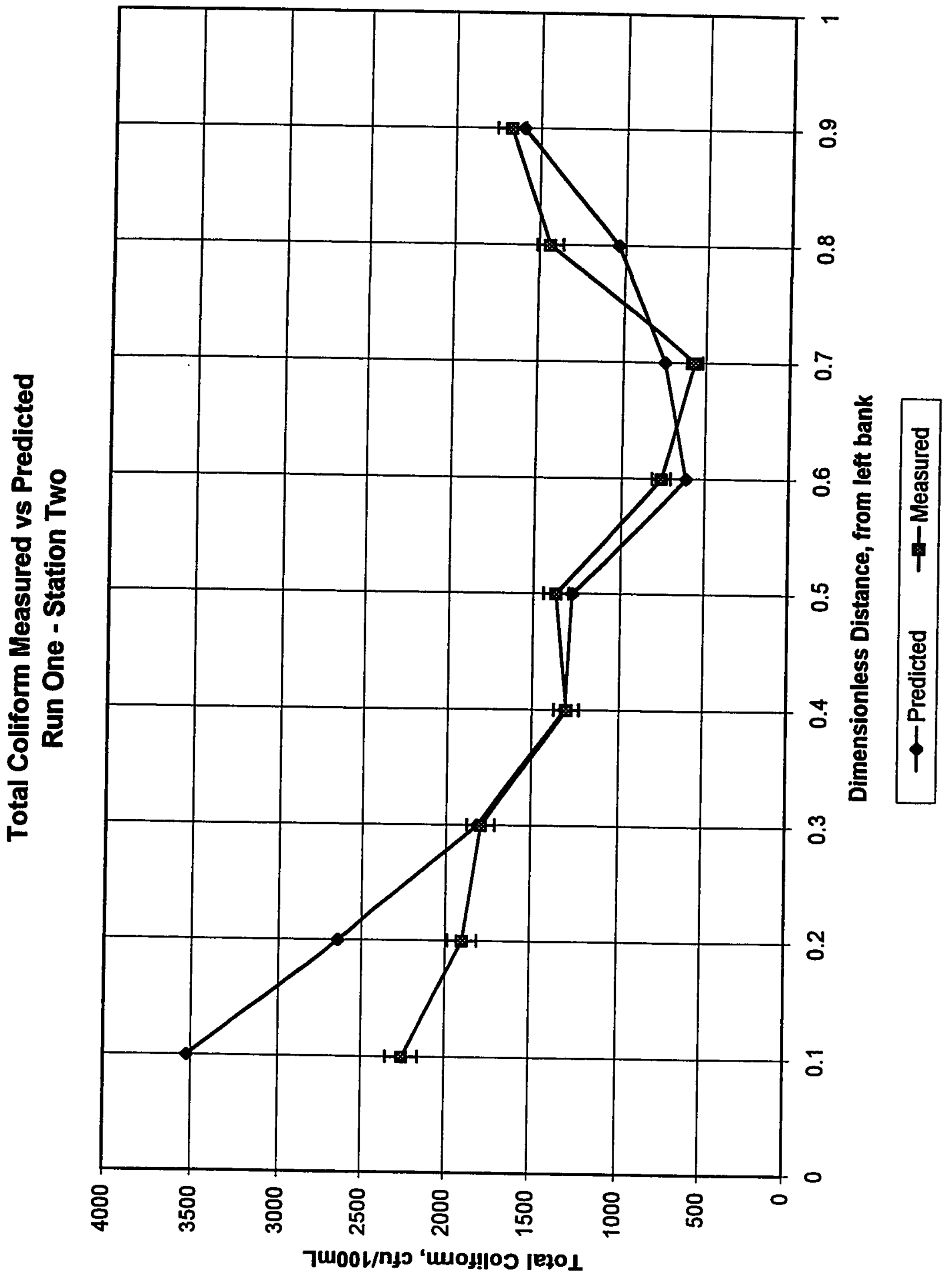
Total Coliform Measured vs Predicted
Run One - Station Four



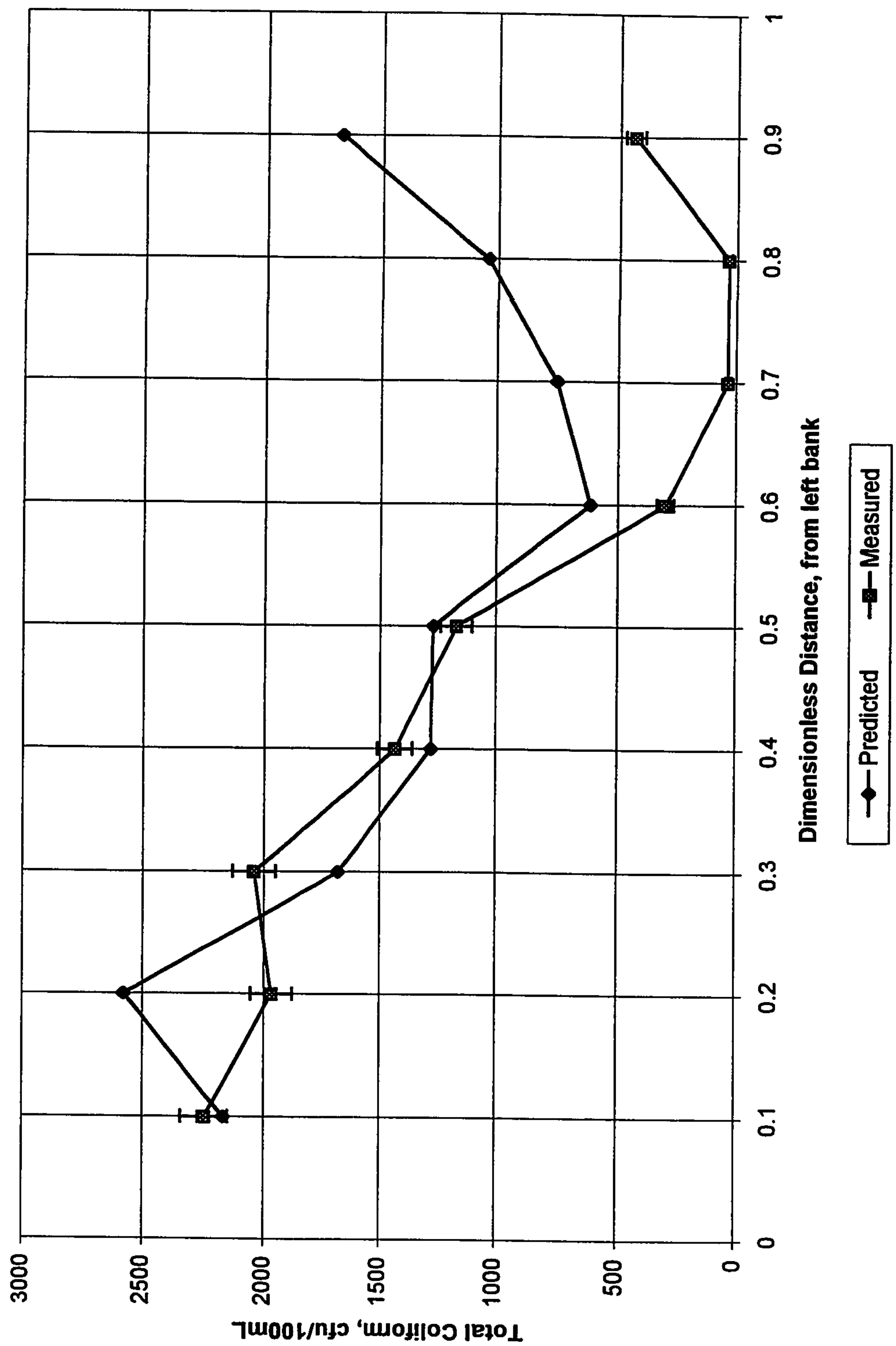
Total Coliform Measured vs Predicted
Run One - Station Three

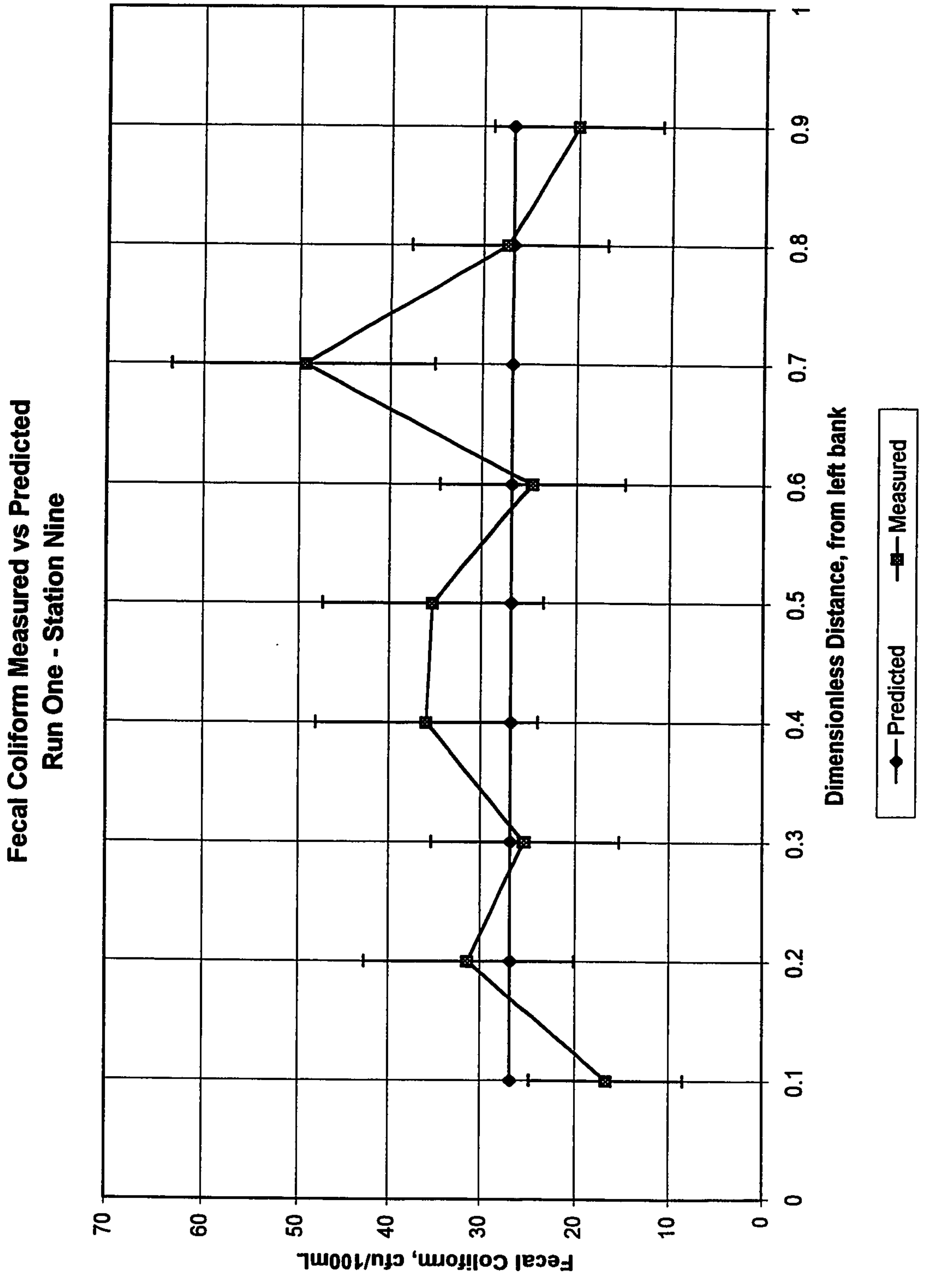


Total Coliform Measured vs Predicted
Run One - Station Two

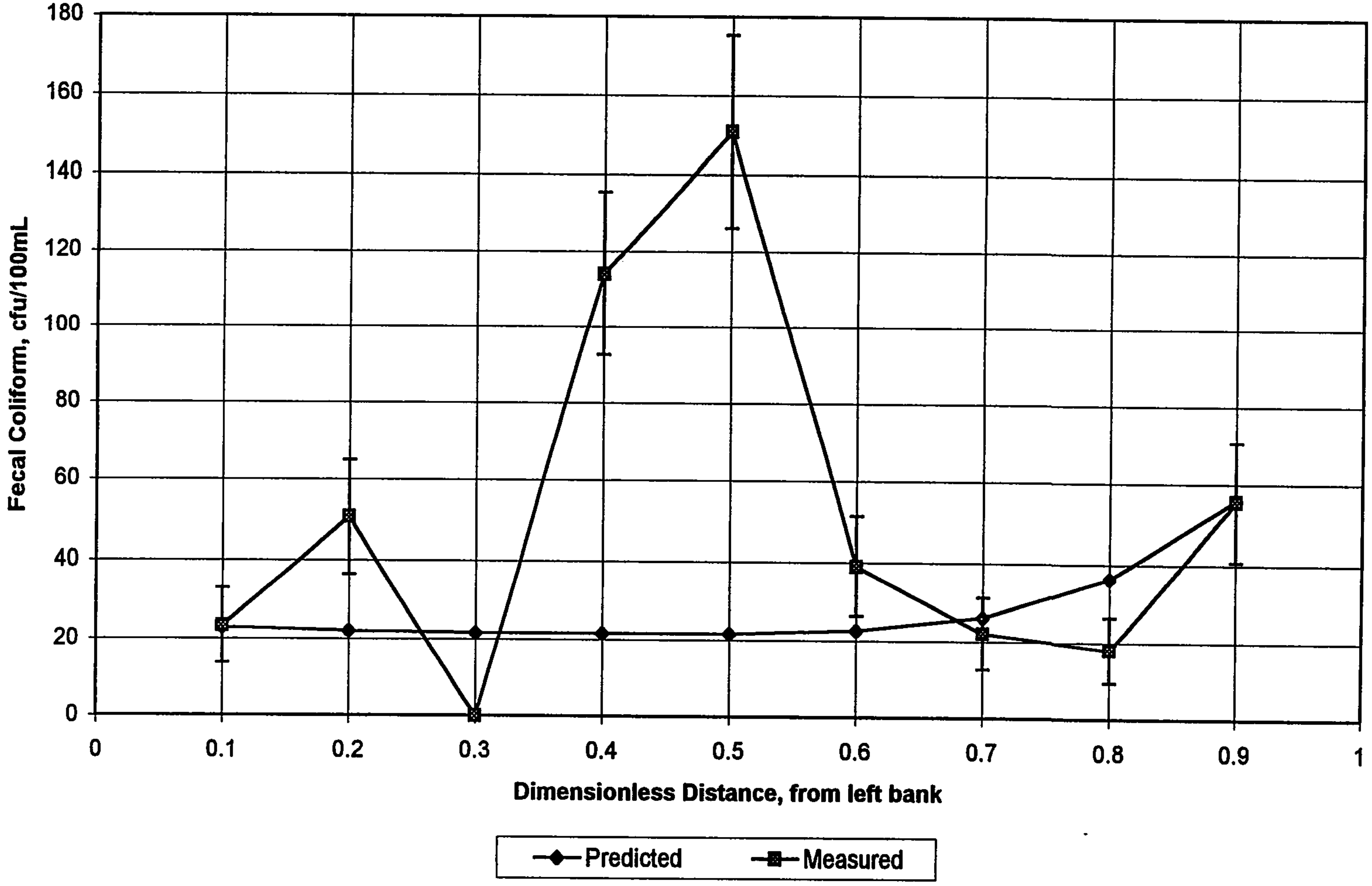


Total Coliform Measured vs Predicted
Run One - Station One

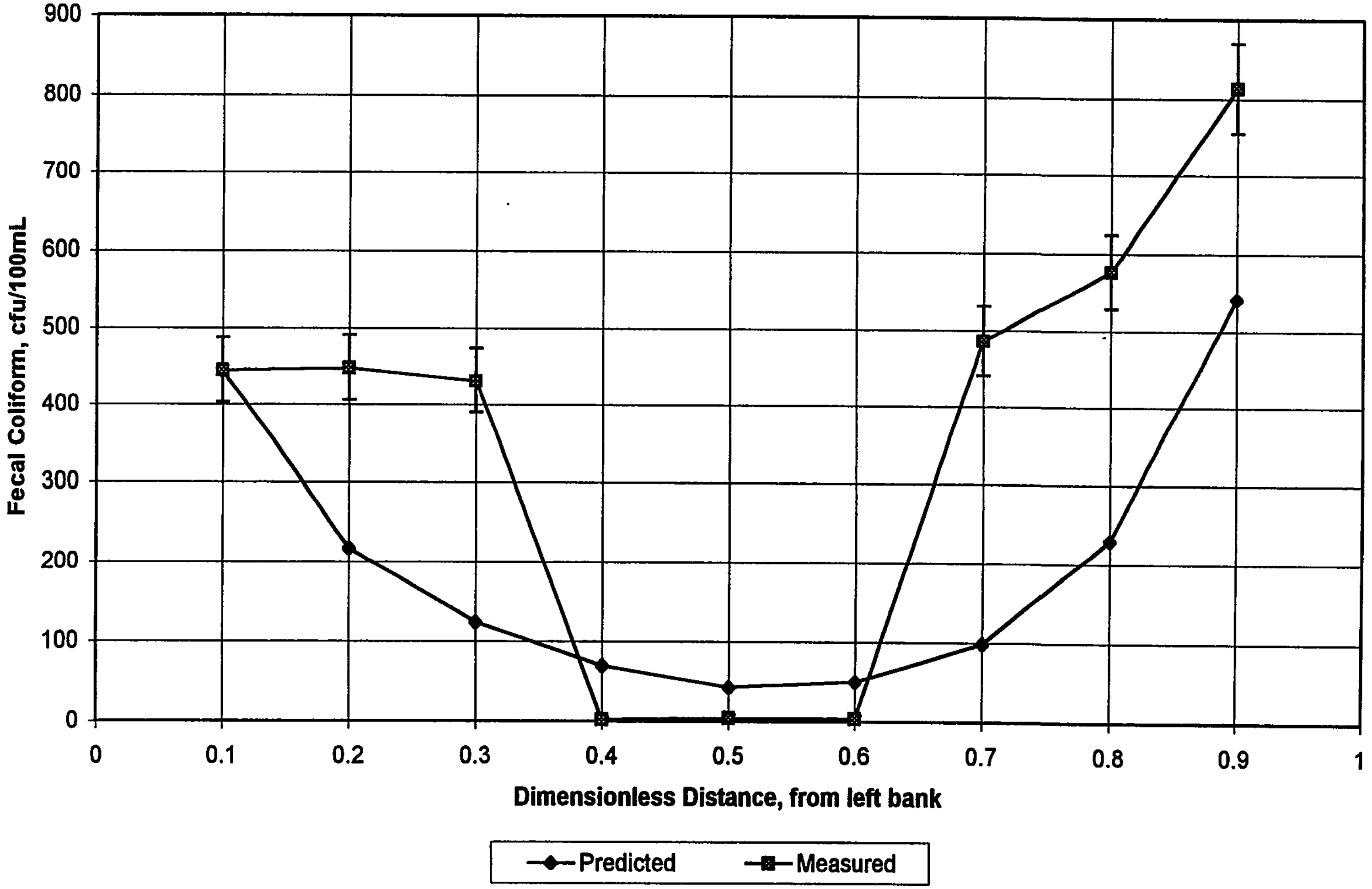


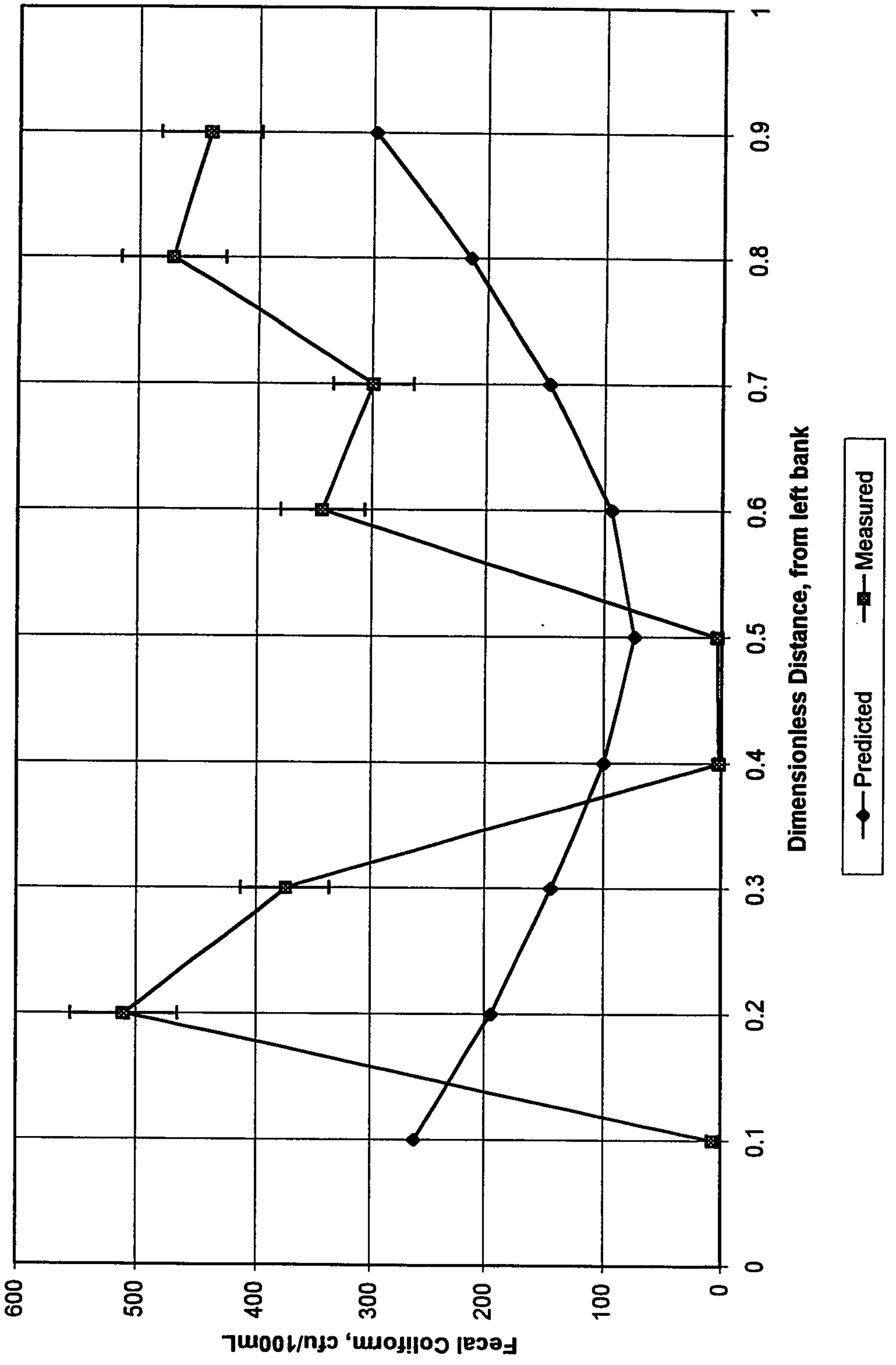

Fecal Coliform Measured vs Predicted
Run One - Station Nine
Fecal Coliform, cfu/100mL
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

Fecal Coliform Measured vs Predicted
Run One - Station Eight



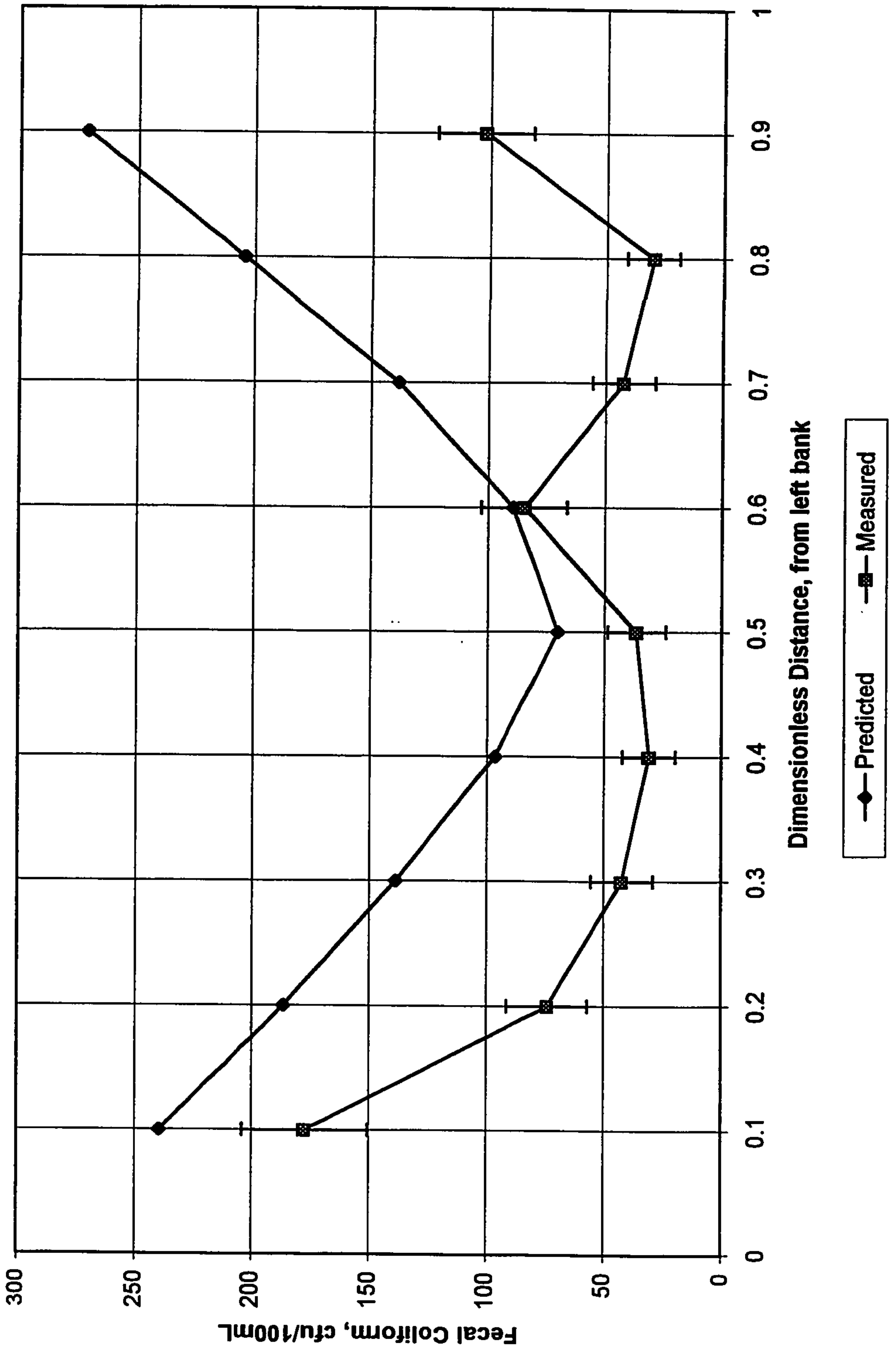
Fecal Coliform Measured vs Predicted
Run One - Station Seven

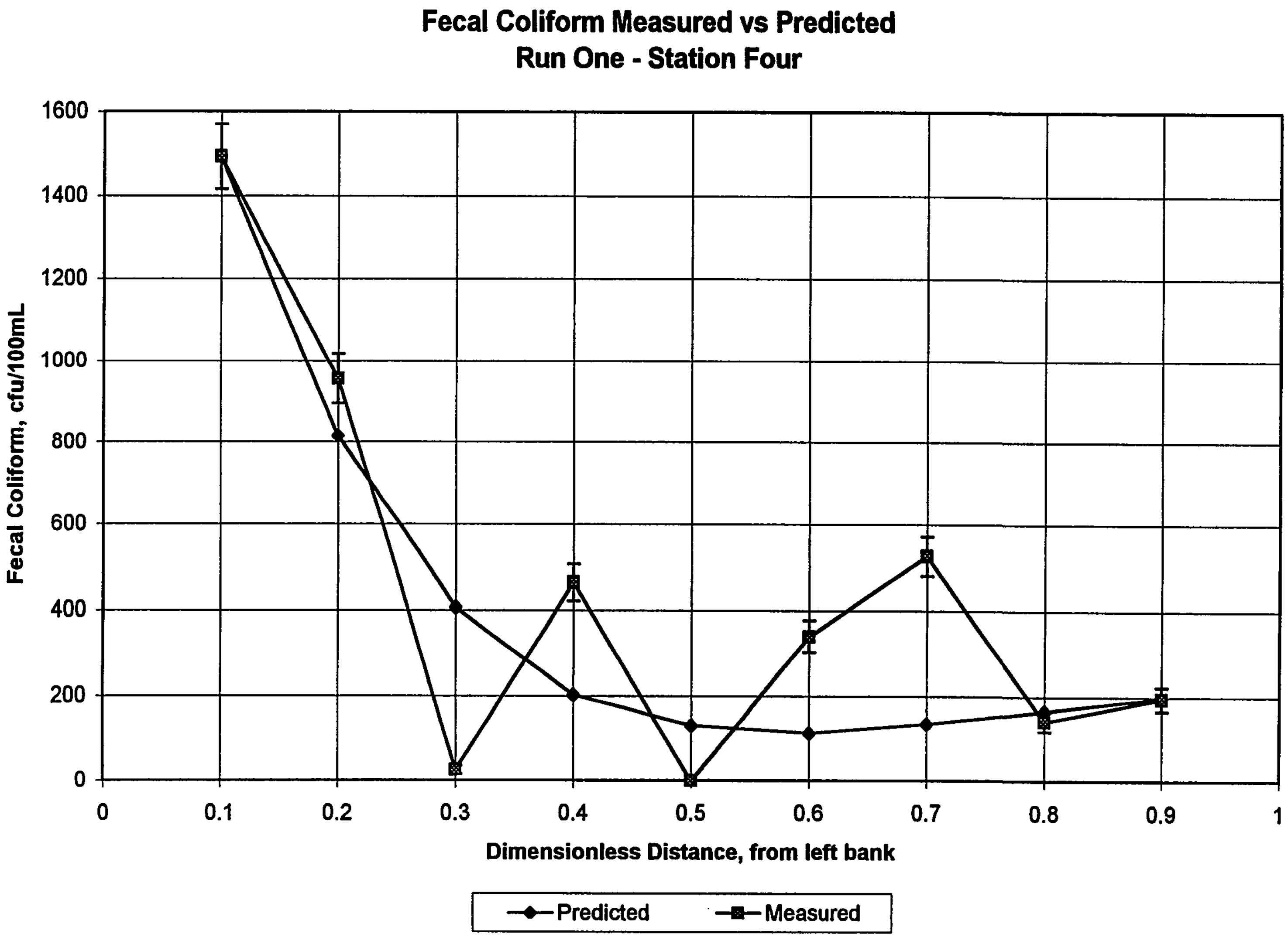


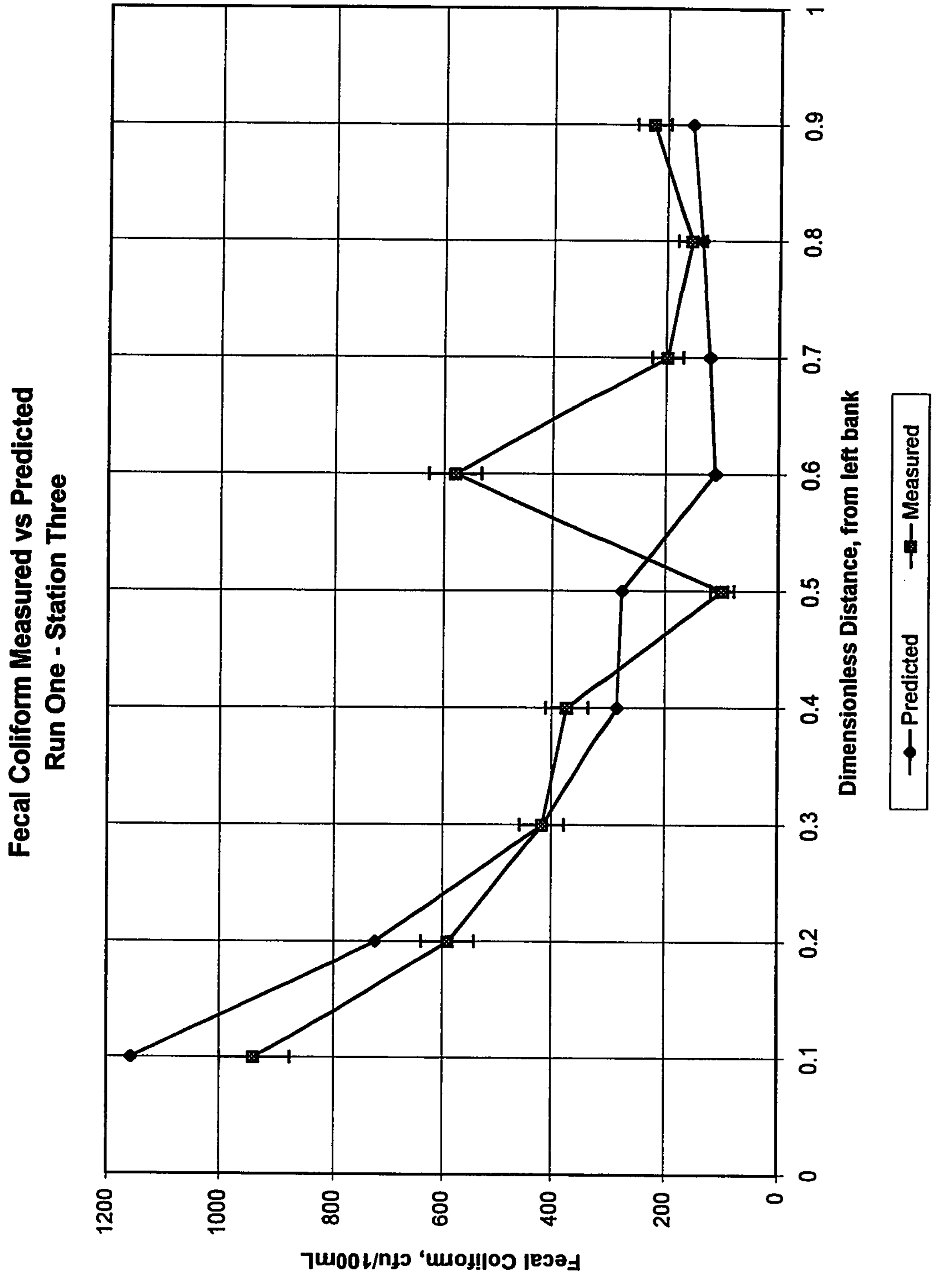


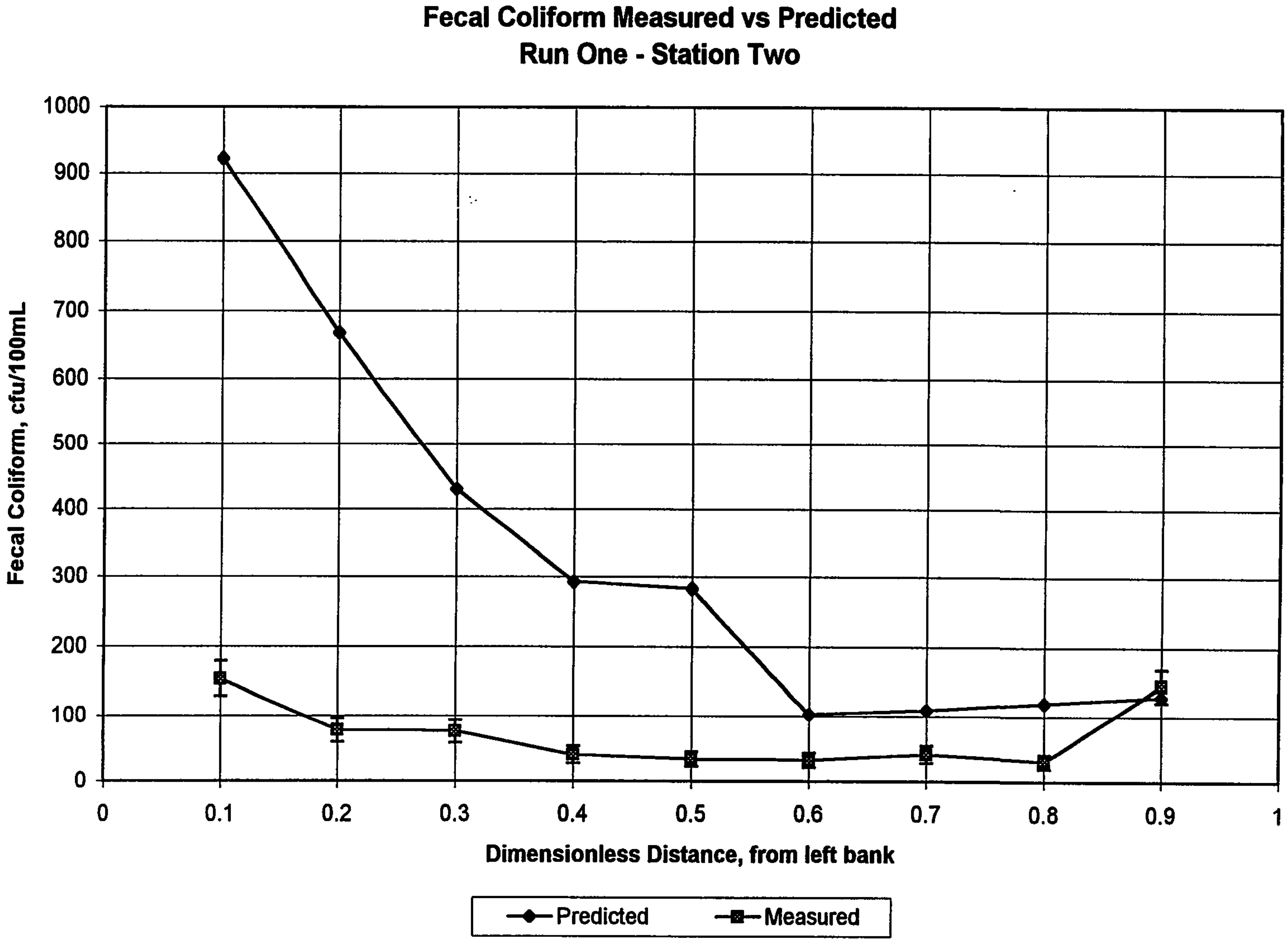
Fecal Coliform Measured vs Predicted
Run One - Station Six

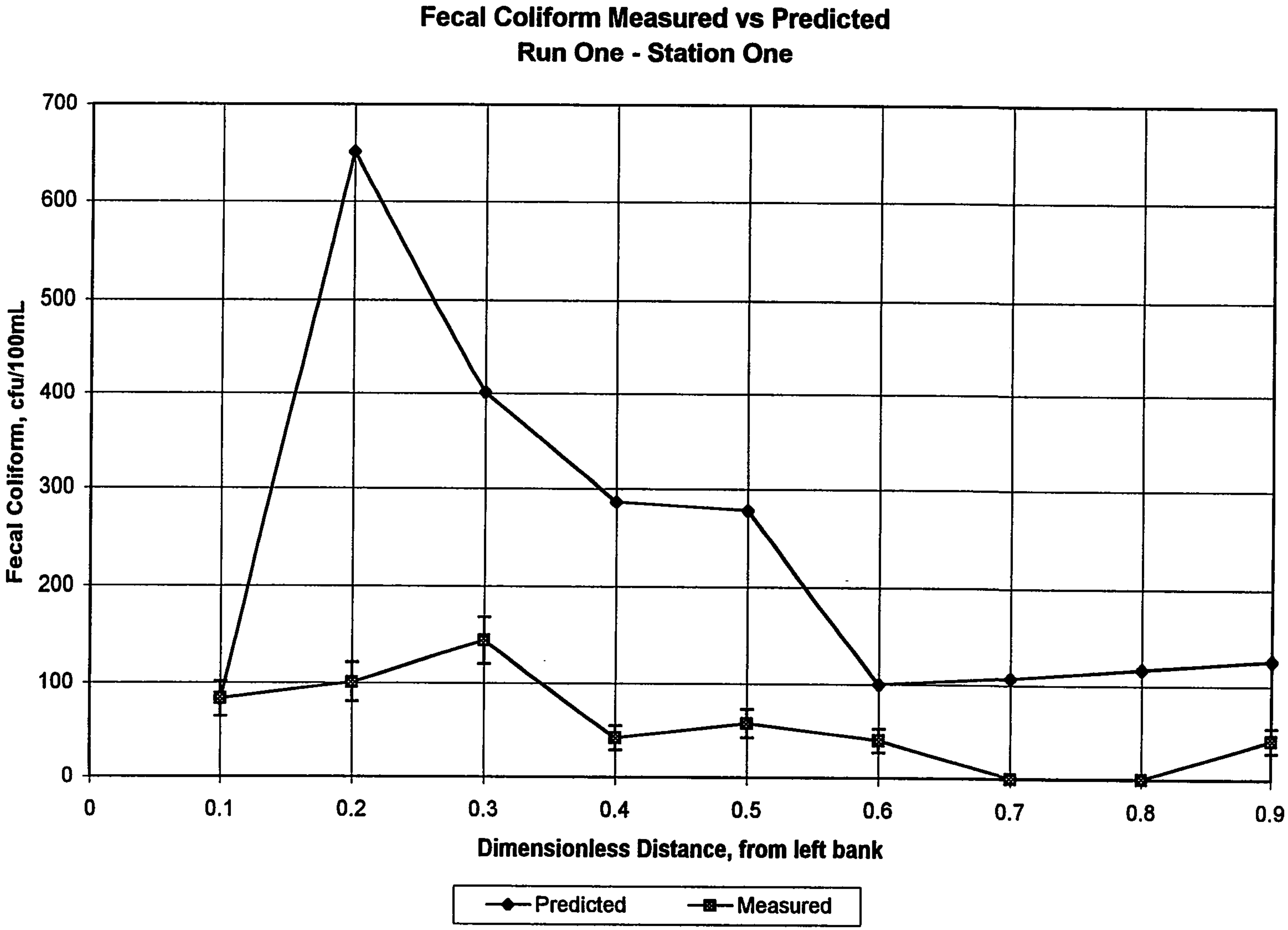
Fecal Coliform Measured vs Predicted
Run One - Station Five

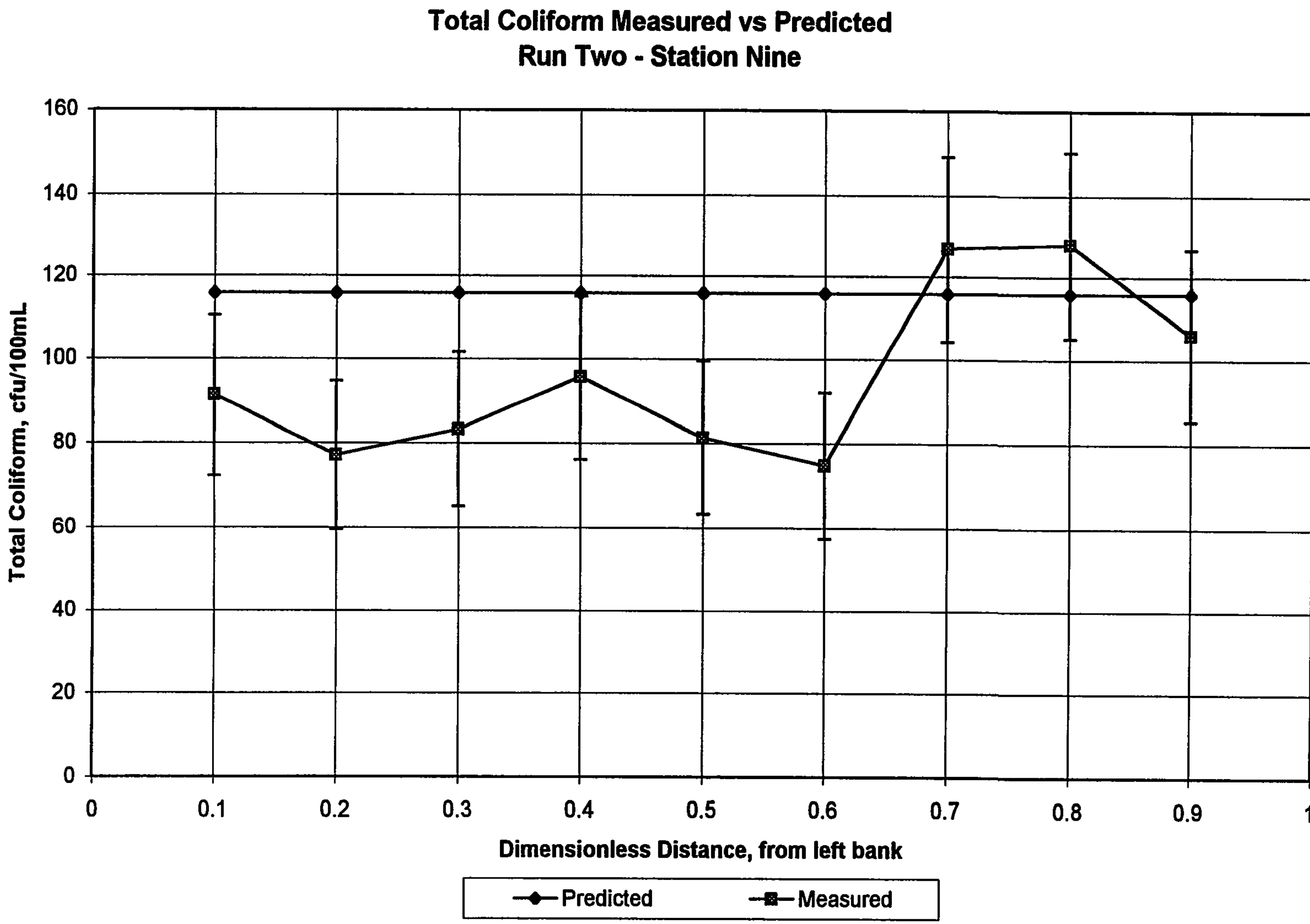


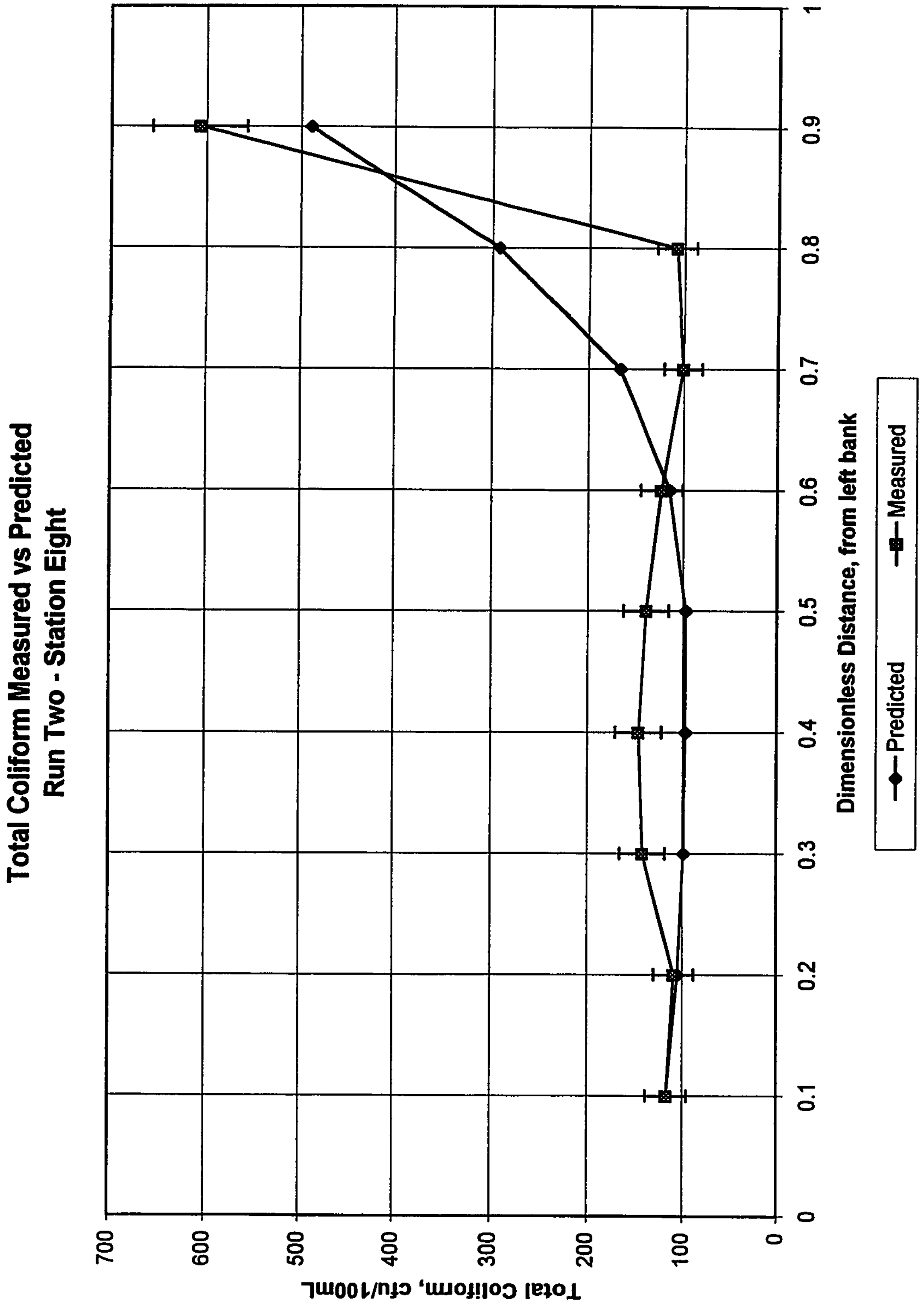

Fecal Coliform Measured vs Predicted
Run One - Station Four
Fecal Coliform, cfu/100mL
1600
1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured


Fecal Coliform Measured vs Predicted
Run One - Station Three
Fecal Coliform, cfu/100mL
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

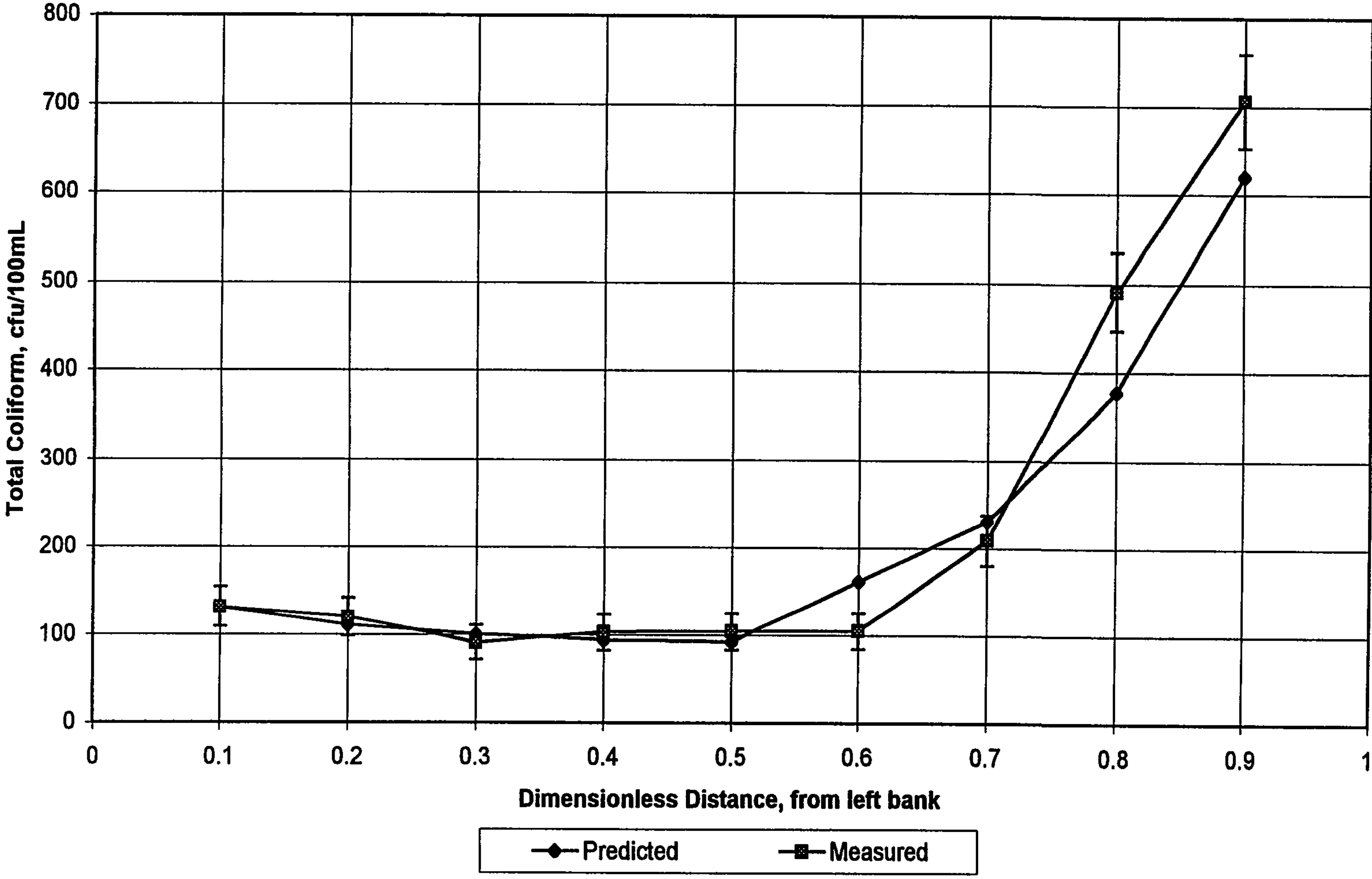

Fecal Coliform Measured vs Predicted
Run One - Station Two
Fecal Coliform, cfu/100mL
1000
900
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured


Fecal Coliform Measured vs Predicted
Run One - Station One
Fecal Coliform, cfu/100mL
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Dimensionless Distance, from left bank
—◆— Predicted
—▨— Measured

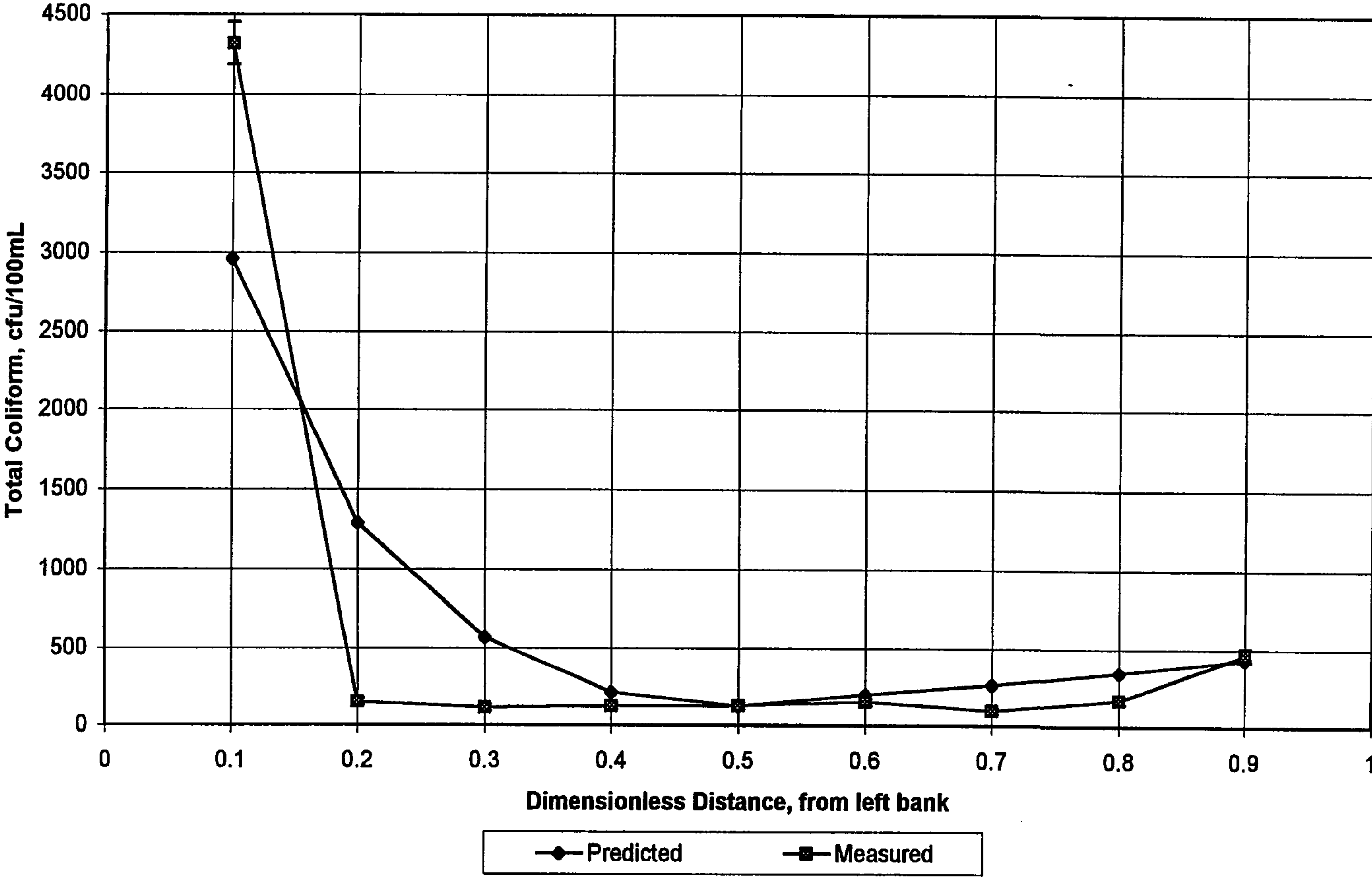

Total Coliform Measured vs Predicted
Run Two - Station Nine

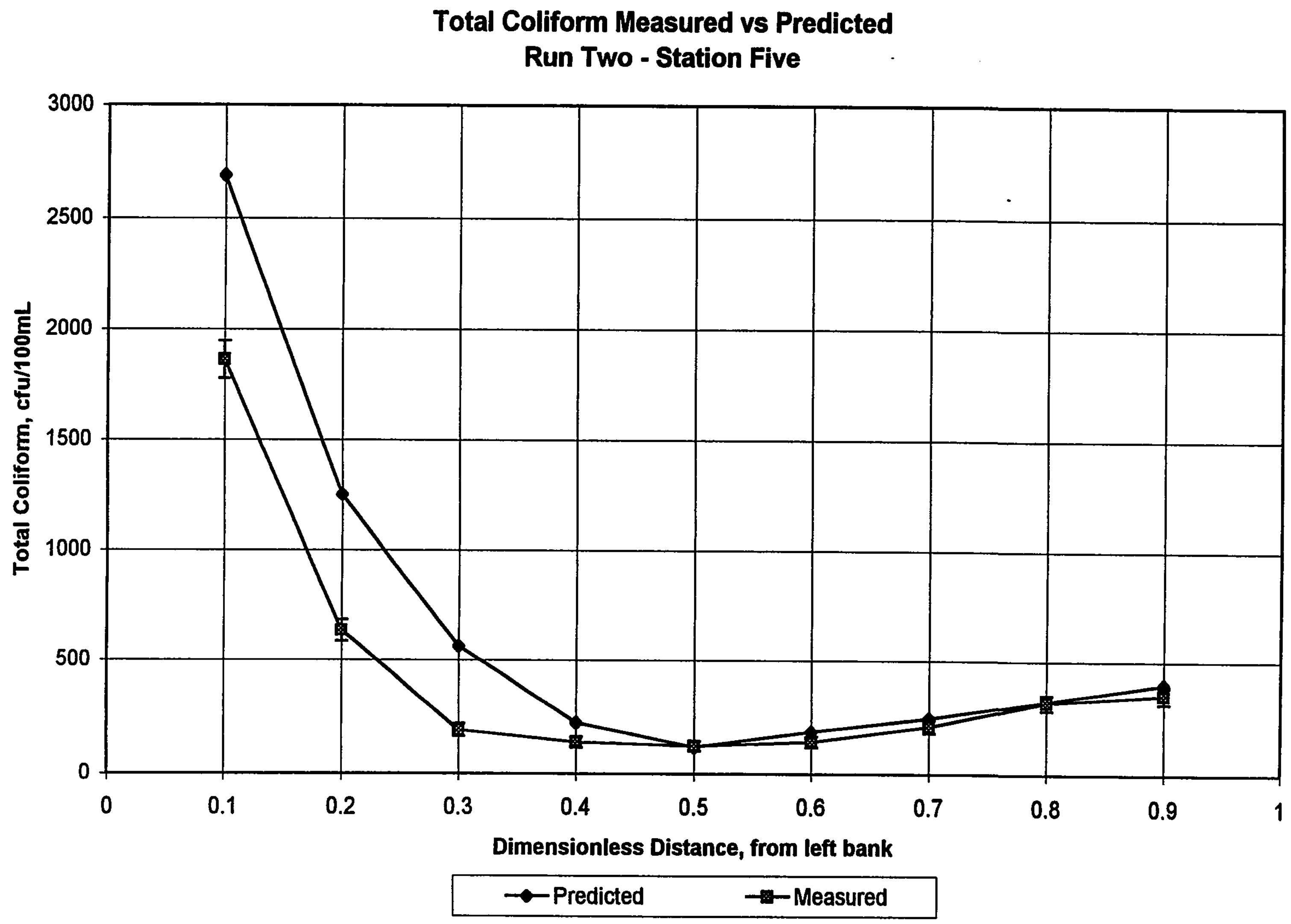

Total Coliform Measured vs Predicted
Run Two - Station Eight
Total Coliform, cfu/100mL
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

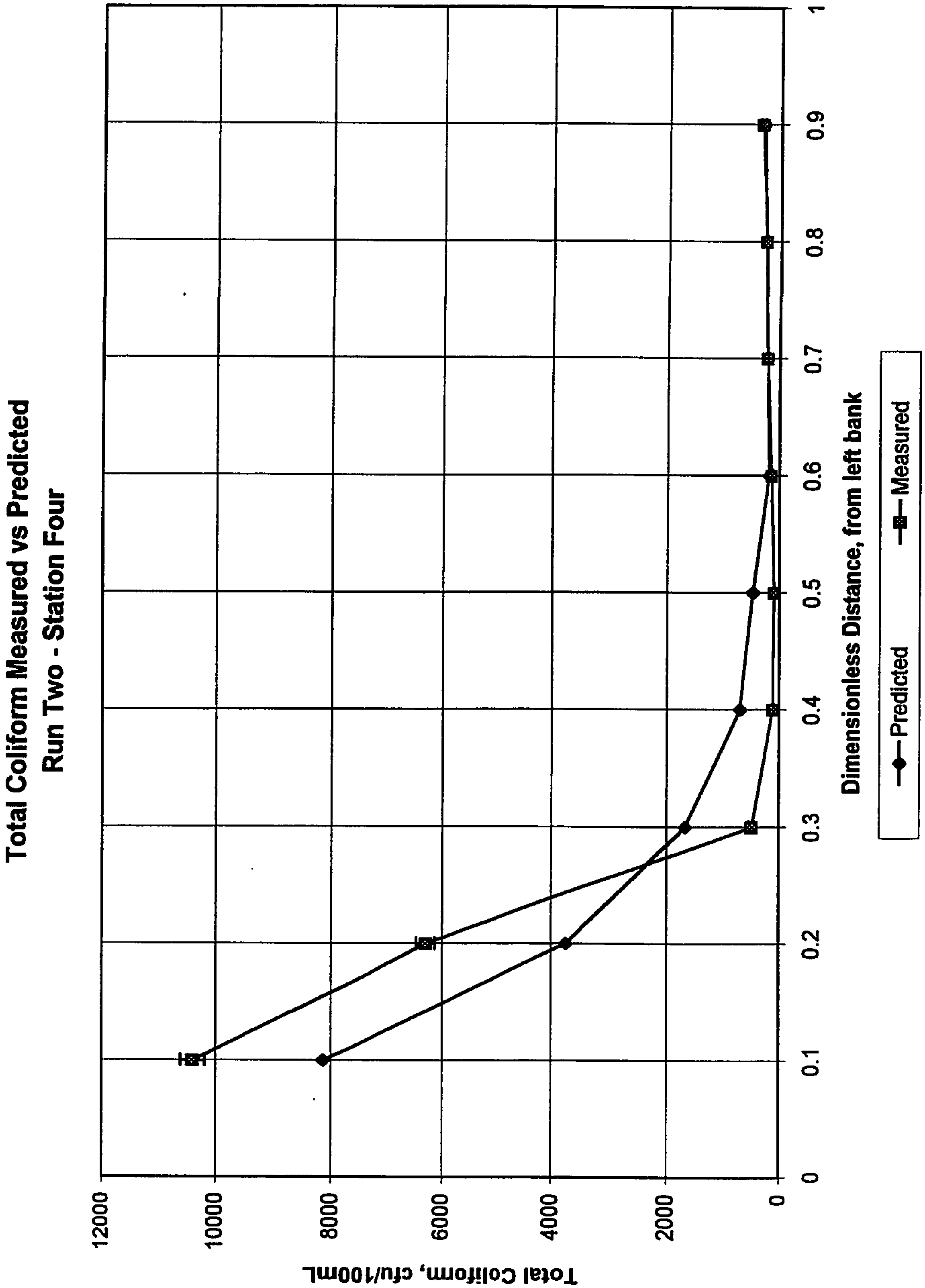
Total Coliform Measured vs Predicted
Run Two - Station Seven



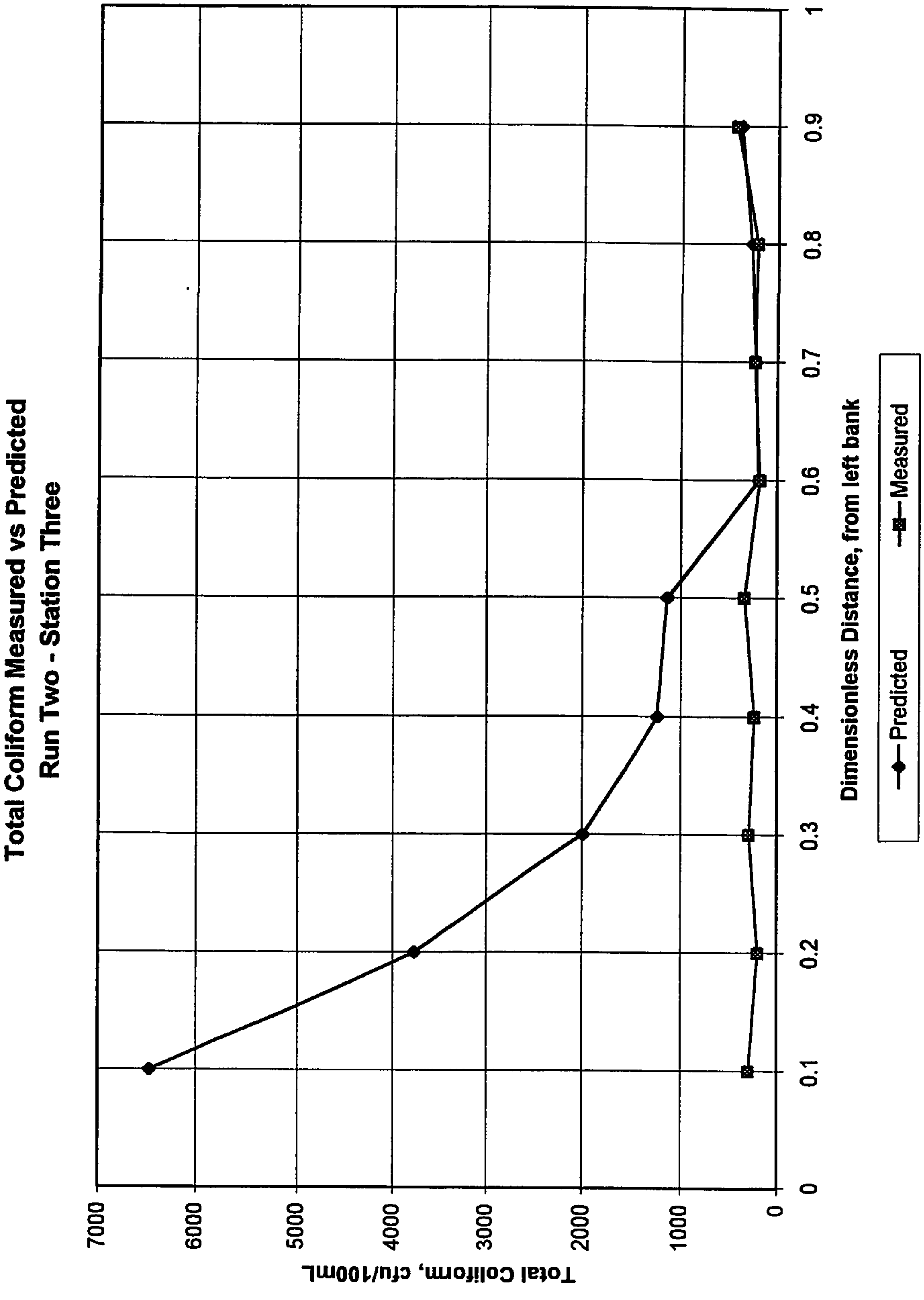
Total Coliform Measured vs Predicted
Run Two - Station Six



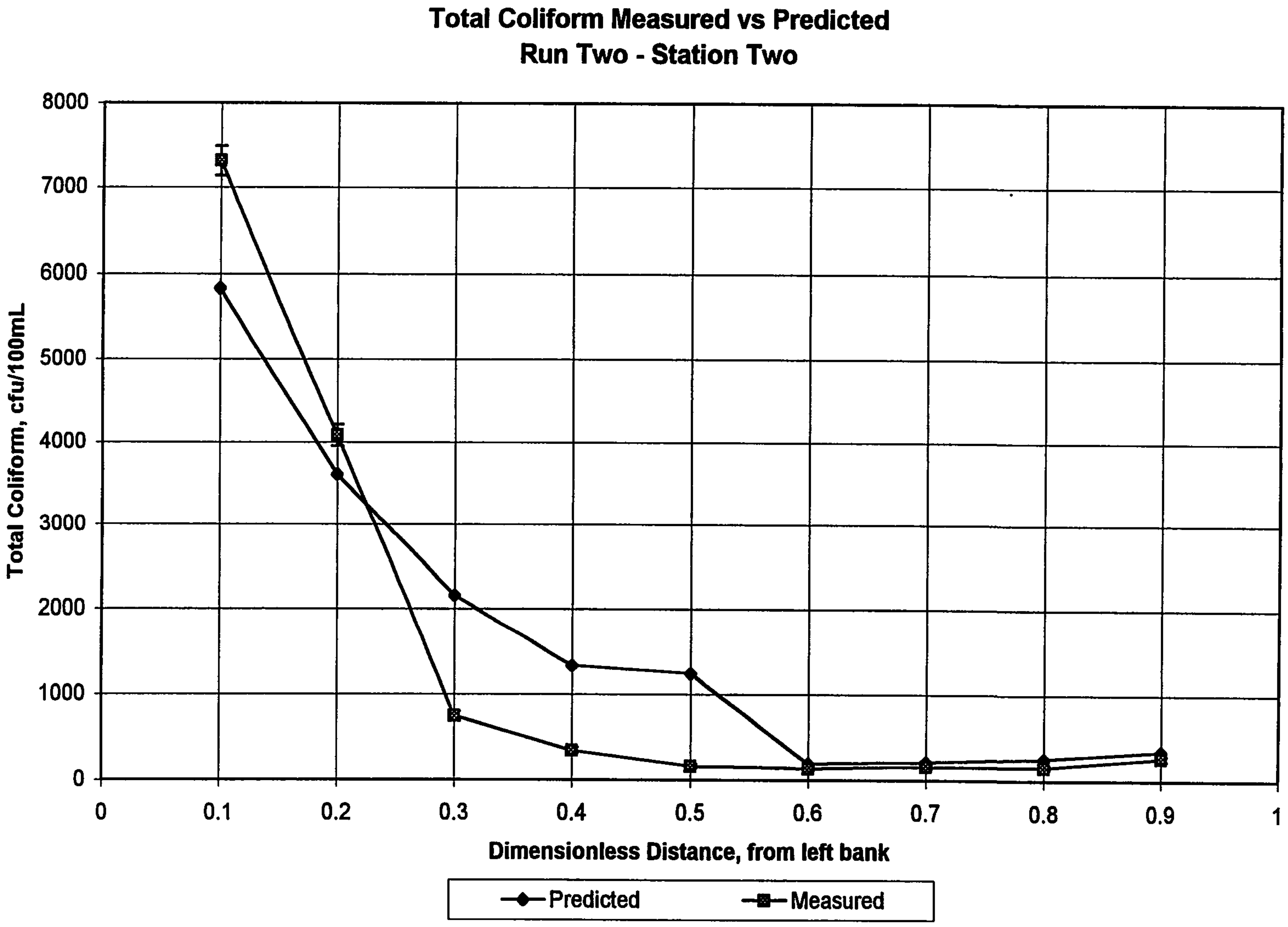

Total Coliform Measured vs Predicted
Run Two - Station Five
Total Coliform, cfu/100mL
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured



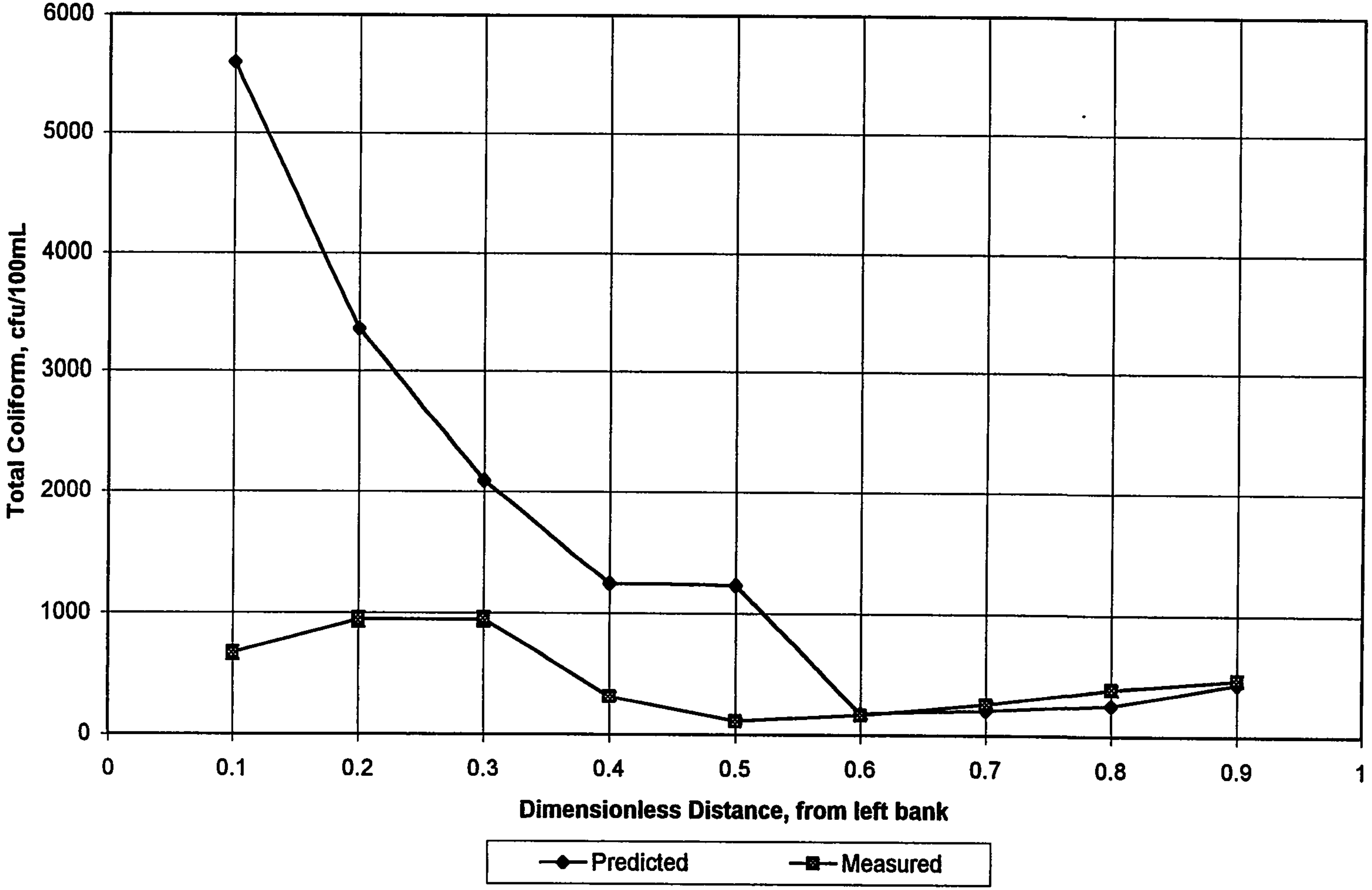
Total Coliform Measured vs Predicted
Run Two - Station Four

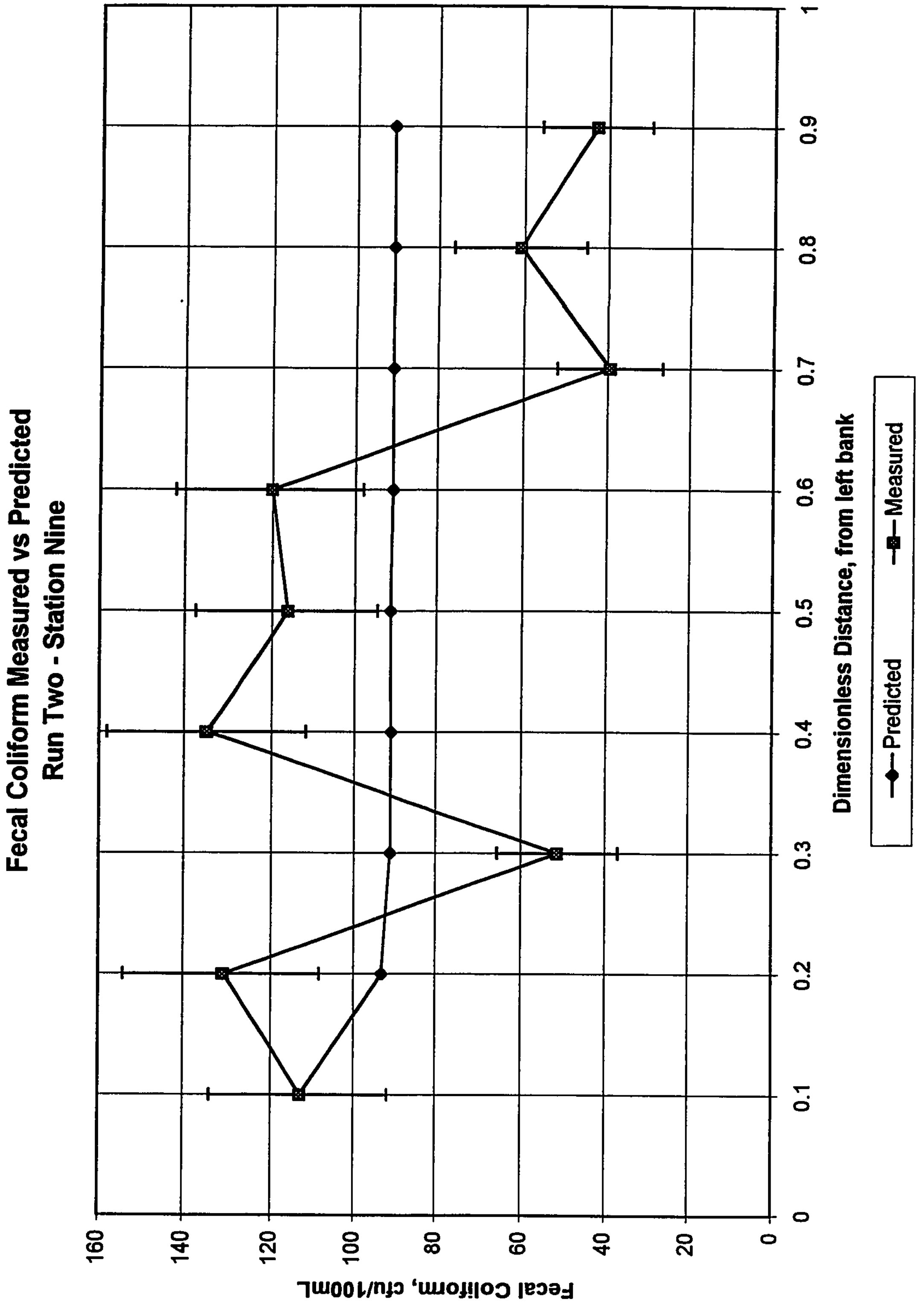


Total Coliform Measured vs Predicted
Run Two - Station Three

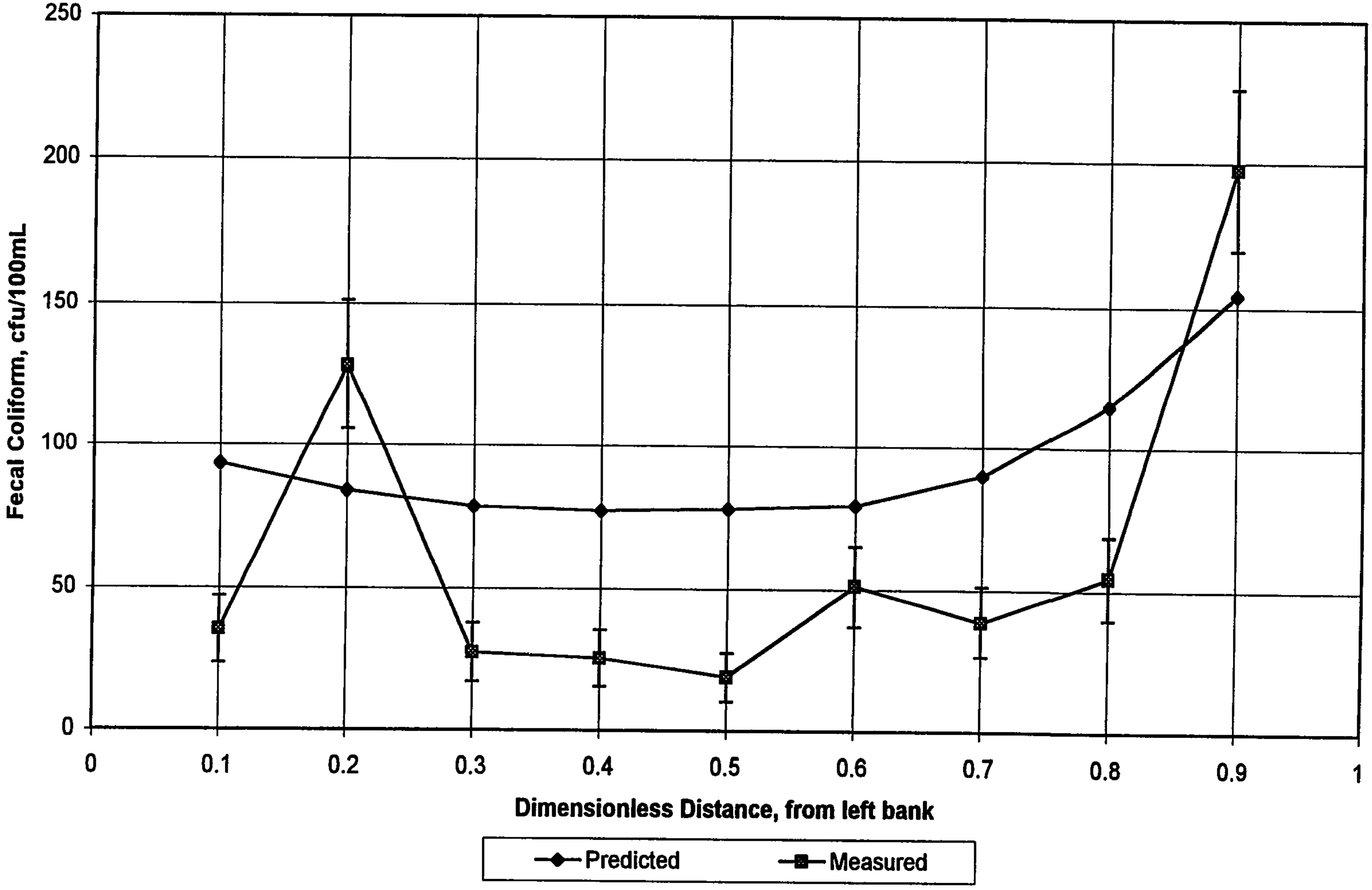

Total Coliform Measured vs Predicted
Run Two - Station Two
Total Coliform, cfu/100mL
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

Total Coliform Measured vs Predicted
Run Two - Station One

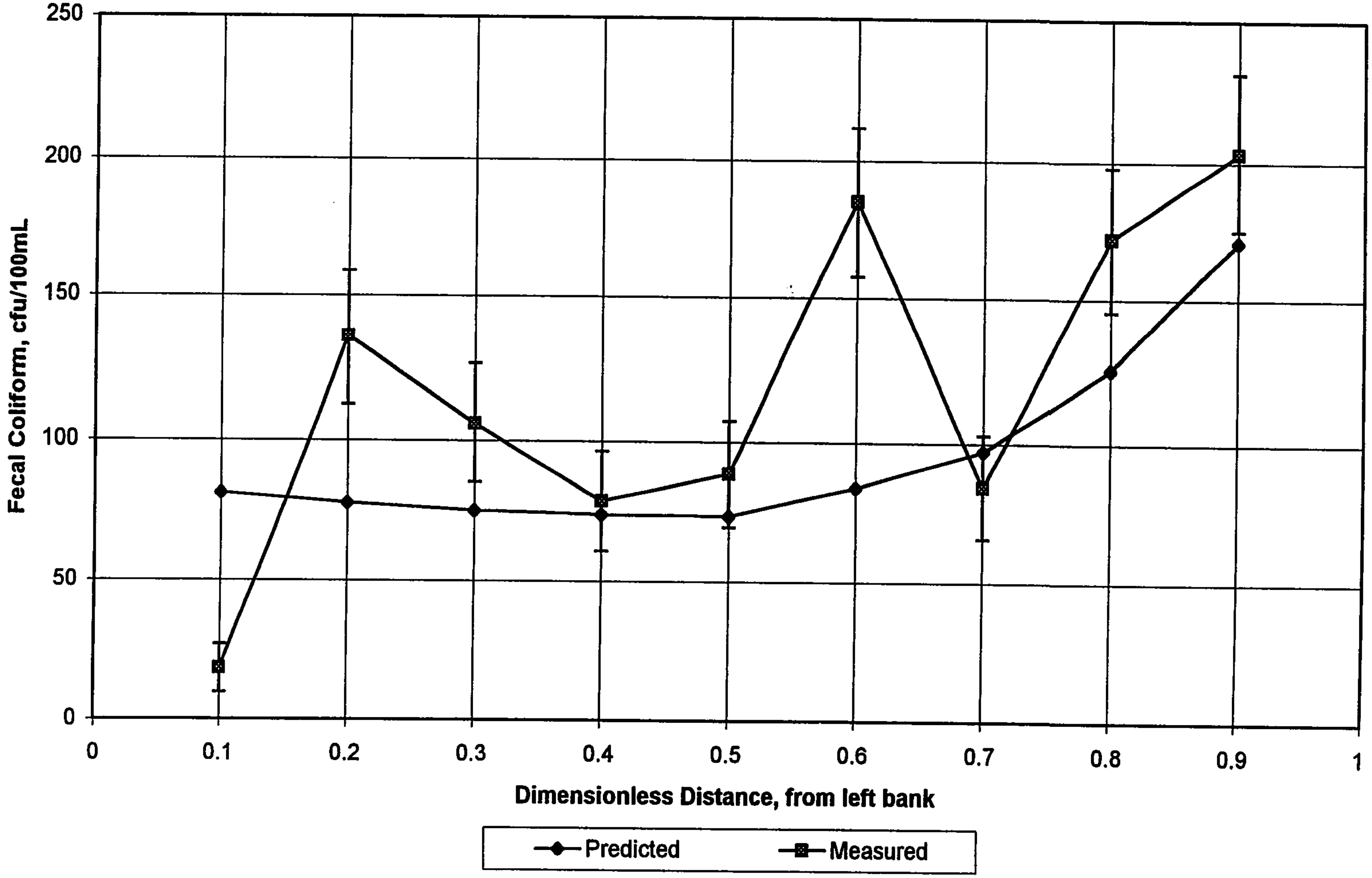


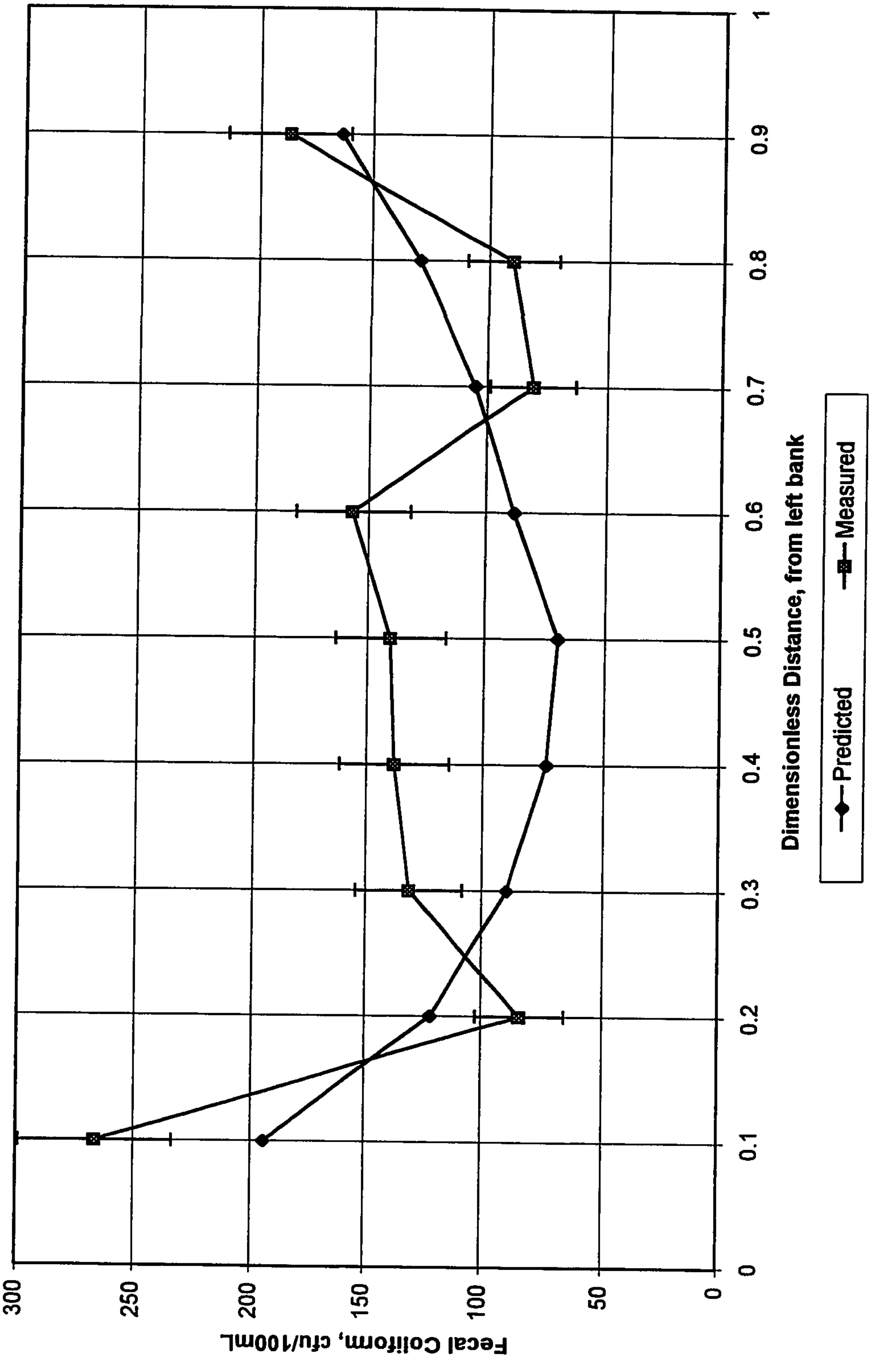

Fecal Coliform Measured vs Predicted
Run Two - Station Nine
Fecal Coliform, cfu/100mL
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

Fecal Coliform Measured vs Predicted
Run Two - Station Eight

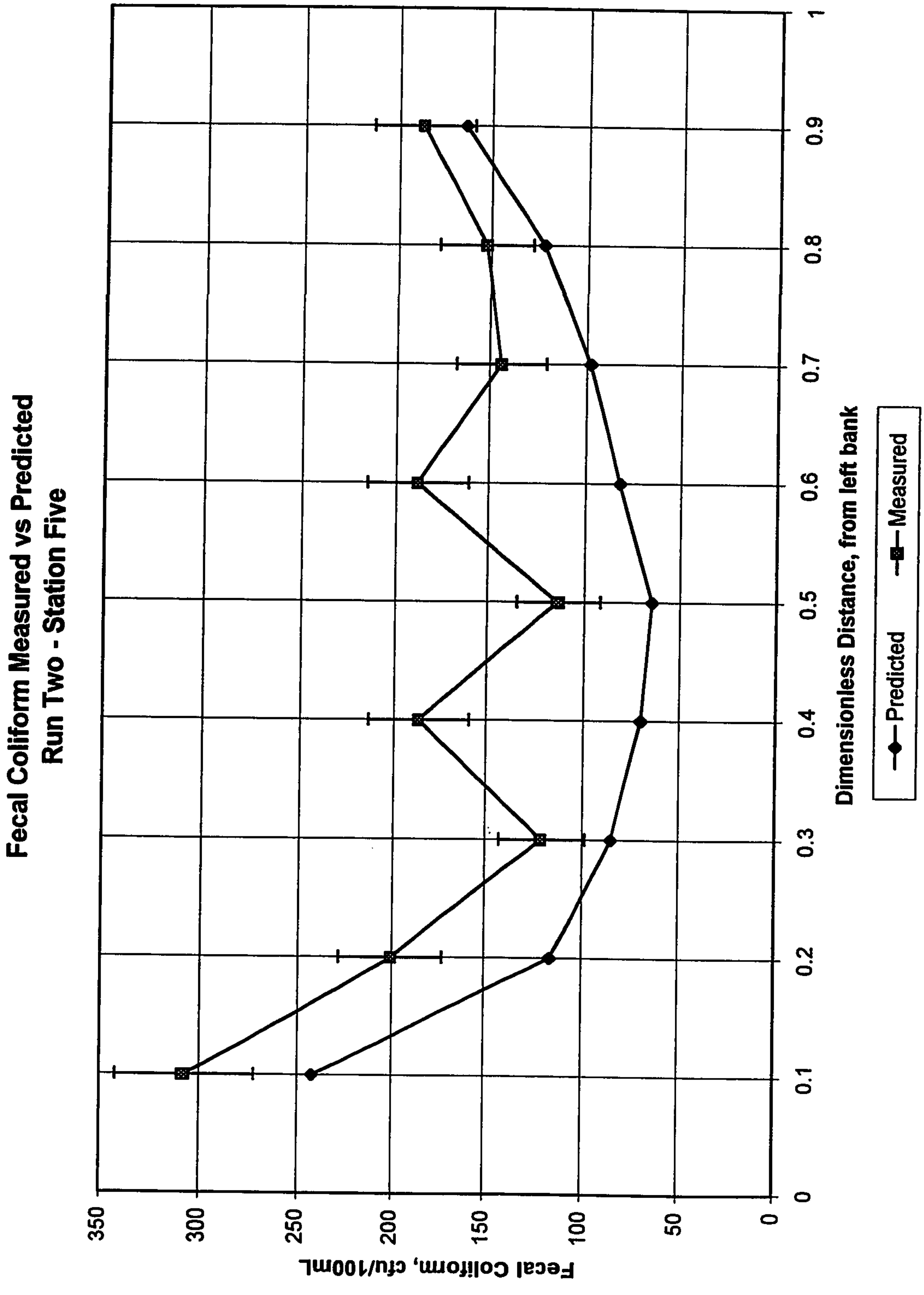


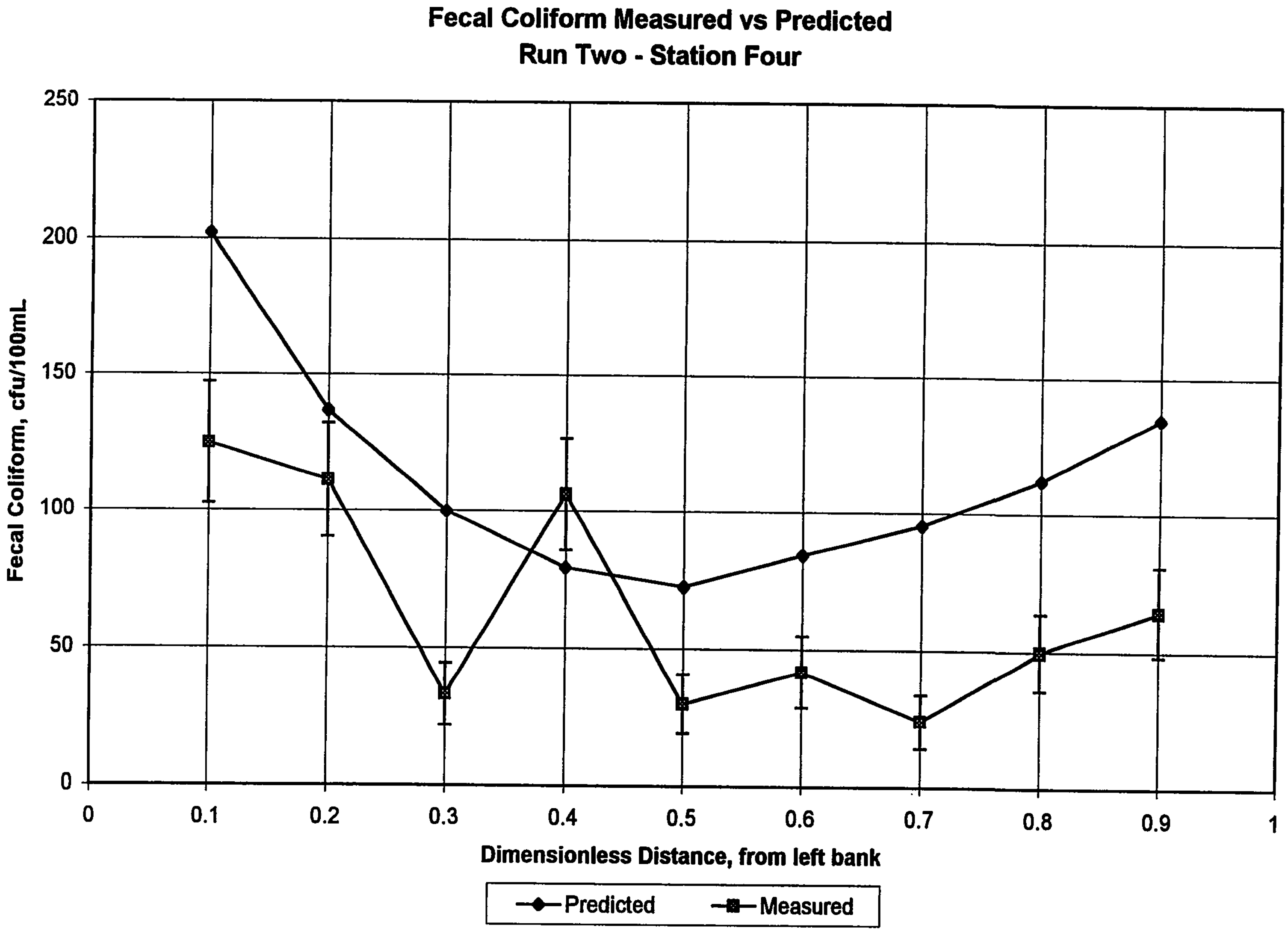
Fecal Coliform Measured vs Predicted
Run Two - Station Seven

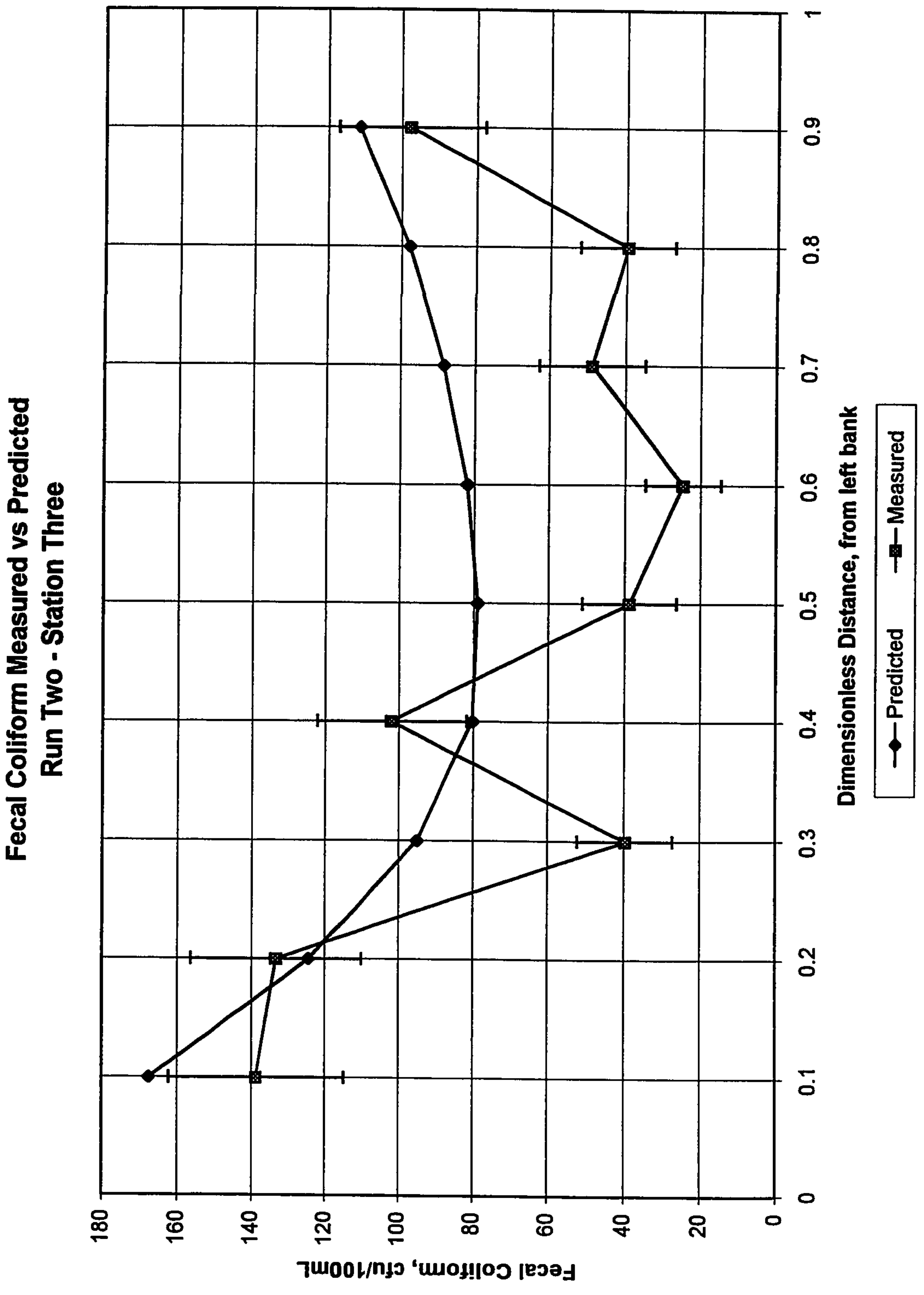




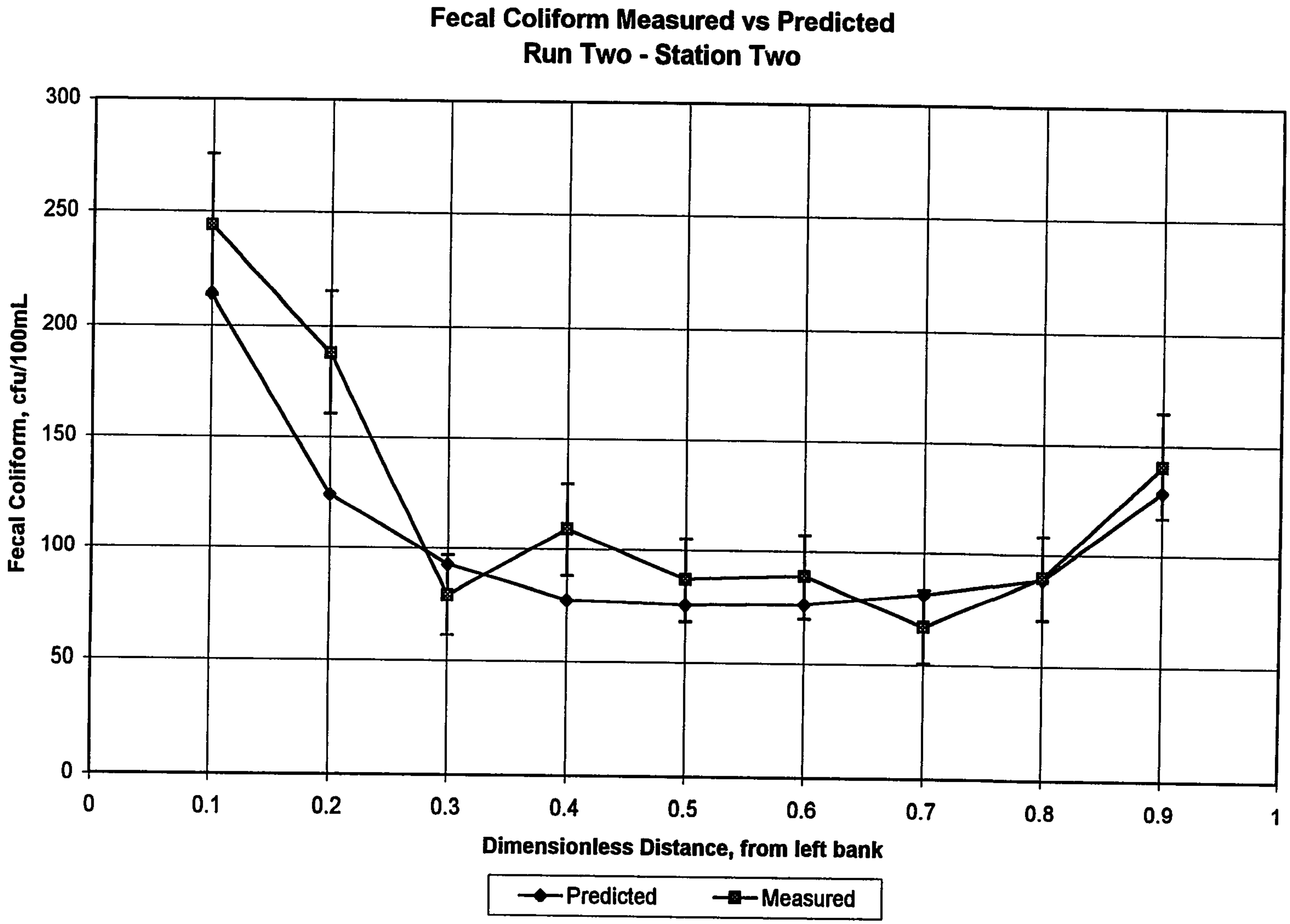
Fecal Coliform Measured vs Predicted
Run Two - Station Six

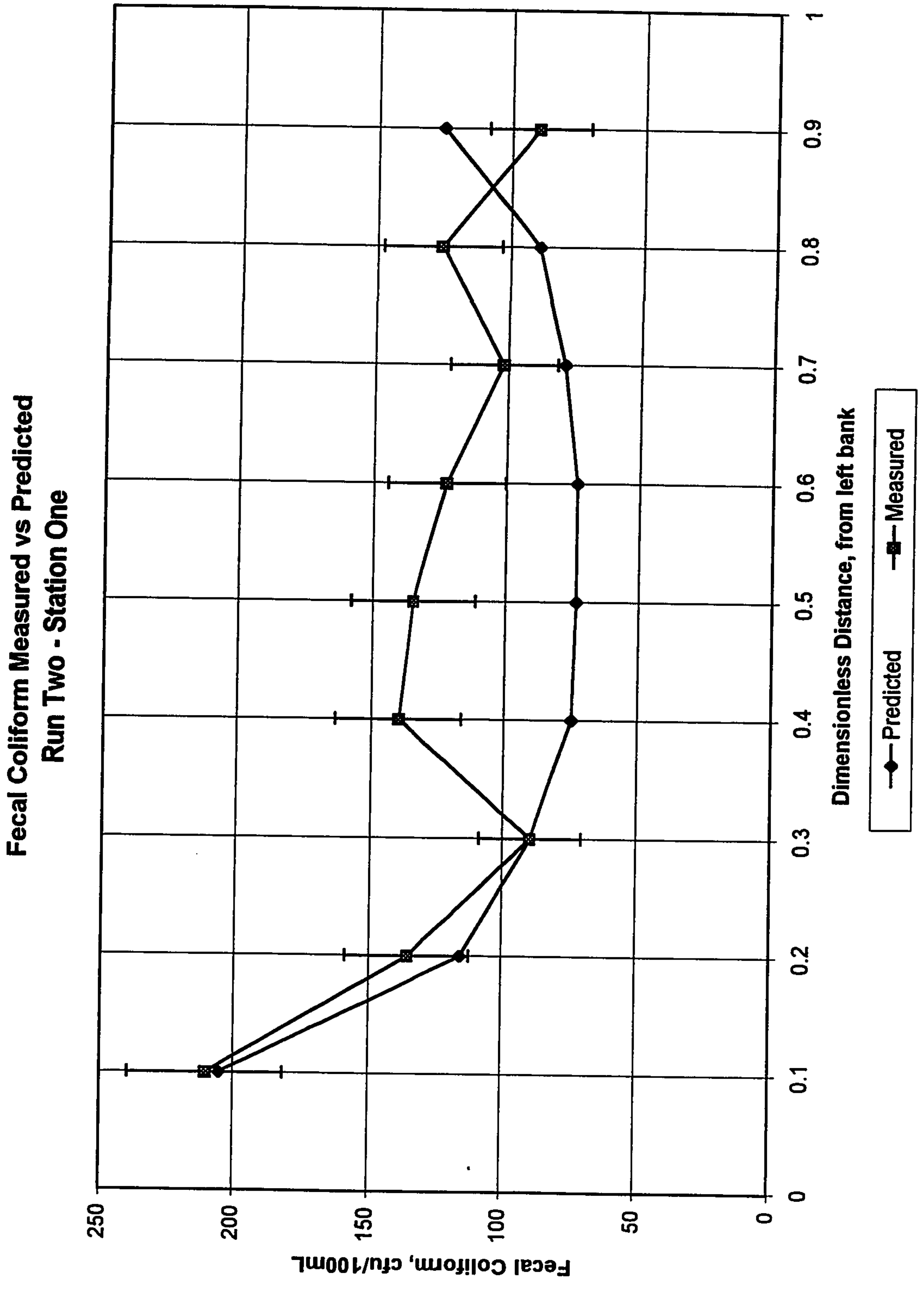

Fecal Coliform Measured vs Predicted
Run Two - Station Five
Fecal Coliform, cfu/100mL
0
50
100
150
200
250
300
350
Dimensionless Distance, from left bank
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Predicted
Measured


Fecal Coliform Measured vs Predicted
Run Two - Station Four
Fecal Coliform, cfu/100mL
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured



Fecal Coliform Measured vs Predicted
Run Two - Station Three

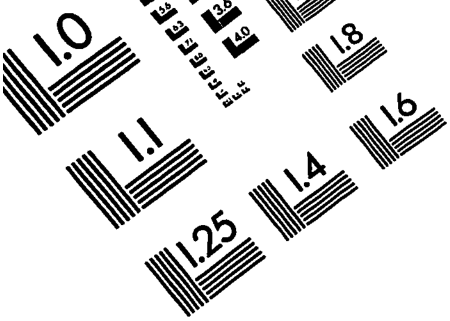

Fecal Coliform Measured vs Predicted
Run Two - Station Two
Fecal Coliform, cfu/100mL
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

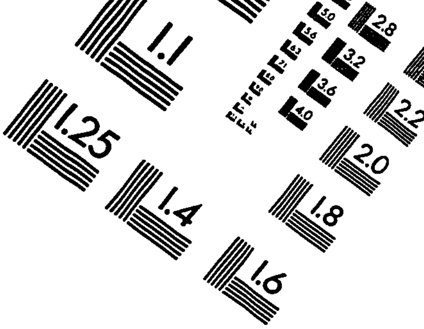

Fecal Coliform Measured vs Predicted
Run Two - Station One
Fecal Coliform, cfu/100mL
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dimensionless Distance, from left bank
Predicted
Measured

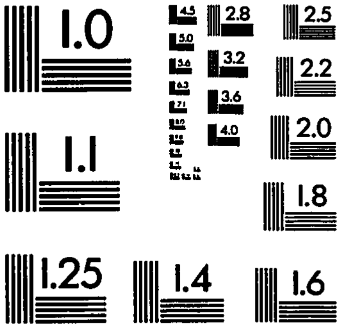
Appendix G Environment Canada Weather Data

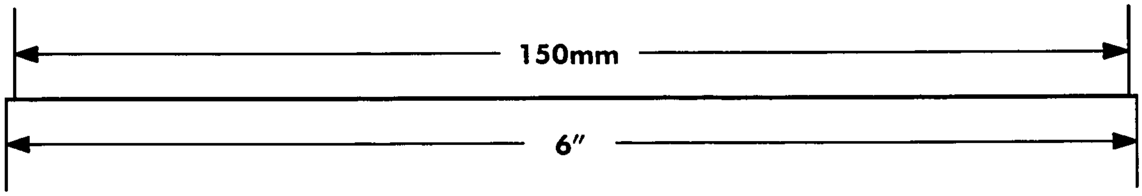
Environment Canada

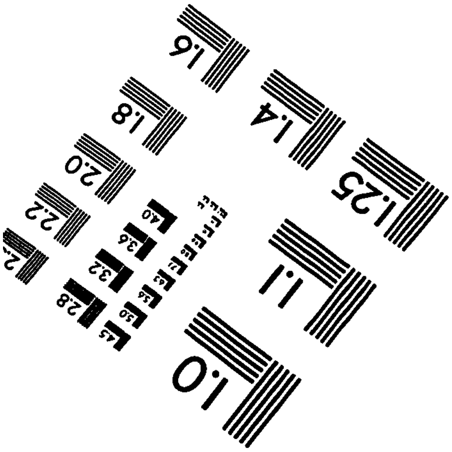
Date	Edmonton Municipal Airport (Environment Canada, 1996a)								Edmonton International Airport (Environment Canada, 1996b)							
	Lat: 53° 34'N			Long: 113° 31'		Elevation:	671 m		Lat: 53° 19'N			Long: 113° 35'		Elevation:	723 m	
	Temperature			Relative Humidity		Precipitation	Wind	Bright	Temperature			Relative Humidity		Precipitation	Wind	Bright
	max	min	mean	max	min	Rainfall	Avg Speed	Sunshine	max	min	mean	max	min	Rainfall	Avg Speed	Sunshine
	°C	°C	°C	%	%	mm	km/h	hours	°C	°C	°C	%	%	mm	km/h	hours
1-Aug-96	25.7	10.7	18.2	96	43		11.5	14.3	24.9	8.4	16.7	90	40		9.7	13.9
2-Aug-96	27.1	13.8	20.5	83	32	3.0	17.6	8.1	25.5	12.8	19.2	80	49	1.0	17.3	10.2
3-Aug-96	15.2	12.1	13.7	100	34	12.3	16.5	0.4	14.5	11.7	13.1	88	76	31.8	13.4	1.3
4-Aug-96	19.8	11.7	15.8	100	70	4.2	25.6	9.0	19.1	9.0	14.1	85	48	4.8	19.8	10.3
5-Aug-96	15.1	9.6	12.4	86	52	14.6	24.6	0.1	14.2	8.4	11.3	85	67	8.6	21.8	0.6
6-Aug-96	19.0	10.1	14.6	100	80	3.0	23.3	7.1	18.0	10.2	14.1	83	58	2.5	17.7	7.4
7-Aug-96	20.6	8.6	14.6	98	59		12.2	14.6	20.6	6.6	13.6	83	45		8.1	14.5
8-Aug-96	25.1	11.4	18.3	83	44		13.5	12.8	24.2	9.1	16.7	86	54		12.1	13.3
9-Aug-96	26.6	13.4	20.0	90	51		10.9	13.2	26.6	12.0	19.3	86	51		5.9	13.8
10-Aug-96	25.0	14.5	19.8	95	50		9.2	11.6	24.6	12.0	18.3	87	48		7.5	11.3
11-Aug-96	24.6	14.4	19.5	81	50	0.5	15.5	9.4	23.6	12.1	17.9	86	54		14.9	10.4
12-Aug-96	22.1	13.5	17.8	99	45	3.3	23.3	6.5	22.5	12.2	17.4	85	47	trace	19.4	7.7
13-Aug-96	24.0	11.4	17.7	86	53		11.7	14.2	23.8	8.2	16.0	79	44		7.1	14.2
14-Aug-96	27.0	14.5	20.8	74	40	trace	11.3	11.2	25.8	10.1	18.0	83	50	0.2	8.6	10.8
15-Aug-96	22.1	12.0	17.1	100	48	1.2	14.6	6.7	21.6	11.2	16.4	85	59	12.4	11.0	9.4
16-Aug-96	18.4	11.2	14.8	98	59	5.9	13.2	0.4	18.9	10.6	14.8	85	69	14.6	13.0	1.3
17-Aug-96	18.0	8.4	13.2	100	77	2.7	14.0	10.1	18.0	7.4	12.7	86	46	1.6	11.6	9.8
18-Aug-96	19.5	6.7	13.1	99	45		12.6	11.5	18.7	3.6	11.2	86	48	trace	9.9	12.5
19-Aug-96	20.8	8.5	14.7	93	52	trace	10.8	13.0	19.7	6.3	13.0	85	52	0.8	7.5	11.8
20-Aug-96	20.4	9.0	14.7	97	47	trace	14.6	12.6	19.9	6.1	13.0	87	39		8.9	13.5
21-Aug-96	20.6	8.7	14.7	85	37		12.9	7.6	20.5	4.5	12.5	83	34		7.9	8.8
22-Aug-96	23.0	9.5	16.3	93	36		7.7	12.8	22.8	6.9	14.9	82	41		6.4	13.0
23-Aug-96	28.0	11.5	19.8	82	42		11.2	12.9	27.4	8.3	17.9	80	41		7.5	12.9
24-Aug-96	22.2	11.6	16.9	88	40		10.4	11.1	21.9	11.7	16.8	83	50	1.4	6.6	11.5
25-Aug-96	25.3	10.3	17.8	79	49		5.5	11.8	24.3	9.1	16.7	82	51		3.8	12.9
26-Aug-96	30.0	12.3	21.2	99	46		6.8	12.5	29.0	8.8	18.9	87	30		4.6	12.8
27-Aug-96	29.3	13.5	21.4	98	37		8.1	11.1	28.1	9.8	19.0	84	38		8.3	11.6
28-Aug-96	30.6	12.8	21.7	100	35		13.5	11.2	28.5	9.6	19.1	86	48		11.3	11.6
29-Aug-96	28.1	18.1	23.1	59	34		15.4	11.7	27.8	13.2	20.5	78	46		11.3	11.6
30-Aug-96	29.6	14.5	22.1	96	49	0.8	10.3	9.4	28.3	14.6	21.5	83	50	0.8	7.6	9.5
31-Aug-96	23.2	9.4	16.3	99	45	0.3	14.7	8.4	22.3	6.9	14.6	84	36	0.2	11.4	8.5

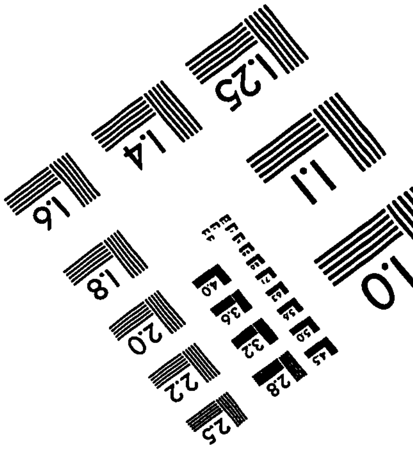












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