BACTERIAL INACTIVATION AND DISPERSION IN COLD OCEAN WATERS

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By

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ABSTRACT

For discharge of sewage into the ocean, two parameters need to be estimated, namely the T_{90} time and the diffusion coefficient (K). The T_{90} time is a measure of the rate of decay of the bacterial contained in the sewage, representing a 90% reduction from the initial value. The diffusion coefficient (K) is a measure of how fast a plume of sewage will grow or disperse once released into the ocean.

Both the T_{90} value and the diffusion coefficient (K) depend upon local conditions, such as latitude and sea conditions. Published values are based upon tests that generally have been carried out in lower latitudes and/or in temperate waters, and may not accurately predict sewage dispersion and bacterial decay in local waters. It was therefore important to determine acceptable values that can be used for sewage outfalls in Newfoundland.

It was the goal of this study to determine acceptable ranges for both bacterial decay and dispersion that accurately depict conditions encountered in Newfoundland, and to determine generally if water temperature appears to have a important effect on the T_{90} value.

For the T_{90} study, a clear lexan container was filled with sewage and allowed to float around in the ocean, thus simulating natural conditions as much as possible. Samples of the sewage were taken every half hour and analyzed for total coliform count. The results gave an average T_{90} time of 4 hours in the summer (July to September) and 6.5 hours in winter (September to March). These values agree with current literature.

For the dispersion study, several floats were released into the ocean and tracked over a period of time. Using analysis methods proposed by other authors, the rate of plume growth was determined. The values that were obtained estimated the rate of dispersion to be greater than anticipated. Weather and conditions of the test may have contributed to this. In addition, no significant difference was found between dispersion rates for both inshore and open ocean tests.

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First and foremost, I would like to thank my supervisor, professor Dr. J.J. Sharp, for his continual reinforcement, patience, advice and guidance in preparing this thesis. Without his help, this document would never have been complete.

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1.0 INTRODUCTION

There are many types of sewage disposal systems currently in operation, ranging from various types of treatment plants to long sea outfalls. However in all designs the treated sewage is released into the environment and in most of these systems the ocean is the best solution. Generally, ocean sewage disposal is the best choice and is an efficient system for environmental control of coastal city waste. As noted by the Institute of Sanitary Engineering (1982), the ocean is the most effective natural sewage treatment system of all water bodies.

Discharge of municipal waste into the ocean results in the contamination of the seawater surrounding the outfall. A plume of contamination may be transported a significant distance as it is dispersed and diluted, affecting the coastal environment in several potentially detrimental ways. With the growing concern about health risks associated with sewage disposal and damage to the ecology, great efforts have been made to improve the efficiency of these systems. Factors such as the rate of bacterial decay and dispersion are important to the total effectiveness of any treatment system. Bacterial decay results from two independent phenomena: dilution and inactivation. The first is due to mixing with the ocean and is dependent on the turbulent diffusion coefficient, which is a measure of how quickly the effluent will disperse due to turbulence in the ocean. The latter is mainly due to ultraviolet radiation and bacteriophages present in the water. This die-off is indicated by T_{90}, the time

required to reduce the bacterial population by 90%. Dispersion is the actual motion and spreading that a sewage field in the ocean undergoes.

It is through the proper understanding of dispersion and bacterial decay in a particular location that safe treatment of sewage is achieved. Since only the largest outfall constructions can afford a detailed study of dispersion and bacterial decay, most designs are developed using average test values from around the world. These values may not be appropriate to any one particular location, so it is important to understand dispersion and bacterial decay to make the necessary adjustments.

1.1 THE PROCESS OF OCEAN SEWAGE DISPOSAL

The process of sewage disposal by sea outfalls is a simple system compared to the more common sewage treatment plants. A sewage treatment plant will breakdown organic material in the sewage by physical and biological means, accelerating the decay and removal of bacteria and other harmful substances. This involves a great deal of processing and treatment of the sewage, both of which are costly and time consuming. Ocean outfalls on the other hand dispose of the raw sewage into the ocean where natural processes of purification act on the sewage, achieving the same result as the treatment plant. Bacteria and other microorganisms stabilize the wastes in the same manner as a treatment plant. Sharp (1991)

explains that this system is designed to disperse the waste matter for effective treatment without degrading the natural receiving water quality. To ensure natural purification, ocean outfalls rely on good mixing with receiving waters to guarantee an adequate supply of dissolved oxygen so purification can take place without reducing dissolved oxygen concentrations to unacceptable levels. In a treatment plant, the same purification process takes place in enclosed basins.

A properly designed outfall includes a primary treatment stage to break up the faecal matter. This usually consists of a series of screens that would catch large objects and undesirable wastes in the raw sewage (ie. sticks, plastic). The waste is then released through a submerged pipe discharging far offshore through one or more outfall ports, known as diffusers. The distance, depth and number of ports are dependent on the effluent flow and the nature of the receiving water. Figure 1.1 shows a typical layout for a small ocean outfall.

The sewage released through the diffuser of an outfall can rise to the water surface or become trapped at some intermediate depth, depending on the stratification of the water column. Along its path toward the level of equilibrium, the sewage mingles with sea water and undergoes an initial dilution. The diluted sewage is then carried away by sea currents and the dilution process continues along its path but at a lower intensity.

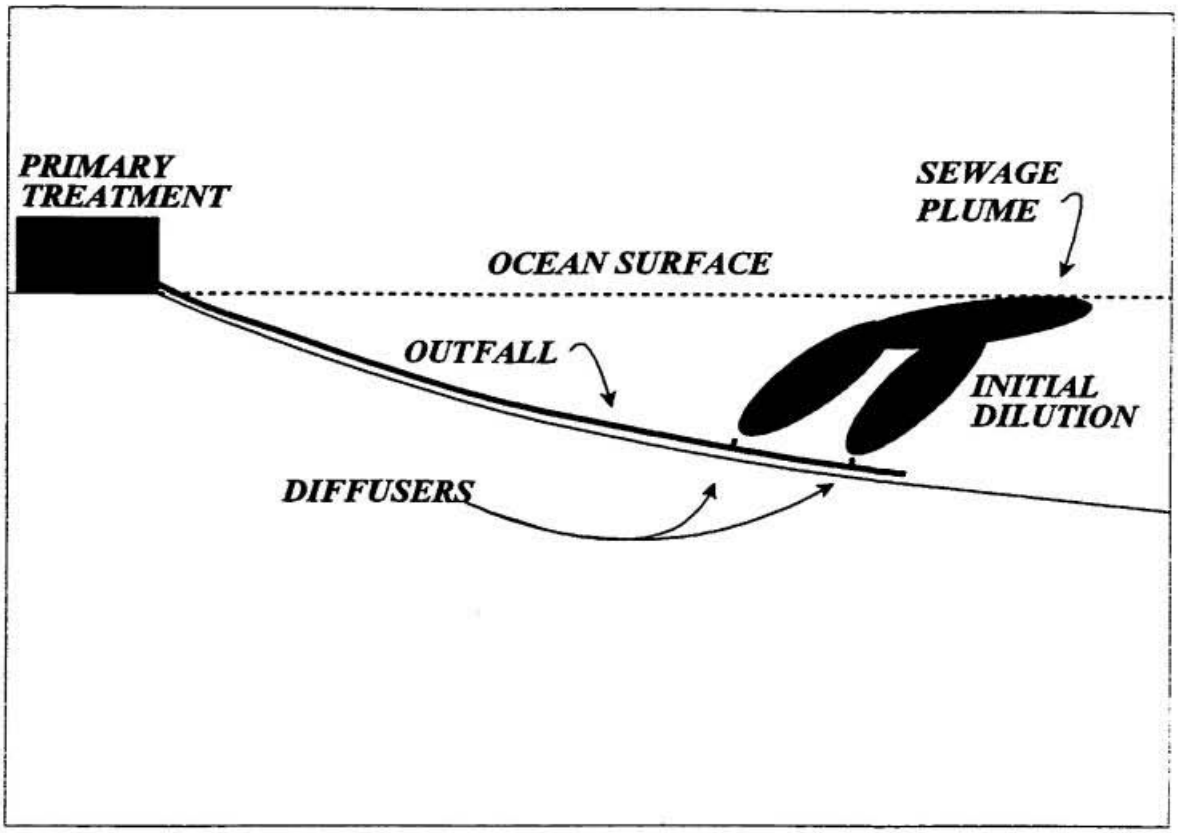


Figure 1.1 Typical Ocean Outfall Method

1.2 DISPERSION PROCESS

Once the initial dilution due to the mixing with the ocean water and formation of a sewage field has occurred, the effluent is subjected to further diffusion and transport in the ocean. This process is known as secondary dispersion.

The process contributing to the secondary dispersion involves both an advective component (which is a transport process) and a diffusive component (which is a mixing and a growth

process). The National Water and Soil Conservation Authority (1985), has classified large scale movements with respect to the size of the sewage field as transport, while the smaller turbulent movements as eddy diffusion.

A sewage field is moved by currents in the ocean. Clearly this is advection. However, this current may be part of a very large eddy the scale of which is several times larger than that of the diffusing patch. If the patch is being advected by the local part of the larger system, then the larger eddy cannot be causing growth of the field. Therefore it is possible to make the generalization that the eddies that influence the spread of a substance are only those that have a scale smaller than the size of the patch. As the surface plume grows in size the larger scale eddies, which at first merely move plume elements, gradually become active in the mixing process. (See Figure 1.2.) Thus the rate at which effluent constituents spread depends on the relative size of the surface plume elements compared to the scale of the mixing mechanisms operating on it. The more eddying in the patch, the faster the spread of the patch and the higher the rate of diffusion. This rate of diffusion is indicated by a coefficient of diffusion (D for molecular and K for turbulent flow).

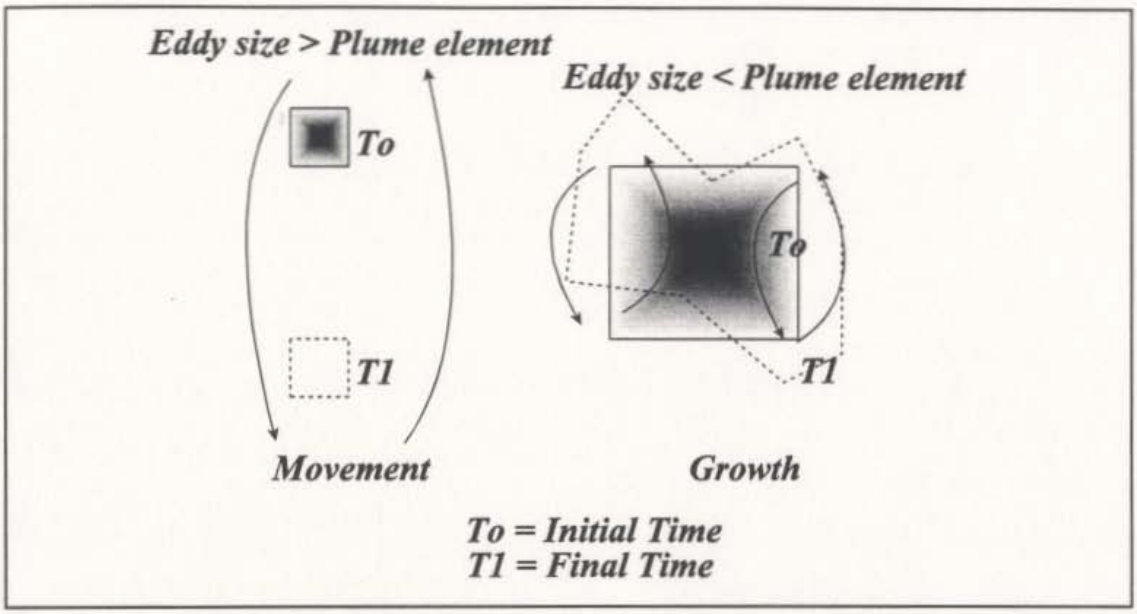


Figure 1.2 - Eddy Size vs Plume Element

1.4 BACTERIAL INACTIVATION

1.4.1 GENERAL

In addition to the physical dispersion of a wastewater field, as it moves away from the discharge zone, various non-conservative constituents in the effluent will be subject to further biological or chemical decay.

Once sewage is discharged into the ocean, the additional reduction in bacteria is due to a loss

of viability which depends on causes such as: solar radiation, pH, predation by other organisms, osmotic stress (moving from fresh to saline waters), degree of treatment of the effluent, presence of organic material, water temperature, chemicals and turbidity of the receiving waters. Other environmental factors which influence the inactivation rate are: effluent field and receiving water clarity, and nutrient deficiencies.

1.4.2 PATHOGENS AND INDICATOR CONCEPTS

Sewage contains many different microorganisms, some of which cause illness or diseases in humans. These are known as pathogens. The effect of these varies greatly with the state of community health and the nature and degree of sewage treatment. Pathogens can infect both recreational water users and those consuming shellfish.

Pathogens include the categories below:

1) Bacteria - are single celled microorganisms and are the lowest form of life capable of synthesizing protoplasm from the surrounding environment. Among other diseases cholera is transmitted by these organisms.

2) Viruses - are the smallest biological structures known to contain all the genetic information necessary for their own reproduction. Waterborne viral pathogens are known to

cause poliomyelitis and infectious hepatitis.

3) Protozoa - are unicellar organisms more complex in their functional activity than bacteria or viruses. Protozoal infections are usually associated with gastrointestinal disorders.

4) Helminths - are parasitic worms that use animals as their host.

To contain the risk of contracting pathogenic diseases, various public health and water resources agencies have developed microbiological guidelines and standards for receiving waters. Tchobanoglous (1985), has noted that while the most logical approach would be to test for these pathogens directly this would not provide the necessary degree of protection. Also some pathogens are often absent except when an epidemic occurs in the community. This has led to the use of microbial indicators as a surrogate for pathogens. The presence and degree of faecal contamination can be easily and routinely established by micro-organisms such as the coliform group, which are normally present in faeces in large numbers. A high concentration of coliform bacteria might also indicate a high concentration of pathogens.

1.4.3 FAECAL INDICATOR CONCEPTS

The traditional and most used indicator is the coliform group of bacteria. They are prevalent

in sewage, meatworks wastes and occur in runoff from pastures. Composed of several strains of bacteria, these organisms are found exclusively in the intestinal tract of warm-blooded animals and are excreted in large numbers with faeces. (See Table 1.1.) Faecal coliform organisms are nonpathogenic and are believed to have a longer survival time outside the animal body than do most pathogens. Because the die off rate of faecal coliforms is logarithmic, the number of surviving organisms may be an indication of the time lapse since contamination. This makes it possible to predict microbial contamination and hence be in a position to ascertain the health risk.

Table 1.1 - Typical concentrations of faecal indicator bacteria per 100 ml (Gelreich, 1978)

Wastewater	Total Coliforms	Faecal Coliforms
Raw Sewage	22×10^6	8×10^6
Meatworks	1×10^8	4.2×10^7

1.5 OBJECTIVES OF THIS STUDY

Both the T_{90} value and the diffusion coefficient (K) depend upon local conditions, such as latitude and sea conditions. Published values are based upon tests that generally have been carried out in lower latitudes and/or in temperate waters, and may not accurately predict sewage dispersion and bacterial decay in local waters. It is therefore important to determine acceptable values that can be used for sewage outfalls in Newfoundland. In addition there

is little information on the effect of cold water temperature on bacterial decay .

It is the goal of this study to determine acceptable ranges for both bacterial decay and dispersion that accurately depict conditions encountered in Newfoundland, and to determine generally if temperature appears to have an important effect on the T_{90} value.

2.0 BACKGROUND THEORY

In this section the equations and concepts underlying molecular and turbulent diffusion will be presented. Molecular diffusion by itself cannot describe the turbulent motions found in the ocean but can be used as a building block upon which specialized theories can be developed. In addition, the mathematical principles for bacterial inactivation will also be presented. It should be noted here that these mathematical principles and underlying concepts are primarily based upon the work of Fisher (1979) and the following explanations are a summary of this work.

2.1 THE MOLECULAR MIXING PROCESS

The process of molecular mixing can be described by Fick's Law, which states that the mass of a solute crossing a unit area per unit time in a given direction, is proportional to the gradient of solute concentration in that direction. Stated mathematically:

$$q = -D \frac{\partial C}{\partial X} \qquad 2.1$$

where:

q is the solute mass flux (i.e. mass flow per unit area)

C is the mass concentration of diffusing solute

D is the coefficient of proportionality, termed the coefficient of molecular diffusion. The minus sign indicates that transport occurs from high to low concentrations.

$\partial c/\partial x$ is the concentration gradient.

In other words the flux is the movement of mass past a unit area in unit time under the influence of a concentration gradient. The conservation of mass principle leads to a second relationship which is true despite the transport process. Figure 2.1 illustrates a one-dimensional transport process in which mass is being transferred in the x direction.

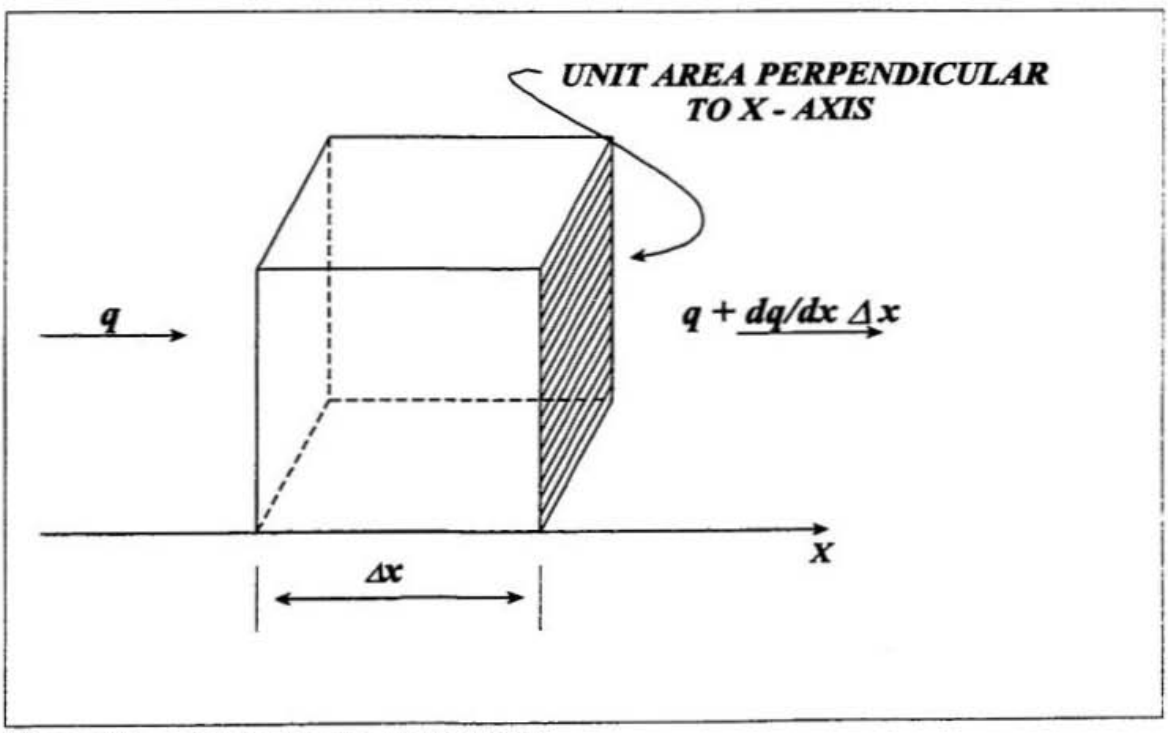


Figure 2.1 - One Dimensional Transport

Two parallel surfaces of unit area are drawn perpendicular to the x axis and separated by distance Δx. If C is the mass per unit volume at the point x at time t, then there is a mass $C\Delta x$ in the line segment bounded by the parallel planes. Since molecules are passing in and out of the volume defined by each bounding surface, there is a time rate change of mass in the volume given by $(\partial c/\partial t)\Delta x$.

The time rate of change must be equal to the difference in the flux or rate of passage of molecules through each surface. Suppose the mass rate of flow per unit area across the surface located at x is q then the mass rate of flow per unit area across the surface at $x + \Delta x$ is $q + \partial q/\partial x \, \Delta x$, and the difference between the two is $\partial q/\partial x \, \Delta x$. This is the net rate of change of mass flow out of the volume in the x direction. This difference must be equal to the rate of change of mass in the volume in order to satisfy the conservation of mass. Equating the net flow out of the volume to the rate of change in mass gives

$$\frac{\partial q}{\partial x}\Delta x + \frac{\partial C}{\partial t}\Delta x = 0 \qquad \textbf{2.2}$$

Eliminating the Δx term

$$\frac{\partial q}{\partial x} + \frac{\partial C}{\partial t} = 0 \qquad \textbf{2.3}$$

Differentiating equation 2.1 with respect to x and substituting in equation 2.3 gives the one dimensional diffusion equation.

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad \textbf{2.4}$$

A similar analysis in three dimensions would (assuming the coefficient of proportionality is constant in all directions) lead to

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right) \qquad \textbf{2.5}$$

The above equation is written for diffusion in three dimensions x, y and z, and is important in describing how mass can be transferred by a Fickian process. This equation is valid only for fluids with a zero mean velocity. (i.e. stationary) and does not account for mixing due to eddies. It cannot account for turbulent diffusion in the ocean.

2.1.1 THE COEFFICIENT OF PROPORTIONALITY

In the preceding section the rate of change of concentration with respect to time was related to the rate of change of concentration with respect to location through the coefficient of proportionality (D). D can be expressed as

$$D = \frac{1}{2}\frac{\partial \sigma^2}{\partial t} \qquad 2.6$$

where σ^2 is the variance of the concentration distribution.

As a proof of this consider the variance of a concentration distribution defined as follows

$$\text{zeroth moment} = M_0 = \int_{-\infty}^{\infty} C\,dx \qquad 2.7$$

$$\text{first moment} = M_1 = \int_{-\infty}^{\infty} xC\,dx \qquad 2.8$$

$$\text{second moment} = M_2 = \int_{-\infty}^{\infty} x^2C\,dx \qquad 2.9$$

Where C is the concentration at position x at time t.

The mean (μ) and the variance (σ^2) of a distribution are found from the moments by the equations

$$\mu = \mathbf{M_1 / M_0} \qquad \textbf{2.10}$$

$$\sigma^2 = \int_{-\infty}^{\infty} (\mathbf{x} - \mu)^2 \, \mathbf{C} \, \mathbf{dx} / \mathbf{M_0} = (\mathbf{M_2 / M_0}) - \mu^2 \qquad \textbf{2.11}$$

Multiplying equation 2.4 by x^2 and integrating over the range $x = -\infty$ to $x = +\infty$ gives

$$\int_{-\infty}^{\infty} \frac{\partial C}{\partial t} x^2 dx = \int_{-\infty}^{\infty} D x^2 \frac{\partial^2 C}{\partial x^2} dx \qquad \textbf{2.12}$$

On the left hand side the time derivative can be taken outside the integral, while the right hand side can be integrated by parts. This gives

$$\frac{\partial}{\partial t} \int_{-\infty}^{\infty} C x^2 dx = 2D \int_{-\infty}^{\infty} C dx \qquad \textbf{2.13}$$

A similar analysis will show that $(\partial/\partial t)\int Cx \, dx = 0$, so the mean ($\mu$) can be taken as zero. With variance defined according to equation 2.11, equation 2.13 can be rewritten as

$$2D = \frac{\frac{\partial}{\partial t}\int_{-\infty}^{\infty} Cx^2 dx}{\int_{-\infty}^{\infty} C dx} = \frac{\partial}{\partial t}\sigma^2 \qquad 2.14$$

This relationship states that the variance of a distribution increases at the rate equal to twice the coefficient of molecular diffusion (D). This is independent of the shape of the distribution. From this relationship, estimates of the value of D can be produced by determining the variance of the concentration.

2.2 THE TRANSPORT PROCESS

In any sewage field there is motion due to winds, tides and other processes acting on the ocean. This motion or movement of the sewage field, known as advection, is the second important parameter in sewage dispersion.

The rate of mass transport is directly proportional to the velocity of the sewage field in that direction. This is because the rate at which fluid volume passes through a unit area is multiplied by the concentration of mass in that direction. For example, the rate at which a fluid passes the y-z plane is dependent on the velocity in the x-direction. (See Figure 2.2.)

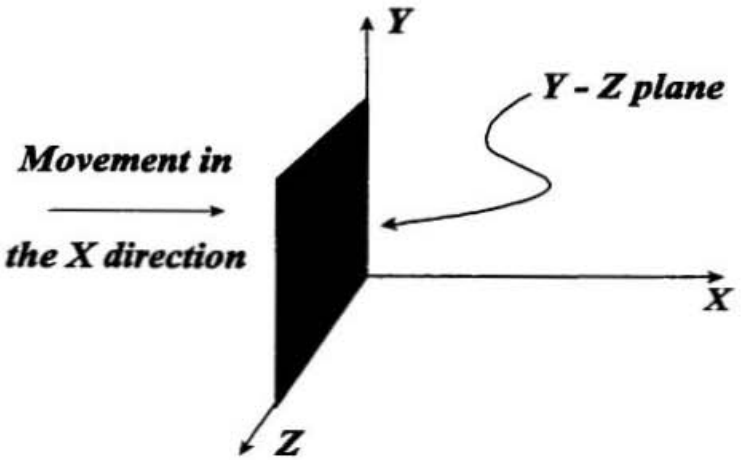


Figure 2.2 - Mass Transport

Simply stated the mass flow rate or mass flux per unit area is equal to the product of velocity (u) and concentration (C).

$$q = uC \qquad \textbf{2.15}$$

However, it is also necessary to account for the diffusion of the material as motion occurs. In essence, the sewage field is growing as it moves. (See Figure 2.3.)

Combining the above equation for advection with the process of Fickian diffusion (equation 2.1) gives

$$q = uC - D\frac{\partial C}{\partial x} \qquad \textbf{2.16}$$

Which is the total rate of mass transport from both advection and molecular diffusion. Substituting this into the equation for conservation of mass (equation 2.3) and differentiating with respect to x gives the advective diffusion equation.

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2} \qquad 2.17$$

This is for one dimension only. For three dimensions

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right) \qquad 2.18$$

where u, v, and w are the components of the transport velocity in the x, y and z directions, respectively.

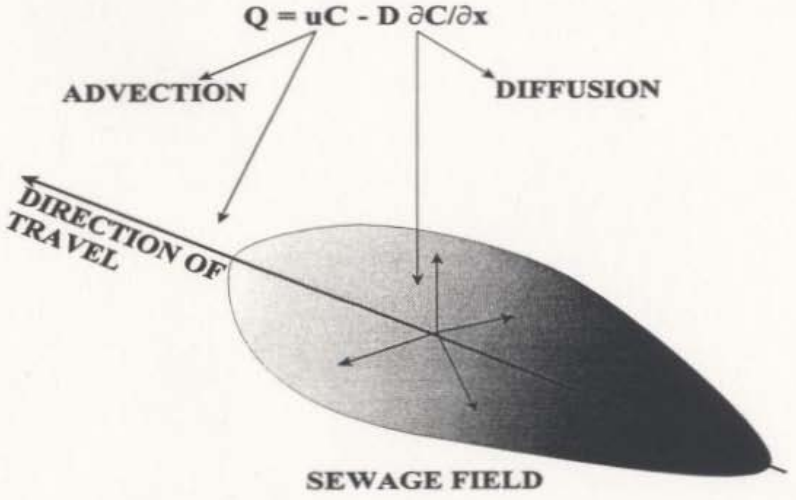


Figure 2.3 - Advection - Diffusion Equation

This equation is referred to as the three dimensional "advective diffusion" equation, and through its use, dispersion can be mathematically presented. However, this equation is for laminar flow and molecular diffusion. Several changes are required for turbulent flow found in the ocean.

2.3 TURBULENT DISPERSION

The equations developed so far describe the transport and diffusion of waste in the ocean assuming a non-turbulent process. However, most fluid motions in the ocean are considered to be turbulent. Turbulent motion can be thought of as a random motion of the fluid particles due to eddies in the ocean. Both velocity and concentration in turbulent flow can be considered as the sum of an average value and a random component. This random component represents the fluctuations due to eddies in the ocean. Thus the velocity and concentration at any one time can be written as:

$$u = \underline{u} + u' \qquad 2.19$$

$$v = \underline{v} + v' \qquad 2.20$$

$$w = \underline{w} + w' \qquad 2.21$$

$$C = \underline{C} + C' \qquad 2.22$$

Where the underlined terms represent the average values and the prime terms represent the random components. These expressions can then be substituted into the equation for advective diffusion (equation 2.18) to give:

$$\frac{\partial(\underline{C}+C')}{\partial t} + (\underline{u}+u')\frac{\partial(\underline{C}+C')}{\partial x} + (\underline{v}+v')\frac{\partial(\underline{C}+C')}{\partial y} + (\underline{w}+w')\frac{\partial C}{\partial z} = D\left(\frac{\partial^2(\underline{C}+C')}{\partial x^2} + \frac{\partial^2(\underline{C}+C')}{\partial y^2} + \frac{\partial^2(\underline{C}+C')}{\partial z^2}\right) \qquad \textbf{2.23}$$

Simplifying and rearranging

$$\frac{\partial \underline{C}}{\partial t} + \underline{u}\frac{\partial \underline{C}}{\partial x} + \underline{v}\frac{\partial \underline{C}}{\partial y} + \underline{w}\frac{\partial \underline{C}}{\partial z} = D\left(\frac{\partial^2 \underline{C}}{\partial x^2} + \frac{\partial^2 \underline{C}}{\partial y^2} + \frac{\partial^2 \underline{C}}{\partial z^2}\right) + \frac{\partial(\underline{C'u'})}{\partial x} + \frac{\partial(\underline{C'v'})}{\partial v} + \frac{\partial(\underline{C'w'})}{\partial w} \qquad \textbf{2.24}$$

The last three terms on the right - hand side of equation 2.24 account for the turbulent nature of the flow. The cross product terms such as C'u' represent the mass flow rates (q) due to the turbulent behavior. By analogy with Fick's Law of molecular diffusion (Equation 2.1) they can be represented by an equivalent diffusive mass transport in which the mass flow rate is proportional to the mean concentration gradient, i.e.

$$\underline{C'u'} = K_x \partial C/\partial x \qquad 2.25$$

$$\underline{C'v'} = K_y \partial C/\partial y \qquad 2.26$$

$$\underline{C'w'} = K_z \partial C/\partial z \qquad 2.27$$

Where K_x, K_y and K_z are the coefficients of turbulent diffusion also called eddy diffusion in the x, y and z directions, respectively. Rewriting equation 2.24 with these terms and omitting the underlining gives

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right)$$

$$+ K_x \frac{\partial^2 C}{\partial x^2} + K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} \qquad 2.28$$

This is the advective - diffusive equation for turbulent flow, accounting for transport in the ocean by both molecular and turbulent diffusion. However in most cases the turbulent transport is many orders higher than the molecular transport. As a result the terms with molecular transport can be omitted from equation 2.28, which can then be written as

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = K_x \frac{\partial^2 C}{\partial x^2} + K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} \qquad 2.29$$

2.3.1 THE COEFFICIENT OF TURBULENT DIFFUSION

The analysis given in section 2.1.1 can be applied equally well to molecular diffusion or turbulent diffusion. Thus for a sewage field in which the diffusion occurs primarily by turbulent processes.

$$K = \frac{1}{2} \frac{d\sigma^2}{dt} \qquad 2.30$$

Where: σ^2 is the variance of the concentration of the sewage field.

The coefficient of turbulent diffusion essentially expresses the intensity of the mixing process in a certain sea zone. The more intense these natural mixing processes are, the faster is the dispersion of the sewage field . From this it is apparent that as the sewage patch grows, the diffusion coefficient must increase faster than the length scale (L) of the patch. This is because, more and more eddies contribute to the diffusion of the patch as the patch grows in size. It is commonly suggested that a good relationship to use for diffusion in open ocean is the diffusion coefficient to the four-thirds power of the length scale of the patch (Grace, 1978). This is expressed as Richardson's Law .

$$K = \alpha L^{\frac{4}{3}} \qquad 2.31$$

L = Length scale (the width of the surface plume perpendicular to the mean current direction.)

α = A dissipation parameter

More details are given in the literature review.

2.4 BACTERIAL INACTIVATION

Knowledge of the inactivation rate is essential to any calculations of bacterial indicator concentrations associated with a sewage outfall discharge. The concentration of faecal indicator bacteria in a wastewater field decreases faster than can be explained by physical dilution alone. The additional reduction effect can be best described as bacterial inactivation.

2.4.1 INACTIVATION RATES

The bacterial inactivation (or decay) process is generally approximated by first order group population kinetics, where the rate of inactivation is proportional to the concentration, C, of indicator bacteria i.e.

$$\frac{dC}{dT} = -k_1 C \qquad 2.32$$

where k_1 is the inactivation rate-constant.

Rearranging and differentiating gives:

$$\ln C = -k_1 t + constant \qquad 2.33$$

However at time t = 0, the concentration is $C = C_o$. Thus the constant = $\ln C_o$

Substituting this constant back in equation 2.33, gives

$$\ln \frac{C}{C_o} = -k_1 t \qquad \textbf{2.34}$$

The concentration C at time t is then

$$C = C_o\, e^{(-k_1 t)} \qquad \textbf{2.35}$$

or

$$\frac{C}{C_o} = e^{(-k_1 t)} \qquad \textbf{2.36}$$

Where:

C = Concentration of bacteria at time t

Co = Initial concentration of bacteria at t = 0

k_1 = Rate constant obtained from experimental data

Alternatively

$$\frac{C}{C_o} = 10^{-k t} \qquad \textbf{2.37}$$

Where $k = 0.431k_t$

The inactivation rate is conventionally expressed in terms of the time required for the bacteria to decrease to one-tenth of their original number, excluding physical dilution. This value is defined as the T_{90} value. To determine this value, C, Co and t will be defined as follows:

$Co = 100$

$C = 10$

$t = T_{90}$

Substituting these values into equation 2.36 gives:

$$\frac{10}{100} = 10^{-k\,T_{90}} \qquad \textbf{2.38}$$

Rearranging and taking the logarithms of both sides

$$-1 = -k\,T_{90} \qquad \textbf{2.39}$$

Solving for k gives

$$k = \frac{1}{T_{90}} \qquad \textbf{2.40}$$

Substituting in equation 2.36 gives

$$\frac{C}{C_o} = 10^{\frac{-t}{T_{90}}} \qquad \textbf{2.41}$$

3.0 LITERATURE SURVEY

In this section a review of current literature regarding bacterial inactivation and dispersion will be presented, along with accepted values for T_{90} and dispersion rates.

3.1 SAMPLE STORAGE AND ITS EFFECTS

3.1.1 FRESH WATER

In most insitu bacterial studies whether freshwater or seawater, samples are collected and transported to a lab for analysis. The time between collection and analysis could prove to have an important effect upon the analysis, if a substantial amount of bacterial decay occurs during transport. It is a common practice to refrigerate or store samples in ice to reduce bacterial activity during transport. Even so, bacterial decay or growth may still occur under these conditions. The American Public Health Association (1983) and the Environmental Protection Agency (1979) stipulate that they should ice or refrigerate all water samples and analyze them immediately after collection, recommending a maximum transport time of six to eight hours. This is helpful in maintaining accurate samples, but often a six-hour transport time is impossible. For instance, water samples taken in remote areas may take several days to reach the nearest lab. In addition, if the sample reaches the lab late in the day, it may be stored overnight before analysis. McCarthy (1957), has shown that large changes in bacterial concentrations can occur in un-iced samples.

The effects of holding time and temperature on microbiological analysis of drinking water remains undetermined after nearly 100 years. Concern for this problem can be traced back to 1899 when Jordan and Irons (1899) stated that all experienced water analysts should insist upon analysis of a sample of water immediately after collection. It is generally recognized that water samples collected for microbiological analysis must be examined as soon as possible because of the changes that could occur in the bacterial densities owing to the chemical and physical characteristics of the sample and the interaction with other organisms in the water.

Many investigations have been reported, but differences in the conditions of the studies make comparisons difficult, if not impossible. Jordan (1900) observed a gradual decrease in bacterial densities of polluted waters held at either ambient or refrigerated temperatures. Caldwell and Parr (1933) compared coliform recovery from iced and ambient well water samples held for various time periods and reported losses of 40 - 50 percent within a few hours at both temperatures. The Public Health Laboratory Service Water Subcommittee of Great Britain reported that storage of samples for six hours at ambient temperature was not always satisfactory. By their standards, some samples showed significant changes after six hours in the refrigerator. At each temperature approximately one sample in four showed a significant variation after six hour storage. (The Public Health Laboratory of Great Britain, 1953) (See Table 3.1.) In a second study by the Public Health Laboratory Service Water

Subcommittee of Great Britain (1953), overnight storage of coliform samples was investigated. One hundred and fifty one samples from eighty locations around England were used. Significant changes were again found in coliform counts before and after the storage interval. (See Table 3.2). Their conclusions stated that overnight storage of a sample at refrigerator temperatures is still likely to show a significant change in coliform content.

Table 3.1 - Effect of Storage (The Public Health Laboratory of Great Britain, 1953)

Period of storage (Hours)	Temperature of storage	Percentage showing		
		Increase	No change	Decrease
6	Refrigerator	8.8	75.0	16.2
	Room	8.6	75.3	16.1
24	Refrigerator	6.5	66.1	27.4
	Room	14.5	61.7	23.8

Table 3.2 - Effect of Overnight Storage (The Public Health Laboratory of Great Britain, 1953)

Temperature of storage	Percentage showing		
	Increase	No change	Decrease
Refrigerator	6.6	76.2	17.2
Room	15.2	65.6	19.2

In agreement with these findings, Geldreich (1955) found the mean coliform density after 24 hours storage was 72 percent of the mean after two hours storage for 18 samples collected from wells, lakes, and rivers and held at 5°C. On the other hand, Lonsane (1967) examined marginally polluted waters held at ambient and refrigerator temperatures and reported that membrane filter (MF) counts of coliforms from samples held up to 48 hours were not significantly different from those found initially. Standridge and Lesar (1977) examined 28 samples of heavily polluted water with initial coliform counts that ranged between 10^2/ml and 10^6/ml and found little change after storage at 2°C - 4°C for 24 hours. Dutka and El-Shaarawi (1980) stored waters with various pollution loads at 1.5°C and reported that at least 75 percent of the samples had a constant level of bacteria for 24 hours, but there was little evidence that populations were stable over 48 hours. It seems for every study that reports significant changes in coliform counts over time, there is another study that finds no significant changes.

The major problems in interpreting data from earlier studies, in terms of the effects of holding time and temperature on water samples, are that most of the samples had high bacterial counts rather than the relatively low counts found in drinking waters. In addition most results were based upon the multiple-tube fermentation method, with results reported in the most probable number (MPN) rather than the more precise membrane filtration (MF) method.

3.1.2 WASTEWATER CONCERNS

To further complicate the problem, samples with high concentrations of coliforms or other bacteria, as in raw sewage, are more prone to the effects of storage, than samples with low concentrations. After examination of 400 samples from the New York and Massachusetts departments of public health, McCarthy (1957), found that bacterial samples with relatively low coliform densities will remain more stable over time than samples initially containing high coliform densities. It was concluded that 24-hour storage results somewhat more reliable for samples initially containing a low coliform pollution than with samples of higher numbers. The rationale is that changes are less likely to occur in drinking water samples because they are usually of good quality and have low bacterial densities, which are more hardy and better able to survive the storage interval. Coliforms, like any other organisms will have variations with both healthy and weak members; it would be reasonable to assume samples containing low concentrations would mainly consist of more hardy coliforms as the

weaker ones have already died or have been eliminated by some treatment or natural predation. A sample with low concentrations would then be expected to show less change over a storage interval. On the other hand a sample of water containing a high concentration of coliforms, as in the case of raw sewage, would contain numerous weaker coliforms that could die off quite rapidly during storage.

In agreement with this, Gameson (1984) has noted that the survival of coliform bacteria in seawater may depend upon the initial count. In a series of five experiments carried out in the summer of 1966, with high concentrations of sewage (between 34 and 40 million per ml), bacteria counts increased during the first day and did not fall to their initial values until two to three days after the start of the experiment. However it should be noted that the samples were kept in the dark, so the effect of inactivation due to sunlight was not determined.

To keep changes in bacterial densities to a minimum and to provide more valid results, Standard Methods for the Examination of Water and Wastewater (1992) recommend polluted samples be held at temperatures less than 10°C and from 1°C - 4°C, respectively, and be analyzed within six hours of collection. The American Public Health Association (1985), recommends to hold temperature of all stream pollution, drinking, and wastewater samples below 10 °C during a maximum transport time of six hours.

3.2 STUDIES OF DECAY RATES - T_{90}

The large influence which local conditions have on the inactivation of indicator bacteria in a wastewater field causes wide variations in decay rates. Factors such as solar radiation, pH, predation by other organisms, osmotic stress (moving from fresh water to saline waters), degree of treatment of the effluent, presence of organic material, water temperature and turbidity of the receiving waters, all affect the rate of bacterial decay. This makes it advisable to carry out field measurements of the inactivation of the bacteria near the proposed outfall site. In this procedure, a tracer of known concentration is released into the ocean and samples are taken to find the change in concentration over distance and time. Using this data the T_{90} time can be calculated.

Mitchell and Chamberlin (1978) have summarized decay rates of coliform bacteria in seawater from various studies performed around the world. See Table 3.3.

Table 3.3 - Decay Rates of Coliform Bacteria (Mitchell, 1978)

Location	Treatment before discharge.	T_{90} (Hours)
Denmark	none	2.0
England	none	0.78 - 3.50
Gentoffe, Denmark	none	1.16
Istanbul, Turkey	none	0.80 - 3.00
Manila Bay, Philippines	none	1.78 - 3.45
Nice, France	none	1.5
Rio de Janeiro, Brazil	none	< 1.0
Santa Barbara, California	primary	0.37 - 5.47
Santa Monica, California	primary	1.50 - 4.00
Seaside Heights, New Jersey	primary	1.05
Sidmouth and Bridport, England	None	0.57 - >>4
Tatahi Bay, New Zealand	none	0.65

Gameson (1984) has carried out a great deal of investigation in the area of coliform inactivation and T_{90} studies. A series of 25 experiments conducted between 1969 and 1980 show a wide range in T_{90}, from 34 minutes to nine hours in daytime studies. See Table 3.4.

Table 3.4 - T_{90} Values (Gameson, 1984)

Number	Year	Outfall	Date	T_{90} (Hours)
1	1969	C	Aug 21	3.8
2	1969	C	Aug 22/23	-
3	1969	C	Aug 25	3.9
4	1969	C	Aug 26	3.1
5	1970	DD	May 14	3.3
6	1971	DC	July 7	-
7	1971	DC	July 15	.57
8	1971	DB	Sept 14	3.9
9	1971	DB	Sept 15	9.0
10	1971	DB	Sept 17	1.36
11	1971	DB	Sept 19	1.6
12	1972	DB	Apr 26	8.2
13	1972	DB	May 2	5.3
14	1972	DB	May 5	8.1
15	1972	DB	May 11	3.4
16	1973	DD	May 10	2.2
17	1973	DD	May 12	.89
18	1973	DD	May 15	.75
19	1973	DD	May 16	4.0
20	1973	DD	May 20	3.9
21	1980	C	Sept 30	1.3
22	1980	C	Oct 1	2.8
23	1980	C	Oct 2	1.4
24	1980	C	Oct 3	2.2
25	1980	C	Oct 4	3.5

Outfall C is at Sidmouth, England (discharging 440 m offshore), DD is at Bridgeport (1360 m offshore), and DC and DB are the outlets (at 680 m and 430 m respectively) on the same outfall pipe at Bridgeport.

3.2.1 EFFECT OF SOLAR RADIATION

Solar Radiation is the most important factor affecting the rate of bacterial inactivation. Various studies have been undertaken in this area, and generally the results are the same. Tchobanoglous, (1985) has noted that the main process which leads to a loss of viability in seawater of coliforms with time is the effect of ultra-violet radiation. However, there is a noticeable variation in the rate of bacterial decay, indicated in published values for T_{90}, ranging from one hour to extremes of nine or more hours, during daylight conditions. As the amount of ultra-violet radiation reaching the ocean surface depends on factors like latitude and physical geography, it would be reasonable to suggest that T_{90} values would vary from location to location. Currently Newfoundland outfall designs are based upon tests conducted at lower latitudes and/or warmer sea states. These values may not be accurate for local conditions.

In a series of studies by Gameson (1985) it was concluded that solar radiation is the dominant factor, the inactivation rate of bacteria exposed to sunlight is typically up to two or more orders of magnitude greater than for the same bacteria kept in the dark. The radiation

intensities are dependant on the solar elevation and weather conditions and therefore vary throughout the day and seasonally. (See Figure 3.1.) Clear skies and a high solar radiation elevation produces the most rapid inactivation. The lethality of solar radiation also decreases with increasing wavelength, which is measured in nanometers - nm (10^9 m). Previous studies (Calkins, 1960) have shown that the ultraviolet UV-B band (280 -320 nm) is the most

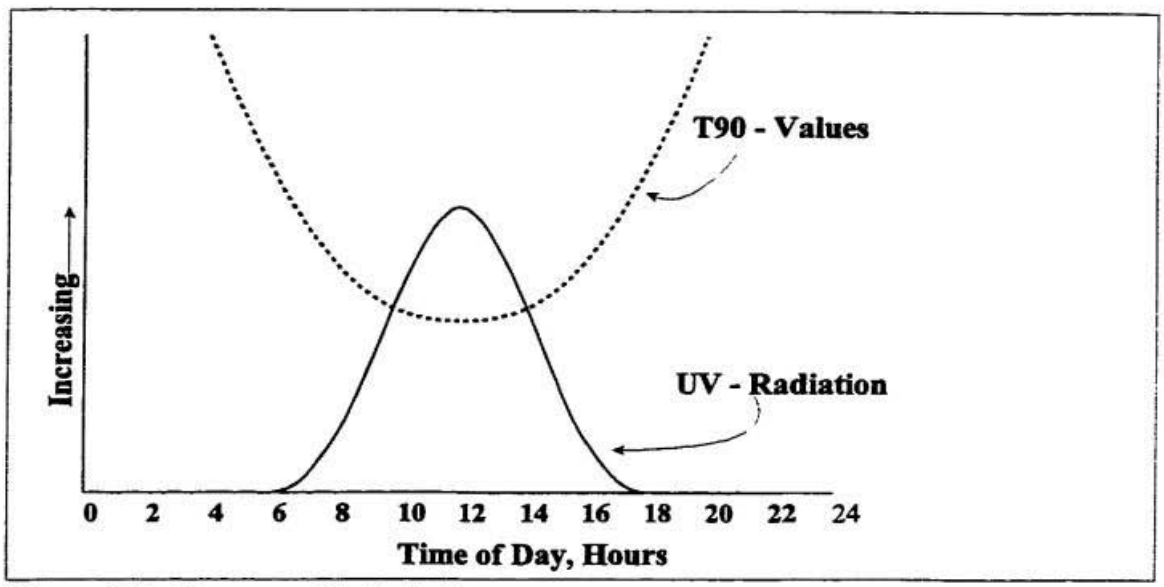


Figure 3.1 - T_{90} versus Uv Radiation

bactericidal portion of the solar spectrum at sea level. This very short wave length band causes direct damage by photon action on DNA, although some cell damage may be temporary as bacteria can subsequently undertake either sunlight-induced or dark enzymatic repair (Gameson, 1985). The bactericidal action of solar radiation on indicator bacteria progressively decreases with increasing wavelength through the UV-A band (320 - 400 nm).

This contrasts with the DNA response, which has a sharp cut off at 315 -320 nm in the UV-B band.(Calkins,1960) Therefore while less intrinsically damaging than the UV-B, the more intense UV-A and even short wave visible light in the violet-green band are also important contributors to bacterial inactivation mechanisms, suggesting that other mechanisms exist besides direct damage to their DNA.

Based on the experimental results of Gameson and Gould (1985), it would appear that half the inactivation of coliforms at the water surface is attributable to wavelengths below 379 nm, a quarter to the near visible UV-A band and a quarter the violet -green region (400-500 nm) of the visible solar spectrum. When it comes to bacterial inactivation at depths below the sea surface, selection absorption of shorter wavelengths by dissolved organic matter, chlorophyll and particulates, becomes an important factor particularly as the short wavelength UV-B, which do much of the damage, are strongly attenuated in productive coastal waters.

3.2.2 COLD WATER EFFECTS

It has been generally assumed that water temperature has little or no effect upon the rate of bacterial decay. This may be due in part to the fact that the majority of studies were carried out in relatively warm water. The few studies that have attempted to analyze this condition have shown a noticeable variation in T_{90}. However most of these previous studies dealt with freshwater in streams rather than ocean water.

Smith's (1992) investigation into bacterial decay at Rankin Inlet, N.W.T., showed very little decay of bacteria in an ice filled harbor. Decay rates varied from 0.04 d^{-1} to 0.24 d^{-1}. However the effect of the ice cover upon the decay rate is unclear. "Results from this study coincide with those from previous investigations that have found that the combination of cold water temperature and ice cover significantly reduce the decay of microorganisms."

Springthorp, Loh, Robertson and Satter (1993) investigating the behavior of coliform bacteria in the Ottawa and Rideau Rivers during the winter and spring of 1991 - 1992, noted that almost no decay was observed at temperatures of 2 - 4°C.

Gameson and Gould (1985), in a investigation of bacteria decay during daylight conditions, using data from 1966 to 1972 noted that water temperature had no effect upon the rate of decay, even though water temperatures were varied from 3 - 27°C. However in a similar study during night conditions consisting of 200 samples, water temperature was deemed to be very important and a noticeable increase in decay rates with increasing water temperature was evident. Using regression analysis two equations relating water temperature to the T_{90} time were derived:

For temperatures 10°C and less

$$TD = 2.345 - 0.0443\Theta \qquad 3.1$$

For temperatures 15°C and greater

$$TD = 2.076 - 0.0226\Theta \qquad 3.2$$

Where TD is the T_{90} time in the dark and Θ is the water temperature in degrees Celsius. No explanation was given for the need for two equations.

It seems from the studies presented that temperature does have an effect on bacteria inactivation, but the effect of sunlight may be so great that temperature effects are not noticeable in daylight conditions. This would explain the differences between daylight and night conditions and the effect of ice cover.

3.3 DISPERSION

3.3.1 GENERAL

One of the most important parameters in the prediction of dispersion is the horizontal diffusion coefficient (K) and the corresponding relationship:

$$K = \alpha L^n \qquad 3.3$$

Where K is the diffusion coefficient and L is the length scale (the width of the surface plume perpendicular to the mean current direction) α and n are constants which are described below.

In many mathematical analyses involving diffusion, it is assumed that K is a constant for all time and space and the same for all directions. In this case K represents the rate of spread or growth of a concentration patch. Basically there are three forms of $K = \alpha L^n$ with corresponding values of n as 0, 1 or 4/3, which account for a reduced diffusion coefficient due to closeness to shorelines. Values of α are more difficult to define as it is really not a constant but related to energy absorption from the eddies. Ozmidov (1990) reasoned that the parameter α is actually the rate at which energy passes from large energy containing eddies to smaller eddies. On this basis α will decrease with an increase in length scale. The reason is that energy is fed by ocean turbulence at roughly three scales; by wind waves at about 10 metres, tidal motions at 10 kilometers and by atmospheric pressure systems at about 1000 kilometers. Okubo (1971) has shown that allowing for the increase in energy passed through as the scale decreases does result in a better fit. (See Figure 3.2.)

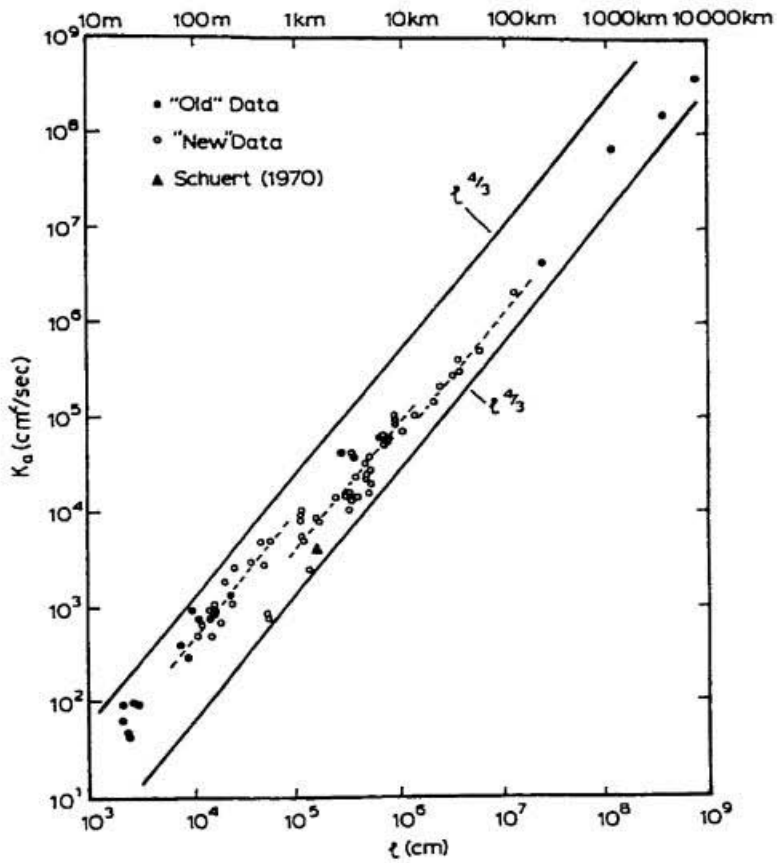


Figure 3.2 - Okubo's fitting of Richardsons law (Okubo,1971)

However unless the length scale is very large a reasonable estimate of α is given as 0.002 - 0.01 $cm^{2/3}/s$. This would be the case in most outfall designs since once the length scale exceeds 10 km, the sewage would be expected to be far offshore and most bacterial inactivation would have occurred. In most instances dispersion calculations are required for nearshore conditions, with smaller length scales.

3.3.1 RICHARDSON'S ANALYSIS

The earliest work in the definition of K was carried out by Richardson (1926). This was based upon dispersion in the atmosphere. In his analysis he introduced the fundamental notion that the rate of separation of a pair of particles at any instant is dependant on the separation itself. As the separation increases so also does the rate of separation. In doing so, he developed what is known as the Richardsons's law. Richardson's work was primarily related to atmospheric diffusion, however it holds true for diffusion in the ocean. In Fickian diffusion the distribution of particles is given as a function of distance from a chosen origin, and in the simplest case can be written (as given in Chapter 2)

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial x^2} \qquad \textbf{2.17}$$

Richardson was concerned with the effect of the separation between particles, so he suggested presenting the coefficient of relative diffusion of particles (F) as the function of

the mutual separation of particles (l). The diffusion was presented by him for the density particle distribution function (q) according to their mutual distances in the following form:

$$q(l) = \frac{1}{Q}\int_{-\infty}^{+\infty} C(x)\ C(x + l)\ \partial x \qquad 3.4$$

Where Q is the total number of particles.

Having analyzed atmospheric data, Richardson established that by expressing the coefficient L as 2K the following relationship can be obtained

$$K = 0.2L^{\frac{4}{3}} \qquad 3.5$$

This relationship, known as Richardson's law, has proved to be very effective in the prediction of dispersion in the ocean. The majority of other studies in this area have been concerned with either providing further proofs of this law or refining it.

3.3.2 USE OF DROGUES

One method of determining the horizontal diffusion coefficients is through the deployment of drogues at an outfall site. These drogues are nothing more than underwater sails attached to surface floats. As the water currents and eddies act upon the drogues, their movements can be tracked by noting the movement of the surface floats. Analysis of the movements of the drogues, can then be used to determine the horizontal diffusion coefficient. See Figure 3.3.

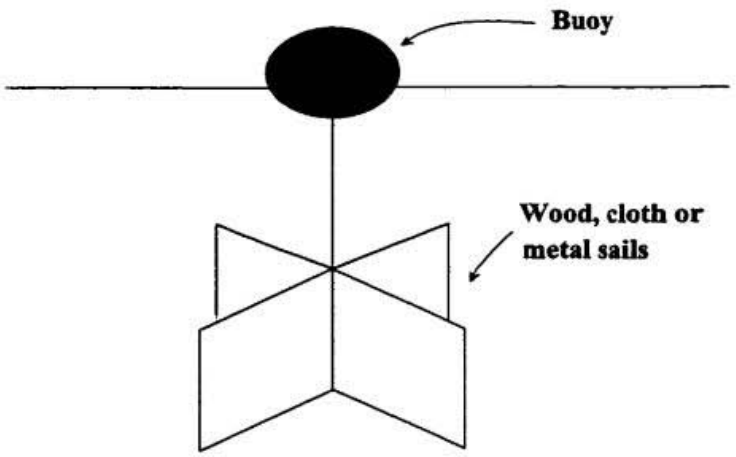


Figure 3.3 - Typical Ocean Drogue

The movement of the drogues relative to each other can be used to determine the horizontal diffusion coefficient. This was first presented by Stommel (1949) who presented a method of estimating diffusivity as a function of neighbor separation, based on Richardsons' earlier work. Stommel's approach was to release the floats in pairs at an initial separation L_0 then to measure the separation L_1 after an elapsed time T. If the initial and final separations of the ith float pair are represented by L_0 and L_1, respectively. Then the scale of the process for the ith pair can be written as:

$$L = \frac{1}{2}(L_{o_i} + L_{1_i}) \qquad 3.6$$

For a group of N floats the scale would be

$$L = \frac{1}{2N}\sum_{i=1}^{N}(L_{o_i} + L_{1_i}) \qquad 3.7$$

Stommel has shown that the dispersion coefficient (K) of length scale (L) is given by:

$$K = \frac{\sum_{i=1}^{N}(L_{1_i} - L_{1_i})^2}{2NT} \qquad 3.8$$

3.3.3 BROOKS' MODEL

The basic Fickian equation was used by Brooks (1960) to describe the dispersion of sewage effluent from a line source in an ocean current, such as a typical sewage diffuser at the end of an outfall pipe. Brooks assumed that the diffusion law with variable eddy diffusivity K was valid, and that there was no vertical or lateral diffusion. This reduced the problem to one dimension:

$$q = -K \frac{\partial C}{\partial x} \qquad 1.1$$

Other assumptions were that K is a function of the length scale L, which was taken as the width of the sewage field, vertical mixing is negligible, longitudinal mixing is negligible and flow is steady. For the value of the coefficient of eddy diffusion, Brooks used Richardsons law with several changes to the value of the exponent. He chose three different values of the exponent n: 0, 1 and 3/4. The first of these corresponds to an assumed constant diffusion coefficient, the second is consistent with a coastline situation and the latter with open ocean. The three values of n account for restrictions on mixing due to reduced eddy size near shorelines and its effect upon plume growth.

$$K = \alpha L^n \qquad \textbf{3.9}$$

It is this definition of eddy diffusion along with the advection - diffusion equation that forms the basis of dispersion calculations in the ocean. However it should be noted that since Brooks assumed that the flow is steady, values of K and α will vary due to local ocean conditions. Normally field studies using dyes or floats are undertaken to determine the values of the constants α an n.

3.3.4 DISPERSION STUDIES

There have been many field experiments conducted to measure K, so it is a common practice in outfall design to use a value from literature. However, to ensure an accurate estimate of sewage dispersion field measurements should be carried out whenever possible. Findings from most studies tend to reinforce Brooks idea that n will vary depending on closeness to shorelines. Thus it can be assumed that values of n will vary depending upon location and physical geography of the outfall area.

The first experiments on the diffusion of particles in the ocean were undertaken by Richardson and Stommel (1948). The distances between 45 pairs of individual particles were measured at the initial time (to) and at the moment $t_1 = t_0 + T$, where T = 30 seconds. Based on this data, the coefficient of diffusion K or F(l) was calculated by Stommel's equation. (equation 3.5) The coefficient n was determined to be 4/3.

A large series of experiments on diffusion was conducted by Ozmidov (1990) in 1955 - 1958. These experiments were carried out in artificial ponds, from oil trestles in the Caspian Sea and in the Pacific Ocean. In the first two cases, sheets of paper served as indicators, while in the ocean experiments submerged buoys with radar reflectors were used. The position of the paper sheets was determined by photography and that of the buoys by radar. The distances between the pairs of the diffusing particles varied from centimetres to several

kilometres. These computations showed a significant decrease in K with the increasing length scale. In most cases the dependence of K on size was rather well approximated by a power function with the exponent of 4/3. A log - log plot of K versus L gave a straight line given by the equation $K = 0.01\ L^{4/3}$.

In several studies dependence of the diffusion coefficient on the phenomenon scale was approximated by a power function of the form $F = L^n$, with the exponent n sometimes being different from 4/3. In the summer of 1974, experiments with discrete particles were conducted by Zhurbas, Mamedov and Tataraev (Zhurbas, 1990) in the Caspian Sea. Small buoys with radar reflectors and underwater parachutes were used as indicators. In each experiment four buoys were released. The distances to the buoys and their azimuths were determined every 600 - 900 seconds with the help of a radar system installed in a former oil derrick's basement. Averaging in the formula (equation 3.5) was made when calculating the dispersion coefficient K over groups of values L = 0 - 50; 50 - 100; 100 - 150; 150 - 200; 200 - 250; 250 - 300 m. All the experimental data fitted onto a unique straight line with n being equal to 1.14. The authors account for such a deviation of the experimental results from the 4/3 power law by the peculiarities of energy supply in the shallow sea areas where the experiment was staged.

Tushinsky (Tushinsky, 1990) carried out similar studies in Lake Baikal. Special floating beacons 2.5 meters long with cross like sails with cross sections about 2 m^2 were used as

indicators. The positions of floats in the course of diffusion was determined by photographing from a ship. Floats were released near the city of Baikalsk at distances of 0.5 and 12 km from shore. The length scale L in the experiments varied from 6 to 103 meters, and the respective values of the diffusion coefficient K was from 84 to 5983 cm/s. The relationship K obtained through these experiments was approximated by two power relationships, with the exponent n = 0.98 for smaller scales and with n close to 4/3 for L exceeding 30 - 60 m.

A review of data from a number of experiments is given in Okubto (1971 , who selected twenty sets of data, obtained during the period 1961 - 67 from studies off the east coast of the United States. By plotting the apparent diffusivity K against length scale L, Okubo found the relation.

here L is in cm and K is in cm^2/s. See figure 3.4.

$$K = 0.01031L^{1.15} \qquad 3.10$$

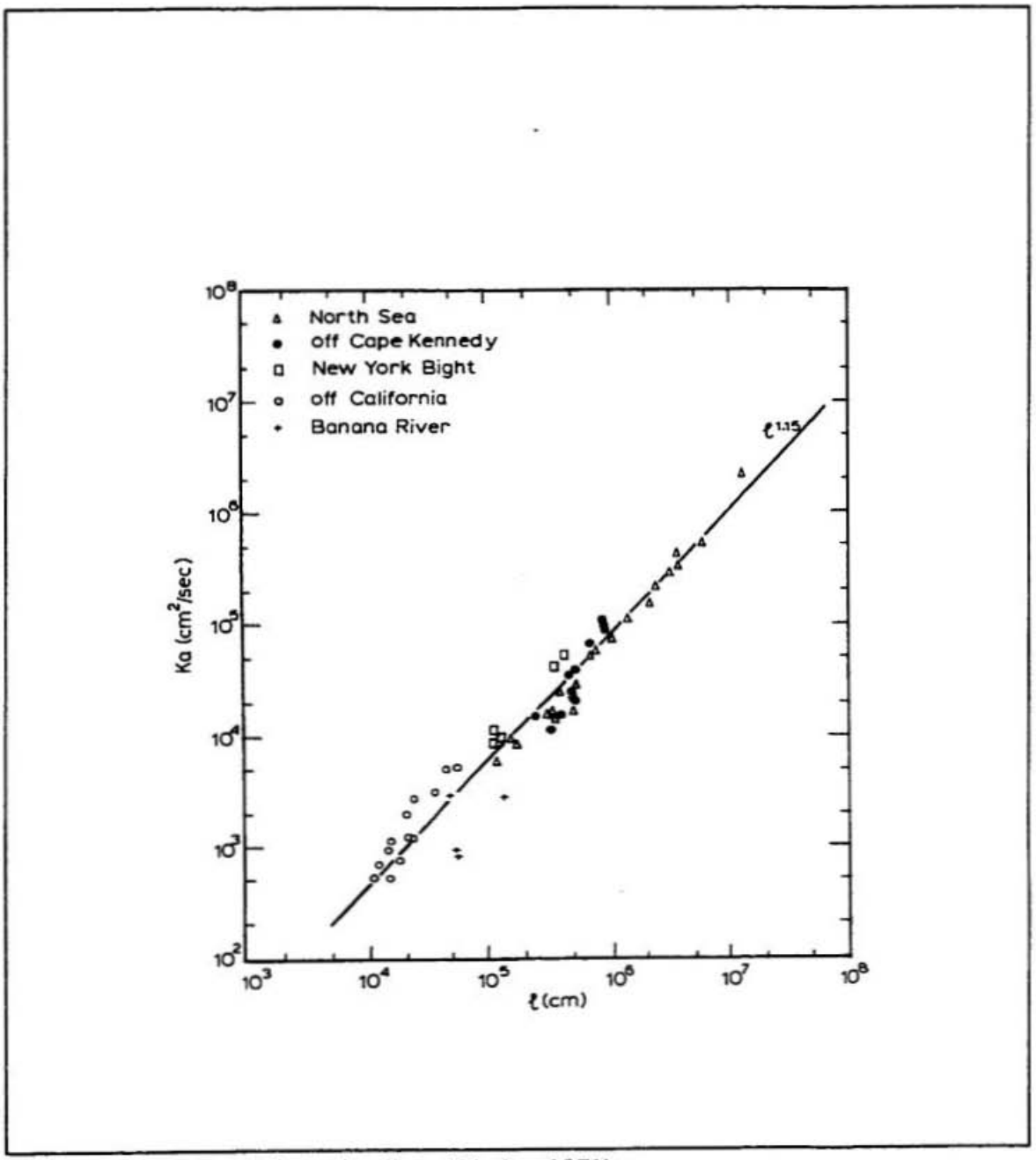


Figure 3.4 - Okubo's Dispersion Data (Okubo, 1971)

4.0 EFFECTS OF STORAGE

As noted in the literature review, there is a wide variation in the accepted effects of storage on bacterial samples. For this study it was deemed important to find if storage of the samples would have any effect upon the analysis results. If this were the case, special precautions would have to be taken to ensure that the study results were accurate. In addition the effect of temperature in comparison with sunlight was also studied. This was because some studies have noted an effect of temperature on samples during dark conditions but not in the light (Gameson, 1985) .

4.1 METHODOLOGY

To check the effects of storage under different conditions, approximately 5 litres of raw sewage was obtained from a trunk sewer in Mount Pearl, at an access chamber near Park Avenue. (See Figure 4.1). This location was chosen because it allowed easy access to the main trunk sewer, which carries all of the waste from Mount Pearl and surrounding areas to an outfall in St. John's. In addition, by the time the sewage reached this location, most of the solid material had been broken down into a watery mixture. This made preparation of the samples much easier.

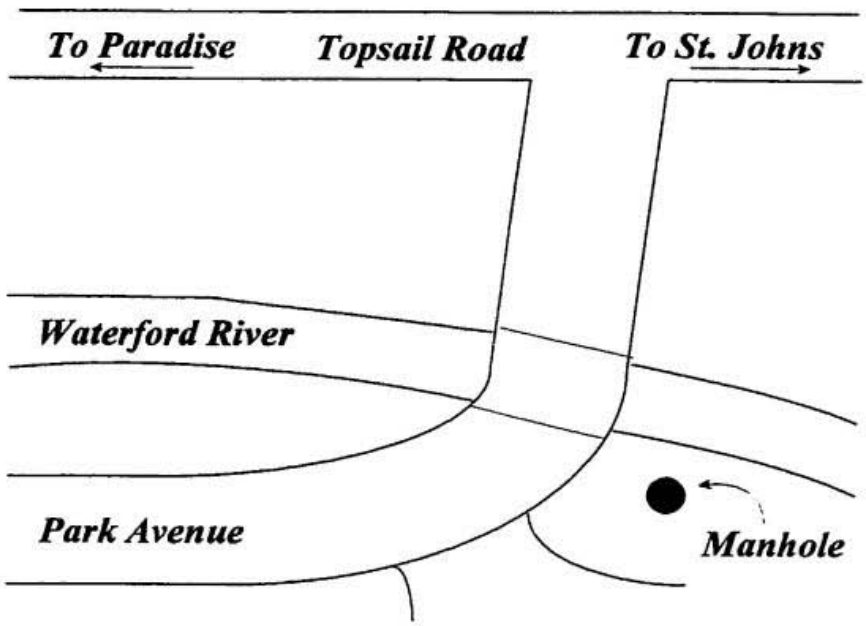


Figure 4.1 - Location of Sewage Source

The sewage was mixed with ocean water obtained from the municipal wharf in St. Phillips. This is the area where the T_{90} studies were taken and use of water from the same location would aid in the determination of how storage would affect the T_{90} values. The sewage was added at the ratio of 1 part of sewage per 99 parts of seawater or 1%, which is a typical concentration of sewage used for testing and which made the calculations simpler.

Immediately after retrieval the sewage was mixed to eliminate any bacterial die-off before sampling. It was then divided into four parts and stored. Because the purpose of this test was to determine the effects of storage time, sunlight and temperature upon wastewater samples during normal sampling, the samples were stored in a car. This would be normal procedure during transport. Description of the samples are as follows:

Sample A - The first sample was stored in trunk of a car, in a cooler packed with ice to simulate the normal storage of a sample prior to testing. It was stored cool and in the dark. Temperature of the sample remained between 2° and 3°C during storage.

Sample B - The second sample was wrapped in aluminum foil and stored in the sunlight, to simulate a sample in the dark but kept warm. Temperature of the sample remained between 18° and 22°C during storage.

Sample C - The third sample was partially immersed in a clear glass container filled with ice water, to simulate a cool sample stored in sunlight. The ice was routinely replaced to keep the temperature similar to that of a sample stored in a cooler. Temperature of the sample remained between 2° and 4°C during storage.

Sample D - The fourth sample was stored with no protection from sunlight or temperature.

Temperature of the sample remained between 18° and 24°C during storage.

Table 4.1 shows a breakdown of experimental conditions for the four samples.

Table 4.1 - Sample Conditions

Sample Number	Storage Temperature	Exposed to Light
Sample A	Cool	No
Sample B	Warm	No
Sample C	Cool	Yes
Sample D	Warm	Yes

Fifteen ml of each sample were abstracted every hour and investigated for total coliform counts by the membrane filtration method. Taking samples every half hour would have been more desirable but the analysis involves dilution of the samples, which is a time-consuming process. One hour between each set of sampling was the smallest time required to perform all the necessary analysis.

In the membrane filtration method a filter of minute pore size is used to retain bacteria from a known volume of wastewater (usually 100 ml). This filter is then stored in a warm environment for 24 hours, allowing bacteria colonies to grow. The colonies are then counted and it is assumed that each colony represents one coliform. For example, if twelve colonies were counted then the concentration would be recorded as twelve total coliforms per 100 ml.

Further details of this method are given in Appendix "A."

Testing was conducted twice, once on the May 17, 1994 and the second on May 18, 1994. For each sample the membrane filtration test was repeated three times, giving a total of six sets of data for each experimental condition, (ie A, B, C and D). The first three (Set 01, Set 02 and Set 03) refers to May 17 while the latter (Set 04, Set 05 and Set 06) refer to May 18.

4.2 RESULTS

Tables 4.2 to 4.5 give the resulting counts for each sample from the membrane filtration method. Both Samples A and B have data for six one hour intervals and an additional value measured after twenty-four hours. Because both samples were stored in the dark, the tests could continue overnight. However temperatures in sample B would have dropped overnight and, as a result, its total coliform count at twenty-four hours might not be accurate. For samples C and D the test was stopped at six hours, as there was no way to simulate natural light for continued testing. The numbers in the table represent the actual count from the filter media, not the count per 100 ml. Because of the high concentration of coliforms in sewage, the samples had to be further diluted at the laboratory. Thus, a count of fifty in the tables would represent 5×10^7 coliforms in the raw sewage.

Table 4.2 - Coliform counts for sample A.

Coliform Counts - Stored in Ice and in the Dark - Sample A						
Time	Count (x 10^{-6})					
	Set 01	Set 02	Set 03	Set 04	Set 05	Set 06
0	50	47	47	75	48	60
1	47	44	40	80	45	58
2	45	40	37	74	42	55
3	45	36	35	69	39	51
4	37	35	33	65	38	44
5	35	33	33	60	36	45
6	33	33	31	56	37	43
24	28	34	30	53	36	40

Table 4.3 - Coliform Counts for Sample B.

Coliform Counts - Stored in Warm and in the Dark - Sample B						
Time	Count (x 10^{-6})					
	Set 01	Set 02	Set 03	Set 04	Set 05	Set 06
0	45	41	49	52	45	43
1	41	43	43	42	40	41
2	38	32	40	26	35	38
3	34	25	38	31	31	35
4	32	24	35	27	31	33
5	28	25	30	27	35	30
6	25	22	25	26	26	27
24	10	21	15	27	25	16

Table 4.4 - Coliform counts for sample C.

Coliform Counts - Stored in Cool and in Sunlight - Sample C						
Time	Count (x 10^{-6})					
	Set 01	Set 02	Set 03	Set 04	Set 05	Set 06
0	41	43	51	39	44	41
1	23	30	41	21	27	32
2	15	21	33	26	21	25
3	10	17	19	10	13	15
4	6	20	10	8	8	17
5	7	7	4	5	10	12
6	4	2	3	0	1	7

Table 4.5 - Coliform counts for sample D.

Coliform Counts - Stored Warm and in Sunlight - Sample D						
Time	Count (x 10^{-6})					
	Set 01	Set 02	Set 03	Set 04	Set 05	Set 06
0	41	43	51	38	41	43
1	21	28	31	20	35	45
2	10	15	24	18	29	29
3	8	12	18	12	15	18
4	5	6	15	5	12	8
5	3	3	10	3	4	5
6	1	2	5	3	1	3

4.3 ANALYSIS OF DATA

The coliform count data was analyzed for effects of storage time and the combined effects of temperature and sunlight. For comparison all coliform counts were normalized against the initial values (time = 0) using the formula Ct/Co, where Co is the initial value of each set and Ct is the actual coliform count for each set at each time interval. This was expressed as percent survival - the proportion of total coliforms remaining after a time interval. For example if the count at time zero had been 100 coliforms and the count after one hour had been 25 coliforms, the resulting ratio would have been 25/100 or 0.25. This would indicate that 25 percent of the coliforms had survived for one hour. The average for each sample is shown in Table 4.6.

Table 4.6 - Average Percent Survival

	SAMPLE			
Time (Hours)	A	B	C	D
0	1.000	1.000	1.000	1.000
1	0.984	0.907	0.666	0.630
2	0.923	0.744	0.542	0.449
3	0.864	0.685	0.322	0.302
4	0.801	0.644	0.268	0.196
5	0.776	0.628	0.177	0.103
6	0.749	0.536	0.066	0.054
24	0.674	0.414		

Figures 4.2 to 4.9 show the percent survival for each test condition for both linear and log scales, while figures 4.10 and 4.11 show a comparison of the four samples using the averaged data from Table 4.6.

What is immediately apparent from figure 4.11 is the difference in survival rates. Both samples stored in the dark (A and B) have higher survival rates than samples stored in the light (C and D), and therefore smaller changes in concentration due to storage before testing. In addition the samples are grouped together in terms of whether they were exposed to sunlight or kept in darkness, according to temperature differences. This could suggest that temperature differences in the samples do not have an important effect.

4.3.1 EFFECTS OF STORAGE

As can be seen from Table 4.6, the percent survival for samples stored in the dark (A and B) was much higher than samples stored in sunlight (C and D). In fact after six hours an average of 64 percent of the coliforms for samples A and B were still remaining, compared to an average of 6 percent for samples C and D. It should be noted from Figure 4.10 that the rate of decay for each sample is constant. This is shown by the linearity of the graph, as each sample has a relatively constant slope.

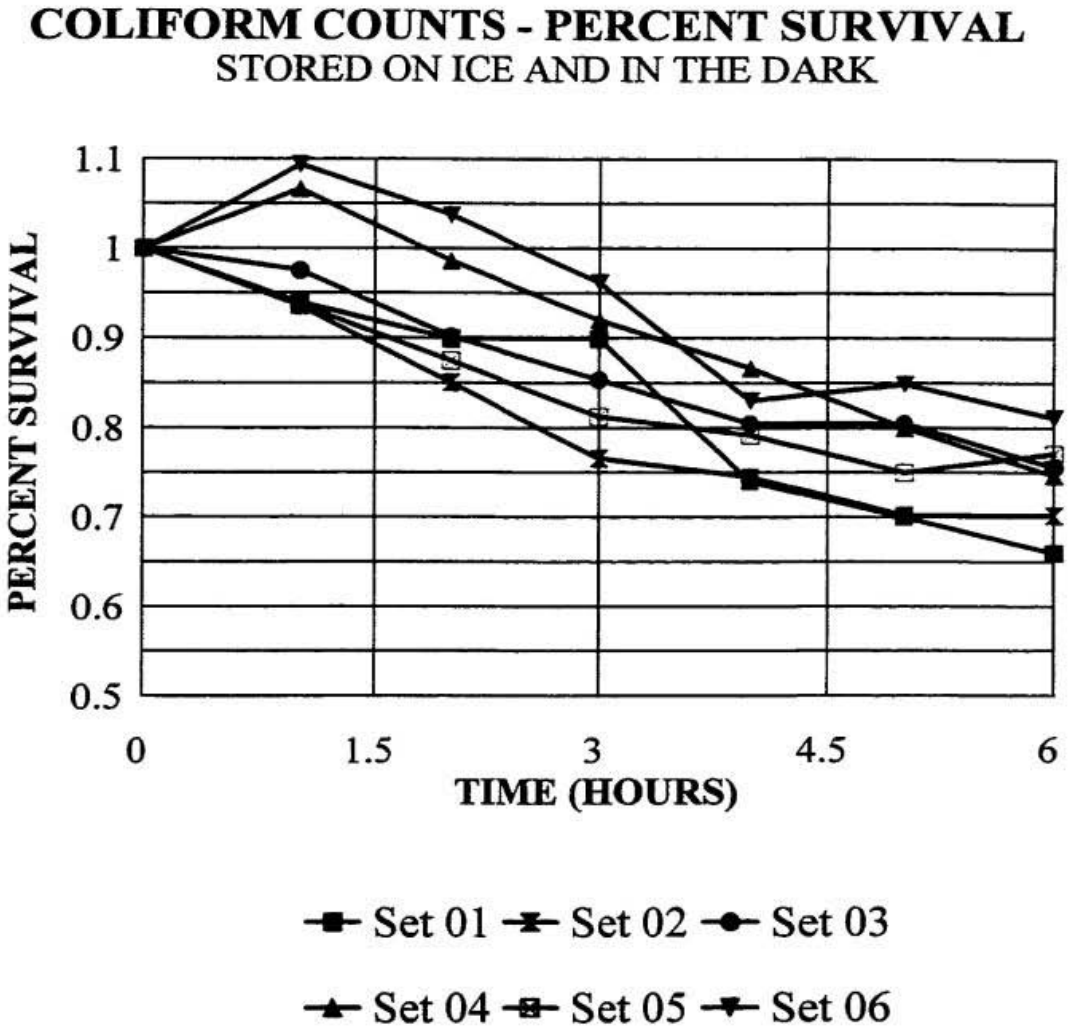


Figure 4.2 - Sample "A" Percent Survival (normal graph)

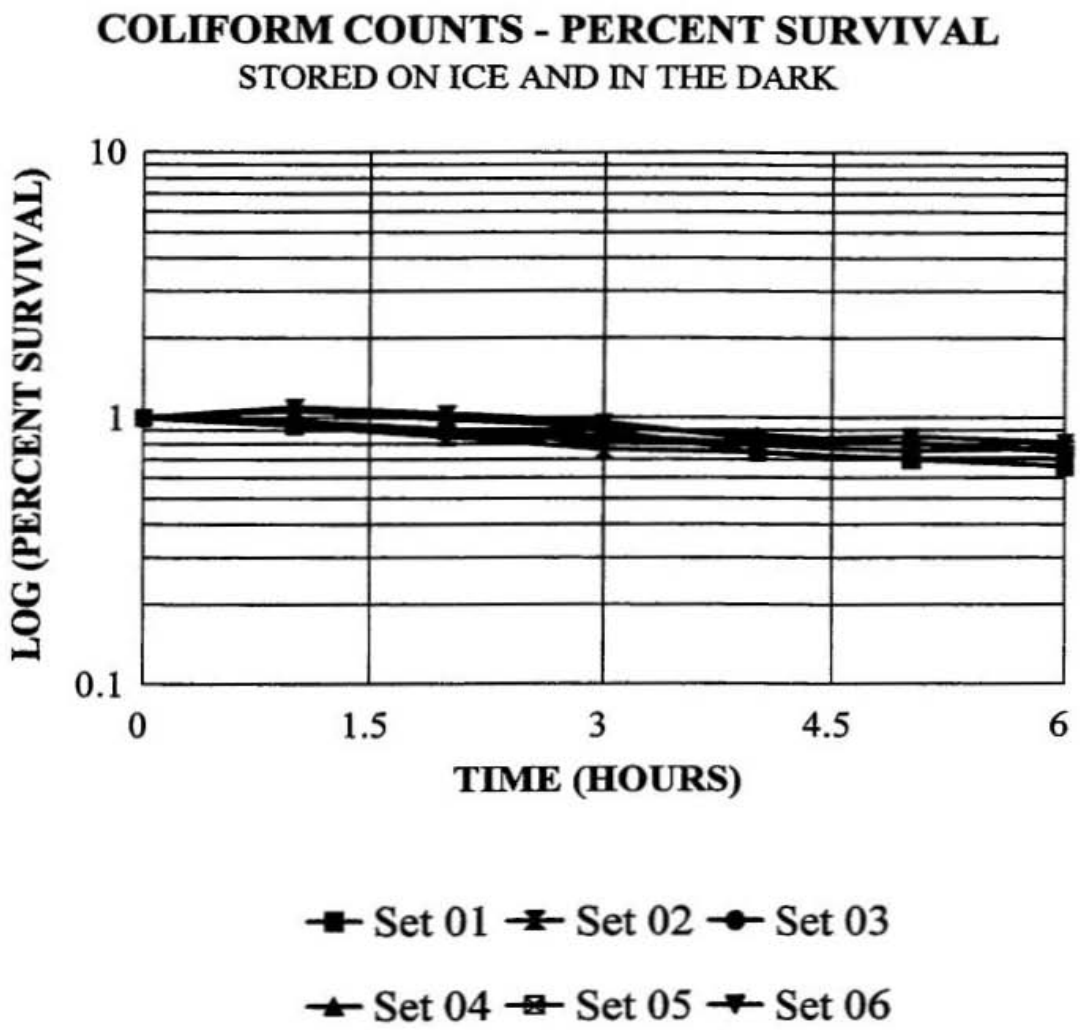


Figure 4.3 - Sample "A" Percent Survival (log graph)

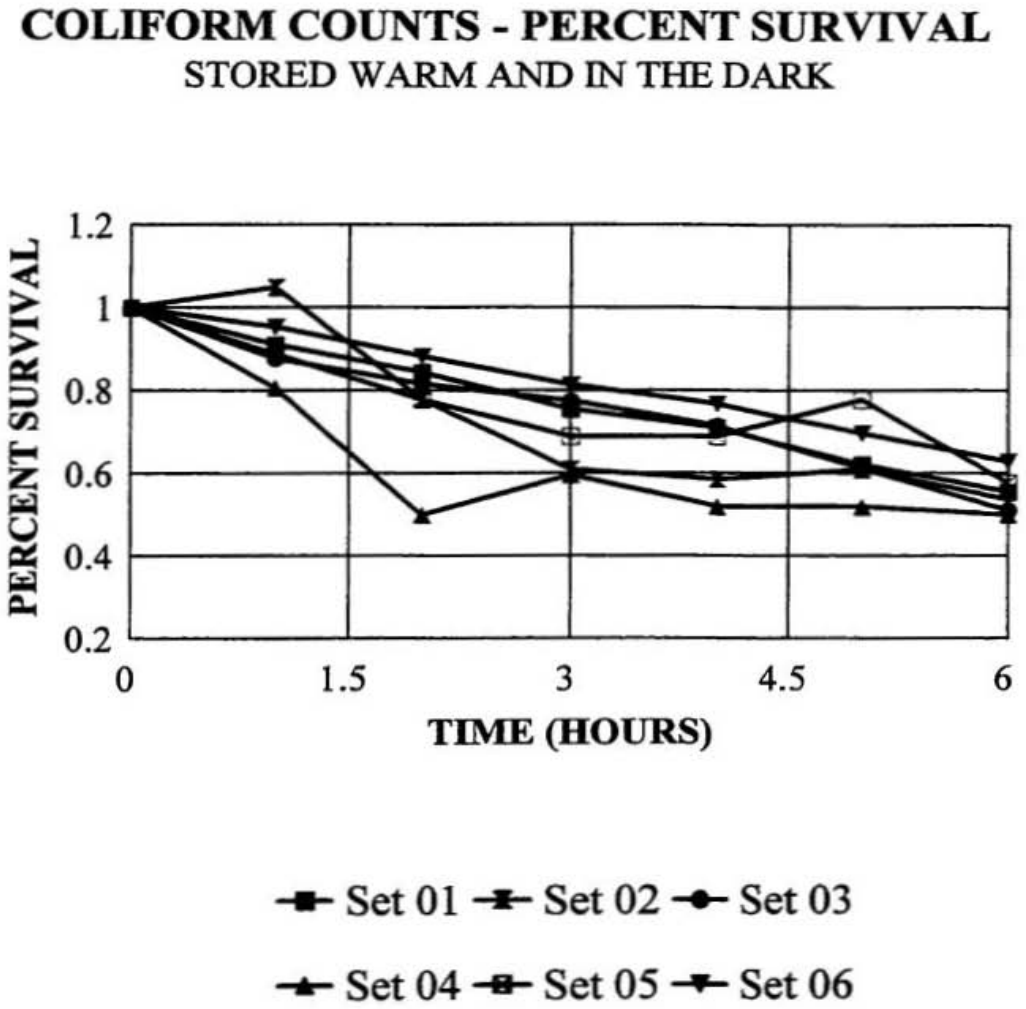


Figure 4.4 - Sample "B" Percent Survival (normal graph)

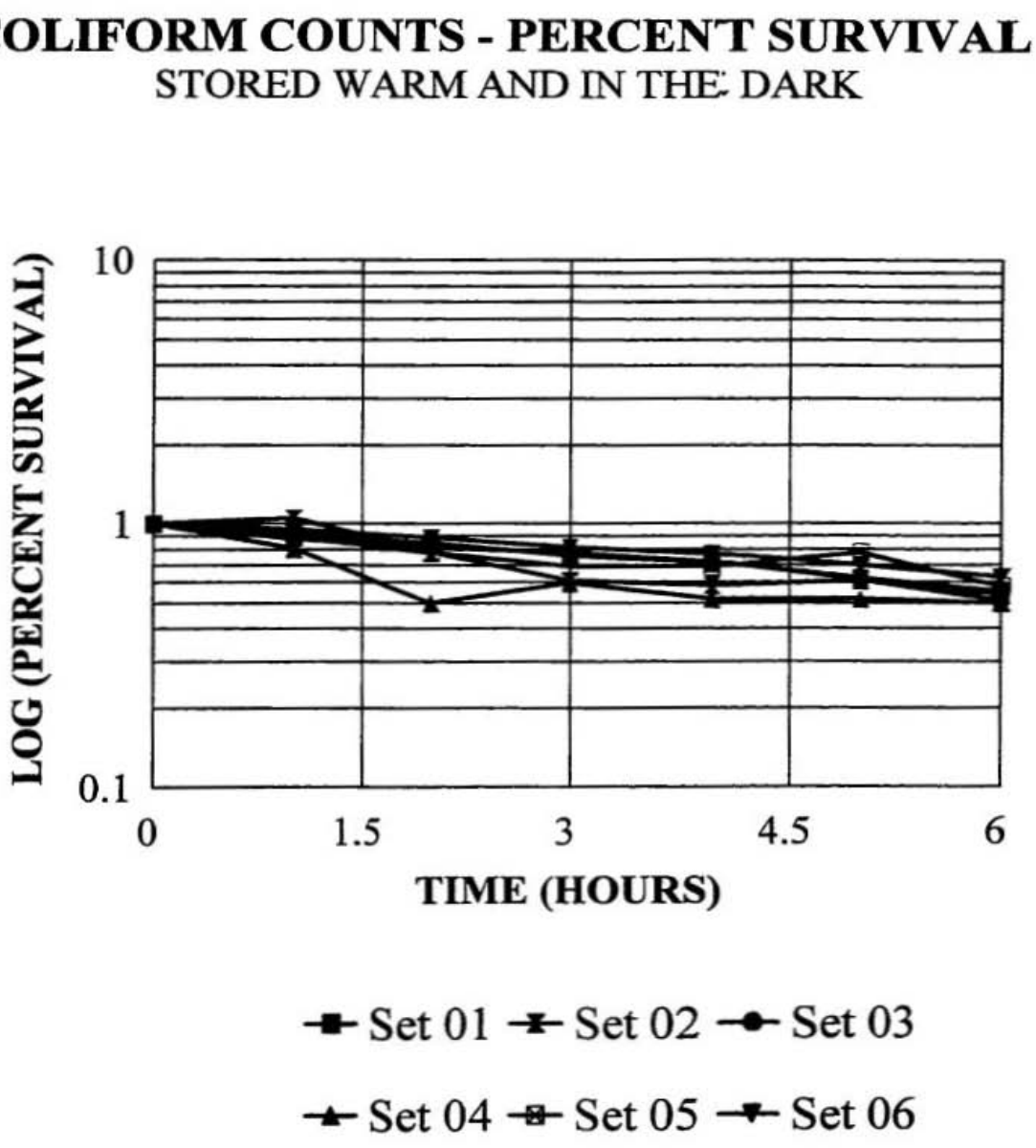


Figure 4.5 - Sample "B" Percent Survival (log graph)

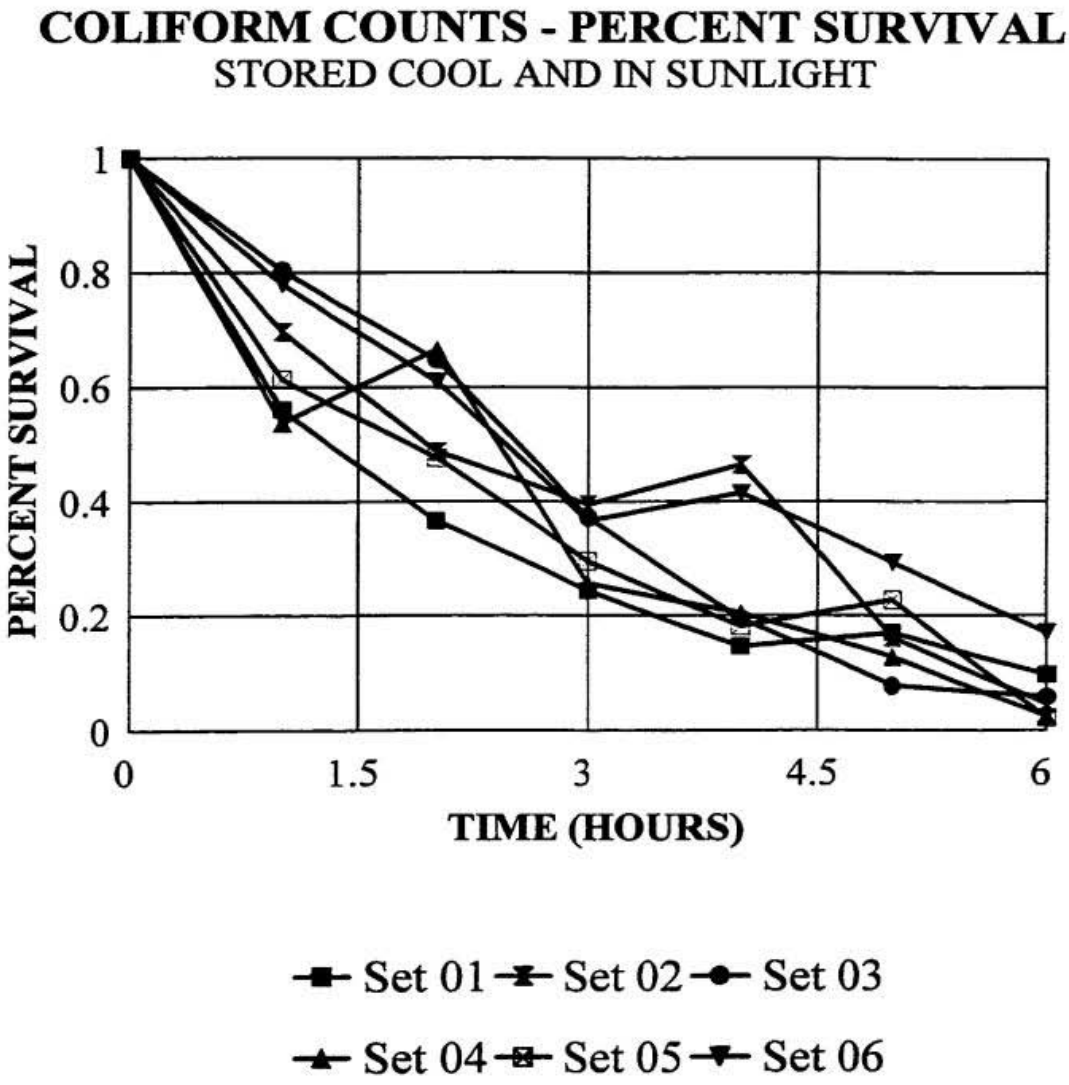


Figure 4.6 - Sample "C" Percent Survival (normal graph)

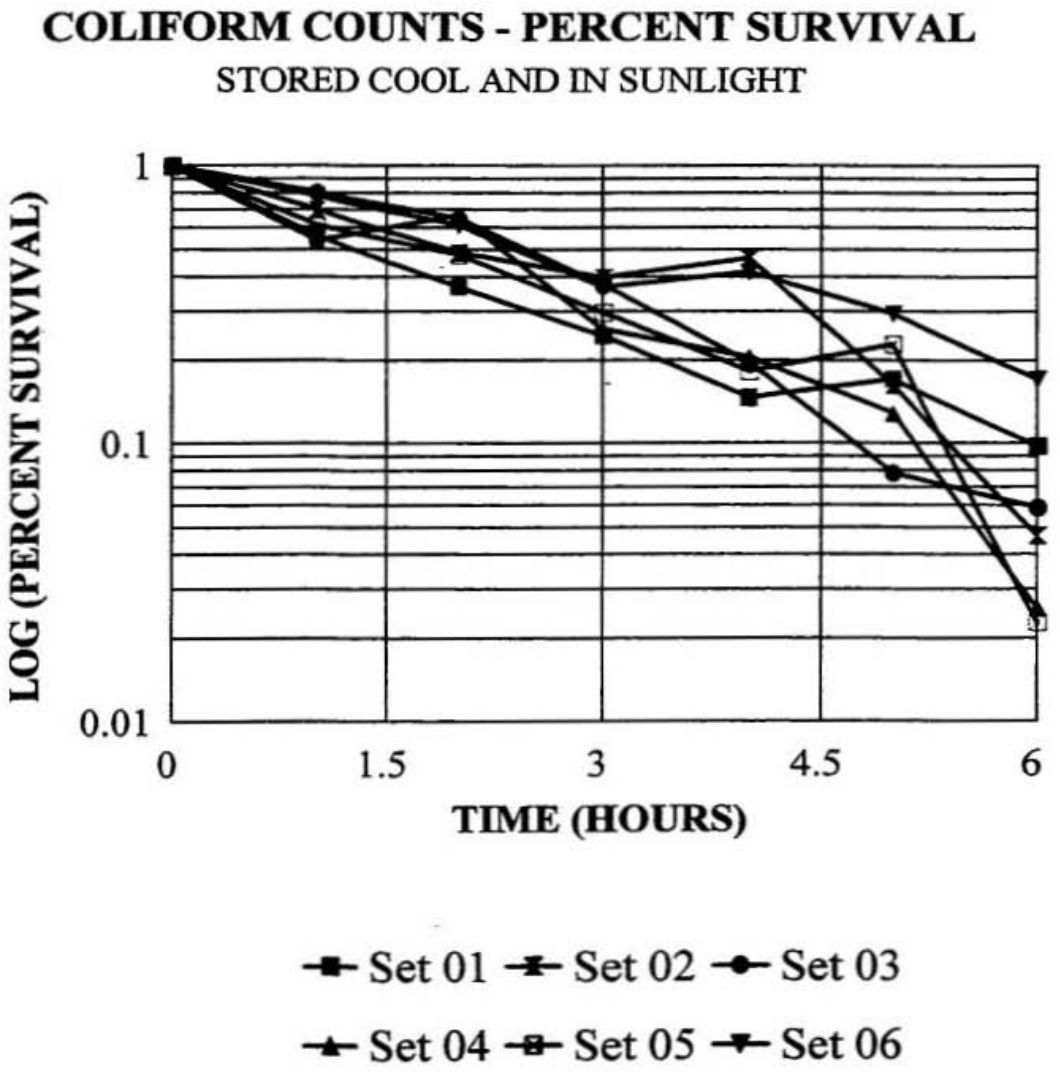


Figure 4.7 - Sample "C" Percent Survival (log graph)

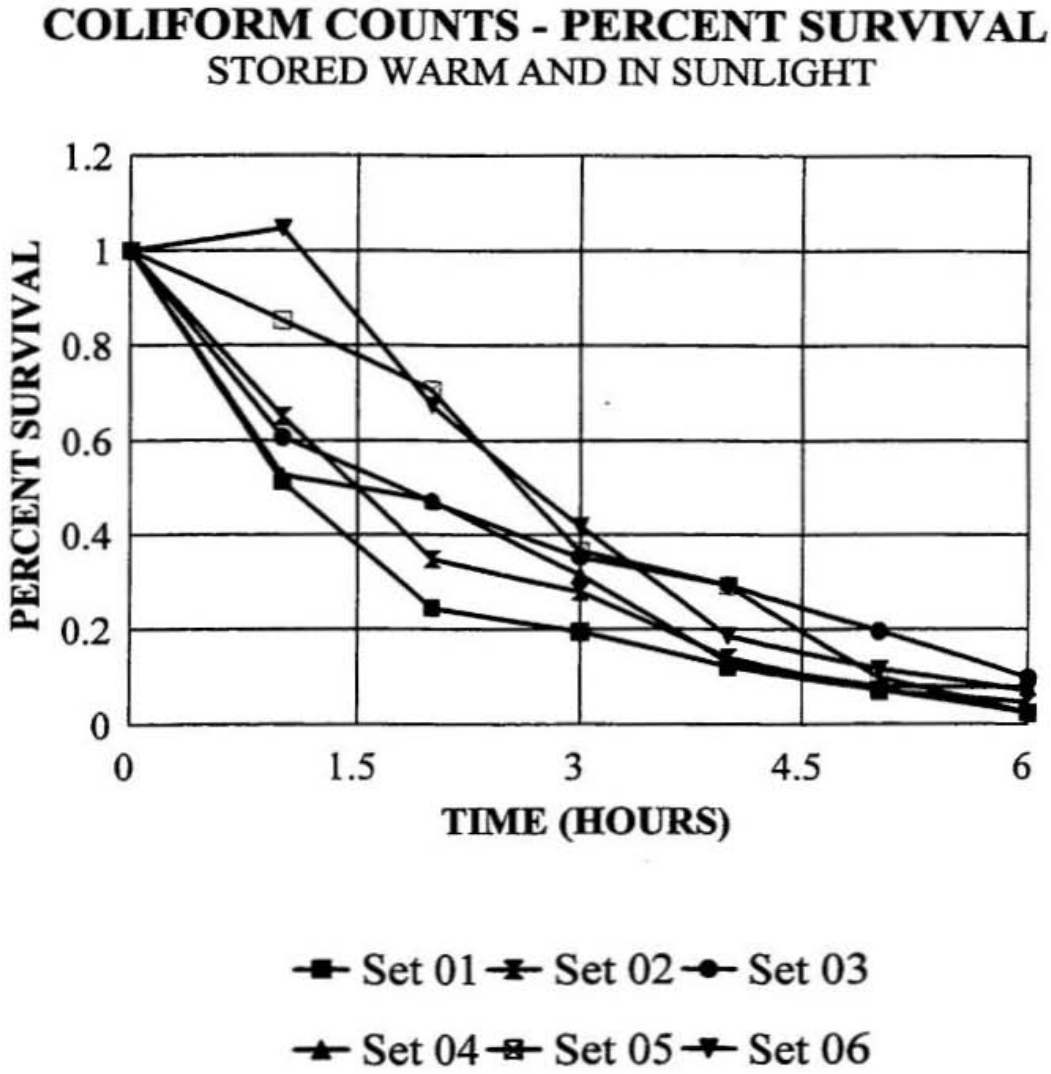


Figure 4.8 - Sample "D" Percent Survival (normal graph)

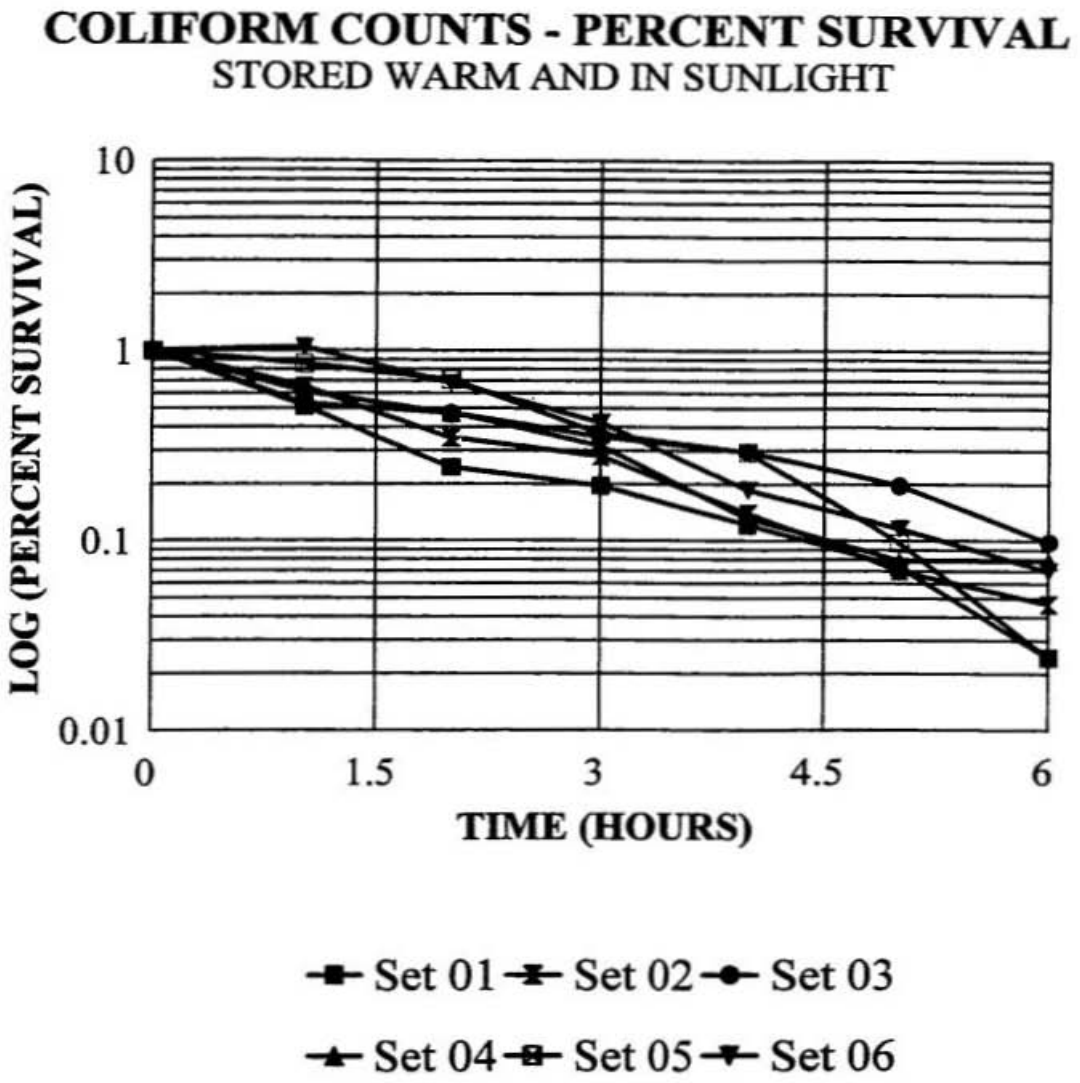


Figure 4.9 - Sample "D" Percent Survival (log graph)

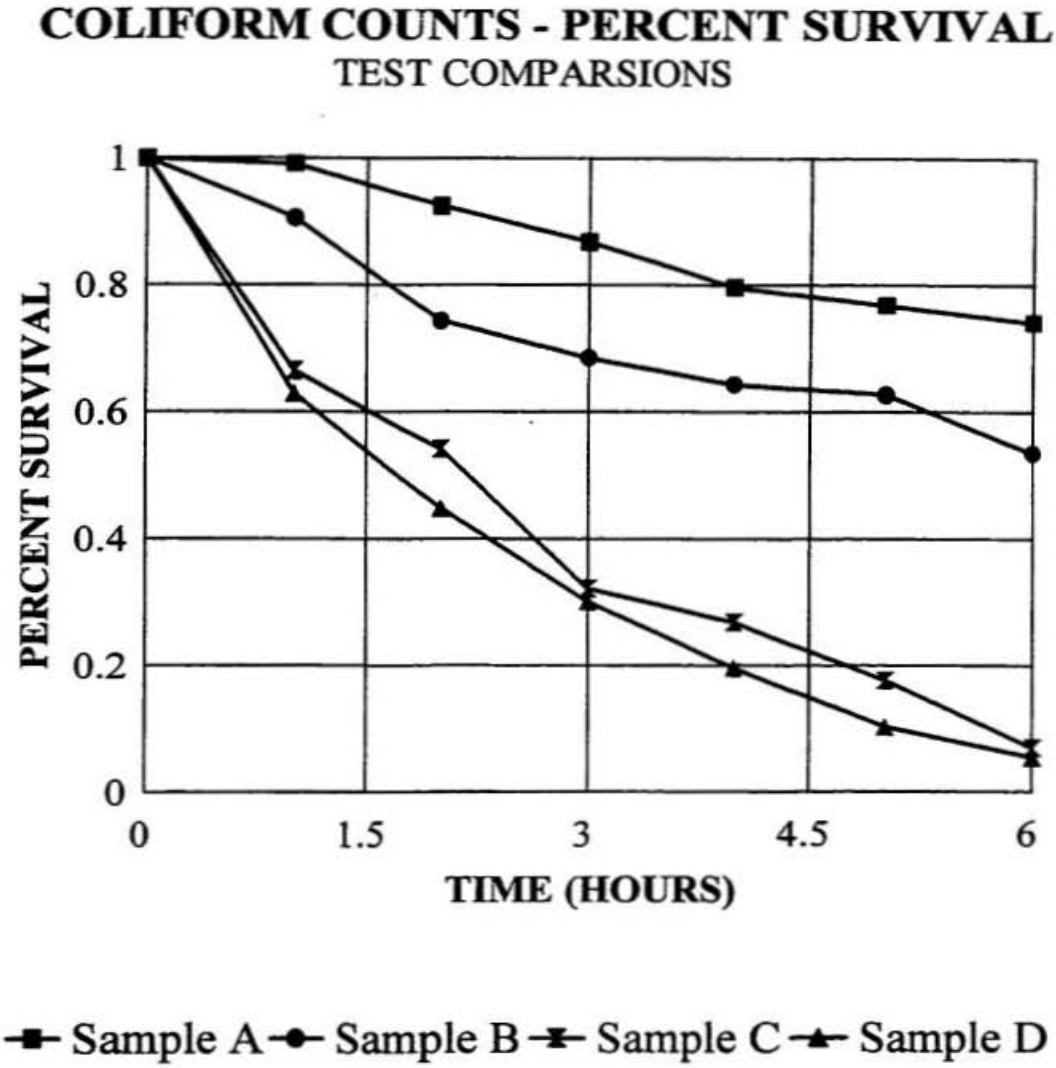


Figure 4.10 - Test Comparisons

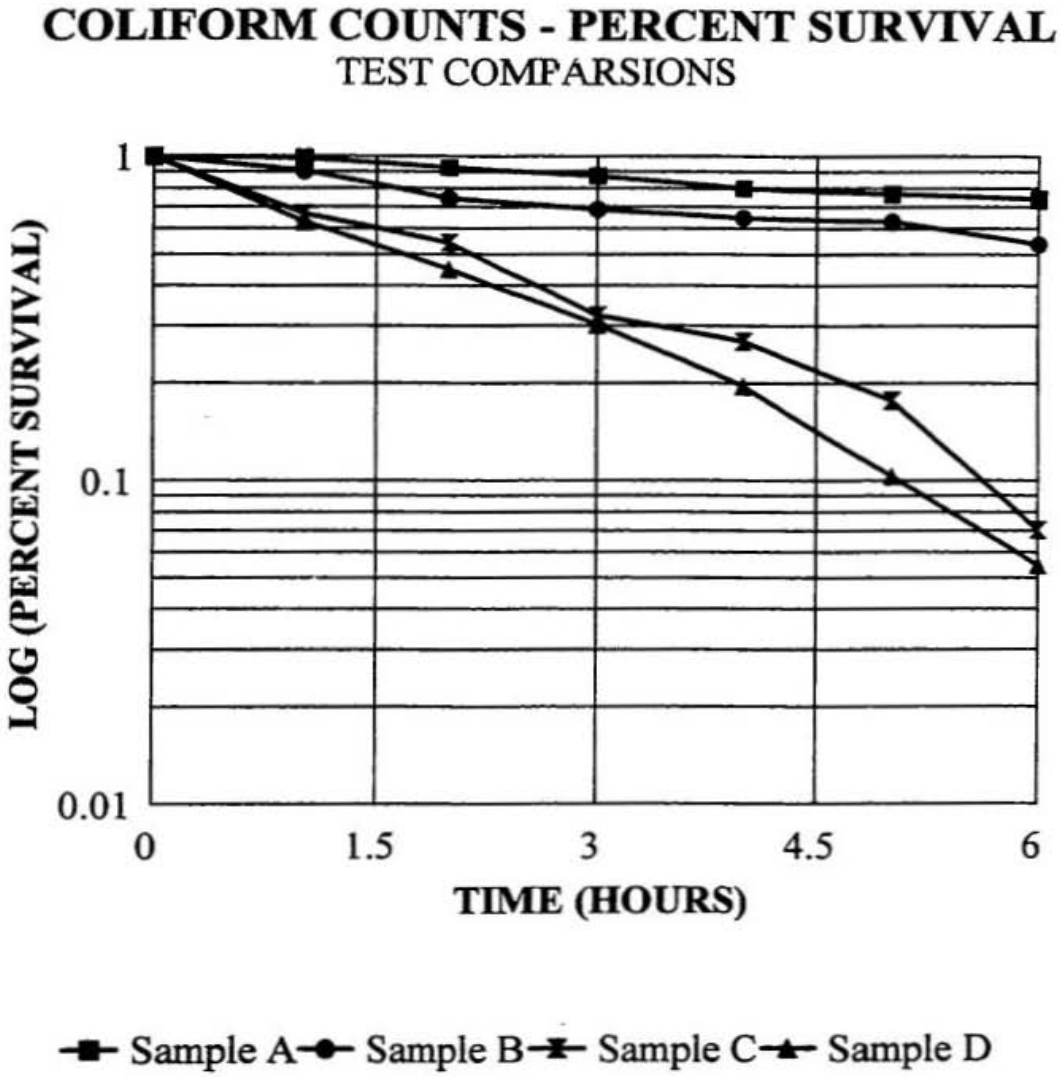


Figure 4.11 - Test Comparisons (log scale)

4.3.2 EFFECTS OF TEMPERATURE AND SUNLIGHT

Logs were taken of the survival rates (Ct/Co) and regression analysis was used to determine the equation of the line each set, from this the T_{90} was determined by taking the inverse slope of each line. This is because as (outlined in Chapter two) the relationship between T_{90} and Ct/Co is:

$$\frac{C}{C_o} = 10^{-\frac{t}{T_{90}}} \qquad \textbf{2.39}$$

By taking the logs of both sides and solving for $1/T_{90}$

$$\frac{1}{T_{90}} = \frac{\log\frac{C}{Co}}{t} \qquad \textbf{4.1}$$

The right-hand side of equation 4.1 is the slope of a graph of log percent survival versus time. Using this relationship T_{90} values were obtained for all four test conditions. These values are presented in Table 4.7.

Table 4.7 - T_{90} Times

Sample	T_{90} - Hours					
	Set 01	Set 02	Set 03	Set 04	Set 05	Set 06
A (Cool, Dark)	31.746	36.364	47.847	40.984	48.540	47.619
B (Warm, Dark)	24.096	19.920	22.422	22.026	31.949	30.488
C (Cool, Sunlight)	6.290	5.320	4.484	2.604	4.528	8.475
D (Warm, Sunlight)	4.082	4.425	6.623	5.076	4.082	4.717

In order to determine the effects of sunlight and water temperature on the T_{90} times of the stored samples, a two way analysis of variance (ANOVA) test was conducted. An ANOVA test compares the means of several groups to determine if the differences in means are statistically significant. In the ANOVA test a null hypothesis (Ho) is tested against its alternative (Ha) at a level of significance indicated by a P value. In this case Ho, Ha and the level of significance would be:

Ho = The sample means are the same

Ha = The sample means are different

Level of significance = 0.95

The P value, which is the smallest level of significance at which Ho could be rejected, would determine if Ho is accepted or rejected. For a 95 percent significance, if the value of P from

the test exceeds 0.05 then the test is said to pass, and Ho is not rejected, otherwise Ha is considered to be true.

Basically the answers to three questions were sought:

1) Does sunlight have a significant effect on the T_{90} time of the samples.

2) Does water temperature have a significant effect on the T_{90} times of the samples.

3) Do the effects of water temperature and sunlight interact. In other words, is the difference between the T_{90} times for the samples stored at different temperatures the same for all sunlight conditions.

The data from Table 4.7 was entered as shown in Table 4.8 into a statistical software package for analysis. The results of this analysis can be seen in Table 4.9. A complete output of the results is given in Appendix "B".

Table 4.8 - ANOVA Data

	T_{90} Time (Hours)											
	Cool						Warm					
Dark	31.746	36.364	47.847	40.984	48.54	47.619	24.096	19.92	22.422	31.026	31.949	30.488
Light	6.29	5.32	4.484	2.604	4.528	8.475	4.0820	4.425	6.623	5.076	4.082	4.717

Table 4.9 - ANOVA Results

Source of Variation	% of Total Variation	P Value	Significant
Temperature	7.43	0.0002	Yes
Sunlight	79.56	Less than 0.0001	Yes
Interaction	6.68	Less than 0.0001	Yes

From these results it can be seen that both sunlight and water temperature have a significant effect on the T_{90} time of the samples as the P value is less than 0.05 in all cases. In addition interaction is also significant.

The relative strength of the percent variance for each factor (Temperature at 7.43% and Sunlight at 79.56%) would suggest that while temperature is significant its actual effects are very small compared to the effect of sunlight. As a further proof of this, the mean T_{90} times for the samples stored in dark and light were also compared using a T test. The T test is similar to the ANOVA test, but can only compare two groups. The level of significance and the hypothesis remain the same. The results of which can be seen in Table 4.10

The test here is to see if the means are identical. For example if the mean T_{90} time for

samples stored warm and in sunlight and the mean for samples stored cool and in sunlight are the sample it can be assumed that this data belongs to the same group and that water temperature did not have an important effect.

Table 4.10 - T_{90} Mean Comparison

Samples	Difference in Means	t Value	P Value	Significant
Dark	17.03	6.674	Less than 0.001	Yes
Light	0.04493	0.1761	Greater than 0.05	No

For the samples stored in the dark the difference was found to be significant. In other words, the conditions of the test (one set stored warm and one stored cool) did have an effect. This would indicate that water temperature was significant.

For the samples stored in the sunlight the difference in means was not significant. Water temperature did not have any noticeable effect. Whether the samples were stored warm or cool did not change the resulting mean T_{90} time.

This effect can also be seen in Figure 4.12. Here it the differences in the T_{90} times can be clearly seen. The samples stored in the dark did differ noticeably while the samples stored in light did not.

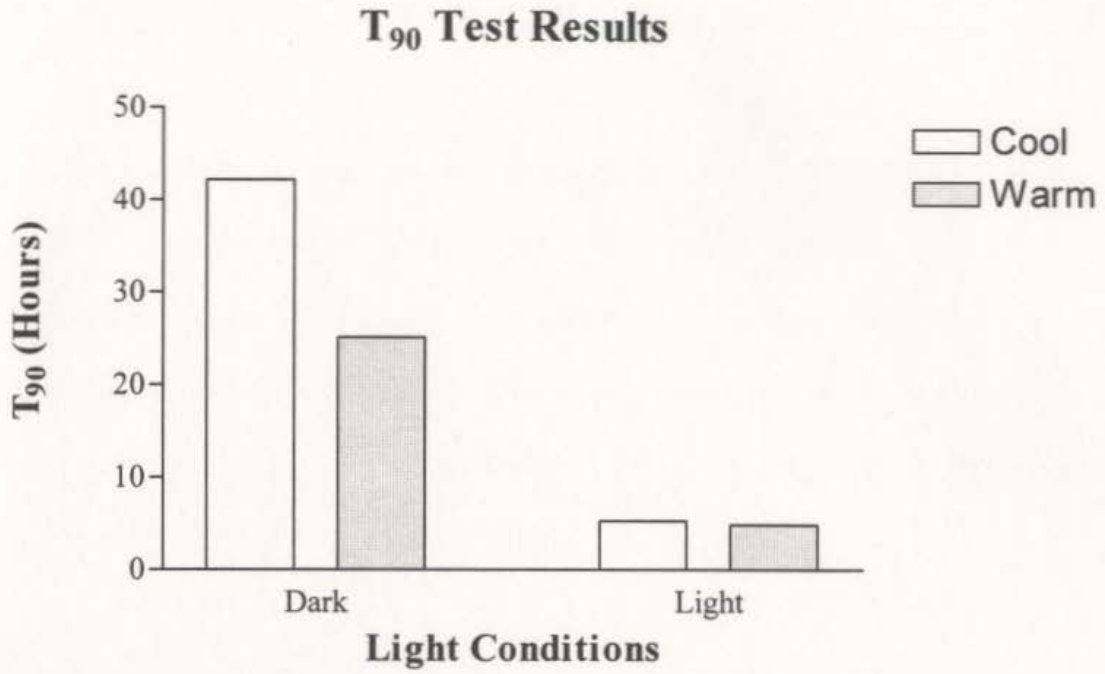


Figure 4.12 - T_{90} time vs Light Conditions

4.4 DISCUSSION

The effect of temperature on storage of coliform samples does have some significance, as a difference was noted in T_{90} times for both samples stored in the dark (A and B). However, when the effect of sunlight is added, temperature effects cannot be seen as in the comparison of samples C and D. It seems that the effect of sunlight is so much greater than that of temperature, that the effect of temperature is not noticeable in daylight conditions.

As for the effects of storage time, samples stored on ice and in the dark (Sample A) had the best survival rate of all samples tested. In six hours of storage, an average of 75 percent of coliforms survived, as compared to 54, 6.6 and 5.4 percent for samples B, C and D respectively. However overnight storage would still lead to a 33 percent reduction in coliform counts under conditions of sample A. (ie. stored in the dark and kept on ice). The best recommendation for sample storage is to store the sample on ice and keep it in the dark. Even so, analysis should still be done as soon as possible, as bacterial decay will still occur under these conditions. The concentrations of coliforms in all the samples did experience a 25 percent reduction over a six-hour period.

Since the purpose of this pre-study was to determine the effect of bacterial decay on the results of T_{90} testing, it can be seen from Figure 4.10 that the slopes of the graphs are essentially linear. The T_{90} time is derived from the slope of these graphs, so a constant slope would indicate a constant T_{90}. In other words, the decay of bacteria during transport and storage from the sampling site to the laboratory would not affect the results. No adjustment in the T_{90} values would be needed. If the graphs had not been linear, such as a large initial drop followed by a gradual die-off, then an adjustment of the T_{90} counts for each sample would have to be preformed.

5.0 BACTERIAL DECAY IN COLD OCEAN WATERS

5.1 INTRODUCTION

As discussed earlier, the primary purpose of this study was to determine the T_{90} time for sewage decay in Newfoundland waters and to learn if cold water temperatures around Newfoundland would affect the rate of bacterial inactivation. This was studied by measuring the rate of decay of coliform bacteria in ocean water.

5.2 METHODOLOGY

Samples of raw sewage were obtained from a trunk sewer in Mount Pearl, the same site used in the sample storage tests, as outlined in Chapter 4. To ensure a good sample, the sewage was obtained in the early morning before the test started, (around 7:30 A.M.). The sewage was then brought to the test site, which was the wharf in St. Phillips, and was mixed with ocean water at the dilution ratio of 1 part sewage per 99 parts ocean water. This was the same dilution ratio used in the bacteria storage testing from Chapter 4.

Immediately after mixing the container was lowered into the ocean, and a sample was taken. This initial sample would be the start of the testing.

5.2.1 SEWAGE MIXTURE CONTAINER

To simulate ocean conditions, a large floating box was used to hold the sewage sample in the ocean. The dimensions of the box were 100 cm high by 50 cm wide and 50 cm deep. The typical procedure during sampling was to half fill the box with the sewage mixture, giving a sample size of 50 x 50 x 50 cm, or 125 liters. With the box only half full it floated quite well and enough of the box remained out of the ocean to stop waves from entering and thus diluting the sample. The box itself was constructed of clear lexan which allowed sunlight to pass through. See Figure 5.1

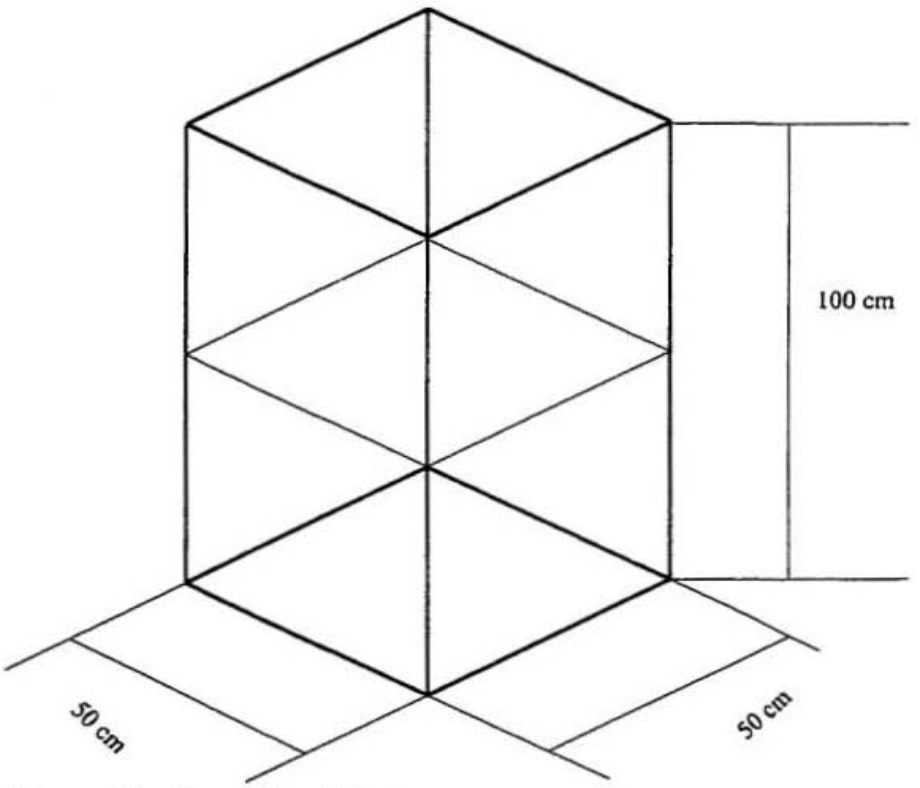


Figure 5.1 - Sample Container

5.2.2 SAMPLING PROCEDURE

Three 300 ml samples of the sewage mixture were taken every half hour, at different positions in the box (ie. the middle, bottom and side). These samples were then labeled, placed on ice and stored in a portable cooler to keep them in the dark. The temperature of the water was also taken at this time and recorded.

The sewage mixture in the box was also stirred every fifteen minutes to simulate ocean conditions and to ensure that the sewage was evenly mixed and had been exposed to sunlight. A total of 17 tests were completed using this procedure, nine in the summer months of 1993 and eight in the following winter months of 1994. The dates of the test are shown in Table 5.1.

Table 5.1 - Test Dates

Test Number	Date
1	July 18, 1993
2	July 21, 1993
3	August 8, 1993
4	August 17, 1993
5	August 25, 1993
6	September 7, 1993
7	September 13, 1993
8	September 19, 1993
9	September 22, 1993
10	January 12, 1994
11	January 25, 1994
12	February 1, 1994
13	February 13, 1994
14	February 23, 1994
15	March 6, 1994
16	March 16, 1994
17	March 23, 1994

5.2.3 TESTING PROCEDURE

After the last sample for the day had been taken at 3:00 P.M., the container was recovered from the ocean and flushed with ocean water. The samples were then brought to the Public Health Lab in St. John's for total coliform analysis by the Membrane Filtration Method. Each sampling time had three samples, so they were combined to ensure a representative sample, (ie. the thee sample bottles were poured into one container and mixed). In addition, each of these combined samples was analysed twice, and the results averaged. The full set of data sheets for the Membrane Filtration Method can be found in Appendix "C"

Table 5.2 gives the results of the Membrane Filtration Method, where count is the actual number of bacteria colonies found in each sample. It is an assumption of the Membrane Filtration Method that each colony originated from one bacterium, so ten colonies would represent 10 coliforms in the test sample.

Table 5.2 - Bacteria Counts for each test.

	Colony Count for each Test Number																
Time	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**	**#17**
9:00	47	51	39	53	48	51	42	44	53	61	50	52	61	57	56	54	41
9:30	14	54	39	31	36	59	31	41	47	53	41	55	41	45	40	45	30
10:00	23	43	46	25	27	41	24	37	41	45	40	40	40	46	41	37	25
10:30	18	54	53	29	24	35	22	22	51	47	37	35	35	29	32	35	32
11:00	18	34	26	18	30	37	17	20	51	32	26	30	34	22	30	28	24
11:30	15	36	13	12	16	20	13	19	42	29	30	32	36	25	28	29	19
12:00	10	33	13	21	9	18	11	21	47	25	27	25	28	25	22	27	18
12:30	6	20	9	7	10	15	8	17	31	25	28	23	20	21	28	25	18
1:00	4	21	5	4	7	12	5	8	23	20	25	22	26	17	18	18	15
1:30	2	10	4	3	4	7	4	6	14	19	17	20	24	15	16	13	13
2:00	2	7	3	2	4	4	7	4	16	17	15	12	20	12	12	10	14
2:30	1	4	2	0	3	5	3	6	10	12	12	6	13	12	7	9	9
3:00	2	1	0	2	0	2	4	3	6	8	5	5	10	7	3	6	5

5.3 DETERMINATION OF T_{90} TIME

For comparison, all coliform counts were normalized against the initial values (time = 0) using the formula Ct/Co, where Co is the initial value of each set and Ct is the actual coliform count at any given time. This was expressed as percent survival - the proportion of total coliforms remaining after a time interval. For example if the count at time t = 0 had been 100 coliforms and the count at time = 1 hour had been 25 coliforms, the resulting ratio would have been 25/100 or 0.25. This would show that 25 percent of the coliforms had survived for one hour.

Logs were taken of the survival rates (Ct/Co) and a regression analysis was used to determine the equation of the line for each test. From this the T_{90} time was determined by taking the inverse slope of each line. This procedure was described in Chapter 4. Table 5.3 lists the T_{90} values for each test.

Table 5.3 - T_{90} Values

Test Number	Date	T_{90} Time (hours)
1	July 18, 1993	3.92
2	July 21, 1993	4.18
3	August 8, 1993	3.74
4	August 17, 1993	4
5	August 25, 1993	4.42
6	September 7, 1993	4.37
7	September 13, 1993	5.46
8	September 19, 1993	5.23
9	September 22, 1993	6.85
10	January 12, 1994	8.19
11	January 25, 1994	6.6
12	February 1, 1994	6.4
13	February 13, 1994	9.7
14	February 23, 1994	7.6
15	March 6, 1994	5.2
16	March 16, 1994	6.7
17	March 23, 1994	6.3

5.3.1 AVERAGE T_{90} VALUES

The average T_{90} values for the summer (July to September) were computed to be approximately four hours, while the winter values (September to March) were higher, at six and one half hours.

5.4 ANALYSIS OF RESULTS

First the relationship between bacterial decay, water temperature and UV data was needed. It is assumed that there is a strong relationship between the bacterial decay and the amount of ultraviolet radiation, as current literature suggests, but the relationship between the rate of bacterial decay and the water temperature was unclear, and thus became the major purpose of this study.

5.4.1 EFFECT OF WATER TEMPERATURE

Besides the determination of the T_{90} time, the effect of the water temperature on the rate of coliform decay was also studied. The assumption was that the colder water temperatures found around Newfoundland, would cause a reduction in the decay. A plot of water temperature vs. T_{90} times as shown in Figure 5.2 seemed to confirm this. As the water temperature increased, the T_{90} time dropped.

While it appears a trend between the water temperature and the T_{90} time, suggesting that bacteria decay is affected by water temperature, this was not found. The shape of the graph is due to the fact that the colder water temperatures were encountered in the winter months, in which the strength of the UV radiation is lower than the summer months. Figure 5.3 clearly shows this effect, with less UV radiation, the bacteria decay rate was decreased and the T_{90} time increased. This effect is discussed in the next section.

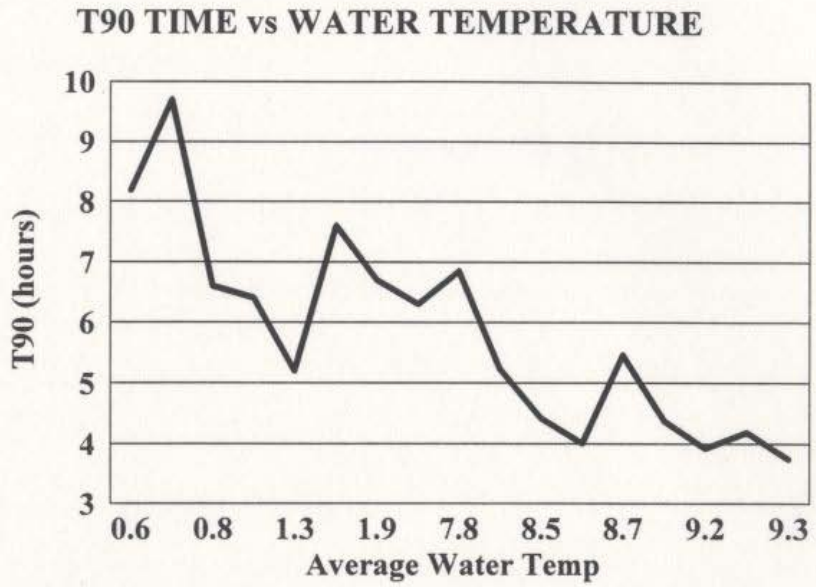


Figure 5.2 - T_{90} Time vs Water Temperature

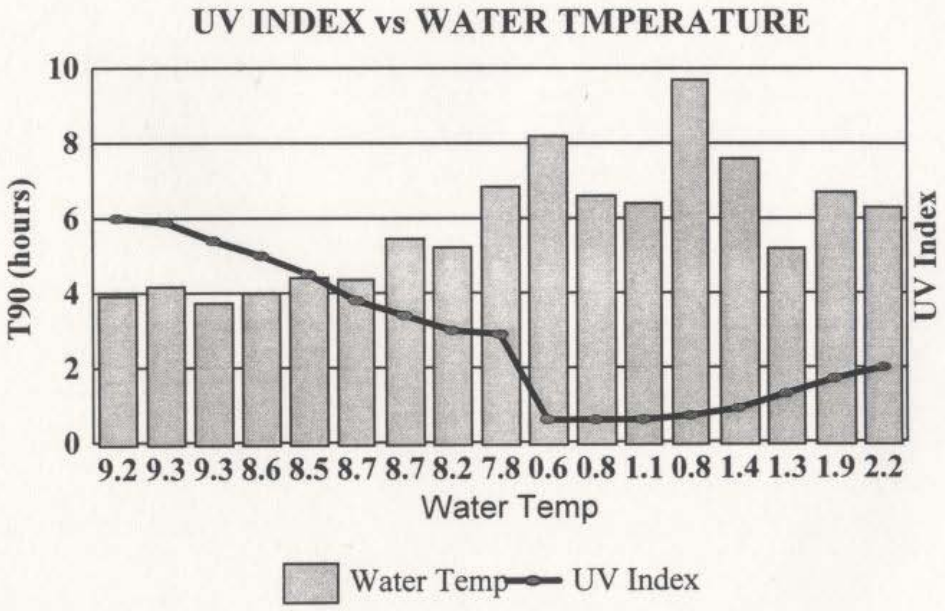


Figure 5.3 - UV Index vs Water Temperature

5.4.2 REGRESSION ANALYSIS

To figure out the relationship, values of the average water temperature, T_{90} time and the UV index were combined in a regression analysis. The data for the UV index was obtained from Environment Canada. Minitab, a popular statical analysis program was used to perform the regression analysis.

Table 5.4 - Regression Values

Average Water Temperature	T_{90} Time (hours)	UV Index
9.2	3.92	6
9.3	4.18	5.9
9.3	3.74	5.4
8.6	4	5
8.5	4.42	4.5
8.7	4.37	3.8
8.7	5.46	3.4
8.2	5.23	3
7.8	6.85	2.9
0.6	8.19	0.6
0.8	6.6	0.6
1.1	6.4	0.6
0.8	9.7	0.7
1.4	7.6	0.9
1.3	5.2	1.3
1.9	6.7	1.7
2.2	6.3	2

Originally a simple linear regression model was used to figure out the relationship between average water temperature, T_{90} time and the UV index.

The results from the regression calculation were:

T_{90} = 7.86 - 0.014 Avg Temp - 0.693 UV Index **5.1**

Table 5.5 - Linear Regression Results

Predictor	**Coefficient**	**Standard Deviation**	**t-ratio**	**p value**
Constant	7.8568	0.4267	18.41	0.000
Avg Temp	-0.0141	0.1680	-0.08	0.934
UV Index	-0.6927	0.3287	-2.11	0.054
s = 0.9832	**R-sq = 70.4%**		**R-sq(adj) = 66.2%**	

This table contains the estimate for each of the regression coefficients (Average water temperature, UV Index), their standard deviations and the t ratios and p values for testing the hypothesis that a coefficient is zero. In other words, a high p value would imply that a coefficient does not affect the regression equation. The p value for average water temperature was extremely high, thus suggesting that water temperature may not affect the T_{90} time. In addition, the R-sq term represents the accuracy or fit of the model. In this case 66.2% of the T_{90} values can be explained by equation 5.1.

Since a linear regression model was used in this analysis, determining the appropriateness of a linear model is important. In order for linear model to be correct, several assumptions have to be proved:

1) The error term has a normal distribution. In other words, the difference between the actual data and the model has a normal distribution.

2) The error term has a constant variance. The difference between the actual data and the model will be randomly scattered and not follow any pattern.

3) The error term has to be independent. The errors associated with the model should not be affected by other variables.

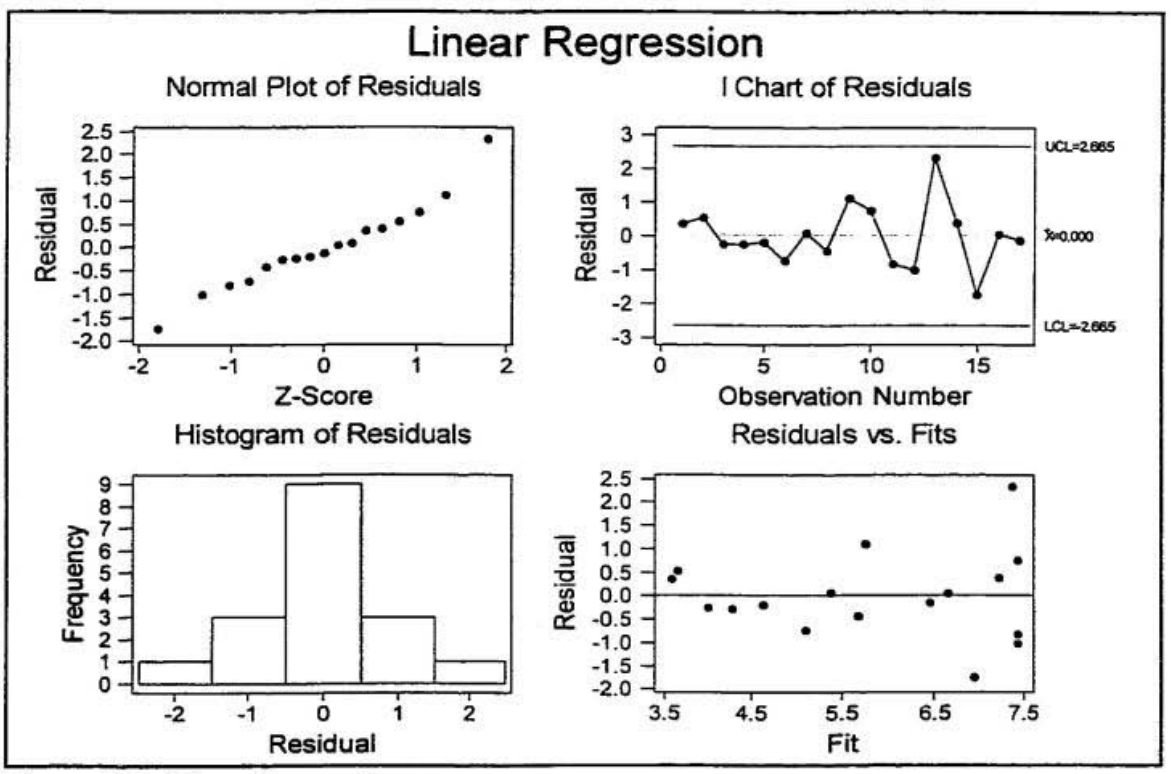


Figure 5.4 - Linear Regression

To determine this, several graphs were constructed, and can be seen in Figure 5.4. The Normal plot of Residuals gives an indication if the error term is normal. If the error is normal the plot will resemble a straight line. The I Chart of Residuals indicates the independence of the residuals by plotting the residuals against the observation number. If the error term is not independent then some pattern may be seen.

The Histogram of Residuals indicates if the error term follows a normal distribution, the graph should follow a Gaussian distribution.

Of particular interest, is the graph of Residual vs. Fits, as shown in the lower right corner of the figure. In a regression analysis, the object is to find the equation of a line that best fits all the data. The plot of residual vs. fits, graphs the residuals, which are the differences between the regression line and the actual data, versus the actual fitted line or model. For a linear model, the plot should show a constant variance or spread of data. Here, it is noted that the graph tends to flare out toward the right-hand side. In addition, from the I Chart of Residuals, it can be seen that the magnitude of the error increases with the observation number. The variance increases as the fitted values increases, suggesting that a transformation of the Y values (T_{90}) should be conducted to counteract this variance. This was conducted by inverting the T_{90} values and again performing the regression analysis.

The new regression equation is:

$$INVT_{90} = 0.119 - 0.00265 \text{ Avg Temp} + 0.0282 \text{ UV Index} \qquad \textbf{5.2}$$

Table 5.6 - Regression Results - $1/T_{90}$

Predictor	Coefficient	Standard Deviation	t-ratio	p value
Constant	0.119148	0.009859	12.09	0.000
Avg Temp	-0.002647	0.003882	-0.68	0.506
UV Index	0.028167	0.007594	3.71	0.002
s = 0.02272 R-sq = 82.6% R-sq(adj) = 80.1%				

The accuracy of the model has increased from 66.2 % to 80.1%, suggesting that the

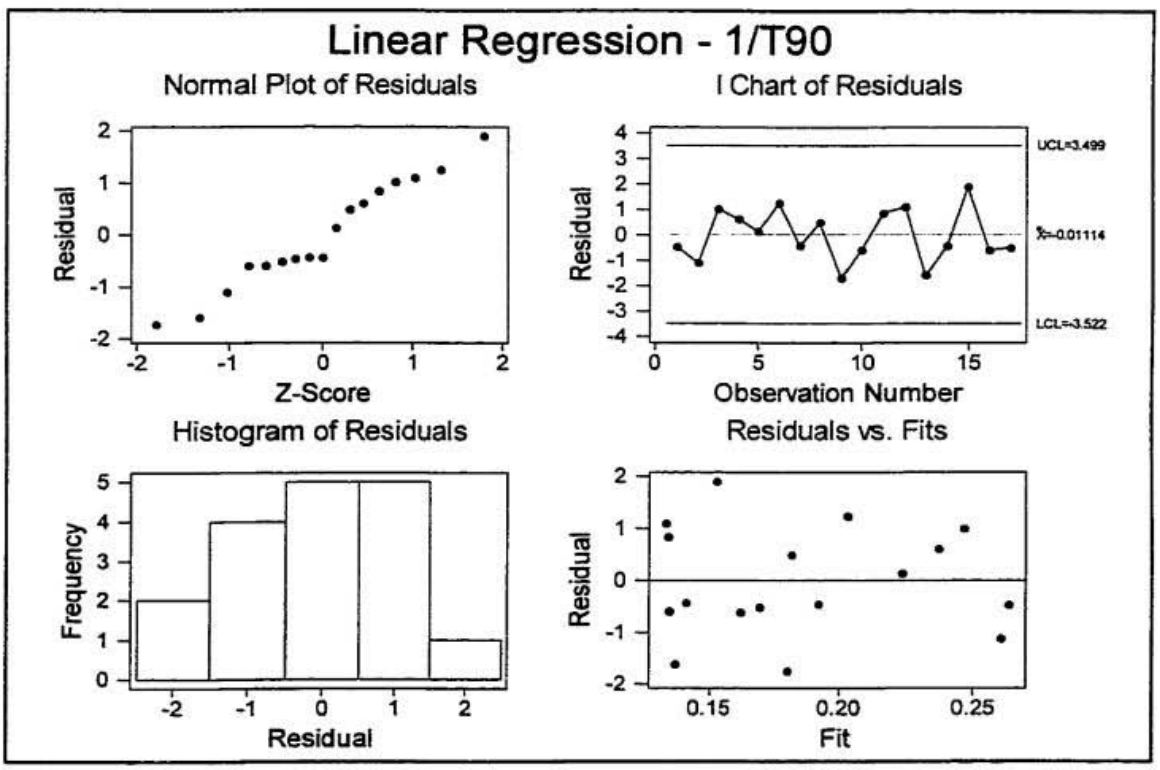


Figure 5.4 - Linear Regression with $1/T_{90}$

transformation was effective. Similar graphs of the residuals were also created for this analysis and can be found in Figure 5.5. It can be seen that the spread of the residual versus fitted values is much more consistent here.

The p value for the Average Temperature is still quite high, suggesting that the average temperature term has no value in the equation. To confirm this, a regression analysis was done again, but with only T_{90} and the UV index.

The regression equation without the water temperature term is:

$$INVT90 = 0.119 + 0.0234 \text{ UV Index} \qquad \textbf{5.3}$$

Table 5.7 - Regression results - $1/T_{90}$ without Water Temperature

Predictor	**Coefficient**	**Standard Deviation**	**t-ratio**	**p value**
Constant	0.118996	0.009679	12.29	0.000
UV Index	0.023375	0.002825	8.27	0.000
s = 0.02231 R-sq = 82.0% R-sq(adj) = 80.8%				

The accuracy of the model has increased slightly without the average water temperature coefficient. The water temperature had no significant effect upon the rate of bacterial decay.

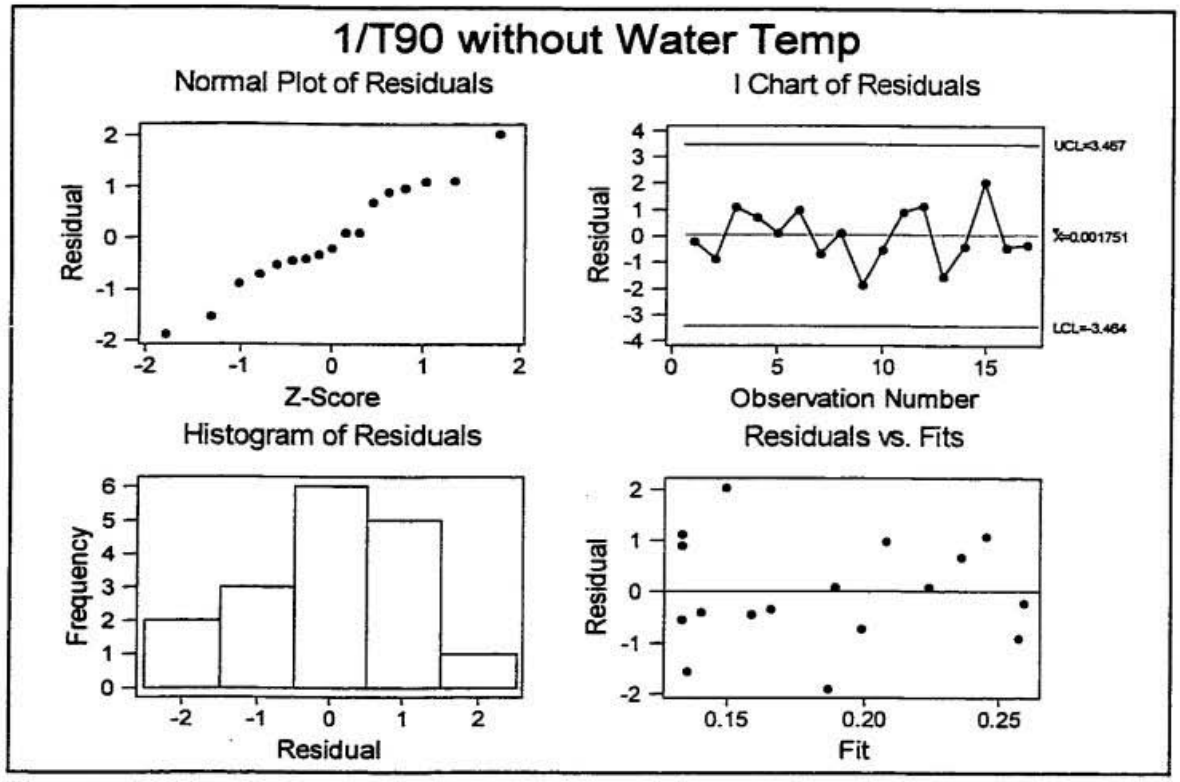


Figure 5.6 - Linear Regression with $1/T_{90}$ and no Water Temperature

In essence the regression equation for determining the amount of bacteria remaining could be written without the factor for water temperature, without any loss in fit to the model. Again as a check of the accuracy of the regression model, residual charts were constructed, and can be found in Figure 5.6.

5.5 DISCUSSION

The T_{90} time for bacterial decay in Newfoundland waters was determined to be approximately four hours in the summer months, while the winter values were higher, at

seven hours. These values agree with current literature, as discussed in Chapter 3.

Water temperatures were not found to have any significant effect upon the rate of bacterial decay, which agrees with the results from the effects of storage testing presented in Chapter 4. The effect of UV radiation may be so strong that it overrides any other mechanism acting on the bacteria. As these tests were conducted in daylight conditions, the effect of water temperature would not be noticeable.

6.0 DISPERSION

6.1 INTRODUCTION

As explained earlier, the primary purpose of this study was to determine the rate of bacterial inactivation in the cold Newfoundland waters. During the bacterial sampling, a local engineering company, Newfoundland Design Associates, had begun dispersion studies in Bonavista, Newfoundland for the purpose of construction of a new sewage outfall. It was thought the inclusion of this data would help define the rate of dispersion.

Since Bonavista harbour is in a fairly open sea environment it was thought that the rate of dispersion would be close to the rate experienced in open seas. As a comparison, a second study was performed in Carbonear harbour, which is a more sheltered and enclosed bay. The purpose of this section is therefore to evaluate the differences between the dispersion rates found in each harbour, by ascertaining the diffusion coefficient (K).

K represents the rate of growth or spread of a sewage plume in the ocean and is related to the size of the plume by the following equation:

$$K = \alpha L^{n} \text{ (Richardson, 1926)} \qquad \textbf{3.3}$$

Where L is the length scale of the plume, and α and n are constants relating the rate of growth of the plume. More detail on these coefficients is provided in Chapter 3.

6.2 METHODOLOGY

The process of determining the diffusion constant (K), as explained in section 3.2, was first proposed by Richardson (1926) and then refined by Stommel (1949). The principle is that a group of floats are placed in the water and their positions are tracked over a period of time. By measuring how fast the floats move apart, the rate of dispersion can be calculated.

Stommel's approach was to release the floats in pairs at an initial separation L_0 then to measure the separation L_1 after an elapsed time T. If the initial and final separations of the ith float pair are represented by L_0 and L_1, respectively. Then the scale of the process for the ith pair can be written as:

$$L = \frac{1}{2}(L_o + L_1) \qquad 3.6$$

For a group of N floats the scale would be

$$L = \frac{1}{2N} \sum_{i=1}^{N} (L_{o_i} + L_{1_i}) \qquad 3.7$$

Stommel (1949) has shown that the dispersion coefficient (K) of length scale (L) is given by:

$$K = \frac{\sum_{i=1}^{N} (L_{f_i} - L_{i_i})^2}{2NT} \qquad 3.8$$

Where:

L_f = the distance between two drogues at the end of a time period.

L_i = the distance between two drogues at the beginning of a time period.

N = the number of drogue pairs

T = the time period (Seconds)

It should be noted here that this procedure is used for the determination of lateral dispersion, or growth perpendicular to the ocean current movement, and has been used as a standard method of determining ocean dispersion.

6.3 DROGUE STUDIES

For the purposes of this study three float tests were conducted. The first in Bonavista harbour while the second and third in Carbonear harbour. The first of the Carbonear studies was performed in an open environment outside of the bay, while the second was performed inside the sheltered bay. The complete original measurements and survey notes for these

studies can be found in Appendix "D"

Basically, the procedure of these studies was to place four drogues into the water offshore. In these cases a boat was used for this purpose. The positions of the drogues were then tracked until retrieval was necessary as they had drifted far away from the starting point.

The complete breakdown of the tests was as follows:

Bonavistia Study - Three sets of float studies carried out, ranging from one half hour to 2 hours before the floats were retrieved. High winds and heavy seas were encountered during testing.

Carbonear Study #1 (Outside Harbour) - Two sets of float studies carried out, with the floats remaining in the water for a period of 3 hours before retrieval. High winds and heavy seas were encountered during testing, but the positions of the observers allowed the drogues to drift far offshore.

Carbonear Study #2 (Inside Harbour) - Two sets of float studies carried out, with the floats remaining in the water for a period of 3 hours before retrieval. Relatively calm seas and low winds were encountered during testing.

The drogues used are shown in Figure 6.1. The drogues consisted of two 1 meter by 1 meter aluminum sheets bent at right angles and welded together at these bends. A Styrofoam buoy was used to keep the drogues at a constant depth of 1.5 meters below the water surface and had a flag attached to aid in tracking of the drogue movements.

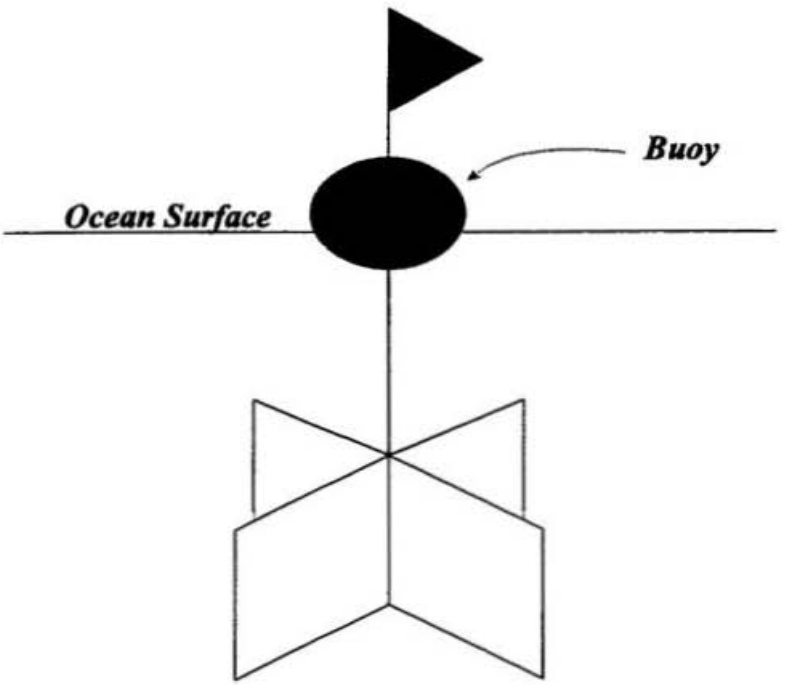


Figure 6.1 - Ocean Drogue

6.4 PROCEDURE

Four drogues were released from a boat offshore and the time recorded. The positions of each float was then determined at five or ten minute intervals, by the use of two transits, as shown in figure 6.2. Knowing the distance between the two transits (L) and the angles to each drogue, the position of the drogue can be calculated from simple geometry.

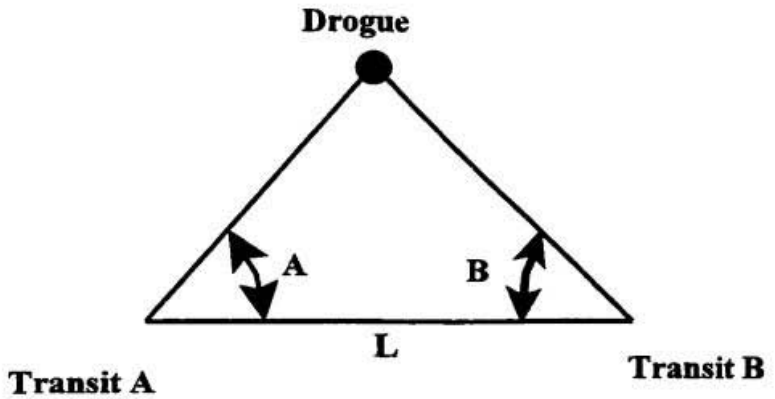


Figure 6.2 - Transit setup

6.4.1 DETERMINATION OF K

All calculations were performed on a spreadsheet, and for clarity because of the large number

of calculations involved and the complexity of the spreadsheet, a step by step example is given. The data for the Bonavista study is shown below, with the transit measurements for two time periods, 9:30 AM and 9:45 AM.

Step 1 - Convert transit "A"readings of degrees, minutes and seconds to degrees, and calculate the sine of the angle.

Table 6.1 - Transit "A" readings

TIME	DEGREES	MINUTES	SECONDS	CONVERTED	RADIANS	SIN A
9:30 AM	76.00	17.00	40.00	76.29	1.33	0.97
9:45 AM	85.00	53.00	20.00	85.89	1.50	1.00

Step 2 - Convert transit "B" readings of degrees, minutes and seconds to degrees, and calculate the sine of the angle.

Table 6.2 - Transit "B" readings

TIME	DEGREES	MINUTES	SECONDS	CONVERTED	RADIANS	SIN B
9:30 AM	48.00	40.00	0.00	48.67	0.85	0.75
9:45 AM	34.00	28.00	0.00	34.47	0.60	0.57

Step 3 - Calculate the remaining angle "C" of the triangle and use the sine laws to determine the distance from transit "A" to the drogue. (See Figure 6.3)

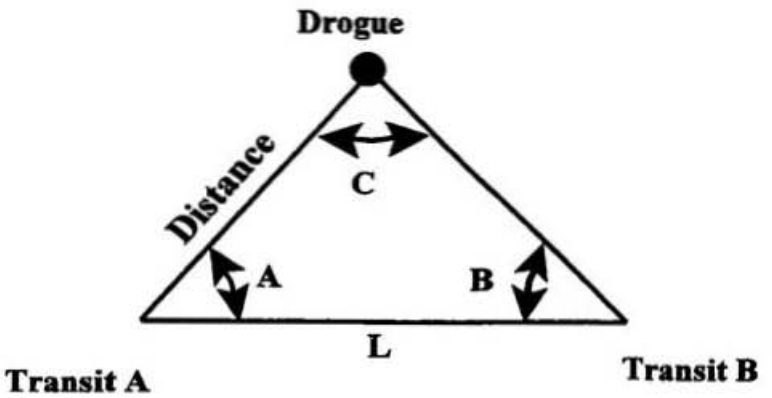


Figure 6.3- Distance to Drogue

Table 6.3 - Drogue distance from transit "A"

TIME	Angle C		Sin C		Length L	ANGLE	
						Radians	Degrees
9:30 AM	0.96		0.82		17408.18	1.33	76.29
9:45 AM	1.04		0.86		12460.93	1.50	85.89

Step 4 - Convert the position of the drogue into X and Y coordinates with transit "A" at the origin.

Table 6.4 - Drogue Coordinates

Time	Angle A	X	Y
9:30 AM	76.29	4124.56	16912.50
9:45 AM	85.89	893.34	12428.86

Once the positions of the drogues had been converted into rectangular coordinates, the starting position of each drogue was subtracted from each subsequent position. This caused the starting distances between each drogue to be zero and allowed an estimation of the direction of travel for each drogue to be calculated. This procedure is explained below.

For each set of drogues (i.e. 1, 2, 3 and 4) the direction of travel was calculated for each drogue and the results of the four averaged. For example, if drogue #1 moved away at an angle of 50°, drogue #2 at an angle of 48°, drogue #3 at an angle of 52° and drogue #4 at an angle of 54°, the average direction of travel would be 51°. This angle would be used to calculate the rate of growth of distance between the drogues. It was assumed that the average direction of movement (in this example 51°) was caused by the ocean current and that any movement perpendicular to this, would be caused by dispersion. See Figure 6.4.

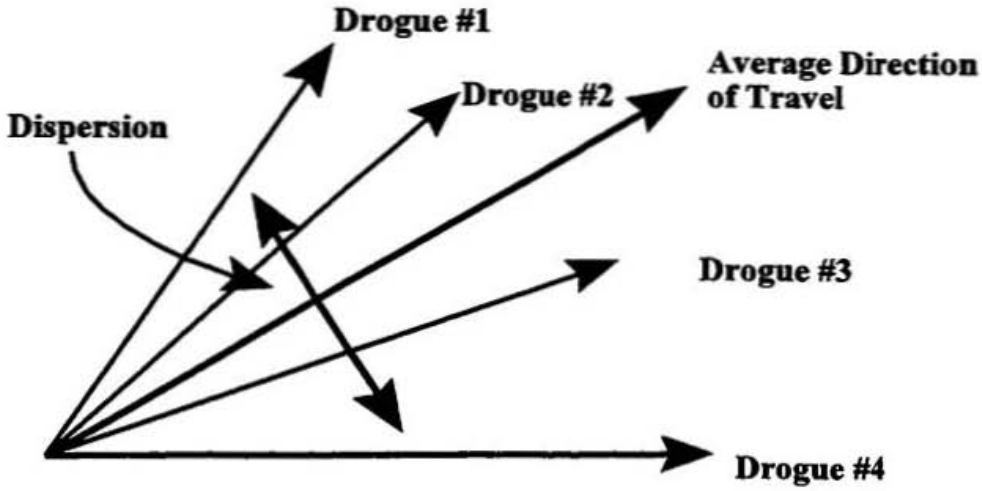


Figure 6.4 - Drogue Dispersion

This step was necessary, as in each test (ie four drogues) there could have been only one average direction of travel due to the ocean current. If each pair had been considered separately, six different values of current direction would have been obtained.

Since the purpose of this study was to determine the rate of dispersion, only growth perpendicular to the ocean current was used, as outlined in Stommel's method. For each drogue pair, their separation distance perpendicular to the direction of travel was calculated and this was used to determine both the dispersion coefficient (K) and the length scale (L) by using Stommel's equations, as explained earlier as equation 3.7 and 3.8 respectively.

In order to calculate the perpendicular direction that each drogue traveled, it was necessary to adjust the axis by a method known as coordinate transformation. Simply stated, the XY axis was rotated about the orgion by an amount equal to the average current direction. This caused any drogue movement in the X direction to be along the average current and any movement in the Y direction to be perpendicular to it. This is shown in Figure 6.5

For example, in Figure 6.6 , point A has coordinates Xa and Ya. If the axis is rotated by θ degrees, the new coordinates of A will be:

$$X'a = Xa\cos\theta - Ya\sin\theta \qquad \textbf{6.1}$$

$$Y'a = Ya\sin\theta + Ya\cos\theta \qquad \textbf{6.2}$$

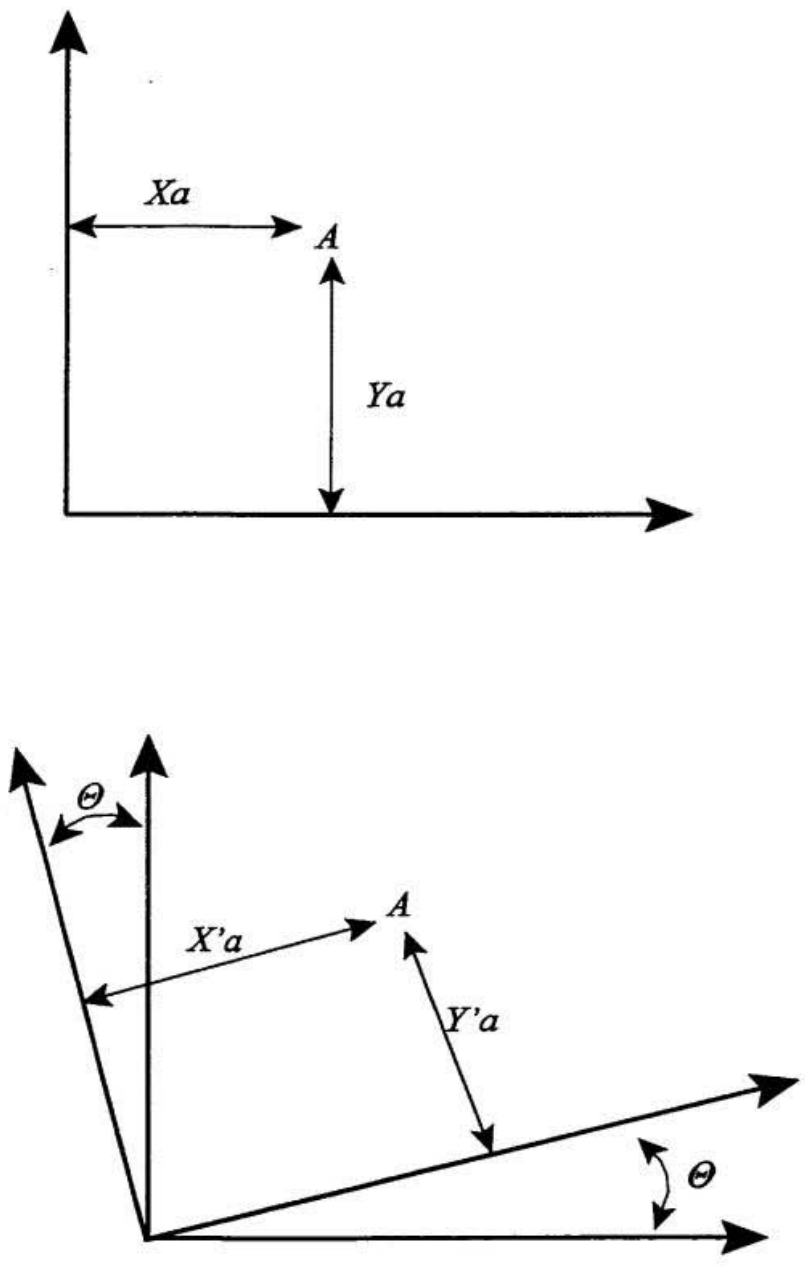
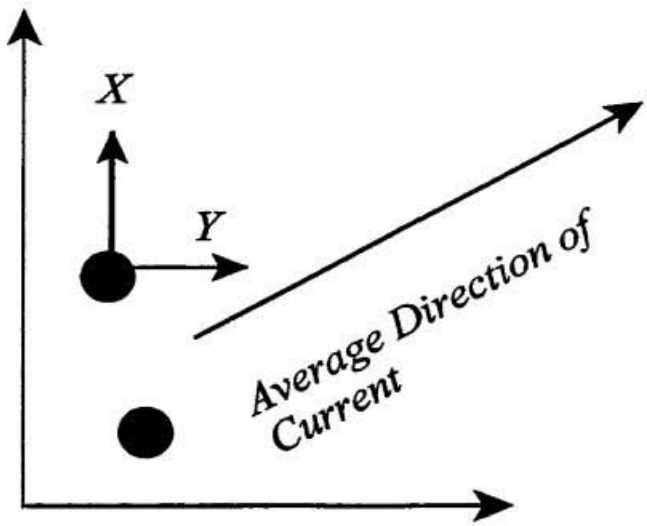


Figure 6.6 - Coordinate Transformation



Before Rotation

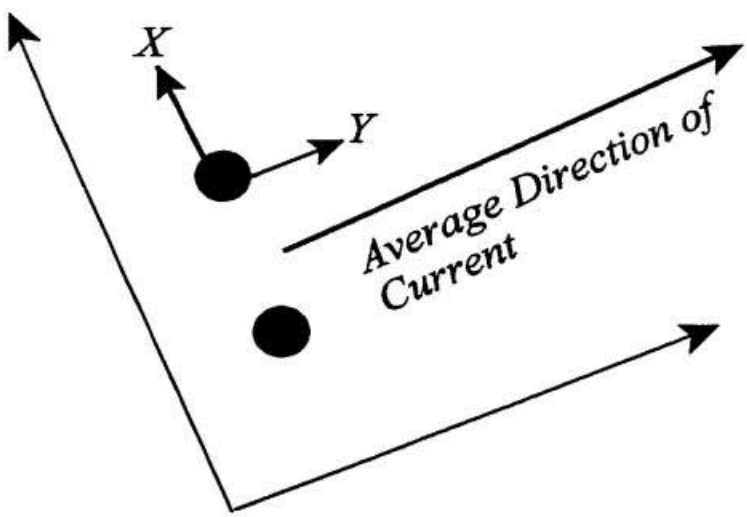


Figure 6.5 - Axis Rotation

For each drogue test the coordinates were transformed this way, leaving a new set of X and Y coordinates for each drogue. This is shown in Table 6.5. The data used for these examples was taken from the Carbonear #1 test.

Table 6.5 - X and Y Positions of Drogues (cm)

Time	Drogue 1		Drogue 2		Drogue 3		Drogue 4	
	X	Y	X	Y	X	Y	X	Y
10.35 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10:50 AM	144.19	1657.87	-131.55	1600.18	630.94	781.91	-385.67	2374.31
11:05 AM	-2.64	4233.95	-179.41	4592.85	-14.97	4959.95	156.29	4283.03
11:20 AM	-783.35	8518.64	-1046.31	9792.90	-869.88	9850.74	-575.60	9106.03
11:35 AM	-194.86	12655.58	-469.34	14253.12	63.36	14545.45	-213.44	13239.46
11:50 AM	-857.93	15726.28	1006.23	16891.16	-1218.75	18062.00	-1048.85	16297.05
12:05 PM	-1664.00	18017.68	-1189.99	15307.48	-2273.09	20516.40	-1855.03	18793.98
12:20 PM	-572.28	21316.06	-862.67	17188.09	-1977.38	24220.12	-1115.51	22499.72
12:35 PM	-704.07	28073.66	-547.43	19354.95	-1407.22	27609.03	-630.46	25685.31
12:50 PM	105.85	28180.67	653.17	24470.40	-827.01	32225.20	-143.20	29933.63

Using only the Y distances, the distances between each drogue pair was calculated for each time period. This is simply the difference in Y coordinates of each drogue. See Table 6.6.

Table 6.6 - Distances Between Drogues (cm)

TIME	1-2	1-3	1-4	2-3	2-4	2-4
10.35 AM	0.00	0.00	0.00	0.00	0.00	0.00
10:50 AM	275.74	486.75	529.86	762.49	254.12	1016.61
11:05 AM	176.77	12.33	158.94	164.44	335.70	171.26
11:20 AM	262.96	86.53	207.75	176.43	470.71	294.28
11:35 AM	274.48	258.22	18.59	532.70	255.90	276.80
11:50 AM	1864.16	360.81	190.92	2224.98	2055.08	169.90
12:05 PM	474.02	609.09	191.03	1083.10	665.05	418.06
12:20 PM	290.39	1405.10	543.23	1114.71	252.85	861.87
12:35 PM	156.65	703.15	73.61	859.80	83.03	776.76
12:50 PM	547.32	932.86	249.05	1480.18	796.37	683.81

Following Stommel's method as outlined earlier, $(L_1 - L_0)^2$ and $(L_0 + L_1)/2$ were calculated in order to determine K and L. For each case L_0 was taken as the start of testing. This was done to avoid any negative values for separation growth, as in several cases the drogues moved closer together.

Table 6.7 - Rate of Separation Growth

$(L_1 - L_0)^2$					
1-2	1-3	1-4	2-3	2-4	3-4
76031.50	236927.80	280749.98	581391.61	64577.16	1033497.44
31245.90	151.90	25261.16	27040.63	112696.30	29330.79
69149.18	7487.63	43158.93	31127.97	221567.51	86599.75
75340.79	66675.69	345.45	283768.37	65482.97	76619.76
3475099.83	130186.86	36448.56	4950518.79	4223341.58	28865.71
224691.02	370987.63	36493.27	1173112.93	442288.80	174770.33
84323.92	1974306.51	295102.27	1242588.11	63931.78	742814.75
24537.81	494418.61	5418.65	739246.68	6894.65	603356.95
299558.00	870225.90	62027.07	2190926.64	634207.18	467591.53

Table 6.8 - Average Distance Between Drogues

$(L_0 + L_1)/2$						
1-2	**1-3**	**1-4**	**2-3**	**2-4**	**3-4**	**Avg**
137.869	243.376	264.929	381.245	127.060	508.305	277.131
88.383	6.162	79.469	82.220	167.851	85.631	84.953
131.481	43.266	103.874	88.216	235.355	147.139	124.888
137.241	129.108	9.293	266.350	127.948	138.401	134.724
932.081	180.407	95.458	1112.488	1027.539	84.950	572.154
237.008	304.544	95.516	541.552	332.524	209.028	286.695
145.193	702.550	271.617	557.357	126.424	430.934	372.346
78.323	351.575	36.806	429.897	41.517	388.380	221.083
273.659	466.429	124.526	740.089	398.186	341.903	390.799

Values of K and L were then calculated using equations 3.7 and 3.8. A complete set of all the K and L values can be found in Appendix "E"

Table 6.9 - K and L

Time	L	K
10.35 AM	277.131	210.479
10:50 AM	84.953	10.450
11:05 AM	124.888	14.169
11:20 AM	134.724	13.154
11:35 AM	572.154	237.860
11:50 AM	286.695	37.382
12:05 PM	372.346	58.242
12:20 PM	221.083	21.688
12:35 PM	390.799	46.549

6.5 ANALYSIS OF DATA

With values of K and L for each test, a regression analysis was performed to determine the relationship and the values of the constants n and α. The statistical software package Minitab was again used in this analysis. Since Minitab only performs linear regression and the relationship between K and L has been described as a nonlinear ($K=\alpha L^n$), a transformation of this relationship was performed. Logs were taken of both sides of the equation and the following linear equation was derived:

$$LogK = Log\alpha + nLogL \qquad 6.3$$

This is in the form of a linear equation($y = mx + b$) with n as the slope and log α as the y-intercept. A regression analysis was performed on each data set and a full output of the statistical analysis can be found in Appendix "F". Table 6.10 gives a summary of the regression analysis. Figures 6.7 - 6.9 illustrate the regression equation versus the actual data.

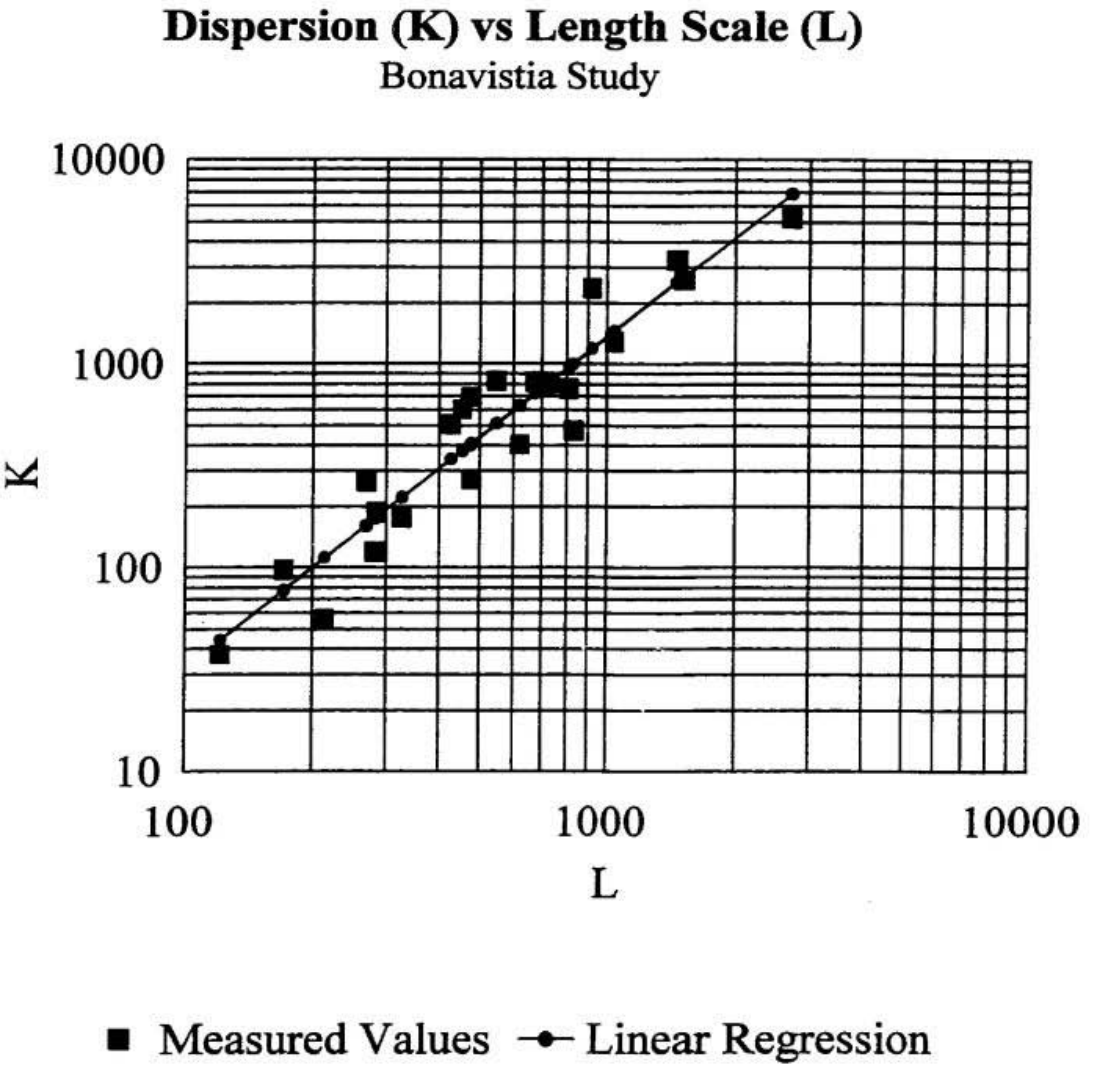


Figure 6.7 - Bonavistia Study Regression Fit

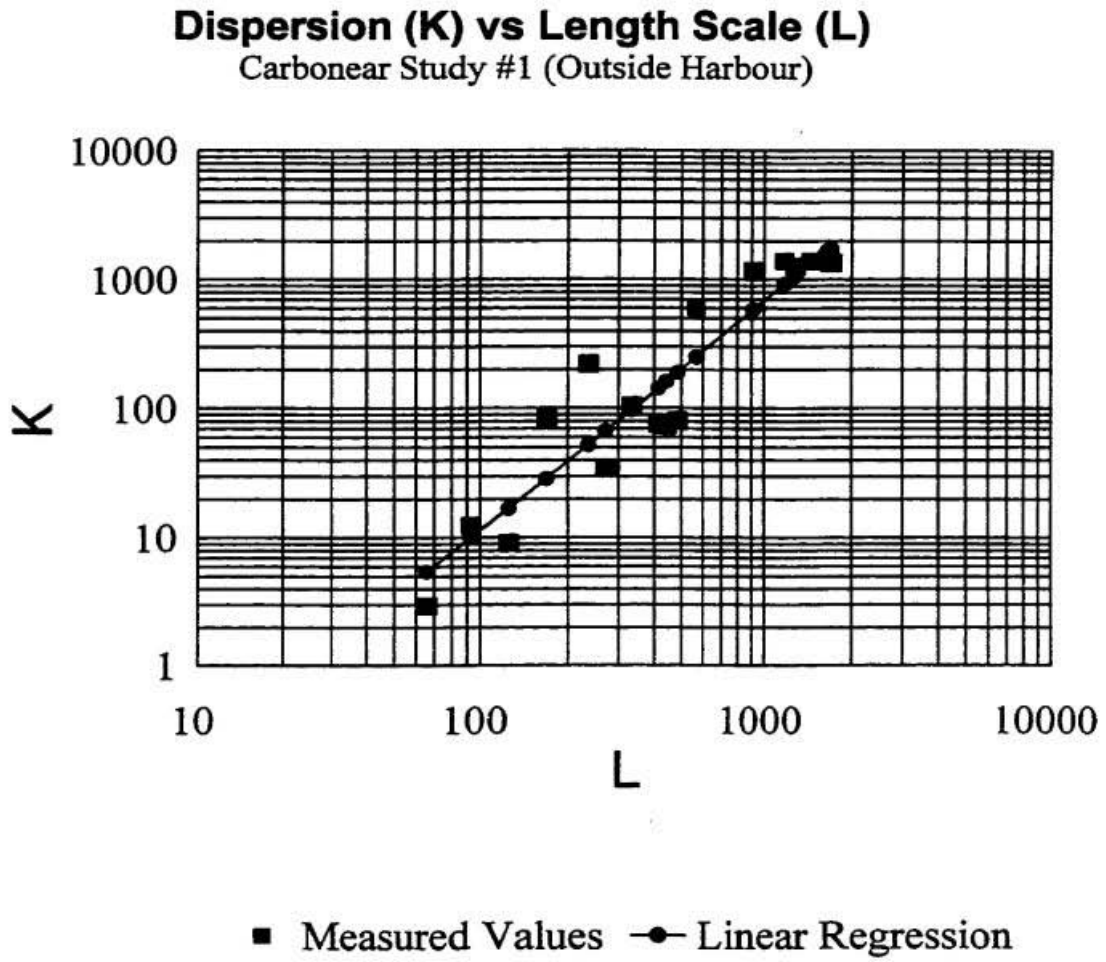


Figure 6.8 - Carbonear Study #1 Regression Fit

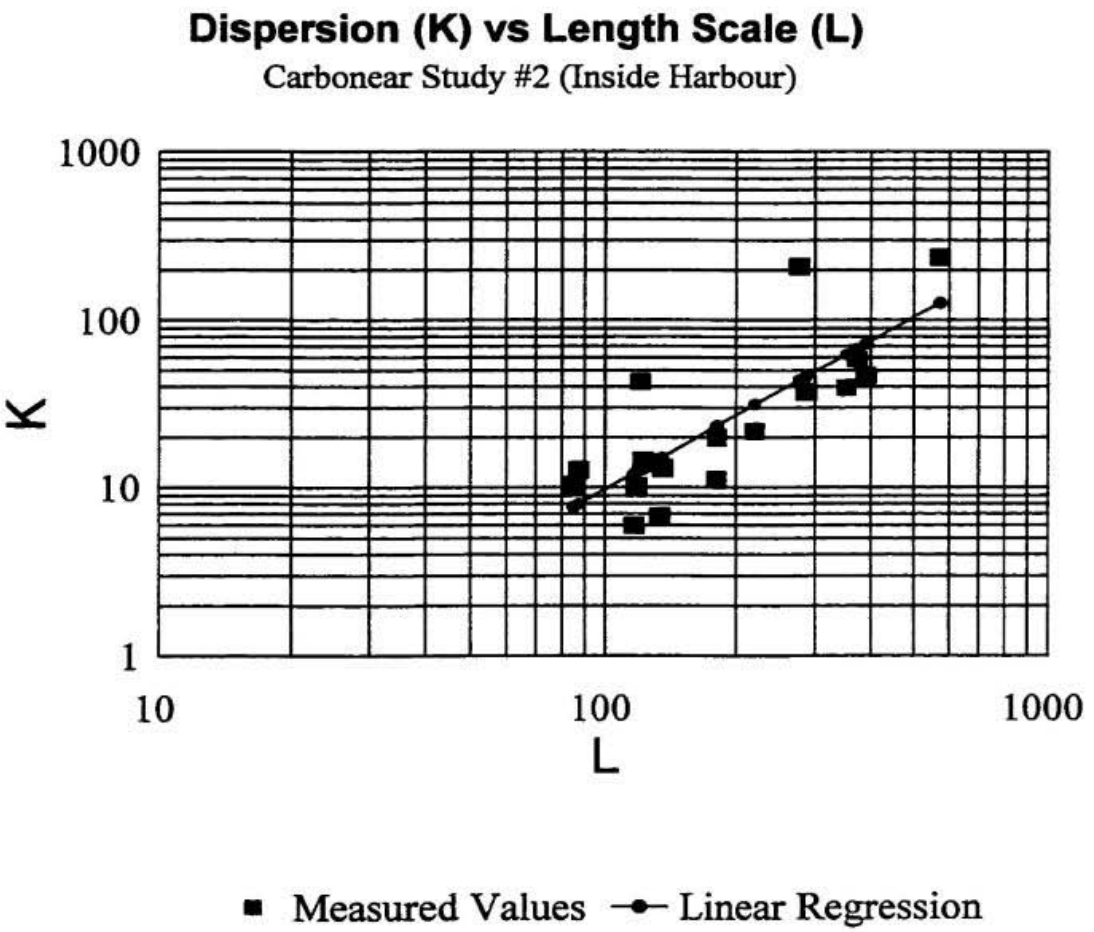


Figure 6.9 - Carbonear Study #2 Regression Fit

Table 6.10 - Dispersion Study Results

Location	Alpha	n	Equation
Carbonear #1 (Outside Harbor)	0.002	1.82	$K = 0.002\ L^{1.82}$
Carbonear #2 (Inside Harbor)	0.011	1.474	$K = 0.011\ L^{1.474}$
Bonavistia	0.018	1.624	$K = 0.018L^{1.624}$

These graphs generally show a good fit of the model to the data. However in Figure 6.9 (Carbonear study #2) it can be seen that three points are far above the regression line, and influence the analysis greatly. These points are far away from the remainder of the data and thus influence the shape of the graph. A plot of the Residuals versus Fits, as shown in Figure 6.10, also reveals these three points are being separate from the rest of the data. In order to accurately predict the relationship between K and L it was decided to remove these three points and run the regression analysis again. The new plot of the predicted model versus the actual data is given in Figure 6.11. Here it can be clearly seen that a better fit has been obtained. The new relationship between K and L for the Carbonear #2 study is given in Table 6.11 along with the results from the other tests for comparison.

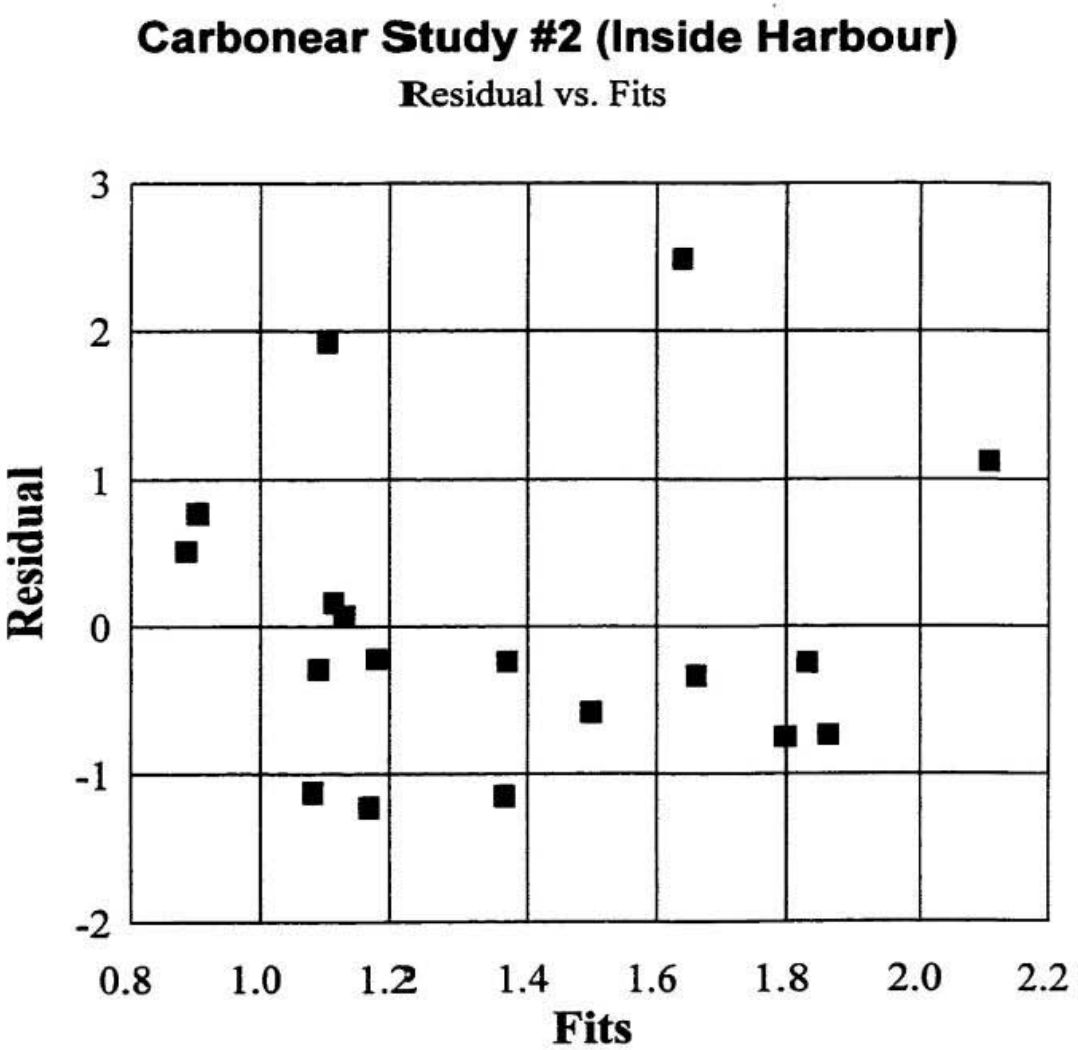


Figure 6.10 - Carbonear Study #2 Regression Residual versus Fits

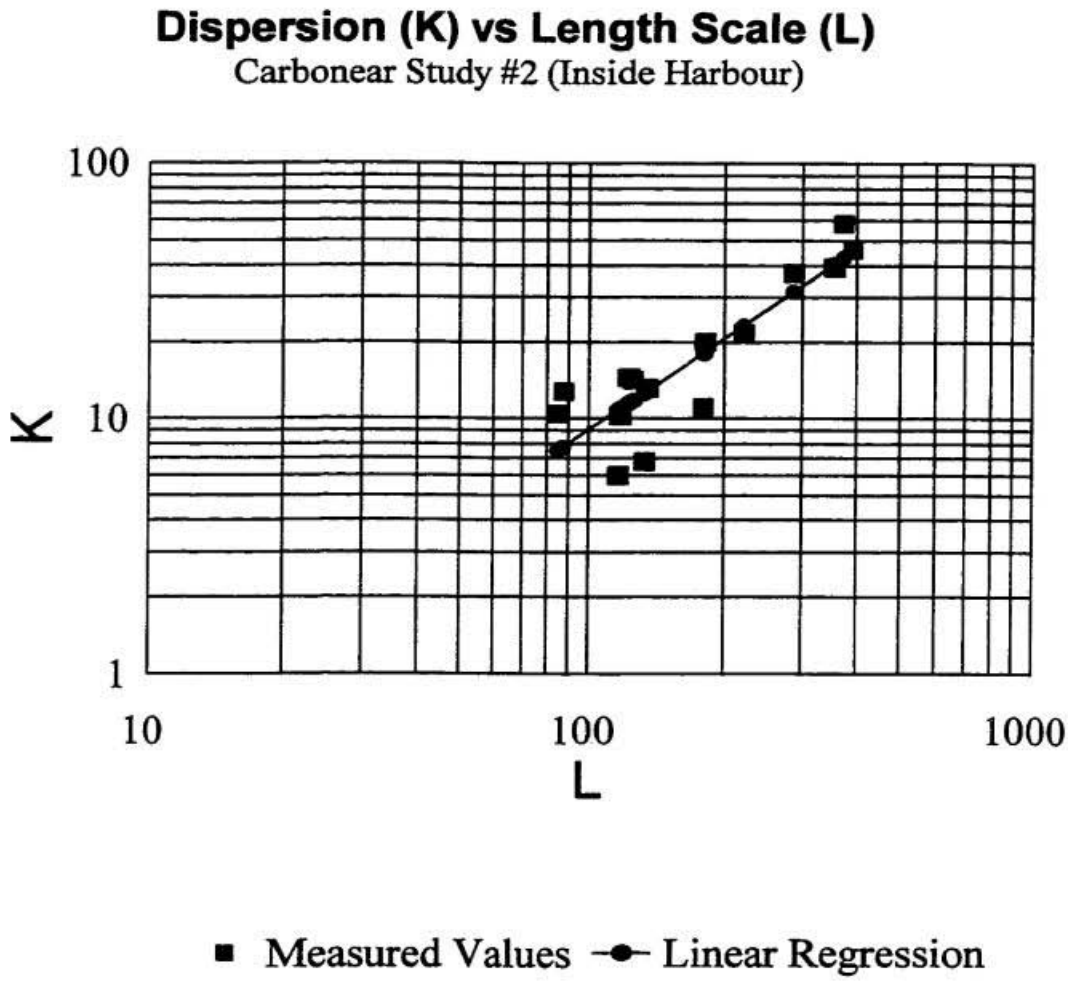


Figure 6.11 - Carbonear Study #2 Regression Fit after Modification

Table 6.11 - Dispersion Study Results after Modification

Location	Alpha	n	Equation
Carbonear #1 (Outside Harbor)	0.003	1.82	$K = 0.003\ L^{1.82}$
Carbonear #2 (Inside Harbor)	0.011	1.18	$K = 0.011\ L^{1.18}$
Bonavistia	0.018	1.624	$K = 0.018L^{1.624}$

As a final check of the regression analysis, Residual vs Fit graphs were created for all three studies, and can be seen in Figures 6.12, 6.13 and 6.14. These graphs generally show a good scatter of the residuals and thus verify the regression analysis.

6.6 ANCOVA ANALYSIS

As a confirmation test of the data, an Analysis of Covariance (ANCOVA) test was performed. An ANCOVA test is simply a combination of an ANOVA test and a regression analysis. (Lye, 1998) The purpose is to determine if two or more sets of data are actually from the same group. In this test a regression analysis was performed on the data and the slope and y-intercepts are compared. If two regression lines have the same slope and Y-intercept, then they are actually the same line and could be modeled using one equation.

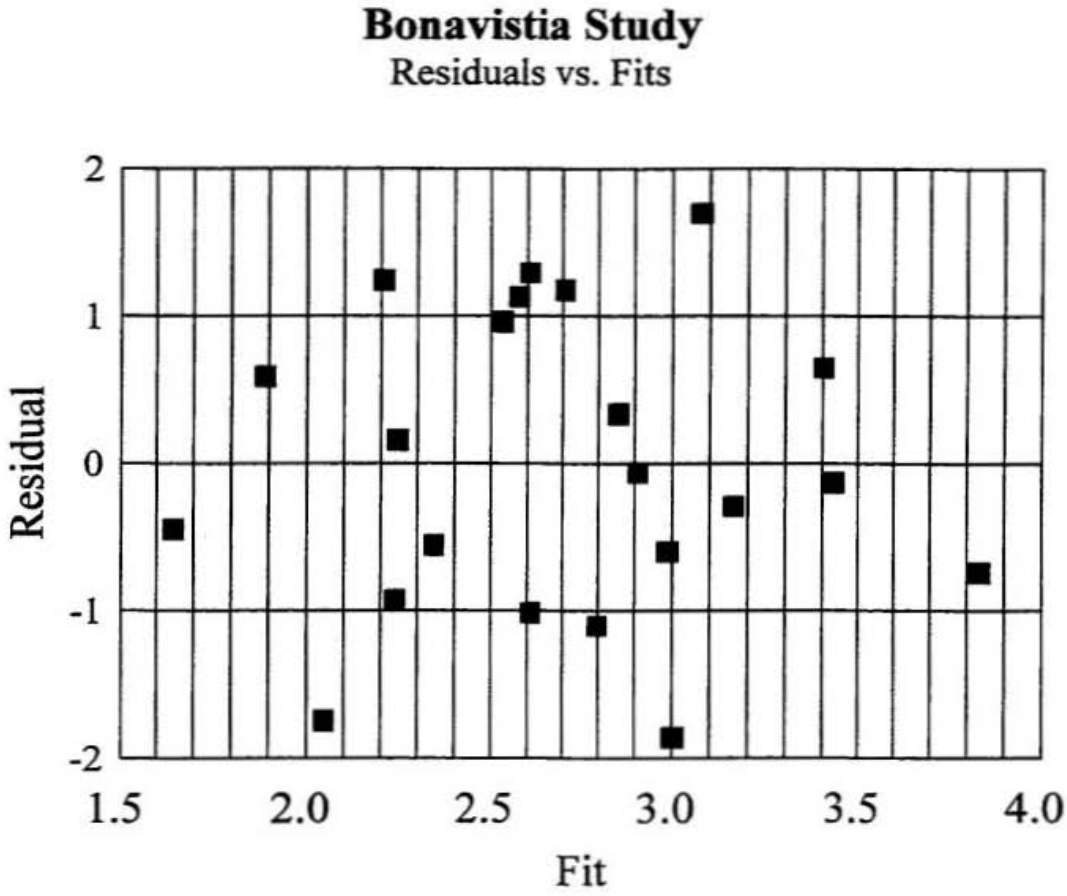


Figure 6.12 - Bonavistia Regression Residual versus Fits

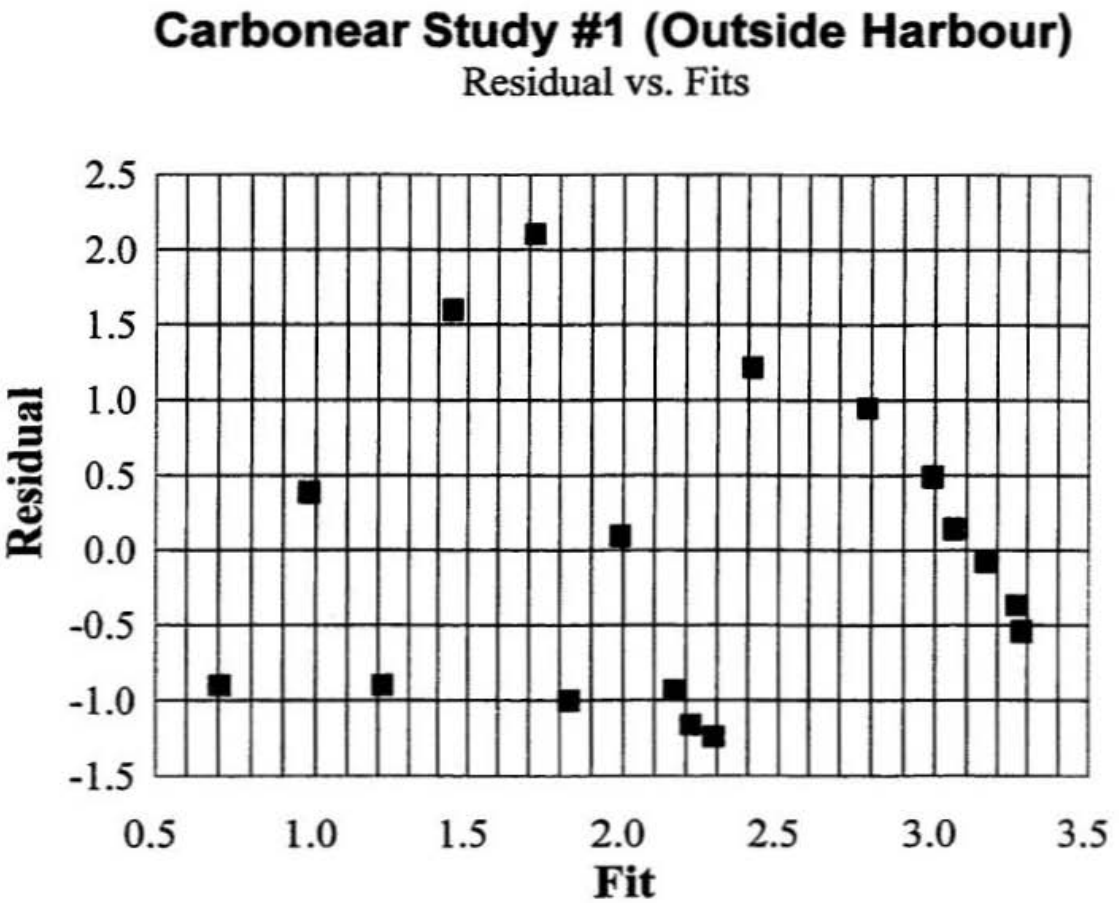


Figure 6.13 - Carbonear Study #1 Regression Residual versus Fits

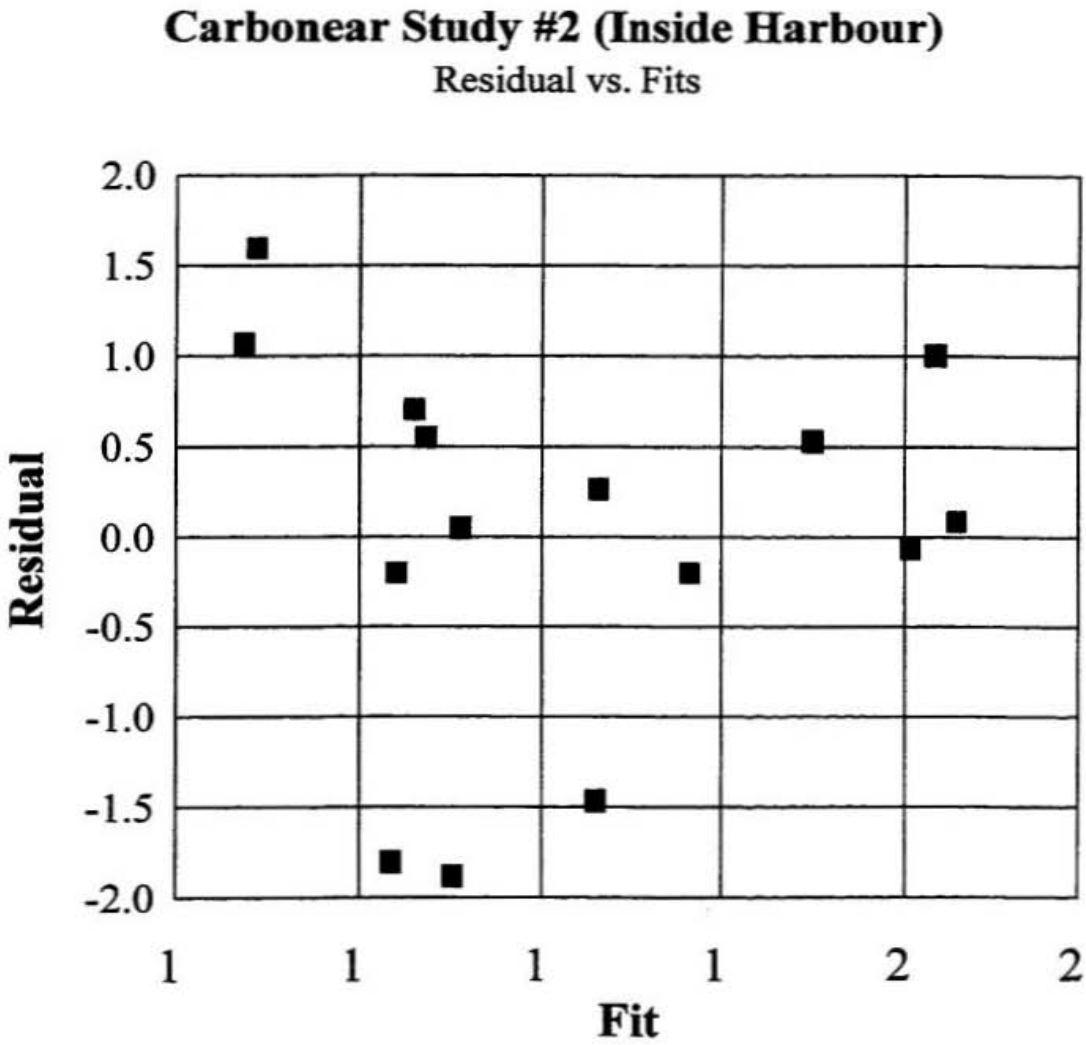


Figure 6.14 - Carbonear Study #2 Regression Residual versus Fits after Modification

For this analysis, it was important to determine if the inside and outside harbour data was actually from the same set. In other words, was the rate of dispersion for inside and outside the harbour actually the same

The model tested was:

$$LogK = Log\alpha + \beta 1 LogL + \beta 2 Z + \beta 3 ZLogL \qquad \textbf{6.4}$$

This is the same linear regression equation used for the previous regression, with the addition of a dummy variable (Z). This was used to indicate if the test was performed inside the harbour or outside in the open ocean. A value of Z =0 was given for inshore testing and a value of Z = 1 for open ocean.

An ANCOVA test compares the slopes and Y-Intercepts of several graphs to determine if the regression equations are the same. In the ANCOVA test a null hypothesis (Ho) is tested against its alternative (Ha) at a level of significance. In this case Ho, Ha and the level of significance would be:

Ho: $\beta_2 = \beta_3 = 0$

Ha: β_2 and /or $\beta_3 \neq 0$

Level of significance = 0.05

For the comparison a nested F statistic is computed:

$$F = \frac{(SSE_S - SSE_C) / (df_S - df_C)}{(MSE_C)} \qquad 6.5$$

Where S refers to the simpler model (no dummy Z terms) and C refers to the more complex model as given in equation 6.4.

This F value is compared to a standard F value for statistical tests and Ho is rejected if F is the greater of the two.

Two regression analysis were performed, one with the dummy Z variable and one without. The results of these tests, along with a complete set of data, can be seen in Appendix "G"

From this analysis the F statistic was calculated to be 1.108, the critical value of F, obtained from a standard textbook was found to be approximately 3.3. Thus Ho is accepted and $\beta_2 = \beta_3 = 0$.

What this means is that one equation can be written for all the Carbonear data and that there is no statistical significance to indicate a difference in values obtained inshore or in the open ocean. The new regression equation is given in Table 6.12.

Table 6.12 - Dispersion Study Results after ANCOVA

Location	Alpha	n	Equation
All Carbonear Data	0.002	1.83	$K = 0.002\ L^{1.83}$

Figures 6.15 shows the fit of this model to the data.

6.7 DISCUSSION

Following the ANCOVA analysis of the Carbonear data, it appears that no statistical difference was found in dispersion rates from tests both inside enclosed bays or in the open ocean. The value for this combined dispersion rate was found to be 1.83. The value of dispersion for Bonavistia was calculated to be 1.612. While these rates of dispersion may be greater than appears in current literature, this may be a function of both the sea conditions and the testing procedure.

The drogues may have been moved about by the sea and the surface float could have been affected by the high winds and wave action. This would have caused movement of the drogues and thus affected the dispersion rate. In two of the tests, high winds and heavy seas were encountered.

In addition the time span of the studies may not have been long enough to give representative results. The rate of dispersion would be high during the initial growth of a plume and would only slow down as it reached some limiting factor. In the inshore case, this limiting factor would be the presence of shorelines and shallow waters. In the open sea, the limiting factor would be reached when the distance of separation of the drogues equaled the mean eddy size encountered.

It is quite possible that in both cases the drogues did not spread apart far enough, or as in the case of the inshore test, reach a point where the boundaries became a limiting factor on the rate of growth. Until this occurred, both the inshore and offshore dispersion rates would be the same.

Many of the studies mentioned in the literature review, had time spans of days or in several cases, weeks. This would have allowed the drogues to reach a much larger size and thus obtain a lower value of the dispersion coefficient.

Although the ANCOVA analysis did not find any statistical difference between inshore or offshore dispersion rates in the Carbonear testing, and suggested a higher rate of dispersion, this may not be entirely valid. The Carbonear #2 data (Inshore) when viewed separately

seems to agree with current literature, as n is approximately 1.0. This would represent

nearshore growth that is limited due to shorelines. This is exactly the case encountered in Carbonear harbour. In addition, the sea was much calmer on the days of this study, thus wind and wave action may not have been as an important factor. While the analysis may suggest similar dispersion rates for both inshore and ocean sea conditions, it is just as important to view the data separately.

In general, the results found do not suggest that a difference in dispersion rates does exist between enclosed bays and the open sea. However this result is based upon one set of tests and may not prove to be consistent with all dispersion rates. The actual result for the inshore testing was close to the accepted value of 1.0.

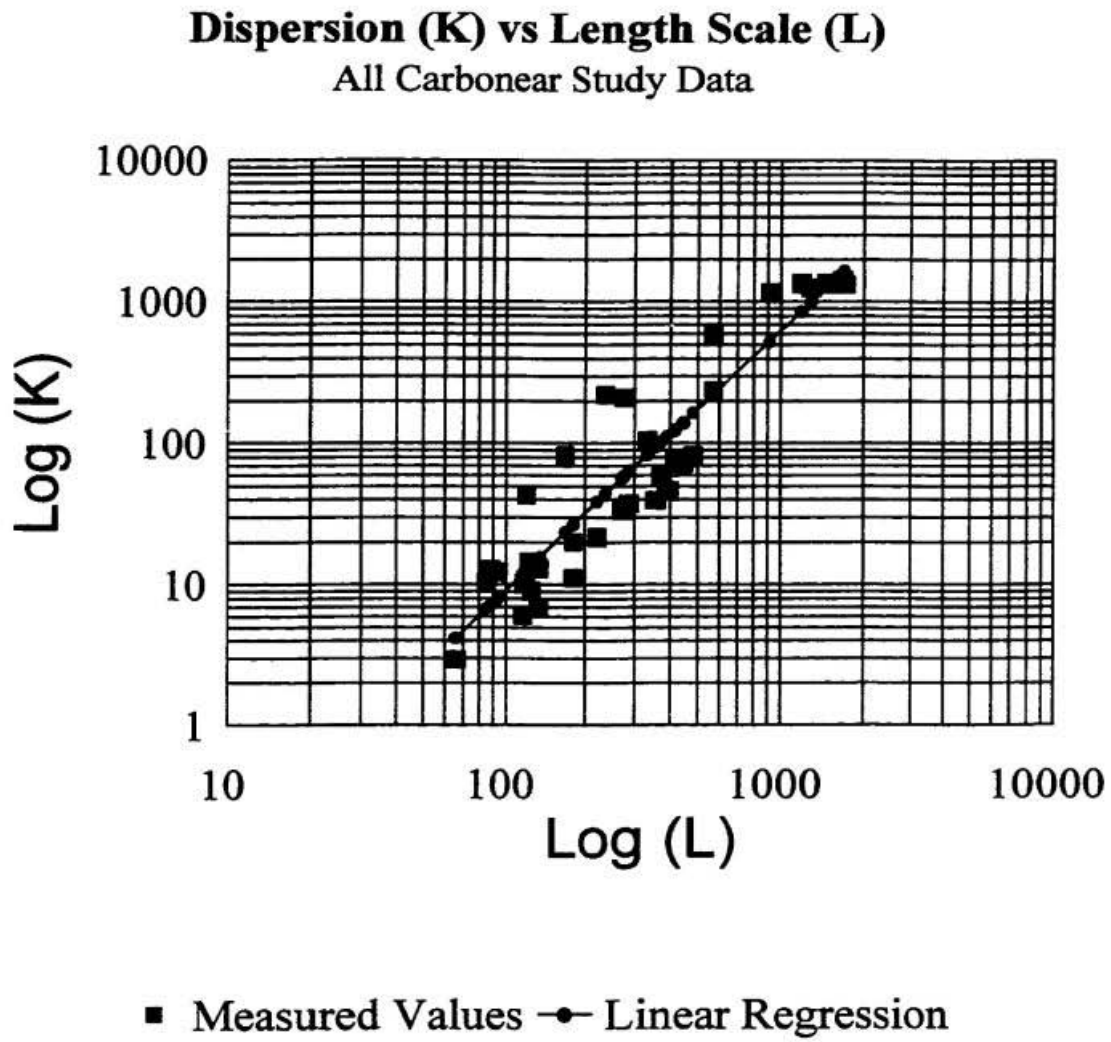


Figure 6.15 - All Carbonear Study Data

7.0 SUMMARY AND CONCLUSIONS

7.1 GENERAL

Both the T_{90} value and the diffusion coefficient (K) depend upon local conditions, such as latitude and sea conditions. Published values are based upon tests that generally have been carried out in lower latitudes and/or in temperate waters, and may not accurately predict sewage dispersion and bacterial decay in local waters. It was therefore important to determine acceptable values that can be used for sewage outfalls in Newfoundland. In addition there is little information on the effect of cold water temperature on bacterial decay.

It was the goal of this study to determine acceptable ranges for both bacterial decay and dispersion that accurately depict conditions encountered in Newfoundland, and to determine generally if water temperature appears to have a important effect on the T_{90} value.

7.2 T_{90} TIME

The T_{90} time for bacterial decay in Newfoundland waters was determined to be approximately four hours for the summer (July to September), while the winter values (September to March) were higher, at six and one half hours. These values agree with current literature, as discussed in Chapter 3. Table 7.1 repeats the information found in Chapter 5.

Table 7.1 - T_{90} Values

Test Number	Date	T_{90} Time (hours)
1	July 18, 1993	3.92
2	July 21, 1993	4.18
3	August 8, 1993	3.74
4	August 17, 1993	4
5	August 25, 1993	4.42
6	September 7, 1993	4.37
7	September 13, 1993	5.46
8	September 19, 1993	5.23
9	September 22, 1993	6.85
10	January 12, 1994	8.19
11	January 25, 1994	6.6
12	February 1, 1994	6.4
13	February 13, 1994	9.7
14	February 23, 1994	7.6
15	March 6, 1994	5.2
16	March 16, 1994	6.7
17	March 23, 1994	6.3

7.3 EFFECT OF WATER TEMPERATURE ON STORED SAMPLES

While water temperature was found to have a significant effect upon the rate of bacterial decay, their effects were only noticeable in samples stored in the dark. The effect of UV radiation seems to be so strong that it overrides any other mechanism acting on the bacteria. Figure 7.1 illustrates the difference between samples stored in the dark and in sunlight at different temperatures.

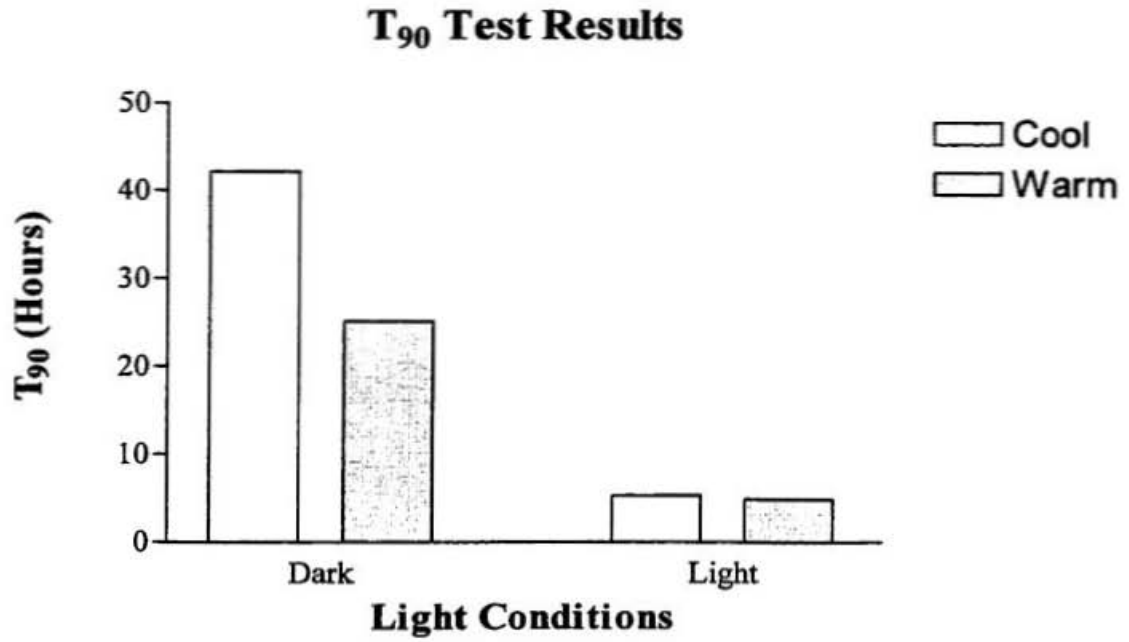


Figure 7.1 - T_{90} time vs Light Conditions

As can be clearly seen from the figure, a noticeable difference is apparent between samples stored in the dark and in the light. While the difference between cool and warm water temperature is only evident in the samples stored in the dark.

7.4 OCEAN DISPERSION

Since this portion of the study was a minor portion of the work, and only several tests were performed a detailed analysis of the dispersion would have been impractical. The findings of this study suggest that the rate of dispersion encountered is greater than 4/3. In addition, no significant difference was found between inshore and open sea conditions. Table 7.2 presents these findings.

Table 7.2 - Dispersion Study Results

Location	Alpha	n	Equation
Carbonear #1 (Outside Harbor)	0.003	1.77	$K = 0.003\ L^{1.77}$
Carbonear #2 (Inside Harbor)	0.011	1.474	$K = 0.011\ L^{1.474}$
Bonavistia	0.018	1.624	$K = 0.018 L^{1.624}$
All Carbonear Data	0.002	1.83	$K = 0.002\ L^{1.93}$

For two of the studies (Carbonear #1 and Bonavistia) the value of n is greater than 4/3, this would suggest a larger rate of dispersion. However, wind and wave action on the drogues and their floats may have caused this higher rate. None of the previously published studies have mentioned this as a factor, however the majority of these studies are based upon deep sea drogues, in which wind and waves would not have been important. The Carbonear

#2 study, performed inside an enclosed bay, did agree with current literature, as n is close to 1.0, which is the suggested rate of dispersion for enclosed areas. However, following an ANCOVA analysis, no statistical difference was found between dispersion rates both inside of Carbonear harbour and the open sea. The combined value for the Carbonear dispersion was determined to be 1.83

7.5 SUMMARY OF FINDINGS

The values for dispersion rates as expressed by the coefficient n, were determined to be larger than anticipated with n as high as 1.83. No significant difference was found between dispersion rates inside and outside the harbour.

The T_{90} value for bacterial inactivation was determined to be 4 hours in the summer (July to September) and 6.5 hours in winter (September to March). These values agree with current literature.

Both water temperature and sunlight (UV Radiation) were found to have an important effect upon the rate of bacterial decay. However, the effect of sunlight is so much greater in magnitude, that effect of water temperature is not noticeable when the two are combined.

7.6 RECOMMENDATIONS

As stated in the analysis section, no significance difference was found between the dispersion rates for inshore and offshore dispersion. This may have been due primarily to the limited number of tests conducted and for further study it is recommended that a large number of float test be performed. In addition more physical information on the harbour types, such as water depth and current speed should be collected. This information would help to classify the type of dispersion to be encountered. A small deep harbour with strong currents may experience dispersion rates close to open sea conditions.

While the method used for determining the dispersion rates is a standard method, some items need to be addressed. The depth of the underwater sail should be studied and modified to ensure that wave action does not affect the results. In addition, the size of the surface float should be minimized for the same reason. The location of the test should also be carefully considered so the drogues can be tracked for as long as possible.

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APPENDIX A

MEMBRANE FILTRATION METHOD

Membrane Filtration Method for Total Coliform

Preparation of medium:

M-Endo Broth - Prepare as directed by manufacturer daily. (When this is not possible, prepared medium can be stored in refrigerator no longer than 3 days)

Preparation of Petri Dishes:

Aseptically pipette 2 ml of M-Endo medium onto nutrient pad in petri dish. Replace lid, mark it appropriately for sample identification and set aside (no longer than 1 hour).

Assembling Filtering Unit:

1) Aseptically insert filter holder base into neck of a 2 litre side-arm flask.
2) Using alcohol-flamed forceps place a sterile membrane filter with grid side up on the filter holder base.
3) Lock filter holder funnel in place and connect flsak to vacuum pump by rubber hose.

Filtration:

1) Add the required amount of water sample to a sterile sample cup, and if less than 20 ml, add phosphate buffer to make up 30 ml.
2) Pour sample into funnel of filter holder and turn on vacuum pump.
3) Following filtration of sample, rince with at least equal amount of phosphate buffer.
4) Detach funnel - using alcohol - flamed forceps, remove, membrane filter and place it with grid side up into prepared petri dish. Promptly replace Petri dish lid.
5) Wash filter holder unit by adding approximately 125 ml sterile distilled water and applying suction.
6) Dry funnel and sample cup with gauze sponge, sterilize both wsing UV sterilizer at least 2 minutes. If longer than 30 minutes elapses between sample filtrations, use a freshly sterilized filter-holder unit.
7) Incubate inverted plates 35C for 22 - 24 hours.

Counting:

1) Allow plates to incubate at room temperature for 1 hour before counting.
2) Use a microscope (10 - 15X) with fluorescent light source above and approximately perpendicular to the filter membrane.
3) Count all colonies that produce a golden green metallic sheen with 24 hour incubation.

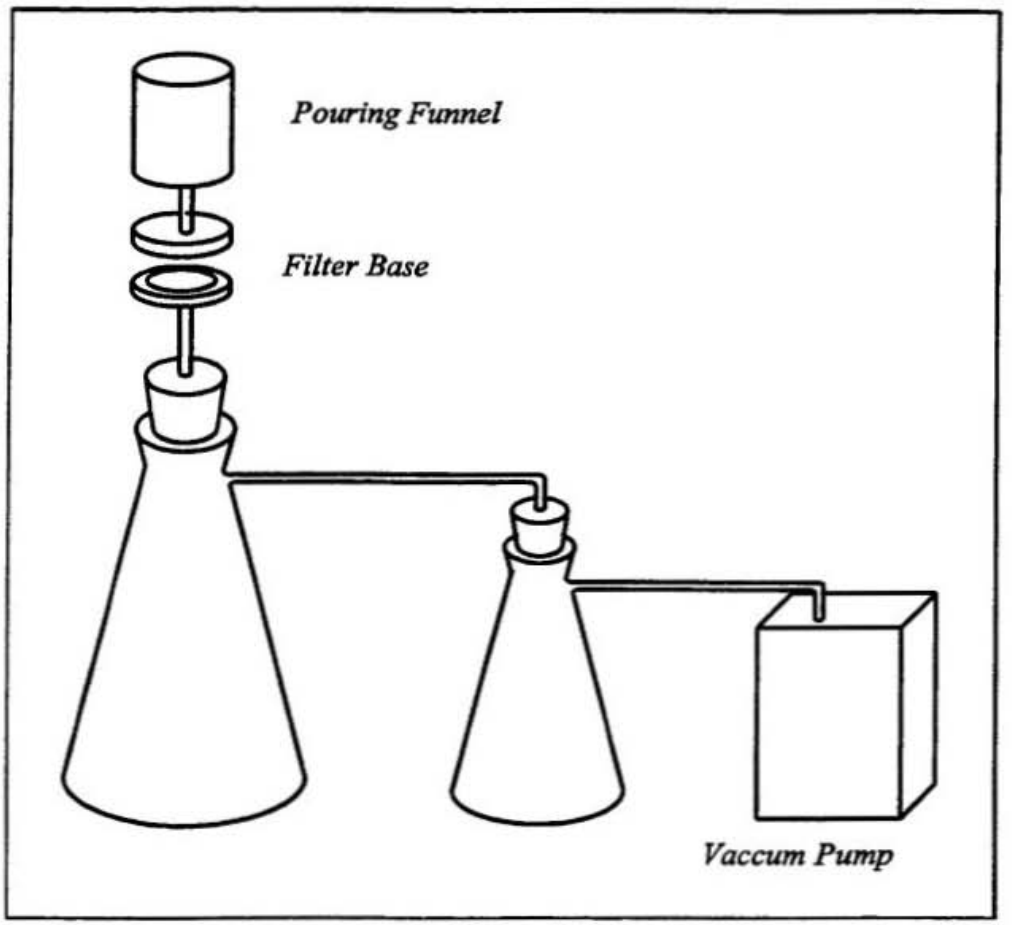

Figure A.1 - Membrane Filtration Equipment Setup

APPENDIX B

T_{90} STATISTICAL ANALYSIS OUTPUT

Table Analyzed	Storage Tests	
Two-Way ANOVA		
Source of Variation	% of Total Variation	P Value
Interaction	6.68	0.0002
Temp	7.43	P<0.0001
Light	79.56	P<0.0001

Source of Variation	P Value Summary	Significant?
Interaction	***	Yes
Temp	***	Yes
Light	***	Yes

Source of Variation	Df	Sum-of-Squares	Mean Square	F
Interaction	1	412.5	412.5	21.11
Temp	1	458.5	458.5	23.46
Light	1	4910	4910	251.3
Residual	20	390.8	19.54	

Number of Missing Values 0

T-Test Results

Light	Cool	Warm	Difference	95% CI
Dark	42.18	25.15	17.03	-23.22 to -10.85
Light	5.284	4.834	0.4493	-6.634 to 5.735

Light	Difference	t	P Value	Summary
Dark	17.03	6.674	P<0.001	***
Light	0.4493	0.1761	P<0.05	ns

APPENDIX C

BACTERIA STORAGE TEST DATA

Table C.1 - Bacteria Storage Test #1

	Test #	**Date**	**Julian**	**T90**		
	1	July 18	199	3.92		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water Temp**
				(MEDS/	**Exposure**	
9:00 AM	0	47	1.000	0.060	0.030	7
9:30 AM	0.5	14	0.298	0.132	0.096	8
10:00 AM	1	23	0.489	0.271	0.232	9
10:30 AM	1.5	18	0.383	0.489	0.476	8
11:00 AM	2	18	0.383	0.773	0.863	9
11:30 AM	2.5	15	0.319	1.131	1.428	9
12:00 AM	3	10	0.213	1.538	2.197	10
12:30 PM	3.5	6	0.128	1.963	3.179	10
1:00 PM	4	4	0.085	2.359	4.358	10
1:30 PM	4.5	2	0.043	2.720	5.718	10
2:00 PM	5	2	0.043	3.015	7.226	10
2:30 PM	5.5	1	0.021	3.258	8.855	10
3:00 PM	6	2	0.043	3.424	10.567	10

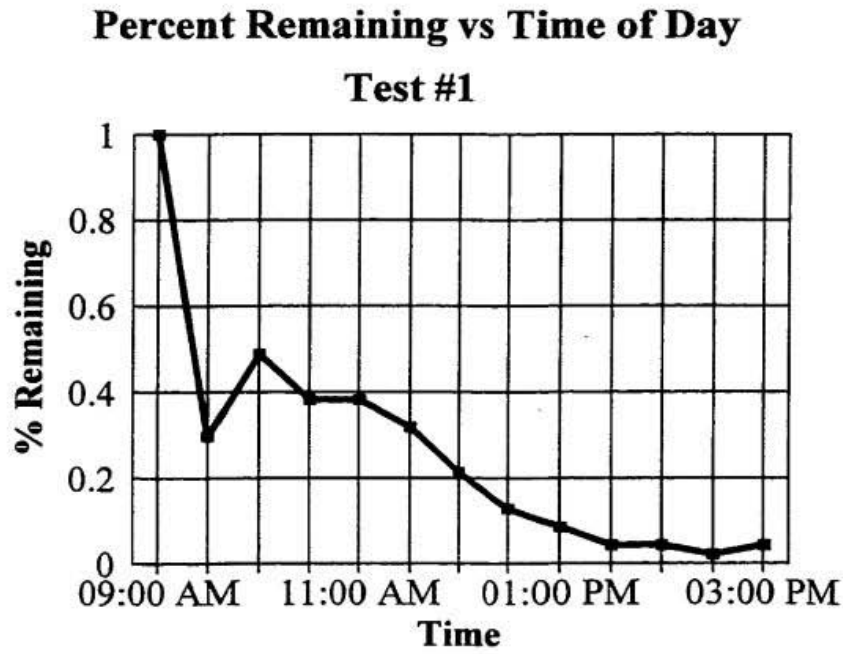

Figure C.1 - Bacteria Storage Test #1

Table C.2 - Bacteria Storage Test #2

	Test #	Date	Julian	T90		
	2	July 21	202	4.18		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	51	1.000	0.040	0.020	8
9:30 AM	0.5	54	1.059	0.110	0.075	8
10:00 AM	1	43	0.843	0.214	0.182	9
10:30 AM	1.5	54	1.059	0.415	0.390	9
11:00 AM	2	34	0.667	0.688	0.734	9
11:30 AM	2.5	36	0.706	1.004	1.236	9
12:00 AM	3	33	0.647	1.341	1.906	10
12:30 PM	3.5	20	0.392	1.255	2.534	10
1:00 PM	4	21	0.412	1.551	3.309	9
1:30 PM	4.5	10	0.196	1.839	4.229	10
2:00 PM	5	7	0.137	2.400	5.429	10
2:30 PM	5.5	4	0.078	2.633	6.745	10
3:00 PM	6	1	0.020	2.816	8.153	10

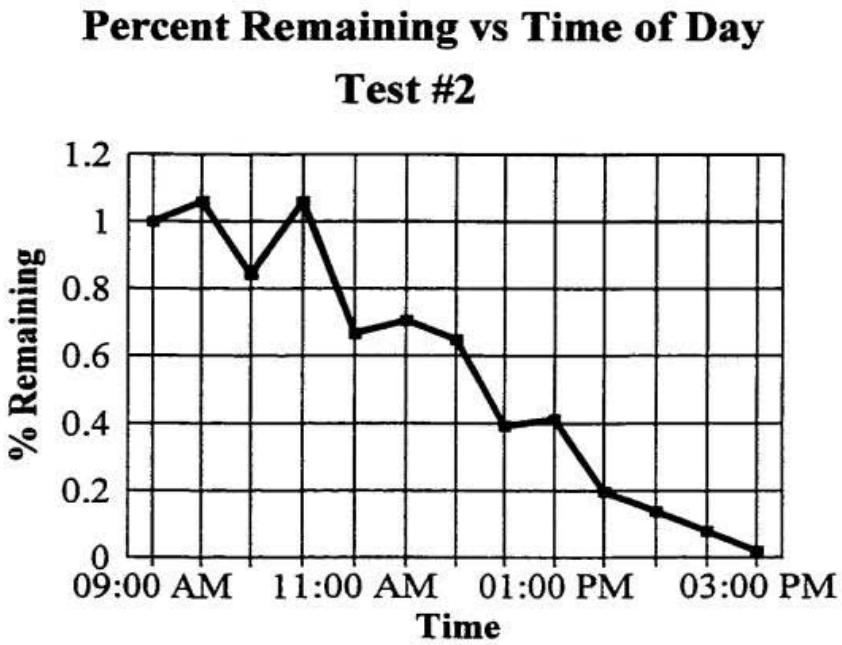

Figure C.2 - Bacteria Storage Test #2

Table C.3 - Bacteria Storage Test #3

	Test #	Date	Julian	T90		
	3	Aug 8	220	3.74		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water Temp**
				(MEDS/	**Exposure**	
9:00 AM	0	39	1.000	0.030	0.015	8
9:30 AM	0.5	39	1.000	0.041	0.036	8
10:00 AM	1	46	1.179	0.061	0.066	9
10:30 AM	1.5	52	1.333	0.168	0.150	8
11:00 AM	2	26	0.667	0.411	0.356	9
11:30 AM	2.5	13	0.333	0.490	0.601	9
12:00 AM	3	13	0.333	0.435	0.818	10
12:30 PM	3.5	9	0.231	0.680	1.158	10
1:00 PM	4	5	0.128	1.044	1.680	9
1:30 PM	4.5	4	0.103	0.898	2.129	10
2:00 PM	5	3	0.077	1.340	2.799	10
2:30 PM	5.5	2	0.051	0.948	3.273	10
3:00 PM	6	0	0.000	1.379	3.963	11

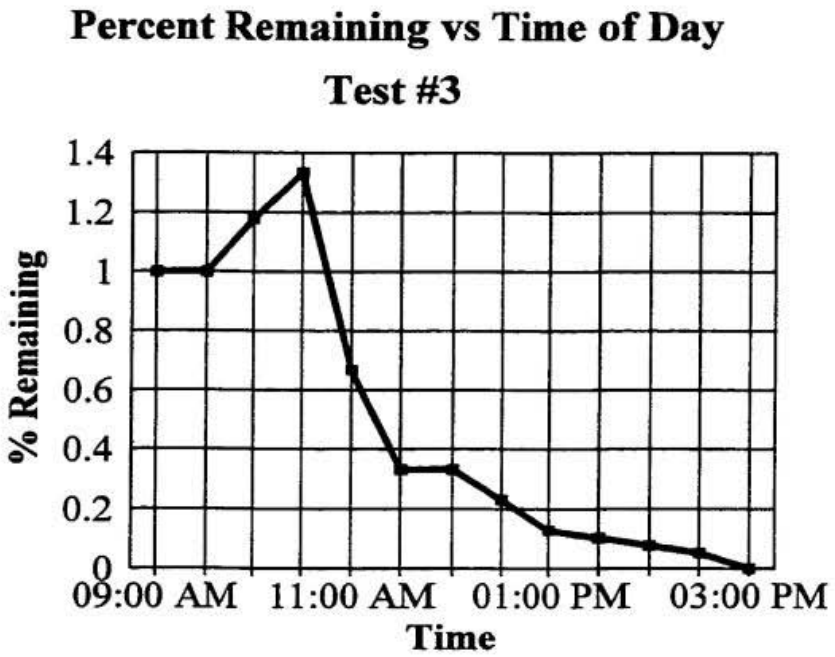

Figure C.3 - Bacteria Storage Test #3

Table C.4 - Bacteria Storage Test #4

	Test #	Date	Julian	T90		
	4	Aug 17	229	4		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	53	1.000	0.030	0.015	7
9:30 AM	0.5	31	0.585	0.050	0.040	8
10:00 AM	1	25	0.472	0.132	0.106	9
10:30 AM	1.5	29	0.547	0.253	0.233	8
11:00 AM	2	18	0.340	0.432	0.449	9
11:30 AM	2.5	12	0.226	0.679	0.788	9
12:00 AM	3	21	0.396	0.616	1.096	9
12:30 PM	3.5	7	0.132	1.386	1.789	9
1:00 PM	4	4	0.075	1.740	2.659	8
1:30 PM	4.5	3	0.057	2.054	3.686	9
2:00 PM	5	2	0.038	2.306	4.839	9
2:30 PM	5.5	0	0.000	2.512	6.095	9
3:00 PM	6	2	0.038	2.679	7.435	9

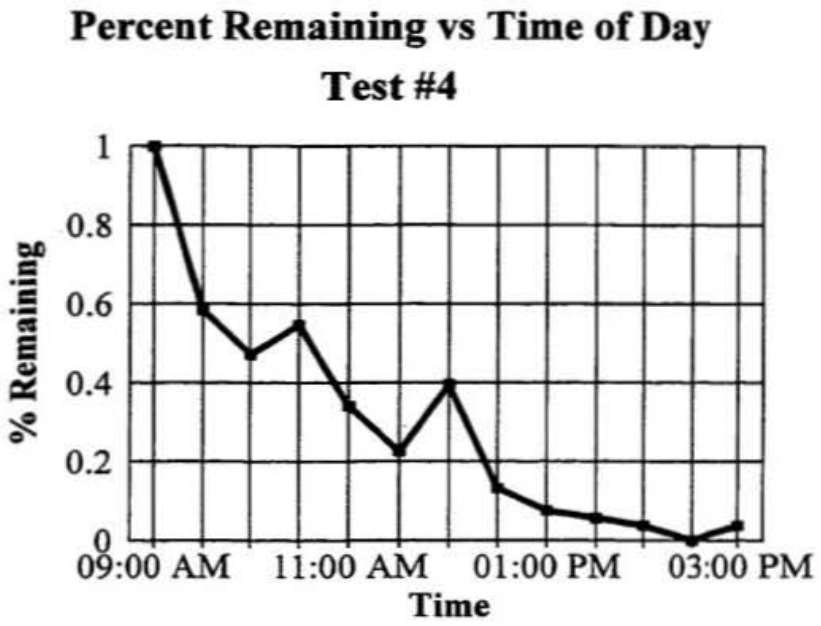

Figure C.4 - Bacteria Storage Test #4

Table C.5 - Bacteria Storage Test #5

	Test #	Date	Julian	T90		
	5	Aug 25	237	4.42		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	48	1.000	0.010	0.005	7
9:30 AM	0.5	36	0.750	0.030	0.020	8
10:00 AM	1	27	0.563	0.100	0.070	9
10:30 AM	1.5	24	0.500	0.228	0.184	8
11:00 AM	2	30	0.625	0.425	0.397	9
11:30 AM	2.5	16	0.333	0.685	0.739	9
12:00 AM	3	9	0.188	0.996	1.237	9
12:30 PM	3.5	10	0.208	1.349	1.912	9
1:00 PM	4	7	0.146	1.693	2.758	9
1:30 PM	4.5	4	0.083	2.022	3.769	9
2:00 PM	5	4	0.083	2.289	4.914	8
2:30 PM	5.5	3	0.063	2.485	6.156	9
3:00 PM	6	0	0.000	2.623	7.468	8

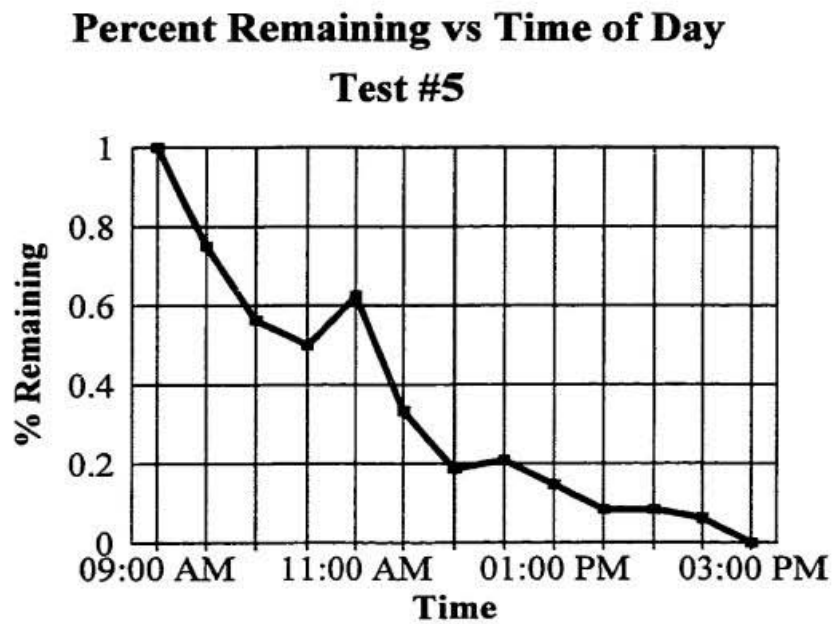

Figure C.5 - Bacteria Storage Test #5

Table C.6 - Bacteria Storage Test #6

	Test #	Date	Julian	T90		
	6	Sept 7	250	4.37		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	51	1.000	0.040	0.020	8
9:30 AM	0.5	59	1.157	0.085	0.062	8
10:00 AM	1	41	0.804	0.171	0.148	9
10:30 AM	1.5	35	0.686	0.311	0.303	8
11:00 AM	2	37	0.725	0.489	0.548	9
11:30 AM	2.5	20	0.392	0.802	0.949	9
12:00 AM	3	18	0.353	0.975	1.436	9
12:30 PM	3.5	15	0.294	1.260	2.066	9
1:00 PM	4	12	0.235	1.590	2.861	9
1:30 PM	4.5	7	0.137	1.830	3.776	9
2:00 PM	5	4	0.078	1.950	4.751	8
2:30 PM	5.5	5	0.098	2.210	5.856	9
3:00 PM	6	2	0.039	2.180	6.946	9

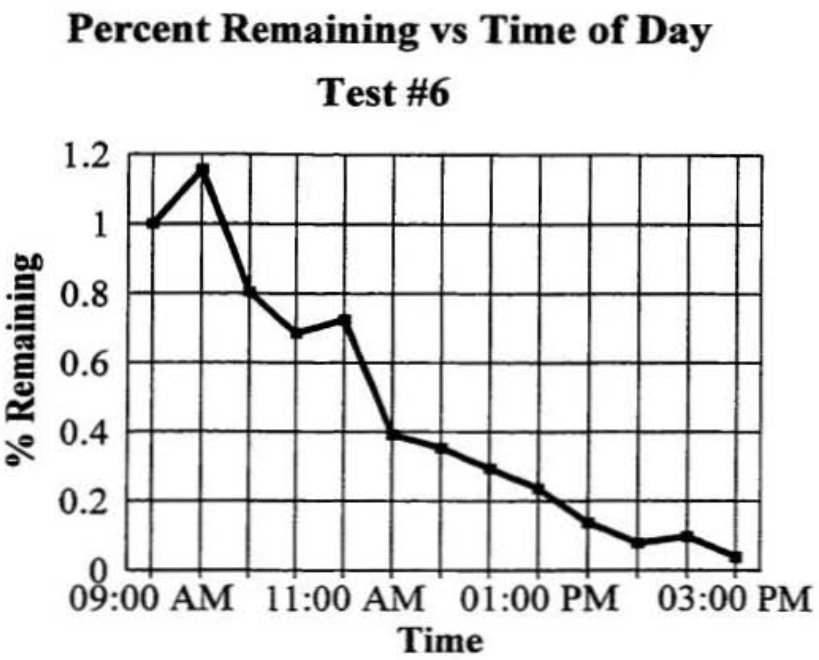

Figure C.6 - Bacteria Storage Test #6

Table C.7 - Bacteria Storage Test #7

	Test #	Date	Julian	T90		
	7	Sept 13	256	5.46		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	42	1.000	0.040	0.020	7
9:30 AM	0.5	31	0.738	0.089	0.065	7
10:00 AM	1	24	0.571	0.204	0.167	8
10:30 AM	1.5	22	0.524	0.425	0.379	8
11:00 AM	2	17	0.405	0.558	0.658	9
11:30 AM	2.5	13	0.310	0.327	0.822	8
12:00 AM	3	11	0.262	0.986	1.315	9
12:30 PM	3.5	8	0.190	1.380	2.005	9
1:00 PM	4	5	0.119	1.750	2.880	9
1:30 PM	4.5	4	0.095	1.790	3.775	9
2:00 PM	5	7	0.167	2.100	4.825	9
2:30 PM	5.5	3	0.071	2.390	6.020	9
3:00 PM	6	4	0.095	2.350	7.195	9

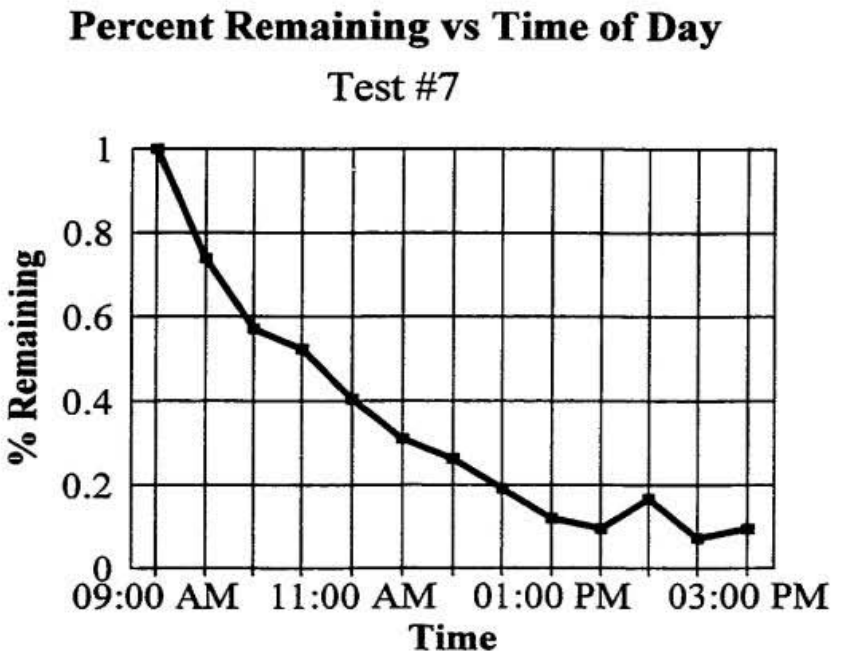

Figure C.7 - Bacteria Storage Test #7

Table C.8 - Bacteria Storage Test #8

	Test #	Date	Julian	T90		
	8	Sept 19	262	5.23		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	44	1.000	0.030	0.015	9
9:30 AM	0.5	41	0.932	0.075	0.053	9
10:00 AM	1	37	0.841	0.128	0.117	9
10:30 AM	1.5	22	0.500	0.325	0.279	8
11:00 AM	2	20	0.455	0.385	0.472	9
11:30 AM	2.5	19	0.432	0.656	0.800	8
12:00 AM	3	21	0.477	0.798	1.199	8
12:30 PM	3.5	17	0.386	0.958	1.678	7
1:00 PM	4	8	0.182	1.250	2.303	8
1:30 PM	4.5	6	0.136	1.430	3.018	8
2:00 PM	5	4	0.091	1.590	3.813	8
2:30 PM	5.5	6	0.136	1.860	4.743	8
3:00 PM	6	3	0.068	1.790	5.638	8

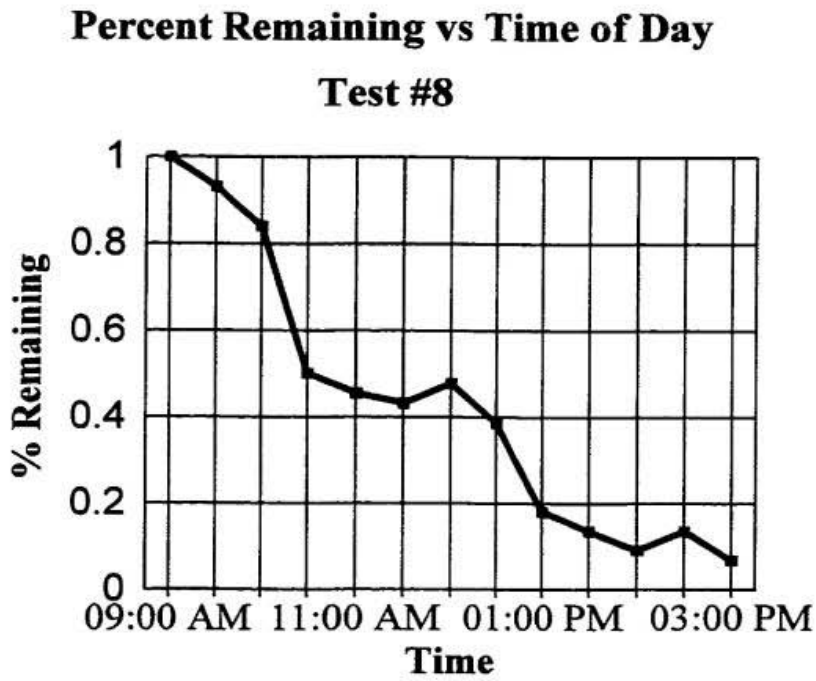

Figure C.8 - Bacteria Storage Test #9

Table C.9 - Bacteria Storage Test #9

	Test #	Date	Julian	T90		
	9	Sept 22	265	6.85		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	53	1.000	0.000	0.000	7
9:30 AM	0.5	47	0.887	0.020	0.010	7
10:00 AM	1	41	0.774	0.063	0.042	7
10:30 AM	1.5	51	0.962	0.143	0.113	8
11:00 AM	2	51	0.962	0.361	0.294	8
11:30 AM	2.5	42	0.792	0.431	0.509	8
12:00 AM	3	47	0.887	0.712	0.865	8
12:30 PM	3.5	31	0.585	0.898	1.314	8
1:00 PM	4	23	0.434	1.022	1.825	8
1:30 PM	4.5	14	0.264	0.955	2.303	8
2:00 PM	5	16	0.302	0.789	2.697	8
2:30 PM	5.5	10	0.189	0.867	3.131	8
3:00 PM	6	6	0.113	0.916	3.589	8

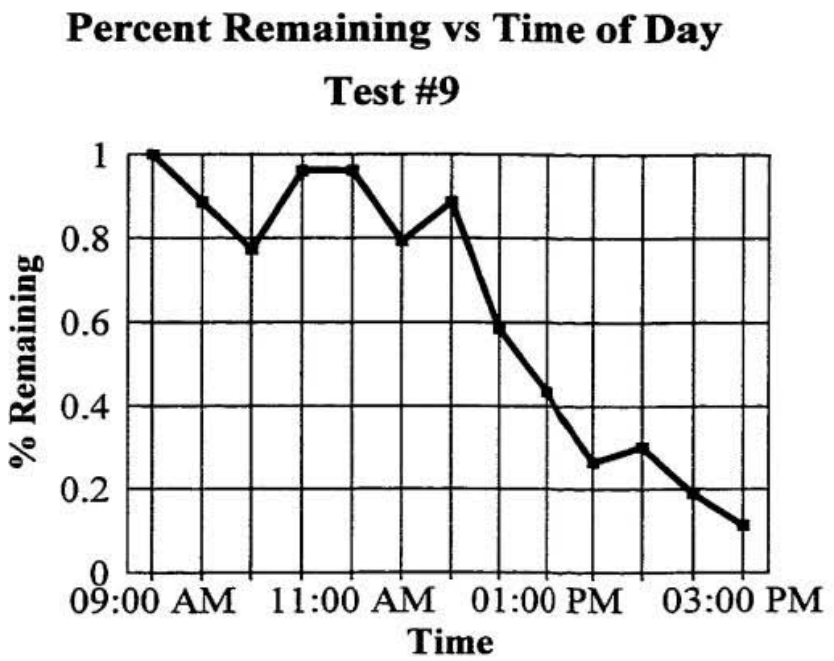

Figure C.9 - Bacteria Storage Test #9

Table C.10 - Bacteria Storage Test #10

	Test #	Date	Julian	T90		
	10	Jan 12	12	8.19		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water Temp**
				(MEDS/	**Exposure**	
9:00 AM	0	61	1.000	0.002	0.001	0
9:30 AM	0.5	53	0.869	0.002	0.002	0
10:00 AM	1	45	0.738	0.007	0.006	0
10:30 AM	1.5	47	0.770	0.011	0.011	0
11:00 AM	2	32	0.525	0.022	0.022	0
11:30 AM	2.5	29	0.475	0.056	0.050	1
12:00 AM	3	25	0.410	0.049	0.075	1
12:30 PM	3.5	25	0.410	0.166	0.158	1
1:00 PM	4	20	0.328	0.165	0.240	1
1:30 PM	4.5	19	0.311	0.099	0.290	1
2:00 PM	5	17	0.279	0.248	0.414	1
2:30 PM	5.5	12	0.197	0.162	0.495	1
3:00 PM	6	8	0.131	0.17	0.580	1

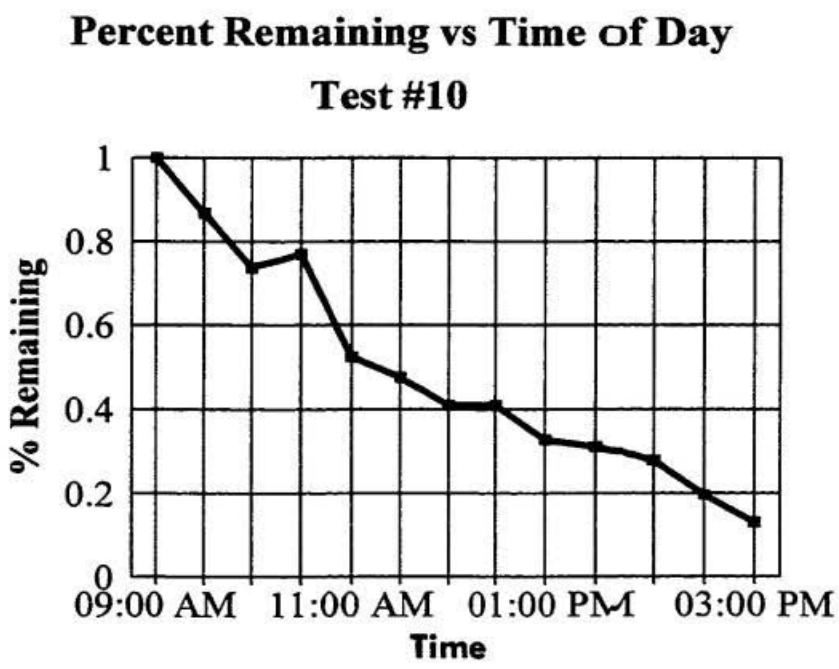

Figure C.10 - Bacteria Storage Test #10

Table C.11 - Bacteria Storage Test #11

	Test #	Date	Julian	T90		
	11	Jan 25	25	6.6		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	50	1.000	0.002	0.001	0
9:30 AM	0.5	41	0.820	0.002	0.002	0
10:00 AM	1	40	0.800	0.014	0.009	0
10:30 AM	1.5	37	0.740	0.023	0.021	0
11:00 AM	2	26	0.520	0.041	0.041	1
11:30 AM	2.5	30	0.600	0.072	0.077	1
12:00 AM	3	27	0.540	0.117	0.136	1
12:30 PM	3.5	28	0.560	0.138	0.205	1
1:00 PM	4	25	0.500	0.201	0.305	1
1:30 PM	4.5	17	0.340	0.236	0.423	1
2:00 PM	5	15	0.300	0.214	0.530	1
2:30 PM	5.5	12	0.240	0.258	0.659	2
3:00 PM	6	5	0.100	0.322	0.820	2

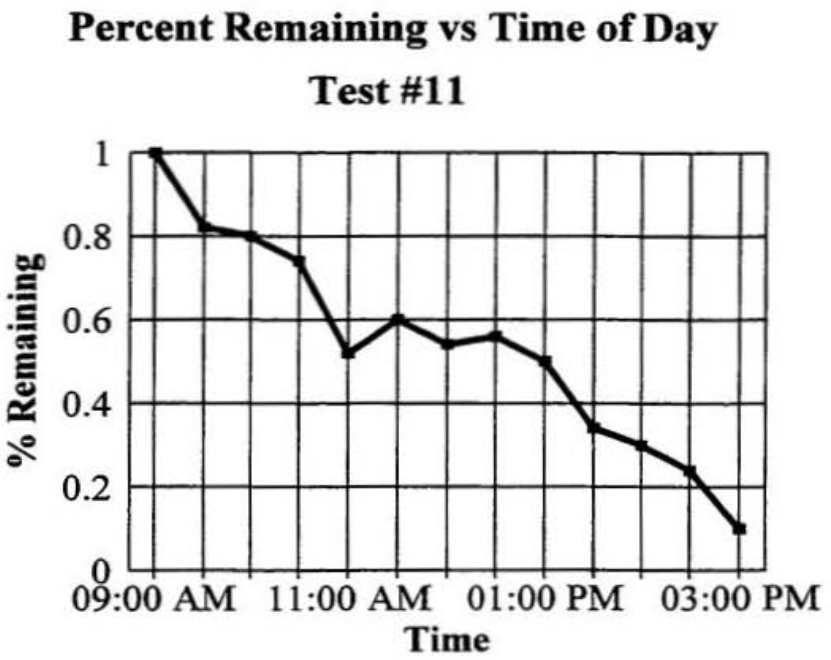

Figure C.11 - Bacteria Storage Test #11

Table C.12 - Bacteria Storage Test #12

	Test #	Date	Julian	T90		
	12	Feb 1	32	6.4		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	52	1.000	0.004	0.002	0
9:30 AM	0.5	55	1.058	0.006	0.005	0
10:00 AM	1	40	0.769	0.016	0.013	0
10:30 AM	1.5	35	0.673	0.031	0.029	1
11:00 AM	2	30	0.577	0.052	0.055	1
11:30 AM	2.5	32	0.615	0.081	0.095	1
12:00 AM	3	25	0.481	0.074	0.132	1
12:30 PM	3.5	23	0.442	0.166	0.215	2
1:00 PM	4	22	0.423	0.209	0.320	1
1:30 PM	4.5	20	0.385	0.246	0.443	2
2:00 PM	5	12	0.231	0.277	0.581	2
2:30 PM	5.5	6	0.115	0.301	0.732	2
3:00 PM	6	5	0.096	0.321	0.892	1

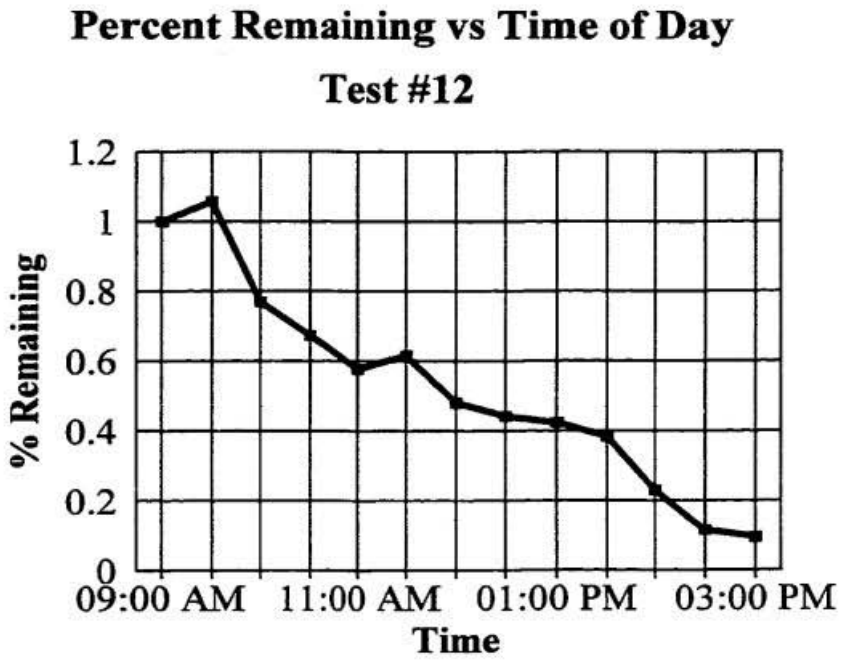

Figure C.12 - Bacteria Storage Test #12

Table C.13 - Bacteria Storage Test #13

	Test #	Date	Julian	T90		
	13	Feb 13	44	9.7		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	61	1.000	0.001	0.001	0
9:30 AM	0.5	41	0.672	0.004	0.003	0
10:00 AM	1	40	0.656	0.009	0.007	0
10:30 AM	1.5	35	0.574	0.015	0.015	1
11:00 AM	2	34	0.557	0.025	0.027	1
11:30 AM	2.5	36	0.590	0.022	0.038	1
12:00 AM	3	28	0.459	0.033	0.055	0
12:30 PM	3.5	20	0.328	0.019	0.064	1
1:00 PM	4	26	0.426	0.029	0.079	2
1:30 PM	4.5	24	0.393	0.037	0.097	1
2:00 PM	5	20	0.328	0.071	0.133	1
2:30 PM	5.5	13	0.213	0.121	0.193	1
3:00 PM	6	10	0.164	0.139	0.263	1

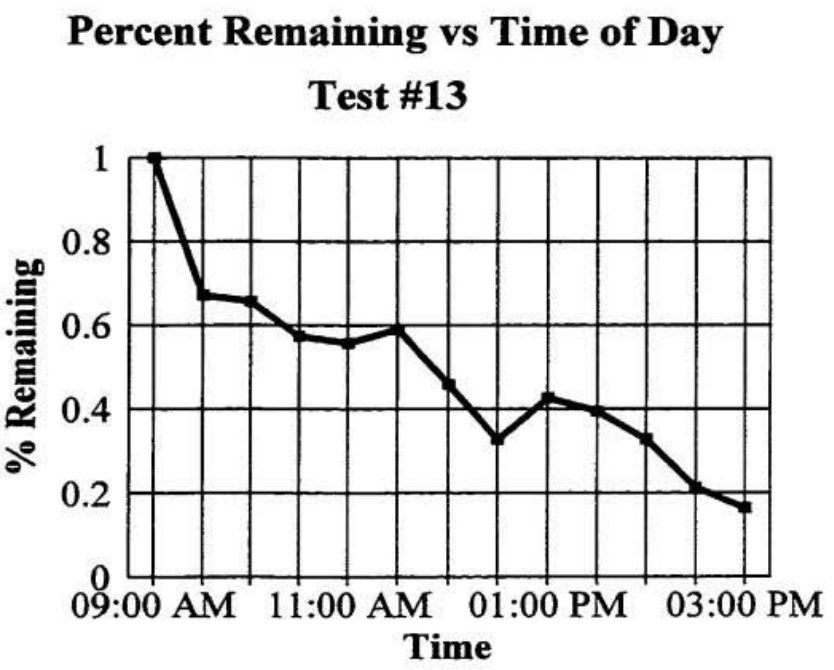

Figure C.13 - Bacteria Storage Test #13

Table C.14 - Bacteria Storage Test #14

	Test #	Date	Julian	T90		
	14	Feb 2.3	54	7.6		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water**
				(MEDS/	**Exposure**	
9:00 AM	0	57	1.000	0.003	0.002	0
9:30 AM	0.5	45	0.789	0.005	0.004	0
10:00 AM	1	46	0.807	0.015	0.012	1
10:30 AM	1.5	29	0.509	0.056	0.040	1
11:00 AM	2	22	0.386	0.08	0.080	2
11:30 AM	2.5	25	0.439	0.137	0.148	1
12:00 AM	3	25	0.439	0.205	0.251	2
12:30 PM	3.5	21	0.368	0.279	0.390	2
1:00 PM	4	17	0.298	0.383	0.582	1
1:30 PM	4.5	15	0.263	0.44	0.802	2
2:00 PM	5	12	0.211	0.478	1.041	2
2:30 PM	5.5	12	0.211	0.479	1.280	2
3:00 PM	6	7	0.123	0.526	1.543	2

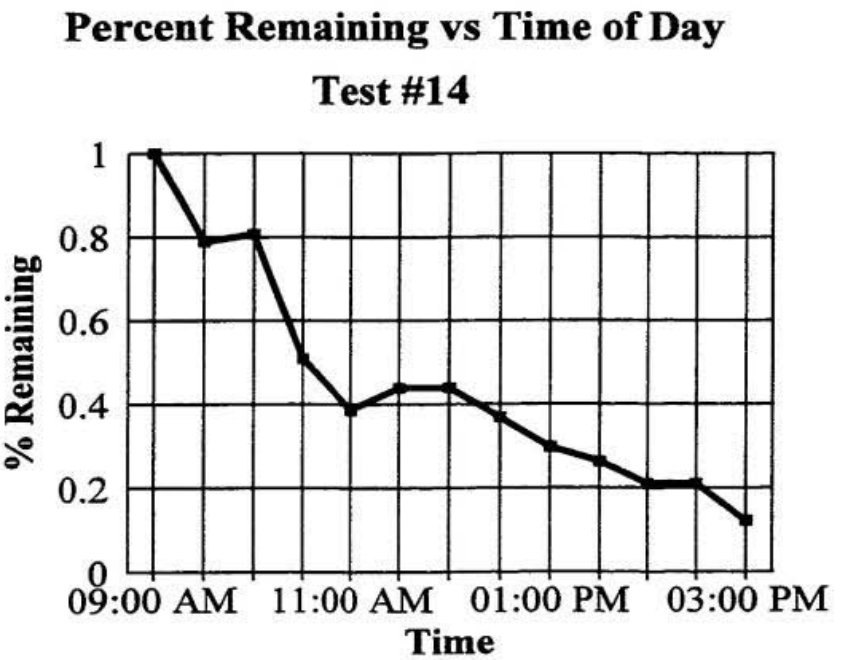

Figure C.14 - Bacteria Storage Test #14

Table C.15 - Bacteria Storage Test #15

	Test #	Date	Julian	T90		
	15	March 6	65	5.2		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water Temp**
				(MEDS/	**Exposure**	
9:00 AM	0	56	1.000	0.008	0.004	0
9:30 AM	0.5	40	0.714	0.026	0.017	1
10:00 AM	1	41	0.732	0.052	0.043	1
10:30 AM	1.5	32	0.571	0.078	0.082	2
11:00 AM	2	30	0.536	0.13	0.147	1
11:30 AM	2.5	28	0.500	0.181	0.238	1
12:00 AM	3	22	0.393	0.233	0.354	1
12:30 PM	3.5	28	0.500	0.433	0.571	1
1:00 PM	4	18	0.321	0.446	0.794	2
1:30 PM	4.5	16	0.286	0.563	1.075	1
2:00 PM	5	12	0.214	0.586	1.368	2
2:30 PM	5.5	7	0.125	0.762	1.749	2
3:00 PM	6	3	0.054	0.495	1.997	2

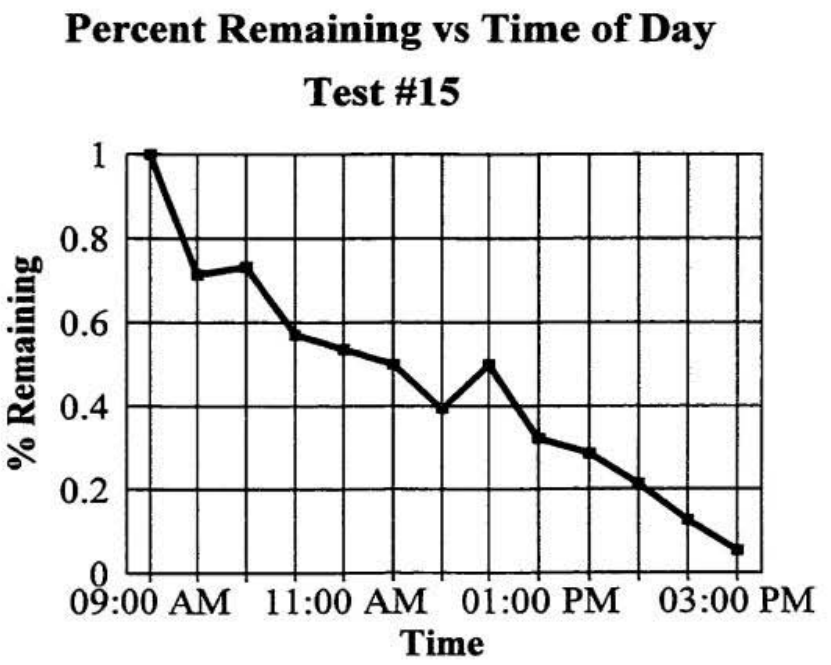

Figure C.15 - Bacteria Storage Test #15

Table C.16 - Bacteria Storage Test #16

	Test #	Date	Julian	T90		
	16	March 16	75	6.7		
Time	Elapsed	Count	C/Co	UV	UV	Water Temp
				(MEDS/	Exposure	
9:00 AM	0	54	1.000	0.009	0.005	1
9:30 AM	0.5	45	0.833	0.025	0.017	2
10:00 AM	1	37	0.685	0.034	0.034	2
10:30 AM	1.5	35	0.648	0.117	0.093	2
11:00 AM	2	28	0.519	0.165	0.175	2
11:30 AM	2.5	29	0.537	0.233	0.292	1
12:00 AM	3	27	0.500	0.247	0.415	2
12:30 PM	3.5	25	0.463	0.489	0.660	2
1:00 PM	4	18	0.333	0.594	0.957	2
1:30 PM	4.5	13	0.241	0.693	1.303	3
2:00 PM	5	10	0.185	0.779	1.693	2
2:30 PM	5.5	9	0.167	0.872	2.129	2
3:00 PM	6	6	0.111	0.673	2.465	2

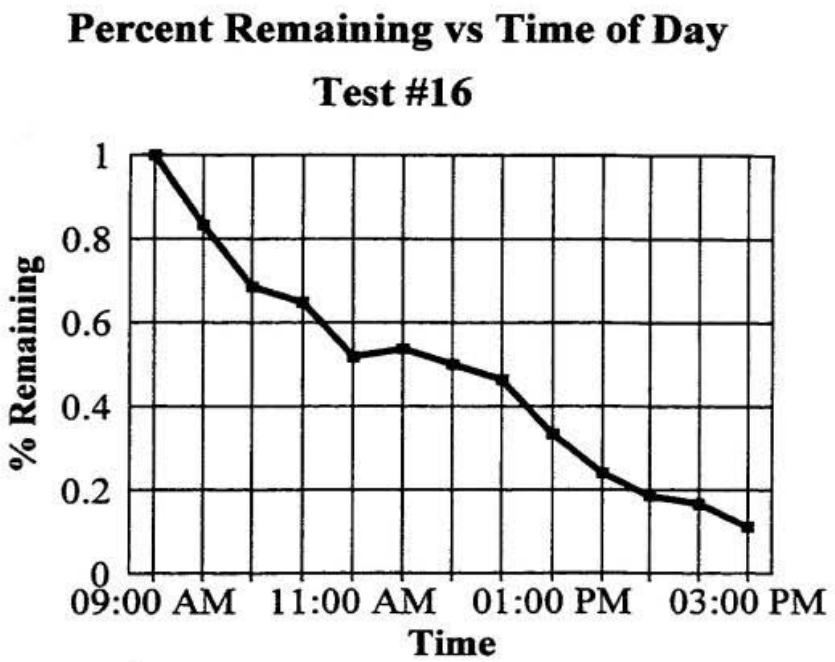

Figure C.16 - Bacteria Storage Test #16

Table C.17 -Bacteria Storage Test #17

	Test #	Date	Julian	T90		
	17	March 23	82	6.3		
Time	**Elapsed**	**Count**	**C/Co**	**UV**	**UV**	**Water Temp**
				(MED	**Exposure**	
9:00 AM	0	41	1.000	0.005	0.003	1
9:30 AM	0.5	30	0.732	0.008	0.007	2
10:00 AM	1	25	0.610	0.025	0.019	2
10:30 AM	1.5	32	0.780	0.069	0.054	2
11:00 AM	2	24	0.585	0.135	0.121	3
11:30 AM	2.5	19	0.463	0.368	0.305	2
12:00 AM	3	18	0.439	0.569	0.590	3
12:30 PM	3.5	18	0.439	0.963	1.071	2
1:00 PM	4	15	0.366	1.236	1.689	2
1:30 PM	4.5	13	0.317	1.365	2.372	2
2:00 PM	5	14	0.341	1.789	3.266	3
2:30 PM	5.5	9	0.220	2.025	4.279	3
3:00 PM	6	5	0.122	2.536	5.547	2

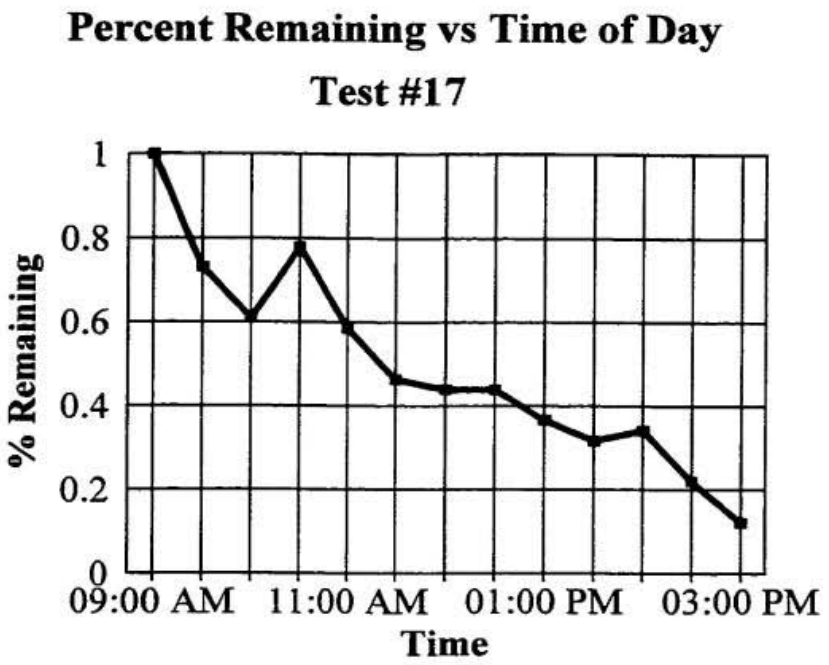

Figure C.17 - Bacteria Storage Test #17

APPENDIX D

DROGUE STUDY SURVEY NOTES

CARBONEAR STUDY #1 (OUTSIDE HARBOUR)

Set 01

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*10:35 AM*	1.000	53.000	0.000	357.000	57.000	40.000
	10:50 AM	9.000	31.000	0.000	352.000	1.000	20.000
	11:05 AM	24.000	1.000	0.000	346.000	53.000	40.000
	11:20 AM	61.000	36.000	20.000	343.000	19.000	0.000
	11:35 AM	91.000	57.000	40.000	337.000	44.000	0.000
	11:50 AM	108.000	35.000	40.000	337.000	19.000	20.000
	12:05 PM	118.000	26.000	40.000	337.000	44.000	0.000
	12:20 PM	119.000	46.000	0.000	333.000	58.000	20.000
	12:35 PM	127.000	9.000	0.000	332.000	1.000	20.000
	12:50 PM	125.000	8.000	40.000	330.000	43.000	20.000
Float 02	*10:35 AM*	5.000	18.000	20.000	355.000	15.000	40.000
	10:50 AM	12.000	37.000	0.000	351.000	29.000	20.000
	11:05 AM	33.000	49.000	0.000	345.000	47.000	20.000
	11:20 AM	84.000	37.000	4.000	342.000	2.000	20.000
	11:35 AM	105.000	58.000	0.000	337.000	3.000	0.000
	11:50 AM	119.000	42.000	20.000	332.000	23.000	0.000
	12:05 PM	127.000	53.000	0.000	338.000	3.000	0.000
	12:20 PM	130.000	59.000	40.000	336.000	16.000	0.000
	12:35 PM	131.000	48.000	0.000	334.000	36.000	20.000
	12:50 PM	132.000	38.000	40.000	330.000	43.000	20.000

Float 03	*10:35 AM*	4.000	33.000	20.000	356.000	8.000	40.000
	10:50 AM	11.000	9.000	20.000	350.000	59.000	0.000
	11:05 AM	37.000	52.000	20.000	345.000	24.000	0.000
	11:20 AM	86.000	28.000	40.000	342.000	6.000	40.000
	11:35 AM	106.000	7.000	40.000	336.000	10.000	40.000
	11:50 AM	120.000	34.000	40.000	337.000	1.000	40.000
	12:05 PM	128.000	4.000	40.000	337.000	47.000	20.000
	12:20 PM	130.000	4.000	0.000	335.000	38.000	0.000
	12:35 PM	130.000	30.000	40.000	333.000	34.000	0.000
	12:50 PM	131.000	21.000	0.000	331.000	32.000	20.000
Float 04	*10:35 AM*	4.000	21.000	0.000	355.000	36.000	20.000
	10:50 AM	14.000	7.000	0.000	350.000	49.000	20.000
	11:05 AM	28.000	59.000	20.000	344.000	48.000	20.000
	11:20 AM	71.000	12.000	40.000	341.000	6.000	20.000
	11:35 AM	97.000	5.000	0.000	336.000	43.000	40.000
	11:50 AM	112.000	9.000	20.000	336.000	51.000	0.000
	12:05 PM	121.000	8.000	0.000	337.000	10.000	40.000
	12:20 PM	123.000	26.000	40.000	334.000	7.000	0.000
	12:35 PM	125.000	8.000	40.000	332.000	14.000	0.000
	12:50 PM	127.000	4.000	20.000	330.000	25.000	40.000

Set 02

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*09:25 AM*	3.000	25.000	40.000	354.000	57.000	40.000
	09:40 AM	5.000	46.000	40.000	351.000	0.000	20.000
	09:55 AM	8.000	46.000	0.000	345.000	7.000	40.000
	10:10 AM	12.000	32.000	8.000	339.000	11.000	40.000
	10:25 AM	13.000	48.000	40.000	337.000	46.000	40.000
	10:40 AM	13.000	63.000	40.000	339.000	52.000	40.000
	10:55 AM	11.000	52.000	40.000	342.000	37.000	0.000
	11:10 AM	16.000	21.000	40.000	338.000	8.000	40.000
	11:25 AM	23.000	3.000	40.000	333.000	24.000	0.000
	11:40 AM	36.000	37.000	20.000	322.000	9.000	20.000
Float 02	*09:25 AM*	3.000	35.000	40.000	355.000	14.000	0.000
	09:40 AM	6.000	13.000	20.000	350.000	44.000	20.000
	09:55 AM	8.000	59.000	20.000	345.000	19.000	40.000
	10:10 AM	12.000	52.000	20.000	339.000	3.000	0.000
	10:25 AM	14.000	13.000	20.000	337.000	38.000	0.000
	10:40 AM	13.000	35.000	20.000	339.000	42.000	40.000
	10:55 AM	12.000	36.000	20.000	342.000	19.000	0.000
	11:10 AM	17.000	38.000	40.000	338.000	1.000	20.000
	11:25 AM	26.000	14.000	40.000	331.000	38.000	40.000
	11:40 AM	40.000	24.000	20.000	318.000	36.000	40.000

Float 03	*09:25 AM*	2.000	18.000	20.000	356.000	32.000	40.000
	09:40 AM	4.000	49.000	40.000	352.000	39.000	40.000
	09:55 AM	7.000	32.000	40.000	346.000	59.000	20.000
	10:10 AM	12.000	13.000	20.000	338.000	49.000	40.000
	10:25 AM	13.000	20.000	40.000	336.000	57.000	40.000
	10:40 AM	12.000	49.000	40.000	338.000	49.000	40.000
	10:55 AM	10.000	58.000	0.000	342.000	12.000	40.000
	11:10 AM	16.000	6.000	40.000	337.000	4.000	20.000
	11:25 AM	24.000	14.000	40.000	330.000	21.000	20.000
	11:40 AM	36.000	27.000	20.000	314.000	44.000	40.000
Float 04	*09:25 AM*	4.000	7.000	20.000	353.000	36.000	20.000
	09:40 AM	6.000	29.000	40.000	349.000	22.000	20.000
	09:55 AM	9.000	52.000	40.000	342.000	17.000	14.000
	10:10 AM	14.000	20.000	0.000	335.000	39.000	20.000
	10:25 AM	15.000	42.000	0.000	333.000	56.000	20.000
	10:40 AM	14.000	23.000	20.000	336.000	29.000	40.000
	10:55 AM	13.000	49.000	20.000	338.000	30.000	0.000
	11:10 AM	19.000	6.000	0.000	334.000	48.000	0.000
	11:25 AM	28.000	18.000	20.000	328.000	43.000	20.000
	11:40 AM	41.000	30.000	20.000	315.000	8.000	0.000

CARBONEAR STUDY #2 (INSIDE HARBOUR)

Set 01

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*09:00 AM*	0.000	46.000	40.000	358.000	36.000	20.000
	09:15 AM	2.000	25.000	40.000	355.000	56.000	40.000
	09:30 AM	6.000	40.000	40.000	349.000	24.000	40.000
	09:45 AM	16.000	14.000	0.000	339.000	17.000	20.000
	10:00 AM	24.000	24.000	0.000	328.000	31.000	20.000
	10:15 AM	35.000	35.000	40.000	318.000	43.000	40.000
	10:30 AM	47.000	47.000	20.000	310.000	27.000	40.000
	10:45 AM	54.000	35.000	20.000	307.000	6.000	20.000
	11:00 AM	60.000	3.000	0.000	301.000	50.000	20.000
	11:15 AM	64.000	28.000	0.000	298.000	56.000	40.000
Float 02	*09:00 AM*	2.000	24.000	20.000	355.000	46.000	0.000
	09:15 AM	6.000	26.000	20.000	350.000	15.000	0.000
	09:30 AM	13.000	10.000	0.000	339.000	58.000	20.000
	09:45 AM	23.000	19.000	40.000	332.000	34.000	20.000
	10:00 AM	33.000	25.000	20.000	319.000	11.000	0.000
	10:15 AM	46.000	8.000	20.000	308.000	6.000	0.000
	10:30 AM	56.000	6.000	0.000	300.000	22.000	0.000
	10:45 AM	62.000	39.000	40.000	295.000	29.000	0.000
	11:00 AM	68.000	5.000	0.000	291.000	31.000	0.000
	11:15 AM	70.000	48.000	20.000	289.000	55.000	0.000

Float 03	*09:00 AM*	1.000	23.000	0.000	357.000	32.000	20.000
	09:15 AM	4.000	1.000	40.000	353.000	24.000	20.000
	09:30 AM	10.000	20.000	20.000	343.000	38.000	20.000
	09:45 AM	20.000	56.000	20.000	329.000	23.000	40.000
	10:00 AM	31.000	33.000	0.000	322.000	2.000	20.000
	10:15 AM	44.000	39.000	40.000	310.000	21.000	0.000
	10:30 AM	54.000	39.000	0.000	302.000	15.000	20.000
	10:45 AM	61.000	9.000	40.000	297.000	18.000	40.000
	11:00 AM	65.000	51.000	0.000	292.000	58.000	0.000
	11:15 AM	68.000	17.000	0.000	290.000	54.000	0.000

Float 04	*09:00 AM*	1.000	27.000	20.000	357.000	27.000	20.000
	09:15 AM	3.000	48.000	40.000	353.000	19.000	20.000
	09:30 AM	9.000	51.000	0.000	343.000	58.000	40.000
	09:45 AM	20.000	29.000	20.000	333.000	2.000	40.000
	10:00 AM	30.000	58.000	0.000	322.000	17.000	40.000
	10:15 AM	44.000	56.000	20.000	310.000	38.000	40.000
	10:30 AM	55.000	14.000	40.000	303.000	27.000	40.000
	10:45 AM	61.000	47.000	0.000	298.000	7.000	20.000
	11:00 AM	66.000	59.000	40.000	294.000	24.000	0.000
	11:15 AM	69.000	30.000	20.000	292.000	21.000	0.000

Set 02

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*12:30 PM*	22.000	22.000	0.000	346.000	53.000	20.000
	12:45 PM	50.000	28.000	20.000	338.000	54.000	40.000
	01:00 PM	82.000	1.000	20.000	325.000	7.000	40.000
	01:15 PM	95.000	37.000	20.000	320.000	42.000	0.000
	01:30 PM	102.000	53.000	40.000	313.000	40.000	0.000
	01:45 PM	105.000	43.000	0.000	310.000	26.000	40.000
	02:00 PM	108.000	53.000	40.000	309.000	19.000	0.000
	02:15 PM	112.000	56.000	40.000	309.000	40.000	20.000
	02:30 PM	114.000	23.000	20.000	309.000	3.000	40.000
Float 02	*12:30 PM*	17.000	28.000	20.000	345.000	1.000	20.000
	12:45 PM	33.000	15.000	0.000	334.000	14.000	0.000
	01:00 PM	50.000	32.000	0.000	318.000	15.000	0.000
	01:15 PM	61.000	2.000	0.000	309.000	38.000	40.000
	01:30 PM	74.000	18.000	0.000	303.000	14.000	0.000
	01:45 PM	83.000	19.000	40.000	300.000	9.000	0.000
	02:00 PM	89.000	19.000	20.000	299.000	16.000	0.000
	02:15 PM	96.000	39.000	20.000	300.000	50.000	0.000
	02:30 PM	100.000	35.000	0.000	300.000	40.000	20.000
Float 03	12:30 PM	16.000	2.000	20.000	346.000	17.000	0.000
	12:45 PM	31.000	42.000	0.000	335.000	3.000	0.000
	01:00 PM	50.000	43.000	20.000	317.000	3.000	40.000
	01:15 PM	61.000	18.000	20.000	308.000	57.000	20.000
	01:30 PM	73.000	1.000	40.000	301.000	40.000	20.000
	01:45 PM	82.000	23.000	40.000	298.000	50.000	40.000
	02:00 PM	88.000	25.000	0.000	298.000	14.000	20.000
	02:15 PM	95.000	44.000	40.000	299.000	26.000	20.000
	02:30 PM	100.000	0.000	20.000	299.000	52.000	20.000

Float 04	*12:30 PM*	13.000	33.000	20.000	349.000	23.000	0.000
	12:45 PM	29.000	2.000	20.000	339.000	12.000	40.000
	01:00 PM	48.000	6.000	0.000	322.000	58.000	40.000
	01:15 PM	57.000	33.000	0.000	312.000	59.000	20.000
	01:30 PM	71.000	13.000	20.000	304.000	36.000	0.000
	01:45 PM	83.000	12.000	20.000	302.000	12.000	20.000
	02:00 PM	90.000	1.000	0.000	300.000	58.000	40.000
	02:15 PM	98.000	5.000	0.000	302.000	32.000	0.000
	02:30 PM	102.000	8.000	20.000	302.000	17.000	40.000

BONAVISTIA STUDY

Set 01

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*09:30 AM*	76.000	17.000	40.000	48.000	40.000	0.000
	09:45 AM	85.000	53.000	20.000	34.000	28.000	
	09:58 AM	75.000	8.000	40.000	54.000	46.000	
	10:14 AM	82.000	39.000	40.000	48.000	35.000	
	10:29 AM	87.000	41.000	20.000	43.000	54.000	
	10:45 AM	92.000	48.000	40.000	39.000	41.000	
	11:00 AM	98.000	49.000	0.000	35.000	22.000	
	11:11 AM	88.000	22.000	20.000	42.000	28.000	
	11:26 AM	95.000	49.000	40.000	37.000	31.000	
	11:40 AM	103.000	52.000	0.000	32.000	34.000	
	11:55 AM	114.000	57.000	28.000	30.000	24.000	
Float 02	09:30 AM	65.000	35.000	20.000	49.000	22.000	
	09:45 AM	87.000	42.000	20.000	32.000	42.000	
	09:58 AM	70.000	45.000	0.000	57.000	39.000	
	10:14 AM	81.000	20.000	0.000	49.000	39.000	
	10:29 AM	88.000	51.000	0.000	44.000	31.000	
	10:45 AM	98.000	43.000	0.000	39.000	41.000	
	11:00 AM	110.000	9.000	20.000	38.000	15.000	
	11:11 AM	84.000	48.000	0.000	43.000	12.000	
	11:26 AM	91.000	34.000	40.000	38.000	8.000	
	11:40 AM	96.000	25.000	40.000	35.000	4.000	
	11:55 AM	102.000	13.000	40.000	32.000	49.000	

Float 03	09:30 AM	75.000	31.000	40.000	46.000	23.000
	09:45 AM	91.000	26.000	0.000	32.000	59.000
	09:58 AM	67.000	33.000	20.000	60.000	41.000
	10:14 AM	72.000	44.000	40.000	53.000	59.000
	10:29 AM	77.000	4.000	20.000	47.000	17.000
	10:45 AM	82.000	14.000	20.000	45.000	0.000
	11:00 AM	84.000	1.000	40.000	44.000	0.000
	11:11 AM	80.000	40.000	20.000	43.000	12.000
	11:26 AM	89.000	38.000	40.000	35.000	
	11:40 AM	109.000	21.000	40.000	29.000	38.000
	11:55 AM	134.000	38.000	20.000	21.000	51.000
Float 04	09:30 AM	79.000	43.000	0.000	45.000	26.000
	09:45 AM	95.000	41.000	40.000	30.000	16.000
	09:58 AM	63.000	19.000	40.000	64.000	9.000
	10:14 AM	69.000	5.000	40.000	54.000	33.000
	10:29 AM	75.000	24.000	40.000	47.000	10.000
	10:45 AM	85.000	13.000	0.000	36.000	
	11:00 AM	93.000	32.000	20.000	41.000	46.000
	11:11 AM	77.000	26.000	0.000	44.000	33.000
	11:26 AM	86.000	55.000	0.000	37.000	48.000
	11:40 AM	113.000	30.000	40.000	26.000	28.000
	11:55 AM	148.000	40.000	20.000	18.000	35.000

Set 02		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*01:28 PM*	358.000	4.000	20.000	3.000	44.000	0.000
	01:44 PM	9.000	56.000	40.000	352.000	5.000	
	01:48 PM	340.000	59.000	40.000	27.000	52.000	
	02:05 PM	345.000	52.000	0.000	11.000	57.000	
	02:21 PM	357.000	35.000	0.000	1.000	5.000	
	02:28 PM	341.000	5.000	0.000	67.000	43.000	
	02:44 PM	347.000	37.000	0.000	19.000	33.000	
	03:00 PM	0.000	33.000	0.000	359.000	36.000	
Float 02	*01:28 PM*	350.000	40.000	40.000	12.000	46.000	
	01:44 PM	359.000	16.000	20.000	0.000	50.000	
	01:48 PM	337.000	5.000	44.000	34.000	47.000	
	02:05 PM	339.000	49.000	20.000	19.000	0.000	
	02:21 PM	345.000	27.000	0.000	10.000	56.000	
	02:28 PM	340.000	42.000	0.000	73.000	26.000	
	02:44 PM	344.000	15.000	0.000	31.000	9.000	
	03:00 PM	346.000	16.000	0.000	13.000	8.000	
Float 03	*01:28 PM*	345.000	16.000	0.000	19.000	43.000	
	01:44 PM	357.000	31.000	40.000	2.000	20.000	
	01:48 PM	333.000	39.000	40.000	41.000	11.000	
	02:05 PM	334.000	40.000	8.000	24.000	38.000	
	02:21 PM	343.000	15.000	0.000	12.000	27.000	
	02:28 PM	337.000	55.000	0.000	81.000	6.000	
	02:44 PM	339.000	30.000	0.000	37.000	48.000	
	03:00 PM	340.000	45.000	0.000	18.000	52.000	

Float 04	*01:28 PM*	340.000	7.000	20.000	26.000	26.000
	01:44 PM	344.000	46.000	0.000	11.000	57.000
	01:48 PM	330.000	26.000	0.000	44.000	28.000
	02:05 PM	326.000	12.000	20.000	25.000	26.000
	02:21 PM	332.000	25.000	0.000	12.000	40.000
	02:28 PM	335.000	10.000	0.000	82.000	54.000
	02:44 PM	336.000	42.000	0.000	59.000	19.000
	03:00 PM	336.000	39.000	0.000	38.000	5.000

Set 03

		STATION 01			STATION 02		
	TIME	DEGREES	MIN	SEC	DEGREES	MIN	SEC
Float 01	*09:00 AM*	63.000	3.000	0.000	306.000	46.000	0.000
	09:14 AM	60.000	52.000	0.000	292.000	27.000	
	09:30 AM	56.000	20.000	0.000	276.000	7.000	
	10:00 AM	309.000	9.000	0.000	48.000	28.000	
	10:15 AM	300.000	30.000	0.000	40.000	7.000	
	10:30 AM	294.000	4.000	0.000	35.000	53.000	
	10:45 AM	285.000	9.000	0.000	36.000	12.000	
	10:55 AM	316.000	15.000	0.000	43.000	10.000	
	11:13 AM	312.000	6.000	0.000	44.000	35.000	
	11:29 AM	311.000	10.000	0.000	42.000	25.000	
	11:45 AM	311.000	5.000	0.000	36.000	11.000	
	12:00 PM	300.000	12.000	0.000	36.000	47.000	
Float 02	*09:00 AM*	68.000	25.000	0.000	305.000	17.000	
	09:14 AM	67.000	50.000	0.000	297.000	34.000	
	09:30 AM	67.000	47.000	0.000	291.000	39.000	
	10:00 AM	306.000	45.000	0.000	50.000	29.000	
	10:15 AM	294.000	4.000	0.000	39.000	32.000	
	10:30 AM	284.000	6.000	0.000	33.000	26.000	
	10:45 AM	272.000	26.000	0.000	34.000	16.000	
	10:55 AM	313.000	49.000	0.000	44.000	46.000	
	11:13 AM	308.000	44.000	0.000	45.000	4.000	
	11:29 AM	308.000	22.000	0.000	41.000	32.000	
	11:45 AM	302.000	23.000	0.000	35.000	14.000	
	12:00 PM	300.000	57.000	0.000	32.000	24.000	

Float 03	*09:00 AM*	72.000	49.000	0.000	304.000	29.000
	09:14 AM	74.000	27.000	0.000	302.000	40.000
	09:30 AM	77.000	24.000	0.000	298.000	53.000
	10:00 AM	304.000	30.000	0.000	51.000	7.000
	10:15 AM	293.000	0.000	0.000	38.000	9.000
	10:30 AM	282.000	48.000	0.000	33.000	26.000
	10:45 AM	271.000	18.000	0.000	34.000	4.000
	10:55 AM	311.000	1.000	0.000	47.000	4.000
	11:13 AM	305.000	38.000	0.000	45.000	48.000
	11:29 AM	304.000	37.000	0.000	41.000	39.000
	11:45 AM	298.000	5.000	0.000	36.000	38.000
	12:00 PM	286.000	57.000	0.000	36.000	44.000
Float 04	*09:00 AM*	77.000	46.000	0.000	303.000	52.000
	09:14 AM	78.000	1.000	0.000	301.000	38.000
	09:30 AM	75.000	22.000	0.000	295.000	19.000
	10:00 AM	300.000	51.000	0.000	52.000	15.000
	10:15 AM	288.000	11.000	0.000	42.000	47.000
	10:30 AM	274.000	50.000	0.000	37.000	9.000
	10:45 AM	264.000	14.000	0.000	36.000	16.000
	10:55 AM	308.000	38.000	0.000	49.000	10.000
	11:13 AM	303.000	52.000	0.000	46.000	37.000
	11:29 AM	301.000	33.000	0.000	42.000	30.000
	11:45 AM	297.000	23.000	0.000	37.000	22.000
	12:00 PM	287.000	40.000	0.000	36.000	26.000

APPENDIX E

DISPERSION STUDY DATA

Table E.1 - Carbonear #1(Outside Harbour)

	L	K
Set 1	277.131	210.479
	84.953	10.450
	124.888	14.169
	134.724	13.154
	572.154	237.860
	286.695	37.382
	372.346	58.242
	221.083	21.688
	390.799	46.549
Set 2	120.077	42.922
	87.333	12.762
	121.927	14.482
	117.233	10.269
	181.085	20.020
	115.967	5.996
	132.517	6.794

Table E.2 - Carbonear #2(Inside Harbour)

	L	K
Set 1	168.391	82.853
	93.076	12.272
	334.331	104.993
	65.623	2.926
	125.058	9.053
	271.576	33.653
	415.190	76.138
	443.675	73.096
	485.566	81.635
Set 2	236.634	221.494
	570.269	600.612
	916.202	1170.257
	1185.867	1368.842
	1292.088	1264.087
	1467.476	1372.194
	1667.325	1437.129
	1702.707	1336.950

Table E.3 - Bonavistia Study

	L	K
Set 1	922.951	2364.783
	454.372	598.073
	728.556	792.620
	1043.942	1294.758
	2706.539	5247.475
	268.939	264.912
	327.510	177.090
	1528.778	2570.147
Set 2	427.239	505.592
	171.307	97.220
	214.619	56.144
	121.325	37.479
	281.707	119.304
Set 3	474.165	684.328
	1466.739	3254.496
	547.384	826.425
	674.657	822.167
	813.917	761.775
	284.106	187.775
	476.424	268.885
	621.576	399.113
	831.280	473.591

APPENDIX F

DISPERSION STUDY REGRESSION DATA

Bonavista Regression Output

MTB > Name c3 = 'SRES1' c4 = 'FITS1' c5 = 'RESI1' c6 = 'COEF1'

MTB > Regress 'Log K' 1 'Log L';

SUBC> SResiduals 'SRES1';

SUBC> Fits 'FITS1';

SUBC> Residuals 'RESI1';

SUBC> Coefficients 'COEF1'.

The regression equation is

Log K = - 1.74 + 1.62 Log L

Predictor	Coef	Stdev	t-ratio	p
Constant	-1.7392	0.3321	-5.24	0.000
Log L	1.6237	0.1210	13.42	0.000

s = 0.1820 R-sq = 90.0% R-sq(adj) = 89.5%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	5.9659	5.9659	180.06	0.000
Error	20	0.6627	0.0331		
Total	21	6.6286			

Carbonear #1 Outside Harbour Regression

Macro is running ... please wait

MTB > Plot 'SRES1'*'FITS1';

SUBC> Symbol.

MTB > Name c7 = 'SRES2' c8 = 'FITS2' c9 = 'RESI2' c10 = 'COEF2'

MTB > Regress 'Log K' 1 'Log L';

SUBC> SResiduals 'SRES2';

SUBC> Fits 'FITS2';

SUBC> Residuals 'RESI2';

SUBC> Coefficients 'COEF2'.

The regression equation is

Log K = - 2.60 + 1.82 Log L

Predictor	Coef	Stdev	t-ratio	p
Constant	-2.6030	0.4643	-5.61	0.000
Log L	1.8198	0.1734	10.50	0.000

s = 0.3109 R-sq = 88.0% R-sq(adj) = 87.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	10.650	10.650	110.16	0.000
Error	15	1.450	0.097		
Total	16	12.100			

Unusual Observations

Obs.	Log L	Log K	Fit	Stdev.Fit	Residual	St.Resid
10	2.37	2.3454	1.7173	0.0886	0.6280	2.11R

R denotes an obs. with a large st. resid.

Carbonear #2 Inside Harbour Regression

MTB > Name c3 = 'SRES1' c4 = 'FITS1' c5 = 'RESI1' c6 = 'COEF1'

MTB > Regress 'Log K' 1 'Log L';

SUBC> SResiduals 'SRES1';

SUBC> Fits 'FITS1';

SUBC> Residuals 'RESI1';

SUBC> Coefficients 'COEF1'.

The regression equation is

Log K = - 1.96 + 1.47 Log L

Predictor	Coef	Stdev	t-ratio	p
Constant	-1.9600	0.6438	-3.04	0.008
Log L	1.4745	0.2828	5.21	0.000

s = 0.2869 R-sq = 62.9% R-sq(adj) = 60.6%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	2.2361	2.2361	27.17	0.000
Error	16	1.3166	0.0823		
Total	17	3.5526			

Unusual Observations

Obs.	Log L	Log K	Fit	Stdev.Fit	Residual	St.Resid
1	2.44	2.3232	1.6417	0.0845	0.6815	2.49R

R denotes an obs. with a large st. resid.

APPENDIX G

CARBONEAR DISPERSION STUDY ANCOVA DATA

Table G.1 - ANCOVA Data

K	L	Inside (Z)	Comb (ZX)
2.3232	2.4427	1	2.4427
1.0191	1.9292	1	1.9292
1.1513	2.0965	1	2.0965
1.1191	2.1294	1	2.1294
2.3763	2.7575	1	2.7575
1.5727	2.4574	1	2.4574
1.7652	2.5709	1	2.5709
1.3362	2.3446	1	2.3446
1.6679	2.5920	1	2.5920
1.6327	2.0795	1	2.0795
1.1059	1.9412	1	1.9412
1.1608	2.0861	1	2.0861
1.0115	2.0691	1	2.0691
1.3015	2.2579	1	2.2579
0.7779	2.0643	1	2.0643
0.8321	2.1223	1	2.1223
1.9183	2.2263	0	0.0000
1.0889	1.9688	0	0.0000
2.0212	2.5242	0	0.0000
0.4663	1.8171	0	0.0000
0.9568	2.0971	0	0.0000
1.5270	2.4339	0	0.0000
1.8816	2.6182	0	0.0000
1.8639	2.6471	0	0.0000
1.9119	2.6862	0	0.0000
2.3454	2.3741	0	0.0000
2.7786	2.7561	0	0.0000
3.0683	2.9620	0	0.0000
3.1364	3.0740	0	0.0000
3.1018	3.1113	0	0.0000
3.1374	3.1666	0	0.0000
3.1575	3.2220	0	0.0000
3.1261	3.2311	0	0.0000

Carbonear ANCOVA Regression Analysis without Dummy Variable Z

The regression equation is

Log K = - 2.68 + 1.83 Log L

Predictor	Coef	StDev	T	P
Constant	-2.6809	0.3173	-8.45	0.000
Log L	1.8318	0.1278	14.34	0.000

S = 0.2983 R-Sq = 86.9% R-Sq(adj) = 86.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	18.286	18.286	205.53	0.000
Residual Error	31	2.758	0.089		
Total	32	21.044			

Unusual Observations

Obs	Log L	Log K	Fit	StDev Fit	Residual	St Resid
26	2.37	2.3454	1.6679	0.0528	0.6775	2.31R

R denotes an observation with a large standardized residual

Carbonear ANCOVA Regression Analysis with Dummy Variable Z

The regression equation is

Log K = - 2.44 + 1.76 Log L - 0.125 Outside

Predictor	Coef	StDev	T	P
Constant	-2.4368	0.3925	-6.21	0.000
Log L	1.7569	0.1460	12.03	0.000
Outside	-0.1251	0.1187	-1.05	0.301

S = 0.2978 R-Sq = 87.4% R-Sq(adj) = 86.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	18.3844	9.1922	103.68	0.000
Residual Error	30	2.6597	0.0887		
Total	32	21.0441			

Source	DF	Seq SS
Log L	1	18.2860
Outside	1	0.0984

Unusual Observations

Obs	Log L	Log K	Fit	StDev Fit	Residual	St Resid
1	2.44	2.3232	1.7297	0.0798	0.5936	2.07R
26	2.37	2.3454	1.7342	0.0821	0.6112	2.14R

R denotes an observation with a large standardized residual