ENTROPY PRINCIPLES IN THE PREDICTION OF
WATER QUALITY VALUES
AT DISCONTINUED MONITORING STATIONS

By

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ABSTRACT

This study examines an issue associated with the design and operation of water quality monitoring networks, namely, the situation, where, because of reductions in the budget allocated to water quality monitoring, or because the budget allocated to water quality monitoring is not increasing at the same rate at which the cost of operation of the network is increasing, or the need for a monitoring station is more acute in another location, one or more existing monitoring stations have to be discontinued. The particular question addressed in relation to this scenario is the development of an improved methodology for the prediction of water quality values at the discontinued stations.

The methodology proposed for the improved prediction of these water quality is derived from the information theory interpretation of the entropy principle, as formulated in terms of the Principle of Maximum Entropy (POME) and the Minimum Discrimination Information (MDI). The methodology itself is a non-linear optimisation model in which an entropy function of the form $p_i \ln p_i$, where p_i represents the probability of event x_i , is maximised subject to a series of constraints on the form and statistics of the probability function from which the p_i values are derived. An important feature of the probability distribution predictions provided by the model is that they are the 'most likely' distributions and therefore are unbiased, being affected only by the information which the user chooses to include in the constraints imposed on the optimisation, and on the historical values of the probability distributions which are incorporated into the non-linear objective function.

The approach is demonstrated by application to a series of water quality monitoring networks in Queensland, Australia. The model was evaluated on the basis of these cases in a verification step involving a comparison of the accuracy of the predictions provided by the entropy technique with the accuracy of the predictions available from a traditional regression based approach. The predictions from the entropy based approach were on average more accurate than those obtained from the regression approach 61% of the time.

The performance of the approach in terms of the accuracy of its predictions, the unbiased nature of those predictions, and the fact that it requires the same type and amount of data as traditional regression techniques, indicates that the technique represents a significant advance in the prediction of water quality values at discontinued water quality monitoring stations.

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Declaration

I hereby declare that this thesis is an original work, and I am the sole author of this thesis.

Agus S. Kusmulyono

CHAPTER 1

INTRODUCTION

Water quality monitoring is the activity of obtaining, analysing and interpreting quantitative information on the physical, chemical and biological characteristics of water via sampling and statistical analysis (Sanders et al., 1983). The objectives of water quality monitoring can generally be divided into three groups (Ward and Loftis, 1989). The first objective is to monitor the condition of the water body to determine baseline conditions. The second objective is to ascertain whether changes in water quality are occurring. The third objective is to observe the extreme conditions of the water body over a period of time. However, Duckstein et al. (1976) and Whitfield (1988) also highlighted another major objective, namely to observe the impacts on the water quality resulting, for example, from the introduction of water quality treatment measures or from projects and activities which have the potential to cause a deterioration in the quality of water.

One of the major issues in water quality monitoring is the cost of conducting the appropriate level of sampling that is to be undertaken on a routine basis. This cost is related to the variety and nature of the variables to be sampled, the number of locations of sampling (monitoring), and the frequency of sampling required to get the desired information within specified confidence limits. While the costs of monitoring are relatively easy to calculate, the benefits of water quality monitoring are more difficult to quantify. It is easy to argue that there are environmental benefits associated with water quality monitoring. However, it is not an easy task to quantify the benefit of knowing that water quality has increased to a certain level. The benefits of knowing that water quality has decreased to a certain level and remedial actions have to be taken are similarly difficult to quantify.

The difficulties associated with expressing the benefits quantitatively make analysis of the feasibility or desirability of a water quality monitoring network and monitoring program on a purely economic basis a very complex, if not impossible, task. Furthermore, the issues associated with expressing the economic benefits of water quality data can in turn mitigate against obtaining funding to support the continued operation and/or expansion of a water quality

monitoring network. Difficulties in obtaining funding for establishment of a water quality monitoring network have been noted by a number of people involved in this field, e.g., Alpaslan et al. (1992).

In recognition of this problem, a number of studies have been directed at optimisation of the design of water quality monitoring networks so as to obtain the maximum amount of information for a given budget, or conversely to minimise the cost of obtaining a given amount of information. These efforts have been focused predominantly in determining the appropriate sampling frequencies (Sanders and Adrian, 1978; Loftis and Ward, 1980; Casey et al., 1983), the selection of locations for monitoring stations (Sanders et al., 1983; Lettenmaier et al., 1984; Alpaslan and Harmancioglu, 1990), and the choice of variables to sample (Sanders et al., 1983; Ward et al., 1990; Alpaslan et al., 1992).

However, a more recent problem that is occurring in water quality monitoring, particularly in times of economic recession, is the discontinuation of existing water quality monitoring stations. These problems can arise directly as the result of actual declines in the budget allocated to water quality monitoring, or indirectly where the budget allocated to water resources is either static or increasing but the cost

of operation is increasing more rapidly than the budget, resulting in an effective shortfall in funding.

These conditions may lead to the decision to discontinue one or more water quality monitoring stations in a network. Even in the case of stable budgeting conditions there may be pressure to move a monitoring station from an existing location to another site where there is a greater need for water quality data. Regardless of the cause of the discontinuation of an existing station, the net result is the same, namely, loss of information about water quality at the site where monitoring has been discontinued. Accurate 'predictions' of the water quality at the discontinued sites are therefore highly desirable. It is this problem to which this thesis is directed.

The thesis proposes the use of the information theory of entropy as an improved method for predicting water quality values at water quality monitoring stations which have been in operation for a period of time sufficient to define or establish the probability distribution of water quality values at that location but which have been subsequently discontinued for one reason or another, and for which water quality values are still desired.

The thesis initially discusses the current state

of the art of water quality monitoring, water quality monitoring network design and water quality data analysis. A history of the use of entropy theory in water resources engineering is also provided. The principle of entropy, particularly as it is used in this thesis to predict water quality values, is then described.

Following this discussion of the theoretical background on the entropy based approach, the specific models used to predict the water quality values are formulated for a range of conditions. The various versions of the model are subsequently demonstrated by application to water quality monitoring networks in Queensland, Australia. Evaluation of the performance of the models is undertaken by comparing the results obtained from the models with those predicted using traditional regression techniques. Finally, the potential application of the model to the problem of identifying the locations of causes of observed changes (trend) in water quality is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 HISTORICAL BACKGROUND IN THE UNITED STATES AND AUSTRALIA

In the United States, water quality monitoring/management directed at pollution control began during the 1930s. (Interestingly, Federal laws on water pollution control were not actually passed in the United States until the 1940s and 1950s.) In 1965 the focus of water quality monitoring in the United States was on surface water quality. In 1972, the objective of monitoring was water quality management, i.e., to control discharges to streams by creating a discharge permit system (Ward et al., 1990). At the same time, in order to account for the stochastic nature of water quality variation, statistical considerations began to play an increasingly important role in the design of the networks and sampling programs.

In Australia, management of the water resources was started later than in the United States. The Australian Water Resources Council was established in

1962 with the primary objectives of conducting a comprehensive and continuous assessment of Australia's water resources, and the extension of measurement and research to aid in the planning of future development (Atlas of Australian Resources, 1967).

In the state of Queensland, the Clean Waters Act has been in operation since March 1973 with the aim of preserving, restoring and enhancing the quality of Queensland's water. The tasks of the Water Resources Council, which has responsibility for administering the Act, are; to determine the conditions for licences; to undertake research and investigation into water quality; to set standards; to carry out surveillance of waste discharges; and to give advice and information to interested organisations and people. (Queensland Resources Atlas, 1980).

2.1.2 GENERAL BACKGROUND ON WATER QUALITY MONITORING

Water quality monitoring is a complicated task. This complexity is related to a number of factors involved in the process of water quality monitoring, ranging from actual collection of the data to the process of translating the data into useful information. In the data collection process itself, factors such as selection of location of monitoring stations, selection of variables to monitor (sample),

and selection of frequency of sampling have to be considered.

Ideally, monitoring is performed continuously. However, it is almost impossible to monitor all, or even a few, of the variables on a continuous basis. Sampling is, therefore, often the only viable alternative method for monitoring most water quality variables.

Previous research on water quality monitoring can be classified into two major categories. The first category is concerned with the actual collection of data describing the quality of water, i.e., design of water quality monitoring programs and water quality monitoring networks. The second category of research deals with the analysis of the data, i.e., extraction of as much information as possible from the data. It has been noted that large sets of data, often collected with considerable effort, do not always satisfy the objectives for monitoring (Ward et al., 1986). Unless the sampling programme is matched appropriately to the specified objectives for the water quality monitoring, the actual data collected may be inappropriate or at best only partially useful. In water quality monitoring, this case is designated as the 'data-rich information-poor syndrome' (Ward et al., 1986).

In the following sections, previous research on water quality monitoring will be reviewed. Work on the analysis of water quality data will be examined first. Previous studies on the collection of the data and on the more complicated problems of design of the monitoring programs and the design of the network themselves will then be reviewed. Some applications of the entropy 'information' theory (on which the proposed model will be based upon) in a wide area of water resources problems, will also be presented.

2.2 WATER QUALITY DATA ANALYSIS

The primary objective of water quality data analysis is to extract information, i.e., determine the condition of the water body from collected data which are usually obtained by sampling. The values derived from the analysis can then be utilised to serve such objectives of water quality monitoring, as verifying compliance to specified standards, identifying trends, and detecting extreme values.

The problem of ascertaining whether water quality is complying with a specified standard has received some considerable attention in the literature. Schaeffer et al. (1980) and Herricks et al. (1985) discussed how to determine when violations occur. Berthouex and Hau (1991) reported on how to judge

compliance using highly censored samples, while Valiela and Whitfield (1989) examined the issue of designing monitoring strategies to determine compliance.

Determining when a violation does occur is a relatively complex task. One reason for this complexity is that, while the standard can be defined as a fixed value, the actual water quality values are generally determined on the basis of samples which are representative rather than absolute statements of the actual population. Any decision based on the values derived from the sampling must therefore recognise the statistical variability of both the population at large and the values derived from the sampling process. In their examination of assessment of compliance of water quality, Herricks et al. (1985), noted that regulatory authorities involved in water quality management must recognise the stochastic nature of data collected or reported to them. With respect to the process of addressing non-compliance with water quality standards, Herricks et al. (1985) also noted that :

"Until both the natural systems and the harm done to them can be accurately measured, it may be inappropriate to impose penalties without regard to some form of fault".

A number of approaches have been proposed to address this problem of variability in the sample

values. Schaeffer et al. (1980) developed a simple graphical method which takes into account process variability, average performance and type of sample collected (grab or composite) when determining violations. A method to estimate the probability that a single grab sample will violate a given stream standard was subsequently proposed by Loftis and Ward (1981) who also provided a procedure for determining the expected number of violations in a given number of samples from the cumulative density functions of water quality random variables themselves.

Berthouex and Hau (1991) proposed a simple rule for judging compliance of effluent against effluent standards in the case when the effluent limit is set at a level below the limit of detection for the sampling method employed. Their rule was based on the binomial probability distribution and recognised the possibility of compliance even if a proportion of the samples were found to violate the effluent limit. In this latter case, effluent values observed to violate the limit are taken as a warning that initiates additional, more intensive monitoring. If the additional monitoring fails to detect further non-compliance within the time frame specified for the additional monitoring, the effluent is assumed to still be meeting the standards.

Another paper by Valiela and Whitfield (1989)

examined the suitability of two existing sampling strategies designed to test effluent discharge for compliance against standards established in relation to particular water quality objectives. The following results were derived from their analysis.

"For objectives based on long-term mean requirements, fixed frequency sampling at frequent intervals is most advantageous regardless of the underlying distribution of the data. For objectives that are based on maximum allowable concentrations, effective sampling strategies increase the likelihood of detecting noncompliance. If data are highly autocorrelated or sharply seasonal in distribution, an exceedance-driven sampling strategy is more effective and efficient for detecting violations than fixed frequency sampling. However, data generated by exceedance-driven sampling provide biased estimates of mean and standard deviation."

In spite the importance of monitoring for determining compliance with a given standard, thereby assisting water quality control authorities in enforcing rules for maintenance of the quality of water, monitoring also serves a number of other purposes, such as, assessing the existing conditions in the water body and any short and long term trends that

might be occurring in those conditions. Detection of trends, particularly those involving deterioration in water quality, is one of the main objectives in water quality monitoring. Appropriate monitoring assists in ensuring that conditions of decreasing water quality can be detected as early as possible, and any measures which might be implemented to maintain the water quality are put in place within an appropriate time scale.

The importance of detecting trends in water quality is indicated by the amount of research published on this particular subject. A number of papers by Hirsch et al. (1982), Hirsch and Slack (1984) and Belle and Hughes (1984) discussed techniques of trend analysis for water quality data. These papers noted that, due to such factors as non-normal distributions, seasonality, flow relatedness, missing values, values below the limits of detection and serial correlation, the analysis of water quality time series is complex. A range of methods to address that complexity were then proposed. The non-parametric test, known as the seasonal Kendall test, was demonstrated by Hirsch et al. (1982), as being applicable for data with seasonality, missing values, or values reported as 'less than'. Hirsch and Slack (1984) subsequently modified this method to incorporate problems associated with data with serial dependence. Two types of

nonparametric tests for trends called intrablock methods and aligned rank methods were also introduced by Belle and Hughes (1984) about this time.

In a later study Hirsch (1988) discussed statistical methods and sampling designs to estimate step trends in surface water quality. That paper focused on the identification of a robust estimator appropriate to the data characteristics expected in water quality time series. Eight different existing estimators were evaluated to identify the robust estimator. The effectiveness of various existing sampling strategies were examined using Monte Carlo simulation coupled with application of the estimator.

An application of the trend detection method was reported by Alexander and Smith (1988) who used the Seasonal Kendall test for an investigation of the lead concentration in major rivers in the United States and observed the relationship between lead concentration and historical changes in gasoline-lead consumption. Lettenmaier et al. (1991) applied the same method and a related multivariate test to identify trends in stream quality in the continental United States for the period 1978-1987. Interestingly, the Lettenmaier et al. (1991) paper indicated that most of the stations with downward trends, i.e., decreasing concentrations in arsenic and cadmium concentrations were in the major population

areas of the east and the midwest.

Selection of appropriate methods for trend tests has been discussed by Hirsch et al. (1991) and Harcum et al. (1992). In the Harcum et al. (1992) paper, synthetic data were used in a simulation study to compare the power of selected methods for trend detection. The method used in that comparison were the Mann Kendall on deseasonalised data and the Seasonal Kendall (with and without correction for serial correlation).

Based on their experience with a wide variety of trend detection methods Hirsch et al. (1991) also provide guidance on the selection of existing statistical techniques for trend detection. The following issues were examined by Hirsch et al. (1991) in developing their guideline; step trend versus monotonic trend, parametric versus non parametric methods, concentration versus flux; effect of discharge, seasonal variability, and censored data.

It is important to note that in addition to the issues discussed above in relation to data analysis, the scale on which a conclusion will be derived should not be overlooked. It has been demonstrated by Loftis et al. (1991) that results of analysis of water quality data can vary significantly if different time scales

are chosen. It is possible that a trend may be detected if one is interested in only a short time period. However, when a longer time period is considered, the existence of the trend suspected on the basis of a short term may no longer be evident. In conjunction with its effects on the detection of trends, the choice of the time scale will also affect the estimated value of the mean and have relevance as to the assumption of the independence of the data in the sample, i.e., data points collected over a short time scale with high frequency are likely to be more dependent than the same number of data points collected over a longer time scale. This importance of the spatial scale in estimating the condition of water body at a particular location was also noted by Loftis et al.(1991).

2.3 WATER QUALITY MONITORING NETWORKS

As noted earlier in their examination of issues related to the design and operation of water quality monitoring networks, Ward et al. (1986) asserted that one of the problems in water quality monitoring systems is that of the "data rich but information poor" syndrome. In the same context, Ward et al.(1986) argued that in order to have an effective monitoring system, it is necessary to view the problem as a complete system. Ward et al.(1986) then proposed a set of five steps which should be followed in the design of the

monitoring network. These steps are (1) evaluate information expectation; (2) establish statistical design criteria; (3) design the monitoring network; (4) develop operating plans and procedures; and (5) develop information reporting procedures.

Before beginning design of the water quality monitoring network, it is essential to identify explicitly the objective(s) of the monitoring. In the first instance determination of this/these objective(s) involves the definition of the needs for the type of information expected from the monitoring system. Once the objectives of the monitoring have been defined or agreed upon, the design of the monitoring network, including specification of the statistical criteria can be initiated. A good operational plan, including procedures for monitoring, then has to be established. Finally, but by no means the least, information reporting procedures have to be developed so that the information produced by the system will reach every user in the right format and within an appropriate time frame.

It should be noted that the nature and objectives of monitoring are dynamic, and therefore, periodic reviews of the stated design objectives for a particular network as they relate to the current situation are recommended (Steele, 1987). In their

comparison of the effectiveness of water quality monitoring using fixed stations and intensive surveys, Belle and Hughes (1983) concluded, not unexpectedly, that intensive surveys are effective only for studying short term fluctuations and are not appropriate for the evaluation of long term trends in water quality. Their study also supported the assertion of Ward et al. (1986) that it is necessary to define the objectives before designing the network.

The following sections examine the following aspects of design; selection of sampling locations, sampling frequency and variables to sample. Note that the 'mechanical' processes involving in the actual sampling and the subsequent chemical, biological etc. analysis of the samples are not part of this study.

The selection of a sampling location in a river depends on two decisions; 1) where to take the sample from within a cross-section (micro-location), and 2) at which cross-section (along the length) of the river the sample should be taken (macro-location). The selection of the micro-location, must recognise the need for the sample to be representative of overall rather than local conditions in the water body at that cross-section. For example, the sample should be taken from the point in the cross-section where the solution is estimated to be completely mixed. A method for

calculating the mixing length for straight channels where such sampling is appropriate has been proposed by Sanders et al. (1977) to address this issue.

In determining the macro-location for sampling, the following factors need to be considered: the objective(s) of the monitoring to be undertaken by stations in the network, accessibility of the location, how fast the results are expected and where detection with respect to a suspected potential source of pollution is to take place (Steele, 1987).

A method for the selection of macro-location based on the 'percent areal coverage' using basin centroids was presented by Sanders et al. (1983). The 'percent areal coverage' in this method is defined as the number of sampling stations divided by the magnitude of the basin. Note that this definition only indicates that as more monitoring stations are installed the percent areal coverage will increase. However, it may not indicate the 'real' percentage of coverage of the basin, as might be expected. The method essentially consists of dividing the river network into sections with equal numbers of contributing tributaries.

The procedure itself is based on determining the 'centroid' of a river system. To determine this centroid, each exterior tributary (one which has no

tributaries or one with a certain minimum mean flow) is given a value of one. The value assigned to the stream at the confluence of each tributary with another tributary (or main stream) is determined by summing the values assigned to each of the streams which meet at that confluence point. Continuing the same process downstream, results in a value for the total of the contributing tributaries at each confluence and at the mouth of the river. Dividing this value by two, the centroid of the river basin is determined.

The sampling stations with the highest order (priority) are then located at the mouth of the river and in the section of the river where the centroid is located. A similar procedure can be applied to each section of the basin to allocate the higher order sampling stations. The result of the method is a location plan showing a hierarchy of monitoring stations, such that the stations with the highest rank can be built first, followed as funds become available, by stations with lower ranks. The cost, which is a function of the number of monitoring stations and their distance and accessibility, will of course be a consideration in the determination of the number and the macro-locations of monitoring stations under this process. Application of this method has been demonstrated by Alpaslan and Harmancioglu (1990) for the Gediz River basin in Turkey.

The next and most important issue in data collection is the determination of sampling frequencies. This issue has been discussed intensively in many papers. Sanders and Adrian (1978), expressed its importance as follows :

"Sampling frequency is a very important consideration in the design of a water quality monitoring network. A large portion of the cost of operating a monitoring network is related directly to the frequency of sampling. In addition, the reliability and utility of water quality data derived from a monitoring network are likewise related to the frequency of sampling."

The sampling frequency issue has also been identified by Casey et al. (1983) as one of the most complex aspects of water quality network design and operation. From the perspective of the objective of monitoring, selection of sampling frequency becomes further complicated when multiple objectives have been identified for the monitoring program, a situation that is not uncommon. To detect extreme values, for example, frequent sampling must be conducted. On the other hand for detection of long term trends occurring over long periods of time, less frequent sampling would be more appropriate. From the statistical view point, design of the sampling programme, and in particular the frequency

of sampling, can be considered on the basis of sampling theory, i.e., in terms of simple random sampling, systematic sampling, and stratified random sampling (Bruton, 1982).

Sanders and Adrian (1978) introduced a measure for determining sampling frequency based on the confidence interval of the mean of random component. Ward et al. (1979) also proposed a statistically based method to evaluate sampling frequencies in monitoring networks. The underlying principle of their procedure was to obtain uniform or equal information from all stations in the network. This goal was achieved by allocating the number of samples to be collected at a station as a function of the variations in the value of the water quality constituent of interest at that station, relative to the total variation for that constituent in the network.

Dunnette (1980) on the other hand, proposed the use of a water quality index to optimise the sampling frequency. This water quality index implicitly aggregates the relative importance of the various parameters to be sampled through a weighting process, and is therefore considered a good method for determining sampling frequency.

Loftis and Ward (1980) subsequently presented

another point of view for the determination of sampling frequency. They suggested that three factors have to be considered in determining sampling frequency, namely, i) random changes due to storms, rainfall, etc., ii) seasonal changes in temperature, rainfall, etc., and iii) serial correlation from sample to sample. From the analysis based on the width of the confidence interval around the sample mean and considering those three factors, three general regions of frequencies were identified, : 1) a region where serial correlation is dominant (the sampling frequency is greater than 30 times per year) ; 2) a region where the effects of seasonal variation and serial correlation tend to cancel each other out (the sampling frequency lies between 10 to 30 per year); and 3) a region where seasonal variation is dominant (the sampling frequency can be less than 10 per year).

While statistical analysis has an important role in determining the sampling frequency, it should be noted that, in many cases, it is the cost constraints that play the dominant role in the selection of sampling frequency (Sanders and Adrian, 1978). Therefore, a compromise between statistical considerations and budgetary limitations is generally needed in the final determination of the sampling frequency.

The other major task in water quality monitoring is the selection of which parameters to sample. This task is very much dependent on the objectives of monitoring (Ward et al., 1990). When the objective is to monitor conditions and observe long term trends, 'indicator' type of measurements would be sufficient. If the objective is for special investigation of a specific water quality problem, the parameters of concern should obviously be those related to the problem. When the objective of monitoring is to examine compliance, for example to a regulatory water quality standard, the parameters chosen for sampling must, at minimum, include all those listed in the standard.

For the situation where there is some choice of parameters to monitor, Sanders et al. (1983) suggest the specification of categories of water quality variables as a means of assisting in data collection planning and data analysis. Their study also suggested that the parameters to be monitored must be specified before the actual design of the water quality monitoring network and monitoring programme can be undertaken in a systematic fashion. This suggestion arises from both the natural or man made variations, that can occur in every water quality variable, the inability, due amongst other things to cost considerations, to consider all variables and their variations simultaneously, and the need to monitor the

complete range of those parameters which are considered important.

Given the complexity of the design of water quality monitoring networks and monitoring programs described in the previous sections, it can be seen that the cost of establishing and operating a monitoring network can be very expensive. For a well designed network and monitoring programme, the greater quantity of data collected, the greater the information. It should be noted, however, in the light of this assertion that while more data will give more information, in a poorly designed network and monitoring programme, the increase in information associated with the collection of the additional data occurs at a slower rate than for a well designed network and monitoring programme. Furthermore, the increase in the cost associated with obtaining additional data, even for a well designed network and monitoring programme, may not always be justified by the increase in actual information gained. Generally, the availability of funding plays a dominant role in the establishment of a water quality monitoring network and monitoring programme. Therefore, financial issues cannot be overlooked in the design of water quality monitoring networks.

Constraints on the budget can influence all

aspects of the design of water quality monitoring networks, from selection of location of sampling stations (as it is related to the number of affordable stations), determination of sampling frequencies and selection of variables to sample. Not unexpectedly, given the importance of these financial issues, a number of studies have addressed the problem of 'optimal' design of water quality monitoring networks.

Heidtke and Armstrong (1979) presented a probabilistic sampling model for water quality management. The objective of their approach was to design an optimum sampling policy for detection of stream standard violation. Lettenmaier et al. (1984) proposed a method based on dynamic programming for systematic consolidation of an existing station water quality monitoring network. The method has been applied to the Municipality of Metropolitan Seattle stream and river quality monitoring network, and resulted in a significant reduction in the number of monitoring stations with relatively little loss of information.

Palmer and MacKenzie (1985) developed an interactive optimisation procedure, involving a modified gradient search algorithm, to select designs which maximise the statistical power of a network for a specified budget or alternatively minimise the cost of a network for a specified statistical power

requirement. The procedure was applied to aquatic monitoring in relation to a New England coastal power plant and showed that numerous solutions may exist for a specified power or cost, thereby providing the designer with many alternatives. Pinter and Somlyódy (1987) subsequently suggested a methodology for optimising the operation of a regional monitoring network being used for water quality management. The particular objective of their study was to provide a reliable estimate of the annual nutrient load of a lake. The model itself minimises the costs of operation of the annual monitoring system under obvious logical (physical) constraints and under constraints on the expected accuracy of the monitoring programme.

Caselton and Husain (1980), on the other hand, introduced a concept based on entropy theory to design a hydrologic data collection network, which might also be applicable in other situations such as water quality monitoring. The concept is based on viewing a hydrologic network as a communication channel which is dedicated to transmitting hydrologic information, and therefore, permits the network to be designed on the basis of its ability to convey hydrologic information. The objective in that paper, is to select n permanent stations sites (where n is specified) from m given locations, in a manner which maximises the information transmission measured with an entropy (measures of

information) expression.

Most recently, Harmancioglu and Alpaslan (1992) re-examined the problem of multi-objective decision making in water quality monitoring network design and proposed a statistical procedure to evaluate the efficiency and cost-effectiveness of a network. The method was demonstrated by application to the Porsuk River in Turkey. This application indicated that their method has the capability of assessing the efficiency and cost-effectiveness of a network quantitatively. As such the method provides a rational basis for a reduction in either the frequency of sampling or the number of sampling stations.

However, research on optimisation of water quality monitoring networks has focused primarily on obtaining the optimal configuration of stations (Lettenmaier et al., 1984) and optimum sampling frequencies (Heidtke and Armstrong, 1979; Dunnette, 1980). Relatively little research has been directed at the problem of gain in information obtained by establishment of new station or the converse problem of loss of information about water quality at locations where water quality monitoring stations have been discontinued.

One of the existing methods for estimating values at a location where a station has been discontinued by

interpolating data from surrounding stations is the Kriging method (Gambolati and Volpi, 1979). This method, however, does not appear to be applicable for the river network monitoring addressed in this thesis, since the physical characteristics of the problem are different. The Kriging method is applicable to spatial prediction of parameters where the nature of the parameter is changing gradually and continuously from one point to another e.g., water quality values or water levels at various locations across a lake; or piezometric levels or water quality values within an aquifer. The nature of a river network, however, is not a continuum; rather it has a skeletal structure with major 'discontinuities', i.e., a value at one point may not be significantly related to a value from other points which are separated by land masses and/or drainage basins. The Kriging method is not therefore examined in this study.

Another method that may be applicable to the problem addressed in this thesis is 'traditional' regression analysis such as described in many statistical textbooks. Using this technique, values at the discontinued upstream stations can be derived by a function developed from the historical data from the discontinued station and other stations which were in existence during the monitoring period of the discontinued station and which are still in operation.

2.4 USE OF ENTROPY THEORY IN WATER RESOURCES ENGINEERING

Entropy 'information' theory has recently been applied widely in the field of water resources and hydrology. Sonuga (1972), Singh and Singh (1985), Singh et al. (1986) applied the principle to the derivation of frequency distributions. Sonuga (1976) also applied the concept to the derivation of functional rainfall-runoff relationships. Harmancioglu examined use of the entropy principle in the measurement of the information content of random process (Harmancioglu, 1981); evaluation of information transfer between hydrologic processes (Harmancioglu and Yevjevich, 1987); and assessment of recharge systems for a river basin (Harmancioglu and Baran, 1989). Amorocho and Espildora (1973) utilised the principle for assessment of hydrologic model performance while Chiu (1987,1988,1989,1991) and Chiu and Chiou (1986) applied the principle to velocity distributions in open channels. Awumah et al. (1990, 1991) on the other hand developed the principle for use in redundancy measures in water distribution network design.

These few examples demonstrate the versatility of the entropy concept in water resources and hydrology. This demonstrated versatility provided the basis for examination of the application of the entropy theory to

the problem of prediction of water quality values at discontinued monitoring stations described in this thesis.

2.5 CONCLUSION

In this chapter, research in the area of water quality monitoring was presented. The issues discussed ranged from the relatively simple theoretical statistical aspects of sampling, to the more difficult and realistic cases wherein serial correlation and seasonal effects of water quality are addressed. The problem of the monitoring network design and operation was shown to have become increasingly complex as a greater range of the factors relevant to water quality monitoring were included.

A water quality monitoring network may have different users, each with a different objective for monitoring. However, geographic issues also contribute to the complexity. The more complex the configuration of the river system, the more complex the problem of designing a network to monitor the conditions in that network. Similarly the types of land use in the river basin will have an effect on the selection of the parameters to be sampled and perhaps on the selection of location of the sampling, i.e., the location of the water quality monitoring stations.

The need for monitoring is itself growing with the increased emphasis on the environment. Effective environmental monitoring systems need to be in place in order to ensure that the environment is maintained to specified standards.

While the design of a monitoring system is in itself quite a complicated problem, financial considerations add to the complexity of designing effective and cost efficient networks. Furthermore, while the establishment of a good water quality monitoring system requires significant funding, the benefit of the monitoring itself is generally difficult to express in economic or quantitative terms. It is therefore not unusual for water quality monitoring to have a low priority in some countries, particularly in developing countries, where the budgets available for these activities are limited. Some form of optimisation procedure would therefore seem to be appropriate to cope with the problem of designing networks and monitoring programs so as to maximise the information (where information is a surrogate for benefits) able to be obtained for a specified budget. A number of studies have reported on different methodologies and models developed for this purpose and discussed their application to different aspects of water quality monitoring network design.

The particular problem which is of interest in this thesis is the case of an effective reduction of the budget for monitoring network, where such reduction may require the discontinuation of sampling stations. The issue of reducing the number of sampling stations has been discussed as an issue in the optimisation of a water quality monitoring network (Lettenmaier et al., 1984; Palmer and MacKenzie, 1985; Harmancioglu and Alpaslan, 1992).

However, most of this work was directed at obtaining more reliable information from the existing network or designing new and more reliable water quality monitoring networks/procedures. An exception to this generalisation is the work of Lettenmaier et al. (1984) which presented a systematic method for the reduction of sampling stations. Relatively little work focussed on the problems of limited budgets which might lead to a need to discontinue existing monitoring stations. Most of the previous research into water quality monitoring was directed at obtaining better information from established networks or designing new networks to obtain the maximum amount of information. The research described in this thesis is directed at the development of an improved methodology for prediction, within some limitations on the configuration of the network, of water quality values at these discontinued stations.

Discontinuation of sampling stations is a real problem encountered in water quality monitoring networks. The reason for discontinuing stations in a particular river basin or monitoring network are often driven by financial considerations, either from a reduction in the budget allocated to water quality monitoring where such budget reduction might be absolute, or relative because the cost of the operation is increasing more rapidly than the increase in budget (or the budget is in fact static), or because the need for a monitoring station is more urgent in another basin. Either situation may require a station to be discontinued.

Faced with a situation of having to discontinue an existing station, the estimation of water quality values at a discontinued station represents a reasonable way of maintaining some information on the water quality condition at the discontinued station. Furthermore, if an effective method can be developed for estimation purposes, the design of a network can incorporate the possibility of station discontinuation, so that if budget reduction does occur, and some stations have to be discontinued, such discontinuation can take place with minimum reduction in the information able to be provided by the remainder of monitoring network.

The method proposed in this thesis for prediction of water quality values at the discontinued stations is based upon information theory derived from entropy principles. The method is able to incorporate, prior knowledge about both existing (historical) conditions and changes in the watershed which may have caused changes in water quality observed at some downstream locations. The following chapters discuss the theoretical basis of the methodology and describe the application of the method to a series of case studies of water quality monitoring networks. The strength of the method, as demonstrated by the results from these case studies, is then discussed.

CHAPTER 3

APPLICATION OF THE ENTROPY PRINCIPLE TO THE PROBLEM OF PREDICTION

The basic theory adopted in this thesis for prediction of water quality values at discontinued monitoring stations is Entropy (Information) Theory. The decision to consider entropy theory for prediction of water quality values at discontinued monitoring stations arises from one of the interpretations, or characteristics, of the entropy principle, wherein it can be used for the assignment, in an unbiased fashion, of probabilities to a range of events. This characteristic is applicable to the problem of estimating values of water quality at discontinued monitoring stations in that it provides a mechanism for assigning probabilities to a range of possible events (water quality values) at the location(s) of the discontinued monitoring station(s). These water quality 'events' and their associated (assigned) probabilities define, in turn, the distribution, and thereby the mean, of the particular water quality parameter at that location. Due to the unbiased nature of the assignment

of probabilities to each possible outcome, the estimated mean value derived from the assignment of probabilities to the range of possible events using the entropy principle will also be unbiased, i.e., depend only on the information available and no other assumptions.

Basic entropy theory and its extension to the frequency estimation (probability assignment) problem are described in the following sections.

3.1 SHANNON'S ENTROPY (INFORMATION) THEORY

Shannon's entropy based measure of information was formulated as follows. Define the probabilities of a set of n possible events $1, 2, \dots, n$ (outcomes) to be $p_1, p_2, \dots, p_n$ respectively. Now consider a measure of uncertainty about the outcomes, say $H(p_1, p_2, \dots, p_n)$. The measure of uncertainty proposed by Shannon (1948) on the basis of entropy consideration is as follows :

$$H = -K \sum_{i=1}^n p_i \ln p_i \quad (3.1)$$

where :

H = measure of information or measure of uncertainty

K = positive constant, whose value is

determined by the units used

p_i = probability of possible event i

[Since K is a constant for a given problem (assuming use of the same units in each application for that problem), K is omitted in future uses of the entropy expression in this thesis].

The above formula has the following characteristics :

- a. H takes on its maximum value (equal to $\log n$) when all events have the same probability or uncertainty, i.e., $p_i = 1/n$.
- b. H takes on its minimum value (equal to 0) when there is absolute certainty about the events.
- c. Any randomness in the probabilities will give a value of H between these two extremes.
- d. H increases with increase in the number of possible events n .

The characteristic noted in point (a) indicates that, in the case of unbiased prediction such as that achieved through the use of entropy theory, the greater the uncertainty about the likelihood of the outcomes, i.e., the smaller the knowledge about the outcomes, the more uniform the probability of the events should be. In other words, entropy H , as a measure of uncertainty about the outcomes in such a situation, will assume a

larger value. Point (a) also indicates that entropy will take on its maximum value, reflecting the maximum level of uncertainty, when there is no knowledge about the outcomes of the event and hence every event will be assigned exactly the same probability (likelihood), i.e., every event for a process with n outcomes is allocated the same probability $(1/n)$.

The number of possible outcomes for an event also effects the maximum value of the entropy. The result of tossing a coin once only has two possible outcomes. The maximum entropy value for this case ($= 0.693$) will be lower, reflecting the reduced uncertainty about the outcomes than the maximum entropy value ($=1.792$) associated with the outcomes from tossing a die which has six possible outcomes. Based on those characteristics, the expression in Equation 3.1. can therefore be regarded as a measure of uncertainty.

By specifying p_i as a proportion of the whole population with characteristics associated with a group i , this principle can also be used as a measure of diversity within a population. Consistent with the interpretation of larger values of entropy associated with the assignment of probabilities discussed in the previous paragraph, in this case, larger values of entropy will reflect a greater level of diversity

within the population.

The behaviour of the entropy function for an event with two outcomes, X and Y is illustrated in graphical form in Figure 3.1. This figure shows that the entropy value becomes zero when one of the outcomes has a probability of one, i.e., $P(X)$ or $P(Y) = 1$. The maximum value of entropy is reached when X and Y have the same probability of occurrence, i.e., $P(X) = P(Y) = 0.5$. Any other combination of probabilities for the two outcomes results in an entropy value between these two extremes.

Figure 3.1 Entropy Function for Two Possible Outcomes

3.2 THE PRINCIPLE OF MAXIMUM ENTROPY (POME)

One of the characteristics noted for the entropy function as given in Equation 3.1 is that a uniform probability distribution will result in a maximum value of entropy for a set of events. Conversely, maximising the entropy function of Equation 3.1 (given no other constraints except that the sum of the probabilities of all the events must equal one to ensure specification of a complete probability distribution) results in an assignment of uniform probability to every event. In this 'reverse' application, the entropy principle can be used to derive probability distributions by maximising the entropy function subject to constraint(s) specifying any information which may be known about the events. Such information about the events might consist of knowledge that the outcomes of the events in questions are known to be normally distributed.

The mathematical expression for the simplest case of maximising entropy can be written as :

$$\text{Maximise: } H = - \sum_{i=1}^n p_i \ln p_i \quad (3.2)$$

subject to :

$$\sum_{i=1}^n p_i = 1 \quad (3.3)$$

The constraint represented by Equation 3.3 ensures the development of a complete probability distribution. Solving the problem defined by Equations 3.2 and 3.3. will result in a uniform probability distribution with $p_i = 1/n$, where n is the number of possible events.

The principle embedded in the maximisation involved in solving Equation 3.2 and 3.3 is known as **the Principle of Maximum Entropy (POME)** and was first introduced by Jaynes (1957). The basic concept in the POME is that, in assigning probabilities to possible events, the assignment should be as unbiased as possible, and should use, not unreasonably, only the information available.

The principle may be considered as an extension of " **Laplace's Principle of Insufficient Reason** " which states that equal probability should be assigned to all possible outcomes of a random experiment, if there is no information contradicting this assignment (Kapur, 1983).

The question might be asked as to why the probability distribution determined by POME should be the one accepted. This case for use of the entropy derived probability can be clarified by the following explanation. Suppose it is wished to assign

probabilities to events a, b, ... and there is no information at all about the likelihood of these events. There are numerous (infinite) possible combinations of probability values (distributions) for a certain number of possible events n. According to Laplace's Principle of Insufficient Reason, when there is no information at all, every event should be assigned an equal probability. This conclusion means that the outcome will have **the maximum entropy value**. Any other probability distribution in such a situation will have an entropy value less than that associated with the uniform distribution. However, the assignment of a distribution other than the uniform distribution which is associated with the maximum entropy is contradictory since there is no information available that can justify a reduction in the uncertainty and thereby a reduction in the entropy value for that case. Therefore, the probability distribution with the maximum entropy value should be the distribution selected.

It has also been shown by Jaynes (1968), that the probability distribution with the greatest entropy value derived from the results of a series of experiments under a given set of constraints is the probability distribution that can be realised in the greatest number of ways, i.e., it is the most likely

probability distribution. Thus the most likely probability distribution derived from a set of experiments is that associated with the maximum entropy value.

In the situation where information is available about the likelihood of events, such information can be introduced in the entropy maximisation formulation through appropriate constraints. The addition of such constraints reduces the uncertainty about the likelihood of each outcome and thereby also reduces the value of the entropy. Each set of additional information, except where it is redundant, will progressively reduce the value of the entropy reflecting the fact each set of information also implies that there is less uncertainty associated with the likelihood of each of the outcomes.

The addition of new information may, and in fact is likely to, change the probabilities assigned to the events, causing it to be no longer uniform. However, the probability distributions derived by the POME in the 'presence' of this new information (constraints) will still be the most uniform and unbiased *possible*, consistent with the information available.

Examples showing the assignment of probabilities

to set of events under a range of different information about the process for a hypothetical problem are depicted in Figures 3.2(a) to 3.2(e). In these figures, x_i can take on values from 1 to 16 inclusive and $n=16$. Note that the differences in information about the process for each case are incorporated into the problem through the constraint(s) which are different for each case. The different information specified in each case are different values of observed (known) mean and in Figure 3.2(e) the observed (known) standard deviation. It can be seen in the figures that each set of information about the process, i.e., each set of constraints, results in different shapes for the resultant probability distributions.

It can also be seen in these figures that the probability distributions derived by the entropy principle can vary from a uniform distribution to a normal 'bell shaped' distribution. [The normal distribution is derived by the POME whenever observed or known means and standard deviations are specified in the formulation as indicated in the title of Figure 3.2(e)].

Figure 3.2(a) Maximising Entropy with the Constraint that the Sum of the Probabilities is Equal to 1

Figure 3.2(b) Maximising Entropy with the First Order Moment is Set to be Equal to the Median

$$\text{Max } H = - \sum_{i=1}^n p_i \ln p_i$$

s . t . . :

$$\sum_{i=1}^n p_i = 1$$

$$\sum_{i=1}^n p_i x_i = 6.0$$

Figure 3.2(c) Maximising Entropy with the First Order Moment is Set to be Less Than the Median

$$\text{Max } H = - \sum_{i=1}^n p_i \ln p_i$$

s . t . :

$$\sum_{i=1}^n p_i = 1$$

$$\sum_{i=1}^n p_i x_i = 14$$

Figure 3.2(d) Maximising Entropy with the First Order Moment is Set to be Greater Than the Median

Figure 3.2(e) Maximising Entropy with the First and the Second Order Moments are Specified

In fact, a range of common probability distributions can also be derived using this principle (Kapur, 1983; Singh and Singh, 1985; Singh et al., 1986). For example, the Gamma distribution can be derived from maximising the entropy function with the following sets of constraints :

$$\sum_{i=1}^n p_i = 1 \quad (3.4)$$

$$\sum_{i=1}^n p_i x_i = \bar{x} \quad (3.5)$$

$$\sum_{i=1}^n p_i \ln x_i = E[\ln x_i] \quad (3.6)$$

On the other hand, the Log-normal distribution may be derived by the same procedure [i.e., maximising the entropy expression (Eq. 3.2)], but with the following set of constraints :

$$\sum_{i=1}^n p_i = 1 \quad (3.7)$$

$$\sum_{i=1}^n p_i y_i = \bar{y} \quad (3.8)$$

$$\sum_{i=1}^n p_i y^2 = S_y^2 + \bar{y}^2 \quad (3.9)$$

where :

$$y_i = \ln x_i$$

$$\bar{y} = E[y_i]$$

$$S_y = \text{Var}[y_i]$$

In light of the characteristics described above Kapur (1983) suggested that there are other names which may be appropriately given to the Principle of Maximum Entropy (POME), namely, Principle of Maximum Objectivity, Principle of Minimum Bias, Principle of Minimum Prejudice, Principle of Maximum Uniformity, Principle of Maximum Spread-out Distribution, and Principle of Maximum Honesty. All such names reflect the nature of the probability distribution derived by application of the principle.

3.3 THE PRINCIPLE OF MINIMUM DISCRIMINATION INFORMATION (MDI)

Kullback and Leibler (1951) introduced a measure of nearness of two probability distributions where nearness is defined as " the mean information for discrimination between probability distributions P and Q". The measure proposed by Kullback and Leibler can be expressed in the following form :

$$I(P:Q) = \sum_{i=1}^N p_i \ln \frac{p_i}{q_i} \quad (3.10)$$

where :

p_i = probability of event i from a probability distribution P .

q_i = probability of event i from a probability distribution Q .

In this case the probability distributions P and Q represent two manifestations or conditions of similar process, e.g., probability distributions of rainfalls monitored at a location, or probability distributions of flows in a river, etc. As the value of p_i approaches q_i , the value of $I(P:Q)$ will become smaller with the value of $I(P:Q)$ becoming equal to 0 when $p_i = q_i$ for all i .

If Q is a uniform distribution, i.e., $q_i = 1/n$, Equation 3.10 becomes :

$$I(P:Q) = \sum_{i=1}^n p_i \ln np_i = \sum_{i=1}^n p_i \ln p_i + \ln n \quad (3.11)$$

This expression is similar to the entropy function described in the POME except for the term $\ln n$ which, in the case of a known number of possible outcomes (events), is a constant and has no bearing on the

result. It can therefore be seen that, due to the absence of the negative sign in the expression for $I(P:Q)$ given by Equation 3.10, maximising H is equivalent to minimising $I(P:Q)$.

The **MDI** principle can also be considered as the more general expression of the **POME**, because the **POME** expression can be derived from the **MDI** principle by specifying a uniform distribution for q_i . In other words, in the special case, where the probability distribution Q is uniform, the **MDI** principle is the same as the Principle of Maximum Entropy.

The **MDI** principle can also be interpreted as a way of choosing, in an unbiased fashion, the probability distribution P which is closest to **the known (prior) probability distribution** Q , subject to information specified as constraints. In a practical application this process is equivalent to choosing a probability distribution for a water quality parameter for a particular location on a river on the basis of some given or observed information at some other location, and also knowing the historical conditions and probability distribution of the water quality at that location for which the distribution is being determined. Note that, under this interpretation, the prior distribution Q need not be uniform. The **POME**,

through its relationship with **MDI**, can be interpreted in a similar fashion as a way of choosing the probability distribution which is closest to **the uniform probability distribution**, subject to information given as constraints.

3.4 DEMONSTRATION OF THE USE OF ENTROPY BASED PROBABILITY ESTIMATION

In this section, the use of entropy for probability estimation, as it represents the basis for the proposed method for prediction/estimation of the mean of water quality values at the discontinued monitoring stations, is discussed.

The theory behind probability estimation in this manner can be explained from the following example:

If the head of a coin is given a value of one and the tail is given a value of zero, then, for a fair coin, the expected mean value of tossing the coin n times (n is a large number) is 0.5. Suppose a coin is tossed n times (where n is very large) and the mean value happens not to be equal to 0.5, as might be expected from a 'fair' coin, but something else, e.g, 0.6. Setting aside other factors relating to sampling theory and probability of that outcome at this time,

this result indicates that the coin as not likely being fair and also that it is likely that the head and tail occur with probabilities of 0.6 and 0.4 respectively. These probabilities can be seen as the 'new' condition of the coin. In this case, in which only two events are possible, it is relatively easy to calculate the most likely probability for each event of a head or a tail. However, the problem of assigning the probability to the two events could also have been solved using the POME or MDI formulated as :

POME :

$$\text{Max } H = - \sum_{i=1}^n p_i \ln p_i \quad (3.12)$$

or

MDI :

$$\text{Min } H = \sum_{i=1}^n p_i \ln \frac{p_i}{1/n} \quad (3.13)$$

subject to :

$$\sum_{i=1}^n p_i x_i = \bar{x} \quad (3.14)$$

where :

x_i = possible events (0 or 1)

p_i = probability of event x_i

$\bar{x}$ = the mean value

n = number of events

In solving the coin toss problem by this formulation,

the observed mean value $\bar{x}$ is set equal to 0.6 and n is set equal to 2. The two p_i values defined by the formulation then take on values of 0.4 and 0.6 respectively.

A more complicated problem with similar characteristics is known as 'a die problem' as described by Jaynes (1979). This problem can be illustrated as follows :

Suppose a die is tossed $N=1000$ times and the average number of spots up was observed as 4.5 and was not 3.5 as might be expected from a 'fair' die. Mathematically, the mean value (average number) of spots up can be expressed as :

$$\sum_{i=1}^n p_i x_i = \bar{x} \quad (3.15)$$

where :

- $\bar{x}$ = mean value
- x_i = event (1,2,...,6)
- p_i = probability of event x_i
- n = number of events

Given only this information, what estimate should be assigned to the probability (p_i) of the different faces ? The following statements were made by Jaynes (1968) in respect to this problem:

- "The probability distribution which maximises the entropy is numerically identical with the frequency distribution which can be realised in the greatest number of ways"
- "If the information incorporated into the maximum entropy analysis includes all the constraints actually operative in the random experiment, then the distribution predicted by maximum entropy is overwhelmingly the most likely to be observed experimentally, because it can be realised in overwhelmingly the greatest number of ways"

Those two statements strongly suggest that the estimation of the probability for the 'die problem' should be undertaken by maximising the entropy value expressed in Equation 3.12, subject to the constraint expressed in Equation 3.15.

Figures 3.3(a) to 3.3(d) illustrate the above issues in graphical form. Figures 3.3(a) and 3.3(b) show the result of probability estimation for the coin case by maximising the entropy value, where the mean value, $\bar{x}$, in the Equation 3.14 was set as 0.5 and 0.6 respectively. Figures 3.3(c) and 3.3(d) give the results from maximising the entropy function for the die problem, where the mean value, $\bar{x}$, in Equation

Figure 3.3(a) Probability Assignment for the Coin Problem with the Mean Value = 0.5

Figure 3.3(b) Probability Assignment for the Coin Problem with the Mean Value = 0.6

Figure 3.3(c) Probability Assignment for the Die Problem with the Mean Value = 3.5

Figure 3.3(d) Probability Assignment for the Die Problem with the Mean Value = 4.5

3.15 was set as 3.5 and 4.5 respectively.

The assignment of the relative frequency (probability) to every event by maximising the entropy value is unbiased, since it only uses the information available and no other assumptions. As discussed previously the method assigns as uniform a distribution as possible. However, as shown in Figure 3.3, the 'new' information provided by the constraints forces the method to assign non uniform distributions.

The problem addressed in this study, which is described in detail in Chapter 4, has characteristics similar to the two problems described above. The fundamental similarity lies in the fact that, in the water quality case being examined in this study only the outcomes, in this case the water quality value(s) on the mainstem of the river at a downstream location, are known. These downstream observed water quality values are to a large degree the result of the water quality values (events) from upstream tributaries. This downstream, mainstem observed value is therefore similar in concept to the observed mean value $\bar{x}$ of a set of experiments discussed earlier in this chapter in relation to the coin and die problems. The problem is, therefore, how to predict the most likely values for the water quality parameters at the upstream stations

which result in the value observed at the downstream station.

The same basic principle used in assigning the probability distribution to the set of outcomes of experiments discussed previously is employed in this case to assign, in an unbiased manner, the probability distributions of water quality values at the discontinued upstream monitoring stations. The commonality of the features between the water quality estimation problem and the coin and die problems are discussed in more detail in Chapter 4.

3.5 SUMMARY AND CONCLUSION

Entropy theory, through its interpretation as a measure of information and therein uncertainty, is presented as the basic principle for the development of a new approach to predicting water quality values at discontinued stations. The utility of the theory for the problem was argued on the basis of its ability to assign probabilities to every possible event when only the mean value of the outcomes, or its equivalent, from a set of experiments or possibilities is known.

Relatively little theory or applications have been reported for this general case or for the specific case

of predicting water quality values at discontinued stations. The maximum entropy principle has been shown by Jaynes (1979) to be able to give a solution to this type of problem by not only assigning probability to every possible event but also doing so in an unbiased fashion. Furthermore, when applied in this fashion, the entropy principle uses only the available information and no other assumptions when assigning probability for every event.

The unbiasedness of the entropy principle was emphasised in the discussion, since this attribute is important in predicting the water quality values at discontinued monitoring station(s), when violations to water quality standards are believed to be occurring and it is desired to determine the most likely location of these violations, in the absence of direct monitoring and in the face of limited data at other locations.

CHAPTER 4

FORMULATION OF THE ENTROPY APPROACH

4.1 PROBLEM DESCRIPTION

As described in Chapter 1, the objective of this thesis is the estimation/prediction of water quality values at discontinued monitoring station(s). More specifically, this study is directed at one aspect of the budgetary issues associated with water quality monitoring, namely, the case where a reduced budget, or a budget not increasing as fast as the cost of monitoring, or where the needs for monitoring are more acute at other locations, has resulted in the discontinuation of existing monitoring stations. In these circumstances, when information is required about conditions at locations where stations have been discontinued, it becomes necessary to predict water quality at those sites. Such predictions are particularly important where water quality conditions appear to be changing at the locations of the discontinued upstream monitoring stations as might be indicated by changes in the observed water quality at a downstream site where monitoring is ongoing.

The problem can be formulated and illustrated as follows:

Consider a water quality monitoring network which has been established in a river basin for a sufficiently long period of time to define, at each monitoring location, the base-line or historical distributions of the water quality parameters of interest. [The need for, and implications of, knowing the historical (or prior) distributions of water quality values at the discontinued stations are discussed in detail later in this chapter]. Consider, for example, the simplified water quality monitoring network shown schematically in Figure 4.1. This simplified river network is a forked configuration with a mainstem and two upstream channels, one of which might be the mainstream and the other a tributary, or both upstream elements may be tributaries which come together to form a 'new' river.

Consider three water quality monitoring stations in this system, located at points **a**, **b**, and **c** respectively as shown in Figure 4.1. The particular situation addressed in this thesis may arise, for example, where the number of operating monitoring stations has to be reduced due to a shortage of funding. Within this scenario, one, two or even three of the sampling stations may have to be discontinued. Suppose it was determined that two stations have to be

Figure 4.1. Schematic of explanatory example.

discontinued from the particular section highlighted in Figure 4.1. In such a situation, the most likely decision is to discontinue the operation of stations **b** and **c** (upstream), and continue the operation of station **a** (downstream) which is located on the main stream and therefore captures some of the 'information' available in the records obtained from stations **b** and **c**. In fact, considerable information about conditions at locations **b** and **c** is contained in the records at station **a** because the water quality at locations **b** and **c** contributes significantly to the water quality values recorded at station **a**. However, even though some of the information contained in the data recorded for stations **b** and **c** is incorporated in the record for station **a**, actual values at those stations are lost when the stations are discontinued. It is generally highly desirable that some specific information about the water quality at those two locations be "maintained".

One of the alternatives for maintaining information about the water quality at those two locations (besides of course actually continuing to take data at those locations which is impossible when the stations are discontinued) is to estimate the water quality values. Such predictions are likely to be based on historical records at stations **a**, **b** and **c** and the current observations at station **a** and should be as

accurate as possible.

The quality, or value, of the information obtained from the process of prediction/estimation of the values at the discontinued upstream stations will largely depend on how accurately the values at those stations can be estimated. In other words, the question becomes how to estimate the water quality values at the discontinued monitoring stations when the only available information is the set of values recorded at the downstream monitoring station and the historical records for all three stations. (Recall that in the original statement of the problem, it was assumed that all stations had been in operation for a period of time sufficient to define the distribution of the various water quality values at all the stations and thereby establish the baseline conditions at those stations.)

Obviously, it is not possible to achieve perfect predictions of values for variables such as water quality which are stochastic in nature. However, if a method can be developed to estimate the value within a reasonable level of accuracy, the estimated value will be of use for a number of purposes, e.g., assistance in enforcing adherence to water quality standards based on the ability to identify suspected source of pollution, detection of locations that may have caused observed

changes in water quality at a downstream location, etc. Existing and proposed methods for providing the types of prediction required of this problem are described in the following section together with comments on the general topic of monitoring.

4.2 EXISTING METHODS

4.2.1 REGRESSION ANALYSIS

One of the most commonly used existing methods for prediction of unknown values on the basis of one or more known parameters is regression analysis. Detailed explanations of this technique can be found in most statistics textbooks. The objective of regression analysis is to exploit an observed relationship between two (or more) variables such that information about one variable can be achieved through knowing the values of the other variable(s). Regression analysis can be defined as follows:

"Regression analysis is the part of statistics which deals with investigation of the relationship between two or more variables related in a non deterministic fashion " (Devore, 1982).

Regression analysis is essentially based on the

development of a curve (function) which is the best fit to the data from two or more observations, where the value of one observation is considered to be dependent on the value(s) from other observation(s). The curve (function) shows, or embeds, the relationship, derived on the basis of historical data, between one ("unknown") parameter whose value is to be predicted using the expression, and the other known or measurable parameter(s) from which the value of unknown parameter is to be predicted. If this curve (function) can be developed for the water quality prediction problem, the water quality value at one station can be estimated, within a specified range for a certain level of confidence, by using the curve (function) and the water quality value(s) known (observed) at the other station(s).

The simplest and most common regression analysis uses a linear relationship between the data. When a linear function is not an appropriate model of the observed or experimental data, other functions such as polynomial or exponential expressions may be applied. In the simplest case, i.e., for two variables, the linear regression function can be expressed as :

$$Y = \beta_0 + \beta_1 X + e \quad (4.1)$$

where :

Y = dependent variable,
 X = independent variable,
 e = random error (the amount of variation in Y not accounted for by the linear function), assumed to be normally distributed with mean of 0 and variance of σ^2 ,

β_0 and β_1 = regression coefficients which have to be estimated.

Estimation of the values of β_0 and β_1 is usually performed on the principle of least squares which is based on identifying the regression line (function) which minimises the sum of squared deviations (vertical distances) of the observed points from to the corresponding values as indicated by the regression line.

The formulae for estimating the value of β_0 and β_1 , derived using the principle of least squares, can be expressed as follows :

$$\hat{\beta}_1 = \frac{\sum (X_i - \bar{X}) (Y_i - \bar{Y})}{\sum (X_i - \bar{X})^2} = \frac{\sum X_i Y_i - (\sum X_i) (\sum Y_i)}{N \sum X_i^2 - (\sum X_i)^2} \quad (4.2)$$

$$\hat{\beta}_0 = \frac{Y_i - \beta_1 \sum Y_i}{n} \quad (4.3)$$

where :

$\hat{\beta}_0$ and $\hat{\beta}_1$ = estimated values of β_0 and β_1 , respectively

$\bar{X}$ = mean value of the independent variable X

$\bar{Y}$ = mean value of the dependent variable Y.

Regression theory is described in most statistics textbooks, and therefore the technique will not be discussed further in this thesis. It should be noted, however, that the technique has been widely used in situations which involve the estimation of values on the basis of another set of data gained from observation. On the basis of its general acceptance for this type of prediction, regression will also be used in this study to predict the values of water quality parameters at discontinued monitoring station(s). The accuracy with which the values of water quality parameters at the discontinued monitoring station(s) are predicted using the regression technique, will then be compared to the accuracy with which the values of the same water quality parameters are predicted using the entropy method. This comparison will be the basis for as a means of evaluating the performance of the proposed entropy based method.

4.3 THE PROPOSED ENTROPY BASED METHOD

4.3.1 PROBLEM ANALYSIS

Most, if not all, water quality values are

measured and specified as a concentration of a substance within a unit or volume of water (i.e., mg/l, ppm, etc.). Assuming no interaction between water quality variables, a complete mixture of water from two different sources of different quality generally results in a final mixture with a water quality which lies between the two original values in direct proportion to the volumes (flow rates) which give rise to that final mixture.

Consider again Figure 4.1. If, from observation, the mean of the water quality value at station **b** (upstream) = x , and the mean of the water quality value at station **c** (upstream) = y , and assuming that the two streams upon which stations **b** and **c** are located have the same magnitude of flow, it can reasonably be expected that the mean of water quality value at the downstream station **a** is the average of the two water quality values at each of the two upstream stations. If the two rivers have significantly different flows, the water quality value at downstream station **a** can be calculated by weighting the corresponding water quality values from each river in proportion to their respective flows.

This process assumes that the water quality values do not change in passage from locations **b** or **c** to

location **a** as a result of time of transport or the transportation process itself, or that there are no further inflows of water and associated pollutants between locations **b** or **c** and **a**. These assumptions are somewhat unrealistic in a practical context. However, this simple example is being used solely to describe in general terms the situation for which the entropy based prediction model would be used. The implications of changes in water quality arising from time and transport from the upstream to downstream stations and the means for considering those implications are addressed later in this chapter.

Now consider the situation where stations **b** and **c** have been discontinued after a number of years in operation and then, at some later time, it was observed that the mean value at the downstream station **a** had changed significantly from the mean value from a number of years before. The question could then be asked as to "What is the most likely mean value at the upstream stations **b** and **c** under this new water quality regime?" An associated question might be "On which branch, i.e., at which of the two upstream stations **b** and **c**, did the water quality change causing the significant change observed at the downstream station **a** most likely occur?" A new method proposed to answer these two questions on the basis of the entropy principles

discussed in the previous chapter, is described in the following section.

4.3.2 THE ENTROPY BASED MODEL

The fundamental principle of the proposed method is derived from the theory of information entropy, as first introduced by Shannon (1948). This entropy concept was presented in Chapter 3, where its utility for the problem of probability estimation was demonstrated. The proposed method for the prediction of the water quality values at discontinued monitoring stations is based on this same probability estimation principle. The problem of predicting water quality values at discontinued monitoring stations and the proposed solution strategy is logically similar to the problem of estimating probability in the die problem described in Section 3.4.

In the die problem, for a fair die, the probability of each of the single events (1,2,...,6) is likely to be $1/6$. In the water quality case, for a particular water quality parameter, the probability (equivalent to the $1/6$ probability assigned to each outcome in the fair die problem) of each possible value of that parameter at a particular location is derived from (based on) the probability distribution function

of the water quality parameter at each of the relevant upstream stations. This probability distribution is determined from the historical data collected during the initial period of the operation of that station. In both the die and water quality case, those probabilities can be considered as the *prior* probability, i.e., the probability that is believed or known to be true or to exist before any new conflicting evidence is found.

A mean water quality value, observed at the downstream monitoring station in the period following the discontinuation of the upstream monitoring stations, may be different from the mean value for that downstream station, as defined from the historical records collected prior to the discontinuation of the upstream stations. This new mean value can be viewed as being equivalent to the mean value for the die problem, which may not be 3.5 such as expected from a 'fair' die, but some other value. On this basis and with the knowledge of the new mean value at the downstream monitoring station, the new most likely probabilities for each possible water quality values at each of the upstream stations, and thereby the most likely probability distributions of water quality at those upstream stations, can then be generated using the entropy principle.

The basic entropy formulation needed to derive these probabilities is specified by a set of equations based on Equations 3.13 and 3.14. However, this set of equations must be modified to reflect the particular conditions of the water quality prediction problem being addressed in this thesis. Prior to describing these modifications, some terms will be defined to avoid confusion in the interpretation of the proposed model.

4.3.3 DESCRIPTION OF TERMINOLOGY USED IN THE MODEL

(1) Events

Events in the case of the die problem were the number of dots facing up, namely, 1,2,...,6. These numbers represent all possible events for that example. A similar principle is used for the water quality problem, i.e., the events are defined as the range of possible water quality values that might occur at each of the monitoring stations.

To define the possible range of water quality values (events) for the water quality problem, the records collected prior to the discontinuation of the station(s) must be examined. Suppose the data from that historical record show the water quality values in the

past to be normally distributed with a mean value of μ and a standard deviation of σ . From a statistical view point, and from a historical perspective, it is reasonable to assume that the range of possible water quality values at that location lies between $\mu-4\sigma$ and $\mu+4\sigma$. Any values outside these boundaries are very unlikely to happen and therefore can reasonably be eliminated from consideration in the formulation. (Where the water quality values lying within $\mu\pm4\sigma$ are negative for a given station, the corresponding distribution is transformed by translation along the relevant axis until all values are positive. The corresponding distributions from the other stations are also transformed with the same magnitude to avoid distortion in the prediction processes. The results of the entropy model are then transformed back by the reverse process.)

It should be noted that the entropy model was developed by Shannon (1948) for discrete rather than continuous functions. The continuous probability distributions that describe the variation in water quality values, and which are derived from the historical data, therefore have to be discretized for use in the entropy model. The procedure for the discretization can be explained as follows. Once the range of possible values has been determined, the

discrete events are defined by dividing the range of possible values into a specified number of intervals. The 'events' in this model are then defined as the values of the mid-points of every interval arising from application of the discretization procedure to the continuous probability distribution function. Figure 4.2 shows a probability distribution which has been discretized into 24 intervals over the range of possible values $\mu-4\sigma$ to $\mu+4\sigma$. Figure 4.2(b) also shows the events associated with the intervals.

Harmancioglu et al. (1985) and Harmancioglu and Alpaslan (1992) have noted problems in the application of the entropy theory to water quality related problems arising from this discretization process. In particular they found that quite different answers or conclusions could be obtained or drawn depending on the level of discretization, i.e., depending on the size of the intervals of the discretization. However, such problems did not arise in this application. [A more complete discussion of the issues associated with discretization together with evidence that the problems encountered by Harmancioglu et al. (1985) and Harmancioglu and Alpaslan (1992) do not occur in this application of entropy theory is provided in Section 5.3.2].

(a) Continuous Probability Distribution Functions
Developed from the Data Recorded at the Station

(b) The PDF in (a) Discretized into 24 Intervals

Figure 4.2 Discretization of PDF to Define the Candidate Events

(11) Objective Function

It was noted in Section 4.3.2 that the proposed model is based on the theory of information entropy which was introduced by Jaynes (1957) as the Principle of Maximum Entropy. This principle was demonstrated by Jaynes as being capable of addressing the problem of probability estimation. Recall that the basic concept recognises that the probability distribution with the maximum entropy is the probability distribution that can be realised in the greatest number of ways, and is therefore the most likely to occur. The corollary for the water quality prediction problem, namely, that the distribution which constitutes the maximum entropy should be the one chosen for allocation of probabilities to the specific water quality values defined in the discretization process, is re-emphasised here.

Recall also that maximising entropy using POME is, in fact, the same as minimising cross entropy using MDI under the restriction that the underlying (or prior) distribution of the problem is uniform. Hence for the water quality case, where the prior probability distributions at the discontinued station(s) are highly unlikely to be uniform and the new distributions which occur at these stations are also unlikely to be

uniform, the MDI, as the generalised case of POME able to consider distributions other than uniform, must form the objective function in the formulation.

The mathematical expression of the objective function for the water quality problem for assignment of probabilities to water quality events at N stations in this case can therefore be written as follows :

$$\text{Minimise } H = \sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} \ln \frac{p_{ij\dots k}}{q_{ij\dots k}} \quad (4.4)$$

where :

$p_{ij\dots k}$ = joint probability value to be assigned to joint event i at station 1, event j at station 2, ..., and event k at station N,

$q_{ij\dots k}$ = 'prior' joint probability value of joint event i at station 1, event j at station 2, ..., and event k at station N, derived from historical records,

$M(n)$ = number of intervals (discrete water quality values) at station n,

N = number of upstream stations at which the probabilities of events are to be predicted.

The basic principle for the method proposed in this thesis is therefore the determination of new

probability distributions at discontinued monitoring station(s) such that the new probability distributions are as close as possible to the prior probability distributions of water quality at the stations and remain consistent with the information given about the system as expressed by the constraints. Note that when a significant change in the environment is known to have occurred, e.g., a change of land use or development of industries that causes a change in pollutant loading into the river system, the 'prior' probability may be modified to incorporate this 'prior' knowledge about the change in the environment into the model.

(iii) Constraints

Application of the entropy principle to the probability estimation problem through the MDI approach enables information other than the prior probabilities, which are incorporated in the objective function through the q_{ni} values, to be expressed mathematically as constraints within the formulation. This information will govern (constrain) the assignment of the probability to every event. Hence, only relevant and appropriate information on conditions in the system should be included in the constraints. Any other

additional information will tend to increase the prejudice of the model, thereby detracting from the unbiased nature of the predictions obtained from the approach. The importance of maintaining a lack of bias in the prediction relates to the potential use of the method for predicting the likely upstream locations of water quality changes which are the cause(s) of observed water quality changes at the downstream station. (This use of the procedure is discussed in more detail in Section 5.4.)

When using the entropy model to predict water quality values, or more precisely, the distribution of the water quality values, at discontinued monitoring stations, the following types of information could reasonably be considered as appropriate for inclusion in the set of constraints. The first piece of information might be the known or observed mean at the downstream station. The value of this mean determines in part the probability distributions, and thereby the mean values, which are assigned to the upstream stations.

Recall from Section 4.3.1 that the means of the water quality values at the upstream stations **b** and **c** have been defined as **x** and **y** respectively, and the mean of the water quality value at the downstream station **a**

has been similarly defined as z (where z is a function of x and y). Considering the water quality values in terms of concentrations of pollutant (and assuming no changes in flow rates, pollutant loadings, water quality values due to time of transport, the transport itself, or mixing of the flows from the two tributaries on which stations b and c are located), the value of z can be looked upon as a proportional mixture of x and y , expressed as :

$$z = \frac{Q_b \cdot x + Q_c \cdot y}{Q_b + Q_c} \quad (4.5)$$

where :

Q_b and Q_c = discharges at stations b and c respectively.

Ideally these discharges Q_b and Q_c at station b and c should be discharges measured at the same time as the water quality values of interest were measured for those stations. Furthermore, the measurements at stations b and c should be taken at times such that the bodies of water being measured at those separate locations arrive at the downstream station a at the same time. Such situations are rarely practical and occur very rarely, if at all. An approximation is therefore adopted in this study, wherein the values assigned to the flows ("weighting factors") Q_b and Q_c in

Equation 4.5 are the mean annual flows on the respective streams.

Now consider more closely the simplifying assumptions used in the derivation of Equation 4.5. In particular consider those assumptions relating to the time and distance of the travel between the stations and any physical processes affecting water quality and flow rates that might occur over this time and distance. In other words, the water quality measured at **b** or **c** may have changed before it reaches the confluence of the two streams upon which those stations are located. The water quality resulting from the mixing of those two streams may then change again before reaching **a**. This process can be quite complicated and a number of simulation models, e.g., Streeter-Phelps model for the BOD processes in a river (Tchobanoglous and Schroeder, 1985), have been developed to predict the values of water quality parameters in these circumstances.

However, the focus of this thesis, is not in the development of similar simulation models, but rather in the prediction of the values of the water quality at discontinued monitoring stations. The consequences of any of the mixing processes at the confluence or which might be occurring during travel down the river are

addressed through a regression process which relates, at least on a statistical if not on a physical basis, the water quality value at the downstream station **a** ($= z$) to the water quality value ($= z'$) that occurs from the direct weighted mixing of the values measured at the upstream monitoring stations. Implications of the changes that occur during the mixing process itself can also be recognised and incorporated into the formulation through this regression process.

The mathematical expression of this process can be written as :

$$z' = b_0 + b_1 \cdot z \quad (4.6)$$

where :

- z' = water quality value as a weighted mixture of water quality values from upstream locations derived from Equation 4.5,
- z = water quality value observed at the downstream station **a**,
- b_0 and b_1 = regression coefficients for the relationship between z and z' .

The expression given by Equation 4.6 essentially states that the value of the water quality at downstream station **a** is a function of the water quality at the upstream stations mixed in proportion to the

flow. An underlying assumption in this approach is that the rate at which a particular water quality value changes is linear with respect to that value and does not depend on the values of other water quality parameters. As such it assumes that the reactions or processes that cause changes during the transport or mixing process do not depend on threshold or ceiling values. For a number of water quality values, e.g., Conductivity, Dissolved Ions, Dissolved Solids, Hardness, etc., this is not an unreasonable assumption. (In future developments of the technique proposed in this thesis, it may be possible to develop an expression for Equation 4.6 that more accurately reflects the transport and mixing processes, in a simulation rather than statistical modelling sense. However, for use in the current formulation such an equation must be sufficiently simple to be incorporated into the non-linear optimisation problem that the formulation already represents without causing the model to become computationally impractical.)

An additional issue which must be considered in the development of the Equation 4.6 is *"What values from each station should be used in developing Equation 4.6?"*

Consider again the river system in Figure 4.1.

Assume all three stations **a**, **b** and **c** were in operation for a period of observation from 1961 to 1975 inclusive. Let the annual mean water quality values recorded at stations **a**, **b** and **c** through this period be denoted by the variables **z**, **x** and **y** respectively. Regression analysis, using Equations 4.5 and 4.6, can be performed to express the relationship between the annual mean water quality values at station **a** and the combination (weighted by the associated discharges) of the annual mean water quality values from stations **b** and **c**.

The problem to be solved, however, is the prediction of specific values at locations **b** and **c** corresponding to an observed value at the downstream station **a**. These values might be the annual value, or if trends are to be identified, time averaged values over specified time intervals such as a specific number of years. The expression of the relationship function derived by Equations 4.5 and 4.6 therefore should also consider, or carry over, the effect of averaging the values over periods of time longer than one year. This situation can be managed by implementing a 'moving average' procedure in developing the basic relationship function.

The steps for implementing a moving average approach

are as follows :

1. Select the number of years over which the mean value of the water quality is to be predicted, e.g., $\hat{n}$ years.
2. Calculate the mean values over the same number of years ($\hat{n}$) from each stations sequentially, e.g., in the example 1961 to $1961+\hat{n}$; 1962 to $1962+\hat{n}$;; $1975-\hat{n}$ to 1975.
3. Use the values obtained from step 2 to develop the relationship function using Equations 4.5 and 4.6.

In this process the time frame used in the calibration phase must be the same as that for which prediction is required. The values predicted by the entropy model using these functions therefore give the probability distributions (and associated means) associated with the selected time averaging period of the water quality values at the upstream stations.

4.3.4 FORMULATION

The complete mathematical formulation including constraints which assigns the joint probabilities is as follows :

$$\text{Maximise } H = - \sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} \ln \frac{p_{ij\dots k}}{q_{ij\dots k}} \quad (4.7.a)$$

or

$$\text{Minimise } H = \sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} \ln \frac{p_{ij\dots k}}{q_{ij\dots k}} \quad (4.7.b)$$

Subject to :

$$\sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} = 1 \quad (4.8)$$

$$\sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} x_{1i} = \bar{x}_1 \quad (4.9.a)$$

$$\sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} x_{2j} = \bar{x}_2 \quad (4.9.b)$$

$$\begin{array}{ccc} \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \end{array}$$

$$\sum_{i=1}^{M(1)} \sum_{j=1}^{M(2)} \dots \sum_{k=1}^{M(N)} p_{ij\dots k} x_{Nk} = \bar{x}_N \quad (4.9.x)$$

$$\bar{x} = f(\bar{x}_1, \bar{x}_2, \dots, \bar{x}_N) \quad (4.10)$$

(information function)

$$0 \leq p_{ij\dots k} \leq 1 \quad \forall_i; \forall_j; \dots; \forall_k \quad (4.11)$$

$$0 \leq q_{ij\dots k} \leq 1 \quad \forall_i; \forall_j; \dots; \forall_k \quad (4.12)$$

$$x_{1i} ; x_{2j} ; \dots ; x_{Nk} \geq 0 \quad \forall_i; \forall_j; \dots; \forall_k \quad (4.13)$$

where :

$x_{1i}, x_{2j}, \dots, x_{Nk} =$ events (water quality values) in the i^{th} discrete interval at station 1, in the j^{th} discrete interval at station 2, ..., and in the k^{th}

discrete interval at station N respectively,

$p_{ij\dots k}$ = joint probability value to be assigned to the joint event x_{1i} at station 1, event x_{2j} at station 2, ..., and event x_{Nk} at station N, i.e., joint event $[x_{1i}, x_{2j}, \dots, x_{Nk}]$

$q_{ij\dots k}$ = 'prior' joint probability value of the joint event $[x_{1i}, x_{2j}, \dots, x_{Nk}]$ as derived from historical records,

$\bar{x}_1, \bar{x}_2, \dots, \bar{x}_N$ = mean values of water quality to be estimated at discontinued upstream monitoring stations 1, 2, ..., N respectively,

$\bar{x}$ = observed 'mean' value of water quality at the downstream station.

The above formulation can be interpreted as follows :

The objective function (Equation 4.7) minimises the total divergence of joint probability values ($p_{ij\dots k}$) of event $[x_{1i}, x_{2j}, \dots, x_{Nk}]$ from the known prior joint probability $[q_{ij\dots k}]$ for all combinations of these events.

The constraints expressed in Equations 4.8 to 4.13 have the following interpretations :

- Equation 4.8 specifies that the sum of the entropy defined probabilities of all the possible events should be equal to one in order to ensure the definition of a complete probability distribution.
- Equation 4.9 defines the first order moments of the entropy defined marginal probability distributions of the water quality values for each upstream station as being equal to the mean value of the water quality for the corresponding station.
- Equation 4.10 ensures that the observed value at the downstream monitoring station upon which the prediction is based is equal to that derived from the historically derived or known function of mean values from the upstream stations.
- Equations 4.11 and 4.12 establish that the joint probability value of every event is between zero and one.
- Equation 4.13 ensures that there are no negative values in the parameters of interest.

It should be noted that application of this formulation to the problem of predicting water quality values at discontinued monitoring stations results in the specification of a new joint probability

distribution for the range of combinations of water quality values at the upstream stations. It does not derive the probability distributions at each station directly as is the case when the simplified formulation which is described in the following section is used. The distributions at each of these upstream stations must be derived by calculating, from the new joint distribution determined by the entropy formulation, the marginal probability distributions at those stations.

Due to the non-linear characteristics of the problem, the size of the problem, e.g., number of variables, in the formulation stated in Equations 4.7 to 4.13 can be of concern. Consider the case where there are only two upstream stations and the probability space in both dimensions (one for each of the two stations) is discretized into 24 intervals [$M(i)=24$ for $i=1$ and 2]. The number of variables in this problem is 578 ($= 24*24+2$ where the "+2" arises from the mean values of the stations). The situation is even more complex when more than two upstream stations are involved; for the same level of discretization, i.e., 24 intervals, more than 24^3 ($=13824$) variables are needed for three upstream stations. Even this limited size problem can be very demanding on non-linear optimisation algorithms.

However, the formulation can be easily simplified to improve the computational efficiency by reduction in the "dimension" of the problem, i.e., a three dimensional problem corresponding to the two station case of Figure 4.1 can be converted into a two dimensional problem. This simplification step, which reduces the number of variables to be solved is based upon the marginal probabilities as depicted in Figure 4.3. (It should be noted that the problem collapses to a two-dimension problem under the proposed simplification no matter how many upstream stations are being considered.)

The 'prior' mean water quality value at a particular station n can be calculated (for the case of two upstream stations) from the 'prior' marginal distribution as follows :

$$\bar{X}_n = \sum_{i=1}^{M(n)} q_{ni}^* x_{ni} \quad n = 1, 2 \quad (4.14)$$

where :

q_{ni}^* = prior marginal probability of event (water quality value) i at station n
 $\bar{x}_n$ = 'prior' mean water quality value at station n
 x_{ni} = event (water quality value) i at station n

The simplification arises from an interpretation

Figure 4.3 Illustration of the Formulation of the Problem for Two Discontinued Monitoring Stations

of the nature of the joint probability distribution of water quality at each station as derived by the entropy model. It should be noted that the sum of the probabilities over all water quality values at all stations should be always equal to unity. For the simplified two dimensional formulation illustrated by Figure 4.4, all stations have an 'equal likelihood of existence' with an 'equal total likelihood of the complete range of water quality values at that location'. The total probability of all combinations of water quality values at all stations individually must of course also remain equal to 1.

The best way to handle the total likelihood of water quality values at a given station, when there are N stations, is to 'assign' a total probability of $1/N$ to the sum of the probabilities of the water quality variables at each station. This 'sum' has some of the characteristics of the marginal distribution in that, for a given monitoring station, it represents the likelihood of the complete range of different water quality values occurring at that station 'relative' to the complete range of water quality values at all the other upstream stations.

Equations 4.8 and 4.9 can be modified to reflect this observation. In the case of Equation 4.8, the

Figure 4.4 Illustration for the Simplified Two Dimensional Formulation

expression is modified to equate the total probability, i.e., likelihood of the water quality values at the station, to $1/N$. Equation 4.9 on the other hand must be modified to normalise, or standardise, the probabilities of the values of the water quality values such that the correct mean of the water quality values is defined by the model at each station. This step is achieved by dividing the expected value of the water quality at a station by the total probability of the values at that station, namely, $1/N$. (Recall that under the assumptions being used at this time to simplify the problem, the total probability at any of N stations is $1/N$).

It should be noted that when the model was run directly as given in the formulation of Equations 4.15 to 4.21 in the following section, but using $\sum_{i=1}^{M(n)} p_{ni}$ rather than $1/N$ in Equation 4.17 and specifying that sum of all the probabilities is equal to 1 (i.e., $\sum_{n=1}^N \sum_{i=1}^{M(n)} p_{ni} = 1$) to replace Equation 4.16, the probability distribution of water quality values at each station at optimality summed to $1/N$, confirming the validity of the assumption that the 'total probability' of water quality values at each station is $1/N$.

The simplified two dimensional form of the formulation of Equations 4.7 to 4.13 resulting from

these changes can now be written as :

$$\text{Maximise } H = - \sum_{n=1}^N \sum_{i=1}^{M(n)} p_{ni} \ln \frac{p_{ni}}{(\frac{q_{ni}}{N})} \quad (4.15)$$

Subject to :

$$\sum_{i=1}^{M(n)} p_{ni} = \frac{1}{N} \quad (n = 1, 2, \dots, N) \quad (4.16)$$

$$\bar{X}_n = \frac{\sum_{i=1}^{M(n)} p_{ni} x_{ni}}{\sum_{i=1}^{M(n)} p_{ni}} = \frac{\sum_{i=1}^{M(n)} p_{ni} x_{ni}}{\frac{1}{N}} \quad (n = 1, 2, \dots, N) \quad (4.17)$$

$$\bar{X} = f(\bar{X}_1, \bar{X}_2, \dots, \bar{X}_N) \quad (4.18)$$

(information function)

$$0 \leq p_{ni} \leq 1 \quad \forall_n; \forall_i \quad (4.19)$$

$$0 \leq q_{ni} \leq 1 \quad \forall_n; \forall_i \quad (4.20)$$

$$0 \leq \bar{X}_{ni} \quad \forall_n; \forall_i \quad (4.21)$$

where :

x_{ni} = water quality value in the i^{th} discrete interval at station n ,

q_{ni} = prior probability of event x_{ni} ,

$\bar{X}_n$ = mean of the water quality value at station n ,

$\bar{X}$ = observed (changed) mean of the water quality value at the downstream location,

p_{ni} = probability of event x_{ni} to be assigned knowing the mean of water quality level downstream.

Using this formulation for the two dimensional problem for the case of predicting conditions at two stations and 24 intervals in the discretization, there are only 50 ($=24*2+2$) variables to be solved, which is a significant reduction from the 578 variables in the previous formulation. A further advantage of using this simplified formulation lies in the fact that the number of variables to be solved increases linearly with the number of intervals derived from discretization processes, rather than exponentially as in the previous formulation. This reduction in the number of variables is accompanied by a corresponding significant reduction in the processing time. It should also be noted that in addition to the reduction of processing time, the probability distributions of the water quality values at each of the discontinued stations are defined directly by this formulation rather having to be calculated separately through development of the marginal distributions as is the case for the 'multi-dimensional' formulation defined by Equations 4.7 to 4.14.

The formulation of Equation 4.15 to 4.21 has been

verified by comparing the results of this model with those from the formulation for the multi-dimensional case presented in Equations 4.7 to 4.13. Both formulations give exactly the same values for the same set of defined conditions. It should be noted that this process is valid for situations when there is no dependency between the water quality values at the upstream stations. (The issues related to use of the model when dependency exists among data at the upstream stations are discussed later in this chapter.)

A number of different variations of this basic model can be considered in relation to the application of the proposed method to the problem of estimating water quality values. These variations include consideration of a range of types of possible probability distributions for the water quality values, changes in the environment, and possible statistical or physical relationships among the data from different upstream stations.

In the first instance consider the way in which different distributions might be addressed within the approach. The formulation presented in Equations 4.15 to 4.21 is in fact applicable for general probability distribution functions. Hence, application of the formulation to situations where different probability

distribution functions for the water quality values are known to exist, only requires that the prior probability distribution values q_{ni} in the formulation be defined on the basis of these known distributions. In other words, the prior probabilities q_{ni} should be developed on the basis of the probability distribution that best resembles the known probability distribution of the historical data.

Now consider the case where changes effecting water quality are known to have occurred in the basin. In this situation, the new knowledge can be incorporated by replacing the prior probability, specified in the objective function of the model as q_{ni} , with new values estimated, or known, to exist because of these changes. This modification can be accomplished by shifting the prior probability distribution toward the estimated values. The extent to which the q_{ni} values can or should be changed is a matter of judgement and experience and is examined in more detail in Chapter 5. No matter how difficult it is to determine the extent of the changes in prior probability that can be justified by knowledge of conditions in the basin, the important feature is that the formulation is theoretically capable of handling the issue.

The last issue relates to the possibility that

statistical (and perhaps physical based) relationships between water quality values in the basin, and in particular between values at the upstream stations. If such a relationship exists, it is possible to incorporate this information implicitly in the formulation through the 'prior' probability distribution values. The inclusion of this relationship should theoretically improve the overall prediction process. Inclusion of this issue is quite complex, however, and requires that the multi-dimensional form of the formulation of Equations 4.7 to 4.13 rather than simplified form of Equations 4.15 to 4.21 be used. Inclusion of this relationship also requires the use of a dependent 'prior' probability distribution.

For a situation in which the water quality variables are correlated and normally distributed, i.e., a multivariate normal distribution exists, the 'prior' probability distribution can be expressed as :

$$q_{ij\dots k} = \frac{\Delta_1 \Delta_2 \dots \Delta_N}{(2\pi)^{ND/2} |S|^{1/2}} e^{-1/2(\mathbf{x}-\bar{\mathbf{x}})'S^{-1}(\mathbf{x}-\bar{\mathbf{x}})} \quad (4.22)$$

where :

$\Delta_1, \Delta_2, \dots, \Delta_N$ = discrete intervals of water quality values at stations $1, 2, \dots, N$ respectively,

S = sample covariance matrix of the multivariate normal distribution,

$\mathbf{x}$ = matrix of water quality data,
 $\bar{\mathbf{x}}$ = sample mean of water quality data matrix
 $\mathbf{x}$
 $\mathbf{ND}$ = number of discontinued monitoring stations

The $q_{ij\dots k}$ values defined in this manner are inserted into Equation 4.7 of the multi-dimensional formulation.

For the case of two discontinued monitoring stations, the above prior probability becomes :

$$q_{ij} = \frac{\Delta x_1 \cdot \Delta x_2}{2\pi \cdot Sx_{1i} Sx_{2j} \sqrt{1-\rho^2}} e^{-\left[\left(\frac{x_{1i} - \bar{x}_1}{Sx_{1i}} \right)^2 - 2\rho \left(\frac{x_{1i} - \bar{x}_1}{Sx_{1i}} \right) \left(\frac{x_{2j} - \bar{x}_2}{Sx_{2j}} \right) + \left(\frac{x_{2j} - \bar{x}_2}{Sx_{2j}} \right)^2 \right] / 2(1-\rho^2)}$$

(4.23)

where :

q_{ij} = joint probability of the joint event x_{1i} and x_{2j} ,
 x_{1i} = water quality value in the i^{th} discrete interval at station 1,
 $\bar{x}_1$ = mean of x_{1i} ,
 x_{2j} = water quality value in the j^{th} discrete interval at station 2,
 $\bar{x}_2$ = mean of x_{2j} ,
 Sx_{1i} = standard deviation of x_{1i} ,
 Sx_{2j} = standard deviation of x_{2j} ,
 ρ = coefficient correlation between events x_{1i} and x_{2j} ,

Δx_1 = width of interval at station 1,
 Δx_2 = width of interval at station 2.

4.4 DISCUSSION

Recall that, given an observed value of water quality at a downstream water quality monitoring station, the proposed method will result in the most likely probability distribution of water quality values being defined for discontinued upstream monitoring stations. If the 'new' or predicted mean values of water quality at the upstream stations derived from those 'new' probability distributions are plotted 'against' the 'prior' probability distributions, the probability of that new mean value, or more precisely the interval containing the mean value, occurring under the historical or original conditions can be calculated.

Application of the method to the case studies described in the following chapter reveals the following phenomenon related to the probability of this 'mean value'. For a given observed downstream water quality value, the product of the probabilities from the *original prior* probability distribution associated with the intervals containing the means of the entropy

defined distribution at each of the upstream stations, is greater than the product of the probabilities of any other combination of water quality values at those upstream stations that can give rise to the observed downstream value. Note that these 'upstream' probabilities are again derived from the intervals containing these values in the *original prior* probability distributions for the corresponding stations.

This phenomenon can be expressed mathematically as:

$$\prod_{n=1}^N p(\bar{\Delta}\mu_n) > \prod_{\substack{n=1 \\ k \in u}}^N p(\bar{\Delta}_{nk}) \quad u \in \bar{u} \quad (4.24)$$

where :

$p(\bar{\Delta}\mu_n)$ = probability of the discrete water quality interval in the *original* prior distribution at station n containing the new mean of the distribution of water quality values at station n as defined by the entropy prediction,

$p(\bar{\Delta}_{nk})$ = probability associated with discrete water quality interval k at station n in the *original prior* distribution of water quality

values at that station,

u = combination of upstream water quality values, one for each upstream station, that gives rise to the observed water quality value at the downstream station,

$\bar{u}$ = set of all possible u ,

N = number of upstream stations.

The phenomenon can perhaps be described more clearly by reference to Figure 4.5 which reflects a situation in which there are two upstream stations (stations 1 and 2) and one downstream station in the same configuration as in Figure 4.1. Assume that means of the entropy defined distributions are A and B for station 1 and 2 respectively. The values of water quality at the two upstream stations, designated by A and B, combine to produce the observed water quality value F at the downstream station. Now consider two other values of water quality C and D at stations 1 and 2 respectively which can also combine to give the observed water quality value F at the downstream station. The product of the probabilities of the intervals containing A and B in the original prior probability distributions (not the probabilities of the intervals containing the values of A and B in the entropy defined distributions) is greater than the

Upstream Station 1

Upstream Station 2

Figure 4.5 Figure for Explanation of Relationship between Products of Probability of Intervals of Water Quality Values that Give Rise to Observed Downstream Values

product of the probabilities of the intervals in the prior distribution containing the values C and D.

(Once again note that the probabilities of the intervals containing C and D are taken from the prior probability distributions not the entropy defined distribution). This same phenomenon occurs for any other combination of water quality values at the two upstream stations that give rise to the observed downstream value. This phenomenon was not observed for the upstream water quality values predicted by the regression analysis used to evaluate and compare the technique in Chapter 5.

The phenomenon confirming that the entropy principle defines the combination of 'new' values that is most likely to occur given prior knowledge about the situation provides further evidence that the new values predicted by the entropy principle should be considered the best estimate.

The following chapters describe the application of the technique to a series of case studies, followed by discussion of the results of those applications.

CHAPTER 5

APPLICATION OF THE TECHNIQUE

In this chapter, the entropy model described in the previous chapter is demonstrated by application to observed data from selected water quality monitoring stations in Queensland, Australia. The utility of the approach is then assessed by comparing its performance, measured in terms of the accuracy of the predictions of water quality values at discontinued stations, with that of another prediction approach.

Recall that the entropy expression (Equation 4.15) used to assign the probability values to the upstream stations requires the specification of the prior probabilities q_{ni} , and the derivation of the relationship between the weighted mixture of flow at the conjunction of a stream and the observed values of water quality at a monitoring station some distance downstream of the mixing point (Section 4.3.3). It is therefore necessary to have a data set on which to 'calibrate' the model. The requirement for prior existence of such a data set is not inconsistent with the nature of the definition of problem being

addressed in this thesis, namely, how to predict water quality values at *discontinued* monitoring stations where the discontinued stations have been in operation for a period of time sufficient to define the characteristics of the distribution of water quality data at that station. (It should be noted that similar restrictions apply for other prediction techniques such as regression.)

5.1 DATABASE DESCRIPTION

The data used in this study are taken from the Water Quality Data System of the Queensland Water Resources Commission in the State of Queensland, Australia. Examination of this data base showed that recording of those data which are appropriate for demonstrating the proposed model were generally only began in the 1970's. Furthermore, no continuous monthly records were available for water quality monitoring activities and only a few records are available for each year. While the lack of good data causes some problems for the calibration and verification of the model, it should be recognised that such lack of data is a common problem. Hence use of this model in what might be termed a typical environment of sparse data may in fact be a better test of its true utility.

The locations of the groupings of stations used to demonstrate the method, and the locations of the stations within those grouping, are shown in Figures 5.1(a) to 5.1(d). An example of the data from one of the groupings of stations is presented in Table 5.1 [The other data sets are presented in Appendix A, Tables A.1(a) to A.1(c)]. In most cases there is more than one value in each year with the data usually being recorded in different seasons. The annual mean value of the water quality parameter is assumed to be equal to the value calculated by averaging the data values in each annual record. The mean value determined in this fashion is recognised as only being an estimate of the actual mean but is one of the best estimates possible from the available data. However, there are also a few cases when only one value was recorded in a given year. In this situation, that single value is assumed to be the mean value for that particular year.

Where a number of daily records are available within a single month, these values were averaged first and the resulting 'averaged' value taken as the data point for that month when calculating the annual average value. This step was performed to reduce bias in calculating the annual average value. It should be recognised that all prediction methods would suffer from these same problems with lack of data. Hence a

Figure 5.1(a) Location of the Water Quality Monitoring Stations in the MacKenzie River Sub-Basin

Figure 5.1(b) Location of the Water Quality Monitoring Stations in the Fitzroy River Basin

Figure 5.1(c) Location of the Water Quality Monitoring Stations in the Nogoa River Basin

Figure 5.1(d) Location of the Water Quality Monitoring Stations in the Logan River Basin

Table 5.1 Water Quality Records in the MacKenzie River Sub-Basin

Table 5.1(a) Station 130401

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
17 6 71	270	7.2	184.2	0	77	72	27	0.0	16.0	9.0
2 9 71	175	7.9	130.2	0	58	56	17	0.0	10.0	8.0
8 12 71	365	7.8	274.1	0	99	120	43	0.0	20.0	12.0
10 4 72	245	7.4	198.1	0	80	84	29	0.0	17.0	9.0
4 7 72	320	7.8	242.1	0	101	100	34	0.0	24.0	10.0
10 10 72	430	8.2	344.1	0	130	130	55	0.0	34.0	11.0
16 12 72	410	8.0	279.2	0	100	102	48	0.0	22.0	11.0
17 4 73	217	7.6	153.8	127	65	62	19	1.0	13.4	7.6
27 6 73	294	7.9	226.9	179	105	100	23.4	1.7	19.8	13.6
27 9 73	230	7.3	168.0	143	60	62	25.5	2.0	13.0	6.7
13 12 73	210	7.6	146.4	114	64	56	19	2.0	14.0	7.0
4 7 74	432	8.0	283.7	244	129	111	36	1.2	26.0	15.6
18 9 74	510	8.6	318.2	255	144	120	38	1.4	28.0	18.0
3 9 75	430	8.1	267.3	218	116	107	34	1.2	25.0	13.0
13 11 75	270	8.1	155.5	134	62	60	20	3.1	13.0	7.2
22 7 76	540	7.8	350.9	294	152	120	49	1.2	31.0	18.0
29 10 76	630	8.1	419.4	346	162	160	59	1.6	40.0	20.0
24 11 76	480	8.3	307.9	269	139	99	40	2.2	31.0	15.0
5 2 77	105	7.5	77.0	72	25	33	9.6	1.8	5.9	2.5
28 3 77	330	7.6	194.8	174	86	80	25	1.4	20.0	8.8
25 7 77	400	8.3	266.8	226	111	110	34	1.2	23.0	13.0
9 9 77	510	8.0	351.3	285	150	142	44	1.4	32.0	17.0
9 12 77	210	7.8	131.6	114	60	50	16	2.7	13.0	6.6
25 5 78	460	8	315.3	271	132	115	42	1.4	28.0	15.0
24 7 78	455	7.7	294.5	255	126	98	44	1.0	24.0	16.0
25 10 79	660	7.6	411.0	343	181	145	59	2.0	36.0	22.0
10 3 80	350	7.6	226.9	199	95	88	30	1.5	20.0	11.0
6 6 80	335	7.2	201.9	181	89	70	29	1.3	19.0	10.0
15 9 80	450	7.2	297.7	248	127	110	40	1.5	26.0	15.0
10 11 80	500	7.7	311.2	264	128	113	44	1.7	25.0	16.0
9 12 80	510	7.7	310.5	267	126	116	46	2.0	24.0	16.0
27 7 81	380	7.5	228.3	197	95	86	32	1.0	20.0	11.0
16 10 81	470	8.5	173.2	240	118	14	41	1.6	24.0	14.0
5 4 82	235	8.4	148.9	140	60	57	21	1.3	13.0	6.6
21 6 82	330	7.9	204.5	180	88	79	27	1.4	19.0	9.8
7 9 82	385	8.1	248.7	200	102	92	35	1.3	21.0	12.0
1 8 83	340	7.5	189.7	170	89	56	30	1.2	19.0	10.0
12 12 83	255	7.8	173.6	150	66	70	25	2.5	14.0	7.6
8 3 84	310	8.0	200.6	170	82	71	27	1.7	17.0	9.6
25 6 84	355	8.0	238.0	200	85	95	37	1.6	18.0	9.8
5 3 85	200	7.2	129.8	130	51	47	17	2.7	11.0	5.6
17 6 85	260	7.8	145.8	130	61	56	23	1.3	13.0	6.9
3 10 85	390	7.5	254.4	210	104	91	35	1.8	22.0	12.0
17 3 86	220	7.7	152.3	120	65	67	18	2.4	16.0	6.0
17 6 86	260	7.9	170.6	150	69	62	22	1.9	15.0	7.7
2 10 86	350	7.8	225.0	180	93	87	32	2.2	20.0	10.5
29 6 87	265	7.4	182.3	140	75	82	22	3.8	17.0	7.8
11 12 87	205	7.9	144.8	120	64	68	14	2.9	15.5	6.1
20 5 88	395	7.5	250.2	220	111	87	32.5	1.9	24.0	12.5
8 10 88	320	7.3	204.1	180	86	74	27	1.5	18.0	10.0
21 6 89	315	7.9	212.9	180	86	81	31	1.3	18.0	10.0
10 10 89	510	7.7	332.5	280	158	120	46	1.7	32.0	19.0

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table 5.1(b) Station 130106

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l as CaCO ₃)	ALKALINITY (mg/l as CaCO ₃)	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
17 11 71	230	7.4	199.3	0	91	110	18.0	0.0	28.0	5.0
19 2 72	130	7.1	137.4	0	60	74	15.0	0.0	14.0	6.0
20 2 72	80	6.9	80.8	0	36	40	7.0	0.0	8.0	4.0
20 2 72	83	6.9	88.1	0	45	44	6.0	0.0	8.0	6.0
21 2 72	80	6.9	85.2	0	48	40	4.0	0.0	6.0	8.0
22 2 72	89	6.9	98.0	0	44	46	6.0	0.0	11.0	4.0
23 2 72	100	6.9	98.0	0	41	52	10.0	0.0	10.0	4.0
23 2 72	105	7.1	105.4	0	46	58	11.0	0.0	10.0	5.0
24 2 72	130	7.1	112.5	0	61	60	7.0	0.0	13.0	7.0
25 2 72	130	7.1	124.4	0	56	66	12.0	0.0	14.0	5.0
26 2 72	135	7.0	124.4	0	65	70	8.0	0.0	13.0	8.0
27 2 72	140	7.1	129.5	0	64	70	11.0	0.0	14.0	7.0
17 3 72	125	7.1	109.5	0	57	60	7.0	0.0	13.0	6.0
1 9 72	205	7.6	169.1	0	70	86	20.0	0.0	18.0	6.0
13 12 72	380	8.0	282.2	0	136	120	32.0	0.0	28.0	16.0
20 3 73	155	7.3	132.3	99	53	72	8.6	5.0	10.5	6.5
6 6 73	180	7.7	162.7	121	73	90	10.0	5.8	17.0	7.5
19 9 73	105	7.3	112.5	81	59	54	7.0	3.8	15.7	4.7
4 1 74	69	8.7	48.3	46	15	20	6.8	2.7	4.5	1.0
31 1 74	120	7.2	80.8	63	33	44	5.5	2.8	7.9	3.1
1 2 74	105	7.3	91.9	72	39	50	6.0	3.0	9.3	3.9
3 2 74	120	7.3	113.2	87	46	60	7.8	3.6	11.5	4.3
4 2 74	130	7.2	111.4	88	45	60	7.6	3.8	11.0	4.3
26 3 74	180	7.2	134.1	101	46	65	15.0	4.1	11.7	4.0
26 3 74	230	7.9	211.0	158	105	114	13.0	3.9	24.5	10.7
6 8 74	270	7.8	212.9	153	104	120	14.0	3.4	23.0	11.3
15 11 74	180	7.5	147.2	115	73	76	10.0	3.7	17.0	7.3
23 1 75	182	7.2	139.5	116	61	72	11.0	4.0	14.0	6.3
23 1 75	180	7.2	139.4	112	60	72	11.0	4.1	14.0	6.0
23 1 75	182	7.2	139.3	110	60	72	11.0	4.1	14.0	6.0
12 2 75	203	7.5	162.6	122	71	92	11.0	4.4	17.0	7.0
3 8 76	410	8.0	347.2	257	162	175	27.0	3.6	35.0	18.0
13 1 77	298	7.7	208.3	162	82	96	26.0	3.3	21.0	7.2
19 4 77	260	8.2	199.9	152	90	107	16.0	4.0	20.0	9.7
17 5 77	115	7.6	96.4	78	33	50	8.5	3.5	7.5	3.5
18 5 77	132	7.7	104.2	82	37	58	9.4	3.7	9.0	3.6
19 5 77	170	7.7	134.2	105	51	72	12.0	3.5	12.0	5.2
22 5 77	180	7.6	140.9	109	56	76	13.0	3.6	13.0	5.6
23 5 77	180	7.9	147.8	111	57	83	12.0	3.8	13.0	6.0
23 5 77	185	8.0	146.9	112	60	83	12.0	4.0	14.0	6.0
24 5 77	176	7.7	131.7	111	61	60	13.0	5.3	14.0	6.4
27 5 77	187	7.7	128.9	109	61	58	13.0	4.7	14.0	6.3
21 6 77	110	7.8	162.3	133	80	76	16.0	4.0	18.0	8.6
27 7 77	270	7.9	212.4	157	91	117	19.0	3.6	20.0	10.0
5 9 77	340	8.0	279.6	202	116	152	25.0	4.0	25.0	13.0
9 2 78	140	7.9	125.6	99	50	68	10.0	3.6	12.0	4.8
22 11 78	180	7.5	129.3	102	60	64	13.0	3.4	14.0	6.0
7 9 79	340	7.6	257.6	199	101	118	30.0	4.0	24.0	10.0
21 1 80	213	7.9	166.4	130	66	80	19.0	3.7	16.0	6.3
31 3 80	250	7.0	165.5	141	67	60	23.0	3.7	16.0	6.6
24 6 80	228	7.2	165.7	134	75	87	15.0	3.7	17.0	7.8
30 1 81	230	7.6	170.9	132	63	85	21.0	2.7	15.0	6.3
27 3 81	178	7.5	136.6	107	61	72	11.0	3.7	14.0	6.2
26 6 81	205	7.9	151.1	112	65	82	13.0	4.8	15.0	6.7
29 6 81	210	7.9	163.3	119	66	86	13.0	4.6	15.0	7.0
28 9 81	223	7.8	173.6	119	53	100	20.0	4.0	8.0	8.0
31 12 81	150	8.0	110.4	100	45	54	9.7	3.3	11.0	4.3
1 3 82	190	7.8	144.0	110	61	77	11.0	3.5	15.0	5.6
28 6 82	195	7.8	148.6	110	66	77	13.0	3.6	16.0	6.2
16 8 82	220	8.0	175.0	130	78	95	15.0	4.1	19.0	7.5
15 10 82	240	7.9	185.7	140	85	99	15.5	4.1	19.0	9.1
28 6 83	110	8.9	83.8	69	27	40	10.0	3.5	8.5	1.5
12 12 83	240	8.3	185.5	140	81	101	16.0	4.3	18.0	8.7
14 3 84	180	8.0	143.2	110	59	74	12.0	3.8	14.0	5.9
9 5 84	230	7.5	175.5	130	71	82	17.0	3.6	17.0	7.0
18 9 84	210	7.5	165.3	130	56	73	20.0	3.7	13.0	5.6
5 3 85	175	7.6	135.4	110	55	67	14.0	4.0	14.0	4.9
27 9 85	310	7.3	196.9	170	76	68	30.0	2.0	16.0	8.7
13 3 86	185	6.4	150.2	110	61	80	13.5	3.4	15.0	5.6

Source: Queensland Water Resources Commission
 Surface Water Resources Branch
 Water Quality Data System

Table 5.1(c) Station 130105

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l as CaCO ₃)	ALKALINITY (mg/l as CaCO ₃)	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
1 9 72	280	7.7	197.1	146	75	82	30.0	0.0	17.0	8.0
12 12 72	300	7.7	202.2	151	86	82	28.0	0.0	18.0	10.0
21 3 73	175	7.7	125.3	104	51	60	13.9	2.9	10.5	6.0
27 3 73	230	7.1	154.9	136	63	60	20.0	1.6	12.5	7.7
5 6 73	205	8.1	143.7	117	60	64	13.8	2.8	13.5	6.5
18 9 73	250	8.1	214.4	186	73	72	25.0	2.5	16.0	8.0
27 3 74	180	7.2	123.3	105	48	52	14.0	2.7	10.0	5.5
7 8 74	440	8.0	299.6	248	129	115	38.0	1.8	26.0	15.6
13 11 74	430	7.7	277.7	229	114	105	36.0	2.0	22.0	14.4
8 1 75	155	7.1	118.0	88	61	54	12.0	3.5	14.0	6.3
8 1 75	153	7.1	113.3	87	61	50	12.0	3.6	14.0	6.3
8 1 75	153	7.0	112.1	105	57	50	11.5	3.4	13.0	6.0
10 1 75	147	7.0	115.6	106	53	56	11.0	3.7	12.0	5.7
12 1 75	135	7.0	104.4	96	45	54	9.0	3.9	11.0	4.3
13 1 75	130	7.1	97.3	90	43	52	3.5	4.2	10.0	4.3
13 1 75	130	7.0	101.8	90	43	52	8.0	4.2	10.0	4.3
13 1 75	130	6.9	98.8	88	44	50	8.5	4.2	10.5	4.3
16 1 75	155	7.1	125.1	103	60	66	9.5	4.3	14.0	6.0
16 1 75	155	7.0	122.8	106	58	66	9.0	4.0	13.5	6.0
16 1 75	157	7.2	134.5	119	62	66	9.5	3.9	14.5	6.3
16 1 75	157	7.1	124.8	106	62	66	9.5	4.2	14.5	6.3
20 1 75	142	7.1	108.4	99	50	54	9.5	3.9	12.0	4.8
20 1 75	142	7.0	106.7	95	47	54	9.0	3.8	11.0	4.7
20 1 75	142	7.1	108.7	96	47	56	9.0	3.8	11.0	4.7
21 1 75	160	7.1	119.6	107	54	62	10.0	4.2	13.0	5.2
21 1 75	160	7.1	121.2	104	51	64	10.0	4.2	11.5	5.3
21 1 75	160	7.1	121.7	107	52	64	10.0	4.2	12.0	5.3
22 1 75	172	7.1	131.2	110	57	68	11.0	4.0	13.0	6.0
22 1 75	175	7.2	131.0	112	56	68	11.0	4.1	13.0	5.7
22 1 75	170	7.2	133.0	112	56	70	11.0	4.1	13.0	5.7
24 1 75	185	7.2	143.8	117	60	75	11.5	4.1	14.0	6.0
24 1 75	187	7.2	145.8	121	65	75	11.5	4.1	16.0	6.0
24 1 75	185	7.2	158.6	135	65	74	11.5	4.1	16.0	6.0
28 1 75	197	7.2	151.4	121	63	80	13.0	3.9	15.0	6.3
11 2 75	220	7.4	162.4	131	68	82	16.0	3.7	15.5	7.0
29 9 75	370	7.6	237.4	195	99	102	29.0	2.2	20.0	12.0
15 12 75	115	7.6	75.4	75	24	28	10.0	3.1	5.3	2.7
5 8 76	555	8.4	351.3	295	164	125	50.0	1.6	36.0	18.0
25 10 76	670	8.0	409.7	342	186	140	60.0	2.0	38.0	22.0
15 12 76	325	8.0	247.5	185	101	119	26.0	4.2	24.0	10.0
10 1 77	250	7.5	157.3	138	67	62	20.0	2.5	16.0	6.6
18 4 77	350	8.1	233.2	196	100	100	29.0	2.0	22.0	11.0
26 7 77	380	8.2	256.9	206	104	116	30.0	2.4	22.0	12.0
4 10 77	460	8.1	346.8	276	138	146	40.0	2.4	29.0	16.0
5 1 78	405	8.1	292.8	238	122	115	37.0	3.6	24.0	15.0
20 11 78	330	7.9	223.5	177	99	96	28.0	3.2	23.0	10.0
2 6 80	375	7.3	228.7	201	104	80	32.0	1.4	22.0	12.0
18 9 80	400	7.5	253.9	217	107	89	38.0	1.6	23.0	12.0
13 11 80	460	7.8	284.8	242	112	91	45.0	2.3	20.0	15.0
23 7 81	248	7.7	176.7	139	71	85	18.0	3.1	15.0	8.1
19 8 82	260	7.9	167.0	150	63	61	27.0	1.7	13.0	7.5
15 3 84	165	8.2	129.0	100	53	60	13.0	3.9	12.0	5.6
18 6 84	290	6.9	196.9	160	77	82	26.0	3.5	17.0	8.4
17 9 84	200	7.4	157.0	120	65	78	15.0	3.8	15.0	6.8
4 12 84	250	7.4	161.2	140	61	67	23.0	4.0	14.0	6.2
4 3 85	265	7.4	184.0	150	72	77	22.0	3.8	16.0	7.8
3 12 85	205	7.9	137.9	130	51	55	18.0	4.0	12.0	5.0
13 3 86	205	8.3	154	120	66	80	13.0	4.0	16.0	6.2
24 6 86	225	8.0	174.9	140	72	81	19.0	3.6	16.0	7.8
26 9 86	335	8.3	234.9	180	104	105	28.0	3.8	22.0	12.0
7 1 87	225	7.8	267.3	130	63	73	18.0	4.1	15.0	6.1
31 3 87	220	7.7	165.7	140	69	83	17.0	4.7	16.0	7.0
16 12 87	185	7.5	118.7	99	51	51	12.5	3.3	12.0	5.2
4 10 88	200	7.1	128	110	55	51	15.5	2.8	13.0	5.5
26 6 89	330	7.8	175.6	150	72	76	24.0	2.2	15.0	8.4
8 12 89	210	8.0	155.5	130	59	65	20.0	2.8	13.0	6.4

Source : Queensland Water Resources Commission
 Surface Water Resources Branch
 Water Quality Data System

comparison, using the same data and assumptions, of the entropy based technique with other estimation techniques on the basis of their performances in prediction as undertaken later in this chapter is valid. Furthermore, the method(s) can be evaluated in an absolute sense, on the basis or in the sense of how well they predict (known) values in a verification step in spite of the problems (shortcomings) in the data used for calibration.

The annual mean values calculated for the data from Table 5.1 are presented in Table 5.2 and for the other sets of data are presented in Appendix A, Tables A.2(a) to A.2(c). The choice of which of the water quality parameters measured at each station would be used in this demonstration was based upon the completeness and length of the record for each parameter. Following review of the records at the stations, the following parameters were selected for analysis: Conductivity, PH, Dissolved Ions, Dissolved Solids, Hardness, Alkalinity, Natrium, Kalium, Calcium and Magnesium.

5.2 APPLICATION OF THE MODEL

In this section, the steps required to calibrate and then apply the model are described.

Table 5.2 Annual Mean Values of the Water Quality Parameters from the MacKenzie River Sub-Basin

Table 5.2(a) Station 130401

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
71	270.0	7.6	196.1	-	78.0	82.7	29.0	-	15.3	9.7
72	351.3	7.9	265.9	-	102.8	104.0	41.5	-	24.3	10.3
73	237.8	7.6	173.8	140.8	73.5	70.0	21.7	1.7	15.1	8.7
74	471.0	8.3	301.0	249.5	136.5	115.5	37.0	1.3	27.0	16.8
75	350.0	8.1	211.4	176.0	89.0	83.5	27.0	2.2	19.0	10.1
76	550.0	8.1	359.4	303.0	157.7	126.3	49.3	1.7	34.0	17.7
77	311.0	7.8	204.3	174.2	86.4	83.0	25.7	1.7	18.8	9.6
78	457.5	7.9	304.9	263.0	129.0	106.5	43.0	1.2	26.0	15.5
79	660.0	7.6	411.0	343.0	181.0	145.0	59.0	2.0	36.0	22.0
80	429.0	7.5	269.6	231.8	113.0	99.4	37.8	1.6	22.8	13.6
81	425.0	8.0	200.8	218.5	106.5	50.0	36.5	1.3	22.0	12.5
82	316.7	8.1	200.7	173.3	83.3	76.0	27.7	1.3	17.7	9.5
84	332.5	8.0	219.3	185.0	83.5	83.0	32.0	1.7	17.5	9.7
85	283.3	7.5	176.7	156.7	72.0	64.7	25.0	1.9	15.3	8.2
86	276.7	7.8	182.6	150.0	75.7	72.0	24.0	2.2	17.0	8.1

Table 5.2(b) Station 130106

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
71	230.0	7.4	199.3	-	91.0	110.0	18.0	-	28.0	5.0
72	204.8	7.4	167.1	-	78.6	80.6	17.0	-	17.5	8.5
73	146.7	7.4	135.8	100.3	61.7	72.0	8.5	4.9	14.4	6.2
74	168.6	7.8	136.1	104.2	61.7	71.8	10.3	3.4	14.5	6.2
75	192.2	7.4	151.0	117.3	65.7	82.0	11.0	4.2	15.5	6.6
76	410.0	8.0	347.2	257.0	162.0	175.0	27.0	3.6	35.0	18.0
77	240.6	7.9	198.6	151.4	85.2	102.6	18.9	3.8	19.3	9.0
78	160.0	7.7	127.5	100.5	55.0	66.0	11.5	3.5	13.0	5.4
79	340.0	7.6	257.6	199.0	101.0	118.0	30.0	4.0	24.0	10.0
80	230.3	7.4	165.9	135.0	69.3	75.7	19.0	3.7	16.3	6.9
81	199.3	7.8	151.0	114.8	58.8	79.8	14.6	3.9	13.0	6.4
82	211.3	7.9	163.3	122.5	72.5	87.0	13.6	3.8	17.3	7.1
84	206.7	7.7	161.3	123.3	62.0	76.3	16.3	3.7	14.7	6.2
85	242.5	7.5	166.2	140.0	65.5	67.5	22.0	3.0	15.0	6.8
86	185.0	6.4	150.2	110.0	61.0	80.0	13.5	3.4	15.0	5.6

Table 5.2(c) Station 130105

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/L)	MAGNESIUM (mg/l)
71	-	-	-	-	-	-	-	-	-	-
72	290.0	7.7	199.7	148.5	80.5	82.0	29.0	-	17.5	9.0
73	215.0	7.8	159.6	135.8	61.8	64.0	18.2	2.4	13.1	7.1
74	350.0	7.6	233.5	194.0	97.0	90.7	29.3	2.2	19.3	11.8
75	235.0	7.5	158.4	133.7	63.7	68.5	16.3	3.2	13.4	6.8
76	516.7	8.1	336.2	274.0	150.3	128.0	45.3	2.6	32.7	16.7
77	360.0	8.0	248.6	204.0	102.3	106.0	29.8	2.3	22.3	10.6
78	367.5	8.0	258.2	207.5	110.5	105.5	32.5	3.4	23.5	12.5
79	-	-	-	-	-	-	-	-	-	-
80	411.7	7.5	255.8	220.0	107.7	86.7	38.3	1.8	21.7	13.0
81	248.0	7.7	176.7	139.0	71.0	85.0	18.0	3.1	15.0	8.1
82	260.0	7.9	167.0	150.0	63.0	61.0	27.0	1.7	13.0	7.5
84	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
85	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
86	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7

5.2.1 DATA PREPARATION

The data described in the previous section were split into two groups, one to calibrate the model, the other to test how well the model performs. In the calibration phase the data are used to :

- i. develop the probability distributions of each of the water quality parameters at each monitoring station, and
- ii. develop the relationship or 'information functions' (see Equations 4.18) between the observed downstream values and the upstream values for each parameter as described in Section 4.3.3.

An example of how the data from the data set shown in Table 5.2 are split into calibration and verification sets is shown in Table 5.3. In this case, the first group of data contains the records from year 1971 to 1980 and the other, records from 1981 to 1986. It can be seen in Table 5.3 that the data sets for the calibration step are larger than those for the verification or validation step. This choice of relative sizes of data sets for the two steps was based on a decision to have a larger set of data in the calibration step in order to provide a sufficient number of data points for a more reliable development of Equation 4.18 when moving average values are used.

**Table 5.3 Annual Mean Values of the Water Quality Parameters (Grouped)
from the MacKenzie River Sub-Basin**

Table 5.3(a) Station 130401

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
71	270.0	7.6	196.1	-	78.0	82.7	29.0	-	15.3	9.7
72	351.3	7.9	265.9	-	102.8	104.0	41.5	-	24.3	10.3
73	237.8	7.6	173.8	140.8	73.5	70.0	21.7	1.7	15.1	8.7
74	471.0	8.3	301.0	249.5	136.5	115.5	37.0	1.3	27.0	16.8
75	350.0	8.1	211.4	176.0	89.0	83.5	27.0	2.2	19.0	10.1
76	550.0	8.1	359.4	303.0	157.7	126.3	49.3	1.7	34.0	17.7
77	311.0	7.8	204.3	174.2	86.4	83.0	25.7	1.7	18.8	9.6
78	457.5	7.9	304.9	263.0	129.0	106.5	43.0	1.2	26.0	15.5
79	660.0	7.6	411.0	343.0	181.0	145.0	59.0	2.0	36.0	22.0
80	429.0	7.5	269.6	231.8	113.0	99.4	37.8	1.6	22.8	13.6
Mean	408.8	7.8	269.7	235.2	114.7	101.6	37.1	1.7	23.8	13.4
Standard Deviation	131.0	0.3	76.4	68.1	35.9	23.0	11.6	0.3	7.2	4.5

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
81	425.0	8.0	200.8	218.5	106.5	50.0	36.5	1.3	22.0	12.5
82	316.7	8.1	200.7	173.3	83.3	76.0	27.7	1.3	17.7	9.5
84	332.5	8.0	219.3	185.0	83.5	83.0	32.0	1.7	17.5	9.7
85	283.3	7.5	176.7	156.7	72.0	64.7	25.0	1.9	15.3	8.2
86	276.7	7.8	182.6	150.0	75.7	72.0	24.0	2.2	17.0	8.1
(2 yearly)										
Mean #1	370.8	8.1	200.7	195.9	94.9	63.0	32.1	1.3	19.8	11.0
Mean #2	324.6	8.1	210.0	179.2	83.4	79.5	29.8	1.5	17.6	9.6
Mean #3	307.9	7.8	198.0	170.8	77.8	73.8	28.5	1.8	16.4	8.9
Mean #4	280.0	7.7	179.7	153.3	73.8	68.3	24.5	2.1	16.2	8.1
(3 yearly)										
Mean #5	358.1	8.0	206.9	192.3	91.1	69.7	32.1	1.4	19.1	10.6
Mean #6	310.8	7.9	198.9	171.7	79.6	74.6	28.2	1.6	16.8	9.1
Mean #7	297.5	7.8	192.9	163.9	77.1	73.2	27.0	1.9	16.6	8.6
(4 yearly)										
Mean #8	339.4	7.9	199.4	183.4	86.3	68.4	30.3	1.6	18.1	10.0
Mean #9	302.3	7.9	194.8	166.3	78.6	73.9	27.2	1.8	16.9	8.9

Note : Mean #1 = Mean of years 81,82
Mean #2 = Mean of years 82,84
Mean #3 = Mean of years 84,85
Mean #4 = Mean of years 85,86
Mean #5 = Mean of years 81,82,84

Mean #6 = Mean of years 82,84,85
Mean #7 = Mean of years 84,85,86
Mean #8 = Mean of years 81,82,84,85
Mean #9 = Mean of years 82,84,85,86

Table 5.3(b) Station 130106

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
71	230.0	7.4	199.3	-	91.0	110.0	18.0	-	28.0	5.0
72	204.8	7.4	167.1	-	78.6	80.6	17.0	-	17.5	8.5
73	146.7	7.4	135.8	100.3	61.7	72.0	8.5	4.9	14.4	6.2
74	168.6	7.8	136.1	104.2	61.7	71.8	10.3	3.4	14.5	6.2
75	192.2	7.4	151.0	117.3	65.7	82.0	11.0	4.2	15.5	6.6
76	410.0	8.0	347.2	257.0	162.0	175.0	27.0	3.6	35.0	18.0
77	240.6	7.9	198.6	151.4	85.2	102.6	18.9	3.8	19.3	9.0
78	160.0	7.7	127.5	100.5	55.0	66.0	11.5	3.5	13.0	5.4
79	340.0	7.6	257.6	199.0	101.0	118.0	30.0	4.0	24.0	10.0
80	230.3	7.4	165.9	135.0	69.3	75.7	19.0	3.7	16.3	6.9
Mean	232.3	7.6	188.6	145.6	83.1	95.4	17.1	3.9	19.8	8.2
Standard Deviation	83.2	0.2	68.2	56.1	31.3	33.1	7.2	0.5	7.1	3.8

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
81	199.3	7.8	151.0	114.8	58.8	79.8	14.6	3.9	13.0	6.4
82	211.3	7.9	163.3	122.5	72.5	87.0	13.6	3.8	17.3	7.1
84	206.7	7.7	161.3	123.3	62.0	76.3	16.3	3.7	14.7	6.2
85	242.5	7.5	166.2	140.0	65.5	67.5	22.0	3.0	15.0	6.8
86	185.0	6.4	150.2	110.0	61.0	80.0	13.5	3.4	15.0	5.6
(2 yearly)										
Mean #1	205.3	7.8	157.2	118.7	65.7	83.4	14.1	3.8	15.1	6.8
Mean #2	209.0	7.8	162.3	122.9	67.3	81.7	15.0	3.8	16.0	6.6
Mean #3	224.6	7.6	163.7	131.7	63.8	71.9	19.2	3.4	14.8	6.5
Mean #4	213.8	6.9	158.2	125.0	63.3	73.8	17.8	3.2	15.0	6.2
(3 yearly)										
Mean #5	205.8	7.8	158.5	120.2	64.4	81.1	14.9	3.8	15.0	6.6
Mean #6	220.1	7.7	163.6	128.6	66.7	76.9	17.3	3.5	15.6	6.7
Mean #7	211.4	7.2	159.2	124.4	62.8	74.6	17.3	3.4	14.9	6.2
(4 yearly)										
Mean #8	214.9	7.7	160.4	125.2	64.7	77.7	16.6	3.6	15.0	6.6
Mean #9	211.4	7.3	160.3	124.0	65.3	77.7	16.4	3.5	15.5	6.4

Note : Mean #1 = Mean of years 81,82
Mean #2 = Mean of years 82,84
Mean #3 = Mean of years 84,85
Mean #4 = Mean of years 85,86
Mean #5 = Mean of years 81,82,84

Mean #6 = Mean of years 82,84,85
Mean #7 = Mean of years 84,85,86
Mean #8 = Mean of years 81,82,84,85
Mean #9 = Mean of years 82,84,85,86

Table 5.3(c) Station 130105

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
71	-	-	-	-	-	-	-	-	-	-
72	290.0	7.7	199.7	148.5	80.5	82.0	29.0	-	17.5	9.0
73	215.0	7.8	159.6	135.8	61.8	64.0	18.2	2.4	13.1	7.1
74	350.0	7.6	233.5	194.0	97.0	90.7	29.3	2.2	19.3	11.8
75	235.0	7.5	158.4	133.7	63.7	68.5	16.3	3.2	13.4	6.8
76	516.7	8.1	336.2	274.0	150.3	128.0	45.3	2.6	32.7	16.7
77	360.0	8.0	248.6	204.0	102.3	106.0	29.8	2.3	22.3	10.6
78	367.5	8.0	258.2	207.5	110.5	105.5	32.5	3.4	23.5	12.5
79	-	-	-	-	-	-	-	-	-	-
80	411.7	7.5	255.8	220.0	107.7	86.7	38.3	1.8	21.7	13.0
Mean	343.2	7.8	231.2	189.7	96.7	91.4	29.8	2.2	20.4	10.9
Standard Deviation	97.6	0.2	58.7	48.3	28.8	21.2	9.6	1.1	6.3	3.3

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
81	248.0	7.7	176.7	139.0	71.0	85.0	18.0	3.1	15.0	8.1
82	260.0	7.9	167.0	150.0	63.0	61.0	27.0	1.7	13.0	7.5
84	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
85	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
86	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7
(2 yearly)										
Mean #1	254.0	7.8	171.9	144.5	67.0	73.0	22.5	2.4	14.0	7.8
Mean #2	243.1	7.7	164.0	140.0	63.5	66.4	23.1	2.8	13.8	7.1
Mean #3	230.6	7.6	161.0	135.0	62.8	68.9	19.6	3.9	14.3	6.6
Mean #4	245.0	7.9	174.4	143.3	71.1	77.3	20.0	3.9	16.0	7.5
(3 yearly)										
Mean #5	244.8	7.7	168.2	139.7	66.0	72.6	21.4	2.9	14.2	7.5
Mean #6	240.4	7.7	163.0	140.0	62.8	66.3	22.1	3.1	13.8	6.9
Mean #7	238.8	7.8	170.0	138.9	68.7	75.5	19.8	3.8	15.5	7.3
(4 yearly)										
Mean #8	242.3	7.7	166.4	139.8	64.9	70.9	21.1	3.1	14.1	7.2
Mean #9	244.1	7.8	169.2	141.7	67.3	71.9	21.6	3.3	14.9	7.3

Note : Mean #1 = Mean of years 81,82
Mean #2 = Mean of years 82,84
Mean #3 = Mean of years 84,85
Mean #4 = Mean of years 85,86
Mean #5 = Mean of years 81,82,84

Mean #6 = Mean of years 82,84,85
Mean #7 = Mean of years 84,85,86
Mean #8 = Mean of years 81,82,84,85
Mean #9 = Mean of years 82,84,85,86

Recall that the prior probabilities, q_{ni} , reflect the historical conditions and are required as an integral part of the entropy prediction model. Hence the longer period of time in the calibration step is also preferred for obtaining the best picture of historical conditions for incorporation in the prior probabilities.

The missing data evident in the calibration data sets listed in Tables 5.2 and 5.3 did limit the number of data points which could be used for the calibration of the 2-year 3-year and 4-year moving average models. The limited number of points available for calibration does in turn reduce the confidence that can be placed in the calibrated model. The problem cannot be avoided for the data used to demonstrate the model in this thesis and is likely to be an issue in the application of the model to other watersheds. Prediction of water quality values by the approach should therefore be performed with a clear understanding of any limitations on the accuracy of the model imposed by small calibration data sets.

5.2.2 DATA ANALYSIS

After the data have been divided into calibration and validation sets, the data set assigned to the calibration step is used to develop the probability

density function for each parameter at each location (monitoring station). It should be noted that the model can only be used for estimation of the values of one water quality parameter at a time. Thus, in order to predict the values for different water quality parameters, the procedure has to be repeated using the probability distributions and relationship function associated with that parameter. The number of calculations therefore increases linearly with the number of parameters to be predicted.

a. DETERMINING THE DISTRIBUTION

After the mean annual average values of the water quality parameters had been determined from the calibration data set, the probability distribution functions for those parameters at each monitoring station were developed. Normality tests using the Saphiro-Wilk W test (Gilbert, 1987) were then conducted to determine whether the data conform to a normal distribution. (The procedure of the Saphiro-Wilk W test is presented in Appendix C). Table 5.4 shows the calculations and results for the normality tests for the water quality parameters listed in Table 5.3.

It can be seen in Table 5.4 that most of the water quality parameters follow normal distributions, and are

Table 5.4 Normality Test for Data (SAPHIRO-WILK W TEST)

Table 5.4(a) Station 130401

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	237.8	7.48	173.8	140.8	73.5	70.00	21.73	1.20	15.05	8.73
x2	270.0	7.60	196.1	174.2	78.0	82.67	25.72	1.30	15.33	9.58
x3	311.0	7.60	204.3	176.0	86.4	83.00	27.00	1.6	18.78	9.67
x4	350.0	7.63	211.4	231.8	89.0	83.50	29.00	1.67	19.00	10.10
x5	351.3	7.84	265.9	249.5	102.8	99.4	37.00	1.68	22.8	10.25
x6	429.0	7.85	269.6	263.0	113.0	104.00	37.8	1.70	24.25	13.60
x7	457.5	7.85	301.0	303.0	129.0	106.50	41.50	2.00	26.00	15.50
x8	471.0	8.07	304.9	343.0	136.5	115.50	43.00	2.15	27.00	16.80
x9	550.0	8.10	359.4		157.7	126.33	49.33		34.00	17.67
x10	660.0	8.30	411.0		181.0	145.00	59.00		36.00	22.00
x	408.8	7.8	269.7	235.2	114.7	101.6	37.1	1.7	23.8	13.4

2. Computation of the Denominator (=d)

$$d = \sum (x_i - \bar{x})^2$$

	(xi-x) ^ 2									
	19251.56	0.04	5421.97	8912.54	1345.54	367.36	64.50	0.00	73.99	13.85
	3306.25	0.00	14.89	205.74	142.36	4.69	19.97	0.14	0.10	9.85
	29241.00	0.05	9208.13	3499.46	1695.93	1013.36	234.27	0.23	78.94	21.75
	3875.06	0.22	974.44	4602.77	476.04	186.78	0.00	0.00	9.40	11.64
	3451.56	0.07	3402.86	3715.66	659.55	336.11	100.62	0.00	24.35	10.82
	19951.56	0.06	8039.99	775.27	1847.71	600.25	151.35	0.22	101.31	18.30
	9555.06	0.00	4281.61	11630.27	799.85	354.69	127.94	0.11	26.57	14.51
	2376.56	0.00	1236.65	11.26	205.01	21.78	35.63	0.00	4.26	4.46
	63126.56	0.05	19956.08		4398.12	1863.36	482.64		145.57	74.15
	410.06	0.12	0.01		2.83	5.92	0.59		1.29	0.04
d =	154545.25	0.62	52536.62	33353.00	11572.95	4754.31	1217.51	0.70	465.77	179.37

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	ai{x(n-i+1)-x(i)}									
	242.33	0.47	136.14	122.40	61.69	43.04	21.39	0.57	12.02	7.62
	92.15	0.16	53.74	40.75	26.22	14.37	7.77	0.22	6.14	2.66
	34.26	0.10	21.54	15.16	10.73	6.96	3.43	0.02	1.76	1.53
	13.16	0.03	10.96	0.99	4.90	2.82	1.53	0.00	0.86	0.66
	3.10	0.00	0.15		0.41	0.18	0.03		0.06	0.13
sum	384.99	0.76	222.54	179.31	103.94	67.37	34.15	0.81	20.84	12.60
sum ^ 2	148220.00	0.58	49521.85	32152.47	10804.34	4538.74	1166.28	0.66	434.35	158.80

	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W= (sum ^ 2/d)	0.9591	0.9400	0.9426	0.9640	0.9336	0.9547	0.9579	0.9433	0.9325	0.8853
W [0.05]	0.842	0.842	0.842	0.818	0.842	0.842	0.842	0.818	0.842	0.842
W [0.02]	0.806	0.806	0.806	0.778	0.806	0.806	0.806	0.778	0.806	0.806
W [0.01]	0.781	0.781	0.781	0.749	0.781	0.781	0.781	0.749	0.781	0.781

Note : reject the normality at i% significance level if W < W [i]

Table 5.4(b) Station 130106

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	146.7	7.35	127.5	100.3	55.0	66.0	8.5	3.4	13.0	5
x2	160.0	7.37	135.8	100.5	61.7	71.8	10.3	3.5	14.4	5.4
x3	168.6	7.40	136.1	104.2	61.7	72.0	11.0	3.6	14.5	6.2
x4	192.2	7.43	151.0	117.3	65.7	75.7	11.5	3.7	15.5	6.2
x5	204.8	7.43	165.9	135.0	69.3	80.6	17.0	3.8	16.3	6.6
x6	230.0	7.60	167.1	151.4	78.6	82.0	18.0	4.0	17.5	6.9
x7	230.3	7.70	198.6	199.0	85.2	102.6	18.9	4.2	19.3	8.5
x8	240.6	7.76	199.3	257.0	91.0	110	19.0	4.9	24.0	9.0
x9	340.0	7.89	257.6		101.0	118	27.0		28.0	10
x10	410.0	8.00	347.2		162.0	175	30.0		35.0	18
$\bar{x}$	232.3	7.6	188.6	145.6	83.1	95.4	17.1	3.9	19.8	8.2

2. Computation of the Denominator (=d)

$$d = \sum (x_i - \bar{x})^2$$

	$(x_i - \bar{x})^2$									
	5.35	0.04	114.55	2048.18	62.26	214.21	0.77	0.95	67.93	10.04
	756.01	0.03	462.02	1713.14	20.21	218.25	0.03	0.22	5.10	0.08
	7335.45	0.03	2784.00	798.45	459.80	545.88	73.78	0.12	28.71	3.74
	4065.84	0.03	2760.66	12412.16	460.52	555.27	46.48	0.09	27.60	3.99
	1611.80	0.06	1413.53	33.22	304.26	178.60	37.49	0.01	18.13	2.62
	31572.35	0.17	25154.92	2033.12	6223.68	6341.88	97.56	0.15	232.31	96.67
	68.73	0.09	99.31	2852.62	4.23	52.12	3.29	0.01	0.17	0.64
	5229.30	0.01	3738.95	112.15	790.16	862.25	31.62	0.04	45.67	7.66
	11596.30	0.00	4761.42		320.06	512.38	165.82		17.99	3.36
	3.92	0.05	516.67		189.79	387.99	3.52		11.73	1.61
d =	62245.05	0.49	41806.04	22003.04	8834.97	9868.82	460.35	1.58	455.35	130.41

3. Computation of the W values

$$w = \frac{\sum a_i \{x(n-i+1) - x(i)\}^2}{d}$$

	$a_i \{x(n-i+1) - x(i)\}^2$									
	151.13	0.37	126.11	94.81	61.41	62.56	12.32	0.88	12.63	7.46
	59.24	0.17	40.07	31.17	12.95	15.20	5.49	0.23	4.48	1.51
	15.43	0.08	13.54	8.22	6.28	8.14	1.71	0.07	2.03	0.60
	4.67	0.03	5.82	0.99	2.39	3.29	0.91	0.01	0.47	0.27
	1.00	0.01	0.05		0.37	0.06	0.04		0.05	0.01
sum	231.47	0.66	185.60	135.19	83.39	89.25	20.48	1.18	19.65	9.86
sum ^ 2	53577.51	0.44	34447.23	18276.37	6954.68	7964.87	419.38	1.40	386.18	97.22

	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W = (sum ^ 2/d)	0.8608	0.8681	0.8240	0.8306	0.7872	0.8071	0.9110	0.8860	0.8481	0.7455
W [0.05]	0.842	0.842	0.842	0.818	0.842	0.842	0.842	0.818	0.842	0.842
W [0.02]	0.806	0.806	0.806	0.778	0.806	0.806	0.806	0.778	0.806	0.806
W [0.01]	0.781	0.781	0.781	0.749	0.781	0.781	0.781	0.749	0.781	0.781

Note : reject the normality at i% significance level if W < W [i]

not able to be rejected at the 5% significance level. Only the Dissolved Ions parameter from Station 130106, the Hardness parameter from Station 130106 require more prescriptive levels of significance, namely, 2% and 1% respectively, in order to be rejected, and the Magnesium parameter from station 130106 is the only parameter able to be rejected at the 1% significant level. All parameters including Magnesium at Station 130106 were therefore assumed to follow normal distributions.

The mean annual average values of the distributions at each station were calculated by :

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (5.2)$$

where :

x_i = annual 'average' water quality value in year i

$\bar{x}$ = mean value of x_i

n = number of data (number of years)

while the variance was calculated as :

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (5.3)$$

where :

s^2 = variance of x_i

Using the results of Equations 5.2 and 5.3 the historical probability distributions of each water quality parameter at each of the monitoring stations were defined. The range of the possible values of each water quality parameter at each of the monitoring stations, e.g., $\bar{x}-4s$ to $\bar{x}+4s$, was also defined using the values of $\bar{x}$ and s determined from Equations 5.2 and 5.3 respectively. (When the data are not normally distributed, a common transformation, such as log-normal transformation, may be applied).

b. DISCRETIZATION OF THE VARIABLES

The method proposed in this thesis uses a discrete form of the entropy principles such as described in Equation 4.13. When applying the principle to actual data, the range for the values of the variables must be discretized. The associated discrete values of the parameters for use in the entropy function is generated by discretizing the range, in this case, from $\bar{x}-4s$ to $\bar{x}+4s$, of the 'possible values' derived from the normal distribution developed from the records, into k intervals of the same width. The mid value of each interval is then taken as the input value, x_i , for the model. An important issue related to this process is how many intervals should be chosen in order to get the best results from the model. This issue is discussed in some

detail later in the thesis.

c. DEVELOPMENT OF THE 'INFORMATION FUNCTION'

A critical requirement for the application of the entropy approach is historical information which can be used to define the historical relationship among the data from the various stations. This relationship may be considered as information introduced into the model and as such may be called the 'information function' as expressed in Equation 4.18. A physically based model or approach which models the actual process of the water quality change while the water is transported from upstream tributary stations to the junction of the streams or to the downstream station itself would be ideal. However, unless the physical processes can be expressed in a few relatively simple expressions it cannot be applied in the optimisation framework upon which the entropy method is based. Furthermore, in order to model the physical processes properly it is generally necessary to have a more complete set of data than simply the water quality values and flow rates at relevant stations. For example, additional data on the cross-sectional characteristics of the channel, the level of turbulence etc. are likely to be needed. In this study, since the primary focus is on prediction of values rather than modelling the physical processes in

the system, a statistical model, in particular a linear regression approach, which expresses the relationship between the values at the downstream station and the mixed values of water quality from the upstream stations, is used for this information function. [The equation and processes for this function have been described in detail in the previous chapter (Equation 4.6).]

d. CASES

A number of cases involving the direct applications of the entropy model to the prediction of water quality values at discontinued monitoring stations, were examined :

CASE I :

Running the model as described by the formulation in Equations 4.15 - 4.21.

CASE II :

Running the model using non-normal distribution for those water quality parameters which had been identified as having non-normal distribution, e.g., Dissolved Ions, Hardness and Magnesium parameters from Station 130106.

CASE III :

Running the model with consideration of possible observed changes in the watershed that may have caused changes in water quality values.

CASE IV :

Running the model with consideration of the statistical or physical dependency that might exist between the data at the upstream stations.

5.3 RESULTS, DISCUSSION AND COMPUTATIONAL PROBLEMS

5.3.1 RESULTS AND DISCUSSION

In this section the results for each of the four cases described above are presented and discussed.

a. CASE I. Normally Distributed Approximation

In this case, the model assigns probabilities to mean water quality values at the discontinued monitoring stations for different periods of time averaging, varying from annual (i.e., 1 yearly) mean average values to four yearly averaged annual mean values. The results from the application of the entropy model for this case are summarised in Tables 5.5 to 5.7. The results obtained from using regression to predict water quality

Table 5.5 Results of Assignment of Water Quality Values in the MacKenzie River Sub-Basin

Table 5.5(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)				(Regression Method)			
	130401	130106	130401	130106	130401	130106	130401	130106	Average	Maximum	130401	130106	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	425.00	199.33	285.63	206.51	312.74	154.19	32.79	3.60			26.42	22.65		
	316.67	211.25	298.72	209.27	323.02	162.36	5.67	0.94			2.01	23.14		
	332.50	206.67	261.84	201.46	294.10	139.38	21.25	2.52			11.55	32.56		
	283.33	242.50	271.43	203.50	301.60	145.34	4.20	16.08			6.45	40.07		
	276.67	185.00	293.26	208.13	318.74	158.96	6.00	12.50	10.56	32.79	15.21	14.08	19.41	40.07
PH	8.0	7.8	7.9	7.6	7.9	7.6	1.88	2.23			1.55	2.98		
	8.1	7.9	7.9	7.6	7.9	7.7	2.50	2.98			3.04	1.94		
	8.0	7.7	7.8	7.6	7.9	7.4	3.13	1.26			1.69	4.00		
	7.5	7.5	7.8	7.6	7.9	7.5	4.40	2.01			4.98	0.79		
	7.8	6.4	8.0	7.7	7.9	8.0	3.08	20.16	4.36	20.16	1.29	24.64	4.69	24.64
Dissolved Ions (mg/l)	200.75	150.98	199.19	159.38	214.62	129.43	0.78	5.56			6.91	14.28		
	200.70	163.33	188.66	155.00	206.35	120.70	6.00	5.10			2.82	26.10		
	219.30	161.33	182.16	152.25	201.26	115.32	16.94	5.63			8.22	28.52		
	176.67	166.15	182.07	152.18	201.20	115.26	3.06	8.41			13.89	30.63		
	182.63	150.20	211.35	164.45	224.19	139.54	15.72	9.49	7.67	16.94	22.75	7.10	16.12	30.63
Dissolved Solids (mg/l)	218.50	114.83	149.07	115.91	163.29	88.73	31.78	0.94			25.27	22.73		
	173.33	122.50	162.58	120.62	174.27	98.30	6.20	1.53			0.54	19.76		
	185.00	123.33	138.06	111.99	154.31	80.90	25.37	9.20			16.59	34.41		
	156.67	140.00	150.30	116.34	164.29	89.60	4.06	16.90			4.87	36.00		
	150.00	110.00	158.40	119.17	170.94	95.40	5.60	8.34	10.99	31.78	13.96	13.27	18.74	36.00
Hardness (mg/l) as CaCO ₃	106.50	58.83	82.67	70.39	89.57	57.21	22.38	19.64			15.90	2.76		
	83.33	72.50	74.14	66.98	82.92	50.18	11.03	7.61			0.49	30.79		
	83.50	62.00	75.20	67.41	83.75	51.06	9.94	8.73			0.30	17.65		
	72.00	65.50	72.55	66.32	81.68	48.86	0.76	1.25			13.44	25.41		
	75.67	61.00	92.97	74.50	97.60	65.71	22.87	22.13	12.63	22.87	28.99	7.71	14.34	30.79
Alkalinity (mg/l) as CaCO ₃	50.00	79.83	92.89	85.97	94.45	82.94	85.78	7.69			88.90	3.89		
	76.00	87.00	73.65	65.10	79.47	53.87	3.09	25.17			4.57	38.08		
	83.00	76.33	82.27	74.45	86.18	66.89	0.88	2.47			3.83	12.37		
	64.67	67.50	77.66	69.45	82.59	59.93	20.09	2.89			27.72	11.22		
	72.00	80.00	95.84	89.14	96.74	87.38	33.11	11.43	19.26	85.78	34.36	9.22	23.42	88.90
Sodium (mg/l)	36.50	14.62	22.98	14.32	27.99	9.10	37.04	2.03			23.32	37.76		
	27.67	13.63	31.92	16.09	41.99	13.88	15.37	18.09			51.75	1.85		
	32.00	16.33	24.22	14.57	29.93	9.76	24.31	10.80			6.46	40.23		
	25.00	22.00	24.96	14.72	31.10	10.16	0.16	33.09			24.40	53.82		
	24.00	13.50	24.96	14.72	31.10	10.16	4.00	9.04	15.39	37.04	29.58	24.74	29.39	53.82
Potassium (mg/l)	1.30	3.85	1.60	3.83	1.61	3.82	23.08	0.52			23.67	0.82		
	1.33	3.83	1.48	3.70	1.58	3.53	11.00	3.27			18.79	7.64		
	1.65	3.70	1.66	3.90	1.62	3.96	0.61	5.41			1.84	7.06		
	1.93	3.00	1.66	3.90	1.62	3.98	14.14	30.00			16.14	32.72		
	2.17	3.40	1.66	3.90	1.62	3.96	23.38	14.71	12.61	30.00	25.25	16.51	15.04	32.72
Calcium (mg/l)	22.00	13.00	17.52	16.57	19.15	13.43	20.36	27.46			12.95	3.32		
	17.67	17.25	15.58	15.57	17.60	11.68	11.81	9.74			0.36	32.29		
	17.50	14.67	17.04	16.32	18.76	12.99	2.63	11.27			7.22	11.40		
	15.33	15.00	16.55	16.07	18.38	12.56	7.93	7.13			19.85	16.29		
	17.00	15.00	20.44	18.05	21.47	16.06	20.24	20.33	13.89	27.46	26.31	7.07	13.71	32.29
Magnesium (mg/l)	12.50	6.42	9.79	6.79	10.16	6.08	21.68	5.82			18.70	5.31		
	9.47	7.10	9.12	6.54	9.61	5.60	3.66	7.89			1.51	21.16		
	9.70	6.17	8.28	6.22	8.92	5.00	14.64	0.86			8.05	18.92		
	8.17	6.80	7.90	6.07	8.60	4.72	3.27	10.74			5.26	30.58		
	8.07	5.60	10.42	7.03	10.68	6.53	29.17	25.54	12.33	29.17	32.45	16.56	15.85	32.45

Table 5.5(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)					
	at Station		at Station		at Station		(Entropy Method)			(Regression Method)		
	130401	130106	130401	130106	130401	130106	at Station	Average	Maximum	at Station	Average	Maximum
(1)	(2)		(3)		(4)		(5)	(6)	(7)	(8)	(9)	(10)
Conductivity (mS/m)	370.83	205.29	306.10	210.82	336.97	151.50	17.46	2.69		9.13	26.20	
	324.58	206.96	295.67	208.62	329.77	143.13	8.91	0.16	6.72	1.60	31.50	20.50
	307.92	224.58	283.70	206.10	321.49	133.50	7.86	8.23		4.41	40.55	
	280.00	213.75	297.48	209.10	331.01	144.57	6.24	2.18		18.22	32.36	40.55
PH	8.07	7.83	7.8	8.2	7.9	7.7	3.55	4.61		1.89	2.23	
	8.07	7.77	7.8	8.2	8.0	7.6	3.55	5.39	5.73	1.42	2.65	3.43
	7.75	7.56	7.8	8.2	8.0	7.5	0.39	8.36		3.16	1.24	
	7.65	6.93	7.8	8.2	7.9	7.8	1.70	18.27		2.89	11.98	11.98
Dissolved Ions (mg/l)	200.73	157.15	208.22	163.15	229.30	122.93	3.73	3.82		14.24	21.78	
	210.00	162.33	201.70	160.44	225.24	115.41	3.95	1.16	4.59	7.26	28.91	20.69
	197.98	163.74	199.11	159.36	223.67	112.51	0.57	2.68		12.97	31.29	
	179.65	158.18	210.41	164.04	230.64	125.41	17.12	3.71		28.39	20.71	31.29
Dissolved Solids (mg/l)	195.92	118.67	173.57	124.40	195.68	82.21	11.41	4.83		0.12	30.73	
	179.17	122.92	169.30	122.93	193.21	77.28	5.51	0.01	5.82	7.84	37.13	24.40
	170.83	131.67	164.57	121.30	190.46	71.80	3.67	7.87		11.49	45.46	
	153.33	125.00	172.43	124.02	195.04	80.93	12.45	0.78		27.20	35.26	45.46
Hardness (mg/l) as CaCO ₃	94.92	65.67	87.18	72.20	96.62	54.24	8.15	9.95		1.80	17.41	
	83.42	67.25	84.44	71.10	94.90	51.15	1.23	5.72	10.33	13.77	23.93	17.68
	77.75	63.75	83.84	70.87	94.53	50.49	7.83	11.17		21.58	20.79	
	73.83	63.25	90.39	73.48	98.63	57.83	22.42	16.17		33.58	8.57	33.58
Alkalinity (mg/l) as CaCO ₃	63.00	83.42	86.80	79.38	92.58	68.40	37.78	4.84		46.95	18.00	
	79.50	81.67	82.86	75.13	90.71	60.18	4.23	8.00	14.75	14.10	26.31	22.31
	73.83	71.92	84.35	76.73	91.41	63.28	14.24	6.69		23.81	12.01	
	68.33	73.75	89.38	82.14	93.81	73.78	30.80	11.38		37.28	0.04	46.95
Sodium (mg/l)	32.08	14.12	28.22	15.36	30.78	10.47	12.04	8.78		4.07	25.86	
	29.83	14.98	28.74	15.46	31.15	10.89	3.66	3.21	10.24	4.40	27.30	23.66
	28.50	19.17	25.78	14.88	29.09	8.54	9.54	22.37		2.05	55.47	
	24.50	17.75	26.09	14.94	29.31	8.79	6.49	15.83		19.62	50.49	55.47
Potassium (mg/l)	1.32	3.84	1.61	3.85	1.64	3.69	22.28	0.33		24.86	3.91	
	1.49	3.76	1.59	3.82	1.63	3.75	6.59	1.53	12.06	9.05	0.40	14.28
	1.79	3.35	1.62	3.85	1.57	3.94	9.58	14.93		12.23	17.49	
	2.05	3.20	1.62	3.85	1.57	3.94	20.98	20.31		23.29	23.00	24.86
Calcium (mg/l)	19.83	15.13	18.11	16.87	20.26	12.76	8.69	11.54		2.15	15.65	
	17.58	15.96	17.93	16.77	20.14	12.54	1.97	5.09	11.42	14.55	21.40	15.63
	16.42	14.83	18.29	16.96	20.38	12.97	11.41	14.34		24.12	12.54	
	16.17	15.00	19.56	17.60	21.20	14.47	20.99	17.33		31.12	3.50	31.12
Magnesium (mg/l)	10.98	6.76	10.39	7.01	11.05	5.72	5.40	3.72		0.57	15.44	
	9.58	6.63	9.77	6.79	10.64	5.13	1.95	2.36	6.97	11.08	22.70	17.41
	8.93	6.48	9.29	6.60	10.32	4.65	3.99	1.80		15.50	28.29	
	8.12	6.20	10.14	6.92	10.89	5.48	24.83	11.61		34.14	11.56	34.14

Table 5.5(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
							(Entropy Method)				(Regression Method)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
130401	130106	130401	130106	130401	130106	130401	130106	130401			130106	130401		
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	358.10	205.80	306.70	210.90	336.92	152.69	14.35	2.48	4.33	14.35	5.91	25.81	18.86	32.07
	310.80	220.10	302.70	210.10	334.18	149.51	2.61	4.54			7.52	32.07		
	297.50	211.40	301.20	209.80	333.18	148.35	1.24	0.76			11.99	29.83		
PH	8.04	7.78	7.96	7.66	8.04	7.59	1.04	1.48	2.13	6.80	0.05	2.43	2.62	6.70
	7.88	7.66	7.95	7.66	8.04	7.57	0.93	0.04			2.12	1.17		
	7.77	7.17	7.96	7.66	8.02	7.65	2.50	6.80			3.21	6.70		
Dissolved Ions (mg/l)	206.90	158.50	208.00	163.00	226.10	128.15	0.53	2.84	3.10	8.61	9.28	19.15	16.90	24.47
	198.90	163.60	203.70	161.20	223.27	123.57	2.41	1.47			12.25	24.47		
	192.90	159.20	209.50	163.60	227.09	129.74	8.61	2.76			17.72	18.51		
Dissolved Solids (mg/l)	192.30	120.20	168.10	122.50	179.48	100.72	12.58	1.91	4.15	12.58	6.67	16.21	12.95	21.50
	171.70	128.60	168.40	122.60	179.70	100.96	1.92	4.67			4.66	21.50		
	163.90	124.40	167.40	122.30	178.89	100.09	2.14	1.69			9.14	19.54		
Hardness (mg/l)as CaCO3	91.10	64.40	88.90	72.90	96.92	57.39	2.41	13.20	11.22	17.90	6.39	10.89	14.58	27.42
	79.60	66.70	86.50	71.90	95.36	54.80	8.67	7.80			19.80	17.84		
	77.10	62.80	90.90	73.70	98.24	59.56	17.90	17.36			27.42	5.15		
Alkalinity (mg/l)as CaCO3	69.66	81.05	87.89	80.53	92.25	72.12	26.17	0.64	12.15	26.17	32.43	11.02	18.05	32.43
	74.55	76.94	84.25	76.61	90.26	65.01	13.01	0.43			21.08	15.51		
	73.22	74.61	89.55	82.34	93.16	75.36	22.30	10.36			27.23	1.01		
Sodium (mg/l)	32.05	14.85	27.08	15.14	29.63	10.25	15.51	1.95	8.42	15.51	7.57	30.97	22.66	46.78
	28.22	17.31	27.67	15.25	30.05	10.68	1.95	11.90			6.49	38.31		
	27.00	17.27	25.61	14.84	28.57	9.19	5.15	14.07			5.82	46.78		
Potassium (mg/l)	1.43	3.79	1.62	3.85	1.65	3.78	13.52	1.56	9.22	17.35	15.42	0.26	9.58	19.15
	1.64	3.51	1.65	3.89	1.66	3.84	0.73	10.89			1.27	9.59		
	1.92	3.37	1.70	3.95	1.69	4.01	11.27	17.35			11.81	19.15		
Calcium (mg/l)	19.05	14.97	18.75	17.19	20.41	13.96	1.57	14.83	12.10	18.62	7.12	6.75	12.29	26.73
	16.83	15.63	18.51	17.07	20.25	13.71	9.98	9.21			20.31	12.27		
	16.61	14.88	19.66	17.65	21.05	14.96	18.36	18.62			26.73	0.55		
Magnesium (mg/l)	10.55	6.56	10.36	7.01	11.09	5.58	1.80	6.84	8.51	18.00	5.08	14.90	16.96	27.13
	9.11	6.69	9.91	6.91	10.78	5.08	8.77	3.32			18.30	24.02		
	8.64	6.19	10.20	6.95	10.99	5.43	18.00	12.31			27.13	12.32		

Table 5.5(d) 4 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)				(Regression Method)			
	130401	130108	130401	130108	130401	130108	at Station 130401	130108	Average	Maximum	at Station 130401	130108	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	339.40	214.90	318.60	213.40	341.60	169.15	6.13	0.70	3.45	6.13	0.65	21.29	13.69	21.29
	302.30	211.40	320.10	213.70	342.67	170.24	5.89	1.09			13.36	19.47		
PH	7.91	7.69	7.97	7.66	8.00	7.57	0.78	0.43	1.79	4.40	1.15	1.56	2.10	4.54
	7.86	7.35	7.98	7.67	7.95	7.68	1.55	4.40			1.16	4.54		
Dissolved Ions (mg/l)	199.40	160.40	215.90	166.40	228.79	141.69	8.27	3.74	7.06	11.91	14.74	11.66	13.73	18.19
	194.80	160.30	218.00	167.20	230.23	143.75	11.91	4.30			18.19	10.32		
Dissolved Solids (mg/l)	183.40	125.20	171.00	123.50	181.09	104.08	6.76	1.36	3.05	6.76	1.26	16.87	10.69	16.87
	168.30	124.00	172.80	124.20	182.48	105.52	3.91	0.16			9.73	14.90		
Hardness (mg/l) as CaCO ₃	86.30	64.70	92.25	74.22	97.25	64.60	6.89	14.71	13.92	19.43	12.69	0.15	9.83	25.19
	78.60	65.30	93.87	74.87	98.40	66.14	19.43	14.66			25.19	1.28		
Alkalinity (mg/l)	68.41	77.66	89.60	82.44	92.36	77.16	30.98	6.16	16.45	30.98	35.00	0.65	15.35	35.00
	73.91	77.70	90.10	82.96	92.64	78.03	21.91	6.77			25.34	0.42		
Sodium (mg/l)	30.29	16.64	28.12	15.34	30.44	10.88	7.16	7.81	6.41	7.81	0.48	34.62	19.98	34.62
	27.16	16.36	28.50	15.42	30.71	11.17	4.93	5.75			13.06	31.75		
Potassium (mg/l)	1.55	3.59	1.64	3.88	1.66	3.83	5.53	7.99	8.01	11.75	6.85	6.69	7.61	11.22
	1.77	3.48	1.65	3.89	1.67	3.87	6.78	11.75			5.69	11.22		
Calcium (mg/l)	18.12	14.97	19.71	17.68	20.91	15.41	8.77	18.10	15.54	19.50	15.37	2.92	11.66	25.84
	16.87	15.47	20.16	17.91	21.23	15.86	19.50	15.77			25.84	2.52		
Magnesium (mg/l)	9.96	6.62	10.58	7.09	10.92	6.41	6.25	7.10	11.34	20.90	9.71	3.22	9.66	24.34
	8.85	6.42	10.70	7.13	11.00	6.50	20.90	11.13			24.34	1.38		

Table 5.6 Summary of Error Values for Entropy and Regression Methods

Table 5.6(a) 1 yearly

Water Quality Parameter	Absolute Values of Errors (%)																			
	MacKenzie River				Fitzroy River				Nogoa River				Logan River				Overall Rivers			
	Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum (Averaged)	Average	Maximum (Averaged)
Conductivity (mS/m)	10.56	32.79	19.41	40.07	21.57	50.71	19.32	50.96	24.78	47.52	25.07	60.09	34.87	118.50	34.70	133.36	22.94	62.38	24.83	71.10
PH	4.36	20.16	4.69	24.64	3.02	9.04	4.13	9.67	3.28	8.63	3.41	9.13	4.21	13.16	4.08	10.04	3.72	12.75	4.08	13.37
Dissolved Ions (mg/l)	7.67	18.94	16.12	30.63	16.15	58.86	14.21	58.67	23.40	51.55	23.70	55.53	32.51	112.97	33.93	137.20	19.93	60.08	21.99	70.51
Dissolved Solids (mg/l)	10.99	31.78	18.74	36.00	18.47	52.26	17.23	51.93	22.27	47.08	22.26	47.17	31.42	99.40	31.72	122.74	20.79	57.63	22.49	64.46
Hardness (mg/l) as CaCO ₃	12.83	22.87	14.34	30.79	18.53	55.80	16.68	55.81	33.28	68.70	33.31	76.50	34.83	112.67	38.22	146.14	24.82	65.28	25.13	77.31
Alkalinity (mg/l) as CaCO ₃	19.26	85.78	23.42	88.90	19.61	59.39	15.41	57.89	21.39	43.12	21.33	48.06	22.62	78.73	36.49	119.52	20.72	66.76	24.16	78.59
Sodium (mg/l)	15.39	37.04	29.39	53.82	27.01	59.10	25.06	58.95	28.84	64.66	28.84	64.40	38.26	123.73	36.64	132.12	27.38	71.13	29.98	77.32
Potassium (mg/l)	12.61	30.00	15.04	32.72	14.99	23.40	15.08	23.57	8.77	28.20	8.36	21.36	12.66	35.28	10.62	37.91	12.31	29.22	12.28	28.89
Calcium (mg/l)	13.89	27.48	13.71	32.26	16.12	46.08	14.54	48.11	31.59	81.20	31.88	102.83	43.74	134.84	27.20	102.20	26.34	72.89	21.63	71.31
Magnesium (mg/l)	12.33	29.17	15.85	32.45	22.33	65.27	19.91	65.27	40.68	72.31	39.53	80.47	39.67	143.68	45.98	170.58	28.50	77.61	30.32	87.19

Table 5.6(b) 2 yearly

Water Quality Parameter	Absolute Values of Errors (%)																			
	MacKenzie River				Fitzroy River				Nogoa River				Logan River				Overall Rivers			
	Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum (Averaged)	Average	Maximum (Averaged)
Conductivity (mS/m)	6.72	17.46	20.50	40.55	15.86	40.09	13.04	39.73	19.00	43.22	21.10	46.03	25.68	76.05	32.81	70.62	16.81	44.21	21.86	49.23
PH	5.73	18.27	3.43	11.98	2.57	5.10	3.87	5.61	5.35	8.59	3.28	7.73	8.17	21.93	8.08	16.51	5.45	13.47	4.67	10.46
Dissolved Ions (mg/l)	4.59	17.12	20.69	31.29	14.34	24.92	11.57	24.00	20.36	39.93	18.44	42.77	20.19	68.71	34.87	60.75	14.87	37.67	21.39	39.70
Dissolved Solids (mg/l)	5.82	12.45	24.40	45.46	15.31	37.28	17.99	36.01	20.72	31.82	19.03	35.84	21.45	69.02	32.12	58.25	15.83	37.64	23.38	43.89
Hardness (mg/l) as CaCO ₃	10.33	22.42	17.68	33.58	17.95	36.14	15.78	35.52	24.78	56.25	24.51	57.65	19.98	61.39	24.98	46.53	18.26	44.05	20.74	43.32
Alkalinity (mg/l) as CaCO ₃	14.75	37.78	22.31	46.95	18.76	33.77	13.12	32.16	16.74	35.95	16.28	37.20	9.07	17.85	25.06	67.37	14.83	31.34	19.19	45.92
Sodium (mg/l)	10.24	22.37	23.66	55.47	19.10	51.53	19.44	50.68	24.84	47.23	23.34	45.39	24.65	47.11	27.72	70.35	19.71	42.06	23.54	55.47
Potassium (mg/l)	12.06	22.28	14.28	24.86	11.47	24.91	12.01	24.86	5.83	16.73	6.01	10.60	12.80	25.00	9.25	24.72	10.54	22.23	10.39	21.26
Calcium (mg/l)	11.42	20.99	15.63	31.12	16.44	30.24	14.61	29.80	19.90	50.93	20.48	45.11	17.34	50.54	21.24	35.88	16.27	38.18	17.99	35.48
Magnesium (mg/l)	6.97	24.93	17.41	34.14	20.31	43.97	16.30	42.97	35.23	66.27	31.45	77.20	36.35	95.07	29.89	61.77	24.72	57.56	23.76	54.02

Table 5.6(c) 3 yearly

Water Quality Parameter	Absolute Values of Errors (%)																			
	MacKenzie River				Fitzroy River				Nogoa River				Logan River				Overall Rivers			
	Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum (Averaged)	Average	Maximum (Averaged)
Conductivity (mS/m)	4.33	14.35	18.86	32.07	14.75	20.82	9.66	19.08	11.60	31.20	11.68	40.09	25.27	66.69	42.78	74.11	13.99	33.27	20.74	41.34
PH	2.13	6.80	2.62	6.70	2.28	3.24	3.94	4.01	1.47	5.00	3.51	7.23	5.29	15.58	6.53	23.96	2.79	7.66	4.15	10.47
Dissolved Ions (mg/l)	3.10	8.61	16.90	24.47	12.52	17.23	9.30	14.75	21.70	42.07	13.21	39.18	14.96	34.99	30.63	64.59	13.07	25.73	17.51	35.75
Dissolved Solids (mg/l)	4.15	12.58	12.95	21.50	12.51	23.11	17.34	19.61	13.72	21.39	11.71	32.40	18.56	48.08	32.67	62.47	12.23	26.29	18.67	33.99
Hardness (mg/l) as CaCO ₃	11.22	17.90	14.58	27.42	18.84	27.98	14.14	25.46	22.13	53.33	32.40	64.63	12.22	35.54	17.50	33.33	16.10	33.69	19.65	37.71
Alkalinity (mg/l) as CaCO ₃	12.15	26.17	18.05	32.43	17.29	23.46	10.57	20.49	20.80	45.21	15.70	35.42	11.31	24.67	21.27	37.17	15.39	29.88	16.40	31.38
Sodium (mg/l)	8.42	15.51	22.66	46.78	16.66	29.04	17.81	25.76	19.38	28.15	13.93	28.39	24.63	57.51	38.21	80.25	17.27	32.55	23.15	45.30
Potassium (mg/l)	9.22	17.35	9.58	19.15	11.60	12.95	11.89	12.59	7.20	13.96	6.36	11.90	18.54	42.86	22.05	35.76	11.64	21.78	12.47	19.85
Calcium (mg/l)	12.10	18.62	12.29	26.73	17.08	24.62	13.81	23.50	16.67	45.74	21.58	49.90	13.58	36.11	18.58	39.41	14.86	31.27	16.56	34.89
Magnesium (mg/l)	8.51	18.00	16.96	27.13	18.95	27.59	13.90	27.54	28.86	67.36	24.56	90.27	14.61	42.66	22.45	35.40	17.73	38.90	19.47	45.08

Table 5.6(d) 4 yearly

Water Quality Parameter	Absolute Values of Errors (%)															
	MacKenzie River				Nogoa River				Logan River				Overall Rivers			
	Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum (Averaged)	Average	Maximum (Averaged)
Conductivity (mS/m)	3.45	6.13	13.69	21.29	4.73	10.29	5.45	11.91	11.36	37.63	17.14	34.92	6.51	18.02	12.09	22.71
PH	1.79	4.40	2.10	4.54	0.81	1.48	3.09	3.59	3.85	9.09	5.26	16.91	2.15	4.99	3.48	8.35
Dissolved Ions (mg/l)	7.06	11.91	13.73	18.19	16.29	27.98	6.58	11.23	8.97	25.16	16.95	38.60	10.77	21.68	12.42	22.67
Dissolved Solids (mg/l)	3.05	6.76	10.69	16.87	6.97	12.32	5.99	10.07	10.54	30.91	16.09	34.58	6.85	16.66	10.92	20.51
Hardness (mg/l) as CaCO ₃	13.91	17.43	9.83	25.19	15.68	25.53	16.01	33.71	10.40	30.53	14.96	27.60	13.33	24.50	13.60	28.84
Alkalinity (mg/l) as CaCO ₃	16.45	30.98	15.35	35.00	4.85	8.51	8.44	13.89	13.77	25.28	23.87	39.89	11.69	21.59	15.89	29.59
Sodium (mg/l)	6.41	7.81	19.98	34.62	10.27	21.41	9.19	15.93	12.44	35.77	15.76	36.69	9.71	21.66	14.98	29.08
Potassium (mg/l)	8.01	11.75	7.61	11.22	8.20	16.17	8.13	14.02	9.60	15.38	12.38	16.77	8.94	14.43	9.37	14.00
Calcium (mg/l)	15.54	19.50	11.66	25.84	13.46	25.03	14.61	27.90	9.40	24.02	14.23	35.10	12.80	22.85	13.50	29.61
Magnesium (mg/l)	11.34	20.90	9.66	24.34	23.38	37.33	18.70	42.07	11.70	34.00	17.06	27.59	15.47	30.75	15.14	31.33

Table 5.7 Summary of the Absolute Errors of the Predicted Values

Water Quality Parameter	Absolute Values of Errors (%)																			
	1 Yearly				2 Yearly				3 Yearly				4 Yearly				Overall Average			
	Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method		Entropy Method		Regression Method	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Conductivity (mS/m)	22.94	62.38	24.63	71.10	16.81	44.21	21.86	49.23	13.99	33.27	20.74	41.34	6.51	18.02	12.09	22.71	15.07	39.47	19.83	46.09
PH	3.72	12.75	4.08	13.37	5.45	13.47	4.67	10.46	2.79	7.66	4.15	10.47	2.15	4.99	3.48	8.35	3.53	9.72	4.09	10.66
Dissolved Ions (mg/l)	19.93	60.08	21.99	70.51	14.87	37.67	21.39	39.70	13.07	25.73	17.51	35.75	10.77	21.68	12.42	22.67	14.66	36.29	18.33	42.16
Dissolved Solids (mg/l)	20.79	57.63	22.49	64.46	15.83	37.64	23.38	43.89	12.23	26.29	18.67	33.99	6.85	16.66	10.92	20.51	13.92	34.56	18.87	40.71
Hardness (mg/l) as CaCO3	24.82	65.26	25.13	77.31	18.26	44.05	20.74	43.32	16.10	33.69	19.65	37.71	13.33	24.50	13.60	28.84	18.13	41.87	19.78	46.79
Alkalinity (mg/l) as CaCO3	20.72	66.76	24.16	78.59	14.83	31.34	19.19	45.92	15.39	29.88	16.40	31.38	11.69	21.59	15.89	29.59	15.66	37.39	18.91	46.37
Sodium (mg/l)	27.38	71.13	29.98	77.32	19.71	42.06	23.54	55.47	17.27	32.55	23.15	45.30	9.71	21.66	14.98	29.08	18.52	41.85	22.91	51.79
Potassium (mg/l)	12.31	29.22	12.28	26.89	10.54	22.23	10.39	21.26	11.64	21.78	12.47	19.85	8.94	14.43	9.37	14.00	10.86	21.92	11.13	21.00
Calcium (mg/l)	26.34	72.89	21.83	71.31	16.27	38.18	17.99	35.48	14.86	31.27	16.56	34.89	12.80	22.85	13.50	29.61	17.57	41.30	17.47	42.82
Magnesium (mg/l)	28.50	77.61	30.32	87.19	24.72	57.56	23.78	54.02	17.73	38.90	19.47	45.08	15.47	30.75	15.14	31.33	21.61	51.20	22.17	54.41
Overall Average																	14.95	35.56	17.35	40.28

values are also shown in these tables. The regression coefficients used in the calculations for the various cases are shown in Table 5.8 and Tables A.5.1 to A.5.3 in the Appendix A. [All the data used for this case are assumed to be normally distributed. As noted previously, only a few parameters are not normally distributed at a 5% rejection level, and can, with the exception of Magnesium at Station 130106, be accepted as normally distributed at the 1% rejection level].

It can be seen from Tables 5.5(a) to 5.5(d) that, for most of the water quality parameters at MacKenzie River, the entropy method predicts the water quality values at discontinued monitoring stations, more accurately, than the regression method using the same data. (Results for other sets of data at different rivers are presented in Tables A 4.1 to A 4.3 in Appendix A).

Tables 5.6(a) to 5.6(d) summarise the results of predicting the values of water quality parameters at discontinued monitoring stations, for each of the four sets of data at the different locations. In particular these tables show the average and maximum errors of the predictions of the entropy or regression methods. The absolute errors in these tables were calculated using the following expression: **Error** = $(XP - XO) / XO$, where XP =

Table 5.8 Regression Coefficients for Various Periods of Time in the MacKenzie River Sub-Basin

Table 5.8(a) Between the Downstream Station 130105 and the Upstream Station 130401

Upstream Value = Bo + Bi * (Downstream Value)

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity (mS/m)	Bo	100.20	168.70	184.12	197.36
	Bi	0.86	0.66	0.62	0.60
	Correlation	0.83	0.80	0.85	0.97
	Coefficient				
PH	Bo	7.49	10.57	10.27	11.07
	Bi	0.05	-0.34	-0.30	-0.40
	Correlation	0.04	0.32	0.32	0.32
	Coefficient				
Dissolved Ions (mg/l)	Bo	64.07	140.10	134.35	142.94
	Bi	0.85	0.52	0.55	0.52
	Correlation	0.81	0.83	0.83	0.99
	Coefficient				
Dissolved Solids (mg/l)	Bo	24.57	116.30	77.80	78.78
	Bi	1.00	0.55	0.73	0.73
	Correlation	0.84	0.81	0.91	0.99
	Coefficient				
Hardness (mg/l) as CaCO ₃	Bo	30.57	63.66	64.77	66.04
	Bi	0.83	0.49	0.49	0.48
	Correlation	0.84	0.79	0.78	0.95
	Coefficient				
Alkalinity (mg/l) as CaCO ₃	Bo	41.41	71.92	69.46	70.51
	Bi	0.62	0.28	0.31	0.31
	Correlation	0.71	0.68	0.67	0.93
	Coefficient				
Sodium (mg/l)	Bo	10.93	17.52	16.03	19.00
	Bi	0.82	0.59	0.64	0.54
	Correlation	0.81	0.88	0.90	0.99
	Coefficient				
Potassium (mg/l)	Bo	1.56	1.76	1.52	1.50
	Bi	0.02	-0.04	0.04	0.05
	Correlation	0.12	0.25	0.25	0.47
	Coefficient				
Calcium (mg/l)	Bo	7.54	13.68	13.61	14.82
	Bi	0.77	0.47	0.48	0.43
	Correlation	0.82	0.83	0.80	0.97
	Coefficient				
Magnesium (mg/l)	Bo	2.70	6.41	7.05	6.90
	Bi	0.92	0.59	0.54	0.56
	Correlation	0.86	0.73	0.77	0.94
	Coefficient				

**Table 5.8(b) Between the Downstream Station 130105
and the Upstream Station 130106**

Upstream Value = Bo + Bi * (Downstream Value)

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity (mS/m)	Bo	-14.70	-44.00	-24.28	23.02
	Bi	0.68	0.77	0.72	0.60
	Correlation Coefficient	0.79	0.79	0.85	0.95
PH	Bo	1.00	1.41	1.46	0.98
	Bi	0.85	0.80	0.80	0.86
	Correlation Coefficient	0.83	0.82	0.92	0.90
Dissolved Ions (mg/l)	Bo	-29.60	-41.90	-20.00	19.12
	Bi	0.90	0.96	0.88	0.74
	Correlation Coefficient	0.73	0.71	0.79	0.92
Dissolved Solid (mg/l)	Bo	-32.20	-76.00	-33.03	-2.49
	Bi	0.87	1.09	0.90	0.76
	Correlation Coefficient	0.76	0.74	0.83	0.94
Hardness (mg/l) as CaCO ₃	Bo	-5.20	-4.76	4.12	23.11
	Bi	0.88	0.88	0.81	0.64
	Correlation Coefficient	0.73	0.69	0.77	0.90
Alkalinity (mg/l) as CaCO ₃	Bo	-20.00	-22.10	-9.39	10.20
	Bi	1.21	1.24	1.12	0.94
	Correlation Coefficient	0.72	0.71	0.78	0.89
Natrium (mg/l)	Bo	-0.46	-4.66	-3.43	-1.21
	Bi	0.53	0.67	0.64	0.57
	Correlation Coefficient	0.82	0.85	0.91	0.98
Kalium (mg/l)	Bo	3.19	3.28	3.10	3.15
	Bi	0.20	0.17	0.24	0.22
	Correlation Coefficient	0.86	0.86	0.91	0.97
Calcium (mg/l)	Bo	0.29	0.75	3.37	6.88
	Bi	0.88	0.86	0.75	0.60
	Correlation Coefficient	0.78	0.73	0.79	0.90
Magnesium (mg/l)	Bo	-0.38	-1.07	-1.01	1.46
	Bi	0.80	0.87	0.89	0.69
	Correlation Coefficient	0.65	0.57	0.71	0.88

values predicted by the entropy method and regression method as appropriate, and XO = observed value.

It can be seen that, in general, the entropy method is 1) a more accurate predictor than the regression method for most of the water quality parameters at the MacKenzie and Logan River; 2) about the same for the Nogoia River, and 3) a little worse for the Fitzroy River. However, the average of over all the rivers, shows that the entropy method is better, overall, than the regression method. It should be recalled that this comparison is very valid in that both the entropy method and regression use the same set of input for their development/calibration and are compared on the basis of the same set of verification data.

It is also important to note that, in general, the maximum errors produced by the entropy method are significantly smaller than the maximum errors produced by the regression technique. Furthermore, as shown in Tables 5.6(a) to 5.6(d), there is also a general tendency that when the entropy method performs better (in term of the value of the average error), the values of those average errors are significantly smaller than the average errors for the regression technique. On the other hand, when the reverse happens, the average errors from the regression technique are generally only

slightly smaller than the error obtained by the entropy method. As might be expected from regression theory, the average and maximum errors in the predictions generally decrease as the value of the correlation coefficient increases.

It can also be seen in Tables 5.5(a) to 5.5(d), that the predicted values for a number of water quality parameters, namely, Conductivity, PH, Dissolved Ions, Dissolved Solids, Sodium and Potassium, tend to have smaller average errors than other water quality parameters. It is suspected that the normality of the distribution of the historical data plays an important role for this case, since these are the parameters which conform most closely to the normal distribution, such as indicated by relatively high W values compared to the W_{cr} values in the Saphiro-Wilk test for the data sets from both upstream stations.

It is also interesting to note that, in general, the errors tend to be smaller for larger periods of time averaging. This fact is not surprising, since the entropy concept is based on a statistical theory developed on the basis of a large number of experiments, and the prediction of the 'new' mean values is conducted by assigning the most likely 'new' probability distribution. Therefore, prediction of a 'new' mean

defined in terms of a longer period of time, i.e., from more data points might be expected to be more accurate.

The percentage errors from running the proposed model for CASE I, using observed data from four sets of stations from Queensland described in Section 5.1 for the selected water quality parameters and for various time averaging intervals are summarised in Table 5.7. Figures 5.2(a) to 5.2(d) are examples of graphical representation of the accuracy of the water quality values observed and assigned by the entropy and regression methods. (Graphs of the similar plots for other water quality parameters are presented in Figures B.3 Appendix B.)

These results indicate that, in general, the entropy model performs better (predicts the values more closely more often) than the classical regression method in predicting values at the discontinued monitoring stations. The total average absolute error of the prediction using the proposed model (with normal approximation) over all the four data sets from different rivers, and for various time averaging is found to be 14.95 % while the same error using the regression method is 17.35 %.

Furthermore, unlike the 'classical' linear

Figure 5.2(a) Plot of Water Quality Values in the MacKenzie River (1 yearly)

Figure 5.2(b) Plot of Water Quality Values in the MacKenzie River (2 yearly)

Figure 5.2(c) Plot of Water Quality Values in the MacKenzie River (3 yearly)

Figure 5.2(d) Plot of Water Quality Values in the MacKenzie River (4 yearly)

regression technique, the proposed method is able to consider explicitly the probability distribution of the water quality at the discontinued monitoring stations, prior to the closure of the stations, as a reference, while also including the relationship among the upstream and the downstream stations. The capability of the model to include this information may be one reason the results are better than those obtained from the 'classical' linear regression approach.

b. CASE II. Non-normal Distribution

Non-normality of the data is the issue of concern for this case. If the data are not normal the model can be run with exactly the same formulation, but with an appropriate probability distribution applied through the prior distribution (q_{ni}). In this case the log-normal transformation was used for those data that did not conform to the normal distribution at the 5% less significance level in the Saphiro-Wilk test. (The results of the tests for normality presented in Table 5.4 and Tables C.3.1 to C.3.3 in Appendix C, show that a number of water quality parameters from the observed data fall within this category.) There are three parameters from the data set from the MacKenzie River, i.e., Dissolved Ions, Hardness and Magnesium at Station 130106; three parameters from the data set from the

Fitzroy River, i.e., Conductivity, Dissolved Ions and Dissolved Solids at Station 130105; four parameters from the data set from the Nogoia River, i.e., Conductivity, Dissolved Ions, Dissolved Solids and Hardness; and five parameters from the data set from the Logan River, i.e., Conductivity, PH, Dissolved Ions, Dissolved Solids and Alkalinity at Station 145010. It should be noted that these data did conform to the normal distribution at the 5% significance level in the Saphiro-Wilk test following their logarithmic transformation.

Comparisons of the results for the data at the MacKenzie river with the normal approximation and the log-normally transformed prior probability are presented in Table 5.9. Results for the sets of transformed data from the other locations are presented in Appendix B, Tables B.1.1 to B.1.3.

Surprisingly, the results presented in these tables show that, even when the log-normal model is a better model of the distribution, use of the log-normal distribution in the prior distribution does not always improve the accuracy of the prediction relative to the results using normal approximation. In some cases the predictions are more accurate while in other cases they are less accurate. It can be seen in Table 5.9 that in the MacKenzie River, use of the log-normal distribution

Table 5.9 Comparison of the Use of Normal and Log-normal Approach in the MacKenzie River

Table 5.9(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
	130401	130106	130401	130106	130401	130106	130401	130106			130401	130106		
Dissolved Ions (mg/l)	200.8	151.0	199.2	159.4	194.8	167.9	0.8	5.6			3.0	11.2		
	200.7	163.3	188.7	155.0	183.3	165.3	6.0	5.1			8.7	1.2		
	219.3	161.3	182.2	152.3	176.2	163.7	16.9	5.6	7.7	16.9	19.6	1.4	7.5	19.6
	176.7	166.2	182.1	152.2	176.1	163.7	3.1	8.4			0.3	1.5		
	182.6	150.2	211.4	164.5	207.9	171.1	15.7	9.5			13.8	13.9		
Hardness (mg/l)as CaCO3	106.5	58.8	82.7	70.4	80.5	74.6	22.4	19.6			24.4	26.7		
	83.3	72.5	74.1	67.0	71.2	72.6	11.0	7.6			14.6	0.2		
	83.5	62.0	75.2	67.4	72.4	72.9	9.9	8.7	12.6	22.9	13.3	17.5	15.8	26.7
	72.0	65.5	72.6	66.3	69.5	72.3	0.8	1.3			3.5	10.3		
	75.7	61.0	93.0	74.5	91.6	77.1	22.9	22.1			21.1	26.3		
Magnesium (mg/l)	12.5	6.4	9.8	6.8	9.5	7.3	21.7	5.8			23.7	13.6		
	9.5	7.1	9.1	6.5	8.8	7.2	3.7	7.9			7.0	0.7		
	9.7	6.2	8.3	6.2	7.9	7.0	14.6	0.9	12.3	29.2	18.8	13.5	14.7	32.5
	8.2	6.8	7.9	6.1	7.5	6.9	3.3	10.7			8.8	1.8		
	8.1	5.6	10.4	7.0	10.2	7.4	29.2	25.5			26.7	32.5		

Table 5.9(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station 130401 130106		at Station 130401 130106		at Station 130401 130106		at Station 130401 130106		Average	Maximum	at Station 130401 130106		Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Dissolved Ions (mg/l)	200.7	157.2	208.2	163.2	204.5	170.2	3.7	3.8	4.6	17.1	1.9	8.3	5.9	15.2
	210.0	162.3	201.7	160.4	197.5	168.6	4.0	1.2			6.0	3.8		
	198.0	163.7	199.1	159.4	194.7	167.9	0.6	2.7			1.7	2.5		
	179.7	158.2	210.4	164.0	206.9	170.8	17.1	3.7			16.2	6.0		
Hardness (mg/l)as CaCO3	94.9	65.7	87.2	72.2	85.4	75.6	8.2	9.9	10.3	22.4	10.0	15.2	12.7	20.8
	83.4	67.3	84.4	71.1	82.4	75.0	1.2	5.7			1.2	11.5		
	77.8	63.8	83.8	70.9	81.8	74.8	7.8	11.2			5.2	17.4		
	73.8	63.3	90.4	73.5	88.9	76.4	22.4	16.2			20.4	20.8		
Magnesium (mg/l)	11.0	6.8	10.4	7.0	10.2	7.4	5.4	3.7	7.0	24.9	7.5	9.5	9.9	22.0
	9.6	6.6	9.8	6.8	9.5	7.3	1.9	2.4			0.8	9.7		
	8.9	6.5	9.3	6.6	9.0	7.2	4.0	1.8			0.6	10.9		
	8.1	6.2	10.1	6.9	9.9	7.4	24.9	11.6			22.0	18.5		

Table 5.9(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
	130401	130106	130401	130106	130401	130106	130401	130106			130401	130106		
Dissolved Ions (mg/l)	206.9	158.5	208.0	163.0	204.2	170.2	0.5	2.8	3.1	8.6	1.3	7.4	4.5	7.6
	198.9	163.6	203.7	161.2	199.5	169.0	2.4	1.5			3.6	6.6		
	192.9	159.2	209.5	163.6	205.8	170.5	8.6	2.8			0.5	7.6		
Hardness (mg/l) as CaCO ₃	91.1	64.4	88.9	72.9	87.2	76.0	2.4	13.2	11.2	17.9	4.2	18.1	13.3	21.9
	79.6	68.7	86.5	71.9	84.7	75.5	8.7	7.8			6.3	13.1		
	77.1	62.8	90.9	73.7	89.4	76.5	17.9	17.4			16.0	21.9		
Magnesium (mg/l)	10.6	6.6	10.4	7.0	10.1	7.4	1.8	6.8	8.5	18.0	3.9	12.8	11.0	19.1
	9.1	6.7	9.9	6.9	9.6	7.3	8.8	3.3			5.6	9.2		
	8.6	6.2	10.2	7.0	10.0	7.4	18.0	12.3			15.6	19.1		

Table 5.9(d) 4 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
	130401	130106	130401	130106	130401	130106	130401	130106			130401	130106		
Dissolved Ions (mg/l)	199.4	160.4	215.9	166.4	212.9	172.3	8.3	3.7	7.1	11.9	2.9	8.7	6.2	9.1
	194.8	160.3	218.0	167.2	215.1	172.9	11.9	4.3			4.0	9.1		
Hardness (mg/l) as CaCO ₃	86.3	64.7	93.9	74.2	90.9	76.9	8.8	14.7	13.9	17.4	5.3	18.8	15.1	18.8
	78.6	65.3	92.3	74.9	92.6	77.3	17.4	14.7			17.8	18.3		
Magnesium (mg/l)	10.0	6.6	10.6	7.1	10.4	7.5	6.2	7.1	11.3	20.9	4.3	12.5	13.0	18.6
	8.9	6.4	10.7	7.1	10.5	7.5	20.9	11.1			18.6	16.4		

in the prior distribution gives more accurate predictions only for Dissolved Ions and even then only for the 1 and 4 yearly time averaged cases. Better values of predictions for the log-normal data are also achieved for Dissolved Ions in the Nogoia River for the 3 and 4 yearly time averaged cases; Conductivity in the Logan River for the 3 and 4 yearly time averaged cases; Dissolved Ions in the Logan River for the 2, 3 and 4 yearly time averaged cases; Dissolved Solids in the Logan River for the 3 and 4 yearly time averaged cases; and Alkalinity in the Logan River for the 2 and 3 yearly time averaged cases [See Appendix B, Tables B.1.1 to B.1.3].

Furthermore, the results do not reveal any general pattern as to when better predictions can be achieved by using the log-normal distribution for the prior probability values. It should also be recalled in assessing these results that the data were originally quite close to normal distribution and that the number of points in the data sets is relatively limited. For these two reasons, the evaluation of the merits of using either the log-normal and normal approximations in the prior distributions, as performed in this study, may not be sufficient to draw any general conclusions with respect to the advantages or disadvantages that may arise from using probability distributions other than

normal in the prior probability distribution even when the other distribution may in fact be a better representation of the probability distribution of the parameter of interest.

c. CASE III. Consideration of observed changes in the watershed that are, or may be, the cause of observed changes in water quality levels

The issue for this case relates to changes in the measured water quality values at the downstream station that have occurred since the upstream stations were discontinued and that can be attributed, completely or in part, to observed or known changes in the upstream region of the basin particularly in those sections of the watershed above the discontinued upstream monitoring stations. This knowledge about changes in the system is addressed by modifying the prior probability, as specified in the objective function of the model through q_{ni} . The modification itself involves the replacement of the 'original' q_{ni} values, which were initially established on the basis of observed historical data, with 'new' values which best reflect the current known changed conditions. The actual process of modification of the q_{ni} values is generally performed by 'shifting' the prior probability distribution values at a particular monitoring station towards the values which

best reflect the effects of observed or known changes in that portion of the watershed. It should be recognised that while change of the q_{ni} values in this manner provides the basis for incorporating knowledge about the situation, it also causes the solution to become more biased.

The impact of this process of incorporating knowledge about locations of the causes of observed changes in water quality on the accuracy of the predictions can be demonstrated by applying the formulation with the modified q_{ni} values to a range of water quality parameters in the river systems examined for CASE I. However, detailed information on conditions in these watersheds which might provide specific guidance as to the quantitative extent of changes in water quality caused by modifications in land use and land management practice, etc. was not available. Furthermore the detailed analysis necessary to generate this information lies beyond the scope of this study. In view of these limitations, in order to demonstrate how knowledge of changes in upstream conditions can be addressed using the approach, the mean values of the prior distribution of the water quality parameters at a particular station, were reduced by an arbitrary selected amount, e.g., the water quality parameters at Station 130106 from the MacKenzie River Sub-Basin data

set were reduced by 10 units.

The magnitude of the change in the q_{ni} values in this demonstration example, namely, a change in the mean of 10 units with an associated equal change in the values of water quality associated with the probability levels across the complete distribution from $\mu-4\sigma$ to $\mu+4\sigma$, is relatively 'small' compared to the historical values. Furthermore, the selection of the value of 10 units was made without reference to the magnitude of the differences in the historical record for the upstream stations, as summarised in Tables 5.3(a) and 5.3(b), between the water quality values contained in the calibration data set (the period 1971 to 1980) used to define the distributions and the water quality values contained in the validation data set (the period 1981 to 1986) used to assess the performance of the formulation. The only reference point involved in the choice of the variation to impose on the q_{ni} values was the knowledge that the values of the various water quality parameters had decreased at the downstream station and were therefore likely to have decreased at one or both of the upstream stations. (It should be noted that improvements in water quality arising from enhanced effluent treatment practices or improved land use practices can be accommodated equally easily within the approach by simply increasing, rather than reducing, the water

quality values by an amount reflecting the effects of those changes.)

The model was then run under the same conditions as for CASE I. The results for this case are presented in Table 5.10 for the MacKenzie River data set, and in Appendix B, Tables B.2.1 to B.2.3 for the data sets from the other river systems.

It can be seen from Table 5.10, that for the MacKenzie River data set, and for the one, two, three yearly time averaged scenarios, the average error of prediction for most of the parameters, with the exception of Hardness actually increased in comparison to CASE I. In the case of the four yearly time averaged data, the average error of prediction decreased for the Dissolved Ions and Hardness. The consistent decrease in error for the Hardness parameter for all time averaging periods indicates that 'shifting' the prior probability for Hardness at Station 130106 appears to have the capacity to improve the accuracy of the prediction for that particular parameter.

Results obtained by testing the case with the data sets from the other river systems, such as presented in Tables B.2.1 to B.2.3, however, do not show any significant improvements, except for Dissolved Ions in

**Table 5.10 Comparison of the Results Obtained by Using Knowledge about Changes in the Watershed
(Incorporated by changing the Prior Probability Distribution at One Upstream Station [Station 130106])
with those Obtained Ignoring that Knowledge [MacKenzie River]**

Table 5.10(a) 1 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (Shifted Distribution)		% Error of Prediction				% Error of Prediction (Average)	
									(Original Distribution)		(Shifted Distribution)		Original Distribution	Shifted Distribution
	Station 130401	Station 130106	(Original)	(Shifted)	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	425.0	199.3	408.8	222.2	285.8	208.5	290.3	197.5	32.8	3.8	31.7	0.9	10.8	10.8
	318.8	211.3			298.7	209.3	303.4	200.3	5.6	1.0	4.2	5.2		
	332.5	206.7			261.8	201.5	266.5	192.5	21.3	2.5	19.8	6.9		
	283.3	242.5			271.4	203.5	278.1	194.5	4.2	16.1	2.5	19.8		
	276.6	185.0			293.3	208.1	298.0	199.1	6.0	12.5	7.7	7.6		
Dissolved Ions (mg/l)	200.7	151.0	269.7	178.6	199.2	159.4	203.5	151.2	0.8	5.5	1.4	0.1	7.7	8.2
	200.7	163.3			188.7	155.0	192.9	148.8	6.0	5.1	3.9	10.1		
	219.3	181.3			182.2	152.3	186.4	144.1	16.9	5.6	15.0	10.7		
	176.6	166.2			182.1	152.2	186.3	144.0	3.1	8.4	5.5	13.3		
	182.8	150.2			211.4	164.5	215.6	166.2	15.7	9.5	18.1	4.0		
Dissolved Solids (mg/l)	218.5	114.8	235.2	135.6	149.1	115.9	153.5	107.5	31.8	1.0	29.8	6.4	11.0	12.1
	173.3	122.5			162.6	120.6	167.0	112.1	6.2	1.5	3.6	8.5		
	185.0	123.3			138.1	112.0	142.4	103.8	26.4	9.2	23.0	16.0		
	158.6	140.0			150.3	118.3	154.7	107.9	4.0	16.9	1.2	22.9		
	150.0	110.0			158.4	119.2	162.8	110.7	5.8	8.3	8.5	0.8		
Hardness (mg/l) as CaCO ₃	108.5	58.8	114.7	73.1	82.7	70.4	87.0	62.1	22.4	19.7	18.3	5.6	12.6	11.3
	83.3	72.5			74.1	67.0	78.4	58.7	11.0	7.6	5.9	19.0		
	83.5	62.0			75.2	67.4	79.5	59.1	9.9	8.7	4.8	4.6		
	72.0	65.5			72.6	66.3	76.8	58.1	0.8	1.3	6.7	11.3		
	75.7	61.0			93.0	74.5	97.3	66.2	22.9	22.1	28.6	8.5		

Table 5.10(b) 2 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (Shifted Distribution)		% Error of Prediction				% Error of Prediction (Average)	
									(Original Distribution)		(Shifted Distribution)		Original Distribution	Shifted Distribution
	Station 130401	Station 130106	(Original)	(Shifted)	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	370.8	205.2	408.8	222.2	306.1	210.8	310.8	201.8	17.4	2.7	16.2	1.7	6.71	7.83
	324.5	208.9			295.7	208.6	300.4	199.6	8.9	0.1	7.4	4.5		
	307.9	224.5			283.7	205.1	288.4	197.1	7.9	8.2	6.3	12.2		
	280.0	213.7			297.5	209.1	302.2	200.0	6.2	2.2	7.9	6.4		
Dissolved Ions (mg/l)	200.7	157.1	269.7	178.6	208.2	163.2	212.5	154.9	3.7	3.9	5.9	1.4	4.61	5.85
	210.0	162.3			201.7	160.4	206.0	152.2	4.0	1.1	1.9	6.2		
	197.9	163.7			199.1	159.4	203.4	151.1	0.6	2.7	2.8	7.7		
	179.8	158.1			210.4	164.0	214.7	155.8	17.2	3.8	19.5	1.4		
Dissolved Solids (mg/l)	195.9	118.6	235.2	135.6	173.6	124.4	178.0	115.9	11.4	4.9	9.2	2.3	5.82	7.44
	179.1	122.9			169.3	122.9	173.7	114.5	5.5	0.0	3.0	6.9		
	170.8	131.6			164.6	121.3	169.0	112.8	3.6	7.8	1.1	14.3		
	153.3	125.0			172.4	124.0	176.8	115.5	12.5	0.8	15.3	7.6		
Hardness (mg/l) as CaCO ₃	94.9	65.7	114.7	73.1	87.2	72.2	91.5	63.9	8.1	10.0	3.6	2.7	10.33	8.23
	83.4	67.3			84.4	71.1	88.7	62.6	1.2	5.7	6.4	6.6		
	77.8	63.8			83.8	70.9	88.2	62.6	7.8	11.2	13.4	1.9		
	73.8	63.3			90.4	73.5	94.7	65.2	22.4	16.2	28.3	3.1		

Table 5.10(c) 3 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130401	Station 130106					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130401	Station 130106	(Original)	(‘Shifted’)	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	358.1	205.8	408.8	222.2	306.7	210.9	313.3	201.9	14.4	2.5	12.5	1.9	4.3	5.3
	310.8	220.1			302.7	210.1	307.4	201.1	2.6	4.5	1.1	8.7		
	297.5	211.4			301.2	209.8	305.9	200.8	1.2	0.8	2.8	5.0		
Dissolved Ions (mg/l)	206.9	158.5	269.7	178.6	208.0	163.0	212.2	154.8	0.5	2.8	2.6	2.3	3.1	4.8
	198.9	163.6			203.7	161.2	207.9	153.0	2.4	1.5	4.5	6.5		
	192.9	159.2			209.5	163.6	213.7	155.4	8.6	2.8	10.8	2.4		
Dissolved Solids (mg/l)	192.3	120.2	235.2	135.6	168.1	122.5	172.5	114.1	12.6	1.9	10.3	5.1	4.2	6.8
	171.7	128.6			168.4	122.6	172.8	114.2	1.9	4.7	0.7	11.2		
	163.9	124.4			167.4	122.3	171.8	113.8	2.1	1.7	4.8	8.5		
Hardness (mg/l) as CaCO ₃	91.1	64.4	114.7	73.1	88.9	72.9	93.2	64.6	2.4	13.2	2.3	0.3	11.2	8.1
	79.6	66.7			86.5	71.9	90.8	63.6	8.7	7.8	14.0	4.6		
	77.1	62.8			90.9	73.7	95.2	65.4	17.9	17.4	23.5	4.1		

Table 5.10(d) 4 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130401	Station 130106					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130401	Station 130106	(Original)	(‘Shifted’)	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	339.4	214.9	408.8	222.2	318.6	213.4	323.3	204.4	6.1	0.7	4.7	4.9	3.45	5.04
	302.3	211.4			320.1	213.7	324.7	204.8	5.9	1.1	7.4	3.1		
Dissolved Ions (mg/l)	199.4	160.4	269.7	178.6	215.9	166.4	220.2	158.1	8.3	3.7	10.4	1.4	7.06	6.70
	194.8	160.3			218.0	167.2	222.3	159.0	11.9	4.3	14.1	0.8		
Dissolved Solids (mg/l)	183.4	125.2	235.2	135.6	171.0	123.5	175.4	115.0	6.8	1.4	4.4	8.1	3.05	6.44
	166.3	124.0			172.8	124.2	177.2	115.7	3.9	0.2	6.6	6.7		
Hardness (mg/l)	86.3	64.7	114.7	73.1	92.3	74.2	96.9	65.9	6.9	14.7	12.3	1.9	13.92	10.27
	78.6	65.3			93.9	74.9	98.2	66.6	19.4	14.7	24.9	2.0		

the Nogoia River for the 3 and 4 yearly time averaging. It appears that changes to the prior distribution in reflection of known changes in the basin do not necessarily improve the accuracy of the predictions available through the entropy method.

From an intuitive basis it might be expected that inclusion of such knowledge would improve the accuracy of the prediction. Part of the problem however, may lie in the problem of determining the magnitude of the change to apply to the 'prior' probability distribution in order to incorporate knowledge of changes in the watershed. Research on how much adjustment should be applied to the prior distribution in light of known or observed changes in conditions, e.g. a change of land use, needs therefore to be undertaken so that the predictions can become more accurate while not compromising the unbiased nature of the predictions through inclusion of such additional information. As the changes in water quality for which this sort of adjustment might be applied are related to physical changes in the basin, this research is likely to involve some work on the physical relationships between basin conditions and water quality values and is outside the scope of this study.

d. **CASE IV. Dependency between the Water Quality at Upstream Discontinued Stations**

It is possible, and perhaps likely, that some level of dependency, at least statistically, exists between the water quality values at the upstream stations. In order to consider this dependency, a 'multi-dimensional' form of the formulation given by Equations 4.7 to 4.13 must be used. A dependent prior probability distribution of the following form (for two discontinued upstream stations) forms the basis for the required modification of the formulation :

$$q_{ij} = \frac{\Delta x_1 \cdot \Delta x_2}{2\pi \cdot Sx_{1i} Sx_{2j} \sqrt{1-\rho^2}} e^{-\left[\left(\frac{x_{1i} - \bar{x}_1}{Sx_{1i}} \right)^2 - 2\rho \left(\frac{x_{1i} - \bar{x}_1}{Sx_{1i}} \right) \left(\frac{x_{2j} - \bar{x}_2}{Sx_{2j}} \right) + \left(\frac{x_{2j} - \bar{x}_2}{Sx_{2j}} \right)^2 \right] / 2(1-\rho^2)} \quad (5.4)$$

where :

- q_{ij} = joint probability of events x_{1i} and x_{2j}
- x_{1i} = water quality value in the i^{th} discrete interval at station 1.
- $\bar{x}_1$ = mean of x_{1i}
- x_{2j} = water quality value in the j^{th} discrete interval at station 2
- $\bar{x}_2$ = mean of x_{2j}
- Sx_{1i} = standard deviation of x_{1i}
- Sx_{2j} = standard deviation of x_{2j}
- ρ = coefficient correlation between events x_{1i} and x_{2j}

Δx_1 = width of interval at station 1

Δx_2 = width of interval at station 2

This equation is used to calculate the prior probability q_{ij} , embedded in the entropy formulation. The impacts of including this dependency are demonstrated by application of this multi-dimensional form of the entropy model, with the q_{ij} values calculated using Equation 5.4 to the data on the MacKenzie River used in the previous demonstrations. The results of the application of this multi-dimensional dependency based form of the formulation are shown in the Table 5.11 (Results from application of this multi-dimensional form of the entropy approach to the data sets from the Fitzroy River and Nogoia River data are shown in Tables B.3.1 and B.3.2). It can be seen that, of the water quality parameters selected in these examples to demonstrate consideration of dependency among the data, the predictions are more accurate only for Hardness parameter from the MacKenzie and the Nogoia River Basins. The predictions for the other parameters are actually less accurate.

These results suggest one or both of two different processes may be in effect. In the first case, the dependency that existed previously in the historical data may no longer hold for the new conditions (except

Table 5.11 Comparison of the Use of Independent and Dependent Data in the MacKenzie River

Table 5.11(a) 1 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
								(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
		Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108		
Conductivity (mS/m)	0.574	425.0	199.3	265.6	206.5	299.4	179.9	32.8	3.6	29.8	9.8	10.6	12.9
		318.7	211.3	298.7	209.3	311.1	165.5	5.7	0.9	1.8	12.2		
		332.5	206.7	261.8	201.5	278.4	169.6	21.3	2.5	16.3	19.0		
		283.3	242.5	271.4	203.5	287.0	173.5	4.2	16.1	1.3	28.5		
		276.7	185.0	293.3	208.1	306.3	183.0	6.0	12.5	10.7	1.1		
Dissolved Ions (mg/l)	0.530	200.8	151.0	199.2	159.4	207.1	144.1	0.8	5.8	3.2	4.6	7.7	10.4
		200.7	163.3	186.7	155.0	197.8	137.5	6.0	5.1	1.5	15.8		
		219.3	181.3	182.2	152.3	192.0	133.4	16.9	5.6	12.5	17.3		
		176.7	166.2	182.1	152.2	191.8	133.4	3.1	8.4	8.6	19.7		
		182.6	150.2	211.4	184.5	217.9	151.9	15.7	9.5	19.3	1.1		
Dissolved Solids (mg/l)	0.542	218.5	114.8	149.1	115.9	159.0	96.9	31.8	0.9	27.3	15.6	11.0	15.5
		173.3	122.5	162.8	120.8	170.9	104.7	6.2	1.5	1.4	14.5		
		185.0	123.3	138.1	112.0	149.1	90.7	25.4	9.2	19.4	26.4		
		156.7	140.0	150.3	116.3	160.0	97.7	4.1	16.9	2.1	30.2		
		150.0	110.0	158.4	119.2	167.2	102.3	5.6	8.3	11.5	7.0		
Hardness (mg/l) as CaCO ₃	0.545	106.5	58.8	82.7	70.4	88.3	63.4	22.4	19.6	19.0	7.7	12.6	12.3
		83.3	72.5	74.1	67.0	78.8	58.1	11.0	7.6	5.5	19.9		
		83.5	62.0	75.2	67.4	79.7	58.6	9.9	8.7	4.6	5.2		
		72.0	65.5	72.6	66.3	77.4	57.0	0.8	1.3	7.5	13.0		
		75.7	61.0	83.0	74.5	85.7	69.7	22.9	22.1	26.5	14.2		

Table 5.11(b) 2 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
								(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
		Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108	Station 130401	Station 130108		
Conductivity (mS/m)	0.814	370.8	205.3	306.1	210.8	318.4	187.2	17.5	2.7	14.1	8.8	8.7	11.2
		324.6	209.0	295.7	206.6	309.2	182.2	8.9	0.2	4.7	12.8		
		307.9	224.6	283.7	206.1	298.6	177.5	7.9	8.2	3.0	21.0		
		280.0	213.6	267.5	209.1	310.7	163.5	6.2	2.2	11.0	14.1		
Dissolved Ions (mg/l)	0.801	200.7	157.2	208.2	163.2	204.6	170.2	3.7	3.6	1.9	8.3	4.6	5.3
		210.0	162.3	201.7	160.4	198.8	166.1	4.0	1.2	5.4	2.3		
		198.0	163.7	199.1	159.4	196.5	164.3	0.8	2.7	0.7	0.4		
		179.7	158.2	210.4	164.0	206.6	171.3	17.1	3.7	15.0	8.3		
Dissolved Solids (mg/l)	0.613	195.9	116.7	173.6	124.4	181.3	106.6	11.4	4.6	7.5	7.6	5.8	10.2
		179.2	122.9	169.3	122.9	177.6	107.1	5.5	0.0	0.9	12.9		
		170.8	131.7	164.6	121.3	173.4	104.3	3.7	7.9	1.5	20.8		
		153.3	125.0	172.4	124.0	180.3	106.0	12.5	0.8	17.6	12.6		
Hardness (mg/l) as CaCO ₃	0.533	94.9	65.7	87.2	72.2	90.2	66.3	8.2	9.9	4.9	1.0	10.3	7.8
		83.4	67.3	84.4	71.1	87.9	64.4	1.2	5.7	5.4	4.2		
		77.8	63.8	83.8	70.9	87.3	64.2	7.8	11.2	12.3	0.7		
		73.6	63.3	90.4	73.5	93.2	68.2	22.4	16.2	26.2	7.8		

Table 5.11(c) 3 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
								Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	0.836	358.1	205.8	306.7	210.9	321.6	182.1	14.4	2.5	10.2	11.5	4.3	10.7
		310.8	220.1	302.7	210.1	318.3	180.1	2.6	4.5	2.4	18.2		
		297.5	211.4	301.2	209.8	317.1	179.3	1.2	0.8	6.6	15.2		
Dissolved Ions (mg/l)	0.762	206.9	158.5	208.0	163.0	216.8	146.1	0.5	2.8	4.8	7.9	3.1	8.8
		198.9	163.6	203.7	161.2	213.1	143.1	2.4	1.5	7.1	12.5		
		192.9	159.2	209.5	163.6	218.0	147.1	8.6	2.8	13.0	7.6		
Dissolved Solids (mg/l)	0.810	192.3	120.2	168.1	122.5	178.1	103.3	12.6	1.9	7.4	14.1	4.2	11.8
		171.7	128.6	168.4	122.6	178.4	103.4	1.9	4.7	3.9	19.6		
		163.9	124.4	167.4	122.3	177.5	102.7	2.1	1.7	8.3	17.4		
Hardness (mg/l) as CaCo3	0.775	91.1	64.4	88.9	72.9	92.6	65.7	2.4	13.2	1.6	2.0	11.2	7.6
		79.6	66.7	86.5	71.9	90.6	64.0	8.7	7.8	13.8	4.0		
		77.1	62.8	90.9	73.7	92.4	65.5	17.9	17.4	19.8	4.3		

Table 5.11(d) 4 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
								Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	0.992	339.4	214.9	318.6	213.4	333.3	185.1	6.1	0.7	1.8	13.9	3.5	9.6
		302.3	211.4	320.1	213.7	334.5	186.0	5.9	1.1	10.7	12.0		
Dissolved Ions (mg/l)	0.940	199.4	160.4	215.9	166.4	224.7	149.6	8.3	3.7	12.7	6.7	7.1	10.3
		194.8	160.3	218.0	167.2	226.4	151.1	11.9	4.3	16.2	5.7		
Dissolved Solids (mg/l)	0.963	183.4	125.2	171.0	123.5	181.6	103.1	6.8	1.4	1.0	17.6	3.0	11.2
		166.3	124.0	172.8	124.2	183.7	104.3	3.9	0.2	10.5	15.9		
Hardness (mg/l) as CaCo3	0.966	86.3	64.7	92.3	74.2	95.9	67.1	6.9	14.7	11.1	3.7	13.9	10.8
		78.6	65.3	93.9	74.9	97.3	68.3	19.4	14.7	23.7	4.7		

in this case, possibly, for the Hardness parameter from the MacKenzie and the Nogoia River Basin). The second possible outcome is that dependency does still exist but its inclusion in the formulation does not improve, and in fact reduces, the accuracy of the predictions.

It should also be recognised that inclusion of dependency in the model actually introduces bias into the solution thereby degrading one of the strengths of the approach, namely, its ability to provide unbiased predictions. It should be similarly noted that the running time for each case with the prior probability calculated by Equation 5.4, and with 24 intervals in the discretization of the probability distributions at each station, takes approximately 7 hours on a Digital VAX 6000-330 with 64 Mbytes memory running VMS. This computational requirement can be contrasted with the approximately 35 seconds needed for the simplified formulation when run on a 486 IBM-Compatible Personal Computer. This very large increase in computational requirement is due mainly to the exponential increase in the number of variables associated with the 'multi-dimensional' formulation.

Consideration of dependency therefore not only appears to reduce the accuracy of prediction in most cases, but it also increases the running time of the

model dramatically. It also introduces bias into the solution. The combination of these factors indicate that, although inclusion of dependency in the formulation is intuitively attractive, it should not be undertaken unless there is very strong evidence in support of the decision.

5.3.2 DISCRETIZATION PROBLEM

One of the steps required for the procedure is to define the "events" to which the entropy model assigning probabilities. As discussed previously this process is performed by discretizing the range of possible values (in this study the range from $\mu-4\sigma$ to $\mu+4\sigma$) at each station into a number of discrete values as required for entropy theory. One problem in this discretization process is how to determine (choose) the size of the intervals such that the best, i.e., most accurate predictions are obtained. In their studies of the application of entropy theory for determination of the extent of transfer of information between water quality variables Harmancioglu et al.(1985) and Harmancioglu and Alpaslan (1992) reported that the choice of the level of discretization has a significant effect on the result. This section of the thesis examines the effect in the discretization procedure that the choice of the number of intervals, and thereby the size of the interval, has

on the performance of the proposed model.

Six different levels of discretization, namely 8, 16, 24, 32, 40 and 48 intervals spread over four standard deviations either side of the mean, were examined for the set of data presented in Table 5.3. This process was undertaken for each of the four water quality parameters of Conductivity, Dissolved Ions, Dissolved Solids and Hardness. The results derived from the MDI formulation for this range of values are presented in Table 5.12 and Figure B.1 in Appendix B (The duration of the interval over which the water quality values were averaged was 4 years for this case. It should be noted that any other duration would have similar results since the only factor to be examined in this case is variation of the number of intervals.)

It is clear from the results shown in Table 5.12 that variation in the level of discretization has very little effect on the value of the entropy H ; doubling the number of intervals from 24 to 48 results in a maximum change of less than 1% in the value of H . Similarly, the variation in the mean values of the water quality values assigned by the entropy function with the different levels of discretization is extremely small with the only changes occurring in the second decimal place. These observations indicate, that unlike the

Table 5.12 Results of Assignment of Water Quality Values with Varying Levels of Discretisation in the MacKenzie River

(for 4 year averaged data)

Water Quality Parameter	Mean Value at Station 130401	Mean Value at Station 130106	Number of Intervals					
			8		1 6		2 4	
			Entropy Value	Time to Reach Solution	Entropy Value	Time to Reach Solution	Entropy Value	Time to Reach Solution
Conductivity (mS/m)	318.6	213.4	0.1314	7.74"	0.1315	14.88"	0.1315	32.08"
	320.1	213.7	0.1271	5.05"	0.1272	15.6"	0.1273	28.29"
Dissolved Ions (mg/l)	215.9	166.4	0.1506	4.23"	0.1509	18.34"	0.1509	43.62"
	218.0	167.2	0.1392	4.62"	0.1393	16.92"	0.1394	33.56"
Dissolved Solids (mg/l)	171.0	123.5	0.2552	3.73"	0.2554	17.25"	0.2557	26.2"
	172.8	124.2	0.2409	3.79"	0.2411	18.5"	0.2414	27.24"
Hardness (mg/l) as CaCO ₃	92.3	74.2	0.1181	6.48"	0.1182	16.48"	0.1183	37.46"
	93.9	74.9	0.1016	5.71"	0.1016	17.41"	0.1018	26.69"

Water Quality Parameter	Mean Value at Station 130401	Mean Value at Station 130106	Number of Intervals					
			3 2		4 0		4 8	
			Entropy Value	Time to Reach Solution	Entropy Value	Time to Reach Solution	Entropy Value	Time to Reach Solution
Conductivity (mS/m)	318.6	213.4	0.1318	72.4"	0.1320	146.10"	0.1320	242.38"
	320.1	213.7	0.1275	89.25"	0.1275	173.84"	0.1276	185.87"
Dissolved Ions (mg/l)	215.9	166.4	0.1510	72.61"	0.1511	143.85"	0.1512	270.01"
	218.0	167.2	0.1396	73.98"	0.1398	106.23"	0.1399	220.48"
Dissolved Solids (mg/l)	171.0	123.5	0.2561	82.00"	0.2563	132.48"	0.2563	246.61"
	172.8	124.2	0.2418	75.19"	0.2418	186.03"	0.2419	270.57"
Hardness (mg/l) as CaCO ₃	92.3	74.2	0.1184	172.74"	0.1185	117.54"	0.1187	393.21"
	93.9	74.9	0.1019	68.44"	0.1019	142.48"	0.1019	246.18"

applications of the entropy function reported by Harmancioglu et al. (1985) and Harmancioglu and Alpaslan (1992), the model is quite insensitive to the level of discretization and therefore very robust in its assignment of water quality values. Hence the level of discretization does not appear to be a significant problem.

As shown in Table 5.12, there are, however, considerable differences in the processing time for different levels of discretization. The times shown in this table are the result of running the model on an IBM-PC Compatible with an Intel 80486 processor, 33 Mhz, and using the non-linear programming package GRG2 (Lasdon and Warren, 1986) to solve the model. The results presented in the table were obtained using the same starting values for every variable in the initialisation of variables required by the program. Different initial values may result in different times to reach the solution, and may therefore results in times to solution which are different from those one presented in Table 5.12. However, it is quite clear that the processing time increases rapidly as the discretization interval becomes smaller.

Since the differences in results for the different levels of discretization are very small, the appropriate

level of discretization can be quite coarse. In this case the level of discretization associated with having only eight intervals would appear to be quite satisfactory.

It should be noted that the time required to reach solution can be reduced if the starting (initial) values are close to the values expected from the model solution. If small intervals of discretization are required, or if necessary to include dependency in the formulation as described in CASE IV in Section 5.3.1, then a careful choice of starting values will overcome, in part, some of the associated computational requirements.

5.3.3 CHOICE OF THE PERIOD OF TIME AVERAGING

Recall that the method proposed in this study is intended primarily to predict the mean values of water quality over selected periods of time. In order to observe the effect of the selection of the period of time over which the function expressed in Equation 4.18 is developed, the entropy formulation was solved for a range of different time intervals. The data from the MacKenzie River, as described in Table 5.3, were used to examine this issue. As in the previous cases, the data from 1971 to 1980 were used for the calibration step and

the data from 1981 on were used in the validation step.

The parameters chosen to examine the effects of the duration over which the values are time averaged are the same as those used in Section 5.3.2 for the examination of the effects of the level of discretization. Due to the limited data (only 8 years of data are available for all stations, except for the Dissolved Solids parameter which has only 7 years of data available for the calibration step, and only 5 years of data available for the validation step) only a limited number of variations in the averaging time period were able to be analysed. In this study, 5, 4, 3 and 2 year duration time averaging periods were selected. The 5 year duration averaging period is included in this examination primarily to show that the correlation coefficient becomes smaller beyond the 4 years duration averaging period and to examine the effects of this decrease. From the 8 data points available for calibration, only 4 data points can be used to calculate the regression coefficients for the 5 year moving average; 5 data points for the 4 year moving average; 6 data points for the 3 year moving average and 7 data points for the 2 year moving average.

The regression coefficients for each of the time averaging periods are shown in Table 5.13 with the

Table 5.13 Regression Coefficients for Various Periods of Time Averaging for MacKenzie River Data

*Summation of Weighted Upstream Values = Bo + Bi * (Downstream Value)*

Conductivity

Regression Coefficient	2 Year Moving Average	3 Year Moving Average	4 Year Moving Average	5 Year Moving Average
Bo	95.96	112.82	137.72	147.89
Bi	0.6990	0.6580	0.5980	0.5689
Correlation Coefficient	0.8767	0.8828	0.9688	0.9322

Dissolved Ions

Regression Coefficient	2 Year Moving Average	3 Year Moving Average	4 Year Moving Average	5 Year Moving Average
Bo	77.88	81.55	100.58	147.23
Bi	0.6693	0.6602	0.5914	0.3936
Correlation Coefficient	0.8526	0.8619	0.9730	0.8175

Dissolved Solids

Regression Coefficient	2 Year Moving Average	3 Year Moving Average	4 Year Moving Average	5 Year Moving Average
Bo	50.59	46.68	50.98	105.98
Bi	0.7355	0.7577	0.7423	0.4668
Correlation Coefficient	0.8607	0.8818	0.9832	0.8112

Hardness

Regression Coefficient	2 Year Moving Average	3 Year Moving Average	4 Year Moving Average	5 Year Moving Average
Bo	40.27	44.02	51.36	74.37
Bi	0.6247	0.5966	0.5351	0.3034
Correlation Coefficient	0.8347	0.8238	0.9390	0.7853

graphical presentations of the regression lines being given in Appendix B. [Figure B.2(a) for Conductivity, Figure B.2(b) for Dissolved Ions, Figure B.2(c) for Dissolved Solids and Figure B.2(d) for Hardness.] It can be seen in Table 5.13, that in most cases, the 4 year moving average gives the highest coefficient of correlation between the water quality values at the downstream station and the summation of the water quality values at the two upstream stations, weighted by their average flows.

It was initially expected that the best entropy prediction would occur for those time intervals with the highest correlation coefficients, e.g., the 4 year interval. The results of the prediction step, as shown in Table 5.14, show that it is not always true. For example, as shown in Table 5.13 the correlation coefficient for a four year averaging interval is significantly larger than those for the other three time intervals considered for all water quality parameters. However, it can be seen that the errors in entropy prediction using the four year time interval are not always better, and in some cases worse, than using the other time periods.

This situation appears to be due in part to the variation in the number of points available for a fixed

Water Quality Parameter	2 Yearly Averaging							3 Yearly Averaging						
	Observed Values		Assigned Values		Absolute Values of Errors (%)			Observed Values		Assigned Values		Absolute Values of Errors (%)		
	at Station		at Station		at Station		Average	at Station		at Station		at Station		Average
130401	130106	130401	130106	130401	130106	130401		130106	130401	130106	130401	130106		
Conductivity (mS/m)	212.50	205.29	306.10	210.82	44.05	2.69	18.66	358.10	205.80	306.70	210.90	14.35	2.48	4.33
	166.25	208.96	295.67	208.62	77.85	0.16		310.80	220.10	302.70	210.10	2.61	4.54	
	307.92	224.58	283.70	206.10	7.86	8.23		297.50	211.40	301.20	209.80	1.24	0.76	
	280.00	213.75	297.48	209.10	6.24	2.18								
Dissolved Ions (mg/l)	200.73	157.15	208.22	163.15	3.73	3.82	4.59	206.90	158.50	208.00	163.00	0.53	2.84	3.10
	210.00	162.33	201.70	160.44	3.95	1.16		198.90	163.60	203.70	161.20	2.41	1.47	
	197.98	163.74	199.11	159.36	0.57	2.68		192.90	159.20	209.50	163.60	8.61	2.76	
	179.65	158.18	210.41	164.04	17.12	3.71								
Dissolved Solids (mg/l)	195.92	118.67	173.57	124.40	11.41	4.83	5.82	192.30	120.20	168.10	122.50	12.58	1.91	4.15
	179.17	122.92	169.30	122.93	5.51	0.01		171.70	128.60	168.40	122.60	1.92	4.67	
	170.83	131.67	164.57	121.30	3.67	7.87		163.90	124.40	167.40	122.30	2.14	1.69	
	153.33	125.00	172.43	124.02	12.45	0.78								
Hardness (mg/l) as CaCO3	94.92	65.67	87.18	72.20	8.15	9.95	10.33	91.10	64.40	88.90	72.90	2.41	13.20	11.22
	83.42	67.25	84.44	71.10	1.23	5.72		79.60	66.70	86.50	71.90	8.67	7.80	
	77.75	63.75	83.84	70.87	7.83	11.17		77.10	62.80	90.90	73.70	17.90	17.36	
	73.83	63.25	90.39	73.48	22.42	16.17								

Table 5.14 (continued)

Water Quality Parameter	4 Yearly Averaging							5 Yearly Averaging						
	Observed Values		Assigned Values		Absolute Values of Errors (%)			Observed Values		Assigned Values		Absolute Values of Errors (%)		
	at Station		at Station		at Station			at Station		at Station		at Station		
	130401	130106	130401	130106	130401	130106	Average	130401	130106	130401	130106	130401	130106	Average
Conductivity (mS/m)	339.40 302.30	214.90 211.40	318.60 320.10	213.40 213.70	6.13 5.89	0.70 1.09	3.45	326.80	209.00	324.90	214.70	0.58	2.73	1.65
Dissolved Ions (mg/l)	199.40 194.80	160.40 160.30	215.90 218.00	166.40 167.20	8.27 11.91	3.74 4.30	7.06	196.00	158.40	235.20	174.40	20.00	10.10	15.05
Dissolved Solids (mg/l)	183.40 166.30	125.20 124.00	171.00 172.80	123.50 124.20	6.76 3.91	1.36 0.16	3.05	176.70	122.10	193.00	131.10	9.22	7.37	8.30
Hardness (mg/l) as CaCO ₃	86.30 78.60	64.70 65.30	93.90 92.30	74.20 74.90	8.81 17.43	14.68 14.70	13.91	84.20	64.00	103.50	78.70	22.92	22.97	22.95

length of record to develop the 'information function' (Equation 4.18 in the formulation) resulting from change in the duration of the intervals over which the water quality values are time averaged. Longer averaging periods result in fewer points for the expression. For example, in the case of a 5 year moving average only 4 data points are available. The smaller numbers of data points may result in good correlation coefficients but, in fact, the resulting expression may not be an accurate or appropriate representation of reality. In the case of smaller intervals over which the values are averaged, the number of points to calculate the regression coefficients will increase, and the resulting expression is likely to be a better reflection of reality. However, the variation of the data in this case may be more evident with a correspondingly smaller correlation coefficient. (It can be noted that, due to the limited numbers of data points suitable for use for the demonstration of the technique, only time averaging up to 4 year duration are chosen for the calculations presented in this thesis.)

These results have some bearing on the issues concerning the appropriate time scale for water quality monitoring analysis identified by Loftis et al. (1991) who indicated that an explicit consideration of time scale in data analysis is important for producing

meaningful statistical information. The decision of choosing the duration of the averaging interval should, therefore, be made on the basis of the time span over which it is desired to calculate average water quality values rather than on a formal statistical evaluation of what time interval is optimal in terms of accuracy of prediction. The same 'time-averaging' period must of course be used in the calibration and prediction steps.

It should also be recognised that use of time averaged values for water quality damps out the effects of short term transient fluctuations in water quality, which although important at their time of occurrence, do not relate directly to the background water quality conditions and to the long term and possibly permanent variation in those background conditions.

The limited data (as low as 3-4 pieces of data in some cases) referred to earlier with respect to the errors in the predictions by the entropy and regression approaches also have the potential to give rise to concerns as to the confidence that can be placed in the predictions of the regression model. Obviously the number of data available for development of the regression model does affect the results of the regressions, and the confidence that can be placed on those results, significantly. However, the degree to

which the data available for the development of the regression model are dispersed within the range of values important to the analysis is also important. A large number of data which are highly clustered may not be as good for prediction within the range for which prediction is required as a smaller number of data dispersed more uniformly within the range of prediction. It can be seen from Figure B.2 in Appendix B that the raw data used to develop the regression models used in this thesis are reasonably well dispersed within the range of values of interest. Hence while the number of points available for the regression analysis is of some concern with respect to the validity of the regression model and the confidence which was given to the predictions from the regression models and therefore to the validity of the comparisons between the accuracy of the entropy model relative to the regression model, the dispersed nature of the data upon which these regression models were developed does allay some of those concerns.

5.4 THE USE OF ENTROPY METHOD FOR IDENTIFICATION OF LOCATIONS OF CAUSES OF CHANGES IN OBSERVED WATER QUALITY VALUES

The entropy formulations described above can also be used for identifying the "most likely" location in the watershed of changes, e.g., new sources of

pollution, which are causing observed and unaccounted for changes in water quality at the downstream continuing monitoring station. The "locations" which are able to be identified in this process are restricted to branches upon which monitoring stations have existed previously but have been discontinued, i.e., the problem has the same "dimensions" as in the use of entropy to predict values at discontinued stations.

Use of the entropy based formulation in this role entails prediction of the water quality values at the discontinued monitoring stations as described in the previous sections. These predicted values are then evaluated as to the extent to which they deviate from the historical mean values, e.g., how many standard deviations are the new values away from the old observed mean [where the distribution of the old mean (specified by a mean and standard deviation) is defined by the historical sampling (observations)].

Recall that according to sampling theory, if a population has a distribution with a standard deviation of σ , then the mean values of a set of random samples from that population will have a standard deviation of:

$$\sigma_n = \frac{\sigma}{\sqrt{n}} \quad (5.5)$$

where :

σ_n = standard deviation of the mean value
 σ = standard deviation of the population
 n = number of samples

The determination of the most likely locations of changes in water quality which are causing the changes in observed values at the downstream station can be demonstrated by using the 'calibration data sets' (listed in Table 5.3) to define the distribution of the **population**, and using the values from the 'validation set' as 'samples from the population'.

Consider the 'new' entropy predicted mean values at the upstream stations, as representing values of the mean derived from 'sampling' undertaken at the downstream monitoring station following discontinuation of the upstream stations.

The number of samples used to define the downstream observed mean value for which changes are noted is implicitly the number of samples used to define the predicted mean(s) at the upstream station(s). The standard deviation of the predicted means at the upstream stations derived from the sampled downstream mean can therefore be defined as $\sigma_{us}/\sqrt{n}$ where σ_{us} is the standard deviation of the water quality at the upstream station, as defined by the prior (calibration) data set,

and n is the number of samples at the downstream station used to define the downstream mean.

Now define distance in terms of the number of standard deviations which the new predicted ('sampled') mean at the upstream station lies away from the "known" mean (as defined from the calibration data set) of the water quality at that upstream station. The greater the distance of the predicted ('sampled') mean from the prior mean for a particular upstream station, i.e., the greater the number of standard deviations the two means are apart, the more likely it is that water quality conditions at that location (or on that branch) have changed and the less likely the difference between the old known and new predicted ('sampled') mean is due to chance alone. For example, if the new value lies outside the range of $\mu \pm 1.96(\sigma_{us}/\sqrt{n})$, then it can be reasonably concluded at a 95% confidence level that changes have occurred at that particular location.

Table 5.15 (and Tables B.4.1 to B.4.3 in the Appendix B), show the results of applying the approach to the data sets used in this thesis. It can be seen in the Table 5.15(c), for the data set from the MacKenzie River Sub-Basin, that the mean value of the water quality as observed at the downstream station (Station 130105) has changed significantly between the

Table 5.15 Evaluation of the Water Quality Values in the MacKenzie River Sub-Basin

Legend :

X_{no} = observed water quality values ($\cong$ X_O in the formula for determination of absolute errors)

X_{ne} = water quality values predicted by the entropy method

X_h = historical mean water quality values

Table 5.15(a) Station 130401

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Chloride (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	408.8	7.8	269.7	235.2	114.7	101.6	37.1	1.7	23.8	13.4
Standard Deviation (s)	131	0.3	76.4	68.1	35.9	23	11.6	0.3	7.2	4.5

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Chloride (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	425.0	8.0	200.8	218.5	106.5	50.0	36.5	1.3	22.0	12.5
(X _{no})	316.7	8.1	20.7	173.3	83.3	76.0	27.7	1.3	17.7	9.5
	332.5	8.0	219.3	185.0	83.5	83.0	32.0	1.7	17.5	9.7
	283.3	7.5	176.7	156.7	72.0	64.7	25.0	1.9	15.3	8.2
	276.7	7.8	182.6	120.0	75.7	72.0	24.0	2.2	17.0	8.1
($\bar{X}_{no}$)	326.8	7.9	196.0	176.7	84.2	69.1	29.0	1.7	17.9	9.6
ENTROPY	285.6	7.9	199.2	149.1	82.7	92.9	23.0	1.6	17.5	9.8
(X _{ne})	298.7	7.9	188.7	162.6	74.1	73.7	31.9	1.5	15.6	9.1
	261.8	7.8	182.2	138.1	75.2	82.3	24.2	1.7	17.0	8.3
	271.4	7.8	182.1	150.3	72.6	77.7	25.0	1.7	16.6	7.9
	293.3	8.0	211.4	158.4	93.0	95.8	25.0	1.7	20.4	10.4
($\bar{X}_{ne}$)	282.2	7.9	192.7	151.7	79.5	84.5	25.8	1.6	17.4	9.1

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Chloride (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-1.4	0.65	-2.16	-1.92	-1.9	-3.16	-1.55	-0.17	-1.83	-1.9
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/V _n]	-2.16	0.6	-2.25	-2.74	-2.19	-1.67	-2.18	-0.66	-1.98	-2.14

Table 5.15(a) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	370.8	8.1	200.7	195.9	94.9	63.0	32.1	1.3	19.8	11.0
	324.6	8.1	210.0	179.2	83.4	79.5	29.8	1.5	17.6	9.6
	307.9	7.8	198.0	170.8	77.8	73.8	28.5	1.8	16.4	8.9
	280.0	7.7	179.7	153.3	73.8	68.3	24.5	2.1	16.2	8.1
($\bar{X}_{no}$)	320.8	7.9	197.1	174.8	82.5	71.2	28.7	1.7	17.5	9.4
ENTROPY (X _{ne})	306.1	7.8	208.2	173.6	87.2	86.8	28.2	1.6	18.1	10.4
	295.7	7.8	201.7	169.3	84.4	82.9	28.7	1.6	17.9	9.8
	283.7	7.8	199.1	164.6	83.8	84.4	25.8	1.6	18.3	9.3
	297.5	7.8	210.4	172.4	90.4	89.4	26.1	1.6	19.6	10.1
($\bar{X}_{ne}$)	295.7	7.8	204.9	170.0	86.5	85.8	27.2	1.6	18.5	9.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/(s/V _n)	-1.34	0.66	-1.90	-1.77	-1.80	-2.65	-1.44	-0.25	-1.75	-1.78
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/(s/V _n)	-1.73	-0.13	-1.70	-1.92	-1.57	-1.37	-1.71	-0.60	-1.48	-1.56

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	358.10	8.04	206.90	192.30	91.10	69.66	32.05	1.43	19.05	10.55
	310.80	7.88	198.90	171.70	79.60	74.55	28.22	1.64	16.83	9.11
	297.50	7.77	192.90	163.90	77.10	73.22	27.00	1.92	16.61	8.64
($\bar{X}_{no}$)	322.1	7.9	199.6	176.0	82.6	72.5	29.1	1.7	17.5	9.4
ENTROPY (X _{ne})	306.70	7.96	208.00	168.10	88.90	87.89	27.08	1.62	18.75	10.36
	302.70	7.95	203.70	168.40	86.50	84.25	27.67	1.65	18.51	9.91
	301.20	7.96	209.50	167.40	90.90	89.55	25.61	1.70	19.66	10.20
($\bar{X}_{ne}$)	303.5	8.0	207.1	168.0	88.8	87.2	26.8	1.7	19.0	10.2

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/(s/V _n)	-1.15	0.55	-1.59	-1.51	-1.55	-2.19	-1.20	-0.23	-1.52	-1.53
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/(s/V _n)	-1.39	0.90	-1.42	-1.71	-1.25	-1.08	-1.54	-0.25	-1.16	-1.25

Table 5.15(a) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	339.4 302.3	7.9 7.9	199.4 194.8	183.4 166.3	86.3 78.6	68.4 73.9	30.3 27.2	1.6 1.8	18.1 16.9	10.0 8.9
$\bar{X}_{no}$	320.9	7.9	197.1	174.9	82.5	71.2	28.7	1.7	17.5	9.4
ENTROPY (X _{ne})	318.6 320.1	8.0 8.0	215.9 218.0	171.0 172.8	92.3 93.9	89.6 90.1	28.1 28.5	1.6 1.7	19.7 20.2	10.6 10.7
$\bar{X}_{ne}$	319.4	8.0	217.0	171.9	93.1	89.9	28.3	1.6	19.9	10.6

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no} - $\bar{X}_h$)/[s/V _n]	-0.95	0.39	-1.34	-1.25	-1.27	-1.87	-1.02	-0.18	-1.24	-1.26
ENTROPY (X _{ne} - $\bar{X}_h$)/[s/V _n]	-0.97	0.82	-0.98	-1.31	-0.85	-0.72	-1.07	-0.26	-0.76	-0.87

Table 5.15(b) Station 130106

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	232.3	7.6	188.6	145.6	83.1	95.4	17.1	3.9	19.8	8.2
Standard Deviation (s)	83.2	0.2	68.2	56.1	31.3	33.1	7.2	0.5	7.1	3.8

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	199.3	7.8	151.0	114.8	58.8	79.8	14.6	3.9	13.0	6.4
($\bar{X}_{no}$)	211.3	7.9	163.3	122.5	72.5	87.0	13.6	3.8	17.3	7.1
	206.7	7.7	161.3	123.3	62.0	76.3	16.3	3.7	14.7	6.2
	242.5	7.5	166.2	140.0	65.5	67.5	22.0	3.0	15.0	6.8
	185.0	6.4	150.2	110.0	61.0	80.0	13.5	3.4	15.0	5.6
($\bar{X}_{no}$)	209.0	7.4	158.4	122.1	64.0	78.1	16.0	3.6	15.0	6.4
ENTROPY	206.5	7.6	159.4	115.9	70.4	86.0	14.3	3.8	16.6	6.8
($\bar{X}_{ne}$)	209.3	7.6	155.0	120.6	67.0	65.1	16.1	3.7	15.6	6.5
	201.5	7.6	152.3	112.0	67.4	74.5	14.6	3.9	16.3	6.2
	203.5	7.6	152.2	116.3	66.3	69.5	14.7	3.9	16.1	6.1
	208.1	7.7	164.5	119.2	74.5	89.1	14.7	3.9	18.1	7.0
($\bar{X}_{ne}$)	205.8	7.6	156.7	116.8	69.1	76.8	14.9	3.8	16.5	6.5

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/(s/Vn)	-0.63	-1.84	-0.99	-0.94	-1.37	-1.17	-0.34	-1.54	-1.52	-1.05
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/(s/Vn)	-0.71	0.25	-1.05	-1.15	-1.00	-1.26	-0.69	-0.24	-1.03	-0.98

Table 5.15(b) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	205.3	7.8	157.2	118.7	65.7	83.4	14.1	3.8	15.1	6.8
	209.0	7.8	162.3	122.9	67.3	81.7	15.0	3.8	16.0	6.6
	224.6	7.6	163.7	131.7	63.8	71.9	19.2	3.4	14.8	6.5
	213.8	6.9	158.2	125.0	63.3	73.8	17.8	3.2	15.0	6.2
($\bar{X}_{no}$)	213.1	7.5	160.4	124.6	65.0	77.7	16.5	3.5	15.2	6.5
ENTROPY (X _{ne})	210.8	8.2	163.2	124.4	72.2	79.4	15.4	3.9	16.9	7.0
	208.6	8.2	160.4	122.9	71.1	75.1	15.5	3.8	16.8	6.8
	206.1	8.2	159.4	121.3	70.9	76.7	14.9	3.9	17.0	6.6
	209.1	8.2	164.0	124.0	73.5	82.1	14.9	3.9	17.6	6.9
($\bar{X}_{ne}$)	208.7	8.2	161.7	123.2	71.9	78.3	15.2	3.8	17.1	6.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-0.46	-0.79	-0.83	-0.75	-1.16	-1.07	-0.17	-1.45	-1.29	-0.88
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / (s/V _n)	-0.57	5.90	-0.79	-0.80	-0.71	-1.03	-0.54	-0.23	-0.77	-0.72

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	205.80	7.78	158.50	120.20	64.40	81.05	14.85	3.79	14.97	6.56
	220.10	7.66	163.60	128.60	66.70	76.94	17.31	3.51	15.63	6.69
	211.40	7.17	159.20	124.40	62.80	74.61	17.27	3.37	14.88	6.19
($\bar{X}_{no}$)	212.4	7.5	160.4	124.4	64.6	77.5	16.5	3.6	15.2	6.5
ENTROPY (X _{ne})	210.90	7.66	163.00	122.50	72.90	80.53	15.14	3.85	17.19	7.01
	210.10	7.66	161.20	122.60	71.90	76.61	15.25	3.89	17.07	6.91
	209.80	7.66	163.60	122.30	73.70	82.34	14.84	3.95	17.65	6.95
($\bar{X}_{ne}$)	210.3	7.7	162.6	122.5	72.8	79.8	15.1	3.9	17.3	7.0

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-0.41	-0.55	-0.72	-0.85	-1.02	-0.93	-0.15	-1.20	-1.13	-0.78
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / (s/V _n)	-0.46	0.52	-0.66	-0.71	-0.57	-0.81	-0.49	-0.01	-0.61	-0.57

Table 5.15(b) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	214.9 211.4	7.7 7.3	160.4 160.3	125.2 124.0	64.7 65.3	77.7 77.7	16.6 16.4	3.6 3.5	15.0 15.5	6.6 6.4
($\bar{X}_{no}$)	213.2	7.5	160.4	124.6	65.0	77.7	16.5	3.5	15.2	6.5
ENTROPY (X _{ne})	213.4 213.7	7.7 7.7	166.4 167.2	123.5 124.2	74.2 74.9	82.4 83.0	15.3 15.4	3.9 3.9	17.7 17.9	7.1 7.1
($\bar{X}_{ne}$)	213.6	7.7	166.8	123.9	74.5	82.7	15.4	3.9	17.8	7.1

Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-0.33	-0.57	-0.59	-0.53	-0.82	-0.76	-0.12	-1.03	-0.91	-0.63
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/V _n]	-0.32	0.46	-0.45	-0.55	-0.39	-0.54	-0.34	-0.04	-0.40	-0.41

Table 5.15 (c) Station 130105

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	343.2	7.8	231.2	189.7	96.7	91.4	29.8	2.6	20.4	10.9
Standard Deviation (s)	97.6	0.2	58.7	48.3	28.8	21.2	9.6	0.6	6.3	3.3

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	248.0	7.7	176.7	139.0	71.0	85.0	18.0	3.1	15.0	8.1
(X _{no})	260.0	7.9	167.0	150.0	63.0	61.0	27.0	1.7	13.0	7.5
	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7
($\bar{X}_{no}$)	244.9	7.8	170.7	141.1	68.0	74.5	20.9	3.3	14.9	7.5

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/Vn]	-2.25	-0.17	-2.30	-2.25	-2.23	-1.78	-2.08	2.46	-1.95	-2.32

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	254.0	7.8	171.9	144.5	67.0	73.0	22.5	2.4	14.0	7.8
(X _{no})	243.1	7.7	164.0	140.0	63.5	66.4	23.1	2.8	13.8	7.1
	230.6	7.6	161.0	135.0	62.8	68.9	19.6	3.9	14.3	6.6
	245.0	7.9	174.4	143.3	71.1	77.3	20.0	3.9	16.0	7.5
($\bar{X}_{no}$)	243.2	7.7	167.8	140.7	66.1	71.4	21.3	3.2	14.5	7.3

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/Vn]	-2.05	-0.56	-2.16	-2.03	-2.13	-1.89	-1.77	2.04	-1.87	-2.21

Table 5.15 (c) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	244.8	7.7	168.2	139.7	66	72.6	21.4	2.9	14.2	7.5
	240.4	7.7	163	140	62.8	66.3	22.1	3.1	13.8	6.9
	238.8	7.8	170	138.9	68.7	75.5	19.8	3.8	15.5	7.3
(X _{no})	241.3	7.7	167.1	139.5	65.8	71.5	21.1	3.3	14.5	7.2

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-1.81	-0.58	-1.89	-1.80	-1.86	-1.63	-1.57	1.92	-1.62	-1.92

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	242.3	7.7	166.4	139.8	64.9	70.9	21.1	3.1	14.1	7.2
	244.1	7.8	169.2	141.7	67.3	71.9	21.6	3.3	14.9	7.3
(X _{no})	243.2	7.7	167.8	140.7	66.1	71.4	21.3	3.2	14.5	7.3

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-1.45	-0.40	-1.53	-1.43	-1.50	-1.33	-1.25	1.44	-1.32	-1.56

calibration data set (1971 to 1980) and the verification data set (1981 to 1985) for most of the water quality parameters. In most cases the change is greater than one standard deviation from the mean of the historical data.

The new values derived for the upstream stations from the entropy formulation on the basis at this observed downstream value are also presented in Table 5.15(a) for Station 130401 and Table 5.15(b) for Station 130106.

It can be seen that in general the differences between the predicted new mean values and corresponding historical means in Table 5.15(a) for Station 130401 are greater, in terms of the standard deviations of the sampled mean, than the differences between the predicted means and corresponding historical means for Station 130106. This difference in 'distances' indicates that the changes observed at the downstream stations are most likely caused by a change in the conditions in the branch upon which Station 130401 is located. If the causes of the predicted changes in water quality on that branch are not evident, then the results suggest that, if the water quality changes are critical, then some effort should be directed at verifying that changes have occurred on this branch (recall that the prediction is one of most likely rather than absolute certainty) and

identifying the causes of the changes. (The results of application of the approach to the other data sets are presented in Tables B.4.1 to B.4.3 in the Appendix B.)

Two other interesting features can be identified in Table 5.15. While significant changes in most of the water quality parameters were identified by sampling at the downstream Station 130105, as evident in the 'distances' between the known and sampled means for parameter being greater than 1.96 (i.e., for the 1 and 2 yearly averaging), there is no indication of an equivalent magnitude of change in the predicted values for the upstream stations. The reasons for this phenomenon are not yet clear.

The second and associated feature in Table 5.15 relates to the general magnitude of the differences between the known and sampled means at the downstream station and the known and entropy predicted (sampled) means at the upstream stations. The sum of the distances between the known and predicted means at the upstream stations is not equal to the distance between the known and sampled mean at the downstream station and does not appear to be different in a consistent manner. Once again the reason for this difference is not clear and is suitable area for further investigation.

It should be noted that the approach to identifying the most likely location in the river system of the source of the observed changes in water quality at the downstream monitoring station described in this section, is based on the assumption that the true (historical) probability distribution of the water quality values is appropriately represented by the data contained in the 'calibration set' in Table 5.3. These data do not necessarily give the true distributions as they are also only sampled from the population. It can therefore be argued that the calibration data may not reflect the true distribution of the population and therefore the comparison is invalid. Another statistical test such as hypothesis testing can be undertaken in these circumstances to justify whether there is a change in the mean value from the two groups of sampling.

Now consider the Null hypothesis that the predicted (new) mean μ_n is equal to the historical mean μ_h , i.e., $H_0 : \mu_h - \mu_n = 0$. The appropriate test statistic for this case is (Bethea et al., 1985) :

$$T = \frac{\bar{X}_h - \bar{X}_{ne}}{\sqrt{\frac{S_h^2}{n_h} + \frac{S_{ne}^2}{n_{ne}}}} \quad (5.6)$$

which follows a t-distribution

where :

$\bar{X}_h$ and $\bar{X}_{ne}$ = sample means for the historical and predicted (new) values respectively,
 n_h and n_{ne} = sample sizes for the historical and predicted (new) values respectively,
 S_h and S_{ne} = sample variances for the historical and predicted (new) values respectively.

The degree of freedom for Equation 5.6 is calculated as follows :

$$v = \frac{\left(\frac{S_h^2}{n_h} + \frac{S_{ne}^2}{n_{ne}} \right)^2}{\frac{\left(\frac{S_h^2}{n_h} \right)^2}{n_h - 1} + \frac{\left(\frac{S_{ne}^2}{n_{ne}} \right)^2}{n_{ne} - 1}} \quad (5.7)$$

On the basis of a t-distribution with v degrees of freedom the Null hypothesis for this case, namely that there is no difference between the predicted mean and the historical mean may therefore be rejected if :

$$T > t_{v, 1 - \frac{\alpha}{2}} \quad (5.8.a)$$

or :

$$T < - t_{v, 1 - \frac{\alpha}{2}} \quad (5.8.b)$$

The use of this test is demonstrated by application to the water quality values data sets used earlier in this thesis. The result of these applications are shown in Table 5.16 (and Tables B.5.1 to B.5.3 in the Appendix B).

It can be seen in Table 5.16 [which contains the data set from the MacKenzie River, that, based on the historical (calibration) samples and the set of values predicted by the entropy method, there is a significant change in the mean water quality values for most of the parameters of interest at the Station 130401, i.e., the Null hypothesis can be rejected at the 5% level. Therefore, a conclusion similar to that of the previous less complex comparison of means, namely that changes in the water quality values at Station 130401 are more likely to be the cause of variations in the water quality values observed downstream, can be drawn.

It should also be recognised that the results of this case using the T statistics are in general very similar to those obtained from use of the more simple statistic, namely the significant changes in the water quality parameters observed at the downstream Station 130105, are not reflected in an equivalent magnitude of changes in the predicted values for the upstream stations. However, both cases show, how the entropy

Table 5.16 Hypothesis Testing for the Water Quality Values in the MacKenzie River Sub-Basin

Table 5.16(a) Station 130401

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	408.8	7.8	269.7	235.2	114.7	101.6	37.1	1.7	23.8	13.4
Standard Deviation (Sh)	131	0.3	76.4	68.1	35.9	23	11.6	0.3	7.2	4.5

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	285.6	7.9	199.2	149.1	82.7	92.9	23.0	1.6	17.5	9.8
	298.7	7.9	188.7	162.6	74.1	73.7	31.9	1.5	15.6	9.1
	261.8	7.8	182.2	138.1	75.2	82.3	24.2	1.7	17.0	8.3
	271.4	7.8	182.1	150.3	72.6	77.7	25.0	1.7	16.6	7.9
	293.3	8.0	211.4	158.4	93.0	95.8	25.0	1.7	20.4	10.4
($\bar{X}_{ne}$)	282.2	7.9	192.7	151.7	79.5	84.5	25.8	1.6	17.4	9.1
(S _{ne})	15.3	0.1	12.6	9.5	8.5	9.6	3.5	0.1	1.8	1.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-3.02	0.75	-3.10	-3.42	-2.94	-2.03	-2.83	-0.79	-2.63	-2.87
Degrees of Freedom (v)	9.48	12.46	9.93	7.43	10.81	12.85	11.72	8.43	11.06	10.75
t [v, 0.975]	2.246	2.170	2.230	2.340	2.206	2.163	2.185	2.287	2.200	2.208
t [v, 0.950]	1.823	1.777	1.813	1.880	1.799	1.773	1.786	1.848	1.795	1.800

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	306.1	7.8	208.2	173.6	87.2	86.8	28.2	1.6	18.1	10.4
	295.7	7.8	201.7	169.3	84.4	82.9	28.7	1.6	17.9	9.8
	283.7	7.8	199.1	164.6	83.8	84.4	25.8	1.6	18.3	9.3
	297.5	7.8	210.4	172.4	90.4	89.4	26.1	1.6	19.6	10.1
($\bar{X}_{ne}$)	295.7	7.8	204.9	170.0	86.5	85.8	27.2	1.6	18.5	9.9
(S _{ne})	9.2	0.0	5.3	4.0	3.0	2.9	1.5	0.0	0.7	0.5

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.71	-0.21	-2.67	-2.70	-2.47	-2.13	-2.64	-0.85	-2.31	-2.43
Degrees of Freedom (v)	9.22	9.00	9.22	7.10	9.31	9.67	9.71	7.06	9.46	9.49
t [v, 0.975]	2.255	2.262	2.255	2.359	2.252	2.239	2.238	2.361	2.246	2.245
t [v, 0.950]	1.828	1.833	1.828	1.892	1.827	1.819	1.818	1.893	1.823	1.823

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table 5.16(a) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	306.7	8.0	208.0	168.1	88.9	87.9	27.1	1.6	18.8	10.4
	302.7	8.0	203.7	168.4	86.5	84.3	27.7	1.7	18.5	9.9
	301.2	8.0	209.5	167.4	90.9	89.6	25.6	1.7	19.7	10.2
(X _{ne})	303.5	8.0	207.1	168.0	88.8	87.2	26.8	1.7	19.0	10.2
(S _{ne})	2.8	0.0	3.0	0.5	2.2	2.7	1.1	0.0	0.6	0.2

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.54	1.65	-2.59	-2.79	-2.27	-1.93	-2.77	-0.40	-2.10	-2.27
Degrees of Freedom (v)	9.03	9.02	9.09	7.00	9.22	9.76	9.48	7.63	9.41	9.15
t [v, 0.975]	2.261	2.261	2.259	2.365	2.254	2.236	2.246	2.328	2.248	2.257
t [v, 0.950]	1.832	1.833	1.831	1.895	1.828	1.817	1.823	1.873	1.824	1.830

Note : reject the Null hypothesis if
or $T > t []$
 $T < -t []$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	318.6	8.0	215.9	171.0	92.3	89.6	28.1	1.6	19.7	10.6
	320.1	8.0	218.0	172.8	93.9	90.1	28.5	1.7	20.2	10.7
(X _{ne})	319.4	8.0	217.0	171.9	93.1	89.9	28.3	1.6	19.9	10.6
(S _{ne})	1.1	0.0	1.5	1.3	1.1	0.4	0.3	0.0	0.3	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.16	1.84	-2.17	-2.94	-1.89	-1.56	-2.35	-0.56	-1.67	-1.93
Degrees of Freedom (v)	9.01	9.05	9.03	7.02	9.09	9.02	9.05	7.03	9.17	9.03
t [v, 0.975]	2.262	2.260	2.261	2.364	2.259	2.261	2.260	2.363	2.256	2.261
t [v, 0.950]	1.833	1.832	1.832	1.894	1.831	1.833	1.832	1.894	1.829	1.832

Note : reject the Null hypothesis if
or $T > t []$
 $T < -t []$

Table 5.16(b) Station 130106

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	232.3	7.6	188.6	145.6	83.1	95.4	17.1	3.9	19.8	8.2
Standard Deviation (S_h)	83.2	0.2	68.2	56.1	31.3	33.1	7.2	0.5	7.1	3.8

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	206.5	7.6	159.4	115.9	70.4	86.0	14.3	3.8	16.6	6.8
	209.3	7.6	155.0	120.6	67.0	65.1	16.1	3.7	15.6	6.5
	201.5	7.6	152.3	112.0	67.4	74.5	14.6	3.9	16.3	6.2
	203.5	7.6	152.2	116.3	66.3	69.5	14.7	3.9	16.1	6.1
	208.1	7.7	164.5	119.2	74.5	89.1	14.7	3.9	18.1	7.0
($\bar{X}_{ne}$)	205.8	7.6	156.7	116.8	69.1	76.8	14.9	3.8	16.5	6.5
(S _{ne})	3.2	0.0	5.3	3.3	3.4	10.4	0.7	0.1	0.9	0.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.01	0.33	-1.47	-1.45	-1.40	-1.62	-0.96	-0.30	-1.44	-1.37
Degrees of Freedom (v)	9.05	10.70	9.21	7.08	9.41	11.86	9.33	7.66	9.61	9.38
t [v, 0.975]	2.260	2.209	2.255	2.360	2.248	2.182	2.251	2.326	2.241	2.249
t [v, 0.950]	1.832	1.801	1.829	1.892	1.824	1.784	1.826	1.872	1.820	1.825

Note : reject the Null hypothesis if $T > t_{\alpha/2}$
or $T < -t_{\alpha/2}$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	210.8	8.2	163.2	124.4	72.2	79.4	15.4	3.9	16.9	7.0
	208.6	8.2	160.4	122.9	71.1	75.1	15.5	3.8	16.8	6.8
	206.1	8.2	159.4	121.3	70.9	76.7	14.9	3.9	17.0	6.6
	209.1	8.2	164.0	124.0	73.5	82.1	14.9	3.9	17.6	6.9
($\bar{X}_{ne}$)	208.7	8.2	161.7	123.2	71.9	78.3	15.2	3.8	17.1	6.8
(S _{ne})	2.0	0.0	2.2	1.4	1.2	3.1	0.3	0.0	0.4	0.2

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.90	9.33	-1.24	-1.13	-1.13	-1.61	-0.85	-0.32	-1.22	-1.14
Degrees of Freedom (v)	9.02	9.00	9.05	7.02	9.07	9.36	9.07	7.03	9.12	9.10
t [v, 0.975]	2.261	2.262	2.260	2.364	2.260	2.249	2.259	2.364	2.258	2.259
t [v, 0.950]	1.832	1.833	1.832	1.894	1.832	1.825	1.831	1.894	1.830	1.831

Note : reject the Null hypothesis if $T > t_{\alpha/2}$
or $T < -t_{\alpha/2}$

Table 5.16(b) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	210.90	7.66	163.00	122.50	72.90	80.53	15.14	3.85	17.19	7.01
	210.10	7.66	161.20	122.60	71.90	76.61	15.25	3.89	17.07	6.91
	209.80	7.66	163.60	122.30	73.70	82.34	14.84	3.95	17.65	6.95
($\bar{X}_{ne}$)	210.3	7.7	162.6	122.5	72.8	79.8	15.1	3.9	17.3	7.0
(S _{ne})	0.6	0.0	1.2	0.2	0.9	2.9	0.2	0.1	0.3	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.84	0.95	-1.20	-1.17	-1.04	-1.47	-0.89	-0.02	-1.11	-1.03
Degrees of Freedom (v)	9.00	9.00	9.02	7.00	9.05	9.45	9.05	7.36	9.11	9.01
t [v, 0.975]	2.262	2.262	2.261	2.365	2.260	2.247	2.260	2.343	2.258	2.262
t [v, 0.950]	1.833	1.833	1.833	1.895	1.832	1.824	1.832	1.882	1.831	1.833

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	213.40	7.66	166.40	123.50	74.22	82.44	15.34	3.88	17.68	7.09
	213.70	7.67	167.20	124.20	74.87	82.96	15.42	3.89	17.91	7.13
	213.6	7.7	166.8	123.9	74.5	82.7	15.4	3.9	17.8	7.1
($\bar{X}_{ne}$)	213.6	7.7	166.8	123.9	74.5	82.7	15.4	3.9	17.8	7.1
(S _{ne})	0.2	0.0	0.6	0.5	0.5	0.4	0.1	0.0	0.2	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.71	1.02	-1.01	-1.10	-0.86	-1.21	-0.76	-0.08	-0.89	-0.91
Degrees of Freedom (v)	9.00	9.11	9.01	7.00	9.02	9.01	9.01	7.01	9.05	9.00
t [v, 0.975]	2.262	2.258	2.262	2.365	2.261	2.262	2.262	2.364	2.260	2.262
t [v, 0.950]	1.833	1.831	1.833	1.895	1.833	1.833	1.833	1.895	1.832	1.833

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table 5.16(c) Station 130105

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	343.2	7.8	231.2	189.7	96.7	91.4	29.8	2.6	20.4	10.9
Standard Deviation (S_h)	97.6	0.2	58.7	48.3	28.8	21.2	9.6	0.6	6.3	3.3

[1 Yearly Averaging]**New Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	248.0	7.7	176.7	139.0	71.0	85.0	18.0	3.1	15.0	8.1
	260.0	7.9	167.0	150.0	63.0	61.0	27.0	1.7	13.0	7.5
	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7
($\bar{X}_{ne}$)	244.9	7.8	170.7	141.1	68.0	74.5	20.9	3.3	14.9	7.5
(S_{ne})	14.0	0.3	11.6	7.7	7.9	12.0	3.5	0.9	1.9	0.9

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.80	-0.11	-2.83	-2.79	-2.66	-1.84	-2.39	1.39	-2.31	-2.76
Degrees of Freedom (v)	7.46	6.63	7.84	7.56	8.59	10.97	9.58	6.36	8.83	8.66
t [v, 0.975]	2.338	2.395	2.315	2.332	2.280	2.202	2.242	2.417	2.269	2.277
t [v, 0.950]	1.879	1.913	1.865	1.875	1.844	1.797	1.821	1.926	1.838	1.842

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

[2 Yearly Averaging]**New Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	254.0	7.8	171.9	144.5	67.0	73.0	22.5	2.4	14.0	7.8
	243.1	7.7	164.0	140.0	63.5	66.4	23.1	2.8	13.8	7.1
	230.6	7.6	161.0	135.0	62.8	68.9	19.6	3.9	14.3	6.6
	245.0	7.9	174.4	143.3	71.1	77.3	20.0	3.9	16.0	7.5
($\bar{X}_{ne}$)	243.2	7.7	167.8	140.7	66.1	71.4	21.3	3.2	14.5	7.3
(S_{ne})	9.6	0.2	6.4	4.3	3.8	4.8	1.8	0.7	1.0	0.5

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.87	-0.54	-3.02	-2.85	-2.96	-2.54	-2.42	1.40	-2.58	-3.04
Degrees of Freedom (v)	7.27	7.77	7.32	7.22	7.48	8.31	7.89	5.25	7.70	7.70
t [v, 0.975]	2.349	2.320	2.346	2.352	2.337	2.292	2.313	2.541	2.323	2.324
t [v, 0.950]	1.886	1.868	1.884	1.887	1.878	1.852	1.864	1.997	1.870	1.870

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

Table 5.16(c) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	244.8 240.4 238.8	7.7 7.7 7.8	168.2 163 170	139.7 140 138.9	66 62.8 68.7	72.6 66.3 75.5	21.4 22.1 19.8	2.9 3.1 3.8	14.2 13.8 15.5	7.5 6.9 7.3
($\bar{X}_{ne}$)	241.3	7.7	167.1	139.5	65.8	71.5	21.1	3.3	14.5	7.2
(S _{ne})	3.1	0.1	3.6	0.6	3.0	4.7	1.2	0.5	0.9	0.3

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.95	-0.85	-3.07	-2.94	-2.99	-2.50	-2.51	1.88	-2.58	-3.11
Degrees of Freedom (v)	7.04	8.92	7.14	7.01	7.38	8.45	7.53	4.66	7.69	7.31
t [v, 0.975]	2.363	2.266	2.357	2.365	2.343	2.286	2.334	2.640	2.324	2.347
t [v, 0.950]	1.894	1.835	1.890	1.895	1.882	1.848	1.876	2.055	1.871	1.884

Note : reject the Null hypothesis if
or $T > t_{[]}$
 $T < -t_{[]}$

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	242.3 244.1	7.7 7.8	166.4 169.2	139.8 141.7	64.9 67.3	70.9 71.9	21.1 21.6	3.1 3.3	14.1 14.9	7.2 7.3
($\bar{X}_{ne}$)	243.2	7.7	167.8	140.7	66.1	71.4	21.3	3.2	14.5	7.3
(S _{ne})	1.2	0.1	2.0	1.4	1.7	0.6	0.4	0.1	0.5	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.90	-0.60	-3.05	-2.88	-2.99	-2.66	-2.49	2.52	-2.61	-3.12
Degrees of Freedom (v)	7.01	4.21	7.06	7.04	7.19	7.05	7.07	6.99	7.36	7.05
t [v, 0.975]	2.364	2.732	2.361	2.362	2.354	2.362	2.361	2.366	2.344	2.362
t [v, 0.950]	1.895	2.107	1.893	1.893	1.888	1.893	1.892	1.895	1.882	1.893

Note : reject the Null hypothesis if
or $T > t_{[]}$
 $T < -t_{[]}$

method can be used, not just to predict water quality values at discontinued monitoring station, but also how the results can be used to identify the most likely location(s) of changes which are causing variations in the water quality values being observed at some downstream point.

CHAPTER 6

SUMMARY AND CONCLUSION

Efficient water quality monitoring is a very complex problem involving definition of the objectives of monitoring, the amount of information to collect including which parameters to monitor and the value of that information, and the costs associated with the establishment and maintenance of both the monitoring network itself and the monitoring program to be undertaken with that network. While establishment of a water quality monitoring network and program is very costly, the assessment, in economic or quantitative terms, of the benefits accruing as a result of that monitoring is a difficult, if not impossible, task at this time.

However, with the current, and increasing, emphasis on the protection and enhancement of the environment, water quality and its monitoring has been, and continues to be, the focus of attention by water authorities, governments, special interest groups and the general public. Optimisation of water quality monitoring networks has therefore been given an

increasing level of attention by researchers in recent times. Even with the increased emphasis on the environment and the associated consideration of water quality in water resources projects and allocation of budget to monitoring and improving that water quality, in particular cases, when budget is limited, it is not unlikely that discontinuation of existing water quality monitoring stations has to be undertaken.

Reasons for discontinuation of existing stations may be that the cost of operating water quality monitoring is increasing over time with the budget allocated to the monitoring remaining static or not increasing to keep pace with the increasing cost of operation, or monitoring has to be undertaken at another location where the need is more acute. Loss of information due to the discontinuation of existing monitoring stations has the potential to cause decisions, which would have previously been made on the basis of information derived from the discontinued station, to be inappropriate. A new approach to the prediction of water quality values at discontinued monitoring stations has been proposed in this thesis and its value and advantages over a more traditional regression based method demonstrated.

The model has been formulated and validated for

use for monitoring networks on river systems characterised by a number of monitoring stations located on upstream tributaries or on the upstream portions of the mainstem of the river, and a station located on the mainstem downstream of all these stations. The particular problem for which the technique was developed arises when the upstream stations are discontinued and only the downstream mainstem station remains in operation. Water quality values at the discontinued upstream stations are then predicted on the basis of 1) the observed water quality values at the downstream station and 2) the probability distributions of water quality known to exist at the upstream stations prior to their discontinuation. This process assumes that upstream stations were in operation for a period of time sufficient to define adequately the probability distributions of the water quality parameters at these stations.

The approach is based on entropy 'information' theory and is shown to improve the accuracy of prediction of water quality values under the conditions outlined above. The actual technique of prediction is based on the Principle of Maximum Entropy (POME) as articulated in a non-linear programming formulation in which probability is assigned, in an unbiased manner, to all possible event/outcomes, i.e., values of water

quality parameters, at discontinued monitoring stations on the basis of information about prior conditions at those stations. The assignment of these probabilities is performed in a manner which maximises the mathematical statement of the entropy function.

The method also utilises the Minimum Discrimination Information principle wherein, since the characteristics of the basin are reflected in the historical observations, the probability regime predicted by the formulation has to fulfil specified constraints as well as making the predicted probability distributions as close as possible to the observed historical (prior) probability distributions.

Application of the model to water quality monitoring networks in Queensland, Australia demonstrates the power of the technique and reveals a number of advantages that complement the inherent unbiased nature of its predictions. In the first instance the model performs better in predicting water quality values at the upstream stations than traditional techniques such as regression (It should be noted that regression analysis also requires the same level of prior data as the entropy formulation). In fact, in the demonstration examples, in comparison with the regression method using the same data, the entropy

method makes more accurate predictions in terms of the average error 61% of the time. The largest error in prediction from the entropy based formulation being 26.90% smaller than the largest error derived from regression method. Similarly the overall average maximum error in prediction is 4.72% smaller for the entropy method than that for the regression procedure.

The method is also able to incorporate knowledge about changing conditions in the basin through modification of the 'prior' probability term used in the formulation. Care has to be taken, however, in modifying these prior probability terms in order to avoid eliminating one of the strengths of the technique, namely the unbiased nature of its predictions, by inappropriately prejudicing the results.

In the original formulation of the model the water quality values on each tributary were assumed to be independent of each other. The model was modified to allow for consideration of statistical dependency where such dependency was observed. However, it was found that inclusion of this dependency did not improve the performance of the model in terms of the accuracy of the predictions. Furthermore, inclusion of the dependency increases the size (number of variables) of

the formulation significantly with, because of the non-linear nature of the formulation, an associated exponential increase in computational time and effort. For this reason, unless there are overriding reasons, it is not recommended that dependency be included in the formulation.

The entropy function upon which the approach is based assumes discrete probability distributions for the events under consideration. Hence, when the model is applied to prediction of water quality it is necessary to discretize the range of water quality values. Previous application of entropy theory to problems involving continuous variables indicated that the level (fineness) of the discretization had a significant impact on the accuracy of the results and the decisions that would be made on the basis of these results. The particular application described in the thesis appears to be relatively insensitive to the level of discretization as demonstrated by the result that changing the discretization from 48 to 8 intervals caused less than 1% change to the predicted water quality values.

Furthermore, although the entropy approach assumes a normal distribution for the variables, experience with the model in the case study indicates that the

model is quite robust, with similar results and in fact better predictions, being obtained when normal distribution is assumed and applied to data which are not strictly normal.

The method was also shown to have the potential for assisting in the identification of the most likely locations of causes of changes to water quality which are being observed at a downstream monitoring station.

The combination of these features indicate that the approach has considerable potential for prediction of water quality values at discontinued monitoring stations in certain spatial configurations and is therefore an important step forward in the area of prediction of water quality values.

There are still a number of areas, however, which require further investigation before the model can be implemented on an operational basis. In the first instance there is a need for an analysis of how prior knowledge about changes in the basin can be most appropriately incorporated into the model. In particular, there is a need to develop some better understanding of the appropriate magnitude of the quantitative changes that should be made to the prior probability in order to reflect the known changes in

the system.

Further work is also required to determine how water quality distributions which are very different from normal might be handled by the formulation.

There is also considerable merit in undertaking a more comprehensive range of case studies using different data bases to validate the performance of the technique on a more global basis.

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ENTROPY PRINCIPLES IN THE PREDICTION OF
WATER QUALITY VALUES
AT DISCONTINUED MONITORING STATIONS

By

Agus Suprpto Kusmulyono

A Thesis Submitted to
the Central Queensland University
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for the Degree of

DOCTOR OF PHILOSOPHY

VOLUME II
[Appendices]

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Appendix A

Table A.1(a) Water Quality Records in the Fitzroy River Basin

Station 130322

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
26 11 64	200	7.3	176.2	124	65	72	26.5	0.0	16.0	6.0
9 6 65	405	8	279.2	274	84	100	54.0	0.0	24.0	5.8
7 1 66	175	8.2	165.2	105	64	80	23.0	0.0	14.0	7.0
17 5 66	255	8	217.2	152	86	104	28.0	0.0	26.0	5.0
29 1 67	190	7.6	182.1	133	50	80	34.0	0.0	10.0	6.0
29 1 67	202	7.7	182.1	133	50	80	34.0	0.0	10.0	6.0
30 1 67	266	8.2	270	0	100	110	38.0	0.0	30.0	6.0
30 1 67	168	7.9	182	0	50	75	31.0	0.0	18.0	6.0
20 2 68	70	8	64	0	12	24	15.0	0.0	3.0	1.0
23 11 69	280	6.9	210.7	0	65	90	36.0	0.0	22.0	2.5
24 11 69	250	6.9	190.7	0	65	90	29.0	0.0	16.0	6.0
26 11 69	250	7	174.1	0	75	85	20.0	0.0	20.0	6.0
11 12 70	100	7	76.3	0	32	36	9.0	0.0	8.0	3.0
12 12 70	114	6.9	91.3	0	33	46	12.0	0.0	10.0	2.0
15 12 70	127	6.8	111.3	0	35	52	18.0	0.0	9.0	3.0
16 12 70	123	6.8	103.3	0	35	52	15.0	0.0	9.0	3.0
18 12 70	130	6.8	103.3	0	35	52	15.0	0.0	9.0	3.0
19 12 70	140	6.8	109.3	0	44	58	13.0	0.0	11.0	4.0
20 12 70	140	6.9	110.3	0	46	58	12.0	0.0	12.0	4.0
21 12 70	150	6.9	113.3	0	51	58	12.0	0.0	12.0	5.0
9 2 71	100	8	72.6	0	26	36	10.0	0.0	4.0	4.0
10 2 71	93	7.8	72.6	0	26	36	10.0	0.0	4.0	4.0
14 2 71	130	7.6	103.6	0	49	54	10.0	0.0	8.0	7
8 6 71	345	7.1	237.1	0	89	96	37.0	0.0	24.0	7.0
26 11 71	790	7.9	491.3	0	142	120	110.0	0.0	32.0	15.0
9 4 73	215	8	176.1	132	62	88	21.3	6.6	15.0	6.0
3 12 73	300	7.9	170.5	135	61	82	21.0	5.8	17.0	4.6
2 4 74	170	7.8	113.9	100	36	44	18.0	4.6	8.0	4.0
3 7 74	225	7.6	167.9	133	58	76	22.0	6.8	15.0	5.0
5 1 75	145	7.1	111.6	92	51	54	12.0	5.1	12.5	4.7
30 9 76	230	7.5	174.7	136	59	80	22.0	6.3	15.0	5.2
5 10 76	190	7.5	137.9	113	50	55	18.0	5.6	13.0	4.2
9 12 76	150	7.6	114	96	43	52	13.0	5.5	12.0	3.1
6 4 77	115	7.7	79.2	72	33	32	9.8	5.4	8.4	2.8
14 12 77	175	7.8	133.6	102	41	60	17.0	4.7	10.0	4.0
16 3 78	190	7.4	146.3	122	49	66	18.0	5.5	12.0	4.5
13 4 81	185	7.5	141.2	110	57	71	12.0	5.0	18.0	3.0
1 6 84	215	7.8	170.9	140	64	83	21.0	5.8	17.0	5.3
23 8 84	190	7.6	148.7	150	47	63	21.0	6.2	12.0	4.1
15 12 84	315	7.9	217.6	180	77	91	31.0	5.3	18.0	7.8
9 3 85	205	7.8	165	140	56	77	17	6.7	14.0	5.2
21 12 85	285	7.6	190.9	160	66	77	26.0	6.0	16.0	6.2
16 3 86	265	8	177.2	140	58	72	27.5	5.4	14.5	5.4
14 12 86	170	7.2	120.8	110	44	55	15.0	4.6	11.0	3.9
26 6 87	275	8	196.8	150	71	87	25.0	5.5	17.0	7.0
14 12 87	170	7.8	122.8	100	44	60	14.0	4.3	11.0	4.1
11 4 88	210	7.6	154	120	54	75	17.5	6.3	13.5	5.0
23 7 88	180	7.5	135.1	100	49	69	14.0	5.1	12.5	4.2
29 8 89	275	7.6	191.4	150	75	82	26.0	5.0	19.0	6.6
7 9 89	260	7.8	183.4	140	71	79	24.0	4.6	18.0	6.2
7 9 89	245	7.8	181.5	140	67	79	23.5	4.4	17.0	6.0
30 11 89	215	7.3	144.9	120	53	69	18.5	5.0	14.0	4.3

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(a) Water Quality Records in the Fitzroy River Basin (continued)

Station 130105

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yy)										
1 9 72	260	7.7	197.1	146	75	82	30.0	-	17.0	8.0
12 12 72	300	7.7	202.2	151	86	82	28.0	-	18.0	10.0
21 3 73	175	7.7	125.3	104	51	60	13.9	2.9	10.5	6.0
27 3 73	230	7.1	154.9	136	63	60	20.0	1.6	12.5	7.7
5 6 73	205	8.1	143.7	117	60	64	13.8	2.8	13.5	6.5
18 9 73	250	8.1	214.4	186	73	72	25.0	2.5	16.0	8.0
27 3 74	180	7.2	123.3	105	48	52	14.0	2.7	10.0	5.5
7 8 74	440	8.0	299.6	248	129	115	38.0	1.8	26.0	15.6
13 11 74	430	7.7	277.7	229	114	105	36.0	2.0	22.0	14.4
8 1 75	155	7.1	118.0	88	61	54	12.0	3.5	14.0	6.3
8 1 75	153	7.1	113.3	87	61	50	12.0	3.6	14.0	6.3
8 1 75	153	7.0	112.1	105	57	50	11.5	3.4	13.0	6.0
10 1 75	147	7.0	115.6	106	53	56	11.0	3.7	12.0	5.7
12 1 75	135	7.0	104.4	96	45	54	9.0	3.9	11.0	4.3
13 1 75	130	7.1	97.3	90.0	43	52	3.5	4.2	10.0	4.3
13 1 75	130	7.0	101.8	90.0	43	52	8.0	4.2	10.0	4.3
13 1 75	130	6.9	98.8	88	44	50	8.5	4.2	10.5	4.3
16 1 75	155	7.1	125.1	103	60	66	9.5	4.3	14.0	6.0
16 1 75	155	7.0	122.8	106	58	66	9.0	4.0	13.5	6.0
16 1 75	157	7.2	134.5	119	62	66	9.5	3.9	14.5	6.3
16 1 75	157	7.1	124.8	106	62	66	9.5	4.2	14.5	6.3
20 1 75	142	7.1	108.4	99	50	54	9.5	3.9	12.0	4.8
20 1 75	142	7.0	106.7	95	47	54	9.0	3.8	11.0	4.7
20 1 75	142	7.1	108.7	96	47	56	9.0	3.8	11.0	4.7
21 1 75	160	7.1	119.6	107	54	62	10.0	4.2	13.0	5.2
21 1 75	160	7.1	121.2	104	51	64	10.0	4.2	11.5	5.3
21 1 75	160	7.1	121.7	107	52	64	10.0	4.2	12.0	5.3
22 1 75	172	7.1	131.2	110	57	68	11.0	4.0	13.0	6.0
22 1 75	175	7.2	131.0	112	56	68	11.0	4.1	13.0	5.7
22 1 75	170	7.2	133.0	112	56	70	11.0	4.1	13.0	5.7
24 1 75	185	7.2	143.8	117	60	75	11.5	4.1	14.0	6.0
24 1 75	187	7.2	145.8	121	65	75	11.5	4.1	16.0	6.0
24 1 75	185	7.2	158.6	135	65	74	11.5	4.1	16.0	6.0
28 1 75	197	7.2	151.4	121	63	80	13.0	3.9	15.0	6.3
11 2 75	220	7.4	162.4	131	68	82	16.0	3.7	15.5	7.0
29 9 75	370	7.6	237.4	195	99	102	29.0	2.2	20.0	12.0
15 12 75	115	7.6	75.4	75	24	28	10.0	3.1	5.3	2.7
5 8 76	555	8.4	351.3	295	164	125	50.0	1.6	36.0	18.0
25 10 76	670	8.0	409.7	342	186	140	60.0	2.0	38.0	22.0
15 12 76	325	8.0	247.5	185	101	119	26.0	4.2	24.0	10.0
10 1 77	250	7.5	157.3	138	67	62	20.0	2.5	16.0	6.6
18 4 77	350	8.1	233.2	196	100	100	29	2.0	22.0	11.0
26 7 77	380	8.2	256.9	206	104	116	30.0	2.4	22.0	12.0
4 10 77	460	8.1	346.8	276	138	146	40.0	2.4	29.0	16.0
5 1 78	405	8.1	292.8	236	122	115	37.0	3.6	24.0	15.0
20 11 78	330	7.9	223.5	177	99	96	28.0	3.2	23.0	10.0
2 6 80	375	7.3	228.7	201	104	80	32.0	1.4	22.0	12.0
18 9 80	400	7.5	253.9	217	107	89	38.0	1.6	23.0	12.0
13 11 80	460	7.8	284.8	242	112	91	45.0	2.3	20.0	15.0
23 7 81	248	7.7	176.7	139	71	85	18.0	3.1	15.0	8.1
19 8 82	260	7.9	167.0	150	63	61	27.0	1.7	13.0	7.5
15 3 84	165	8.2	129.0	100	53	60	13.0	3.9	12.0	5.6
18 6 84	290	6.9	196.9	160	77	82	26.0	3.5	17.0	8.4
17 9 84	200	7.4	157.0	120	65	78	15.0	3.8	15.0	6.8
4 12 84	250	7.4	161.2	140	61	67	23.0	4.0	14.0	6.2
4 3 85	265	7.4	184.0	150	72	77	22.0	3.8	16.0	7.8
3 12 85	205	7.9	137.9	130	51	55	18.0	4.0	12.0	5.0
13 3 86	205	8.3	154	120	66	80	13.0	4.0	16.0	6.2
24 6 86	225	8	174.9	140	72	81	19.0	3.6	16.0	7.8
26 9 86	335	8.3	234.9	180	104	105	28.0	3.8	22.0	12.0
7 1 87	225	7.8	267.3	130	63	73	18.0	4.1	15.0	6.1
31 3 87	220	7.7	165.7	140	69	83	17.0	4.7	16.0	7.0
16 12 87	185	7.5	118.7	99	51	51	12.5	3.3	12.0	5.2
4 10 88	200	7.1	128	110	55	51	15.5	2.8	13.0	5.5
26 6 89	330	7.8	175.6	150	72	76	24.0	2.2	15.0	8.4
8 12 89	210	8	155.5	130	59	65	20.0	2.8	13.0	6.4

Source : Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(a) Water Quality Records in the Fitzroy River Basin (continued)

Station 130003

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
2 2 64	225	7.6	170.4	130	72	69	23.0	0.0	14.0	9.0
24 6 64	246	7.3	197.1	140	89	75	25.0	0.0	16.0	12.0
1 9 64	370	8	235.1	156	92	80	39.0	0.0	17.0	12.0
24 11 64	274	7.7	215.5	162	111	113	16.0	0.0	28.0	10.0
1 3 65	236	6.7	203.6	140	65	80	34.0	0.0	16.0	6.0
5 4 65	255	7.6	199.3	140	112	105	12.0	0.0	20.0	15.0
9 12 65	100	7.5	104.2	0	62	50	6.0	0.0	10.0	9.0
29 3 73	177	7.9	134	104	53	66	14.2	3.6	12.0	5.5
26 7 73	190	7.8	147.2	114	62	66	16.0	5.5	15.7	5.6
2 10 75	430	7.5	265.4	215	113	105	35.0	3.0	22.0	14.0
6 8 76	790	7.9	483.2	416	224	135	70.0	1.8	45.0	27.0
14 1 77	280	7.8	174.6	152	72	65	22.0	2.9	17.0	7.1
22 4 77	113	8	238.6	204	111	95	31.0	2.5	23.0	13.0
25 7 77	450	8.2	309.8	257	128	112	40.0	3.0	25.0	16.0
3 10 77	510	8.1	356.2	292	144	130	46.0	2.6	28.0	18.0
4 1 87	405	8.1	284.2	235	115	102	38.0	4.0	23.0	14.0
16 3 78	310	7.7	215	187	86	80	29.0	2.4	18.0	10.0
8 6 78	545	8.2	366.9	318	157	112	51.0	3.0	30.0	20.0
28 5 80	320	7.4	213.6	180	93	88	26.0	2.3	19.0	11.0
23 9 80	330	7.6	224.6	177	89	89	28.0	2.2	19.0	10.0
25 5 82	270	7.1	164.4	150	70	60	23.0	2.0	15.0	7.8
20 8 82	290	7.6	186.1	150	73	67	29.0	1.8	15.0	8.7
12 10 84	205	8.3	151.4	120	51	69	18.0	4.7	13.0	4.5
12 3 85	245	7.7	173.6	140	68	76	20.0	4.7	15.0	7.4
26 6 85	160	7.9	111.6	110	47	42	14.0	3.8	11.0	4.8
2 12 85	160	7.6	108.2	110	46	46	12.0	3.0	10.0	5.0
26 3 86	305	7.8	204.1	170	85	87	25.0	4.0	19.0	9.0
25 6 86	390	7.9	268	210	108	104	35.0	5.2	22.0	13.0
25 9 86	485	8	310.7	280	120	95	51.0	4.4	21.5	16.0
6 1 87	230	7.8	156.3	130	60	65	20.0	4.4	14.0	6.1
11 3 87	335	8	234.7	190	80	95	29.0	4.9	19.0	8.0
25 6 87	300	7.5	192.5	160	73	68	29.0	3.9	16.0	8.1
4 7 88	350	7.7	236.5	200	103	87	32.0	3.5	25.0	9.9
10 11 88	390	7.4	239.2	200	102	76	32.0	4.4	19.5	13.0
25 5 89	165	7.4	113.9	98	48	51	14.0	3.1	11.0	4.9
26 5 89	175	7.7	122.2	100	52	54	16.0	3.8	12.0	5.3
27 5 89	195	7.3	131.2	110	57	54	17.0	2.9	12.0	6.6
31 5 89	150	7.1	102.9	96	42	40	15.0	3.4	9.0	4.7
4 6 89	185	7.5	130.9	110	50	59	16.0	3.3	11.5	5.2
6 6 89	190	7.5	135.9	110	53	60	16.5	3.1	12.0	5.7

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(b) Water Quality Records in the Nogoa River Basin

Station 130202

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
30 8 72	320	7.8	210	151	125	96	25	0	32	11
28 11 72	120	7.4	90.1	60	40	48	9	0	6	6
10 4 73	142	7.8	133.6	87	47	58	8.5	6	12	4.2
31 5 73	172	7.8	144.9	99	60	76	9	4.5	16.4	4.7
7 8 73	190	8.4	141.8	108	70	68	12	4.3	19.5	5.2
6 12 73	150	8	119.9	89	57	66	9.5	1.7	15.2	4.5
26 3 74	350	7.4	269.2	200	113	130	26	5.8	29.4	9.6
10 6 74	330	7.5	224.8	182	97	84	25	7.4	24	9
23 9 74	335	8.5	246.4	198	98	95	26	7	25	8.7
15 10 74	245	7.7	174	137	75	78	20	5.5	20	6
2 12 74	170	7.3	135.4	115	61	70	12	5.2	16	5
19 8 75	380	7.5	257.2	200	115	108	29	5.8	31	9
3 11 75	170	7.4	138.7	110	51	78	15	4.2	14	3.8
2 3 76	155	7.1	111.3	93	49	56	11	5	13	4
10 5 76	240	7.2	176.7	138	76	84	17	4.9	19	7
6 9 76	395	7.3	273	215	115	98	33	6	31	9.2
21 3 77	206	7.8	161.9	129	65	84	15	5.3	18	4.9
11 7 77	475	7.9	306.4	248	123	104	42	6	31	11
16 1 78	225	7.4	178.2	128	78	98	12	4.6	25	3.8
21 8 78	310	7.3	208.8	181	73	60	31	5.5	17	7.5
28 11 80	150	7.8	111.5	83	47	58	10	2.9	13	3.6
26 2 82	150	7.6	115.9	90	49	57	8.5	4.4	13	4
4 4 82	170	8	128.6	100	50	66	9.5	4.3	13	4.3
22 2 83	140	7.5	104.9	87	39	45	10.5	5	10.5	3.2
23 2 83	170	7.6	124.4	94	49	62	9.8	5.9	12	4.5
24 2 83	155	7	126.9	100	48	60	11	6.2	12	4.3
22 3 83	125	7.5	100.2	80	40	52	12	4.5	11	3
22 3 83	110	7.5	93.9	92	32	41	11	5	8	3
4 7 83	220	7.4	163.6	140	68	75	19	4.2	18	5.5
23 9 83	530	7.5	353.9	290	135	103	54	6.4	31	14
15 12 83	210	7.6	163.7	130	61	82	17	5.6	16	5.1
14 3 84	365	7.9	250.3	200	100	104	30	5.3	26	8.6
25 8 84	320	8.5	248.4	200	85	108	31	6	20	8.5
2 9 85	190	7.4	135.8	110	46	64	17	4.4	13	3.4
30 1 86	155	8	118	95	51	58	10	6.3	13	4.5
29 10 86	160	7.9	124.8	100	48	62	12	4.7	13	3.7
8 8 87	145	6.5	105.5	89	41	45	12	4.8	11	3.2
4 11 87	160	7.4	127.7	100	50	62	13	5.6	14	3.7
13 1 88	170	7.3	128.8	98	53	71	11	4.9	15	3.7
17 4 88	125	7.2	91.5	74	35	44	8.3	4.7	9.4	2.8

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(b) Water Quality Records in the Nogoa River Basin (continued)

Station 130212

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
4 12 72	290	7.5	247.1	159	122	142	17	0	39	6
24 2 73	140	7.2	114.6	76	44	62	15	0	6.4	6.8
17 4 73	140	7.5	131.4	96	40	62	13	10	11	3
20 9 73	150	7.5	137.1	95	51	70	14.6	5.3	14	4
1 4 74	130	6.9	89.9	74	34	43	10	4.8	9	2.9
17 10 74	115	7.3	93.7	81	46	40	10	3.7	13	3.2
4 12 74	172	7.3	140.9	102	56	76	12	5.7	15.5	4.3
30 1 75	100	7.3	76.5	71	47	42	0.8	3.6	13.5	3.1
15 4 75	195	7.5	151	127	68	82	14	4.9	19	5
12 12 75	120	7	91.1	75	38	52	8.6	3.1	11	2.6
19 2 76	425	7.6	314.4	236	135	164	35	3.6	39	9
29 6 76	520	7.6	386.6	275	171	188	42	3.6	52	10
7 1 77	145	7.5	115.9	89	47	60	11	3.9	14	2.9
7 3 77	145	7.6	118.2	94	51	60	11	4.7	15	3.2
26 8 77	820	8.3	593.6	454	219	240	85	4.5	58	18
20 10 77	855	7.9	562.2	437	182	209	103	5	40	20
10 1 78	355	7.4	263.5	202	115	120	25	5.4	36	6
14 3 78	370	7.5	260.5	201	102	124	33	3.6	29	7.2
6 6 78	530	8	424.4	324	157	170	62	5.5	43	12
27 7 78	155	7.3	137.1	108	55	64	17	3.2	15	4.2
24 11 80	144	7.8	114.3	87	44	59	11	3.5	12	3.3
6 1 81	120	7.2	118.6	104	55	41	8.8	9	10	7.2
27 2 83	170	7.4	134.5	100	54	72	11	5.2	15	4
30 7 83	255	7.5	208	170	90	107	22	3	26	6
20 9 83	250	6.8	204.2	140	90	111	21	4.2	26	6
18 12 83	210	8.3	190.6	180	78	96	14	5.9	21	6.3
20 2 84	345	8.1	276.6	200	133	154	18	4	40	8.1
26 8 84	150	6.9	115.5	94	46	63	11	3.6	13	3.2
29 11 84	195	7.2	155.1	120	61	86	13	5	17	4.5
30 11 85	125	7.7	97.2	80	37	51	9.5	4.5	10	2.8
28 1 87	120	7.4	95.8	71	36	49	10	3.6	11	2
4 11 87	185	7.3	154.5	110	65	86	14	5	19	4.2
12 1 88	165	7.2	133.9	110	50	70	11	7.8	14	3.7
27 3 88	180	7.2	141.7	100	59	80	11	4.4	17	4

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(b) Water Quality Records in the Nogoa River Basin (continued)

Station 130209

Date Sampled	CONDUCTIVITY @ 25 C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
30 8 72	210	7.5	164.1	111	61	86	20	0	18	4
5 12 72	145	7.2	115.4	76	41	62	16	0	8	5
19 2 73	127	7.5	167.2	86	45	58	6.8	9.8	10.8	4.3
28 2 73	147	8.1	159.8	113	84	70	10	6.5	22	7
1 3 73	159	8	148.7	97	60	72	7.9	6.5	15.3	5.2
5 3 73	158	8.2	140.4	93	60	76	15	0	14.4	5.8
8 3 73	169	7.6	145.3	97	64	78	15	0	16.8	5.3
16 3 73	198	7.9	174	121	80	90	9.6	5.7	21	6.7
10 4 73	153	7.7	146.3	96	54	66	8.7	6	14	4.7
6 8 73	175	7.9	142.1	100	71	74	10.6	4.5	19	5.6
5 12 73	140	7.6	121	89	60	64	11.8	1.6	15.7	5
25 3 74	420	7.9	331.5	238	170	190	22	4.2	35	20
20 8 74	245	7.6	207.6	158	94	92	15	5.4	13	15
27 11 74	168	7.3	142.5	121	59	75	13.5	5.4	15	5.3
31 1 75	160	7.6	129.5	108	61	66	11	5.6	16	5
6 5 75	240	7.8	190.6	143	85	104	19.5	4.6	21	7.9
7 10 75	261	7.5	192.2	135	88	106	15	4.6	21	8.6
15 12 75	134	7.2	100.5	75	42	56	9.3	3.3	12	3
30 3 76	345	7.5	263.2	195	134	146	22	3.5	24	18
12 7 76	880	8.3	708.3	478	271	388	92	3.6	26	50
8 7 77	730	8.4	577.5	410	277	312	53	3.2	45	40
23 8 77	735	8.8	473.3	335	196	245	57	3	11	41
25 1 78	220	7.9	187	132	80	108	11	5	23	5.5
4 5 78	310	7.6	267.8	206	99	132	29	5.1	23	10
10 8 78	350	7.6	267.6	202	112	134	32	3.5	20	15
23 8 80	160	7.5	111.2	91	47	48	13	3.4	13	3.5
5 3 81	193	7.6	162.6	125	65	87	11	4.8	17	5.4
23 9 81	230	7.8	165.3	123	70	78	16	3.7	18	6.1
14 12 82	205	7.6	160.9	120	58	86	15	4.9	15.5	4.8
12 4 83	165	7.2	135.6	110	56	66	15	4.9	16	4
6 10 83	155	7.5	127.7	120	50	66	12	5.5	13	4.3
15 12 83	175	7.5	139.5	110	56	70	12	5.1	15	4.6
13 3 84	255	7.5	198	150	79	99	20	4.7	20	7.1
24 8 84	235	7.4	178.9	140	68	91	19	4.4	16	6.9
30 11 84	305	7.5	231.6	180	87	111	25	6.6	20	9.1
2 9 85	230	7.3	164.2	140	64	63	16	5.3	17	5.3
1 12 85	185	7.6	131.4	100	51	68	13	4.6	14	4
29 1 86	165	8.2	123.5	95	53	65	9.6	5.3	14	4.3
30 10 86	185	8	141	110	57	72	13	4.5	15	4.8
24 3 87	190	7.5	156.6	120	68	86	11	5.1	19	4.9
2 7 87	115	7.5	96.8	77	37	46	12	5.4	10	3
10 12 87	210	7.6	158.7	120	70	86	12	5.6	19	5.4
26 3 88	160	7.4	128.7	100	54	71	11	5	15	3.9
6 11 88	180	7.4	135.3	110	54	71	12	4.8	15.5	3.7
14 1 89	205	8.2	165	130	62	88	17	4.8	16	5.4
11 8 89	185	7.5	143	100	54	72	15	3	14	4.7
6 9 89	250	7.8	181.8	130	79	83	19	3.9	20	7.1
6 9 89	235	8	180.5	130	78	83	19.5	3.6	20	6.8
19 11 90	150	8.2	125.9	100	49	54	12.5	4	13	3.9

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(c) Water Quality Records in the Logan River Basin

Station 145010

Date Sampled			CONDUCTIVITY	PH	DISSOLVED IONS	DISSOLVED SOLIDS	HARDNESS	ALKALINITY	NATRIUM	KALIUM	CALCIUM	MAGNESIUM
			25C									
			(mS/m)		(mg/l)	(mg/l)	(mg/l) as CaCO ₃	(mg/l) as CaCO ₃	(mg/l)	(mg/l)	(mg/l)	(mg/l)
(dd	mm	yr)										
12	10	65	425	8	303.3	280	141	104	40	0	30	16
16	2	66	460	8	318.9	255	166	117	33	0	41.6	15.1
19	5	66	430	8.5	286.6	232	158	102	26	0	40.8	13.6
25	10	66	483	8.2	352.1	290	167	129	44	0	34	20
10	11	66	299	6.7	228.1	171	106	92	28	0	26	10
28	9	67	750	7.5	521.2	409	279	180	54	0	54	35
23	2	68	202	7.2	152.1	115	72	60	18	0	14	9
23	4	68	340	7.4	225.1	172	118	84	24	0	24	14
11	10	68	530	7.2	346.1	268	242	125	14	0	36	37
21	4	71	456	8.1	312.2	244	150	110	39	0	27	20
18	6	71	530	7.9	446.1	354	232	148	51	0	40	32
27	7	71	748	8	502	400	265	165	57	0	40	40
28	9	71	830	8	535.4	419	289	188	52	0	48	41
10	11	71	865	7.5	552.4	436	302	188	58	0	50	43
13	1	72	650	7.7	468.5	353	250	165	52	0	26	45
9	3	72	180	7	148.4	107	72	66	16	0	14	9
10	3	72	185	7.1	163.3	118	76	72	19	0	14	10
21	6	72	310	7.9	202.1	157	125	72	15	0	22	17
9	8	72	405	7.3	313.2	245	144	110	41	0	28	18
11	10	72	530	7.4	364.1	286	199	125	37	0	40	24
17	1	73	450	7.5	330.1	252	150	125	43	0	32	17
8	3	73	194	7.8	132.1	100	60	52	17	0	11	8
10	5	73	450	8.1	291.3	241	170	104	24.8	0.3	31.8	22
10	7	73	155	7.5	113.4	102	56	42	11.5	1	7	9.4
24	8	73	307	7.7	219.2	189	122	80	21	0.5	20.5	17.1
17	10	73	310	8.2	223.6	175	114	86	22	1.1	21	15
28	3	74	256	8.2	191.3	168	94	75	20	1.1	16.6	12.8
31	7	74	564	8	366.1	305	203	135	36	1	36	27.5
11	9	74	655	8.1	406.5	336	227	150	40	2	40	30.8
5	11	74	455	8.3	278.3	283	135	108	33	1.3	21	20
14	2	78	360	7.8	219.4	196	116	87	24	1.2	20	16
4	4	78	310	7.9	192.9	177	101	74	22	1.6	19	13
12	4	78	370	7.5	220.3	200	118	76	24	1.4	21	16
4	7	78	530	7.4	338.7	296	188	105	35	1.6	34	25
26	9	78	560	7.7	402.3	333	208	148	40	1.6	37	28
30	7	79	155	6.8	89.9	95	42	23	12	1.9	8.1	5.4
30	7	79	140	6.7	93.7	93	42	26	15	1.9	7.7	5.6
25	2	80	390	8	260.4	222	132	106	26	1.4	23	18
15	5	80	150	7.8	97.2	96	45	35	11	0.9	8.2	6
29	10	80	540	7.7	347.4	292	172	135	35	1.8	31	23
2	6	81	380	7.8	244.3	212	87	86	39	1.9	15	12
27	8	81	406	8.4	251.8	217	129	93	24	0.9	22	18
12	1	82	480	8.2	336.2	280	166	142	33	1.5	30	22
17	3	82	180	7.7	111.7	110	52	49	12	1	9.7	6.8
17	8	82	540	8.2	336.3	280	180	126	35	1.1	31	25
19	10	82	330	8.1	229.8	200	116	95	20	2	20	16
18	1	83	315	7.6	208.2	180	101	91	22	1.6	16.5	14.5
13	4	83	330	8.3	217.9	190	112	84	26	2.2	20	15
15	6	83	330	8.3	214.8	180	109	88	25	0.9	19	15
31	8	83	440	8.2	295.5	250	147	121	34	1	26	20
1	11	83	610	7.9	414.2	340	205	166	40	1.6	36	28
10	11	83	610	7.9	413.7	340	205	166	40	1.6	36	28
19	1	84	305	7.9	206.8	180	98	91	21	1.2	18	13
21	3	84	425	7.9	291.6	240	145	116	29	1	25	20
9	4	84	115	7.5	81.7	83	34	31	9.1	1.6	6.4	4.3
21	5	84	345	8.0	230.0	190	113	108	24	1.1	22	14
22	8	84	480	8.2	343.8	280	171	138	34	1	29	24

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Station 145010 (continued)

Date Sampled			CONDUCTIVITY	P _H	DISSOLVED IONS	DISSOLVED SOLIDS	HARDNESS	ALKALINITY	NATRIUM	POTASSIUM	CALCIUM	MAGNESIUM
			25C									
			(mS/m)		(mg/l)	(mg/l)	(mg/l) as CaCO ₃	(mg/l) as CaCO ₃	(mg/l)	(mg/l)	(mg/l)	(mg/l)
(dd	mm	yr)										
7	11	84	375	7.9	245.8	210	113	99	27	1.6	19	16
1	2	85	465	8	279.4	250	127	87	38	3.4	21	18
7	2	85	540	7.6	344.5	290	176	136	34	1.6	31	24
11	4	85	160	7.5	110.7	100	48	43	11	0.8	8.7	6.5
4	7	85	265	7.5	165.2	140	80	63	17	0.6	14	11
25	9	85	395	7.8	241.3	200	122	91	24	1	21	17
19	12	85	420	8.2	271.7	230	141	109	28	1.7	25	19
4	3	86	390	8.3	248.2	210	125	101	24	1.2	22	17
7	5	86	325	7.9	190.3	180	103	60	20	1.3	18	14
24	6	86	345	7.9	220.1	180	111	87	21	0.9	19	15.5
22	7	86	380	7.9	235.2	200	122	87	23	1.2	21	17
14	1	87	340	7.8	219.8	190	112	83	24	1.7	20	15
5	3	87	105	7	57.9	61	27	13	7.4	1.7	5.2	3.4
6	3	87	170	7.5	112.1	100	53	46	12	1	9.6	7
9	3	88	140	7.5	92.1	88	41	43	10	1	8	5
1	6	88	240	7.6	185.6	160	96	71	19	0.9	17	13
15	7	88	265	7.5	174	160	79	67	22	1.6	14.5	10.5
3	11	88	670	7.9	438.5	360	233	170	42	1.8	40.5	32
22	2	89	440	7.5	316.7	260	134	116	44	2	25.5	17
31	5	89	255	8.3	184.3	160	85	75	21.5	0.9	16	11

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(c) Water Quality Records in the Logan River Basin (continued)

Station 145013

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
5 11 68	820	7.8	582.2	427	308	250	54	0	54	42
8 7 70	495	8	366.1	274	180	148	41	0	31	25
17 6 71	800	7.8	705.2	533	370	244	78	0	64	51
29 7 71	1040	8.7	733.1	578	379	250	84	0	61	55
23 9 71	1000	7.9	652.2	509	349	230	69	0	54	52
11 11 71	1075	7.8	749.3	563	386	300	78	0	64	55
12 1 72	810	7.8	643.3	480	323	250	72	0	52	47
10 3 72	200	7.3	158.3	117	68	66	21	0	14	8
21 6 72	360	7.8	233.1	180	131	85	22	0	26	16
9 8 72	620	7.8	490.1	381	229	175	63	0	44	29
16 1 73	605	7.6	435.1	336	200	160	57	0	42	23
8 3 73	350	7.8	236.1	177	111	94	28	0	28	10
10 5 73	632	8.2	443	356	253	165	36.5	1.2	50	31
22 6 73	695	8.2	504.8	409	311	185	40	1.5	42	50
4 9 73	700	8	460.7	356	277	184	30	1.6	55	34
17 10 73	520	7.9	368.2	305	189	145	40	1.9	36	24
29 3 74	518	8.1	413.2	326	202	182	46	1.8	34.7	28
10 9 74	986	8.3	652	525	336	255	64	2.8	62	44
6 11 74	650	8	471.2	395	211	155	64	2.2	24	36.6
16 12 77	760	8.6	523.3	416	286	245	49	1.5	52	38
14 2 78	500	7.7	325.3	276	166	140	34	2	32	21
26 4 78	645	8.1	431.7	362	217	162	47	2	39	29
5 7 78	650	7.9	457.6	383	237	164	50	1.5	42	32
1 8 79	450	8	266.7	261	130	100	29	2	24	17
6 2 80	387	7.5	256	225	117	102	30	3.2	22	15
26 2 80	373	7.7	239.2	208	117	98	26	1.5	22	15
22 8 80	510	8	332.7	276	161	135	36	1.6	30	21
30 10 80	740	7	507.3	407	248	220	52	2.5	48	31
6 1 81	310	7.9	203.4	182	94	84	24	1.8	18	12
18 3 81	430	7.7	270.2	231	127	110	29	1.7	23	17
2 6 81	350	8.1	226.1	196	105	93	25	1.2	19	14
26 8 81	640	8.5	405.5	343	201	153	43	0.8	36	27
11 1 82	500	7.6	346.4	290	168	140	36	1.9	31	22
11 1 82	580	7.9	212.8	350	204	23	45	1.5	37	27
15 3 82	150	8	89.2	96	42	31	12	1.4	8.1	5.4
16 8 82	640	8.2	427.3	350	222	172	45	1.6	41	29
18 10 82	275	7.3	200.2	180	96	82	23	1.6	17	13
17 1 83	325	7.7	220	0	100	99	23.5	1.9	18.5	13
11 4 83	380	7.4	254.5	210	123	107	28	1.7	23	16
14 6 83	425	7.8	283.2	230	141	124	31.5	1.4	25	19
30 8 83	570	7.9	388.5	310	185	166	45	1.6	33	25
11 11 83	770	7.9	490.3	410	213	149	68	3.2	39	28
19 1 84	345	8.3	240.8	200	118	109	26	1.5	21	16
21 3 84	640	8.1	436.7	360	219	184	45	1.8	40	29
23 5 84	520	8.0	340.3	280	170	146	37	1.3	30	23
22 8 84	680	8.0	511.9	400	243	220	52	1.9	43	33
7 11 84	440	7.5	287.2	240	132	124	32	1.7	23	18
7 2 85	670	8.4	460.4	370	222	208	44	2	41	29
11 4 85	290	7.6	205.2	180	94	86	20	1.6	18	12
12 4 85	1400	7.9	784.9	710	298	145	145	5.9	55	39
4 7 85	350	7.9	240.5	200	119	104	24	1	23	15

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Station 145013 (continued)

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(dd mm yr)										
19 12 85	540	8.2	356.2	290	175	151	37.5	2.2	33	22.5
5 3 86	520	8.2	382.5	300	185	180	35	3	36	23
7 5 86	255	8.1	177.7	150	81	83	18	1.1	16	10
24 6 86	370	8.1	257.8	210	128	121	23	1.2	24	16.5
23 7 86	400	8.3	278.0	220	135	130	25	1.3	26	17
24 11 86	445	7.9	313.0	250	153	153	27	1.8	30	19
14 1 87	395	8.1	276.3	230	137	125	27	2.4	27	17
2 4 87	200	7.5	135.9	120	63	62	14	1.2	12	7.9
26 8 87	295	7.5	197.6	170	94	76	22	1.2	18	12
9 3 88	210	7.7	134.4	120	67	54	14	0.9	12	9
2 6 88	375	8	276.9	230	134	116	28.5	1.3	25	17.5
8 8 88	540	7.9	368	300	191	153	38.5	1.5	36	24.5
3 11 88	780	7.9	540	430	273	224	53	2.8	50	36
23 1 89	245	7.7	183.6	150	75	82	24	1.6	15.5	8.7

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Table A.1(c) Water Quality Records in the Logan River Basin (continued)

Station 145008

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/L)	DISSOLVED SOLIDS (mg/L)	HARDNESS (mg/L) as CaCO ₃	ALKALINITY (mg/L) as CaCO ₃	NATRIUM (mg/L)	KALIUM (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)
(dd mm yr)										
15 3 61	269	7.3	185.2	150	76	68	28	0	14	10
28 3 63	292	7.5	190.3	175	68	70	32	0	14	8
31 3 63	350	7.5	228.2	220	90	80	36	0	18	11
30 1 64	880	7.6	610.1	520	265	200	92	0	50	34
9 6 64	555	8.5	397.4	320	173	131	60	0	33	22
8 9 64	880	8.1	613.1	520	282	195	86	0	60	32
4 8 65	597	7.5	386.1	319	181	108	54	0	38	21
13 1 66	590	8.3	377.7	311	188	124	48.5	0	48	16.5
29 9 67	1050	7.9	730.3	579	370	244	88	0	69	48
7 12 67	1030	7.6	725.3	581	340	230	101	0	62	45
22 2 68	377	7.1	280.2	217	121	102	40	0	32	10
22 4 68	640	7.9	424.1	323	204	162	51	0	39	26
10 10 68	920	7.5	606.1	471	354	218	53	0	56	52
5 11 68	900	7.8	646.2	491	300	250	83	0	54	40
8 9 70	630	7.7	413.2	320	209	150	48	0	36	29
29 4 71	890	8	581.3	462	275	193	76	0	54	34
29 7 71	1130	8.2	785.3	636	370	240	109	0	64	51
16 8 71	1320	8.3	836.4	636	372	236	129	0	70	48
23 9 71	1052	8	692.3	562	317	210	101	0	56	43
11 11 71	1275	8.1	868.3	682	408	300	115	0	76	53
12 1 72	885	7.9	672.3	520	342	245	78	0	56	49
8 3 72	300	7.2	238.3	185	123	85	27	0	18	19
28 4 72	530	7.4	392.1	315	121	124	78	0	32	10
21 6 72	415	7.7	270.1	211	138	95	31	0	24	19
12 10 72	820	7.5	579.1	452	276	205	75	0	48	38
16 1 73	625	7.5	412.2	344	138	110	81	0	34	13
9 3 73	390	7.4	265.1	204	108	98	39	0	30	8
10 5 73	820	8.1	537.9	442	269	175	64	1.3	55	32
10 7 73	251	7.8	168.9	149	81	50	22.4	2.8	10	13.6
4 9 73	800	8.4	477.7	413	241	164	68	1.6	47	30
15 10 73	520	7.6	342.8	289	155	115	50	2.3	29	20
13 3 74	127	7	98.8	92	34	42	12.5	2.3	6.8	4.2
30 7 74	1020	8.3	698.9	574	355	249	84	1.6	68	45
6 11 74	450	8.7	259	229	89	70	50	2.4	12	14.4
12 2 76	260	7.3	174.4	155	70	68	22	2.5	17	6.7
12 2 76	230	7.4	147.8	139	58	54	22	2.3	13	6.1
13 12 77	600	8	369.2	298	169	150	50	2	33	21
14 2 78	630	7.9	404.1	339	176	145	60	2.5	34	22
26 4 78	780	7.9	486.8	417	220	150	69	2.5	42	28
5 7 78	900	7.9	575.1	494	260	163	85	2.5	48	34
26 2 80	540	8	358.7	298	160	140	43	2.5	31	20
14 5 80	300	7.7	185.3	168	78	62	26	1.9	15	9.8
30 10 80	710	8.3	465.7	377	207	181	60	2.8	40	26
5 1 81	340	7.6	208.4	184	88	76	28	2.1	17	11
4 6 81	690	7.3	387.5	349	155	90	70	2.3	29	20
26 8 81	854	8.7	535.9	447	235	181	75	1.5	43	31
12 1 82	390	7.9	256.8	220	102	91	37	2.2	21	12
15 6 82	480	7.9	308.7	260	138	116	41	1.9	26.5	17.5
17 8 82	720	8.1	465.3	380	204	171	66	2	39	26
19 10 82	440	7.9	293.4	250	123	99	40	7	23	16
17 1 83	485	8.2	316.9	270	133	117	47	2.5	24.5	17.5

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

Station 145008 (continued)

Date Sampled	CONDUCTIVITY 25C (mS/m)	PH	DISSOLVED IONS (mg/L)	DISSOLVED SOLIDS (mg/L)	HARDNESS (mg/L) as CaCO3	ALKALINITY (mg/L) as CaCO3	NATRIUM (mg/L)	KALIUM (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)
(dd mm yr)										
12 4 83	475	7.7	298.4	250	135	103	44	1.9	26	17
15 6 83	480	7.9	308.8	260	138	116	41	1.9	26.5	17.5
1 8 83	650	7.9	418.7	350	181	153	61	2.1	33	24
23 3 84	630	8.2	407.8	340	184	155	51	1.8	34	24
25 5 84	650	7.9	402.0	330	188	149	52	1.5	34	25
22 8 84	730	8.3	522.5	430	228	194	68	2.1	42	30
16 11 84	520	7.7	338.5	290	143	128	48	3.5	26	19
6 2 85	670	7.6	443.9	360	195	173	54	2.4	37	25
11 4 85	335	7.6	221.8	190	92	82	28	1.7	17	12
5 7 85	450	8	270.5	230	123	100	35	1.2	23	1
17 12 85	395	7.6	239.4	210	101	80	37	2	19	13
5 3 86	465	8.3	292.1	240	122	105	41	2.4	24	15
6 5 86	430	8.1	297	240	135	125	32	1.7	26	17
24 6 86	600	8.2	401.3	320	191	159	44.5	1.8	37	24
17 7 86	590	8.4	396.5	310	180	157	44	2.1	34	23
7 8 86	460	7.9	292.3	240	126	104	40	1.8	24	16
2 10 86	500	7.1	313.7	270	102	94	60	1	21	12
3 10 86	340	6.9	200	180	69	49	39	3.5	14	8.2
1 12 86	420	8	275.7	230	128	108	39	2.1	25	16
5 1 87	250	7.5	136.8	130	46	37	24	2.8	9.7	5.4
2 4 87	250	7.8	133.1	140	70	65	21	1.5	14	8.4
29 4 87	210	7.5	136.5	120	59	54	17	1.2	12	7.1
23 2 88	275	8	173.4	150	79	69	23	1.4	15	10
11 8 88	730	8.5	476.5	390	214	166	67	2	42	26.5
31 10 88	910	7.5	611.1	500	281	224	76	3.1	53	36
3 4 89	480	8.5	323.2	280	146	107	45.5	2.3	20.5	23

Source: Queensland Water Resources Commission
Surface Water Resources Branch
Water Quality Data System

**Table A.2(a) Annual Mean Values of the Water Quality Parameters
from the Fitzroy River Basin**

Station 130322

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
64	200.0	7.3	176.2	124.0	65.0	72.0	26.5	0.0	16.0	6.0
65	405.0	8.0	279.2	274.0	84.0	100.0	54.0	0.0	24.0	5.8
66	215.0	8.1	191.2	128.5	75.0	92.0	25.5	0.0	20.0	6.0
67	206.5	7.9	204.1	133.0	69.5	90.0	36.3	0.0	15.0	6.0
68	70.0	8.0	64.0	0.0	12.0	24.0	15.0	0.0	3.0	1.0
69	260.0	6.9	191.8	0.0	68.3	88.3	28.3	0.0	19.3	4.8
70	128.0	6.9	102.3	0.0	38.9	51.5	13.3	0.0	10.0	3.4
71	171.6	7.7	195.4	0.0	66.4	68.4	35.4	0.0	14.4	7.4
73	257.5	8.0	173.3	133.5	61.5	85.0	21.2	6.2	16.0	5.3
74	197.5	7.7	140.9	116.5	47.0	60.0	20.0	5.7	11.5	4.5
75	145.0	7.1	111.6	92.0	51.0	54.0	12.0	5.1	12.5	4.7
76	190.0	7.5	142.2	115.0	50.7	62.3	17.7	5.8	13.3	4.2
77	145.0	7.8	106.4	87.0	37.0	46.0	13.4	5.1	9.2	3.4
78	190.0	7.4	146.3	122.0	49.0	66.0	18.0	5.5	12.0	4.5
81	185.0	7.5	141.2	110.0	57.0	71.0	12.0	5.0	18.0	3.0
84	240.0	7.8	179.1	156.7	62.7	79.0	24.3	5.8	15.7	5.7
85	245.0	7.7	178.0	150.0	61.0	77.0	21.5	6.4	15.0	5.7
86	217.5	7.6	149.0	125.0	51.0	63.5	21.3	5.0	12.8	4.7
87	222.5	7.9	159.8	125.0	57.5	73.5	19.5	4.9	14.0	5.6
88	195.0	7.6	144.6	110.0	51.5	72.0	15.8	5.7	13.0	4.6
89	248.8	7.6	175.3	137.5	66.5	77.3	23.0	4.8	17.0	5.8

Station 130105

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	290.0	7.7	199.7	148.5	80.5	82.0	29.0		17.5	9.0
73	215.0	7.8	159.6	135.8	61.8	64.0	18.2	2.4	13.1	7.1
74	350.0	7.6	233.5	194.0	97.0	90.7	29.3	2.2	19.3	11.8
75	235.0	7.5	158.4	133.7	63.7	68.5	16.3	3.2	13.4	6.8
76	516.7	8.1	336.2	274.0	150.3	128.0	45.3	2.6	32.7	16.7
77	360.0	8.0	248.6	204.0	102.3	106.0	29.8	2.3	22.3	10.6
78	367.5	8.0	258.2	207.5	110.5	105.5	32.5	3.4	23.5	12.5
80	411.7	7.5	255.8	220.0	107.7	86.7	38.3	1.8	21.7	13.0
81	248.0	7.7	176.7	139.0	71.0	85.0	18.0	3.1	15.0	8.1
82	260.0	7.9	167.0	150.0	63.0	61.0	27.0	1.7	13.0	7.5
84	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
85	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
86	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7
87	210.0	7.7	183.9	123.0	61.0	69.0	15.8	4.0	14.3	6.1
88	200.0	7.1	128.0	110.0	55.0	51.0	15.5	2.8	13.0	5.5
89	270.0	7.9	165.6	140.0	65.5	70.5	22.0	2.5	14.0	7.4

**Table A.2(a) Annual Mean Values of the Water Quality Parameters
from the Fitzroy River Basin (continued)**

Station 130003

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
64	278.8	7.7	204.5	147.0	91.0	84.3	25.8	0.0	18.8	10.8
65	197.0	7.3	169.0	140.0	79.7	78.3	17.3	0.0	15.3	10.0
73	183.5	7.9	140.6	109.0	57.5	66.0	15.1	4.6	13.9	5.6
75	430.0	7.5	265.4	215.0	113.0	105.0	35.0	3.0	22.0	14.0
76	790.0	7.9	483.2	416.0	224.0	135.0	70.0	1.8	45.0	27.0
77	338.3	8.0	269.8	226.3	113.8	100.5	34.8	2.8	23.3	13.5
78	420.0	8.0	288.7	246.7	119.3	98.0	39.3	3.1	23.7	14.7
80	325.0	7.5	219.1	178.5	91.0	88.5	27.0	2.3	19.0	10.5
82	280.0	7.4	175.3	150.0	71.5	63.5	26.0	1.9	15.0	8.3
84	205.0	8.3	151.4	120.0	51.0	69.0	18.0	4.7	13.0	4.5
85	188.3	7.7	131.1	120.0	53.7	54.7	15.3	3.8	12.0	5.7
86	393.3	7.9	260.9	220.0	104.3	95.3	37.0	4.5	20.8	12.7
87	288.3	7.8	194.5	160.0	71.0	76.0	26.0	4.4	16.3	7.4
88	370.0	7.6	237.9	200.0	102.5	81.5	32.0	4.0	22.3	11.5
89	176.7	7.4	122.8	104.0	50.3	53.0	15.8	3.3	11.3	5.4

**Table A.2(b) Annual Mean Values of the Water Quality Parameters
from the Nogoa River Basin**

Station 130202

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	220.0	7.6	150.1	105.5	82.5	72.0	17.0	-	19.0	8.5
73	163.5	8.0	135.1	95.8	58.5	67.0	9.8	4.1	15.8	4.7
74	286.0	7.7	210.0	166.4	88.8	91.4	21.8	6.2	22.9	7.7
75	275.0	7.5	198.0	155.0	83.0	93.0	22.0	5.0	22.5	6.4
76	263.3	7.2	187.0	148.7	80.0	79.3	20.3	5.3	21.0	6.7
77	340.5	7.9	234.2	188.5	94.0	94.0	28.5	5.7	24.5	8.0
78	267.5	7.4	193.5	154.5	75.5	79.0	21.5	5.1	21.0	5.7
80	150.0	7.8	111.5	83.0	47.0	58.0	10.0	2.9	13.0	3.6
82	160.0	7.8	122.3	95.0	49.5	61.5	9.0	4.4	13.0	4.2
83	246.5	7.5	179.4	147.9	69.1	72.4	22.4	5.3	17.2	6.3
84	342.5	8.2	249.4	200.0	92.5	106.0	30.5	5.7	23.0	8.6
85	190.0	7.4	135.8	110.0	46.0	64.0	17.0	4.4	13.0	3.4
86	157.5	8.0	121.4	97.5	49.5	60.0	11.0	5.5	13.0	4.1
87	152.5	7.0	116.6	94.5	45.5	53.5	12.5	5.2	12.5	3.5
88	147.5	7.3	110.2	86.0	44.0	57.5	9.7	4.8	12.2	3.3

Station 130212

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	290.0	7.5	247.1	159.0	122.0	142.0	17.0	-	39.0	6.0
73	143.3	7.4	127.7	89.0	45.0	64.7	14.2	5.1	10.5	4.6
74	139.0	7.2	108.2	85.7	45.3	53.0	10.7	4.7	12.5	3.5
75	138.3	7.3	106.2	91.0	51.0	58.7	7.8	3.9	14.5	3.6
76	472.5	7.6	350.5	255.5	153.0	176.0	38.5	3.6	45.5	9.5
77	491.3	7.8	347.5	268.5	124.8	142.3	52.5	4.5	31.8	11.0
78	352.5	7.6	271.4	208.8	107.3	119.5	34.3	4.4	30.8	7.4
80	144.0	7.8	114.3	87.0	44.0	59.0	11.0	3.5	12.0	3.3
81	120.0	7.2	118.6	104.0	55.0	41.0	8.8	9.0	10.0	7.2
83	221.3	7.5	184.3	147.5	78.0	96.5	17.0	4.6	22.0	5.6
84	230.0	7.4	182.4	138.0	80.0	101.0	14.0	4.2	23.3	5.3
85	125.0	7.7	97.2	80.0	37.0	51.0	9.5	4.5	10.0	2.8
87	152.5	7.4	125.2	90.5	50.5	67.5	12.0	4.3	15.0	3.1
88	172.5	7.2	137.8	105.0	54.5	75.0	11.0	6.1	15.5	3.9

**Table A.2(b) Annual Mean Values of the Water Quality Parameters
from the Nogoia River Basin (continued)**

Station 130209

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	177.5	7.4	139.8	93.5	51.0	74.0	18.0	-	13.0	4.5
73	155.2	7.8	145.0	97.3	63.1	69.4	10.3	4.7	16.4	5.3
74	277.7	7.6	227.2	172.3	107.7	119.0	16.8	5.0	21.0	13.4
75	198.8	7.5	153.2	115.3	69.0	83.0	13.7	4.5	17.5	6.1
76	612.5	7.9	485.8	336.5	202.5	267.0	57.0	3.6	25.0	34.0
77	732.5	8.6	525.4	372.5	236.5	278.5	55.0	3.1	28.0	40.5
78	293.3	7.7	240.8	180.0	97.0	124.7	24.0	4.5	22.0	10.2
80	160.0	7.5	111.2	91.0	47.0	48.0	13.0	3.4	13.0	3.5
81	211.5	7.7	164.0	124.0	67.5	82.5	13.5	4.3	17.5	5.8
82	205.0	7.6	160.9	120.0	58.0	86.0	15.0	4.9	15.5	4.8
83	165.0	7.4	134.3	113.3	54.0	67.3	13.0	5.2	14.7	4.3
84	265.0	7.5	202.8	156.7	78.0	100.3	21.3	5.2	18.7	7.7
85	207.5	7.5	147.8	120.0	57.5	65.5	14.5	5.0	15.5	4.7
86	175.0	8.1	132.3	102.5	55.0	68.5	11.3	4.9	14.5	4.6
87	171.7	7.5	137.4	105.7	58.3	72.7	11.7	5.4	16.0	4.4
88	170.0	7.4	132.0	105.0	54.0	71.0	11.5	4.9	15.3	3.8
89	210.8	7.9	163.1	120.0	64.8	81.0	17.1	3.9	16.7	5.7
90	150.0	8.2	125.9	100.0	49.0	54.0	12.5	4.0	13.0	3.9

**Table A.2(c) Annual Mean Values of the Water Quality Parameters
from the Logan River Basin**

Station 145010

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
65	425.0	8.0	303.3	280.0	141.0	104.0	40.0	0.0	30.0	16.0
66	418.0	7.9	296.4	237.0	149.3	110.0	32.8	0.0	35.6	14.7
67	750.0	7.5	521.2	409.0	279.0	180.0	54.0	0.0	54.0	35.0
68	357.3	7.3	241.1	185.0	144.0	89.7	18.7	0.0	24.7	20.0
71	685.8	7.9	469.6	370.6	247.6	159.8	51.4	0.0	41.0	35.2
72	376.7	7.4	276.6	211.0	144.3	101.7	30.0	0.0	24.0	20.5
73	311.0	7.8	218.3	176.5	112.0	81.5	23.2	0.5	20.6	14.8
74	482.5	8.2	310.6	273.0	164.8	117.0	32.3	1.4	28.4	22.8
78	426.0	7.7	274.7	240.4	146.2	98.0	29.0	1.5	26.2	19.6
79	147.5	6.8	91.8	94.0	42.0	24.5	13.5	1.9	7.9	5.5
80	360.0	7.8	235.0	203.3	116.3	92.0	24.0	1.4	20.7	15.7
81	393.0	8.1	248.1	214.5	108.0	89.5	31.5	1.4	18.5	15.0
82	382.5	8.1	253.5	217.5	128.5	103.0	25.0	1.4	22.7	17.5
83	439.2	8.0	294.1	246.7	146.5	119.3	31.2	1.5	25.6	20.1
84	340.8	7.9	233.3	197.2	112.3	97.2	24.0	1.3	19.9	15.2
85	348.5	7.8	220.2	188.0	108.5	83.5	53.4	1.3	10.1	16.9
86	360.0	8.0	223.5	192.5	115.3	83.8	22.0	1.2	20.0	15.9
87	205.0	7.4	129.9	117.0	64.0	47.3	14.5	1.5	11.6	8.5
88	328.8	7.6	222.6	192.0	112.3	87.8	23.3	1.3	20.0	15.1
89	347.5	7.9	250.5	210.0	109.5	95.5	32.8	1.5	20.8	14.0

Station 145013

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
68	820.0	7.8	582.2	427.0	308.0	250.0	54.0	0.0	54.0	42.0
70	495.0	8.0	366.1	274.0	180.0	148.0	41.0	0.0	31.0	25.0
71	978.8	8.1	710.0	545.8	371.0	256.0	77.3	0.0	60.8	53.3
72	497.5	7.7	381.2	289.5	187.8	144.0	44.5	0.0	34.0	25.0
73	583.7	8.0	408.0	323.2	223.5	155.5	38.6	1.0	42.2	28.7
74	718.0	8.1	512.1	415.3	249.7	197.3	58.0	2.3	40.2	36.2
77	760.0	8.6	523.3	416.0	286.0	245.0	49.0	1.5	52.0	38.0
78	598.3	7.9	404.9	340.3	206.7	155.3	43.7	1.8	37.7	27.3
79	450.0	8.0	266.7	261.0	130.0	100.0	29.0	2.0	24.0	17.0
80	541.0	7.6	359.7	297.0	175.3	151.0	38.0	1.9	33.3	22.3
81	432.5	8.1	276.3	238.0	131.8	110.0	30.3	1.4	24.0	17.5
82	429.0	7.8	255.2	253.2	146.4	89.6	32.2	1.6	26.8	19.3
83	494.0	7.7	327.3	232.0	152.4	129.0	39.2	2.0	27.7	20.2
84	525.0	8.0	363.4	296.0	176.4	156.6	38.4	1.6	31.4	23.8
85	650.0	8.0	409.4	350.0	181.6	138.8	54.1	2.5	34.0	23.5
86	398.0	8.1	281.8	226.0	136.4	133.4	25.6	1.7	26.4	17.1
87	296.7	7.7	203.3	173.3	98.0	87.7	21.0	1.6	19.0	12.3
88	476.3	7.9	329.8	270.0	166.3	136.8	33.5	1.6	30.8	21.8
89	245.0	7.7	183.6	150.0	75.0	82.0	24.0	1.6	15.5	8.7

**Table A.2(c) Annual Mean Values of the Water Quality Parameters
from the Logan River Basin (continued)**

Station 145020

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
74	680.6	8.0	418.8	364.4	96.2	96.2	71.4	2.5	31.9	21.0
77	465.0	7.8	280.3	222.0	115.0	115.0	42.0	2.0	23.0	14.0
78	677.0	7.7	396.4	356.0	89.8	89.8	71.0	2.5	29.4	19.2
80	856.7	7.7	519.6	444.7	141.0	141.0	87.3	3.1	39.7	25.7
81	539.7	8.1	311.7	271.3	87.3	87.3	52.7	2.0	23.3	15.3
82	402.5	7.7	262.3	227.5	90.8	83.3	42.8	2.3	19.8	12.1
83	617.5	7.9	362.2	317.5	135.8	98.8	64.5	2.5	25.6	17.4
84	571.3	8.1	350.5	305.0	132.3	103.5	59.8	1.9	24.5	17.3
85	397.5	7.8	241.7	210.0	86.3	73.5	41.3	2.1	17.0	10.7
86	434.0	7.9	264.4	224.0	96.2	81.0	45.0	2.6	19.3	11.6
87	268.3	7.5	162.5	143.3	57.3	47.3	29.5	1.7	11.8	6.8
88	645.0	7.9	400.6	340.0	159.3	119.3	66.8	2.3	32.0	19.3
89	631.7	7.9	425.9	366.7	172.7	123.7	69.7	2.4	31.7	22.7

Station 145008

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/L)	DISSOLVED SOLIDS (mg/L)	HARDNESS (mg/L) as CaCO ₃	ALKALINITY (mg/L) as CaCO ₃	NATRIUM (mg/L)	KALIUM (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)
61	269.0	7.3	185.2	150.0	76.0	68.0	28.0	0.0	14.0	10.0
63	321.0	7.5	209.3	197.5	79.0	75.0	34.0	0.0	16.0	9.5
64	771.7	8.1	540.2	453.3	240.0	175.3	79.3	0.0	47.7	29.3
65	597.0	7.5	386.1	319.0	181.0	108.0	54.0	0.0	38.0	21.0
66	590.0	8.3	377.7	311.0	188.0	124.0	48.5	0.0	48.0	16.5
67	1040.0	7.8	727.8	580.0	355.0	237.0	94.5	0.0	65.5	46.5
68	709.3	7.6	489.2	375.5	244.8	183.0	56.8	0.0	45.3	32.0
70	630.0	7.7	413.2	320.0	209.0	150.0	48.0	0.0	36.0	29.0
71	1133.4	8.1	752.7	595.6	348.4	235.8	106.0	0.0	64.0	45.8
72	590.0	7.5	430.4	336.6	200.0	150.8	57.8	0.0	35.6	27.0
73	567.7	7.8	367.4	306.8	165.3	118.7	54.1	1.6	34.2	19.4
74	532.3	8.0	352.2	298.3	159.3	120.3	48.8	2.1	28.9	21.2
76	245.0	7.4	161.1	147.0	64.0	61.0	22.0	2.4	15.0	6.4
77	600.0	8.0	369.2	298.0	169.0	150.0	50.0	2.0	33.0	21.0
78	770.0	7.9	488.7	416.7	218.7	152.7	71.3	2.5	41.3	28.0
80	516.7	8.0	336.6	281.0	148.3	127.7	43.0	2.4	28.7	18.6
81	628.0	7.9	377.3	326.7	159.3	115.7	57.7	2.0	29.7	20.7
82	546.7	8.0	355.8	296.7	155.0	128.7	49.0	3.6	899.0	19.8
83	535.0	7.8	342.0	286.7	151.3	124.0	48.7	2.0	28.5	19.5
84	633.3	8.0	421.0	350.0	186.3	157.0	56.0	2.4	34.0	24.7
85	393.3	7.7	243.9	210.0	105.3	87.3	33.3	1.6	19.7	8.7
86	475.6	7.9	308.6	253.8	131.6	112.6	42.4	2.1	25.6	16.4
87	236.7	7.6	135.5	130.0	58.3	52.0	20.7	1.8	11.9	7.0
88	638.3	8.0	420.3	346.7	191.3	153.0	55.3	2.2	36.7	24.2
89	480.0	8.5	323.2	280.0	146.0	107.0	45.5	2.3	20.5	23.0

**Table A.3(a) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Fitzroy River Basin**

Station 130105

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
73	215.0	7.8	159.6	135.8	61.8	64.0	18.2	2.4	13.1	7.1
75	235.0	7.5	158.4	133.7	63.7	68.5	16.3	3.2	13.4	6.8
76	516.7	8.1	336.2	274.0	150.3	128.0	45.3	2.6	32.7	16.7
77	360.0	8.0	248.6	204.0	102.3	106.0	29.8	2.3	22.3	10.6
78	367.5	8.0	258.2	207.5	110.5	105.5	32.5	3.4	23.5	12.5
84	226.3	7.5	161.0	130.0	64.0	71.8	19.3	3.8	14.5	6.8
85	235.0	7.7	161.0	140.0	61.5	66.0	20.0	3.9	14.0	6.4
86	255.0	8.2	187.9	146.7	80.7	88.7	20.0	3.8	18.0	8.7
Mean	301.3	7.8	208.8	171.4	86.8	87.3	25.2	3.2	18.9	9.4
Standard Deviation	105.7	0.3	65.7	52.0	32.1	23.7	10.0	0.7	6.9	3.6

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
87	210.0	7.7	183.9	123.0	61.0	69.0	15.8	4.0	14.3	6.1
88	200.0	7.1	128.0	110.0	55.0	51.0	15.5	2.8	13.0	5.5
89	270.0	7.9	165.6	140.0	65.5	70.5	22.0	2.5	14.0	7.4
(2 yearly)										
Mean #1	205.0	7.4	156.0	116.5	58.0	60.0	15.7	3.4	13.7	5.8
Mean #2	235.0	7.5	146.8	125.0	60.3	60.8	18.8	2.7	13.5	6.5
(3 yearly)										
Mean #3	226.7	7.6	159.2	124.3	60.5	63.5	17.8	3.1	13.8	6.3

Note : Mean #1 = Mean of years 87,88
Mean #2 = Mean of years 88,89
Mean #3 = Mean of years 87,88,89

**Table A.3(a) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Fitzroy River Basin (continued)**

Station 130322

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
73	257.5	8.0	173.3	133.5	61.5	85.0	21.2	6.2	16.0	5.3
75	145.0	7.1	111.6	92.0	51.0	54.0	12.0	5.1	12.5	4.7
76	190.0	7.5	142.2	115.0	50.7	62.3	17.7	5.8	13.3	4.2
77	145.0	7.8	106.4	87.0	37.0	46.0	13.4	5.1	9.2	3.4
78	190.0	7.4	146.3	122.0	49.0	66.0	18.0	5.5	12.0	4.5
84	240.0	7.8	179.1	156.7	62.7	79.0	24.3	5.8	15.7	5.7
85	245.0	7.7	178.0	150.0	61.0	77.0	21.5	6.4	15.0	5.7
86	217.5	7.6	149.0	125.0	51.0	63.5	21.3	5.0	12.8	4.7
Mean	203.8	7.6	148.2	122.6	53.0	66.6	18.7	5.6	13.3	4.8
Standard Deviation	43.7	0.3	28.3	24.8	8.6	13.2	4.3	0.5	2.2	0.8

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
87	222.5	7.9	159.8	125.0	57.5	73.5	19.5	4.9	14.0	5.6
88	195.0	7.6	144.6	110.0	51.5	72.0	15.8	5.7	13.0	4.6
89	248.8	7.6	175.3	137.5	66.5	77.3	23.0	4.8	17.0	5.8
(2 yearly)										
Mean #1	208.8	7.7	152.2	117.5	54.5	72.8	17.6	5.3	13.5	5.1
Mean #2	221.9	7.6	159.9	123.8	59.0	74.6	19.4	5.2	15.0	5.2
(3 yearly)										
Mean #3	222.1	7.7	159.9	124.2	58.5	74.3	19.4	5.1	14.7	5.3

Note : Mean #1 = Mean of years 87,88
Mean #2 = Mean of years 88,89
Mean #3 = Mean of years 87,88,89

**Table A.3(a) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Fitzroy River Basin (continued)**

Station 130003

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
73	183.5	7.9	140.6	109.0	57.5	66.0	15.1	4.6	13.9	5.6
75	430.0	7.5	265.4	215.0	113.0	105.0	35.0	3.0	22.0	14.0
76	790.0	7.9	483.2	416.0	224.0	135.0	70.0	1.8	45.0	27.0
77	338.3	8.0	269.8	226.3	113.8	100.5	34.8	2.8	23.3	13.5
78	420.0	8.0	288.7	246.7	119.3	98.0	39.3	3.1	23.7	14.7
84	205.0	8.3	151.4	120.0	51.0	69.0	18.0	4.7	13.0	4.5
85	188.3	7.7	131.1	120.0	53.7	54.7	15.3	3.8	12.0	5.7
86	393.3	7.9	260.9	220.0	104.3	95.3	37.0	4.5	20.8	12.7
Mean	368.6	7.9	248.9	209.1	104.6	90.4	33.1	3.5	21.7	12.2
Standard Deviation	199.7	0.2	114.9	100.4	56.5	26.0	18.1	1.0	10.6	7.3

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
87	288.3	7.8	194.5	160.0	71.0	76.0	26.0	4.4	16.3	7.4
88	370.0	7.6	237.9	200.0	102.5	81.5	32.0	4.0	22.3	11.5
89	176.7	7.4	122.8	104.0	50.3	53.0	15.8	3.3	11.3	5.4
(2 yearly)										
Mean #1	329.2	7.7	216.2	180.0	86.8	78.8	29.0	4.2	19.3	9.4
Mean #2	273.3	7.5	180.3	152.0	76.4	67.3	23.9	3.6	16.8	8.4
(3 yearly)										
Mean #3	278.3	7.6	185.1	154.7	74.6	70.2	24.6	3.9	16.6	8.1

Note : Mean #1 = Mean of years 87,88
Mean #2 = Mean of years 88,89
Mean #3 = Mean of years 87,88,89

**Table A.3(b) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Nogoia River Basin**

Station 130202

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	220.00	7.60	150.05	105.50	82.50	72.00	17.00	-	19.00	8.50
73	163.50	8.00	135.05	95.75	58.50	67.00	9.75	4.13	15.78	4.65
74	286.00	7.68	209.96	166.40	88.80	91.40	21.80	6.18	22.88	7.66
75	275.00	7.45	197.95	155.00	83.00	93.00	22.00	5.00	22.50	6.40
76	263.33	7.20	187.00	148.67	80.00	79.33	20.33	5.30	21.00	6.73
77	340.50	7.85	234.15	188.50	94.00	94.00	28.50	5.65	24.50	7.95
78	267.50	7.35	193.50	154.50	75.50	79.00	21.50	5.05	21.00	5.65
80	150.00	7.80	111.50	83.00	47.00	58.00	10.00	2.90	13.00	3.60
Mean	245.73	7.62	177.40	137.16	76.16	79.22	18.86	4.28	19.96	6.39
Standard Deviation	64.18	0.27	41.30	37.59	15.78	13.14	6.39	2.02	3.87	1.69

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
83	246.50	7.47	179.40	147.93	69.07	72.43	22.39	5.33	17.20	6.32
84	342.50	8.20	249.35	200.00	92.50	106.00	30.50	5.65	23.00	8.55
85	190.00	7.40	135.80	110.00	46.00	64.00	17.00	4.40	13.00	3.40
87	152.50	6.95	116.60	94.50	45.50	53.50	12.50	5.20	12.50	3.45
88	147.50	7.25	110.15	86.00	44.00	57.50	9.65	4.80	12.20	3.25
(2 yearly)										
Mean #1	294.5	7.8	214.37	173.97	80.78	89.22	26.44	5.49	20.10	7.44
Mean #2	266.3	7.8	192.58	155.00	69.25	85.00	23.75	5.03	18.00	5.98
Mean #3	171.3	7.2	126.20	102.25	45.75	58.75	14.75	4.80	12.75	3.43
Mean #4	150.0	7.1	113.38	90.25	44.75	55.50	11.08	5.00	12.35	3.35
(3 yearly)										
Mean #5	259.67	7.69	188.18	152.64	69.19	80.81	23.30	5.13	17.73	6.09
Mean #6	228.33	7.52	167.25	134.83	61.33	74.50	20.00	5.08	16.17	5.13
Mean #7	163.33	7.20	120.85	96.83	45.17	58.33	13.05	4.80	12.57	3.37
(4 yearly)										
Mean #8	232.88	7.51	170.29	138.11	63.27	73.98	20.60	5.15	16.43	5.43
Mean #9	208.13	7.45	152.98	122.63	57.00	70.25	17.41	5.01	15.18	4.66

Note : Mean #1 = Mean of years 83,84
Mean #2 = Mean of years 84,85
Mean #3 = Mean of years 85,87
Mean #4 = Mean of years 87,88
Mean #5 = Mean of years 83,84,85

Mean #6 = Mean of years 84,85,87
Mean #7 = Mean of years 85,87,88
Mean #8 = Mean of years 83,84,85,87
Mean #9 = Mean of years 84,85,87,88

**Table A.3(b) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Nogoia River Basin (continued)**

Station 130212

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/L)	DISSOLVED SOLIDS (mg/L)	HARDNESS (mg/L) as CaCO ₃	ALKALINITY (mg/L) as CaCO ₃	NATRIUM (mg/L)	KALIUM (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)
72	290.00	7.50	247.10	159.00	122.00	142.00	17.00	-	39.00	6.00
73	143.33	7.40	127.70	89.00	45.00	64.67	14.20	5.10	10.47	4.60
74	139.00	7.17	108.17	85.67	45.33	53.00	10.67	4.73	12.50	3.47
75	138.33	7.27	106.20	91.00	51.00	58.67	7.80	3.87	14.50	3.57
76	472.50	7.60	350.50	255.50	153.00	176.00	38.50	3.60	45.50	9.50
77	491.25	7.83	347.48	268.50	124.75	142.25	52.50	4.53	31.75	11.03
78	352.50	7.55	271.38	208.75	107.25	119.50	34.25	4.43	30.75	7.35
80	144.00	7.80	114.30	87.00	44.00	59.00	11.00	3.50	12.00	3.30
Mean	271.36	7.51	209.10	155.55	86.54	101.89	23.24	3.72	24.56	6.10
Standard Deviation	152.86	0.23	107.47	79.07	44.82	48.59	16.38	1.62	13.84	2.95

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/L)	DISSOLVED SOLIDS (mg/L)	HARDNESS (mg/L) as CaCO ₃	ALKALINITY (mg/L) as CaCO ₃	NATRIUM (mg/L)	KALIUM (mg/L)	CALCIUM (mg/L)	MAGNESIUM (mg/L)
<i>(1 yearly)</i>										
83	221.25	7.50	184.33	147.50	78.00	96.50	17.00	4.58	22.00	5.58
84	230.00	7.40	182.40	138.00	80.00	101.00	14.00	4.20	23.33	5.27
85	125.00	7.70	97.20	80.00	37.00	51.00	9.50	4.50	10.00	2.80
87	152.50	7.35	125.15	90.50	50.50	67.50	12.00	4.30	15.00	3.10
88	172.50	7.20	137.80	105.00	54.50	75.00	11.00	6.10	15.50	3.85
<i>(2 yearly)</i>										
Mean #1	225.6	7.5	183.4	142.8	79.0	98.8	15.5	4.4	22.7	5.4
Mean #2	177.5	7.6	139.8	109.0	58.5	76.0	11.8	4.4	16.7	4.0
Mean #3	138.8	7.5	111.2	85.3	43.8	59.3	10.8	4.4	12.5	3.0
Mean #4	162.5	7.3	131.5	97.8	52.5	71.3	11.5	5.2	15.3	3.5
<i>(3 yearly)</i>										
Mean #5	192.08	7.53	154.64	121.83	65.00	82.83	13.50	4.43	18.44	4.55
Mean #6	169.17	7.48	134.92	102.83	55.83	73.17	11.83	4.33	16.11	3.72
Mean #7	150.00	7.42	120.05	91.83	47.33	64.50	10.83	4.97	13.50	3.25
<i>(4 yearly)</i>										
Mean #8	182.19	7.49	147.27	114.00	61.38	79.00	13.13	4.39	17.58	4.19
Mean #9	170.00	7.41	135.64	103.38	55.50	73.63	11.63	4.78	15.96	3.75

Note : Mean #1 = Mean of years 83,84
Mean #2 = Mean of years 84,85
Mean #3 = Mean of years 85,87
Mean #4 = Mean of years 87,88
Mean #5 = Mean of years 83,84,85

Mean #6 = Mean of years 84,85,87
Mean #7 = Mean of years 85,87,88
Mean #8 = Mean of years 83,84,85,87
Mean #9 = Mean of years 84,85,87,88

**Table A.3(b) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Nogoia River Basin (continued)**

Station 130209

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
72	177.50	7.35	139.75	93.50	51.00	74.00	18.00	-	13.00	4.50
73	155.20	7.79	145.00	97.30	63.10	69.40	10.28	4.66	16.40	5.34
74	277.67	7.60	227.20	172.33	107.67	119.00	16.83	5.00	21.00	13.43
75	198.75	7.53	153.20	115.25	69.00	83.00	13.70	4.53	17.50	6.13
76	612.50	7.90	485.75	336.50	202.50	267.00	57.00	3.55	25.00	34.00
77	732.50	8.60	525.40	372.50	236.50	278.50	55.00	3.10	28.00	40.50
78	293.33	7.70	240.80	180.00	97.00	124.67	24.00	4.53	22.00	10.17
80	160.00	7.50	111.20	91.00	47.00	48.00	13.00	3.40	13.00	3.50
Mean	325.93	7.75	253.54	182.30	109.22	132.95	25.98	3.60	19.49	14.70
Standard Deviation	222.23	0.39	162.02	112.12	71.77	89.95	18.98	1.62	5.47	14.40

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
83	165.00	7.40	134.27	113.33	54.00	67.33	13.00	5.17	14.67	4.30
84	265.00	7.47	202.83	156.67	78.00	100.33	21.33	5.23	18.67	7.70
85	207.50	7.45	147.80	120.00	57.50	65.50	14.50	4.95	15.50	4.65
87	171.67	7.53	137.37	105.67	58.33	68.50	11.30	4.90	14.50	4.55
88	170.00	7.40	132.00	105.00	54.00	72.67	11.67	5.37	16.00	4.43
(2 yearly)										
Mean #1	215.0	7.4	168.6	135.0	66.0	83.8	17.2	5.2	16.7	6.0
Mean #2	236.3	7.5	175.3	138.3	67.8	82.9	17.9	5.1	17.1	6.2
Mean #3	189.6	7.5	142.6	112.8	57.9	67.0	12.9	4.9	15.0	4.6
Mean #4	170.8	7.5	134.7	105.3	56.2	70.6	11.5	5.1	15.3	4.5
(3 yearly)										
Mean #5	212.50	7.44	161.63	130.00	63.17	77.72	16.28	5.12	16.28	5.55
Mean #6	214.72	7.48	162.67	127.44	64.61	78.11	15.71	5.03	16.22	5.63
Mean #7	183.06	7.46	139.06	110.22	56.61	68.89	12.49	5.07	15.33	4.54
(4 yearly)										
Mean #8	202.29	7.46	155.57	123.92	61.96	75.42	15.03	5.06	15.83	5.30
Mean #9	203.54	7.46	155.00	121.83	61.96	76.75	14.70	5.11	16.17	5.33

Note : Mean #1 = Mean of years 83,84
Mean #2 = Mean of years 84,85
Mean #3 = Mean of years 85,87
Mean #4 = Mean of years 87,88
Mean #5 = Mean of years 83,84,85

Mean #6 = Mean of years 84,85,87
Mean #7 = Mean of years 85,87,88
Mean #8 = Mean of years 83,84,85,87
Mean #9 = Mean of years 84,85,87,88

**Table A.3(c) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Logan River Basin**

Station 145010

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
78	426.0	7.7	274.7	240.4	146.2	98.0	29.0	1.5	26.2	19.6
79	147.5	6.8	91.8	94.0	42.0	24.5	13.5	1.9	7.9	5.5
80	360.0	7.8	235.0	203.3	116.3	92.0	24.0	1.4	20.7	15.7
81	393.0	8.1	248.1	214.5	108.0	89.5	31.5	1.4	18.5	15.0
82	382.5	8.1	253.5	217.5	128.5	103.0	25.0	1.4	22.7	17.5
83	439.2	8.0	294.1	246.7	146.5	119.3	31.2	1.5	25.6	20.1
84	340.8	7.9	233.3	197.2	112.3	97.2	24.0	1.3	19.9	15.2
Mean	355.6	7.8	232.9	201.9	114.3	89.1	25.5	1.5	20.2	15.5
Standard Deviation	98.0	0.5	65.9	50.9	35.4	30.1	6.2	0.2	6.1	4.9

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
85	348.5	7.8	220.2	188.0	108.5	83.5	53.4	1.3	10.1	16.9
86	360.0	8.0	223.5	192.5	115.3	83.8	22.0	1.2	20.0	15.9
87	205.0	7.4	129.9	117.0	64.0	47.3	14.5	1.5	11.6	8.5
88	328.8	7.6	222.6	192.0	112.3	87.8	23.3	1.3	20.0	15.1
89	347.5	7.9	250.5	210.0	109.5	95.5	32.8	1.5	20.8	14.0
(2 yearly)										
Mean #1	354.3	7.9	221.8	190.3	111.9	83.6	37.7	1.2	15.1	16.4
Mean #2	282.5	7.7	176.7	154.8	89.6	65.5	18.2	1.3	15.8	12.2
Mean #3	266.9	7.5	176.2	154.5	88.1	67.5	18.9	1.4	15.8	11.8
Mean #4	338.1	7.8	236.5	201.0	110.9	91.6	28.0	1.4	20.4	14.6
(3 yearly)										
Mean #5	304.5	7.7	191.2	165.8	95.9	71.5	29.9	1.3	13.9	13.8
Mean #6	297.9	7.7	192.0	167.2	97.2	72.9	19.9	1.3	17.2	13.2
Mean #7	293.8	7.7	201.0	173.0	95.3	76.9	23.5	1.4	17.5	12.5
(4 yearly)										
Mean #8	310.6	7.7	199.0	172.4	100.0	75.6	28.3	1.3	15.4	14.1
Mean #9	310.3	7.7	206.6	177.9	100.3	78.6	23.1	1.3	18.1	13.4

Note : Mean #1 = Mean of years 85,86
Mean #2 = Mean of years 86,87
Mean #3 = Mean of years 87,88
Mean #4 = Mean of years 88,89
Mean #5 = Mean of years 85,86,87

Mean #6 = Mean of years 86,87,88
Mean #7 = Mean of years 87,88,89
Mean #8 = Mean of years 85,86,87,88
Mean #9 = Mean of years 86,87,88,89

**Table A.3(c) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Logan River Basin (Continued)**

Station 145013

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
78	598.3	7.9	404.9	340.3	206.7	155.3	43.7	1.8	37.7	27.3
79	450.0	8.0	266.7	261.0	130.0	100.0	29.0	2.0	24.0	17.0
80	541.0	7.6	359.7	297.0	175.3	151.0	38.0	1.9	33.3	22.3
81	432.5	8.1	276.3	238.0	131.8	110.0	30.3	1.4	24.0	17.5
82	429.0	7.8	255.2	253.2	146.4	89.6	32.2	1.6	26.8	19.3
83	494.0	7.7	327.3	232.0	152.4	129.0	39.2	2.0	27.7	20.2
84	525.0	8.0	363.4	296.0	176.4	156.6	38.4	1.6	31.4	23.8
Mean	495.7	7.9	321.9	273.9	159.9	127.4	35.8	1.8	29.3	21.1
Standard Deviation	63.2	0.2	57.2	38.9	27.8	27.9	5.4	0.2	5.1	3.7

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO ₃	ALKALINITY (mg/l)as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
85	650.0	8.0	409.4	350.0	181.6	138.8	54.1	2.5	34.0	23.5
86	398.0	8.1	281.8	226.0	136.4	133.4	25.6	1.7	26.4	17.1
87	296.7	7.7	203.3	173.3	98.0	87.7	21.0	1.6	19.0	12.3
88	476.3	7.9	329.8	270.0	166.3	136.8	33.5	1.6	30.8	21.8
89	245.0	7.7	183.6	150.0	75.0	82.0	24.0	1.6	15.5	8.7
(2 yearly)										
Mean #1	524.0	8.1	345.6	288.0	159.0	136.1	39.9	2.1	30.2	20.3
Mean #2	347.3	7.9	242.5	199.7	117.2	110.5	23.3	1.6	22.7	14.7
Mean #3	386.5	7.8	266.5	221.7	132.1	112.2	27.3	1.6	24.9	17.0
Mean #4	360.6	7.8	256.7	210.0	120.6	109.4	28.8	1.6	23.1	15.2
(3 yearly)										
Mean #5	448.2	7.9	298.2	249.8	138.7	120.0	33.6	1.9	26.5	17.6
Mean #6	390.3	7.9	271.6	223.1	133.6	119.3	26.7	1.6	25.4	17.1
Mean #7	339.3	7.8	238.9	197.8	113.1	102.1	26.2	1.6	21.8	14.3
(4 yearly)										
Mean #8	455.2	7.9	306.1	254.8	145.6	124.2	33.6	1.9	27.5	18.7
Mean #9	354.0	7.8	249.6	204.8	118.9	110.0	26.0	1.6	22.9	15.0

Note : Mean #1 = Mean of years 85,86
Mean #2 = Mean of years 86,87
Mean #3 = Mean of years 87,88
Mean #4 = Mean of years 88,89
Mean #5 = Mean of years 85,86,87

Mean #6 = Mean of years 86,87,88
Mean #7 = Mean of years 87,88,89
Mean #8 = Mean of years 85,86,87,88
Mean #9 = Mean of years 86,87,88,89

**Table A.3(c) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Logan River Basin (Continued)**

Station 145020

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
78	677.0	7.7	396.4	356.0	89.8	89.8	71.0	2.5	29.4	19.2
79	-	-	-	-	-	-	-	-	-	-
80	856.7	7.7	519.6	444.7	141.0	141.0	87.3	3.1	39.7	25.7
81	539.7	8.1	311.7	271.3	87.3	87.3	52.7	2.0	23.3	15.3
82	402.5	7.7	262.3	227.5	90.8	83.3	42.8	2.3	19.8	12.1
83	617.5	7.9	362.2	317.5	135.8	98.8	64.5	2.5	25.6	17.4
84	571.3	8.1	350.5	305.0	132.3	103.5	59.8	1.9	24.5	17.3
Mean	523.5	6.7	314.7	274.6	96.7	86.2	54.0	2.0	23.2	15.3
Standard Deviation	273.0	3.0	162.5	141.0	49.5	43.3	28.0	1.0	12.2	8.0

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
85	397.5	7.8	241.7	210.0	86.3	73.5	41.3	2.1	17.0	10.7
86	434.0	7.9	264.4	224.0	96.2	81.0	45.0	2.6	19.3	11.6
87	268.3	7.5	162.5	143.3	57.3	47.3	29.5	1.7	11.8	6.8
88	645.0	7.9	400.6	340.0	159.3	119.3	66.8	2.3	32.0	19.3
89	631.7	7.9	425.9	366.7	172.7	123.7	69.7	2.4	31.7	22.7
(2 yearly)										
Mean #1	415.8	7.9	253.0	217.0	91.2	77.3	43.1	2.4	18.2	11.1
Mean #2	351.2	7.7	213.5	183.7	76.8	64.2	37.3	2.2	15.6	9.2
Mean #3	456.7	7.7	281.5	241.7	108.3	83.3	48.1	2.0	21.9	13.0
Mean #4	638.3	7.9	413.2	353.3	166.0	121.5	68.2	2.3	31.8	21.0
(3 yearly)										
Mean #5	366.6	7.7	222.9	192.4	79.9	67.3	38.6	2.1	16.0	9.7
Mean #6	449.1	7.8	275.8	235.8	104.3	82.5	47.1	2.2	21.0	12.5
Mean #7	515.0	7.7	329.6	283.3	129.8	96.8	55.3	2.1	25.2	16.3
(4 yearly)										
Mean #8	436.2	7.8	267.3	229.3	99.8	80.3	45.6	2.2	20.0	12.1
Mean #9	494.8	7.8	313.3	268.5	121.4	92.8	52.7	2.2	23.7	15.1

Note : Mean #1 = Mean of years 85,86
Mean #2 = Mean of years 86,87
Mean #3 = Mean of years 87,88
Mean #4 = Mean of years 88,89
Mean #5 = Mean of years 85,86,87

Mean #6 = Mean of years 86,87,88
Mean #7 = Mean of years 87,88,89
Mean #8 = Mean of years 85,86,87,88
Mean #9 = Mean of years 86,87,88,89

**Table A.3(c) Annual Mean Values of the Water Quality Parameters (Grouped)
from the Logan River Basin (Continued)**

Station 145008

(Calibration set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
78	770.0	7.9	488.7	416.7	218.7	152.7	71.3	2.5	41.3	28.0
79	-	-	-	-	-	-	-	-	-	-
80	516.7	8.0	336.6	281.0	148.3	127.7	43.0	2.4	28.7	18.6
81	628.0	7.9	377.3	326.7	159.3	115.7	57.7	2.0	29.7	20.7
82	546.7	8.0	355.8	296.7	155.0	128.7	49.0	3.6	899.0	19.8
83	535.0	7.8	342.0	286.7	151.3	124.0	48.7	2.0	28.5	19.5
84	633.3	8.0	421.0	350.0	186.3	157.0	56.0	2.4	34.0	24.7
Mean	518.5	6.8	331.6	279.7	145.6	115.1	46.5	2.1	151.6	18.8
Standard Deviation	247.9	3.0	157.9	133.8	69.9	53.7	22.7	1.1	334.5	9.0

(Validation set)

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
(1 yearly)										
85	393.3	7.7	243.9	210.0	105.3	87.3	33.3	1.6	19.7	8.7
86	475.6	7.9	308.6	253.8	131.6	112.6	42.4	2.1	25.6	16.4
87	236.7	7.6	135.5	130.0	58.3	52.0	20.7	1.8	11.9	7.0
88	638.3	8.0	420.3	346.7	191.3	153.0	55.3	2.2	36.7	24.2
89	480.0	8.5	323.2	280.0	146.0	107.0	45.5	2.3	20.5	23.0
(2 yearly)										
Mean #1	434.5	7.8	276.2	231.9	118.5	100.0	37.9	1.8	22.6	12.5
Mean #2	356.1	7.7	222.0	191.9	95.0	82.3	31.6	1.9	18.8	11.7
Mean #3	437.5	7.8	277.9	238.3	124.8	102.5	38.0	2.0	24.3	15.6
Mean #4	559.2	8.3	371.8	313.3	168.7	130.0	50.4	2.2	28.6	23.6
(3 yearly)										
Mean #5	368.5	7.7	229.3	197.9	98.4	84.0	32.1	1.8	19.1	10.7
Mean #6	450.2	7.8	288.1	243.5	127.1	105.9	39.5	2.0	24.7	15.8
Mean #7	451.7	8.0	293.0	252.2	131.9	104.0	40.5	2.1	23.0	18.0
(4 yearly)										
Mean #8	436.0	7.8	277.1	235.1	121.7	101.2	37.9	1.9	23.5	14.1
Mean #9	457.7	8.0	296.9	252.6	131.8	106.2	41.0	2.1	23.7	17.6

Note : Mean #1 = Mean of years 85,86
Mean #2 = Mean of years 86,87
Mean #3 = Mean of years 87,88
Mean #4 = Mean of years 88,89
Mean #5 = Mean of years 85,86,87

Mean #6 = Mean of years 86,87,88
Mean #7 = Mean of years 87,88,89
Mean #8 = Mean of years 85,86,87,88
Mean #9 = Mean of years 86,87,88,89

Table A.4.1 Results of Assignment of Water Quality Values in the Fitzroy River Basin

Table A.4.1(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)				(Regression Method)			
	130105	130322	130105	130322	130105	130322	130105	130322	Average	Maximum	130105	130322	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	210.00	222.50	266.53	202.44	264.48	213.28	26.92	9.02			25.94	4.14		
	200.00	195.00	301.42	203.75	301.72	204.30	50.71	4.49	21.57	50.71	50.86	4.77	19.32	50.86
	270.00	248.75	218.82	200.64	213.56	225.57	18.96	19.34			20.90	9.32		
PH	7.67	7.90	7.80	7.59	7.81	7.51	1.67	3.94			1.91	4.93		
	7.10	7.55	7.74	7.58	7.79	7.38	9.04	0.37	3.02	9.04	9.67	2.29	4.13	9.67
	7.90	7.63	7.71	7.57	7.77	7.30	2.42	0.71			1.64	4.32		
Dissolved Ions (mg/l)	183.90	159.80	182.73	147.15	180.99	155.72	0.64	7.92			1.59	2.56		
	128.00	144.55	203.36	147.99	203.09	150.08	58.88	2.38	16.15	58.88	58.67	3.83	14.21	58.67
	165.55	175.30	148.57	145.76	144.44	165.03	10.26	16.85			12.75	5.86		
Dissolved Solids (mg/l)	123.00	125.00	150.26	121.58	148.60	129.90	22.16	2.74			20.81	3.92		
	110.00	110.00	167.49	122.44	167.12	125.10	52.26	11.31	18.47	52.26	51.93	13.73	17.23	51.93
	140.00	137.50	126.14	120.37	122.67	136.62	9.90	12.46			12.38	0.64		
Hardness (mg/l) as CaCO ₃	61.00	57.50	69.99	52.99	69.38	55.84	14.74	7.84			13.73	2.89		
	55.00	51.50	85.69	53.23	85.70	53.32	55.80	3.36	18.53	55.80	55.81	3.53	16.66	55.81
	65.50	66.50	59.68	52.82	58.67	57.49	8.89	20.57			10.42	13.54		
Alkalinity (mg/l) as CaCO ₃	69.00	73.50	77.66	65.95	76.40	72.39	12.55	10.27			10.73	1.51		
	51.00	72.00	81.29	66.19	80.52	70.47	59.39	8.07	19.61	59.39	57.89	2.13	15.41	57.89
	70.50	77.25	62.48	64.91	59.18	80.44	11.38	15.97			16.06	4.13		
Sodium (mg/l)	15.83	19.50	22.03	18.54	21.85	19.41	39.14	4.92			37.99	0.46		
	15.50	15.75	24.66	18.65	24.64	18.81	59.10	18.41	27.01	59.10	58.95	19.43	25.06	58.95
	22.00	23.00	17.53	18.36	17.08	20.44	20.32	20.17			22.36	11.15		
Potassium (mg/l)	4.03	4.90	3.44	5.63	3.42	5.69	14.83	14.92			15.18	16.04		
	2.80	5.70	3.30	5.61	3.29	5.64	17.71	1.54	14.99	23.40	17.48	1.09	15.08	23.57
	2.50	4.75	3.09	5.58	3.09	5.56	23.40	17.56			23.57	17.13		
Calcium (mg/l)	14.33	14.00	15.84	13.23	15.73	13.85	10.51	5.50			9.73	1.05		
	13.00	13.00	19.25	13.31	19.25	13.38	48.08	2.38	16.12	48.08	48.11	2.92	14.54	48.11
	14.00	17.00	12.93	13.16	12.70	14.26	7.64	22.59			9.30	16.12		
Magnesium (mg/l)	6.10	5.55	7.36	4.75	7.28	5.17	20.66	14.41			19.40	6.92		
	5.50	4.60	9.09	4.77	9.09	4.88	65.27	3.70	22.33	65.27	65.27	6.14	19.91	65.27
	7.40	5.78	6.51	4.74	6.39	5.31	12.03	17.92			13.63	8.12		

Table A.4.1(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)			(Regression Method)				
	130105	130322	130105	130322	130105	130322	130105	130322	Average	Maximum	130105	130322	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	205.00	208.75	287.19	203.22	286.45	208.16	40.09	2.65	15.86	40.09	39.73	0.28	13.04	39.73
	235.00	221.88	262.95	202.31	259.72	218.30	11.89	8.82			10.52	1.61		
PH	7.38	7.73	7.76	7.58	7.80	7.46	5.10	1.88	2.57	5.10	5.61	3.41	3.87	5.61
	7.50	7.59	7.73	7.57	7.78	7.38	3.07	0.23			3.79	2.68		
Dissolved Ions (mg/l)	155.95	152.18	194.82	147.64	193.37	154.73	24.92	2.98	14.34	24.92	24.00	1.68	11.57	24.00
	146.78	159.93	178.11	146.97	174.83	162.28	21.35	8.10			19.12	1.47		
Dissolved Solids (mg/l)	116.50	117.50	159.93	122.06	158.45	129.63	37.28	3.88	15.31	37.28	36.01	10.32	17.99	36.01
	125.00	123.75	147.80	121.46	144.78	135.89	18.24	1.85			15.82	9.81		
Hardness (mg/l) as CaCO3	58.00	54.50	78.96	53.13	78.60	55.06	36.14	2.51	17.95	36.14	35.52	1.03	15.78	35.52
	60.25	59.00	74.15	53.05	73.51	56.30	23.07	10.08			22.00	4.58		
Alkalinity (mg/l) as CaCO3	60.00	72.75	80.26	66.12	79.29	70.67	33.77	9.11	18.76	33.77	32.16	2.86	13.12	32.16
	60.75	74.63	72.96	65.63	70.88	75.21	20.10	12.05			16.68	0.78		
Natrium (mg/l)	15.67	17.63	23.74	18.61	23.61	19.29	51.53	5.59	19.10	51.53	50.68	9.47	19.44	50.68
	18.75	19.38	21.54	18.52	21.16	20.29	14.88	4.41			12.88	4.74		
Kalium (mg/l)	3.42	5.30	3.65	5.66	3.63	5.78	6.83	6.79	11.47	24.91	6.13	9.00	12.01	24.86
	2.65	5.23	3.31	5.61	3.31	5.65	24.91	7.37			24.86	8.04		
Calcium (mg/l)	13.67	13.50	17.80	13.27	17.74	13.58	30.24	1.70	16.44	30.24	29.80	0.59	14.61	29.80
	13.50	15.00	16.48	13.24	16.33	13.94	22.07	11.73			20.98	7.06		
Magnesium (mg/l)	5.80	5.08	8.35	4.78	8.29	5.07	43.97	5.81	20.31	43.97	42.97	0.01	16.30	42.97
	6.45	5.19	7.96	4.77	7.87	5.18	23.41	8.05			22.01	0.20		

Table A.4.1(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)				(Regression Method)			
	130105	130322	130105	130322	130105	130322	130105	130322	Average	Maximum	130105	130322	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	226.60	222.00	273.77	202.72	269.83	222.54	20.82	8.68	14.75	20.82	19.08	0.24	9.66	19.08
PH	7.56	7.69	7.80	7.59	7.86	7.39	3.24	1.31	2.28	3.24	4.01	3.86	3.94	4.01
Dissolved Ions (mg/l)	159.10	159.80	186.51	147.31	182.57	165.95	17.23	7.82	12.52	17.23	14.75	3.85	9.30	14.75
Dissolved Solids (mg/l)	124.30	124.10	153.02	121.72	148.68	142.81	23.11	1.92	12.51	23.11	19.61	15.08	17.34	19.61
Hardness (mg/l) as CaCO ₃	60.50	58.50	77.43	52.83	75.91	56.86	27.98	9.69	18.84	27.98	25.48	2.81	14.14	25.48
Alkalinity (mg/l) as CaCO ₃	63.50	74.25	78.40	66.00	76.51	74.73	23.46	11.11	17.29	23.46	20.49	0.65	10.57	20.49
Sodium (mg/l)	17.77	19.41	22.93	18.58	22.35	21.32	29.04	4.28	16.66	29.04	25.78	9.84	17.81	25.78
Potassium (mg/l)	3.11	5.12	3.51	5.64	3.50	5.69	12.95	10.24	11.60	12.95	12.59	11.20	11.89	12.59
Calcium (mg/l)	13.77	14.66	17.16	13.26	17.01	14.05	24.62	9.55	17.08	24.62	23.50	4.13	13.81	23.50
Magnesium (mg/l)	6.33	5.31	8.08	4.76	8.08	5.29	27.59	10.32	18.95	27.59	27.54	0.27	13.90	27.54

Table A.4.2 Results of Assignment of Water Quality Values in the Nogoa River Basin

Table A.4.2(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)				(Regression Method)			
	130202	130212	130202	130212	130202	130212	130202	130212	Average	Maximum	130202	130212	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	246.50	221.25	215.18	170.19	212.70	174.56	12.71	23.08	24.78	47.52	13.71	21.10	25.07	60.09
	342.50	230.00	263.48	181.58	233.22	234.70	23.07	21.05			31.91	2.04		
	190.00	125.00	235.71	175.03	221.42	200.12	24.06	40.02			16.54	60.09		
	152.50	152.50	218.40	170.95	214.07	178.57	43.21	12.10			40.37	17.09		
	147.50	172.50	217.59	170.76	213.72	177.57	47.52	1.01			44.90	2.94		
PH	7.47	7.50	7.53	7.48	7.57	7.41	0.76	0.27	3.29	8.63	1.23	1.21	3.41	9.13
	8.20	7.40	7.55	7.48	7.58	7.43	7.93	1.08			7.62	0.40		
	7.40	7.70	7.54	7.48	7.57	7.42	1.89	2.86			2.33	3.58		
	6.95	7.35	7.55	7.49	7.58	7.45	8.63	1.90			9.13	1.36		
	7.25	7.20	7.52	7.48	7.57	7.41	3.72	3.89			4.35	2.91		
Dissolved Ions (mg/l)	179.40	184.33	159.33	139.41	156.85	143.76	11.19	24.37	23.40	51.55	12.57	22.01	23.70	55.53
	249.35	182.40	169.71	179.44	168.65	181.31	31.94	1.62			32.37	0.60		
	135.80	97.20	161.38	147.31	159.18	151.17	18.84	51.55			17.22	55.53		
	116.60	125.15	159.80	141.23	157.39	145.46	37.05	12.85			34.98	16.23		
	110.15	137.80	158.99	138.09	156.46	142.52	44.34	0.21			42.05	3.42		
Dissolved Solids (mg/l)	147.93	147.50	120.54	113.62	120.48	113.69	18.52	22.97	22.27	47.08	18.56	22.92	22.28	47.17
	200.00	138.00	130.98	139.96	130.96	139.98	34.51	1.42			34.52	1.44		
	110.00	80.00	122.14	117.66	122.09	117.73	11.04	47.08			10.99	47.17		
	94.50	90.50	118.67	108.95	118.63	109.03	25.58	20.39			25.53	20.48		
	86.00	105.00	118.52	108.54	118.46	108.63	37.81	3.37			37.75	3.46		
Hardness (mg/l) as CaCO ₃	69.07	78.00	70.65	61.18	69.11	63.87	2.29	21.56	33.28	69.70	0.07	18.12	33.31	76.50
	92.50	80.00	73.04	72.20	72.18	73.72	21.04	9.75			21.97	7.85		
	46.00	37.00	71.00	62.79	69.56	65.31	54.35	69.70			51.22	76.50		
	45.50	50.50	71.08	63.17	69.67	65.65	56.22	25.09			53.11	30.00		
	44.00	54.50	70.65	61.18	69.11	63.87	60.57	12.26			57.08	17.19		
Alkalinity (mg/l) as CaCO ₃	72.43	96.50	75.61	73.77	74.21	76.23	4.39	23.55	21.39	43.12	2.46	21.01	21.33	48.06
	106.00	101.00	77.42	87.90	76.72	89.13	26.96	12.97			27.62	11.75		
	64.00	51.00	75.51	72.99	74.07	75.51	17.98	43.12			15.74	48.06		
	53.50	67.50	75.68	74.27	74.30	76.68	41.46	10.03			38.88	13.61		
	57.50	75.00	75.90	76.06	74.62	78.31	32.00	1.41			29.77	4.42		
Natrium (mg/l)	22.39	17.00	16.16	13.14	16.14	13.17	27.81	22.71	28.84	64.66	27.89	22.51	28.84	64.40
	30.50	14.00	17.89	19.62	17.89	19.64	41.34	40.14			41.35	40.26		
	17.00	9.50	16.48	14.31	16.46	14.34	3.06	50.63			3.19	50.91		
	12.50	12.00	15.81	11.82	15.79	11.85	26.48	1.50			26.30	1.21		
	9.65	11.00	15.89	12.11	15.86	12.14	64.66	10.09			64.40	10.36		
Kalium (mg/l)	5.33	4.58	5.50	4.36	5.29	4.71	3.19	4.70	8.77	28.20	0.74	2.95	8.36	21.36
	5.65	4.20	5.53	4.36	5.32	4.74	2.12	3.81			5.91	12.84		
	4.40	4.50	5.36	4.33	5.21	4.62	21.82	3.78			18.36	2.57		
	5.20	4.30	5.33	4.33	5.19	4.59	2.50	0.70			0.22	6.84		
	4.80	6.10	5.61	4.38	5.37	4.80	16.87	28.20			11.82	21.36		
Calcium (mg/l)	17.20	22.00	18.89	16.77	17.41	19.36	9.83	23.77	31.59	81.20	1.19	11.98	31.88	102.63
	23.00	23.33	19.77	23.24	19.52	23.67	14.04	0.40			15.12	1.46		
	13.00	10.00	19.07	18.12	17.85	20.26	46.69	81.20			37.28	102.63		
	12.50	15.00	18.85	16.49	17.32	19.19	50.80	9.93			38.54	27.90		
	12.20	15.50	19.18	18.92	18.11	20.80	57.21	22.06			48.45	34.20		
Magnesium (mg/l)	6.32	5.58	5.59	4.71	5.86	4.25	11.55	15.52	40.68	72.31	7.30	23.79	39.53	80.47
	8.55	5.27	5.85	5.17	6.03	4.85	31.58	1.84			29.44	7.83		
	3.40	2.80	5.61	4.77	5.88	4.31	65.00	70.36			72.83	53.96		
	3.45	3.10	5.61	4.75	5.87	4.29	62.61	53.23			70.16	38.49		
	3.25	3.85	5.60	4.73	5.87	4.27	72.31	22.86			80.47	10.97		

Table A.4.2(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Entropy Method)			(Regression Method)				
	130202	130212	130202	130212	130202	130212	130202	130212	Average	Maximum	130202	130212	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	294.50	225.63	237.12	175.36	227.84	191.72	19.48	22.28	19.00	43.22	22.64	15.03	21.10	46.03
	266.25	177.50	247.85	177.90	232.07	205.65	6.91	0.23			12.84	15.86		
	171.25	138.75	224.30	172.37	222.78	175.07	30.98	24.23			30.09	26.18		
	150.00	162.50	214.83	170.10	219.04	162.78	43.22	4.68			46.03	0.17		
PH	7.84	7.45	7.48	7.90	7.65	7.32	4.55	6.04	5.35	8.59	2.33	1.68	3.28	7.73
	7.80	7.55	7.48	7.90	7.65	7.34	4.10	4.64			1.92	2.83		
	7.18	7.53	7.49	7.91	7.65	7.35	4.39	5.12			6.56	2.29		
	7.10	7.28	7.48	7.90	7.65	7.34	5.35	8.59			7.73	0.90		
Dissolved Ions (mg/l)	214.37	141.10	163.98	157.33	167.34	151.44	23.51	11.50	20.36	39.93	21.94	7.33	18.44	42.77
	192.58	139.80	165.04	161.43	168.44	155.48	14.30	15.47			12.53	11.22		
	126.20	111.18	159.90	141.61	163.14	135.92	26.70	27.38			29.27	22.26		
	113.38	131.48	158.65	136.82	161.86	131.20	39.93	4.07			42.77	0.21		
Dissolved Solids (mg/l)	173.97	142.75	125.62	126.44	129.43	119.77	27.79	11.43	20.72	31.82	25.60	16.10	19.03	35.84
	155.00	109.00	126.46	128.55	130.20	122.01	18.41	17.94			16.00	11.94		
	102.25	85.25	120.04	112.38	124.32	104.87	17.40	31.82			21.59	23.02		
	90.25	97.75	118.15	107.62	122.60	99.83	30.91	10.10			35.84	2.13		
Hardness (mg/l)as CaCO3	80.78	79.00	71.00	62.80	71.71	61.60	12.11	20.51	24.78	56.25	11.24	22.03	24.51	57.65
	69.25	58.50	71.19	63.70	71.91	62.46	2.80	8.89			3.84	6.77		
	45.75	43.75	70.11	58.74	70.76	57.63	53.25	34.26			54.66	31.73		
	44.75	52.50	69.92	57.86	70.55	56.77	56.25	10.21			57.65	8.13		
Alkalinity (mg/l)as CaCO3	89.22	98.75	76.21	78.46	77.08	76.96	14.58	20.55	16.74	35.95	13.61	22.06	16.28	37.20
	85.00	76.00	76.16	78.08	77.01	76.58	10.40	2.74			9.40	0.76		
	58.75	59.25	75.25	70.97	75.90	69.84	28.09	19.78			29.19	17.88		
	55.50	71.25	75.45	72.57	76.15	71.36	35.95	1.85			37.20	0.15		
Sodium (mg/l)	26.44	15.50	17.11	16.69	17.35	16.26	35.30	7.68	24.84	47.23	34.37	4.93	23.34	45.39
	23.75	11.75	17.27	17.30	17.52	16.87	27.28	47.23			26.23	43.55		
	14.75	10.75	16.19	13.23	16.41	12.83	9.76	23.07			11.28	19.34		
	11.08	11.50	15.88	12.08	16.10	11.69	43.39	5.04			45.39	1.64		
Potassium (mg/l)	5.49	4.39	5.40	4.34	5.21	4.68	1.64	1.08	5.83	16.73	5.11	6.56	6.01	10.60
	5.03	4.35	5.36	4.33	5.20	4.63	6.67	0.46			3.49	6.48		
	4.80	4.40	5.33	4.33	5.19	4.56	11.04	1.59			8.03	3.74		
	5.00	5.20	5.37	4.33	5.20	4.65	7.40	16.73			4.08	10.60		
Calcium (mg/l)	20.10	22.67	19.03	17.82	18.63	18.51	5.32	21.38	19.90	50.93	7.29	18.32	20.48	45.11
	18.00	16.67	19.14	18.63	18.84	19.17	6.33	11.78			4.69	15.02		
	12.75	12.50	18.58	14.51	17.80	15.88	45.73	16.08			39.57	27.07		
	12.35	15.25	18.64	15.00	17.92	16.28	50.93	1.64			45.11	6.74		
Magnesium (mg/l)	7.44	5.42	5.68	4.87	6.00	4.32	23.60	10.16	35.23	66.27	19.29	20.36	31.45	77.20
	5.98	4.03	5.70	4.89	6.01	4.35	4.60	21.24			0.56	7.88		
	3.43	2.95	5.58	4.68	5.94	4.04	62.92	58.64			73.45	37.09		
	3.35	3.48	5.57	4.67	5.94	4.02	66.27	34.39			77.20	15.77		

Table A.4.2(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
							(Entropy Method)				(Regression Method)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	259.67	192.08	229.99	173.68	234.06	166.59	11.43	9.58	11.60	31.20	9.86	13.27	11.68	40.09
	228.33	169.17	231.18	173.95	234.46	168.25	1.25	2.83			2.68	0.55		
	163.33	150.00	214.29	169.98	228.80	144.56	31.20	13.32			40.09	3.63		
PH	7.69	7.53	7.56	7.49	7.73	7.19	1.69	0.53	1.47	5.00	0.49	4.49	3.51	7.23
	7.52	7.48	7.56	7.49	7.71	7.22	0.53	0.13			2.57	3.43		
	7.20	7.42	7.56	7.49	7.72	7.21	5.00	0.94			7.23	2.87		
Dissolved Ions (mg/l)	188.18	154.64	145.34	173.52	171.37	127.87	22.77	12.21	21.70	42.07	8.93	17.31	13.21	39.18
	167.25	134.92	145.82	173.66	171.51	128.59	12.81	28.71			2.55	4.69		
	120.85	120.05	134.90	170.56	168.20	112.14	11.63	42.07			39.18	6.59		
Dissolved Solids (mg/l)	152.64	121.83	122.84	119.43	132.25	102.93	19.52	1.97	13.72	21.39	13.36	15.51	11.71	32.40
	134.83	102.83	122.15	117.72	131.72	100.92	9.40	14.48			2.30	1.85		
	96.83	91.83	117.54	106.10	128.20	87.40	21.39	15.54			32.40	4.82		
Hardness (mg/l) as CaCO ₃	69.19	82.83	70.03	58.37	74.87	49.88	1.21	29.53	22.13	53.33	8.21	39.77	32.40	64.63
	61.33	73.17	70.21	59.14	74.98	50.77	14.48	19.17			22.26	30.61		
	45.17	64.50	69.26	54.80	74.36	45.85	53.33	15.04			64.63	28.92		
Alkalinity (mg/l) as CaCO ₃	80.81	65.00	75.49	72.92	79.42	66.02	6.58	12.18	20.80	45.21	1.72	1.57	15.70	35.42
	74.50	55.83	75.52	73.10	79.44	66.21	1.37	30.93			6.63	18.60		
	58.33	47.33	74.96	68.73	78.99	61.65	28.51	45.21			35.42	30.25		
Sodium (mg/l)	23.30	13.50	16.74	15.29	17.58	13.81	28.15	13.26	19.38	28.15	24.55	2.29	13.93	28.39
	20.00	11.83	16.61	14.80	17.45	13.31	16.95	25.11			12.73	12.52		
	13.05	10.83	15.87	12.04	16.75	10.50	21.61	11.17			28.39	3.09		
Potassium (mg/l)	5.13	4.43	5.48	4.35	5.38	4.55	6.82	1.81	7.20	13.96	4.90	2.63	6.36	11.90
	5.08	4.33	5.47	4.35	5.36	4.52	7.68	0.46			5.56	4.32		
	4.80	4.97	5.47	4.35	5.37	4.53	13.96	12.47			11.90	8.85		
Calcium (mg/l)	17.73	18.44	18.63	14.91	19.21	13.90	5.08	19.14	16.67	45.74	8.34	24.61	21.58	49.90
	16.17	16.11	18.62	14.76	19.19	13.76	15.15	8.38			18.65	14.57		
	12.57	13.50	18.32	12.62	18.84	11.69	45.74	6.52			49.90	13.39		
Magnesium (mg/l)	6.09	4.55	5.71	4.92	6.43	3.66	6.24	8.13	28.86	67.36	5.53	19.50	24.56	90.27
	5.13	3.72	5.72	4.93	6.43	3.68	11.50	32.53			25.30	1.05		
	3.37	3.25	5.64	4.79	6.41	3.44	67.36	47.38			90.27	5.69		

Table A.4.2(d) 4 yearly

Water Quality Parameter	Observed Values		Assigned Values (Entropy Method)		Assigned Values (Regression Method)		Absolute Values of Errors (%)							
							(Entropy Method)				(Regression Method)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	232.88	182.19	228.90	173.43	232.69	166.80	1.71	4.81	4.73	10.29	0.0801	8.4479	5.45	11.91
	208.13	170.00	229.55	173.58	232.91	167.67	10.29	2.11			11.908	1.3687		
PH	7.51	7.49	7.56	7.49	7.71	7.22	0.67	0.01	0.61	1.48	2.7012	3.59	3.09	3.59
	7.45	7.41	7.56	7.49	7.71	7.22	1.48	1.07			3.5283	2.5491		
Dissolved Ions (mg/l)	170.29	147.27	145.79	173.66	170.24	130.78	14.39	17.92	16.29	27.98	0.0275	11.195	6.58	11.23
	152.98	135.64	145.55	173.59	170.16	130.42	4.86	27.98			11.232	3.8488		
Dissolved Solids (mg/l)	138.11	114.00	122.07	117.47	130.59	102.53	11.61	3.04	6.97	12.32	5.4475	10.065	5.99	10.07
	122.63	103.38	121.53	116.12	130.15	101.00	0.90	12.32			6.1315	2.2981		
Hardness (mg/l) as CaCO ₃	63.27	61.38	71.55	65.32	76.21	57.14	13.09	6.42	15.68	25.53	20.457	6.91	16.01	33.71
	57.00	55.50	71.55	65.32	76.21	57.14	25.53	17.69			33.707	2.9525		
Alkalinity (mg/l) as CaCO ₃	73.98	79.00	76.16	78.10	79.95	71.44	2.95	1.14	4.65	8.51	8.0711	9.5882	8.44	13.89
	70.25	73.63	76.23	78.63	80.01	72.00	8.51	6.79			13.89	2.2195		
Sodium (mg/l)	20.60	13.13	16.19	13.24	17.32	11.27	21.41	0.84	10.27	21.41	15.935	14.172	9.19	15.93
	17.41	11.63	16.11	12.95	17.25	10.96	7.47	11.35			0.936	5.7201		
Potassium (mg/l)	5.15	4.39	5.79	4.41	5.69	4.58	12.43	0.46	9.20	16.17	10.432	4.2659	8.13	14.02
	5.01	4.78	5.82	4.41	5.71	4.60	16.17	7.74			14.016	3.8197		
Calcium (mg/l)	16.43	17.58	18.89	16.79	19.30	16.09	14.97	4.49	13.46	25.03	17.452	8.5004	14.61	27.90
	15.18	15.96	18.98	17.45	19.42	16.69	25.03	9.34			27.899	4.5963		
Magnesium (mg/l)	5.43	4.19	5.85	5.15	6.62	3.80	7.73	22.91	23.38	37.33	21.928	9.3735	18.70	42.07
	4.66	3.75	5.85	5.15	6.62	3.80	25.54	37.33			42.074	1.426		

Table A.4.3 Results of Assignment of Water Quality Values in the Logan River Basin

Table A.4.3(a) 1 yearly

Water Quality Parameter	Observed Values			Assigned Values (Entropy Method)			Assigned Values (Regression Method)			Absolute Values of Errors (%)									
	at Station			at Station			at Station			(Entropy Method)				(Regression Method)					
	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average	Maximum	145010	145013	145020	Average	Maximum
(1)	(2)			(3)			(4)			(5)			(6)	(7)	(8)			(9)	(10)
Conductivity (mS/m)	348.50	650.00	397.50	354.90	495.40	601.60	370.06	425.97	619.62	1.84	23.78	51.35	34.87	118.50	6.19	34.47	55.88	34.70	133.36
	360.00	398.00	434.00	355.90	495.90	609.80	377.91	456.05	616.18	1.14	24.60	40.51			4.97	14.58	41.98		
	205.00	296.67	268.33	352.90	494.50	586.30	355.11	388.72	626.18	72.15	66.69	118.50			73.22	24.29	133.36		
	328.75	476.25	645.00	351.70	496.70	625.80	393.44	515.51	609.37	6.98	4.29	2.98			19.68	8.24	5.52		
	347.50	245.00	631.67	355.90	495.90	610.20	378.33	457.64	616.00	2.42	102.41	3.40			8.87	86.79	2.46		
PH	7.76	8.00	7.78	8.16	7.95	8.14	8.07	8.02	8.07	5.15	0.62	4.69	4.21	13.16	4.01	0.29	3.85	4.08	10.04
	8.00	8.12	7.94	7.85	7.89	7.92	7.97	7.90	7.94	1.88	2.83	0.25			0.32	2.74	0.05		
	7.43	7.70	7.47	8.31	7.97	8.24	8.17	8.15	8.22	11.79	3.51	10.36			9.93	5.89	10.04		
	7.63	7.88	7.88	7.69	7.86	7.82	7.87	7.76	7.79	0.85	0.19	0.70			3.23	1.41	1.09		
	7.90	7.70	7.87	6.86	7.70	7.31	7.50	7.28	7.25	13.16	0.04	7.08			5.13	5.50	7.78		
Dissolved Ions (mg/l)	220.17	409.44	241.65	231.60	320.80	358.90	251.16	245.78	377.50	5.19	21.65	48.52	32.51	112.97	14.07	39.97	56.22	33.93	137.20
	223.45	281.80	264.44	232.80	321.90	366.70	253.54	284.39	372.80	4.18	14.23	38.67			13.47	0.92	40.98		
	129.93	203.27	162.47	229.50	319.00	346.00	247.16	181.05	385.38	76.63	56.94	112.97			90.22	10.93	137.20		
	222.55	329.83	400.60	235.60	323.70	380.00	257.67	351.10	384.67	5.86	1.86	5.14			15.78	6.45	8.97		
	250.50	183.60	425.87	233.10	322.10	368.40	254.08	293.12	371.73	6.95	75.44	13.49			1.43	59.65	12.71		
Dissolved Solids (mg/l)	188.00	350.00	210.00	199.50	272.40	302.10	210.50	208.04	319.69	6.12	22.17	43.86	31.42	99.40	11.97	40.56	52.24	31.72	122.74
	192.50	226.00	224.00	200.80	273.20	310.90	214.05	233.64	319.93	4.31	20.86	38.79			11.19	3.38	42.83		
	117.00	173.33	143.33	197.30	270.90	285.80	204.02	161.22	319.26	68.63	56.29	99.40			74.37	6.99	122.74		
	192.00	270.00	340.00	203.30	274.80	330.00	221.58	288.02	320.45	5.89	1.78	2.94			15.41	6.67	5.75		
	210.00	150.00	366.67	201.40	273.60	316.40	216.18	249.01	320.08	4.10	82.40	13.71			2.94	66.00	12.71		
Hardness (mg/lies CaCO3)	108.50	181.60	86.25	110.80	157.50	129.60	113.70	116.20	141.04	2.12	13.27	49.10	34.83	112.67	4.79	36.02	63.52	38.22	148.14
	115.25	136.40	96.20	112.80	158.87	135.30	118.84	136.02	140.99	2.13	16.47	40.64			3.11	0.28	46.56		
	64.00	98.00	57.33	107.30	155.10	116.30	104.51	80.76	141.12	67.66	58.27	102.85			63.29	17.59	146.14		
	112.25	166.25	159.25	117.10	161.80	116.30	130.52	181.03	140.89	4.32	2.68	26.97			16.27	8.89	11.53		
	109.50	75.00	172.67	113.80	159.50	139.20	121.65	146.86	140.97	3.93	112.67	19.38			11.10	95.81	18.36		
Alkalinity (mg/lies CaCO3)	83.50	138.80	73.50	84.60	123.00	92.90	102.16	79.58	101.85	1.32	11.38	26.39	22.62	78.73	22.34	42.67	38.57	38.49	119.52
	83.75	133.40	81.00	88.10	126.40	98.90	100.91	107.78	101.18	5.19	5.25	22.10			20.48	19.21	24.91		
	47.33	87.67	47.33	71.70	118.40	84.60	103.91	40.18	102.78	51.48	35.06	78.73			119.52	54.17	117.14		
	87.75	136.75	119.25	93.70	131.80	108.40	98.91	152.80	100.11	6.78	3.62	9.10			12.71	11.74	16.05		
	95.50	82.00	123.67	87.30	125.70	97.60	101.18	101.51	101.33	8.59	53.29	21.08			5.95	23.79	18.06		
Sodium (mg/l)	23.20	54.10	41.25	25.60	35.90	65.20	24.67	32.91	66.41	10.34	33.64	58.06	38.26	123.73	6.33	39.17	61.00	38.64	132.12
	22.00	25.60	45.00	25.50	35.90	64.70	25.88	34.67	64.93	15.91	40.23	43.78			17.62	35.42	44.29		
	14.47	21.00	29.50	25.60	35.90	66.00	22.99	30.46	68.48	76.96	70.95	123.73			58.91	45.07	132.12		
	23.25	33.50	66.75	25.50	35.90	63.90	27.59	37.16	62.83	9.68	7.16	4.27			18.65	10.92	5.88		
	32.75	24.00	69.67	25.50	35.90	64.50	26.28	35.26	64.43	22.14	49.58	7.42			19.75	46.91	7.52		
Potassium (mg/l)	1.32	2.54	2.13	1.50	1.80	2.30	1.41	1.75	2.34	13.64	29.13	8.24	12.86	35.29	6.54	31.08	10.20	10.82	37.91
	1.15	1.68	2.60	1.50	1.80	2.30	1.40	1.73	2.35	30.43	7.14	11.54			21.87	3.08	9.71		
	1.47	1.60	1.70	1.50	1.80	2.30	1.40	1.74	2.34	2.27	12.50	35.29			4.27	8.85	37.91		
	1.33	1.63	2.30	1.50	1.80	2.30	1.40	1.73	2.35	13.21	10.77	0.00			5.68	6.24	2.14		
	1.45	1.60	2.37	1.50	1.80	2.30	1.40	1.72	2.35	3.45	12.50	2.82			3.54	7.52	0.66		
Calcium (mg/l)	18.94	34.00	17.00	35.00	36.40	15.90	19.51	21.62	25.16	84.79	7.06	6.47	43.74	134.84	3.03	36.40	47.99	27.20	102.20
	20.00	26.40	19.30	35.00	36.40	18.60	20.89	25.89	26.10	75.00	37.88	3.63			4.45	1.94	35.24		
	11.60	19.00	11.83	18.60	28.00	19.80	17.72	16.07	23.93	60.34	47.37	67.32			52.79	15.43	102.20		
	20.00	30.75	32.00	20.90	29.80	29.90	23.44	33.79	27.85	4.50	3.09	6.56			17.18	9.87	12.97		
	20.75	15.50	31.67	35.00	36.40	16.30	19.71	22.22	25.29	68.67	134.84	48.53			5.03	43.36	20.14		
Magnesium (mg/l)	14.90	23.50	10.65	14.80	20.60	15.90	15.31	11.56	18.33	0.67	12.34	46.48	38.67	143.68	2.74	50.81	72.13	45.98	170.58
	15.88	17.10	11.56	15.30	20.90	17.20	16.40	17.52	18.03	3.62	22.22	48.79			3.29	2.45	55.93		
	8.47	12.30	6.80	14.60	20.50	15.20	15.07	10.25	18.40	72.44	66.67	123.53			77.97	16.67	170.58		
	15.13	21.75	19.25	15.90	21.30	18.90	17.49	23.51	17.72	5.12	2.07	1.82			15.65	8.07	7.96		
	14.00	8.70	22.73	15.80	21.20	18.70	17.33	22.61	17.76	12.86	143.68	17.74			23.77	159.84	21.86		

Table A.4.3(b) 2 yearly

Water Quality Parameter	Observed Values			Assigned Values (Entropy Method)			Assigned Values (Regression Method)			Absolute Values of Errors (%)									
	at Station			at Station			at Station			(Entropy Method)				(Regression Method)					
	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average	Maximum	145010	145013	145020	Average	Maximum
(1)	(2)			(3)			(4)			(5)			(6)	(7)	(8)			(9)	(10)
Conductivity (mS/m)	354.25	524.00	415.75	310.40	474.80	258.30	407.62	333.13	275.55	12.38	9.39	37.87	25.68	76.05	15.06	36.43	33.72	32.81	70.62
	282.50	347.33	351.17	261.00	451.70	84.10	415.91	250.97	103.17	7.61	30.05	76.05			47.22	27.74	70.62		
	266.88	386.46	456.67	311.70	473.30	265.30	407.30	336.30	282.19	16.80	22.99	41.91			52.62	12.98	38.21		
	338.13	360.63	636.33	349.10	492.70	554.00	394.42	463.91	549.92	3.25	36.62	13.21			16.65	28.64	13.85		
PH	7.88	8.06	7.86	8.36	7.98	8.27	8.51	8.01	8.23	6.09	0.99	5.25	8.17	21.93	7.95	0.66	4.70	8.08	16.51
	7.72	7.91	7.70	8.75	8.06	8.46	8.80	8.11	8.42	13.39	1.90	9.82			14.10	2.52	9.32		
	7.53	7.79	7.67	8.36	7.98	8.27	8.50	8.00	8.22	11.03	2.47	7.81			12.85	2.78	7.16		
	7.76	7.79	7.87	6.06	7.19	7.11	6.48	7.31	6.90	21.93	7.67	9.67			16.51	6.11	12.29		
Dissolved Ions (mg/l)	221.81	345.62	253.05	199.20	293.70	170.50	262.44	175.95	190.00	10.19	15.02	32.62	20.19	68.71	18.32	49.09	24.91	34.87	60.75
	176.69	242.53	213.45	164.10	264.20	66.80	265.52	95.19	91.77	7.13	8.93	68.71			50.28	60.75	57.01		
	176.24	266.55	281.53	199.90	294.30	173.80	262.35	178.43	193.02	13.42	10.41	36.27			48.86	33.06	31.44		
	236.53	256.71	413.23	233.20	322.10	368.80	257.01	318.26	363.09	1.41	25.47	10.75			8.66	23.98	12.14		
Dissolved Solids (mg/l)	190.25	288.00	217.00	175.90	257.00	137.90	223.56	160.38	155.26	7.54	10.76	36.45	21.45	69.02	17.51	44.31	28.45	32.12	58.25
	154.75	199.67	183.67	148.40	239.20	56.90	225.19	108.67	76.67	4.10	19.80	69.02			45.52	45.58	58.25		
	154.50	221.67	241.67	178.30	258.60	152.00	223.29	168.73	167.94	15.40	16.66	37.10			44.53	23.88	30.51		
	201.00	210.00	353.33	201.60	273.70	318.10	220.22	265.69	315.29	0.30	30.33	9.97			9.56	26.52	10.77		
Hardness (mg/l as CaCO3)	111.88	159.00	91.23	92.85	145.28	67.19	113.17	95.97	77.20	17.01	8.63	26.35	19.98	61.39	1.15	39.64	15.37	24.98	46.53
	89.63	117.20	76.77	76.53	134.10	29.64	106.59	62.67	43.96	14.61	14.42	61.39			18.92	46.53	42.74		
	88.13	132.13	108.29	96.22	147.53	77.88	114.95	104.97	86.19	9.19	11.66	28.08			30.44	20.55	20.41		
	110.88	120.63	165.96	117.56	162.09	152.61	127.22	167.09	148.20	6.03	34.38	8.04			14.74	38.52	10.70		
Alkalinity (mg/l as CaCO3)	83.63	136.10	77.25	74.40	113.30	75.70	91.75	69.68	84.74	11.03	16.75	2.01	9.07	17.85	9.72	48.81	9.70	25.06	67.37
	65.54	110.53	64.17	64.40	103.80	59.60	86.76	36.06	74.99	1.74	6.09	7.12			32.38	67.37	16.87		
	67.54	112.21	83.29	75.80	114.60	70.00	92.47	74.47	86.13	12.23	2.13	15.96			36.90	33.63	3.41		
	91.63	109.38	121.46	90.70	128.90	103.40	100.24	126.80	101.30	1.01	17.85	14.87			9.40	15.93	16.59		
Sodium (mg/l)	22.60	39.85	43.13	24.00	34.60	32.80	30.02	27.79	33.27	6.19	13.17	23.94	24.85	47.11	32.83	30.26	22.86	27.72	70.35
	18.23	23.30	37.25	23.20	33.90	19.70	31.08	24.15	20.50	27.24	45.49	47.11			70.35	3.64	44.97		
	18.86	27.25	48.13	24.00	34.60	33.10	30.00	27.86	33.50	27.26	26.97	31.22			59.09	2.22	30.39		
	28.00	28.75	68.21	25.30	35.70	59.10	27.98	35.00	58.53	9.64	24.17	13.35			0.14	21.73	14.19		
Potassium (mg/l)	1.24	2.11	2.36	1.50	1.80	2.50	1.36	1.80	2.53	21.46	14.69	5.82	12.80	25.00	9.91	14.84	7.06	9.25	24.72
	1.31	1.64	2.15	1.50	1.80	2.50	1.36	1.78	2.51	14.65	9.76	16.28			4.29	8.71	16.61		
	1.40	1.61	2.00	1.50	1.80	2.50	1.37	1.77	2.49	7.46	11.63	25.00			1.95	10.06	24.72		
	1.39	1.61	2.33	1.50	1.80	2.50	1.39	1.74	2.44	8.11	11.63	7.14			0.15	6.04	4.70		
Calcium (mg/l)	19.47	30.20	18.15	17.20	27.00	14.20	20.30	19.48	15.74	11.66	10.60	21.76	17.34	50.54	4.25	35.50	13.26	21.24	35.88
	15.80	22.70	15.57	15.30	25.50	7.70	19.39	14.56	10.06	3.16	12.33	50.54			22.70	35.88	35.40		
	15.80	24.88	21.92	17.90	27.50	17.00	20.68	21.56	18.14	13.29	10.55	22.43			30.89	13.34	17.22		
	20.38	23.13	31.83	19.60	28.80	24.40	21.69	27.01	24.44	3.80	24.54	23.35			6.45	16.79	23.22		
Magnesium (mg/l)	15.39	20.30	11.11	10.80	18.10	5.10	15.00	9.08	6.83	29.81	10.84	54.07	36.35	95.07	2.49	55.27	38.50	29.89	61.77
	12.17	14.70	9.18	10.10	17.60	4.00	14.79	7.88	5.73	17.01	19.73	56.43			21.53	46.37	37.53		
	11.80	17.03	13.03	12.80	19.30	9.70	15.76	13.35	10.74	8.51	13.36	25.53			33.64	21.59	17.56		
	14.56	15.23	20.99	27.00	29.70	16.70	17.77	24.63	21.07	85.41	95.07	20.44			22.04	61.77	0.35		

Table A.4.3(c) 3 yearly

Water Quality Parameter	Observed Values			Assigned Values (Entropy Method)			Assigned Values (Regression Method)			Absolute Values of Errors (%)									
	at Station			at Station			at Station			(Entropy Method)				(Regression Method)					
	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average (6)	Maximum (7)	145010	145013	145020	Average (9)	Maximum (10)
(1)	(2)			(3)			(4)			(5)					(8)				
Conductivity (mS/m)	304.50	446.22	366.61	280.60	460.70	122.10	530.17	303.54	96.87	7.85	2.78	66.69			74.11	32.26	73.58		
	297.90	390.31	449.11	317.90	478.30	306.70	464.83	370.67	294.51	6.71	22.54	31.71	25.27	66.69	56.04	5.03	34.42	42.78	74.11
	293.80	339.31	515.00	318.30	478.60	310.20	463.66	371.87	298.04	8.34	41.05	39.77			57.82	9.60	42.13		
PH	7.70	7.90	7.70	8.90	8.10	8.50	9.54	8.00	8.37	15.58	2.53	10.39			23.96	1.31	8.66		
	7.70	7.90	7.80	8.30	7.98	8.26	8.78	7.93	8.14	7.79	1.01	5.90	5.29	15.58	14.05	0.39	4.41	6.53	23.96
	7.70	7.80	7.70	7.43	7.81	7.64	7.26	7.79	7.70	3.51	0.13	0.78			5.75	0.18	0.03		
Dissolved Ions (mg/l)	191.20	208.20	222.90	193.80	289.10	144.90	314.69	182.93	144.40	1.36	3.05	34.99			64.59	38.65	35.22		
	192.00	271.60	275.80	211.50	304.00	237.40	281.76	234.85	239.71	10.16	11.93	13.92	14.96	34.99	46.75	13.53	13.09	30.63	64.59
	201.00	238.90	329.80	212.90	305.10	245.20	279.02	239.18	247.65	5.92	27.71	25.61			38.82	0.12	24.86		
Dissolved Solids (mg/l)	165.80	249.80	192.40	167.80	251.70	99.90	269.38	158.23	100.10	1.21	0.76	46.08			62.47	36.66	47.97		
	167.20	223.10	235.80	183.70	262.10	186.90	243.84	200.92	188.79	9.87	17.48	20.74	18.56	48.08	45.84	9.94	19.94	32.67	62.47
	173.00	197.80	283.30	186.10	263.60	203.80	238.97	209.06	205.71	7.57	33.27	28.06			38.13	5.69	27.39		
Hardness (mg/l as CaCO3)	95.90	138.70	79.93	92.90	145.40	67.50	127.86	101.09	71.80	3.13	4.83	15.55			33.33	27.11	10.17		
	97.17	133.60	104.30	103.00	152.20	100.90	121.27	124.77	104.63	6.00	13.92	3.26	12.22	35.54	24.80	6.61	0.32	17.50	33.33
	95.25	113.10	129.80	104.60	153.30	106.50	120.16	128.74	110.13	9.82	35.54	17.95			26.16	13.83	15.16		
Alkalinity (mg/l as CaCO3)	71.50	120.00	67.30	79.20	118.00	83.90	94.62	77.97	92.31	10.77	1.67	24.67			32.34	35.03	37.17		
	72.90	119.30	82.50	84.30	122.80	92.40	91.99	99.10	97.81	15.64	2.93	12.00	11.31	24.67	26.19	16.93	18.56	21.27	37.17
	76.90	102.10	96.80	83.80	122.40	91.70	92.22	97.27	97.33	8.97	19.88	5.27			19.92	4.73	0.55		
Sodium (mg/l)	19.90	33.60	38.60	22.90	33.60	16.40	35.87	25.14	15.44	15.08	0.00	57.51			80.25	25.17	59.99		
	19.90	26.70	47.10	24.10	34.60	33.80	32.10	28.65	33.39	21.11	29.59	28.24	24.63	57.51	61.28	7.31	29.11	38.21	80.25
	23.50	26.20	55.30	24.20	34.70	36.10	31.59	29.13	35.81	2.98	32.44	34.72			34.40	11.17	35.24		
Potassium (mg/l)	1.30	1.90	2.10	1.50	1.80	3.00	1.76	1.89	2.85	15.38	5.26	42.86			35.00	0.53	35.76		
	1.30	1.60	2.20	1.50	1.80	2.80	1.68	1.85	2.74	15.38	12.50	27.27	19.54	42.86	29.00	15.37	24.32	22.05	35.76
	1.40	1.60	2.10	1.50	1.80	2.70	1.64	1.82	2.68	7.14	12.50	28.57			17.00	14.00	27.48		
Calcium (mg/l)	16.80	26.50	16.00	16.50	26.40	11.30	23.42	20.33	13.64	1.79	0.38	29.37			39.41	23.27	14.78		
	17.20	25.40	21.00	18.20	27.70	18.30	21.66	24.35	20.84	5.81	9.06	12.86	13.58	36.11	25.94	4.13	0.75	18.58	39.41
	17.50	21.80	25.20	17.70	27.40	16.10	22.20	23.13	18.65	1.14	25.69	36.11			26.83	6.11	25.98		
Magnesium (mg/l)	13.10	17.60	9.70	11.80	18.70	7.20	17.28	11.37	11.37	9.92	6.25	25.77			31.89	35.40	17.22		
	13.20	17.10	12.50	13.80	20.00	12.60	16.31	15.82	15.82	4.55	16.96	0.80	14.61	42.66	23.55	7.50	26.54	22.45	35.40
	12.50	14.30	16.30	14.50	20.40	14.90	15.89	17.74	17.74	16.00	42.66	8.59			27.12	24.03	8.81		

Table A.4.3(d) 4 yearly

Water Quality Parameter	Observed Values			Assigned Values (Entropy Method)			Assigned Values (Regression Method)			Absolute Values of Errors (%)									
	at Station			at Station			at Station			(Entropy Method)				(Regression Method)					
	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average	Maximum	145010	145013	145020	Average	Maximum
(1)	(2)			(3)			(4)			(5)			(6)	(7)	(8)			(9)	(10)
Conductivity (mS/m)	310.60	455.23	436.21	334.20	485.90	434.80	419.06	409.14	435.68	7.60	6.74	0.32	11.36	37.63	34.92	10.12	0.12	17.14	34.92
	310.30	353.96	494.75	337.20	487.20	459.00	410.61	419.11	460.40	8.67	37.83	7.23			32.33	18.40	6.94		
PH	7.7	7.9	7.8	8.4	7.99	8.29	9.00	7.68	8.16	9.09	1.14	6.28	3.85	9.09	16.91	0.22	4.63	5.28	16.91
	7.7	7.8	7.8	7.38	7.803	7.613	7.09	7.84	7.70	4.16	0.04	2.40			7.98	0.45	1.34		
Dissolved Ions (mg/l)	199.00	306.10	267.30	218.8	310.10	281.20	275.82	248.67	285.29	9.95	1.31	5.20	6.97	25.16	38.60	18.76	6.73	16.95	38.60
	206.60	249.60	313.30	221.6	312.40	297.80	267.50	260.88	302.05	7.26	25.16	4.95			29.48	4.52	3.59		
Dissolved Solids (mg/l)	172.4	254.8	229.3	190.6	268.60	236.50	232.02	218.55	241.12	10.56	4.63	3.14	10.54	30.91	34.58	15.01	5.15	16.09	34.58
	177.9	204.8	268.5	193	268.10	253.70	225.89	227.10	257.93	8.49	30.91	5.51			26.98	10.89	3.94		
Hardness (mg/l as CaCO ₃)	100	145.6	99.76	105.40	153.80	109.60	127.61	130.53	111.15	5.40	5.63	9.66	10.40	30.53	27.60	10.35	11.41	14.96	27.60
	100.3	118.9	121.4	107.50	155.20	116.80	124.07	136.10	116.67	7.18	30.53	3.78			23.70	14.47	2.25		
Alkalinity (mg/l as CaCO ₃)	75.6	124.2	80.3	89.10	127.40	100.6	93.53	88.64	112.33	17.86	2.58	25.28	13.77	25.28	23.72	28.63	39.89	23.87	39.89
	78.6	110	92.8	88.90	127.20	100.4	92.83	94.65	110.38	13.10	15.64	8.19			18.11	13.95	18.95		
Sodium (mg/l)	20.7	33.8	45.6	24.7	35.2	46.3	28.29	31.37	46.53	19.32	4.76	1.54	12.44	35.77	38.69	6.05	2.05	15.76	36.69
	23.1	26	52.7	24.8	35.3	48.6	27.86	32.01	49.84	7.36	35.77	5.88			20.61	23.10	5.44		
Potassium (mg/l)	1.3	1.9	2.2	1.5	1.8	2.3	1.52	1.80	2.51	15.38	5.26	4.55	9.60	15.38	16.77	5.32	13.91	12.38	16.77
	1.3	1.6	2.2	1.5	1.8	2.3	1.51	1.77	2.46	15.38	12.50	4.55			15.85	10.44	12.00		
Calcium (mg/l)	17.6	27.5	20	19	28.3	21.7	23.78	26.81	19.24	7.95	2.91	8.50	9.40	24.02	35.10	2.53	3.80	14.23	35.10
	18.1	22.9	23.7	19	28.4	21.9	23.62	24.55	22.23	4.97	24.02	8.02			30.50	7.22	6.21		
Magnesium (mg/l)	13.6	18.7	12.1	14	20.6	13.4	17.35	16.21	13.69	2.94	10.16	10.74	11.70	34.00	27.59	13.33	13.17	17.06	27.59
	13.4	15	15.1	14.7	20.1	15.5	16.37	18.22	15.80	9.70	34.00	2.65			22.18	21.44	4.64		

Table A.5.1 Regression Coefficients for Various Periods of Time in the Fitzroy River Basin

Table A.5.1(a) Between the Downstream Station 130003 and the Upstream Station 130105

$$\text{Upstream Value} = B_o + B_i * (\text{Downstream Value})$$

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly
Conductivity	B _o	133.00	128.80	140.70
	B _i	0.46	0.48	0.46
	Correlation	0.86	0.87	0.89
	Coefficient			
PH	B _o	6.87	7.23	8.24
	B _i	0.12	0.07	-0.05
	Correlation	0.10	0.07	0.06
	Coefficient			
Dissolved Ions	B _o	81.79	81.52	91.73
	B _i	0.51	0.52	0.49
	Correlation	0.89	0.91	0.92
	Coefficient			
Dissolved Solids	B _o	74.52	70.58	74.16
	B _i	0.46	0.49	0.48
	Correlation	0.90	0.93	0.94
	Coefficient			
Hardness	B _o	32.60	35.81	42.04
	B _i	0.52	0.49	0.45
	Correlation	0.91	0.90	0.91
	Coefficient			
Alkalinity	B _o	19.48	21.69	30.77
	B _i	0.75	0.73	0.65
	Correlation	0.82	0.83	0.85
	Coefficient			
Natrium	B _o	9.76	9.79	11.29
	B _i	0.47	0.48	0.45
	Correlation	0.84	0.89	0.89
	Coefficient			
Kalium	B _o	2.13	1.29	1.01
	B _i	0.29	0.56	0.64
	Correlation	0.45	0.83	0.94
	Coefficient			
Calcium	B _o	5.99	7.05	8.80
	B _i	0.60	0.55	0.49
	Correlation	0.92	0.89	0.90
	Coefficient			
Magnesium	B _o	3.98	4.31	4.98
	B _i	0.45	0.42	0.40
	Correlation	0.90	0.91	0.92
	Coefficient			

**Table A.5.1(b) Between the Downstream Station 130003
and the Upstream Station 130322**

*Upstream Value = Bo + Bi * (Downstream Value)*

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly
Conductivity	Bo	245.00	267.90	278.20
	Bi	-0.11	-0.18	-0.20
	Correlation	0.51	0.86	0.88
	Coefficient			
PH	Bo	2.73	4.08	3.58
	Bi	0.62	0.44	0.50
	Correlation	0.54	0.58	0.76
	Coefficient			
Dissolved Ions	Bo	181.00	200.20	212.20
	Bi	-0.13	-0.21	-0.25
	Correlation	0.54	0.82	0.94
	Coefficient			
Dissolved Solid	Bo	149.10	169.80	186.10
	Bi	-0.12	-0.22	-0.28
	Correlation	0.51	0.82	0.95
	Coefficient			
Hardness	Bo	61.52	65.47	65.81
	Bi	-0.08	-0.11	-0.12
	Correlation	0.54	0.78	0.83
	Coefficient			
Alkalinity	Bo	98.99	101.70	103.50
	Bi	-0.35	-0.39	-0.41
	Correlation	0.71	0.92	0.92
	Coefficient			
Natrium	Bo	22.01	24.95	27.71
	Bi	-0.10	-0.19	-0.26
	Correlation	0.43	0.81	0.95
	Coefficient			
Kalium	Bo	5.21	4.81	4.90
	Bi	0.11	0.23	0.20
	Correlation	0.22	0.78	0.71
	Coefficient			
Calcium	Bo	15.16	16.32	16.38
	Bi	-0.08	-0.14	-0.14
	Correlation	0.40	0.71	0.75
	Coefficient			
Magnesium	Bo	5.68	6.04	6.10
	Bi	-0.07	-0.10	-0.10
	Correlation	0.69	0.86	0.92
	Coefficient			

Table A.5.2 Regression Coefficients for Various Periods of Time in the Nogoia River Basin

Table A.5.2(a) Between the Downstream Station 130209 and the Upstream Station 130202

$$\text{Upstream Value} = B_o + B_i * (\text{Downstream Value})$$

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity	Bo	178.84	185.01	196.11	197.05
	Bi	0.21	0.20	0.18	0.18
	Correlation	0.71	0.82	0.92	0.83
	Coefficient				
PH	Bo	5.19	8.68	10.42	10.92
	Bi	0.30	-0.14	-0.36	-4.30
	Correlation	0.21	0.23	0.56	0.20
	Coefficient				
Dissolved Ions	Bo	133.76	140.07	148.69	148.23
	Bi	0.17	0.16	0.14	0.14
	Correlation	0.68	0.76	0.88	0.78
	Coefficient				
Dissolved Solids	Bo	93.07	98.33	105.65	104.65
	Bi	0.24	0.23	0.20	0.21
	Correlation	0.72	0.80	0.90	0.85
	Coefficient				
Hardness	Bo	62.22	63.95	69.99	72.71
	Bi	0.13	0.12	0.08	0.06
	Correlation	0.58	0.72	0.63	0.41
	Coefficient				
Alkalinity	Bo	69.09	71.19	75.66	76.72
	Bi	0.08	0.07	0.05	0.04
	Correlation	0.52	0.57	0.54	0.41
	Coefficient				
Natrium	Bo	13.42	13.57	14.04	14.11
	Bi	0.21	0.22	0.22	0.21
	Correlation	0.62	0.78	0.96	0.84
	Coefficient				
Kalium	Bo	3.31	4.75	4.31	3.16
	Bi	0.38	0.09	0.21	0.50
	Correlation	0.26	0.09	0.27	0.49
	Coefficient				
Calcium	Bo	9.64	10.24	12.94	13.82
	Bi	0.53	0.50	0.38	0.35
	Correlation	0.75	0.82	0.79	0.68
	Coefficient				
Magnesium	Bo	5.64	5.74	6.35	6.63
	Bi	0.05	0.04	0.01	-0.001
	Correlation	0.44	0.58	0.25	0.02
	Coefficient				

**Table A.5.2(b) Between the Downstream Station 130209
and the Upstream Station 130212**

*Upstream Value = Bo + Bi * (Downstream Value)*

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity	Bo	75.33	50.83	7.61	25.30
	Bi	0.60	0.66	0.75	0.70
	Correlation Coefficient	0.71	0.82	0.97	0.95
PH	Bo	5.19	3.81	1.35	1.60
	Bi	0.30	0.47	0.79	0.75
	Correlation Coefficient	0.21	0.23	0.89	0.83
Dissolved Ions	Bo	70.22	50.72	15.21	31.58
	Bi	0.55	0.60	0.70	0.64
	Correlation Coefficient	0.68	0.76	0.94	0.93
Dissolved Solid	Bo	44.92	29.05	0.86	12.31
	Bi	0.61	0.67	0.79	0.73
	Correlation Coefficient	0.72	0.80	0.96	0.94
Hardness	Bo	41.71	29.19	10.99	25.92
	Bi	0.41	0.49	0.62	0.50
	Correlation Coefficient	0.58	0.72	0.94	0.90
Alkalinity	Bo	49.90	41.50	27.53	39.99
	Bi	0.39	0.42	0.50	0.42
	Correlation Coefficient	0.52	0.57	0.93	0.90
Natrium	Bo	3.09	2.45	-0.43	-2.60
	Bi	0.78	0.80	0.87	0.92
	Correlation Coefficient	0.62	0.78	0.94	0.97
Kalium	Bo	2.46	2.58	2.86	2.54
	Bi	0.44	0.40	0.33	0.40
	Correlation Coefficient	0.26	0.09	0.71	0.99
Calcium	Bo	3.56	-7.78	-23.96	-12.22
	Bi	1.08	1.58	2.33	1.79
	Correlation Coefficient	0.75	0.82	0.88	0.87
Magnesium	Bo	3.48	3.15	2.41	2.70
	Bi	0.18	0.19	0.23	0.21
	Correlation Coefficient	0.44	0.58	0.95	0.93

**Table A.5.3 Regression Coefficients for Various Periods
of time in the Logan River Basin**

**Table A.5.3(a) Between the Downstream Station 145008
and the Upstream Station 145010**

Upstream Value = Bo + Bi * (Downstream Value)

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity	Bo	332.52	453.61	825.03	589.17
	Bi	0.10	-0.11	-0.80	-0.39
	Correlation	0.24	0.32	0.56	0.38
	Coefficient				
PH	Bo	13.88	43.44	68.62	83.76
	Bi	-0.75	-4.48	-7.63	-9.58
	Correlation	0.30	0.76	0.62	0.67
	Coefficient				
Dissolved Ions	Bo	242.15	278.15	443.13	392.20
	Bi	0.04	-0.06	-0.57	-0.43
	Correlation	0.09	0.12	0.40	0.34
	Coefficient				
Dissolved Solids	Bo	193.47	233.05	380.21	314.37
	Bi	0.08	-0.04	-0.57	-0.36
	Correlation	0.21	0.10	0.45	0.35
	Coefficient				
Hardness	Bo	93.10	79.98	150.58	170.27
	Bi	0.20	0.28	-0.23	-0.36
	Correlation	0.32	0.35	0.17	0.27
	Coefficient				
Alkalinity	Bo	106.47	63.51	104.71	107.72
	Bi	-0.05	0.28	-0.12	-0.15
	Correlation	0.08	0.30	0.06	0.04
	Coefficient				
Natrium	Bo	20.25	36.25	52.25	33.65
	Bi	0.13	-0.16	-0.51	-0.15
	Correlation	0.37	0.76	0.51	0.23
	Coefficient				
Kalium	Bo	1.43	1.23	2.46	1.63
	Bi	-0.01	0.07	-0.40	-0.07
	Correlation	0.08	0.74	0.82	0.14
	Coefficient				
Calcium	Bo	14.98	14.99	29.42	29.32
	Bi	0.23	0.23	-0.31	-0.32
	Correlation	0.39	0.35	0.29	0.31
	Coefficient				
Magnesium	Bo	14.09	11.87	19.31	21.31
	Bi	0.14	0.25	-0.19	-0.29
	Correlation	0.23	0.30	0.12	0.20
	Coefficient				

**Table A.5.3(b) Between the Downstream Station 145008
and the Upstream Station 145013**

Upstream Value = Bo + Bi * (Downstream Value)

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity	Bo	282.22	-122.50	0.60	208.51
	Bi	0.37	1.05	0.82	0.46
	Correlation	0.53	0.74	0.93	0.91
	Coefficient				
PH	Bo	15.56	20.00	13.58	9.74
	Bi	-0.97	-1.54	-0.72	-0.24
	Correlation	0.36	0.44	0.63	0.08
	Coefficient				
Dissolved Ions	Bo	100.19	-235.50	-19.54	77.73
	Bi	0.60	1.49	0.88	0.62
	Correlation	0.62	0.82	0.95	0.88
	Coefficient				
Dissolved Solids	Bo	85.14	-139.30	-27.97	74.84
	Bi	0.59	1.29	0.94	0.60
	Correlation	0.71	0.91	0.89	0.87
	Coefficient				
Hardness	Bo	36.78	-71.92	19.80	63.41
	Bi	0.75	1.42	0.83	0.55
	Correlation	0.78	0.92	0.95	0.90
	Coefficient				
Alkalinity	Bo	-17.80	-120.50	-3.09	-33.00
	Bi	1.12	1.90	0.97	1.20
	Correlation	0.67	0.80	0.86	0.79
	Coefficient				
Natrium	Bo	26.47	6.00	9.93	23.52
	Bi	0.19	0.58	0.47	0.21
	Correlation	0.39	0.48	0.70	0.55
	Coefficient				
Kalium	Bo	1.82	2.05	2.29	2.10
	Bi	-0.05	-0.14	-0.22	-0.16
	Correlation	0.13	0.29	0.39	0.48
	Coefficient				
Calcium	Bo	7.56	-9.23	6.62	13.34
	Bi	0.72	1.27	0.72	0.49
	Correlation	0.76	0.95	0.94	0.91
	Coefficient				
Magnesium	Bo	4.88	8.56	2.04	8.11
	Bi	0.77	1.47	0.87	0.57
	Correlation	0.80	0.91	0.95	0.91
	Coefficient				

**Table A.5.3(c) Between the Downstream Station 145008
and the Upstream Station 145020**

Upstream Value = Bo + Bi * (Downstream Value)

Water Quality Parameter	Regression Coefficient	1 Yearly	2 Yearly	3 Yearly	4 Yearly
Conductivity	Bo	636.09	-6.80	-795.90	-61.62
	Bi	-0.04	2.20	2.43	1.14
	Correlation	0.03	0.66	0.75	0.65
	Coefficient				
PH	Bo	16.34	31.05	25.54	26.31
	Bi	-1.07	-2.93	-2.23	-2.33
	Correlation	0.38	0.59	0.65	0.71
	Coefficient				
Dissolved Ions	Bo	395.22	-310.40	-227.30	50.73
	Bi	-0.07	1.81	1.62	0.85
	Correlation	0.05	0.64	0.63	0.52
	Coefficient				
Dissolved Solids	Bo	318.54	-300.20	-284.80	15.18
	Bi	0.01	1.96	1.95	0.96
	Correlation	0.00	0.68	0.73	0.60
	Coefficient				
Hardness	Bo	141.22	-90.39	-40.97	20.48
	Bi	-0.00	1.41	1.15	0.75
	Correlation	0.00	0.62	0.56	0.50
	Coefficient				
Alkalinity	Bo	104.15	29.58	71.23	151.88
	Bi	-0.03	0.55	0.25	-0.39
	Correlation	0.02	0.39	0.19	0.30
	Coefficient				
Natrium	Bo	71.84	-43.10	-62.49	6.17
	Bi	-0.16	2.02	2.43	1.07
	Correlation	0.10	0.51	0.67	0.60
	Coefficient				
Kalium	Bo	2.32	2.93	3.90	2.91
	Bi	0.01	-0.22	-0.59	-0.21
	Correlation	0.02	0.25	0.47	0.19
	Coefficient				
Calcium	Bo	22.04	-17.42	-10.94	3.09
	Bi	0.16	1.46	1.29	0.80
	Correlation	0.12	0.74	0.69	0.57
	Coefficient				
Magnesium	Bo	18.68	-9.32	-2.74	5.21
	Bi	-0.04	1.29	1.01	0.60
	Correlation	0.03	0.56	0.49	0.43
	Coefficient				

Appendix B

Table B.1.1 Comparison of the Use of Normal and Log-normal Approach in the Fitzroy River

Table B.1.1(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)					
							(Normal Distribution)			(Log-normal Distribution)		
	at Station		at Station		at Station		at Station	Average	Maximum	at Station	Average	Maximum
(1)	130105	130322	130105	130322	130105	130322	130105	130322	(6)	(7)	130105	130322
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				
Conductivity (mS/m)	210.00	222.50	266.53	202.44	266.66	201.82	26.92	9.02	21.57	50.71	26.98	9.29
	200.00	195.00	301.42	203.75	301.43	203.72	50.71	4.49			50.72	4.47
	270.00	248.75	218.82	200.64	219.45	197.77	18.96	19.34			18.72	20.49
Dissolved Ions (mg/l)	183.90	159.80	182.73	147.15	182.83	146.70	0.64	7.92	16.15	58.88	0.58	8.20
	128.00	144.55	203.36	147.99	203.37	147.92	58.88	2.38			58.88	2.33
	165.55	175.30	148.57	145.76	149.05	143.56	10.26	16.85			9.97	18.11
Dissolved Solids (mg/l)	123.00	125.00	150.26	121.58	150.36	121.12	22.16	2.74	18.47	52.26	22.24	3.10
	110.00	110.00	167.49	122.44	167.51	122.37	52.26	11.31			52.28	11.25
	140.00	137.50	126.14	120.37	126.55	118.49	9.90	12.46			9.61	13.83

Table B.1.1(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)					
							(Normal Distribution)			(Log-normal Distribution)		
	at Station		at Station		at Station		at Station	Average	Maximum	at Station	Average	Maximum
(1)	130105	130322	130105	130322	130105	130322	130105	130322	(6)	(7)	130105	130322
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				
Conductivity (mS/m)	205.00	208.75	287.19	203.22	287.23	203.04	40.09	2.65	15.88	40.09	40.11	2.74
	235.00	221.88	262.95	202.31	263.10	201.60	11.89	8.82			11.96	9.14
Dissolved Ions (mg/l)	155.95	152.18	194.82	147.64	194.86	147.46	24.92	2.98	14.34	24.92	24.95	3.10
	146.78	159.93	178.11	146.97	178.24	146.37	21.35	8.10			21.44	8.48
Dissolved Solids (mg/l)	116.50	117.50	159.93	122.06	159.97	121.87	37.28	3.88	15.31	37.28	37.31	3.72
	125.00	123.75	147.80	121.46	147.92	120.90	18.24	1.85			18.34	2.30

Table B.1.1(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)					
							(Normal Distribution)			(Log-normal Distribution)		
	at Station		at Station		at Station		at Station	Average	Maximum	at Station	Average	Maximum
(1)	130105	130322	130105	130322	130105	130322	130105	130322	(6)	(7)	130105	130322
(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				
Conductivity (mS/m)	226.60	222.00	273.77	202.72	273.86	202.29	20.62	8.68	14.75	20.82	20.86	8.68
Dissolved Ions (mg/l)	159.10	159.80	186.51	147.31	186.59	146.96	17.23	7.82	12.52	17.23	17.28	8.04
Dissolved Solids (mg/l)	124.30	124.10	153.02	121.72	153.10	121.35	23.11	1.92	12.51	23.11	23.17	2.22

Table B.1.2 Comparison of the Use of Normal and Log-normal Approach in the Nogoa River

Table B.1.2(a) 1 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Normal Distribution)			(Log-normal Distribution)				
	130401	130106	130401	130106	130401	130106	at Station 130401	130106	Average	Maximum	at Station 130401	130106	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	246.50	221.25	215.18	170.19	215.17	170.21	12.71	23.08	24.78	47.52	12.71	23.07	24.75	47.50
	342.50	230.00	263.48	181.58	262.49	183.32	23.07	21.05			23.36	20.30		
	190.00	125.00	235.71	175.03	235.45	175.48	24.06	40.02			23.92	40.38		
	152.50	152.50	218.40	170.95	218.36	171.01	43.21	12.10			43.19	12.14		
	147.50	172.50	217.59	170.76	217.56	170.82	47.52	1.01			47.50	0.97		
Dissolved Ions (mg/l)	179.40	184.33	159.33	139.41	154.15	148.50	11.19	24.37	23.40	51.55	14.07	19.44	24.03	58.66
	249.35	182.40	169.71	179.44	168.87	180.91	31.94	1.62			32.28	0.82		
	135.80	97.20	161.38	147.31	157.44	154.22	18.84	51.55			15.94	58.66		
	116.60	125.15	159.80	141.23	154.90	149.81	37.05	12.85			32.85	19.70		
	110.15	137.80	158.99	138.09	153.61	147.51	44.34	0.21			39.46	7.05		
Dissolved Solids (mg/l)	147.93	147.50	120.54	113.62	117.09	119.65	18.52	22.97	22.27	47.08	20.85	18.88	23.17	53.40
	200.00	138.00	130.98	139.96	130.33	141.11	34.51	1.42			34.84	2.25		
	110.00	80.00	122.14	117.66	119.26	122.72	11.04	47.08			8.42	53.40		
	94.50	90.50	118.67	108.95	114.43	116.41	25.58	20.39			21.09	28.63		
	86.00	105.00	118.52	108.54	114.19	116.14	37.81	3.37			32.78	10.61		
Hardness (mg/l)as CaCO3	69.07	78.00	70.65	61.18	69.26	63.62	2.29	21.56	33.28	69.70	0.28	18.44	33.30	75.22
	92.50	80.00	73.04	72.20	72.68	72.84	21.04	9.75			21.43	8.95		
	46.00	37.00	71.00	62.79	69.84	64.83	54.35	69.70			51.83	75.22		
	45.50	50.50	71.08	63.17	69.95	65.14	56.22	25.09			53.74	28.99		
	44.00	54.50	70.65	61.18	69.26	63.62	60.57	12.26			57.41	16.73		

Table B.1.2(b) 2 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
	at Station		at Station		at Station		(Normal Distribution)			(Log-normal Distribution)				
	130401	130106	130401	130106	130401	130106	at Station			at Station				
(1)	(2)		(3)		(4)		130401	130106	Average	Maximum	130401	130106	Average	Maximum
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	294.50	225.63	237.12	175.36	236.84	175.85	19.48	22.28	19.00	43.22	19.58	22.06	19.08	43.21
	266.25	177.50	247.85	177.90	247.33	178.80	6.91	0.23			7.11	0.73		
	171.25	136.75	224.30	172.37	224.20	172.49	30.98	24.23			30.92	24.32		
	150.00	162.50	214.83	170.10	214.81	170.13	43.22	4.68			43.21	4.70		
Dissolved Ions (mg/l)	214.37	141.10	163.98	157.33	161.37	161.91	23.51	11.50	20.36	39.93	24.72	14.75	22.18	34.96
	192.58	139.80	165.04	161.43	162.88	165.22	14.30	15.47			15.42	18.18		
	126.20	111.18	159.90	141.61	155.13	149.97	26.70	27.38			22.92	34.90		
	113.38	131.48	158.65	136.82	153.01	146.72	39.93	4.07			34.96	11.60		
Dissolved Solids (mg/l)	173.97	142.75	125.62	126.44	123.85	129.55	27.79	11.43	20.72	31.82	28.81	9.25	21.89	39.50
	155.00	109.00	126.46	128.55	124.98	131.15	18.41	17.94			19.37	20.32		
	102.25	85.25	120.04	112.38	116.31	118.92	17.40	31.82			13.75	39.50		
	90.25	97.75	118.15	107.62	113.64	115.53	30.91	10.10			25.92	18.19		
Hardness (mg/l)as CaCO3	80.78	79.00	71.00	62.80	69.82	64.90	12.11	20.51	24.78	56.25	13.57	17.85	25.48	52.16
	69.25	58.50	71.19	63.70	70.14	65.55	2.80	8.89			1.29	12.05		
	45.75	43.75	70.11	58.74	68.38	61.78	53.25	34.26			49.46	41.21		
	44.75	52.50	69.92	57.86	68.09	61.04	56.25	10.21			52.16	16.27		

Table B.1.2(c) 3 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
	130401	130106	130401	130106	130401	130106	130401	130106			130401	130106		
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	259.67	192.08	229.99	173.68	229.83	173.98	11.43	9.58	11.60	31.20	11.49	9.43	11.61	31.19
	228.33	169.17	231.18	173.95	231.00	174.27	1.25	2.83			1.17	3.01		
	183.33	150.00	214.29	169.98	214.28	169.99	31.20	13.32			31.19	13.33		
Dissolved Ions (mg/l)	188.18	154.64	145.34	173.52	156.93	153.19	22.77	12.21	21.70	42.07	7.56	0.94	14.38	40.66
	167.25	134.92	145.82	173.66	157.24	153.63	12.81	28.71			4.20	13.87		
	120.85	120.05	134.90	170.56	150.64	142.95	11.63	42.07			40.66	19.08		
Dissolved Solids (mg/l)	152.64	121.83	122.84	119.43	120.19	124.10	19.52	1.97	13.72	21.39	21.26	1.86	15.87	24.73
	134.83	102.83	122.15	117.72	119.28	122.76	9.40	14.48			11.53	19.38		
	96.83	91.83	117.54	106.10	112.74	114.54	21.39	15.54			16.43	24.73		
Hardness (mg/l) as CaCO ₃	69.19	82.83	70.03	58.37	68.28	61.44	1.21	29.53	22.13	53.33	1.32	25.82	18.52	48.22
	61.33	73.17	70.21	59.14	68.56	62.04	14.48	19.17			11.79	15.21		
	45.17	64.50	69.26	54.80	66.95	58.85	53.33	15.04			48.22	8.76		

Table B.1.2(d) 4 yearly

Water Quality Parameter	Observed Values		Assigned Values (Normal Distribution)		Assigned Values (Log-normal Distribution)		Absolute Values of Errors (%)							
							(Normal Distribution)				(Log-normal Distribution)			
	at Station		at Station		at Station		at Station		Average	Maximum	at Station		Average	Maximum
	130401	130106	130401	130106	130401	130106	130401	130106			130401	130106		
(1)	(2)		(3)		(4)		(5)		(6)	(7)	(8)		(9)	(10)
Conductivity (mS/m)	232.88	182.19	228.90	173.43	228.76	173.69	1.71	4.81	4.73	10.29	1.77	4.67	4.73	10.21
	208.13	170.00	229.55	173.58	229.39	173.86	10.29	2.11			10.21	2.27		
Dissolved Ions (mg/l)	170.29	147.27	145.79	173.66	157.19	153.67	14.39	17.92	16.29	27.98	7.69	4.35	5.11	7.69
	152.98	135.64	145.55	173.59	157.04	143.42	4.86	27.98			2.65	5.74		
Dissolved Solids (mg/l)	138.11	114.00	122.07	117.47	119.14	122.62	11.61	3.04	6.97	12.32	13.74	7.56	10.59	17.63
	122.63	103.38	121.53	116.12	118.41	121.61	0.90	12.32			3.44	17.63		
Hardness (mg/l) as CaCO ₃	63.27	61.38	71.55	65.32	70.63	66.93	13.09	6.42	15.68	25.53	11.63	9.04	16.30	23.91
	57.00	55.50	71.55	65.32	70.63	66.93	25.53	17.69			23.91	20.59		

Table B.1.3 Comparison of the Use of Normal and Log-normal Approach in the Logan River

Table B.1.3(a) 1 yearly

Water Quality Parameter	Observed Values			Assigned Values (Normal Distribution)			Assigned Values (Log-normal Distribution)			Absolute Values of Errors (%)									
										(Normal Distribution)			(Log-normal Distribution)						
	at Station			at Station			at Station			at Station			at Station						
145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average	Maximum	145010	145013	145020	Average	Maximum	
(1)	(2)			(3)			(4)			(5)			(6)	(7)	(8)			(9)	(10)
Conductivity (mS/m)	348.50	650.00	397.50	354.90	495.40	601.60	361.70	495.20	599.70	1.84	23.78	51.35	34.87	118.50	3.79	23.82	50.87	35.58	117.90
	360.00	398.00	434.00	355.90	495.90	609.80	363.80	495.80	607.40	1.14	24.60	40.51			1.06	24.57	39.95		
	205.00	296.67	268.33	352.90	494.50	586.30	358.40	494.50	584.70	72.15	66.69	118.50			74.83	66.69	117.90		
	328.75	476.25	645.00	351.70	496.70	625.80	367.59	496.60	623.00	6.98	4.29	2.98			11.81	4.27	3.41		
	347.50	245.00	631.67	355.90	495.90	610.20	363.70	495.70	608.00	2.42	102.41	3.40			4.66	102.33	3.75		
PH	7.76	8.00	7.78	8.16	7.95	8.14	8.21	7.94	8.12	5.15	0.62	4.09	4.21	13.16	5.80	0.75	4.44	5.28	13.00
	8.00	8.12	7.94	7.85	7.89	7.92	8.10	7.49	7.97	1.88	2.83	0.25			1.25	7.76	0.38		
	7.43	7.70	7.47	8.31	7.97	8.24	8.40	7.97	8.21	11.79	3.51	10.36			13.00	3.51	9.96		
	7.63	7.88	7.88	7.69	7.86	7.82	8.14	7.49	7.81	0.85	0.19	0.70			6.75	4.89	0.83		
	7.90	7.70	7.87	6.86	7.70	7.31	6.90	7.70	7.30	13.16	0.04	7.08			12.66	0.00	7.20		
Dissolved Ions (mg/l)	220.17	409.44	241.65	231.60	320.80	358.90	235.50	320.70	357.90	5.19	21.65	48.52	32.51	112.97	6.96	21.67	48.11	32.92	112.66
	223.45	281.80	264.44	232.80	321.90	366.70	238.10	321.70	365.20	4.18	14.23	38.67			6.56	14.16	38.10		
	129.93	203.27	162.47	229.50	319.00	346.00	231.30	319.00	345.50	76.63	56.94	112.97			78.01	56.94	112.66		
	222.55	329.83	400.60	235.60	323.70	380.00	242.80	323.40	377.90	5.86	1.86	5.14			9.10	1.95	5.67		
	250.50	183.60	425.87	233.10	322.10	368.40	238.70	321.90	366.90	6.95	75.44	13.49			4.71	75.33	13.85		
Dissolved Solids (mg/l)	188.00	350.00	210.00	199.50	272.40	302.10	200.60	272.30	301.80	6.12	22.17	43.86	31.42	99.40	6.70	22.20	43.71	31.58	99.47
	192.50	226.00	224.00	200.80	273.20	310.90	202.80	273.10	310.50	4.31	20.88	38.79			5.35	20.84	38.62		
	117.00	173.33	143.33	197.30	270.90	285.80	197.10	270.90	285.90	68.63	56.29	99.40			68.46	56.29	99.47		
	192.00	270.00	340.00	203.30	274.80	330.00	207.30	274.70	328.90	5.89	1.78	2.94			7.97	1.74	3.26		
	210.00	150.00	366.67	201.40	273.60	316.40	204.00	273.50	315.70	4.10	82.40	13.71			2.86	82.33	13.90		
Alkalinity (mg/l) as CaCO ₃	83.50	138.80	73.50	84.60	123.00	92.90	82.80	123.30	93.40	1.32	11.36	26.39	22.62	78.73	0.84	11.17	27.07	24.44	81.48
	83.75	133.40	81.00	88.10	126.40	98.90	90.10	126.10	98.40	5.19	5.25	22.10			7.58	5.47	21.48		
	47.33	87.67	47.33	71.70	118.40	84.60	74.50	119.10	85.90	51.48	35.06	78.73			57.39	35.86	81.48		
	87.75	136.75	119.25	93.70	131.80	108.40	105.30	130.10	105.50	6.78	3.62	9.10			20.00	4.86	11.53		
	95.50	82.00	123.67	87.30	125.70	97.60	88.40	125.50	97.30	8.59	53.29	21.08			7.43	53.05	21.32		

Table B.1.3(b) 2 yearly

Water Quality Parameter	Observed Values			Assigned Values (Normal Distribution)			Assigned Values (Log-normal Distribution)			Absolute Values of Errors (%)									
										(Normal Distribution)			(Log-normal Distribution)						
	at Station			at Station			at Station			at Station			at Station						
(1)	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	Average	Maximum	145010	145013	145020	Average	Maximum
	(2)			(3)			(4)			(5)			(6)	(7)	(8)			(9)	(10)
Conductivity (mS/m)	354.25	524.00	415.75	310.40	474.80	258.30	297.00	474.50	262.20	12.38	9.39	37.87	25.68	76.05	16.16	9.45	36.93	25.68	75.51
	282.50	347.33	351.17	261.00	451.70	84.10	253.10	451.40	86.00	7.61	30.05	76.05			10.41	29.96	75.51		
	269.88	386.46	456.67	311.70	475.30	265.30	298.80	475.20	269.10	16.79	22.99	41.91			11.89	22.96	41.07		
	338.13	360.63	636.33	349.10	492.70	554.00	351.30	492.70	553.30	3.24	36.62	13.21			3.89	36.62	13.32		
PH	7.88	8.06	7.86	8.36	7.98	8.27	8.46	7.97	8.24	6.09	0.99	5.25	8.17	21.91	7.36	1.12	4.87	8.32	20.62
	7.72	7.91	7.70	8.75	8.06	8.46	8.92	8.03	8.41	13.39	1.90	9.82			15.59	1.52	9.17		
	7.53	7.79	7.67	8.36	7.98	8.27	8.46	7.97	8.24	11.03	2.47	7.81			12.36	2.34	7.42		
	7.76	7.79	7.87	6.06	7.19	7.11	6.16	7.18	7.11	21.91	7.70	9.66			20.62	7.83	9.66		
Dissolved Ions (mg/l)	221.81	345.62	253.05	199.20	293.70	170.50	188.10	294.20	173.50	10.19	15.02	32.62	20.19	68.70	15.20	14.88	31.44	20.14	68.05
	176.69	242.53	213.45	164.10	264.20	66.80	158.40	265.00	68.20	7.13	8.93	68.70			10.35	9.26	68.05		
	176.24	266.55	281.53	199.90	294.30	173.80	188.80	294.80	176.90	13.42	10.41	38.27			7.13	10.60	37.17		
	236.53	256.71	413.23	233.20	322.10	368.80	239.00	321.90	367.20	1.41	25.47	10.75			1.04	25.39	11.14		
Dissolved Solids (mg/l)	190.25	288.00	217.00	175.90	257.00	137.90	169.70	257.30	139.60	7.54	10.76	36.45	21.45	69.02	10.80	10.66	35.67	21.46	68.69
	154.75	199.67	183.67	148.40	239.20	56.90	146.00	239.50	57.50	4.10	19.80	69.02			5.65	19.95	68.69		
	154.50	221.67	241.67	178.30	258.60	152.00	171.10	258.90	154.00	15.40	16.66	37.10			10.74	16.80	36.28		
	201.00	210.00	353.33	201.60	273.70	318.10	204.40	273.70	317.30	0.30	30.33	9.97			1.69	30.33	10.20		
Alkalinity (mg/l) as CaCO3	83.63	136.10	77.25	74.40	113.30	75.70	67.80	114.30	77.40	11.03	16.75	2.01	9.07	17.85	16.92	16.02	0.19	8.78	18.92
	65.54	110.53	64.17	64.40	103.80	59.60	58.20	104.80	61.20	1.74	6.09	7.12			11.20	5.19	4.62		
	67.54	112.21	83.29	75.80	114.60	70.00	69.50	115.60	79.70	12.23	2.13	15.96			2.90	3.02	4.31		
	91.63	109.38	121.46	90.70	128.90	103.40	96.90	128.20	102.00	1.01	17.85	14.87			5.75	17.21	16.02		

Table B.1.3(c) 3 yearly

Water Quality Parameter	Observed Values			Assigned Values (Normal Distribution)			Assigned Values (Log-normal Distribution)			Absolute Values of Errors (%)									
										(Normal Distribution)				(Log-normal Distribution)					
	at Station			at Station			at Station			at Station			Average	Maximum	at Station			Average	Maximum
(1)	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	(6)	(7)	145010	145013	145020	(9)	(10)
	(2)			(3)			(4)			(5)					(8)				
Conductivity (mS/m)	304.50	448.22	366.61	280.60	460.70	122.10	268.70	461.30	125.40	7.85	2.78	66.69	25.27	66.69	11.76	2.92	65.79	24.60	65.79
	297.90	390.31	449.11	317.90	478.30	306.70	306.10	478.40	310.10	6.71	22.54	31.71			2.75	22.57	30.95		
	293.80	339.31	515.00	318.30	478.60	310.20	306.90	478.70	313.40	8.34	41.05	39.77			4.46	41.08	39.15		
PH	7.70	7.90	7.70	8.90	8.10	8.50	9.11	8.07	8.47	15.58	2.53	10.39	5.29	15.58	18.31	2.15	10.00	5.85	18.31
	7.70	7.90	7.80	8.30	7.98	8.26	8.43	7.97	8.23	7.79	1.01	5.90			9.48	0.89	5.51		
	7.70	7.80	7.70	7.43	7.81	7.64	7.42	7.81	7.64	3.51	0.13	0.78			3.64	0.13	0.78		
Dissolved Ions (mg/l)	191.20	298.20	222.90	193.80	289.10	144.90	182.80	289.70	147.90	1.36	3.05	34.99	14.96	34.99	4.39	2.85	33.65	14.02	33.65
	192.00	271.60	275.80	211.50	304.00	237.40	202.80	304.30	239.80	10.16	11.93	13.92			5.63	12.04	13.05		
	201.00	238.90	329.60	212.90	305.10	245.20	204.60	305.40	247.50	5.92	27.71	25.61			1.79	27.84	24.91		
Dissolved Solids (mg/l)	165.80	249.80	192.40	167.80	251.70	99.90	161.30	252.00	101.70	1.21	0.76	48.08	18.56	48.08	2.71	0.88	47.14	17.83	47.14
	167.20	223.10	235.80	183.70	262.10	186.90	178.10	262.30	188.50	9.87	17.48	20.74			6.52	17.57	20.06		
	173.00	197.80	283.30	186.10	263.60	203.80	181.10	263.80	205.20	7.57	33.27	28.06			4.68	33.37	27.57		
Alkalinity (mg/l) as CaCO3	71.50	120.00	67.30	79.20	118.00	83.90	74.00	118.70	85.10	10.77	1.67	24.67	11.31	24.67	3.50	1.08	26.45	10.02	26.45
	72.90	119.30	82.50	84.30	122.80	92.40	82.20	123.00	92.90	15.64	2.93	12.00			12.76	3.10	12.61		
	76.90	102.10	96.80	83.80	122.40	91.70	81.40	122.70	92.30	8.97	19.88	5.27			5.85	20.18	4.65		

Table B.1.3(d) 4 yearly

Water Quality Parameter	Observed Values			Assigned Values (Normal Distribution)			Assigned Values (Log-normal Distribution)			Absolute Values of Errors (%)									
										(Normal Distribution)				(Log-normal Distribution)					
	at Station			at Station			at Station			at Station			Average	Maximum	at Station			Average	Maximum
(1)	145010	145013	145020	145010	145013	145020	145010	145013	145020	145010	145013	145020	(6)	(7)	145010	145013	145020	(9)	(10)
Conductivity (mS/m)	310.60	455.23	436.21	334.20	485.90	434.80	327.60	485.70	436.80	7.60	6.74	0.32	11.36	37.63	5.47	6.69	0.14	10.68	37.69
	310.30	353.08	494.75	337.20	487.20	459.00	332.40	487.40	460.30	8.67	37.63	7.23			7.12	37.69	6.96		
PH	7.7	7.9	7.8	8.4	7.99	8.29	8.51	7.98	8.26	9.09	1.14	6.28	3.85	9.09	10.52	1.01	5.90	4.00	10.52
	7.7	7.8	7.8	7.38	7.803	7.613	7.38	7.80	7.81	4.16	0.04	2.40			4.16	0.04	2.38		
Dissolved Ions (mg/l)	199.00	306.10	267.30	218.8	310.10	281.20	213.10	310.30	282.70	9.95	1.31	5.20	8.97	25.16	7.09	1.37	5.76	8.22	25.24
	206.60	249.60	313.30	221.6	312.40	297.80	217.50	312.60	299.00	7.26	25.16	4.95			5.28	25.24	4.56		
Dissolved Solids (mg/l)	172.4	254.8	229.3	190.6	286.60	236.50	187.10	266.70	237.50	10.56	4.63	3.14	10.54	30.91	8.53	4.67	3.58	10.00	30.96
	177.9	204.8	268.5	193	268.10	253.70	190.40	268.20	254.40	8.49	30.91	5.51			7.03	30.96	5.25		
Alkalinity (mg/l)as CaCO3	75.6	124.2	80.3	89.10	127.40	100.6	92.50	126.90	99.70	17.86	2.58	25.28	13.77	25.28	22.35	2.17	24.16	14.77	24.16
	78.6	110	92.8	88.90	127.20	100.4	92.20	126.80	99.60	13.10	15.64	8.19			17.30	15.27	7.33		

**Table B.2.1 Comparison of the Results Obtained by Using Knowledge about Changes in the Watershed
(incorporated by changing the Prior Probability Distribution at One Upstream Station [Station 130105])
with those Obtained Ignoring that Knowledge [Fitzroy River]**

Table B.2.1(a) 1 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130105	Station 130322	(Original Distribution)		(‘Shifted’ Distribution)		(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130105	Station 130322	(‘Shifted’)	(Original)	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322		
Conductivity (mS/m)	210.00	222.50	291.3	203.7	266.53	202.44	266.4	202.8	26.9	9.0	26.9	8.8	21.6	21.5
	200.00	195.00			301.42	203.75	301.3	204.1	50.7	4.5	50.7	4.7		
	270.00	248.75			218.82	200.64	218.7	201.0	19.0	19.3	19.0	19.2		
Dissolved Ions (mg/l)	183.90	159.80	198.8	148.2	182.73	147.15	182.6	147.6	0.6	7.9	0.7	7.7	16.2	18.2
	128.00	144.55			203.96	147.99	203.3	148.4	58.9	2.4	58.8	2.7		
	165.55	175.30			148.57	145.76	148.5	124.2	10.3	18.9	10.3	29.2		
Dissolved Solids (mg/l)	123.00	125.00	161.4	122.6	150.26	121.58	150.2	122.1	22.2	2.7	22.1	2.3	18.5	18.4
	110.00	110.00			167.49	122.44	167.4	122.9	52.3	11.3	52.2	11.8		
	140.00	137.50			126.14	120.37	126.0	120.9	9.9	12.5	10.0	12.1		
Hardness (mg/l) as CaCO ₃	61.00	57.50	76.82	53.0	69.99	52.99	70.0	52.9	14.7	7.8	14.8	8.1	18.5	18.6
	55.00	51.50			85.69	53.23	85.7	53.1	55.8	3.4	55.8	3.1		
	65.50	66.50			59.68	52.82	59.7	52.7	8.9	20.6	8.8	20.7		

Table B.2.1(b) 2 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130105	Station 130322					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130105	Station 130322	(‘Shifted’)	(Original)	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322		
Conductivity (mS/m)	205.00	208.75	291.3	203.7	287.19	203.22	287.1	203.6	40.1	2.6	40.1	2.5	15.9	15.8
	235.00	221.88			262.95	202.31	262.9	202.7	11.9	8.8	11.9	8.7		
Dissolved Ions (mg/l)	155.95	152.18	198.8	148.2	194.82	147.64	194.7	148.1	24.9	3.0	24.9	2.7	14.3	14.3
	146.78	159.93			178.11	146.97	178.6	147.4	21.3	6.1	21.7	7.9		
Dissolved Solids (mg/l)	116.50	117.50	161.4	122.6	159.93	122.06	159.8	122.6	37.3	3.9	37.2	4.3	15.3	15.3
	125.00	123.75			147.80	121.46	147.7	122.0	18.2	1.9	18.2	1.5		
Hardness (mg/l) as CaCO ₃	58.00	54.50	76.82	53.0	78.96	53.13	79.0	53.0	36.1	2.5	36.2	2.7	18.0	18.1
	60.25	59.00			74.15	53.05	74.2	52.9	23.1	10.1	23.1	10.3		

Table B.2.1(c) 3 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130105	Station 130322					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130105	Station 130322	(‘Shifted’)	(Original)	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322	Station 130105	Station 130322		
Conductivity (mS/m)	226.60	222.00	291.3	203.7	273.77	202.72	255.2	202.4	20.8	8.7	12.6	8.8	14.8	10.7
Dissolved Ions (mg/l)	159.10	159.80	198.8	148.2	186.51	147.31	186.4	147.7	17.2	7.8	17.2	7.6	12.5	12.4
Dissolved Solids (mg/l)	124.30	124.10	161.4	122.6	153.02	121.72	152.9	122.2	23.1	1.9	23.0	1.5	12.5	12.3
Hardness (mg/l) as CaCO ₃	60.50	58.50	76.82	53.0	77.43	52.83	76.6	53.0	28.0	9.7	26.7	9.4	18.8	18.0

Table B.2.2(c) 3 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130202	Station 130212					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130202	Station 130212	(Original)	(‘Shifted’)	Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212		
Conductivity (mS/m)	259.67	192.08	245.73	261.4	229.99	173.68	235.0	164.9	11.4	9.6	9.5	14.2	11.6	11.9
	228.33	169.17			231.18	173.95	236.2	165.2	1.2	2.8	3.4	2.4		
	163.33	150.00			214.29	169.98	219.3	161.2	31.2	13.3	34.3	7.4		
Dissolved Ions (mg/l)	188.18	154.84	177.4	199.1	145.34	173.52	161.0	146.0	22.8	12.2	14.4	5.6	21.7	12.0
	167.25	134.92			145.82	173.66	161.2	146.6	12.8	28.7	3.6	8.7		
	120.85	120.05			134.90	170.56	157.2	131.4	11.6	42.1	30.1	9.5		
Dissolved Solids (mg/l)	152.64	121.83	137.16	145.6	122.84	119.43	125.2	115.3	19.5	2.0	18.0	5.3	13.7	12.7
	134.83	102.83			122.15	117.72	124.5	113.6	9.4	14.5	7.7	10.5		
	96.83	91.83			117.54	106.10	119.9	102.0	21.4	15.5	23.8	11.1		
Hardness (mg/l) as CaCO ₃	69.19	82.83	76.16	86.5	70.03	59.37	71.6	55.6	1.2	29.5	3.5	32.9	22.1	25.3
	61.33	73.17			70.21	59.14	71.8	56.4	14.5	19.2	17.0	23.0		
	45.17	64.50			69.26	54.80	70.7	52.3	53.3	15.0	56.5	19.0		

Table B.2.2(d) 4 yearly

Water Quality Parameter	Observed Mean Values		Prior Mean Values		Assigned Mean Values (Original Distribution)		Assigned Mean Values (‘Shifted’ Distribution)		% Error of Prediction				% Error of Prediction (Average)	
			Station 130401	Station 130106					(Original Distribution)		(‘Shifted’ Distribution)		Original Distribution	Shifted Distribution
	Station 130401	Station 130106	(Original)	(‘Shifted’)	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106	Station 130401	Station 130106		
Conductivity (mS/m)	232.88	182.19	245.73	261.4	228.90	173.43	233.9	164.6	1.7	4.8	0.5	9.6	4.7	6.5
	208.13	170.00			229.55	173.58	234.6	164.8	10.3	2.1	12.7	3.1		
Dissolved Ions (mg/l)	170.29	147.27	177.4	199.1	145.79	173.66	161.2	146.6	14.4	17.9	5.3	0.4	16.3	4.7
	152.98	135.64			145.55	173.59	161.1	146.3	4.9	28.0	5.3	7.8		
Dissolved Solids (mg/l)	138.11	114.00	137.16	145.6	122.07	117.47	124.4	113.4	11.6	3.0	9.9	0.6	7.0	5.0
	122.63	103.38			121.53	116.12	123.9	112.0	0.9	12.3	1.0	8.4		
Hardness (mg/l) as CaCO ₃	63.27	61.38	76.16	86.5	71.55	65.32	73.1	62.6	13.1	6.4	15.6	1.9	15.7	14.6
	57.00	55.50			71.55	65.32	73.1	62.6	25.5	17.7	28.3	12.7		

**Table B.2.3 Comparison of the Results Obtained by Using Knowledge about Changes in the Watershed
(Incorporated by changing the Prior Probability Distribution at One Upstream Station [Station 145020])
with those Obtained Ignoring that Knowledge [Logan River]**

Table B.2.3(a) 1 yearly

Water Quality Parameter	Observed Mean Values			Prior Mean Values			Assigned Mean Values (Original Distribution)			Assigned Mean Values (Shifted Distribution)			% Error of Prediction						% Error of Prediction (Average)	
				Station 145010	Station 145013	Station 145020							(Original Distribution)			(Shifted Distribution)			Original Distribution	Shifted Distribution
	Station 145010	Station 145013	Station 145020	(Original)	(Original)	(Shifted)	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020		
Conductivity (mS/m)	348.5	650.0	397.5	355.6	495.7	513.5	354.9	495.4	601.6	355.0	496.0	601.1	1.8	23.8	51.3	2.2	23.7	51.2	34.9	35.1
	360.0	398.0	434.0				355.9	495.9	609.8	357.0	496.4	609.2	1.1	24.8	40.5	0.8	24.7	40.4		
	205.0	286.7	258.3				352.9	494.5	588.3	354.2	495.1	585.7	72.1	86.7	118.5	72.8	86.9	118.3		
	328.8	478.3	645.0				351.7	496.7	625.8	358.9	497.3	625.2	7.0	4.3	3.0	9.2	4.4	3.1		
	347.5	245.0	631.7				355.9	495.9	610.2	356.9	496.3	608.6	2.4	102.4	3.4	2.7	102.6	3.7		
Dissolved Ions (mg/l)	220.2	409.4	241.7	232.9	321.9	304.7	231.6	320.8	358.9	233.1	322.1	358.1	5.2	21.6	48.5	5.9	21.3	48.2	32.5	32.6
	223.5	281.8	284.4				232.8	321.9	386.7	234.3	323.1	385.9	4.2	14.2	38.7	4.9	14.7	38.3		
	129.9	203.3	182.5				228.5	319.0	346.0	230.9	320.3	345.2	76.8	56.9	113.0	77.7	57.6	112.4		
	222.6	329.8	400.6				235.6	323.7	380.0	233.5	322.4	380.9	5.8	1.9	5.1	4.9	2.2	4.9		
	250.5	183.6	425.9				233.1	322.1	368.4	234.6	323.4	367.6	6.8	75.4	13.5	6.3	76.1	13.7		
Dissolved Solids (mg/l)	188.0	350.0	210.0	201.9	273.9	264.6	199.5	272.4	302.1	200.8	273.2	301.5	6.1	22.2	43.9	6.8	22.0	43.6	31.4	33.4
	192.5	226.0	224.0				200.8	273.2	310.9	201.9	273.9	310.5	4.3	20.9	38.6	4.9	21.2	38.6		
	117.0	173.3	143.3				197.3	270.9	285.8	198.6	274.8	285.2	68.6	56.3	99.4	69.7	58.5	99.0		
	192.0	270.0	340.0				203.3	274.8	330.0	202.0	274.0	330.7	5.9	1.8	2.9	5.2	1.5	2.7		
	210.0	150.0	368.7				201.4	273.6	316.4	200.2	272.8	317.1	4.1	82.4	13.7	4.7	81.9	40.8		
Hardness (mg/l) as CaCO ₃	108.5	181.6	86.3	114.3	159.9	86.7	110.8	157.5	128.8	113.2	159.2	127.3	2.1	13.3	49.1	4.3	12.3	47.6	34.8	33.7
	115.3	136.4	96.2				112.8	158.9	135.3	115.2	160.5	134.1	2.1	16.5	40.6	0.0	17.7	39.4		
	84.0	98.0	57.3				107.3	155.1	116.3	109.8	156.8	115.0	67.7	58.3	102.8	71.6	60.0	100.6		
	112.3	166.3	159.3				117.1	161.8	116.3	114.6	160.1	152.2	4.3	2.7	27.0	2.1	3.7	4.4		
	109.5	75.0	172.7				113.8	159.5	139.2	116.2	161.2	137.9	3.9	112.7	19.4	6.1	114.9	20.1		

Table B.2.3(b) 2 yearly

Water Quality Parameter	Observed Mean Values			Prior Mean Values			Assigned Mean Values (Original Distribution)			Assigned Mean Values (Shifted Distribution)			% Error of Prediction						% Error of Prediction (Average)	
				Station 145010	Station 145013	Station 145020							(Original Distribution)			(Shifted Distribution)			Original Distribution	Shifted Distribution
	Station 145010	Station 145013	Station 145020	(Original)	(Original)	(Shifted)	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020		
Conductivity (mS/m)	354.3	524.0	415.8	355.6	495.7	513.5	310.4	474.8	258.3	311.8	475.5	257.6	12.4	9.4	37.9	12.0	9.3	38.0	25.7	25.7
	282.5	347.3	351.2				261.0	451.7	84.1	263.6	452.7	82.5	7.8	30.0	76.1	6.7	30.3	76.5		
	266.9	388.5	456.7				311.7	475.3	265.3	312.9	476.0	264.7	18.8	23.0	41.9	17.2	23.2	42.0		
	338.1	360.6	638.3				349.1	492.7	554.0	350.0	493.2	553.5	3.2	36.6	13.2	3.5	36.8	13.3		
Dissolved Ions (mg/l)	221.5	345.6	253.0	232.9	321.9	304.7	199.2	293.7	170.5	201.0	295.2	169.5	10.2	15.0	32.6	9.4	14.6	33.0	20.2	20.3
	176.7	242.5	213.5				164.1	264.2	66.8	168.4	267.9	64.3	7.1	8.9	68.7	4.7	10.5	69.9		
	176.2	266.5	281.5				199.9	294.3	173.8	201.7	295.7	172.8	13.4	10.4	38.3	14.5	11.0	38.6		
	236.5	258.7	413.2				233.2	322.1	368.8	231.7	320.9	369.7	1.4	25.5	10.8	2.0	25.0	10.5		
Dissolved Solids (mg/l)	190.3	288.0	217.0	201.9	273.9	264.6	175.9	257.0	137.9	177.5	258.1	137.1	7.5	10.8	36.5	6.7	10.4	36.8	21.5	21.5
	154.8	199.7	183.7				148.4	239.2	58.9	153.3	242.4	54.4	4.1	19.8	69.0	0.9	21.4	70.4		
	154.5	221.7	241.7				178.3	258.6	152.0	179.7	259.8	151.3	15.4	16.7	37.1	16.3	17.1	37.4		
	201.0	210.0	353.3				201.6	273.7	318.1	200.4	272.9	318.7	0.3	30.3	10.0	0.3	30.0	9.8		
Hardness (mg/l) as CaCO ₃	111.9	159.0	91.2	114.3	159.9	86.7	92.9	145.3	67.2	95.6	147.1	65.8	17.0	8.6	26.3	14.6	7.5	27.9	20.0	20.0
	89.6	117.2	76.8				76.5	134.1	29.6	81.0	137.2	27.3	14.6	14.4	61.4	9.6	17.0	64.4		
	88.1	132.1	108.3				96.2	147.5	77.9	98.8	149.3	76.8	9.2	11.7	28.1	12.1	13.0	29.3		
	110.9	120.6	168.0				117.5	162.1	152.8	115.1	160.4	153.9	8.0	34.4	8.0	3.8	33.0	7.3		

Table B.2.3(c) 3 yearly

Water Quality Parameter	Observed Mean Values			Prior Mean Values			Assigned Mean Values (Original Distribution)			Assigned Mean Values (Shifted Distribution)			% Error of Prediction						% Error of Prediction (Average)	
				Station 145010	Station 145013	Station 145020							(Original Distribution)			(Shifted Distribution)			Original Distribution	Shifted Distribution
	Station 145010	Station 145013	Station 145020	(Original)	(Original)	(Shifted)	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020		
Conductivity (mS/m)	304.50	448.22	366.81	355.6	495.7	513.5	260.80	460.70	122.10	282.5	461.8	119.9	7.8	2.8	66.7	7.2	3.0	67.3	25.3	25.4
	297.90	390.31	449.11				317.00	478.30	308.70	318.2	478.6	305.2	6.7	22.5	31.7	6.8	22.6	32.1		
	293.80	339.31	515.00				319.30	478.60	310.20	319.1	478.7	308.8	8.3	41.1	39.8	8.6	41.1	40.1		
Dissolved Ions (mg/l)	191.20	298.20	222.90	232.9	321.9	304.7	193.80	289.10	144.90	191.6	287.3	146.1	1.4	3.1	35.0	0.2	3.7	34.5	15.0	14.5
	192.00	271.60	275.80				211.50	304.00	237.40	209.9	302.6	238.3	10.2	11.9	13.9	9.3	11.4	13.6		
	201.00	238.90	329.60				212.90	305.10	245.20	211.3	303.8	246.1	5.9	27.7	25.6	5.1	27.1	25.3		
Dissolved Solids (mg/l)	165.80	249.80	192.40	201.9	273.9	264.6	167.80	251.70	99.90	169.7	253.1	97.9	1.2	0.8	48.1	2.4	1.3	49.1	18.6	19.2
	167.20	223.10	235.80				183.70	262.10	186.90	184.9	262.9	185.3	9.9	17.5	20.7	10.6	17.8	21.4		
	173.00	197.80	283.30				186.10	263.60	203.80	187.3	264.4	202.2	7.6	33.3	28.1	8.3	33.7	28.6		
Hardness (mg/l) as CaCO ₃	95.90	138.70	79.93	114.3	159.9	86.7	92.90	145.40	67.50	95.7	147.2	66.2	3.1	4.8	15.8	0.2	6.1	17.2	12.2	13.3
	97.17	133.60	104.30				103.00	152.20	100.90	106.5	153.9	99.8	6.0	13.9	3.3	8.6	15.2	4.3		
	95.25	113.10	129.80				104.60	153.30	106.50	107.1	155.0	105.4	9.8	35.5	18.0	12.4	37.0	18.8		

Table B.2.3(d) 4 yearly

Water Quality Parameter	Observed Mean Values			Prior Mean Values			Assigned Mean Values (Original Distribution)			Assigned Mean Values (Shifted Distribution)			% Error of Prediction						% Error of Prediction (Average)	
				Station 145010	Station 145013	Station 145020							(Original Distribution)			(Shifted Distribution)			Original Distribution	Shifted Distribution
	Station 145010	Station 145013	Station 145020	(Original)	(Original)	(Shifted)	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020	Station 145010	Station 145013	Station 145020		
Conductivity (mS/m)	310.80	455.23	436.21	355.6	495.7	513.5	334.20	485.90	434.80	335.2	486.3	434.7	7.6	6.7	0.3	7.9	6.8	0.3	11.4	11.5
	310.30	353.98	494.75				337.20	487.20	459.00	338.1	487.8	458.9	8.7	37.6	7.2	8.9	37.8	7.2		
Dissolved Ions (mg/l)	199.00	308.10	267.30	232.9	321.9	304.7	218.8	310.10	281.20	217.3	308.9	282.2	9.9	1.3	5.2	9.2	0.9	5.6	9.0	8.6
	206.80	249.80	313.30				221.6	312.40	297.80	220.1	311.2	298.9	7.3	26.2	4.9	8.5	24.7	4.6		
Dissolved Solids (mg/l)	172.4	254.8	229.3	201.9	273.9	264.6	190.6	266.60	236.50	191.9	267.4	235.9	10.6	4.6	3.1	11.3	5.0	2.9	10.5	10.3
	177.9	204.8	268.5				193	268.10	253.70	194.2	269.0	263.2	8.5	30.9	5.5	9.2	31.3	2.0		
Hardness (mg/l) as CaCO ₃	100	145.6	99.78	114.3	159.9	86.7	105.40	153.80	109.80	108.0	155.6	108.6	5.4	5.6	9.9	8.0	6.8	8.8	10.4	11.7
	100.3	118.9	121.4				107.50	155.20	116.80	110.0	156.9	115.6	7.2	30.5	3.8	9.7	32.0	4.6		

Table B.3.1 Comparison of the Use of Independent and Dependent Data in the Fitzroy River

Table B.3.1(a) 1 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130105	Station 130202	Station 130105	Station 130202	Station 130105	Station 130202	(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
								Station 130105	Station 130202	Station 130105	Station 130202		
Conductivity (mS/m)	0.437	210.00	222.50	266.53	202.44	267.7	196.8	26.9	9.0	27.5	11.6	21.6	22.8
		200.00	195.00	301.42	203.75	301.4	203.7	50.7	4.5	50.7	4.5		
		270.00	248.75	218.82	200.64	221.8	187.0	19.0	19.3	17.8	24.8		
Dissolved Ions (mg/l)	0.371	183.90	159.80	182.73	147.15	183.6	143.3	0.6	7.9	0.2	10.3	16.2	17.1
		128.00	144.55	203.36	147.99	203.5	147.2	58.9	2.4	59.0	1.8		
		165.55	175.30	148.57	145.76	150.5	136.9	10.3	16.9	9.1	21.9		
Dissolved Solids (mg/l)	0.391	123.00	125.00	150.26	121.58	151.1	118.0	22.2	2.7	22.8	5.6	18.5	19.7
		110.00	110.00	167.49	122.44	167.6	121.8	52.3	11.3	52.4	10.7		
		140.00	137.50	126.14	120.37	127.8	112.8	9.9	12.5	8.7	18.0		
Hardness (mg/l) as CaCO ₃	0.533	61.00	57.50	69.99	52.99	70.5	50.4	14.7	7.8	15.6	12.3	18.5	20.1
		55.00	51.50	85.69	53.23	85.8	52.8	55.8	3.4	56.0	2.5		
		65.50	66.50	59.68	52.82	60.6	48.8	8.9	20.6	7.5	26.6		

Table B.3.1(b) 2 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130105	Station 130202	Station 130105	Station 130202	Station 130105	Station 130202	(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
								Station 130105	Station 130202	Station 130105	Station 130202		
Conductivity (mS/m)	0.437	205.00 235.00	208.75 221.88	287.19 262.95	203.22 202.31	288.1 265.5	199.0 190.7	40.1 11.9	2.6 8.8	40.5 13.0	4.7 14.0	15.9	18.1
Dissolved Ions (mg/l)	0.371	155.95 146.78	152.18 159.93	194.82 178.11	147.64 146.97	195.7 180.1	143.6 138.1	24.9 21.3	3.0 8.1	25.5 22.7	5.6 13.7	14.3	16.9
Dissolved Solids (mg/l)	0.391	116.50 125.00	117.50 123.75	159.93 147.80	122.06 121.46	160.7 149.4	118.6 114.4	37.3 18.2	3.9 1.9	37.9 19.5	1.0 7.6	15.3	16.5
Hardness (mg/l) as CaCO ₃	0.533	58.00 60.25	54.50 59.00	78.96 74.15	53.13 53.05	79.4 74.8	51.2 50.1	36.1 23.1	2.5 10.1	36.9 24.2	6.0 15.1	18.0	20.5

Table B.3.1(c) 3 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130105	Station 130202	Station 130105	Station 130202	Station 130105	Station 130202	(Independent Data)		(Dependent Data)		Independent Data	Dependent Data
								Station 130105	Station 130202	Station 130105	Station 130202		
Conductivity (mS/m)	0.437	226.60	222.00	273.77	202.72	275.7	194.0	20.8	8.7	21.7	12.6	14.8	17.1
Dissolved Ions (mg/l)	0.371	159.10	159.80	186.51	147.31	188.1	140.3	17.2	7.8	18.2	12.2	12.5	15.2
Dissolved Solids (mg/l)	0.391	124.30	124.10	153.02	121.72	154.4	115.4	23.1	1.9	24.2	7.0	12.5	15.6
Hardness (mg/l) as CaCO ₃	0.533	60.50	58.50	77.43	52.83	77.2	50.6	28.0	9.7	27.5	13.6	18.8	20.5

Table B.3.2 Comparison of the Use of Independent and Dependent Data in the Nogoia River

Table B.3.2(a) 1 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212	(Independent Data)		(Dependent Data)		Independent Date	Dependent Date
								Station 130202	Station 130212	Station 130202	Station 130212		
Conductivity (mS/m)	0.570	425.0	199.3	285.8	206.5	210.0	179.9	32.8	3.8	50.6	9.7	10.6	21.0
		318.7	211.3	298.7	209.3	232.2	236.4	5.7	0.9	26.7	11.9		
		332.5	206.7	261.8	201.5	216.5	203.5	21.3	2.5	34.0	1.5		
		283.3	242.5	271.4	203.5	211.6	182.9	4.2	16.1	25.3	24.6		
		276.7	185.0	293.3	208.1	211.2	182.0	6.0	12.5	23.7	1.6		
Dissolved Ions (mg/l)	0.433	200.8	151.0	199.2	159.4	158.2	144.9	0.8	5.6	22.2	4.1	7.7	11.3
		200.7	163.3	188.7	155.0	178.1	163.9	6.0	5.1	11.3	0.4		
		219.3	161.3	182.2	152.3	158.6	152.2	16.9	5.6	27.7	5.7		
		176.7	166.2	182.1	152.2	156.8	146.6	3.1	8.4	11.3	11.8		
		182.6	150.2	211.4	164.5	155.8	143.7	15.7	9.5	14.7	4.4		
Dissolved Solids (mg/l)	0.530	218.5	114.8	149.1	115.9	119.3	115.8	31.8	0.9	45.4	0.8	11.0	19.2
		173.3	122.5	162.6	120.6	130.4	140.9	6.2	1.5	24.8	15.1		
		185.0	123.3	138.1	112.0	121.0	119.6	25.4	9.2	34.6	3.0		
		156.7	140.0	150.3	116.3	117.2	111.5	4.1	16.9	25.2	20.4		
		150.0	110.0	158.4	119.2	117.0	111.0	5.6	8.3	22.0	0.9		
Hardness (mg/l) as CaCO ₃	0.478	106.5	58.8	82.7	70.4	69.3	63.6	22.4	19.6	34.9	6.0	12.6	9.5
		83.3	72.5	74.1	67.0	72.3	73.6	11.0	7.6	13.3	1.5		
		83.5	62.0	75.2	67.4	69.7	65.0	9.9	8.7	16.5	4.8		
		72.0	65.5	72.6	66.3	69.9	65.3	0.8	1.3	3.0	0.3		
		75.7	61.0	93.0	74.5	69.3	63.6	22.9	22.1	8.4	4.2		

Table B.3.2(b) 2 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212	(Independent Data)		(Dependent Data)		Independent Date	Dependent Date
								Station 130202	Station 130212	Station 130202	Station 130212		
Conductivity (mS/m)	0.628	370.8	205.3	306.1	210.8	219.9	205.6	17.5	2.7	40.7	0.2	8.7	20.4
		324.6	209.0	295.7	208.8	224.9	218.1	8.9	0.2	30.7	4.4		
		307.9	224.6	283.7	206.1	214.0	190.4	7.9	8.2	30.5	15.2		
		280.0	213.8	297.5	209.1	208.6	179.2	6.2	2.2	25.1	16.2		
Dissolved Ions (mg/l)	0.469	200.7	157.2	208.2	163.2	161.6	161.6	3.7	3.8	19.5	2.8	4.6	12.6
		210.0	162.3	201.7	160.4	162.8	165.4	4.0	1.2	22.5	1.9		
		198.0	163.7	199.1	159.4	156.7	147.2	0.6	2.7	20.9	10.1		
		179.7	158.2	210.4	164.0	155.2	142.8	17.1	3.7	13.6	9.7		
Dissolved Solids (mg/l)	0.570	195.9	118.7	173.6	124.4	124.7	128.0	11.4	4.8	38.3	7.9	5.8	18.9
		179.2	122.9	169.3	122.9	125.6	130.1	5.5	0.0	29.9	5.8		
		170.8	131.7	164.6	121.3	118.7	114.7	3.7	7.9	30.5	12.9		
		153.3	125.0	172.4	124.0	116.7	110.2	12.5	0.8	23.9	11.8		
Hardness (mg/l) as CaCO ₃	0.404	94.9	65.7	87.2	72.2	69.9	64.8	8.2	9.9	26.4	1.4	10.3	9.2
		83.4	67.3	84.4	71.1	70.1	65.6	1.2	5.7	15.9	2.5		
		77.8	63.8	83.8	70.9	68.8	61.0	7.8	11.2	11.5	4.3		
		73.8	63.3	90.4	73.5	68.6	60.2	22.4	16.2	7.1	4.8		

Table B.3.2(c) 3 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212	(Independent Data)		(Dependent Data)		Independent Date	Dependent Date
								Station 130202	Station 130212	Station 130202	Station 130212		
Conductivity (mS/m)	0.802	358.1	205.8	306.7	210.9	216.0	198.2	14.4	2.5	39.7	3.7	4.3	21.3
		310.8	220.1	302.7	210.1	216.6	199.5	2.6	4.5	30.3	9.4		
		297.5	211.4	301.2	209.8	208.6	179.9	1.2	0.8	29.9	14.9		
Dissolved Ions (mg/l)	0.669	206.9	158.5	208.0	163.0	157.3	152.5	0.5	2.8	24.0	3.8	3.1	14.7
		198.9	163.6	203.7	161.2	157.5	153.2	2.4	1.5	20.8	6.4		
		192.9	159.2	209.5	163.6	152.6	139.5	8.6	2.8	20.9	12.4		
Dissolved Solids (mg/l)	0.746	192.3	120.2	168.1	122.5	121.5	121.9	12.6	1.9	36.8	1.4	4.2	19.3
		171.7	128.6	168.4	122.6	120.8	120.2	1.9	4.7	29.7	6.6		
		163.9	124.4	167.4	122.3	115.7	109.3	2.1	1.7	29.4	12.2		
Hardness (mg/l) as CaCO ₃	0.515	91.1	64.4	88.9	72.9	68.5	61.1	2.4	13.2	24.8	5.2	11.2	11.9
		79.6	66.7	86.5	71.9	68.7	61.9	8.7	7.8	13.7	7.3		
		77.1	62.8	90.9	73.7	67.5	57.9	17.9	17.4	12.5	7.8		

Table B.3.2(d) 4 yearly

Water Quality Parameter	Correlation Coefficient between the two stations	Observed Mean Values		Assigned Mean Values (Independent Data)		Assigned Mean Values (Dependent Data)		% Error of Prediction				% Error of Prediction (Average)	
		Station 130202	Station 130212	Station 130202	Station 130212	Station 130202	Station 130212	(Independent Data)		(Dependent Data)		Independent Date	Dependent Date
								Station 130202	Station 130212	Station 130202	Station 130212		
Conductivity (mS/m)	0.705	339.4	214.9	318.6	213.4	215.1	195.8	5.1	0.7	36.3	8.9	3.5	20.1
		302.3	211.4	320.1	213.7	216.1	197.2	5.9	1.1	28.5	6.7		
Dissolved Ions (mg/l)	0.578	199.4	160.4	215.9	166.4	157.7	152.8	8.3	3.7	20.9	4.7	7.1	12.5
		194.8	160.3	218.0	167.2	157.6	152.2	11.9	4.3	19.1	5.1		
Dissolved Solids (mg/l)	0.700	183.4	125.2	171.0	123.5	120.7	119.9	6.8	1.4	34.2	4.2	3.0	17.6
		166.3	124.0	172.8	124.2	120.1	118.6	3.9	0.2	27.8	4.4		
Hardness (mg/l) as CaCO ₃	0.168	86.3	64.7	92.3	74.2	71.1	66.2	6.9	14.7	17.7	2.3	13.9	7.7
		78.6	65.3	93.9	74.9	71.1	66.2	19.4	14.7	9.6	1.3		

Table B.4.1 Evaluation of the Water Quality Values in the Fitzroy River Basin

Table B.4.1(a) Station 130105

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	301.3	7.8	208.8	171.4	86.8	87.3	25.2	3.2	18.9	9.4
Standard Deviation (s)	105.7	0.3	65.7	52.0	32.1	23.7	10.0	0.7	6.9	3.6

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}$)	210.0	7.7	183.9	123.0	61.0	69.0	15.8	4.0	14.3	6.1
	200.0	7.1	128.0	110.0	55.0	51.0	15.5	2.8	13.0	5.5
	270.0	7.9	165.6	140.0	65.5	70.5	22.0	2.5	14.0	7.4
($\bar{X}_{no}$)	226.7	7.6	159.2	124.3	60.5	63.5	17.8	3.1	13.8	6.3
ENTROPY ($\bar{X}_{ne}$)	266.5	7.8	182.7	150.3	70.0	77.7	22.0	3.4	15.8	7.4
	301.4	7.7	203.4	167.5	85.7	81.3	24.7	3.3	19.3	9.1
	218.8	7.7	148.6	126.1	59.7	62.5	17.5	3.1	12.9	6.5
($\bar{X}_{ne}$)	262.3	7.7	178.2	148.0	71.8	73.8	21.4	3.3	16.0	7.7

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-1.22	-1.79	-1.31	-1.57	-1.42	-1.74	-1.28	-0.19	-1.30	-1.47
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/V _n]	-0.64	-0.56	-0.81	-0.78	-0.81	-0.99	-0.65	0.23	-0.74	-0.84

Table B.4.1(a) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}$)	205.0 235.0	7.4 7.5	156.0 146.8	116.5 125.0	58.0 60.3	60.0 60.8	15.7 18.8	3.4 2.7	13.7 13.5	5.8 6.5
$\bar{X}_{no}$	220.0	7.4	151.4	120.8	59.1	60.4	17.2	3.0	13.6	6.1
ENTROPY ($\bar{X}_{ne}$)	267.2 263.0	7.8 7.7	194.8 178.1	159.9 147.8	79.0 74.2	80.3 73.0	23.7 21.5	3.7 3.3	17.8 16.5	8.4 8.0
$\bar{X}_{ne}$	275.1	7.7	186.5	153.9	76.6	76.6	22.6	3.5	17.1	8.2

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(\bar{X}_{no} - \bar{X}_h)/[s/V_n]$)	-1.09	-2.06	-1.24	-1.38	-1.22	-1.61	-1.13	-0.32	-1.10	-1.28
ENTROPY ($(\bar{X}_{ne} - \bar{X}_h)/[s/V_n]$)	-0.50	-0.67	-0.68	-0.68	-0.64	-0.90	-0.50	0.90	-0.52	-0.70

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}$)	226.7	7.6	159.2	124.3	60.5	63.5	17.8	3.1	13.8	6.3
$\bar{X}_{no}$	226.7	7.6	159.2	124.3	60.5	63.5	17.8	3.1	13.8	6.3
ENTROPY ($\bar{X}_{ne}$)	273.8	7.8	186.5	153.0	77.4	78.4	22.9	3.5	17.2	8.1
$\bar{X}_{ne}$	273.8	7.8	186.5	153.0	77.4	78.4	22.9	3.5	17.2	8.1

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(\bar{X}_{no} - \bar{X}_h)/[s/V_n]$)	-0.71	-1.03	-0.76	-0.91	-0.82	-1.00	-0.74	-0.11	-0.75	-0.85
ENTROPY ($(\bar{X}_{ne} - \bar{X}_h)/[s/V_n]$)	-0.26	-0.13	-0.34	-0.35	-0.29	-0.38	-0.22	0.50	-0.26	-0.37

Table B.4.1(b) Station 130322

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	203.8	7.6	148.2	122.6	53.0	66.6	18.7	5.6	13.3	4.8
Standard Deviation (s)	43.7	0.3	28.3	24.8	8.6	13.2	4.3	0.5	2.2	0.8

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X_{no})	222.5	7.9	159.8	125.0	57.5	73.5	19.5	4.9	14.0	5.6
	195.0	7.6	144.6	110.0	51.5	72.0	15.8	5.7	13.0	4.6
	246.8	7.6	175.3	137.5	66.5	77.3	23.0	4.8	17.0	5.8
($\bar{X}_{no}$)	222.1	7.7	159.9	124.2	58.5	74.3	19.4	5.1	14.7	5.3
ENTROPY (X_{ne})	202.4	7.6	147.2	121.6	53.0	66.0	18.5	5.6	13.2	4.8
	203.8	7.6	148.0	122.4	53.2	66.2	18.7	5.6	13.3	4.8
	200.6	7.6	145.8	120.4	52.8	64.9	18.4	5.6	13.2	4.7
($\bar{X}_{ne}$)	202.3	7.6	147.0	121.5	53.0	65.7	18.5	5.6	13.2	4.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(\bar{X}_{no} - \bar{X}_h) / [s / \sqrt{n}]$)	0.73	0.63	0.71	0.11	1.11	1.01	0.31	-1.59	1.05	1.17
ENTROPY ($(\bar{X}_{ne} - \bar{X}_h) / [s / \sqrt{n}]$)	-0.06	-0.11	-0.08	-0.08	0.01	-0.12	-0.06	0.04	-0.05	-0.04

Table B.4.1(b) (continued)

[2 Yearly Averaging]**New/Predicted Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	208.8 221.9	7.7 7.6	152.2 159.9	117.5 123.8	54.5 59.0	72.8 74.6	17.6 19.4	5.3 5.2	13.5 15.0	5.1 5.2
($\bar{X}_{no}$)	215.3	7.7	156.1	120.6	56.8	73.7	18.5	5.3	14.3	5.1
ENTROPY (X _{ne})	203.2 202.3	7.6 7.6	147.6 147.0	122.1 121.5	53.1 53.1	66.1 65.6	18.6 18.5	5.7 5.6	13.3 13.2	4.8 4.8
($\bar{X}_{ne}$)	202.8	7.6	147.3	121.8	53.1	65.9	18.6	5.6	13.3	4.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / [s/V_n]	0.37	0.33	0.39	-0.12	0.62	0.76	-0.06	-0.90	0.60	0.64
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / [s/V_n]	-0.03	-0.11	-0.05	-0.05	0.02	-0.08	-0.03	0.11	-0.03	0.00

[3 Yearly Averaging]**New/Predicted Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	222.1	7.7	159.9	124.2	58.5	74.3	19.4	5.1	14.7	5.3
($\bar{X}_{no}$)	222.1	7.7	159.9	124.2	58.5	74.3	19.4	5.1	14.7	5.3
ENTROPY (X _{ne})	202.7	7.6	147.3	121.7	52.8	66.0	18.6	5.6	13.3	4.8
($\bar{X}_{ne}$)	202.7	7.6	147.3	121.7	52.8	66.0	18.6	5.6	13.3	4.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / [s/V_n]	0.42	0.36	0.41	0.06	0.64	0.58	0.18	-0.92	0.61	0.68
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / [s/V_n]	-0.02	-0.02	-0.03	-0.04	-0.02	-0.05	-0.02	0.08	-0.02	-0.02

Table B.4.1(c) Station 130003

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	368.6	7.9	248.9	209.1	104.6	90.4	33.1	3.5	21.7	12.2
Standard Deviation (s)	199.7	0.2	114.9	100.4	56.5	26.0	18.1	1.0	10.6	7.3

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X_{no})	288.3 370.0 176.7	7.8 7.6 7.4	194.5 237.9 122.8	160.0 200.0 104.0	71.0 102.5 50.3	76.0 81.5 53.0	26.0 32.0 15.8	4.4 4.0 3.3	16.3 22.3 11.3	7.4 11.5 5.4
($\bar{X}_{no}$)	278.3	7.6	185.1	154.7	74.6	70.2	24.6	3.9	16.6	8.1

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(X_{no}-\bar{X}_h)/[s/\sqrt{n}]$)	-0.78	-2.42	-0.96	-0.94	-0.92	-1.35	-0.81	0.66	-0.83	-0.97

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X_{no})	329.2 273.3	7.7 7.5	216.2 180.3	180.0 152.0	86.8 76.4	78.8 67.3	29.0 23.9	4.2 3.6	19.3 16.8	9.4 8.4
($\bar{X}_{no}$)	301.3	7.6	198.3	166.0	81.6	73.0	26.4	3.9	18.0	8.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(X_{no}-\bar{X}_h)/[s/\sqrt{n}]$)	-0.48	-2.02	-0.62	-0.61	-0.58	-0.95	-0.52	0.48	-0.49	-0.63

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X_{no})	244.8	7.7	168.2	139.7	66	72.6	21.4	2.9	14.2	7.5
($\bar{X}_{no}$)	244.8	7.7	168.2	139.7	66.0	72.6	21.4	2.9	14.2	7.5

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(X_{no}-\bar{X}_h)/[s/\sqrt{n}]$)	-0.62	-0.87	-0.70	-0.69	-0.68	-0.69	-0.64	-0.61	-0.71	-0.64

Table B.4.2 Evaluation of the Water Quality Values in the Nogoa River Basin

Table B.4.2(a) Station 130202

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	245.7	7.6	177.4	137.2	76.2	79.2	18.9	4.3	20.0	6.4
Standard Deviation (s)	64.2	0.3	41.3	37.6	15.8	13.1	6.4	2.0	3.9	1.7

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	246.5	7.5	179.4	147.9	69.1	72.4	22.4	5.3	17.2	6.3
(X_{no})	342.5	8.2	249.4	200.0	92.5	106.0	30.5	5.7	23.0	8.6
	190.0	7.4	135.8	110.0	46.0	64.0	17.0	4.4	13.0	3.4
	152.5	7.0	116.6	94.5	45.5	53.5	12.5	5.2	12.5	3.5
	147.5	7.3	110.2	86.0	44.0	57.5	9.7	4.8	12.2	3.3
($\bar{X}_{no}$)	215.8	7.5	158.3	127.7	59.4	70.7	18.4	5.1	15.6	5.0
ENTROPY	215.2	7.5	159.3	120.5	70.7	75.6	16.2	5.5	18.9	5.6
(X_{ne})	263.5	7.6	169.7	131.0	73.0	77.4	17.9	5.5	19.8	5.9
	235.7	7.5	161.4	122.1	71.0	75.5	16.5	5.4	19.1	5.6
	218.4	7.6	159.8	118.7	71.1	75.7	15.8	5.3	18.9	5.6
	217.6	7.5	159.0	118.5	70.7	75.9	15.9	5.6	19.2	5.6
($\bar{X}_{ne}$)	230.1	7.5	161.8	122.2	71.3	76.0	16.4	5.5	19.2	5.7

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($X_{no}-\bar{X}_h$)/[s/Vn]	-1.04	-1.34	-1.04	-0.56	-2.37	-1.45	-0.16	0.89	-2.53	-1.85
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/Vn]	-0.55	-0.65	-0.84	-0.89	-0.69	-0.54	-0.85	1.32	-0.47	-0.98

Table B.4.2(a) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	294.5	7.8	214.4	174.0	80.8	89.2	26.4	5.5	20.1	7.4
	266.3	7.8	192.6	155.0	69.3	85.0	23.8	5.0	18.0	6.0
	171.3	7.2	126.2	102.3	45.8	58.8	14.8	4.8	12.8	3.4
	150.0	7.1	113.4	90.3	44.8	55.5	11.1	5.0	12.4	3.4
($\bar{X}_{no}$)	220.5	7.5	161.6	130.4	60.1	72.1	19.0	5.1	15.8	5.0
ENTROPY (X _{ne})	237.1	7.5	164.0	125.6	71.0	76.2	17.1	5.4	19.0	5.7
	247.9	7.5	165.0	126.5	71.2	76.2	17.3	5.4	19.1	5.7
	224.3	7.5	159.9	120.0	70.1	75.3	16.2	5.3	18.6	5.6
	214.8	7.5	158.7	118.2	69.9	75.5	15.9	5.4	18.6	5.6
($\bar{X}_{ne}$)	231.0	7.5	161.9	122.6	70.6	75.8	16.6	5.4	18.8	5.6

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / [$s/\sqrt{n}$]	-0.79	-1.02	-0.76	-0.36	-2.03	-1.08	0.05	0.80	-2.16	-1.59
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / [$s/\sqrt{n}$]	-0.46	-0.99	-0.75	-0.78	-0.71	-0.53	-0.70	1.08	-0.57	-0.90

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	259.7	7.7	188.2	152.6	69.2	80.8	23.3	5.1	17.7	6.1
	228.3	7.5	167.3	134.8	61.3	74.5	20.0	5.1	16.2	5.1
	163.3	7.2	120.9	96.8	45.2	58.3	13.1	4.8	12.6	3.4
($\bar{X}_{no}$)	217.1	7.5	158.8	128.1	58.6	71.2	18.8	5.0	15.5	4.9
ENTROPY (X _{ne})	230.0	7.6	145.3	122.8	70.0	75.5	16.7	5.5	18.6	5.7
	231.2	7.6	145.8	122.2	70.2	75.5	16.6	5.5	18.6	5.7
	214.3	7.6	134.9	117.5	69.3	75.0	15.9	5.5	18.3	5.6
($\bar{X}_{ne}$)	225.2	7.6	142.0	120.8	69.8	75.3	16.4	5.5	18.5	5.7

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / [$s/\sqrt{n}$]	-0.77	-0.94	-0.78	-0.42	-1.93	-1.05	-0.02	0.63	-2.00	-1.57
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / [$s/\sqrt{n}$]	-0.56	-0.36	-1.48	-0.75	-0.69	-0.51	-0.67	1.03	-0.64	-0.72

Table B.4.2(a) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	232.9 208.1	7.5 7.5	170.3 153.0	138.1 122.6	63.3 57.0	74.0 70.3	20.6 17.4	5.1 5.0	16.4 15.2	5.4 4.7
— (X _{no})	220.5	7.5	161.6	130.4	60.1	72.1	19.0	5.1	15.8	5.0
ENTROPY (X _{ne})	228.9 229.6	7.6 7.6	145.8 145.6	122.1 121.5	71.6 71.6	76.2 76.2	16.2 16.1	5.8 5.8	18.9 19.0	5.9 5.9
— (X _{ne})	229.2	7.6	145.7	121.8	71.6	76.2	16.2	5.8	18.9	5.9

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no} -X _h)/[s/V _n]	-0.56	-0.72	-0.54	-0.26	-1.44	-0.76	0.03	0.56	-1.52	-1.13
ENTROPY (X _{ne} -X _h)/[s/V _n]	-0.36	-0.29	-1.09	-0.58	-0.41	-0.33	-0.60	1.07	-0.37	-0.45

Table B.4.2(b) Station 130212

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	271.4	7.5	209.1	155.6	86.5	101.9	23.2	3.7	24.6	6.1
Standard Deviation (s)	152.9	0.2	107.5	79.1	44.8	48.6	16.4	1.6	13.8	2.9

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	221.3	7.5	184.3	147.5	78.0	96.5	17.0	4.6	22.0	5.6
($\bar{X}_{no}$)	230.0	7.4	182.4	138.0	80.0	101.0	14.0	4.2	23.3	5.3
	125.0	7.7	97.2	80.0	37.0	51.0	9.5	4.5	10.0	2.8
	152.5	7.4	125.2	90.5	50.5	67.5	12.0	4.3	15.0	3.1
	172.5	7.2	137.8	105.0	54.5	75.0	11.0	6.1	15.5	3.9
($\bar{X}_{no}$)	180.3	7.4	145.4	112.2	60.0	78.2	12.7	4.7	17.2	4.1
ENTROPY	170.2	7.5	139.4	113.6	61.2	73.8	13.1	4.4	16.8	4.7
($\bar{X}_{ne}$)	181.6	7.5	179.4	140.0	72.2	87.9	19.6	4.4	23.2	5.2
	175.0	7.5	147.3	117.7	62.8	73.0	14.3	4.3	18.1	4.8
	171.0	7.5	141.2	109.0	63.2	74.3	11.8	4.3	16.5	4.8
	170.8	7.5	138.1	108.5	61.2	76.1	12.1	4.4	18.9	4.7
($\bar{X}_{ne}$)	173.7	7.5	149.1	117.7	64.1	77.0	14.2	4.4	18.7	4.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-1.33	-0.80	-1.33	-1.23	-1.32	-1.09	-1.44	1.40	-1.19	-1.50
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / (s/V _n)	-1.43	-0.30	-1.25	-1.07	-1.12	-1.15	-1.23	0.87	-0.95	-0.97

Table B.4.2(b) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	225.6	7.5	183.4	142.8	79.0	98.8	15.5	4.4	22.7	5.4
	177.5	7.6	139.8	109.0	58.5	76.0	11.8	4.4	16.7	4.0
	138.8	7.5	111.2	85.3	43.8	59.3	10.8	4.4	12.5	3.0
	162.5	7.3	131.5	97.8	52.5	71.3	11.5	5.2	15.3	3.5
($\bar{X}_{no}$)	176.1	7.5	141.5	108.7	58.4	76.3	12.4	4.6	16.8	4.0
ENTROPY (X _{ne})	175.4	7.9	157.3	126.4	62.8	78.5	16.7	4.3	17.8	4.9
	177.9	7.9	161.4	128.6	63.7	78.1	17.3	4.3	18.6	4.9
	172.4	7.9	141.6	112.4	58.7	71.0	13.2	4.3	14.5	4.7
	170.1	7.9	136.8	107.6	57.9	72.6	12.1	4.3	15.0	4.7
($\bar{X}_{ne}$)	173.9	7.9	149.3	118.7	60.8	75.0	14.8	4.3	16.5	4.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-1.25	-0.54	-1.26	-1.19	-1.25	-1.05	-1.33	1.07	-1.13	-1.45
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / (s/V _n)	-1.27	3.33	-1.11	-0.93	-1.15	-1.11	-1.03	0.76	-1.17	-0.90

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	192.1	7.5	154.6	121.8	65.0	82.8	13.5	4.4	18.4	4.5
	169.2	7.5	134.9	102.8	55.8	73.2	11.8	4.3	16.1	3.7
	150.0	7.4	120.1	91.8	47.3	64.5	10.8	5.0	13.5	3.3
($\bar{X}_{no}$)	170.4	7.5	136.5	105.5	56.1	73.5	12.1	4.6	16.0	3.8
ENTROPY (X _{ne})	173.7	7.5	173.5	119.4	58.4	72.9	15.3	4.4	14.9	4.9
	174.0	7.5	173.7	117.7	59.1	73.1	14.8	4.4	14.8	4.9
	170.0	7.5	170.6	106.1	54.8	68.7	12.0	4.4	12.6	4.8
($\bar{X}_{ne}$)	172.5	7.5	172.6	114.4	57.4	71.6	14.0	4.4	14.1	4.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/V _n)	-1.14	-0.27	-1.17	-1.10	-1.18	-1.01	-1.18	0.92	-1.07	-1.33
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$) / (s/V _n)	-1.12	-0.17	-0.59	-0.90	-1.12	-1.08	-0.97	0.67	-1.31	-0.72

Table B.4.2(b) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}$)	182.2 170.0	7.5 7.4	147.3 135.6	114.0 103.4	61.4 55.5	79.0 73.6	13.1 11.6	4.4 4.8	17.6 16.0	4.2 3.8
$\bar{X}_{no}$	176.1	7.5	141.5	108.7	58.4	76.3	12.4	4.6	16.8	4.0
ENTROPY ($\bar{X}_{ne}$)	173.4 173.6	7.5 7.5	173.7 173.6	117.5 116.1	65.3 65.3	78.1 78.6	13.2 13.0	4.4 4.4	16.8 17.5	5.2 5.2
$\bar{X}_{ne}$	173.5	7.5	173.6	116.8	65.3	78.4	13.1	4.4	17.1	5.2

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(\bar{X}_{no}-\bar{X}_h)/[s/\sqrt{n}]$)	-0.88	-0.38	-0.89	-0.84	-0.89	-0.74	-0.94	0.76	-0.80	-1.02
ENTROPY ($(\bar{X}_{ne}-\bar{X}_h)/[s/\sqrt{n}]$)	-0.91	-0.15	-0.47	-0.69	-0.67	-0.68	-0.88	0.60	-0.76	-0.46

Table B.4.2(c) Station 130209

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	325.9	7.7	253.5	182.3	109.2	132.9	25.0	3.6	19.5	14.7
Standard Deviation (s)	222.2	0.4	162.0	112.1	71.8	90.0	19.0	1.6	5.5	14.4

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	165.0	7.4	134.3	113.3	54.0	67.3	13.0	5.2	14.7	4.3
($\bar{X}_{no}$)	265.0	7.5	202.8	156.7	78.0	100.3	21.3	5.2	18.7	7.7
	207.5	7.5	147.8	120.0	57.5	65.5	14.5	5.0	15.5	4.7
	171.7	7.5	137.4	105.7	58.3	68.5	11.3	4.9	14.5	4.6
	170.0	7.4	132.0	105.0	54.0	72.7	11.7	5.4	16.0	4.4
($\bar{X}_{no}$)	195.8	7.5	150.9	120.1	60.4	74.9	14.4	5.1	15.9	5.1

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/Vn)	-1.31	-1.71	-1.42	-1.24	-1.52	-1.44	-1.37	2.10	-1.48	-1.49

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	215.0	7.4	168.6	135.0	66.0	83.8	17.2	5.2	16.7	6.0
($\bar{X}_{no}$)	236.3	7.5	175.3	138.3	67.8	82.9	17.9	5.1	17.1	6.2
	189.6	7.5	142.6	112.8	57.9	67.0	12.9	4.9	15.0	4.8
	170.8	7.5	134.7	105.3	58.2	70.6	11.5	5.1	15.3	4.5
($\bar{X}_{no}$)	202.9	7.5	155.3	122.9	62.0	76.1	14.9	5.1	16.0	5.3

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$) / (s/Vn)	-1.11	-1.46	-1.21	-1.06	-1.32	-1.26	-1.17	1.84	-1.28	-1.30

Table B.4.2(c) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	212.5	7.4	161.6	130.0	63.2	77.7	16.3	5.1	16.3	5.6
	214.7	7.5	162.7	127.4	64.6	78.1	15.7	5.0	16.2	5.6
	183.1	7.5	139.1	110.2	56.6	68.9	12.5	5.1	15.3	4.5
($\bar{X}_{no}$)	203.4	7.5	154.5	122.6	61.5	74.9	14.8	5.1	15.9	5.2

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED $(\bar{X}_{no} - \bar{X}_h) / [s / \sqrt{n}]$	-0.95	-1.27	-1.06	-0.92	-1.15	-1.12	-1.02	1.58	-1.12	-1.14

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	202.3	7.5	155.6	123.9	62.0	75.4	15.0	5.1	15.8	5.3
	203.5	7.5	155.0	121.8	62.0	76.8	14.7	5.1	16.2	5.3
($\bar{X}_{no}$)	202.9	7.5	155.3	122.9	62.0	76.1	14.9	5.1	16.0	5.3

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED $(\bar{X}_{no} - \bar{X}_h) / [s / \sqrt{n}]$	-0.78	-1.03	-0.86	-0.75	-0.93	-0.89	-0.83	1.30	-0.90	-0.92

Table B.4.3 Evaluation of the Water Quality Values in the Logan River Basin

Table B.4.3(a) Station 145010

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	355.6	7.8	232.9	201.9	114.3	89.1	25.5	1.5	20.2	15.5
Standard Deviation (s)	98.0	0.5	65.9	50.9	35.4	30.1	6.2	0.2	6.1	4.9

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	348.5	7.8	220.2	188.0	108.5	83.5	53.4	1.3	10.1	16.9
(X _{no})	360.0	8.0	223.5	192.5	115.3	83.8	22.0	1.2	20.0	15.9
	205.0	7.4	129.9	117.0	64.0	47.3	14.5	1.5	11.6	8.5
	328.8	7.6	222.6	192.0	112.3	87.8	23.3	1.3	20.0	15.1
	347.5	7.9	250.5	210.0	109.5	95.5	32.8	1.5	20.8	14.0
($\bar{X}_{no}$)	318.0	7.7	209.3	179.9	101.9	79.6	29.2	1.3	16.5	14.1
ENTROPY	354.9	8.2	231.6	199.5	110.8	84.6	25.6	1.5	35.0	14.8
(X _{ne})	355.9	7.9	232.8	200.8	112.8	88.1	25.5	1.5	35.0	15.3
	352.9	8.3	229.5	197.3	107.3	71.7	25.6	1.5	18.6	14.6
	351.7	7.7	235.6	203.3	117.1	93.7	25.5	1.5	20.9	15.9
	355.9	6.9	233.1	201.4	113.8	87.3	25.5	1.5	35.0	15.8
($\bar{X}_{ne}$)	354.3	7.8	232.5	200.5	112.4	85.1	25.5	1.5	28.9	15.3

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-0.86	-0.08	-0.80	-0.97	-0.78	-0.71	1.34	-1.42	-1.36	-0.66
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/V _n]	-0.03	0.06	-0.01	-0.06	-0.12	-0.30	0.03	0.34	3.17	-0.10

Table B.4.3(a) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	354.3	7.9	221.8	190.3	111.9	83.6	37.7	1.2	15.1	16.4
	282.5	7.7	176.7	154.8	89.6	65.5	18.2	1.3	15.8	12.2
	266.9	7.5	176.2	154.5	88.1	67.5	18.9	1.4	15.8	11.8
	338.1	7.8	236.5	201.0	110.9	91.6	28.0	1.4	20.4	14.6
($\bar{X}_{no}$)	310.4	7.7	202.8	175.1	100.1	77.1	25.7	1.3	16.8	13.7
ENTROPY (X _{ne})	310.4	8.4	199.2	175.9	92.9	74.4	24.0	1.5	17.2	10.8
	261.0	8.8	164.1	148.4	76.5	64.4	23.2	1.5	15.3	10.1
	311.7	8.4	199.9	178.3	96.2	75.8	24.0	1.5	17.9	12.8
	349.1	6.1	233.2	201.6	117.6	90.7	25.3	1.5	19.6	27.0
($\bar{X}_{ne}$)	308.1	7.9	199.1	176.1	95.8	76.3	24.1	1.5	17.5	15.2

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/Vn]	-0.92	-0.17	-0.91	-1.05	-0.80	-0.80	0.08	-1.35	-1.13	-0.73
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/Vn]	-0.97	0.52	-1.03	-1.02	-1.04	-0.85	-0.43	0.31	-0.88	-0.13

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	304.5	7.7	191.2	165.8	95.9	71.5	29.9	1.3	13.9	13.8
	297.9	7.7	192.0	167.2	97.2	72.9	19.9	1.3	17.2	13.2
	293.8	7.7	201.0	173.0	95.3	76.9	23.5	1.4	17.5	12.5
($\bar{X}_{no}$)	298.7	7.7	194.7	168.7	96.1	73.8	24.4	1.3	16.2	13.1
ENTROPY (X _{ne})	280.6	8.9	193.8	167.8	92.9	79.2	22.9	1.5	16.5	11.8
	317.9	8.3	211.5	183.7	103.0	84.3	24.1	1.5	18.2	13.8
	318.3	7.4	212.9	186.1	104.6	83.8	24.2	1.5	17.7	14.5
($\bar{X}_{ne}$)	305.6	8.2	206.1	179.2	100.2	82.4	23.7	1.5	17.5	13.4

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/Vn]	-1.00	-0.26	-1.00	-1.13	-0.89	-0.88	-0.28	-1.04	-1.14	-0.84
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/Vn]	-0.88	1.65	-0.71	-0.77	-0.69	-0.38	-0.48	0.26	-0.78	-0.76

Table B.4.3(a) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	310.6 310.3	7.7 7.7	199.0 206.6	172.4 177.9	100.0 100.3	75.6 78.6	28.3 23.1	1.3 1.3	15.4 18.1	14.1 13.4
$\bar{X}_{no}$	310.4	7.7	202.8	175.1	100.1	77.1	25.7	1.3	16.8	13.7
ENTROPY (X _{ne})	334.2 337.2	8.4 7.4	218.8 221.6	190.6 193.0	105.4 107.5	89.1 88.9	24.7 24.8	1.5 1.5	19.0 19.0	14.0 14.7
$\bar{X}_{ne}$	335.7	7.9	220.2	191.8	106.5	89.0	24.8	1.5	19.0	14.4

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-0.65	-0.12	-0.65	-0.74	-0.56	-0.56	0.05	-0.96	-0.80	-0.51
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/V _n]	-0.29	0.39	-0.27	-0.28	-0.31	-0.00	-0.16	0.22	-0.28	-0.34

Table B.4.3(b) Station 145013

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	495.7	7.9	321.9	273.9	159.9	127.4	35.8	1.8	29.3	21.1
Standard Deviation (s)	63.2	0.2	57.2	38.9	27.8	27.9	5.4	0.2	5.1	3.7

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	650.0	8.0	409.4	350.0	181.6	138.8	54.1	2.5	34.0	23.5
($\bar{X}_{no}$)	398.0	8.1	281.8	226.0	136.4	133.4	25.6	1.7	26.4	17.1
	296.7	7.7	203.3	173.3	98.0	87.7	21.0	1.6	19.0	12.3
	476.3	7.9	329.8	270.0	166.3	136.8	33.5	1.6	30.8	21.8
	245.0	7.7	183.6	150.0	75.0	82.0	24.0	1.6	15.5	8.7
($\bar{X}_{no}$)	413.2	7.9	281.6	233.9	131.5	115.7	31.6	1.8	25.1	16.7
ENTROPY	495.4	8.0	320.8	272.4	157.5	123.0	35.9	1.8	36.4	20.6
($\bar{X}_{ne}$)	495.9	7.9	321.9	273.2	158.9	126.4	35.9	1.8	36.4	20.9
	494.5	8.0	319.0	270.9	155.1	118.4	35.9	1.8	28.0	20.5
	496.7	7.9	323.7	274.8	161.8	131.8	35.9	1.8	29.8	21.3
	495.9	7.7	322.1	273.6	159.5	125.7	35.9	1.8	36.4	21.2
($\bar{X}_{ne}$)	495.7	7.9	321.5	273.0	158.6	125.1	35.9	1.8	33.4	20.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/Vn]	-2.92	0.22	-1.58	-2.30	-2.29	-0.93	-1.73	0.55	-1.82	-2.66
ENTROPY ($\bar{X}_{ne} - \bar{X}_h$)/[s/Vn]	-0.00	0.16	-0.02	-0.05	-0.10	-0.18	0.03	0.46	1.81	-0.10

Table B.4.3(b) (continued)

[2 Yearly Averaging]**New/Predicted Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	524.0	8.1	345.6	288.0	159.0	136.1	39.9	2.1	30.2	20.3
	347.3	7.9	242.5	199.7	117.2	110.5	23.3	1.6	22.7	14.7
	386.5	7.8	266.5	221.7	132.1	112.2	27.3	1.6	24.9	17.0
	360.6	7.8	256.7	210.0	120.6	109.4	28.8	1.6	23.1	15.2
($\bar{X}_{no}$)	404.6	7.9	277.9	229.8	132.2	117.1	29.8	1.7	25.2	16.8
ENTROPY (X _{ne})	474.8	8.0	293.7	257.0	145.3	113.3	34.6	1.8	27.0	18.1
	451.7	8.1	264.2	239.2	134.1	103.8	33.9	1.8	25.5	17.6
	475.3	8.0	294.3	258.6	147.5	114.6	34.6	1.8	27.5	19.3
	492.7	7.2	322.1	273.7	162.1	128.9	35.7	1.8	28.8	29.7
($\bar{X}_{ne}$)	473.6	7.8	293.6	257.1	147.3	115.2	34.7	1.8	27.2	21.2

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/[s/V _n]	-2.88	0.28	-1.54	-2.27	-1.99	-0.74	-2.23	-0.09	-1.59	-2.31
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/V _n]	-0.70	-0.70	-0.99	-0.86	-0.91	-0.88	-0.41	0.41	-0.81	0.06

[3 Yearly Averaging]**New/Predicted Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	448.2	7.9	298.2	249.8	138.7	120.0	33.6	1.9	26.5	17.6
	390.3	7.9	271.6	223.1	133.6	119.3	26.7	1.6	25.4	17.1
	339.3	7.8	238.9	197.8	113.1	102.1	26.2	1.6	21.8	14.3
($\bar{X}_{no}$)	392.6	7.9	269.6	223.6	128.4	113.8	28.8	1.7	24.5	16.3
ENTROPY (X _{ne})	460.7	8.1	289.1	251.7	145.4	118.0	33.6	1.8	26.4	18.7
	478.3	8.0	304.0	262.1	152.2	122.8	34.6	1.8	27.7	20.0
	478.6	7.8	305.1	263.6	153.3	122.4	34.7	1.8	27.4	20.4
($\bar{X}_{ne}$)	472.5	8.0	299.4	259.1	150.3	121.1	34.3	1.8	27.2	19.7

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/[s/V _n]	-2.82	0.03	-1.58	-2.24	-1.96	-0.84	-2.25	-0.20	-1.61	-2.23
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/V _n]	-0.63	1.02	-0.68	-0.66	-0.60	-0.39	-0.49	0.36	-0.72	-0.64

Table B.4.3(b) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}$)	455.2 354.0	7.9 7.8	306.1 249.6	254.8 204.8	145.6 118.9	124.2 110.0	33.6 26.0	1.9 1.6	27.5 22.9	18.7 15.0
$\bar{X}_{no}$	404.6	7.9	277.9	229.8	132.2	117.1	29.8	1.7	25.2	16.8
ENTROPY ($\bar{X}_{ne}$)	485.9 487.2	8.0 7.8	310.1 312.4	266.6 268.1	153.8 155.2	127.4 127.2	35.2 35.3	1.8 1.8	28.3 28.4	20.6 20.1
$\bar{X}_{ne}$	486.6	7.9	311.3	267.4	154.5	127.3	35.3	1.8	28.4	20.4

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($(\bar{X}_{no} - \bar{X}_h)/[s/V_n]$)	-2.04	0.20	-1.09	-1.60	-1.41	-0.52	-1.58	-0.06	-1.12	-1.63
ENTROPY ($(\bar{X}_{ne} - \bar{X}_h)/[s/V_n]$)	-0.20	0.28	-0.26	-0.24	-0.27	-0.00	-0.15	0.29	-0.26	-0.27

Table B.4.3(c) Station 145020

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	523.5	6.7	314.7	274.6	96.7	86.2	54.0	2.0	23.2	15.3
Standard Deviation (s)	273.0	3.0	162.5	141.0	49.5	43.3	28.0	1.0	12.2	8.0

[1 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	397.5	7.8	241.7	210.0	86.3	73.5	41.3	2.1	17.0	10.7
($\bar{X}_{no}$)	434.0	7.9	264.4	224.0	96.2	81.0	45.0	2.6	19.3	11.6
	268.3	7.5	162.5	143.3	57.3	47.3	29.5	1.7	11.8	6.8
	645.0	7.9	400.6	340.0	159.3	119.3	66.8	2.3	32.0	19.3
	631.7	7.9	425.9	366.7	172.7	123.7	69.7	2.4	31.7	22.7
($\bar{X}_{no}$)	475.3	7.8	299.0	256.8	114.3	89.0	50.4	2.2	22.4	14.2
ENTROPY	601.6	8.1	358.9	302.1	128.6	92.9	65.2	2.3	15.9	15.6
($\bar{X}_{ne}$)	609.8	7.9	366.7	310.9	135.3	98.9	64.7	2.3	18.6	17.2
	586.3	8.2	346.0	285.8	116.3	84.6	66.0	2.3	19.8	15.2
	625.8	7.8	380.0	330.0	116.3	108.4	63.9	2.3	29.9	18.9
	610.2	7.3	368.4	316.4	139.2	97.6	64.5	2.3	16.3	18.7
($\bar{X}_{ne}$)	606.7	7.9	364.0	309.0	127.1	96.5	64.9	2.3	20.1	17.1

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/[s/V _n]	-0.39	0.77	-0.22	-0.28	0.80	0.14	-0.28	0.45	-0.15	-0.30
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/V _n]	0.68	0.84	0.68	0.55	1.38	0.53	0.87	0.64	-0.57	0.52

Table B.4.3(c) (continued)

[2 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	415.8	7.9	253.0	217.0	91.2	77.3	43.1	2.4	18.2	11.1
	351.2	7.7	213.5	183.7	76.8	64.2	37.3	2.2	15.6	9.2
	456.7	7.7	281.5	241.7	108.3	83.3	48.1	2.0	21.9	13.0
	638.3	7.9	413.2	353.3	166.0	121.5	68.2	2.3	31.8	21.0
$\bar{X}_{no}$	465.5	7.8	290.3	248.9	110.6	86.5	49.2	2.2	21.9	13.6
ENTROPY (X _{ne})	258.3	8.3	170.5	137.9	67.2	75.7	32.8	2.5	14.2	5.1
	84.1	8.5	66.8	56.9	29.6	59.6	19.7	2.5	7.7	4.0
	265.3	8.3	173.8	152.0	77.9	70.0	33.1	2.5	17.0	9.7
	554.0	7.1	368.8	318.1	152.6	103.4	59.1	2.5	24.4	16.7
$\bar{X}_{ne}$	290.4	8.0	195.0	166.2	81.8	77.2	36.2	2.5	15.8	8.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/[s/V _n]	-0.43	0.68	-0.30	-0.36	0.56	0.01	-0.34	0.39	-0.22	-0.42
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/V _n]	-1.71	0.85	-1.47	-1.54	-0.60	-0.42	-1.27	0.97	-1.21	-1.59

[3 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	366.6	7.7	222.9	192.4	79.9	67.3	38.6	2.1	16.0	9.7
	449.1	7.8	275.8	235.8	104.3	82.5	47.1	2.2	21.0	12.5
	515.0	7.7	329.6	283.3	129.8	96.8	55.3	2.1	25.2	16.3
$\bar{X}_{no}$	443.6	7.7	276.1	237.2	104.6	82.2	47.0	2.2	20.8	12.8
ENTROPY (X _{ne})	122.1	8.5	144.9	99.9	67.5	83.9	16.4	3.0	11.3	7.2
	306.7	8.3	237.4	186.9	100.9	92.4	33.8	2.8	18.3	12.6
	310.2	7.6	245.2	203.8	106.5	91.7	36.1	2.7	16.1	14.9
$\bar{X}_{ne}$	246.3	8.1	209.2	163.5	91.6	89.3	28.8	2.8	15.2	11.6

Number of Standard Deviations of the Distribution of Sampled Means by which the New/Predicted Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no}-\bar{X}_h$)/[s/V _n]	-0.51	0.57	-0.41	-0.46	0.28	-0.16	-0.43	0.24	-0.35	-0.53
ENTROPY ($\bar{X}_{ne}-\bar{X}_h$)/[s/V _n]	-1.76	0.79	-1.12	-1.36	-0.18	0.12	-1.56	1.43	-1.13	-0.80

Table B.4.3(c) (continued)

[4 Yearly Averaging]

New/Predicted Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	436.2 494.8	7.8 7.8	267.3 313.3	229.3 268.5	99.8 121.4	80.3 92.8	45.6 52.7	2.2 2.2	20.0 23.7	12.1 15.1
(X _{no})	465.5	7.8	290.3	248.9	110.6	86.5	49.2	2.2	21.9	13.6
ENTROPY (X _{ne})	434.8 459.0	8.3 7.6	281.2 297.8	236.5 253.7	109.6 116.8	100.6 100.4	46.3 49.6	2.3 2.3	21.7 21.8	13.4 15.5
(X _{ne})	446.9	8.0	289.5	245.1	113.2	100.5	48.0	2.3	21.8	14.5

**Number of Standard Deviations of the Distribution of Sampled Means by which
the New/Predicted Mean Values lies from the Historical Mean Values**

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no} -X _h)/[s/V _n]	-0.30	0.48	-0.21	-0.26	0.40	0.01	-0.24	0.28	-0.15	-0.30
ENTROPY (X _{ne} -X _h)/[s/V _n]	-0.40	0.56	-0.22	-0.30	0.47	0.47	-0.31	0.40	-0.17	-0.14

Table B.4.3(d) Station 145008

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	518.5	6.8	331.6	279.7	145.6	115.1	46.5	2.1	151.6	18.8
Standard Deviation (s)	247.9	3.0	157.9	133.8	69.9	53.7	22.7	1.1	334.5	9.0

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	393.3	7.7	243.9	210.0	105.3	87.3	33.3	1.6	19.7	8.7
($\bar{X}_{no}$)	475.6	7.9	308.6	253.8	131.6	112.6	42.4	2.1	25.6	16.4
	236.7	7.6	135.5	130.0	58.3	52.0	20.7	1.8	11.9	7.0
	638.3	8.0	420.3	346.7	191.3	153.0	55.3	2.2	36.7	24.2
	480.0	8.5	323.2	280.0	146.0	107.0	45.5	2.3	20.5	23.0
($\bar{X}_{no}$)	444.8	7.9	286.3	244.1	126.5	102.4	39.5	2.0	22.9	15.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/(s/Vn)	-0.67	0.85	-0.64	-0.59	-0.61	-0.53	-0.70	-0.25	-0.86	-0.72

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED	434.5	7.8	276.2	231.9	118.5	100.0	37.9	1.8	22.6	12.5
($\bar{X}_{no}$)	356.1	7.7	222.0	191.9	95.0	82.3	31.6	1.9	18.8	11.7
	437.5	7.8	277.9	238.3	124.8	102.5	38.0	2.0	24.3	15.6
	559.2	8.3	371.8	313.3	168.7	130.0	50.4	2.2	28.6	23.6
($\bar{X}_{no}$)	446.8	7.9	287.0	243.9	126.7	103.7	39.5	2.0	23.6	15.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/(s/Vn)	-0.58	0.73	-0.57	-0.54	-0.54	-0.42	-0.62	-0.21	-0.77	-0.64

Table B.4.3(d) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	368.5 450.2 451.7	7.7 7.8 8.0	229.3 288.1 293.0	197.9 243.5 252.2	98.4 127.1 131.9	84.0 105.9 104.0	32.1 39.5 40.5	1.8 2.0 2.1	19.1 24.7 23.0	10.7 15.8 18.0
$\bar{X}_{no}$	423.5	7.9	270.1	231.2	119.1	98.0	37.4	2.0	22.3	14.9

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-0.66	0.61	-0.67	-0.63	-0.65	-0.55	-0.70	-0.21	-0.67	-0.75

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED (X _{no})	436.0 457.7	7.8 8.0	277.1 296.9	235.1 252.6	121.7 131.8	101.2 106.2	37.9 41.0	1.9 2.1	23.5 23.7	14.1 17.6
$\bar{X}_{no}$	446.8	7.9	287.0	243.9	126.7	103.7	39.5	2.0	23.6	15.8

Number of Standard Deviations of the Distribution of Sampled Means by which the New Mean Values lies from the Historical Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
OBSERVED ($\bar{X}_{no} - \bar{X}_h$)/[s/V _n]	-0.41	0.51	-0.40	-0.38	-0.38	-0.30	-0.44	-0.15	-0.54	-0.45

Table B.5.1 Hypothesis Testing for the Water Quality Values in the Fitzroy River Basin

Table B.5.1(a) Station 130105

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	301.3	7.8	208.8	171.4	86.8	87.3	25.2	3.2	18.9	9.4
Standard Deviation (S_h)	105.7	0.3	65.7	52.0	32.1	23.7	10.0	0.7	6.9	3.6

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	266.5	7.8	182.7	150.3	70.0	77.7	22.0	3.4	15.8	7.4
	301.4	7.7	203.4	167.5	85.7	81.3	24.7	3.3	19.3	9.1
	218.8	7.7	148.6	126.1	59.7	62.5	17.5	3.1	12.9	6.5
($\bar{X}_{ne}$)	262.3	7.7	178.2	148.0	71.8	73.8	21.4	3.3	16.0	7.7
(S _{ne})	41.5	0.0	27.7	20.8	13.1	10.0	3.6	0.2	3.2	1.3

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.88	-0.88	-1.09	-1.07	-1.10	-1.33	-0.92	0.35	-0.96	-1.19
Degrees of Freedom (v)	8.76	7.86	8.52	8.70	8.63	8.52	8.93	8.81	8.10	8.94
t [v, 0.975]	2.273	2.314	2.283	2.275	2.278	2.283	2.265	2.270	2.302	2.265
t [v, 0.950]	1.839	1.865	1.846	1.841	1.843	1.846	1.835	1.838	1.857	1.835

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	287.2	7.8	194.8	159.9	79.0	80.3	23.7	3.7	17.8	8.4
	263.0	7.7	178.1	147.8	74.2	73.0	21.5	3.3	16.5	8.0
($\bar{X}_{ne}$)	275.1	7.7	186.5	153.9	76.6	76.6	22.6	3.5	17.1	8.2
(S _{ne})	17.1	0.0	11.8	8.6	3.4	5.2	1.6	0.2	0.9	0.3

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.67	-0.93	-0.91	-0.91	-0.89	-1.17	-0.68	1.03	-0.71	-0.98
Degrees of Freedom (v)	7.94	7.32	7.99	7.95	7.54	7.91	7.90	5.48	7.78	7.30
t [v, 0.975]	2.310	2.346	2.306	2.309	2.333	2.311	2.312	2.511	2.319	2.347
t [v, 0.950]	1.862	1.884	1.880	1.862	1.876	1.863	1.863	1.980	1.868	1.885

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table B.5.1 (a) continued

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	273.8	7.8	186.5	153.0	77.4	78.4	22.9	3.5	17.2	8.1
(X _{ne}) (S _{ne})	273.8 0	7.8 0	186.5 0	153.0 0	77.4 0	78.4 0	22.9 0	3.5 0	17.2 0	8.1 0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.74	-0.37	-0.96	-1.00	-0.83	-1.06	-0.63	1.42	-0.73	-1.05
Degrees of Freedom (v)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
t [v, 0.975]	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365
t [v, 0.950]	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

Table B.5.1(b) Station 130322

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	203.8	7.6	148.2	122.6	53.0	66.6	18.7	5.6	13.3	4.8
Standard Deviation (Sh)	43.7	0.3	28.3	24.8	8.6	13.2	4.3	0.5	2.2	0.8

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	202.4	7.6	147.2	121.6	53.0	66.0	18.5	5.6	13.2	4.8
	203.8	7.6	148.0	122.4	53.2	66.2	18.7	5.6	13.3	4.8
	200.6	7.6	145.8	120.4	52.8	64.9	18.4	5.6	13.2	4.7
($\bar{X}_{ne}$)	202.3	7.6	147.0	121.5	53.0	65.7	18.5	5.6	13.2	4.8
(S _{ne})	1.6	0.0	1.1	1.0	0.2	0.7	0.1	0.0	0.1	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.10	-0.18	-0.13	-0.13	0.01	-0.20	-0.10	0.07	-0.09	-0.07
Degrees of Freedom (v)	7.05	7.04	7.06	7.07	7.02	7.10	7.04	7.08	7.04	7.01
t [v, 0.975]	2.362	2.362	2.362	2.361	2.364	2.359	2.362	2.361	2.363	2.364
t [v, 0.950]	1.893	1.893	1.893	1.893	1.894	1.892	1.893	1.892	1.894	1.895

Note : reject the Null hypothesis if
or $T > t_{[]}$
 $T < -t_{[]}$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	203.2	7.6	147.6	122.1	53.1	66.1	18.6	5.7	13.3	4.8
	202.3	7.6	147.0	121.5	53.1	65.6	18.5	5.6	13.2	4.8
($\bar{X}_{ne}$)	202.8	7.6	147.3	121.8	53.1	65.9	18.6	5.6	13.3	4.8
(S _{ne})	0.6	0.0	0.5	0.4	0.1	0.3	0.1	0.0	0.0	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.06	-0.22	-0.09	-0.10	0.04	-0.16	-0.07	0.21	-0.06	0.01
Degrees of Freedom (v)	7.01	7.04	7.02	7.02	7.00	7.04	7.01	7.24	7.01	7.00
t [v, 0.975]	2.364	2.363	2.364	2.364	2.365	2.363	2.364	2.293	2.365	2.365
t [v, 0.950]	1.895	1.894	1.894	1.894	1.895	1.894	1.895	1.854	1.895	1.895

Note : reject the Null hypothesis if
or $T > t_{[]}$
 $T < -t_{[]}$

Table B.5.1(b) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(Xne)	202.7	7.6	147.3	121.7	52.8	66.0	18.6	5.6	13.3	4.8
$\bar{X}_{ne}$ (Sne)	202.7 0	7.6 0	147.3 0	121.7 0	52.8 0	66.0 0	18.6 0	5.6 0	13.3 0	4.8 0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.07	-0.06	-0.09	-0.11	-0.05	-0.13	-0.06	0.24	-0.05	-0.05
Degrees of Freedom (v)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
t {v, 0.975}	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365
t {v, 0.950}	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895

Note : reject the Null hypothesis if $T > t\{\}$
or $T < -t\{\}$

Table B.5.1(c) Station 130003

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}$)	368.6	7.9	248.9	209.1	104.6	90.4	33.1	3.5	21.7	12.2
Standard Deviation (Sh)	199.7	0.2	114.9	100.4	56.5	26.0	18.1	1.0	10.6	7.3

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(Xne)	288.3 370.0 176.7	7.8 7.6 7.4	194.5 237.9 122.8	160.0 200.0 104.0	71.0 102.5 50.3	76.0 81.5 53.0	26.0 32.0 15.8	4.4 4.0 3.3	16.3 22.3 11.3	7.4 11.5 5.4
($\bar{X}$ ne)	278.3	7.6	185.1	154.7	74.6	70.2	24.6	3.9	16.6	8.1
(Sne)	97.1	0.2	58.1	48.2	26.3	15.1	8.2	0.6	5.5	3.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.00	-2.47	-1.21	-1.21	-1.20	-1.60	-1.07	0.65	-1.04	-1.31
Degrees of Freedom (v)	7.78	4.84	7.54	7.86	8.04	6.57	8.17	6.98	7.34	8.52
t [v, 0.975]	2.319	2.604	2.333	2.314	2.304	2.400	2.299	2.367	2.345	2.283
t [v, 0.950]	1.868	2.034	1.876	1.865	1.859	1.916	1.856	1.896	1.883	1.846

Note : reject the Null hypothesis if
 $T > t_{\alpha}$
or
 $T < -t_{\alpha}$

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(Xne)	329.2 273.3	7.7 7.5	216.2 180.3	180.0 152.0	86.8 76.4	78.8 67.3	29.0 23.9	4.2 3.6	19.3 16.8	9.4 8.4
($\bar{X}$ ne)	301.3	7.6	198.3	166.0	81.6	73.0	26.4	3.9	18.0	8.9
(Sne)	39.5	0.1	25.3	19.8	7.3	8.1	3.6	0.4	1.8	0.7

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.89	-2.75	-1.14	-1.13	-1.11	-1.61	-0.96	0.76	-0.93	-1.24
Degrees of Freedom (v)	7.99	3.17	7.90	7.99	7.73	6.53	7.99	5.12	7.97	7.46
t [v, 0.975]	2.306	3.112	2.312	2.306	2.322	2.404	2.307	2.557	2.308	2.338
t [v, 0.950]	1.860	2.315	1.864	1.860	1.870	1.918	1.860	2.007	1.861	1.879

Note : reject the Null hypothesis if
 $T > t_{\alpha}$
or
 $T < -t_{\alpha}$

Table B.5.1(c) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(Xne)	278.3	7.6	185.1	154.7	74.6	70.2	24.6	3.9	16.6	8.1
(Xne) (Sne)	278.3 0.0	7.6 0.0	185.1 0.0	154.7 0.0	74.6 0.0	70.2 0.0	24.6 0.0	3.9 0.0	16.6 0.0	8.1 0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO3	Alkalinity (mg/l)as CaCO3	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.28	-3.95	-1.57	-1.53	-1.50	-2.21	-1.33	0.91	-1.36	-1.59
Degrees of Freedom (V)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
t [v, 0.975]	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365
t [v, 0.950]	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.895

Note : reject the Null hypothesis if $T > t\{\}$
or $T < -t\{\}$

**Table B.5.2 Hypothesis Testing for the Water Quality Values in the
Nogoa River Basin**

Table B.5.2(a) Station 130202

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	245.7	7.6	177.4	137.2	76.2	79.2	18.9	4.3	20.0	6.4
Standard Deviation (S_h)	64.2	0.3	41.3	37.6	15.8	13.1	6.4	2.0	3.9	1.7

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	215.2	7.5	159.3	120.5	70.7	75.6	16.2	5.5	18.9	5.6
	263.5	7.6	169.7	131.0	73.0	77.4	17.9	5.5	19.8	5.9
	235.7	7.5	161.4	122.1	71.0	75.5	16.5	5.4	19.1	5.6
	218.4	7.6	159.8	118.7	71.1	75.7	15.8	5.3	18.9	5.6
	217.6	7.5	159.0	118.5	70.7	75.9	15.9	5.6	19.2	5.6
($\bar{X}_{ne}$)	230.1	7.5	161.8	122.2	71.3	76.0	16.4	5.5	19.2	5.7
(S_{ne})	20.4	0.0	4.5	5.1	1.0	0.8	0.8	0.1	0.4	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.64	-0.82	-1.06	-1.11	-0.87	-0.69	-1.05	1.56	-0.58	-1.24
Degrees of Freedom (v)	9.03	7.05	7.26	7.41	7.09	7.08	7.39	6.06	7.20	7.10
t [v, 0.975]	2.261	2.362	2.349	2.341	2.360	2.360	2.342	2.442	2.353	2.359
t [v, 0.950]	1.832	1.893	1.886	1.881	1.892	1.892	1.881	1.940	1.888	1.892

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	237.1	7.5	164.0	125.6	71.0	76.2	17.1	5.4	19.0	5.7
	247.9	7.5	165.0	126.5	71.2	76.2	17.3	5.4	19.1	5.7
	224.3	7.5	159.9	120.0	70.1	75.3	16.2	5.3	18.6	5.6
	214.8	7.5	158.7	118.2	69.9	75.5	15.9	5.4	18.6	5.6
($\bar{X}_{ne}$)	231.0	7.5	161.9	122.6	70.6	75.8	16.6	5.4	18.8	5.6
(S_{ne})	14.5	0.0	3.1	4.1	0.6	0.5	0.7	0.0	0.3	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.62	-1.40	-1.06	-1.09	-1.00	-0.74	-0.98	1.43	-0.81	-1.27
Degrees of Freedom (v)	8.29	7.01	7.16	7.33	7.04	7.04	7.31	6.00	7.14	7.04
t [v, 0.975]	2.293	2.364	2.356	2.346	2.362	2.363	2.346	2.447	2.356	2.362
t [v, 0.950]	1.852	1.895	1.890	1.884	1.893	1.894	1.884	1.943	1.890	1.893

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

Table B.5.2(a) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	230.0	7.6	145.3	122.8	70.0	75.5	16.7	5.5	18.6	5.7
	231.2	7.6	145.8	122.2	70.2	75.5	16.6	5.5	18.6	5.7
	214.3	7.6	134.9	117.5	69.3	75.0	15.9	5.5	18.3	5.6
(X _{ne})	225.2	7.6	142.0	120.8	69.8	75.3	16.4	5.5	18.5	5.7
(S _{ne})	9.4	0.0	6.2	2.9	0.5	0.3	0.5	0.0	0.2	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.88	-0.59	-2.35	-1.22	-1.13	-0.84	-1.08	1.57	-1.05	-1.18
Degrees of Freedom (v)	7.74	7.00	7.76	7.21	7.04	7.02	7.20	6.00	7.08	7.02
t [v, 0.975]	2.321	2.365	2.320	2.352	2.363	2.364	2.353	2.447	2.360	2.364
t [v, 0.950]	1.869	1.895	1.868	1.887	1.894	1.894	1.888	1.943	1.892	1.894

Note : reject the Null hypothesis if
or $T > t []$
 $T < -t []$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	228.9	7.6	145.8	122.1	71.6	76.2	16.2	5.8	18.9	5.9
	229.6	7.6	145.6	121.5	71.6	76.2	16.1	5.8	19.0	5.9
(X _{ne})	229.2	7.6	145.7	121.8	71.6	76.2	16.2	5.8	18.9	5.9
(S _{ne})	0.5	0.0	0.2	0.4	0.0	0.0	0.1	0.0	0.1	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.70	-0.59	-2.08	-1.14	-0.83	-0.65	-1.19	2.01	-0.74	-0.91
Degrees of Freedom (v)	7.00	7.00	7.00	7.01	7.00	7.00	7.00	6.00	7.02	7.00
t [v, 0.975]	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.447	2.364	2.365
t [v, 0.950]	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.943	1.894	1.895

Note : reject the Null hypothesis if
or $T > t []$
 $T < -t []$

Table B.5.2(b) Station 130212

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	271.4	7.5	209.1	155.6	86.5	101.9	23.2	3.7	24.6	6.1
Standard Deviation (Sh)	152.9	0.2	107.5	79.1	44.8	48.6	16.4	1.6	13.8	2.9

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	170.2	7.5	139.4	113.6	61.2	73.8	13.1	4.4	16.8	4.7
	181.6	7.5	179.4	140.0	72.2	87.9	19.6	4.4	23.2	5.2
	175.0	7.5	147.3	117.7	62.8	73.0	14.3	4.3	18.1	4.8
	171.0	7.5	141.2	109.0	63.2	74.3	11.8	4.3	16.5	4.8
	170.8	7.5	138.1	108.5	61.2	76.1	12.1	4.4	18.9	4.7
($\bar{X}_{ne}$)	173.7	7.5	149.1	117.7	64.1	77.0	14.2	4.4	18.7	4.8
(S _{ne})	4.8	0.0	17.3	13.0	4.6	6.2	3.2	0.0	2.7	0.2

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.81	-0.38	-1.55	-1.32	-1.40	-1.43	-1.52	1.03	-1.16	-1.22
Degrees of Freedom (v)	7.02	7.01	7.57	7.59	7.24	7.36	7.82	6.00	7.84	7.10
t [v, 0.975]	2.364	2.365	2.331	2.330	2.351	2.344	2.316	2.447	2.315	2.359
t [v, 0.950]	1.894	1.895	1.875	1.874	1.887	1.882	1.866	1.943	1.866	1.892

Note : reject the Null hypothesis if
 $T > t_{\{ \}$
or
 $T < -t_{\{ \}$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	175.4	7.9	157.3	126.4	62.8	78.5	16.7	4.3	17.8	4.9
	177.9	7.9	161.4	128.6	63.7	78.1	17.3	4.3	18.6	4.9
	172.4	7.9	141.6	112.4	58.7	71.0	13.2	4.3	14.5	4.7
	170.1	7.9	136.8	107.6	57.9	72.6	12.1	4.3	15.0	4.7
($\bar{X}_{ne}$)	173.9	7.9	149.3	118.7	60.8	75.0	14.8	4.3	16.5	4.8
(S _{ne})	3.4	0.0	11.9	10.3	2.9	3.8	2.6	0.0	2.0	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.80	4.71	-1.55	-1.29	-1.62	-1.55	-1.42	1.00	-1.61	-1.27
Degrees of Freedom (v)	7.01	7.01	7.34	7.47	7.12	7.17	7.66	6.00	7.59	7.05
t [v, 0.975]	2.364	2.364	2.345	2.338	2.358	2.355	2.326	2.447	2.330	2.362
t [v, 0.950]	1.895	1.895	1.883	1.879	1.891	1.889	1.872	1.943	1.874	1.893

Note : reject the Null hypothesis if
 $T > t_{\{ \}$
or
 $T < -t_{\{ \}$

Table B.5.2(b) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	173.7	7.5	173.5	119.4	58.4	72.9	15.3	4.4	14.9	4.9
	174.0	7.5	173.7	117.7	59.1	73.1	14.8	4.4	14.8	4.9
	170.0	7.5	170.6	106.1	54.8	68.7	12.0	4.4	12.6	4.8
($\bar{X}_{ne}$)	172.5	7.5	172.6	114.4	57.4	71.6	14.0	4.4	14.1	4.9
(S _{ne})	2.2	0.0	1.8	7.3	2.3	2.5	1.8	0.0	1.3	0.1

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.83	-0.28	-0.96	-1.46	-1.83	-1.76	-1.56	1.03	-2.11	-1.17
Degrees of Freedom (v)	7.01	7.00	7.01	7.30	7.10	7.10	7.41	6.00	7.31	7.03
t [v, 0.975]	2.365	2.365	2.364	2.347	2.359	2.359	2.341	2.447	2.347	2.363
t [v, 0.950]	1.895	1.895	1.895	1.884	1.892	1.892	1.881	1.943	1.884	1.894

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	173.4	7.5	173.7	117.5	65.3	78.1	13.2	4.4	16.8	5.2
	173.6	7.5	173.6	116.1	65.3	78.6	13.0	4.4	17.5	5.2
($\bar{X}_{ne}$)	173.5	7.5	173.6	116.8	65.3	78.4	13.1	4.4	17.1	5.2
(S _{ne})	0.1	0.0	0.0	1.0	0.0	0.4	0.2	0.0	0.5	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.81	-0.30	-0.93	-1.39	-1.34	-1.37	-1.75	1.13	-1.52	-0.91
Degrees of Freedom (v)	7.00	7.00	7.00	7.01	7.00	7.00	7.01	6.00	7.06	7.00
t [v, 0.975]	2.365	2.365	2.365	2.365	2.365	2.365	2.364	2.447	2.361	2.365
t [v, 0.950]	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.943	1.893	1.895

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table B.5.2(c) Station 130209

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	325.9	7.7	253.5	182.3	109.2	132.9	26.0	3.6	19.5	14.7
Standard Deviation (S_h)	222.2	0.4	162.0	112.1	71.8	90.0	19.0	1.6	5.5	14.4

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	165.0	7.4	134.3	113.3	54.0	67.3	13.0	5.2	14.7	4.3
	265.0	7.5	202.8	156.7	78.0	100.3	21.3	5.2	18.7	7.7
	207.5	7.5	147.8	120.0	57.5	65.5	14.5	5.0	15.5	4.7
	171.7	7.5	137.4	105.7	58.3	68.5	11.3	4.9	14.5	4.6
($\bar{X}_{ne}$)	195.8	7.5	150.9	120.1	60.4	74.9	14.4	5.1	15.9	5.1
(S _{ne})	42.2	0.1	29.7	21.3	10.1	14.5	4.1	0.2	1.7	1.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.61	-2.13	-1.75	-1.52	-1.90	-1.79	-1.67	2.46	-1.75	-1.86
Degrees of Freedom (v)	7.79	7.45	7.73	7.79	7.43	7.57	8.00	6.24	8.92	7.22
t [v, 0.975]	2.319	2.338	2.322	2.318	2.339	2.331	2.306	2.427	2.265	2.352
t [v, 0.950]	1.868	1.879	1.869	1.867	1.880	1.875	1.860	1.931	1.835	1.887

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	215.0	7.4	168.6	135.0	66.0	83.8	17.2	5.2	16.7	6.0
	236.3	7.5	175.3	138.3	67.8	82.9	17.9	5.1	17.1	6.2
	189.6	7.5	142.6	112.8	57.9	67.0	12.9	4.9	15.0	4.6
	170.8	7.5	134.7	105.3	56.2	70.6	11.5	5.1	15.3	4.5
($\bar{X}_{ne}$)	202.9	7.5	155.3	122.9	62.0	76.1	14.9	5.1	16.0	5.3
(S _{ne})	28.7	0.0	19.7	16.3	5.8	8.6	3.2	0.1	1.0	0.9

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.54	-2.06	-1.69	-1.47	-1.85	-1.77	-1.61	2.42	-1.74	-1.84
Degrees of Freedom (v)	7.45	7.11	7.40	7.57	7.18	7.25	7.74	6.11	7.94	7.11
t [v, 0.975]	2.338	2.359	2.341	2.331	2.354	2.350	2.321	2.438	2.310	2.359
t [v, 0.950]	1.879	1.891	1.881	1.875	1.889	1.886	1.869	1.938	1.862	1.891

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

Table B.5.2(c) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	212.5	7.4	161.6	130.0	63.2	77.7	16.3	5.1	16.3	5.6
	214.7	7.5	162.7	127.4	64.6	78.1	15.7	5.0	16.2	5.6
	183.1	7.5	139.1	110.2	56.6	68.9	12.5	5.1	15.3	4.5
($\bar{X}_{ne}$)	203.4	7.5	154.5	122.6	61.5	74.9	14.8	5.1	15.9	5.2
(S _{ne})	17.7	0.0	13.3	10.8	4.3	5.2	2.0	0.0	0.5	0.6

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.55	-2.07	-1.71	-1.49	-1.87	-1.82	-1.64	2.40	-1.81	-1.85
Degrees of Freedom (v)	7.23	7.12	7.25	7.33	7.13	7.12	7.41	6.02	7.34	7.07
t [v, 0.975]	2.351	2.358	2.350	2.345	2.357	2.358	2.341	2.445	2.345	2.361
t [v, 0.950]	1.887	1.891	1.886	1.883	1.890	1.891	1.880	1.942	1.883	1.893

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	202.3	7.5	155.6	123.9	62.0	75.4	15.0	5.1	15.8	5.3
	203.5	7.5	155.0	121.8	62.0	76.8	14.7	5.1	16.2	5.3
($\bar{X}_{ne}$)	202.9	7.5	155.3	122.9	62.0	76.1	14.9	5.1	16.0	5.3
(S _{ne})	0.9	0.0	0.4	1.5	0.0	0.9	0.2	0.0	0.2	0.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.57	-2.07	-1.72	-1.50	-1.86	-1.79	-1.66	2.43	-1.80	-1.84
Degrees of Freedom (v)	7.00	7.00	7.00	7.01	7.00	7.01	7.01	6.02	7.10	7.00
t [v, 0.975]	2.365	2.365	2.365	2.364	2.365	2.365	2.364	2.445	2.359	2.365
t [v, 0.950]	1.895	1.895	1.895	1.895	1.895	1.895	1.895	1.942	1.891	1.895

Note : reject the Null hypothesis if $T > t_{[]}$
or $T < -t_{[]}$

Table B.5.3 Hypothesis Testing for the Water Quality Values in the Logan River Basin

Table B.5.3(a) Station 145010

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	355.6	7.8	232.9	201.9	114.3	89.1	25.5	1.5	20.2	15.5
Standard Deviation (Sh)	98.0	0.5	65.9	50.9	35.4	30.1	6.2	0.2	6.1	4.9

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	354.9	8.2	231.6	199.5	110.8	84.6	25.6	1.5	35.0	14.8
	355.9	7.9	232.8	200.8	112.8	88.1	25.5	1.5	35.0	15.3
	352.9	8.3	229.5	197.3	107.3	71.7	25.6	1.5	18.6	14.6
	351.7	7.7	235.6	203.3	117.1	93.7	25.5	1.5	20.9	15.9
	355.9	6.9	233.1	201.4	113.8	87.3	25.5	1.5	35.0	15.6
($\bar{X}_{ne}$)	354.3	7.8	232.5	200.5	112.4	85.1	25.5	1.5	28.9	15.3
(S _{ne})	1.9	0.6	2.2	2.2	3.6	8.2	0.1	0.0	8.4	0.6

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.04	0.04	-0.02	-0.08	-0.14	-0.33	0.04	0.40	1.97	-0.12
Degrees of Freedom (v)	6.01	7.67	6.02	6.03	6.18	7.19	6.00	6.00	6.96	6.24
t [v, 0.975]	2.446	2.325	2.445	2.444	2.433	2.354	2.447	2.447	2.368	2.427
t [v, 0.950]	1.943	1.871	1.942	1.941	1.935	1.888	1.943	1.943	1.897	1.932

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	310.4	8.4	199.2	175.9	92.9	74.4	24.0	1.5	17.2	10.8
	261.0	8.8	164.1	148.4	76.5	64.4	23.2	1.5	15.3	10.1
	311.7	8.4	199.9	178.3	96.2	75.8	24.0	1.5	17.9	12.8
	349.1	6.1	233.2	201.6	117.6	90.7	25.3	1.5	19.6	27.0
($\bar{X}_{ne}$)	308.1	7.9	199.1	176.1	95.8	76.3	24.1	1.5	17.5	15.2
(S _{ne})	36.1	1.2	28.2	21.8	16.9	10.8	0.9	0.0	1.8	8.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Natrium (mg/l)	Kalium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.15	0.19	-1.18	-1.17	-1.17	-1.01	-0.56	0.40	-1.09	-0.07
Degrees of Freedom (v)	8.26	3.51	8.68	8.68	8.90	8.19	6.41	6.00	7.57	4.32
t [v, 0.975]	2.295	2.974	2.276	2.276	2.266	2.298	2.414	2.447	2.331	2.711
t [v, 0.950]	1.853	2.240	1.842	1.842	1.836	1.855	1.923	1.943	1.875	2.095

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table B.5.3(a) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	280.6 317.9 318.3	8.9 8.3 7.4	193.8 211.5 212.9	167.8 183.7 186.1	92.9 103.0 104.6	79.2 84.3 83.8	22.9 24.1 24.2	1.5 1.5 1.5	16.5 18.2 17.7	11.8 13.8 14.5
($\bar{X}_{ne}$)	305.6	8.2	206.1	179.2	100.2	82.4	23.7	1.5	17.5	13.4
(S _{ne})	21.7	0.7	10.6	9.9	6.3	2.8	0.7	0.0	0.9	1.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.28	0.97	-1.05	-1.13	-1.02	-0.58	-0.73	0.40	-1.16	-1.06
Degrees of Freedom (v)	7.17	2.73	6.68	6.95	6.82	6.24	6.37	6.00	6.54	7.68
t [v, 0.975]	2.355	3.487	2.391	2.369	2.380	2.427	2.417	2.447	2.403	2.325
t [v, 0.950]	1.889	2.507	1.910	1.897	1.904	1.932	1.925	1.943	1.917	1.871

Note : reject the Null hypothesis if
or $T > t_{\alpha}$
 $T < -t_{\alpha}$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	334.2 337.2	8.4 7.4	218.8 221.6	190.6 193.0	105.4 107.5	89.1 88.9	24.7 24.8	1.5 1.5	19.0 19.0	14.0 14.7
($\bar{X}_{ne}$)	335.7	7.9	220.2	191.8	106.5	89.0	24.8	1.5	19.0	14.4
(S _{ne})	2.1	0.7	2.0	1.7	1.5	0.1	0.1	0.0	0.0	0.5

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.50	0.23	-0.49	-0.49	-0.55	-0.01	-0.29	0.40	-0.51	-0.55
Degrees of Freedom (v)	6.02	1.26	6.04	6.05	6.07	6.00	6.01	6.00	6.00	6.39
t [v, 0.975]	2.445	10.562	2.444	2.443	2.441	2.447	2.447	2.447	2.447	2.415
t [v, 0.950]	1.942	5.448	1.941	1.941	1.940	1.943	1.943	1.943	1.943	1.924

Note : reject the Null hypothesis if
or $T > t_{\alpha}$
 $T < -t_{\alpha}$

Table B.5.3(b) Station 145013

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	495.7	7.9	321.9	273.9	159.9	127.4	35.8	1.8	29.3	21.1
Standard Deviation (S_h)	63.2	0.2	57.2	38.9	27.8	27.9	5.4	0.2	5.1	3.7

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	495.4	8.0	320.8	272.4	157.5	123.0	35.9	1.8	36.4	20.6
	495.9	7.9	321.9	273.2	158.9	126.4	35.9	1.8	36.4	20.9
	494.5	8.0	319.0	270.9	155.1	118.4	35.9	1.8	28.0	20.5
	496.7	7.9	323.7	274.8	161.8	131.8	35.9	1.8	29.8	21.3
	495.9	7.7	322.1	273.6	159.5	125.7	35.9	1.8	36.4	21.2
$\bar{X}_{ne}$	495.7	7.9	321.5	273.0	158.6	125.1	35.9	1.8	33.4	20.9
(S _{ne})	0.8	0.1	1.7	1.4	2.5	4.9	0.0	0.0	4.2	0.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.00	0.15	-0.02	-0.06	-0.12	-0.21	0.04	0.55	1.54	-0.12
Degrees of Freedom (v)	6.00	9.89	6.02	6.02	6.13	6.51	6.00	6.00	9.72	6.15
t [v, 0.975]	2.447	2.232	2.446	2.445	2.436	2.405	2.447	2.447	2.237	2.434
t [v, 0.950]	1.943	1.814	1.942	1.942	1.937	1.918	1.943	1.943	1.818	1.936

Note : reject the Null hypothesis if $T > t_{\alpha/2}$
or $T < -t_{\alpha/2}$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	474.8	8.0	293.7	257.0	145.3	113.3	34.6	1.8	27.0	18.1
	451.7	8.1	264.2	239.2	134.1	103.8	33.9	1.8	25.5	17.6
	475.3	8.0	294.3	258.6	147.5	114.6	34.6	1.8	27.5	19.3
	492.7	7.2	322.1	273.7	162.1	128.9	35.7	1.8	28.8	29.7
$\bar{X}_{ne}$	473.6	7.8	293.6	257.1	147.3	115.2	34.7	1.8	27.2	21.2
(S _{ne})	16.8	0.4	23.6	14.1	11.5	10.4	0.7	0.0	1.4	5.7

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.87	-0.28	-1.15	-1.03	-1.05	-1.04	-0.54	0.55	-1.02	0.03
Degrees of Freedom (v)	7.35	3.61	8.59	8.21	8.60	8.28	6.39	6.00	7.37	4.46
t [v, 0.975]	2.344	2.935	2.280	2.297	2.280	2.294	2.415	2.447	2.343	2.681
t [v, 0.950]	1.883	2.218	1.844	1.854	1.844	1.853	1.924	1.943	1.882	2.078

Note : reject the Null hypothesis if $T > t_{\alpha/2}$
or $T < -t_{\alpha/2}$

Table B.5.3(b) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	460.7	8.1	289.1	251.7	145.4	118.0	33.6	1.8	26.4	18.7
	478.3	8.0	304.0	262.1	152.2	122.8	34.6	1.8	27.7	20.0
	478.6	7.8	305.1	263.6	153.3	122.4	34.7	1.8	27.4	20.4
($\bar{X}_{ne}$)	472.5	8.0	299.4	259.1	150.3	121.1	34.3	1.8	27.2	19.7
(S _{ne})	10.2	0.1	8.9	6.5	4.3	2.7	0.6	0.0	0.7	0.9

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.94	0.95	-1.01	-0.98	-0.89	-0.59	-0.73	0.55	-1.07	-0.92
Degrees of Freedom (v)	6.68	4.53	6.64	6.72	6.62	6.25	6.34	6.00	6.48	7.33
t [v, 0.975]	2.391	2.666	2.395	2.388	2.396	2.427	2.419	2.447	2.408	2.345
t [v, 0.950]	1.910	2.069	1.912	1.909	1.913	1.931	1.927	1.943	1.920	1.863

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	485.9	8.0	310.1	266.6	153.8	127.4	35.2	1.8	28.3	20.6
	487.2	7.8	312.4	268.1	155.2	127.2	35.3	1.8	28.4	20.1
	486.6	7.9	311.3	267.4	154.5	127.3	35.3	1.8	28.4	20.4
($\bar{X}_{ne}$)	486.6	7.9	311.3	267.4	154.5	127.3	35.3	1.8	28.4	20.4
(S _{ne})	0.9	0.1	1.6	1.1	1.0	0.1	0.1	0.0	0.1	0.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.38	0.30	-0.49	-0.45	-0.51	-0.01	-0.28	0.55	-0.48	-0.50
Degrees of Freedom (v)	6.01	2.11	6.03	6.03	6.05	6.00	6.01	6.00	6.01	6.35
t [v, 0.975]	2.446	4.185	2.444	2.444	2.443	2.447	2.446	2.447	2.446	2.418
t [v, 0.950]	1.943	2.860	1.941	1.942	1.940	1.943	1.943	1.943	1.943	1.926

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table B.5.3(c) Station 145020

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}$)	523.5	6.7	314.7	274.6	96.7	86.2	54.0	2.0	23.2	15.3
Standard Deviation (Sh)	273.0	3.0	162.5	141.0	49.5	43.3	28.0	1.0	12.2	8.0

[1 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	601.6	8.1	358.9	302.1	128.6	92.9	65.2	2.3	15.9	15.6
	609.8	7.9	366.7	310.9	135.3	98.9	64.7	2.3	18.6	17.2
	586.3	8.2	346.0	285.8	116.3	84.6	66.0	2.3	19.8	15.2
	625.8	7.8	380.0	330.0	116.3	108.4	63.9	2.3	29.9	18.9
	610.2	7.3	368.4	316.4	139.2	97.6	64.5	2.3	16.3	18.7
($\bar{X}_{ne}$)	606.7	7.9	364.0	309.0	127.1	96.5	64.9	2.3	20.1	17.1
(S _{ne})	14.4	0.4	12.6	16.5	10.6	8.7	0.8	0.0	5.7	1.7

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	0.75	0.91	0.74	0.59	1.47	0.57	0.95	0.70	-0.55	0.55
Degrees of Freedom (v)	5.03	5.17	5.07	5.16	5.54	5.48	5.01	5.00	7.34	5.54
t [v, 0.975]	2.567	2.550	2.562	2.551	2.503	2.511	2.570	2.571	2.345	2.504
t [v, 0.950]	2.013	2.003	2.010	2.003	1.976	1.980	2.014	2.015	1.883	1.976

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[2 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	258.3	8.3	170.5	137.9	67.2	75.7	32.6	2.5	14.2	5.1
	84.1	8.5	66.8	56.9	29.6	59.6	19.7	2.5	7.7	4.0
	265.3	8.3	173.8	152.0	77.9	70.0	33.1	2.5	17.0	9.7
	554.0	7.1	368.8	318.1	152.6	103.4	59.1	2.5	24.4	16.7
($\bar{X}_{ne}$)	290.4	8.0	196.0	168.2	81.8	77.2	36.2	2.5	15.8	8.9
(S _{ne})	194.7	0.6	126.1	109.6	51.5	18.7	16.5	0.0	6.9	5.8

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-1.68	1.01	-1.31	-1.36	-0.46	-0.46	-1.26	1.19	-1.21	-1.46
Degrees of Freedom (v)	7.89	5.01	7.67	7.67	6.38	7.25	7.96	5.00	7.92	7.67
t [v, 0.975]	2.313	2.495	2.326	2.326	2.416	2.360	2.308	2.571	2.311	2.314
t [v, 0.950]	1.864	1.971	1.871	1.872	1.925	1.866	1.861	2.015	1.863	1.864

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Table B.5.3(c) (continued)

[3 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	122.1 306.7 310.2	8.5 8.3 7.6	144.9 237.4 245.2	99.9 186.9 203.8	67.5 100.9 106.5	83.9 92.4 91.7	16.4 33.8 36.1	3.0 2.8 2.7	11.3 18.3 16.1	7.2 12.6 14.9
(X̄ _{ne})	246.3	8.1	209.2	163.5	91.6	89.3	28.8	2.8	15.2	11.6
(S _{ne})	107.6	0.4	55.8	55.8	21.1	4.7	10.8	0.2	3.6	4.0

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-2.17	1.10	-1.43	-1.68	-0.21	0.17	-1.94	1.97	-1.47	-0.93
Degrees of Freedom (v)	6.92	5.42	6.70	6.92	6.99	5.23	6.89	5.46	6.40	6.04
t [v, 0.975]	2.372	2.520	2.389	2.371	2.366	2.542	2.374	2.514	2.414	2.370
t [v, 0.950]	1.899	1.985	1.909	1.899	1.896	1.998	1.900	1.982	1.924	1.898

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

[4 Yearly Averaging]

New Mean Values Predicted by the Entropy Method

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	434.8 459.0	8.3 7.6	281.2 297.8	236.5 253.7	109.6 116.8	100.6 100.4	46.3 49.6	2.3 2.3	21.7 21.8	13.4 15.5
(X̄ _{ne})	446.9	8.0	289.5	245.1	113.2	100.5	48.0	2.3	21.8	14.5
(S _{ne})	17.1	0.5	11.7	12.2	5.1	0.1	2.3	0.0	0.1	1.5

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l) as CaCO ₃	Alkalinity (mg/l) as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.68	0.94	-0.38	-0.51	0.80	0.81	-0.52	0.70	-0.29	-0.24
Degrees of Freedom (v)	5.12	5.62	5.15	5.21	5.30	5.00	5.20	5.00	5.00	5.78
t [v, 0.975]	2.557	2.494	2.552	2.545	2.534	2.571	2.546	2.571	2.571	2.475
t [v, 0.950]	2.007	1.970	2.004	2.000	1.994	2.015	2.001	2.015	2.015	1.959

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

Table B.5.3(d) Station 145008

Historical (prior) Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Mean ($\bar{X}_h$)	518.5	6.8	331.6	279.7	145.6	115.1	46.5	2.1	151.6	18.8
Standard Deviation (S_h)	247.9	3.0	157.9	133.8	69.9	53.7	22.7	1.1	334.5	9.0

[1 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	393.3	7.7	243.9	210.0	105.3	87.3	33.3	1.6	19.7	8.7
	475.6	7.9	308.6	253.8	131.6	112.6	42.4	2.1	25.6	16.4
	236.7	7.6	135.5	130.0	58.3	52.0	20.7	1.8	11.9	7.0
	638.3	8.0	420.3	346.7	191.3	153.0	55.3	2.2	36.7	24.2
	480.0	8.5	323.2	280.0	146.0	107.0	45.5	2.3	20.5	23.0
($\bar{X}_{ne}$)	444.8	7.9	286.3	244.1	126.5	102.4	39.5	2.0	22.9	15.8
(S_{ne})	146.3	0.3	105.3	80.8	49.3	36.9	13.1	0.3	9.1	7.9

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.61	0.92	-0.57	-0.54	-0.53	-0.46	-0.64	-0.26	-0.94	-0.57
Degrees of Freedom (v)	8.25	5.16	8.67	8.33	8.82	8.76	8.16	5.68	5.01	8.96
t [v, 0.975]	2.295	2.552	2.276	2.291	2.270	2.273	2.299	2.486	2.570	2.250
t [v, 0.950]	1.853	2.004	1.842	1.851	1.838	1.840	1.856	1.966	2.014	1.827

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

[2 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	434.5	7.8	276.2	231.9	118.5	100.0	37.9	1.8	22.6	12.5
	356.1	7.7	222.0	191.9	95.0	82.3	31.6	1.9	18.8	11.7
	437.5	7.8	277.9	238.3	124.8	102.5	38.0	2.0	24.3	15.6
	559.2	8.3	371.8	313.3	168.7	130.0	50.4	2.2	28.6	23.6
($\bar{X}_{ne}$)	446.8	7.9	287.0	243.9	126.7	103.7	39.5	2.0	23.6	15.8
(S_{ne})	83.8	0.2	62.2	50.7	30.8	19.7	7.9	0.2	4.1	5.4

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.65	0.89	-0.62	-0.59	-0.58	-0.47	-0.70	-0.25	-0.94	-0.64
Degrees of Freedom (v)	6.54	5.09	6.97	6.85	7.30	6.76	6.61	5.34	5.00	7.98
t [v, 0.975]	2.403	2.560	2.368	2.377	2.347	2.385	2.397	2.529	2.571	2.307
t [v, 0.950]	1.917	2.008	1.896	1.902	1.885	1.906	1.914	1.991	2.015	1.881

Note : reject the Null hypothesis if $T > t []$
or $T < -t []$

Table B.5.3(d) (continued)

[3 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	368.5	7.7	229.3	197.9	98.4	84.0	32.1	1.8	19.1	10.7
	450.2	7.8	286.1	243.5	127.1	105.9	39.5	2.0	24.7	15.8
	451.7	8.0	293.0	252.2	131.9	104.0	40.5	2.1	23.0	16.0
(X _{ne})	423.5	7.9	270.1	231.2	119.1	96.0	37.4	2.0	22.3	14.9
(S _{ne})	47.6	0.2	35.4	29.2	18.1	12.1	4.6	0.1	2.9	3.8

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.91	0.86	-0.91	-0.85	-0.87	-0.74	-0.95	-0.29	-0.95	-0.91
Degrees of Freedom (v)	5.69	5.05	5.91	5.86	6.15	5.92	5.74	5.28	5.00	6.98
t [v, 0.975]	2.486	2.565	2.458	2.464	2.434	2.457	2.479	2.536	2.571	2.387
t [v, 0.950]	1.966	2.011	1.950	1.953	1.936	1.949	1.962	1.995	2.015	1.896

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

[4 Yearly Averaging]

New Mean Values

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
(X _{ne})	436.0	7.8	277.1	235.1	121.7	101.2	37.9	1.9	23.5	14.1
	457.7	8.0	296.9	252.6	131.8	106.2	41.0	2.1	23.7	17.6
	446.8	7.9	267.0	243.9	126.7	103.7	39.5	2.0	23.6	15.8
(S _{ne})	15.3	0.1	14.0	12.4	7.2	3.5	2.2	0.1	0.1	2.5

Statistic Test (T), Calculated by Equation 5.6

	Conductivity @ 25 C (mS/m)	PH	Dissolved Ions (mg/l)	Dissolved Solids (mg/l)	Hardness (mg/l)as CaCO ₃	Alkalinity (mg/l)as CaCO ₃	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
T	-0.70	0.89	-0.68	-0.65	-0.65	-0.52	-0.75	-0.25	-0.94	-0.71
Degrees of Freedom (v)	5.11	5.06	5.22	5.24	5.30	5.12	5.25	5.32	5.00	5.98
t [v, 0.975]	2.557	2.564	2.543	2.541	2.534	2.556	2.540	2.532	2.571	2.450
t [v, 0.950]	2.007	2.011	1.999	1.998	1.994	2.006	1.997	1.992	2.015	1.945

Note : reject the Null hypothesis if $T > t[]$
or $T < -t[]$

Figure B.1(a) Assigned Probabilities at Station 130401 (Conductivity)

Figure B.1(b) Assigned Probabilities at Station 130401 (Dissolved Ions)

Figure B.1(c) Assigned Probabilities at Station 130401 (Dissolved Solids)

Figure B.1(d) Assigned Probabilities at Station 130401 (Hardness)

Figure B.2(a) Plot of Regression Lines for Different Periods of Time over which the Conductivity is Averaged

Figure B.2(b) Plot of Regression Lines for Different Periods of Time over which the Dissolved Ions Concentration is Averaged

Figure B.2(c) Plot of Regression Lines for Different Periods of Time over which the Dissolved Solids Concentration is Averaged

Figure B.2(d) Plot of Regression Lines for Different Periods of Time over which the Hardness is Averaged

Figure B.3(a) Plot of Water Quality Values in the MacKenzie River (1 Yearly Averaging)

Figure B.3(a) Plot of Water Quality Values in the MacKenzie River (1 Yearly Averaging)
(continued)

Figure B.3(a) Plot of Water Quality Values in the MacKenzie River (1 Yearly Averaging)
(continued)

Figure B.3(a) Plot of Water Quality Values in the MacKenzie River (1 Yearly Averaging)
(continued)

Figure B.3(b) Plot of Water Quality Values in the MacKenzie River (2 Yearly Averaging)

Figure B.3(b) Plot of Water Quality Values in the MacKenzie River (2 Yearly Averaging)
(continued)

Figure B.3(b) Plot of Water Quality Values in the MacKenzie River (2 Yearly Averaging)
(continued)

Figure B.3(b) Plot of Water Quality Values in the MacKenzie River (2 Yearly Averaging)
(continued)

Figure B.3(c) Plot of Water Quality Values in the MacKenzie River (3 Yearly Averaging)

Figure B.3(c) Plot of Water Quality Values in the MacKenzie River (3 Yearly Averaging)
(continued)

Figure B.3(c) Plot of Water Quality Values in the MacKenzie River (3 Yearly Averaging)
(continued)

Figure B.3(c) Plot of Water Quality Values in the MacKenzie River (3 Yearly Averaging)
(continued)

Figure B.3(d) Plot of Water Quality Values in the MacKenzie River (4 Yearly Averaging)

Figure B.3(d) Plot of Water Quality Values in the MacKenzie River (4 Yearly Averaging)
(continued)

Figure B.3(d) Plot of Water Quality Values in the MacKenzie River (4 Yearly Averaging)
(continued)

Figure B.3(d) Plot of Water Quality Values in the MacKenzie River (4 Yearly Averaging)
(continued)

Appendix C

The Saphiro-Wilk W test

This procedure was developed by Saphiro and Wilk (Gilbert, 1987) and was intended as a test of whether a data set had been drawn from a population with normal distribution and can be explained as follows:

Suppose that a set of values $x_1, x_2, \dots, x_n$ have been drawn randomly from a population. The following hypothesis will be tested :

H_0 : The population has a normal distribution.

versus

H_A : The population does not have a normal distribution.

The procedure for the test is as follows :

1. Compute the denominator d of the W test statistic, using the n data.

$$d = \sum_{i=1}^n (x_i - \bar{x})^2 \quad (C.1)$$

2. Order the n data from smallest to largest to obtain the sample order statistics $x_{[1]} \leq x_{[2]} \leq \dots \leq x_{[n]}$

3. Compute k , where

$$k = \frac{n}{2} \quad \text{if } n \text{ is even} \quad (\text{C.2})$$

$$k = \frac{n-1}{2} \quad \text{if } n \text{ is odd} \quad (\text{C.3})$$

4. Find the relevant coefficients $a_1, a_2, \dots, a_k$ in Table C.1.

5. Compute :

$$W = \frac{1}{d} \left[\sum_{i=1}^k a_i (x_{[n-i+1]} - x_i) \right]^2 \quad (\text{C.4})$$

6. Reject H_0 at the α significance level if W is less than the relevant quantile given in Table C.2.

Table C.1 Coefficients $a[i]$ for the Saphiro-Wilk W Test for Normality

n i	2	3	4	5	6	7	8	9	10
1	0.7071	0.7071	0.6872	0.6646	0.6431	0.6233	0.6052	0.5888	0.5739
2		0	0.1677	0.2413	0.2806	0.3031	0.3164	0.3244	0.3291
3				0	0.0875	0.1401	0.1743	0.1976	0.2141
4						0	0.0561	0.0947	0.1224
5								0	0.0399

n i	11	12	13	14	15	16	17	18	19	20
1	0.5601	0.5475	0.5359	0.5251	0.515	0.5056	0.4968	0.4886	0.4808	0.4734
2	0.3315	0.3325	0.3325	0.3318	0.3306	0.329	0.3273	0.3253	0.3232	0.3211
3	0.226	0.2347	0.2412	0.246	0.2495	0.2521	0.254	0.2553	0.2561	0.2565
4	0.1429	0.1586	0.1707	0.1802	0.1878	0.1939	0.1988	0.2027	0.2059	0.2085
5	0.0695	0.0922	0.1099	0.124	0.1353	0.1447	0.1524	0.1587	0.1641	0.1686
6	0	0.0303	0.0539	0.0727	0.088	0.1005	0.1109	0.1197	0.1271	0.1334
7			0	0.024	0.0433	0.0593	0.0725	0.0837	0.0932	0.1013
8					0	0.0196	0.0359	0.0496	0.0612	0.0711
9							0	0.0163	0.0303	0.0422
10									0	0.014

Source : Statistical Methods for Environmental Pollution Monitoring, by Richard O.Gilbert. 1987

Table C.2 Quantiles of the Saphiro-Wilk W Test for Normality (Values of W such that 100p% of the Distribution of W is less than Wp)

n	W[0.01]	W[0.02]	W[0.05]	W[0.10]	W[0.50]
3	0.753	0.756	0.767	0.789	0.959
4	0.687	0.707	0.748	0.792	0.935
5	0.686	0.715	0.762	0.806	0.927
6	0.713	0.743	0.788	0.826	0.927
7	0.730	0.760	0.803	0.838	0.928
8	0.749	0.778	0.818	0.851	0.932
9	0.764	0.791	0.829	0.859	0.935
10	0.781	0.806	0.842	0.869	0.938
11	0.792	0.817	0.850	0.876	0.940
12	0.805	0.828	0.859	0.883	0.943
13	0.814	0.837	0.866	0.889	0.945
14	0.825	0.846	0.874	0.895	0.947
15	0.835	0.855	0.881	0.901	0.950
16	0.844	0.863	0.887	0.906	0.952
17	0.851	0.869	0.892	0.910	0.956
18	0.858	0.874	0.897	0.914	0.957
19	0.863	0.879	0.901	0.917	0.959
20	0.868	0.884	0.905	0.920	0.960

Source : Statistical Methods for Environmental Pollution Monitoring,
by Richard O.Gilbert, 1987

Table C.3.1 Normality Test for Data from the Fitzroy River Basin (SAPHIRO-WILK W TEST)

Table C.3.1(a) Station 130105

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO3	ALKALINITY (mg/l) as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	215.00	7.48	158.40	130.00	61.50	64.00	16.26	2.30	13.13	6.40
x2	226.25	7.53	159.58	133.67	61.75	66.00	18.18	2.33	13.42	6.75
x3	235.00	7.65	160.95	135.75	63.67	68.46	19.25	2.60	14.00	6.80
x4	235.00	7.75	161.03	140.00	64.00	71.75	20.00	3.25	14.50	7.05
x5	255.00	7.98	187.93	146.67	80.67	88.67	20.00	3.40	18.00	8.67
x6	360.00	8.00	248.55	204.00	102.25	105.50	29.75	3.80	22.25	10.58
x7	367.50	8.10	258.15	207.50	110.50	106.00	32.50	3.80	23.50	12.50
x8	516.70	8.20	336.20	274.00	150.30	128.00	45.30	3.90	32.70	16.70
x	301.31	7.84	208.85	171.45	86.83	87.30	25.15	3.17	18.94	9.43

2. Computation of the Denominator [d]

$$d = \sum (x_i - \bar{x})^2$$

	$(x_i - \bar{x})^2$									
	7448.77	0.13	2544.99	1717.93	641.57	542.75	79.11	0.76	33.77	9.18
	5633.44	0.09	2427.82	1427.42	628.96	453.57	48.71	0.72	30.48	7.19
	4396.52	0.03	2294.21	1274.34	536.50	354.84	34.86	0.33	24.37	6.90
	4396.52	0.01	2287.03	988.97	521.17	241.71	26.57	0.01	19.68	5.67
	2144.27	0.02	437.42	614.11	37.98	1.88	26.57	0.05	0.88	0.58
	3444.96	0.03	1576.26	1059.64	237.80	331.35	21.12	0.40	10.98	1.31
	4381.61	0.07	2430.70	1299.75	560.31	349.80	53.96	0.40	20.83	9.42
	46394.47	0.13	16218.55	10516.93	4028.55	1656.73	405.85	0.53	189.44	52.84
d =	78240.55	0.51	30216.98	18899.10	7192.64	3932.62	696.74	3.18	330.43	93.10

3. Computation of the W values

$$w = \frac{\sum a_i \{x(n-i+1) - x(i)\}^2}{d}$$

	$a_i \{x(n-i+1) - x(i)\}^2$									
	162.59	0.44	107.60	87.15	53.74	38.73	17.58	0.97	11.85	6.23
	44.69	0.18	31.19	23.36	15.42	12.66	4.53	0.47	3.19	1.82
	21.79	0.06	15.27	11.90	6.73	6.46	1.83	0.21	1.44	0.66
	1.12	0.01	1.51	0.37	0.94	0.95	0.00	0.01	0.20	0.09
sum	250.19	0.69	155.57	122.78	76.83	58.79	23.94	1.65	16.67	8.80
sum ^ 2	62594.96	0.48	24202.62	15074.84	5902.29	3456.72	573.01	2.73	277.96	77.46

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO3	ALKALINITY (mg/l) as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W = (sum ^ 2/d)	0.800	0.934	0.801	0.798	0.821	0.879	0.822	0.859	0.841	0.832
W [0.05]	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803
W [0.02]	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
W [0.01]	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Note : reject the normality at i% significance level if $W < W [i]$

Table C.3.1(b) Station 130322

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	145.00	7.10	106.40	87.00	37.00	46.00	12.00	5.00	9.20	3.40
x2	145.00	7.40	111.60	92.00	49.00	54.00	13.40	5.05	12.00	4.20
x3	190.00	7.50	142.20	115.00	50.70	62.30	17.70	5.10	12.50	4.50
x4	190.00	7.60	146.30	122.00	51.00	63.50	18.00	5.50	12.75	4.65
x5	217.50	7.70	149.00	125.00	51.00	66.00	21.15	5.77	13.30	4.70
x6	240.00	7.75	173.30	133.50	61.00	77.00	21.25	5.80	15.00	5.30
x7	245.00	7.77	177.95	150.00	61.50	79.00	21.50	6.20	15.67	5.70
x8	257.50	7.95	179.07	156.67	62.67	85.00	24.33	6.35	16.00	5.73
x	203.75	7.60	148.23	122.65	52.98	66.60	18.67	5.60	13.30	4.77

2. Computation of the Denominator [d]

$$d = \sum (x_i - \bar{x})^2$$

	(xi-x) ^ 2									
	3451.56	0.25	1749.50	1270.63	255.47	424.36	44.44	0.36	16.83	1.88
	3451.56	0.04	1341.54	939.17	15.87	158.76	27.74	0.30	1.70	0.33
	189.06	0.01	36.33	58.46	5.21	18.49	0.93	0.25	0.64	0.07
	189.06	0.00	3.71	0.42	3.93	9.61	0.44	0.01	0.30	0.02
	189.06	0.01	0.60	5.54	3.93	0.36	6.17	0.03	0.00	0.01
	1314.06	0.02	628.65	117.81	64.27	108.16	6.67	0.04	2.88	0.28
	1701.56	0.03	883.45	748.25	72.53	153.76	8.03	0.37	5.59	0.86
	2889.06	0.13	951.08	1157.42	93.77	338.56	32.11	0.57	7.28	0.92
d =	13375.00	0.48	5594.87	4297.69	514.98	1212.06	126.54	1.91	35.22	4.37

3. Computation of the W values

$$w = \left[\frac{\sum a_i \{x(n-i+1) - x(i)\}}{\sum^2} \right]^2 / d$$

	ai {x(n-i+1)-x(i)}									
	68.09	0.51	43.98	42.16	15.53	23.60	7.46	0.82	4.12	1.41
	31.64	0.12	20.99	18.35	3.96	7.91	2.56	0.36	1.16	0.47
	8.72	0.04	5.42	3.22	1.80	2.56	0.62	0.12	0.44	0.14
	1.54	0.01	0.15	0.17	0.00	0.14	0.18	0.01	0.03	0.00
sum	109.98	0.68	70.54	63.91	21.28	34.22	10.82	1.32	5.74	2.03
sum ^ 2	12096.21	0.46	4976.34	4084.02	453.00	1170.68	117.13	1.74	32.97	4.12

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W= (sum ^ 2/d)	0.904	0.957	0.889	0.950	0.880	0.966	0.926	0.908	0.936	0.943
W [0.05]	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803
W [0.02]	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
W [0.01]	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Note : reject the normality at i% significance level if W < W [i]

Table C.3.2 Normality Test for Data from the Nogoia River Basin (SAPHIRO-WILK W TEST)

Table C.3.2(a) Station 130202

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	150.00	7.20	111.50	83.00	47.00	58.00	9.75	2.90	13.00	3.60
x2	163.50	7.35	135.05	95.75	58.50	67.00	10.00	4.13	15.78	4.65
x3	220.00	7.45	150.05	105.50	75.50	72.00	17.00	5.00	19.00	5.65
x4	263.33	7.60	187.00	148.67	80.00	79.00	20.33	5.05	21.00	6.40
x5	267.50	7.68	193.50	154.50	82.50	79.33	21.50	5.30	21.00	6.73
x6	275.00	7.80	197.95	155.00	83.00	91.40	21.80	5.65	22.50	7.66
x7	286.00	7.85	209.96	166.40	88.80	93.00	22.00	6.18	22.88	7.95
x8	340.50	8.00	234.15	188.50	94.00	94.00	28.50		24.50	8.50
x	245.73	7.62	177.40	137.16	76.16	79.22	18.86	4.89	19.96	6.39

2. Computation of the Denominator [d]

$$d = \sum (x_i - x)^2$$

	(xi-x) ^ 2									
	9164.07	0.17	4342.15	2933.80	850.45	450.15	83.00	3.95	48.40	7.80
	6761.64	0.07	1793.10	1715.17	311.96	149.25	78.51	0.58	17.49	3.04
	661.99	0.03	747.75	1002.65	0.44	52.08	3.46	0.01	0.92	0.55
	309.91	0.00	92.26	132.30	14.73	0.05	2.17	0.03	1.09	0.00
	473.97	0.00	259.37	300.52	40.16	0.01	6.97	0.17	1.09	0.12
	856.78	0.03	422.51	318.10	46.75	148.43	8.64	0.58	6.47	1.61
	1621.74	0.05	1060.48	854.71	159.71	189.08	9.86	1.67	8.54	2.42
	8981.51	0.15	3221.13	2635.33	318.18	218.55	92.92		20.64	4.44
d =	28831.61	0.51	11938.74	9892.57	1742.38	1208.50	285.52	6.99	104.63	19.98

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	ai{x(n-i+1)-x(i)}									
	115.29	0.48	74.23	63.85	28.44	21.79	11.35	2.04	6.96	2.97
	38.76	0.16	23.70	22.35	9.59	8.23	3.80	0.46	2.25	1.04
	9.59	0.06	8.35	8.63	1.31	3.38	0.84	0.04	0.61	0.35
	0.23	0.00	0.36	0.33	0.14	0.02	0.07	0.00	0.00	0.02
sum	163.87	0.71	106.64	95.16	39.48	33.41	16.05	2.55	9.82	4.38
sum ^ 2	26853.33	0.50	11372.71	9054.92	1558.58	1116.48	257.49	6.50	96.39	19.17

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W= (sum ^ 2/d)	0.931	0.979	0.953	0.915	0.895	0.924	0.902	0.929	0.921	0.960
W [0.05]	0.842	0.842	0.842	0.818	0.842	0.842	0.842	0.818	0.842	0.842
W [0.02]	0.806	0.806	0.806	0.778	0.806	0.806	0.806	0.778	0.806	0.806
W [0.01]	0.781	0.781	0.781	0.749	0.781	0.781	0.781	0.749	0.781	0.781

Note : reject the normality at i% significance level if W < W [i]

Table C.3.2(b) Station 130212

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	138.33	7.17	106.20	85.67	44.00	53.00	7.80	3.50	10.47	3.30
x2	139.00	7.27	108.17	87.00	45.00	58.67	10.67	3.60	12.00	3.47
x3	143.33	7.40	114.30	89.00	45.33	59.00	11.00	3.87	12.50	3.57
x4	144.00	7.50	127.70	91.00	51.00	64.67	14.20	4.43	14.50	4.60
x5	290.00	7.55	247.10	159.00	107.25	119.50	17.00	4.53	30.75	6.00
x6	352.50	7.60	271.38	208.75	122.00	142.00	34.25	4.73	31.75	7.35
x7	472.50	7.80	347.48	255.50	124.75	142.25	38.50	5.10	39.00	9.50
x8	491.25	7.83	350.50	268.50	153.00	176.00	52.50		45.50	11.03
x	271.36	7.51	209.10	155.55	86.54	101.89	23.24	4.25	24.56	6.10

2. Computation of the Denominator [d]

$$d = \sum (x_i - \bar{x})^2$$

	(xi-x) ^ 2									
	17697.31	0.12	10588.84	4863.97	1809.79	2389.78	238.38	0.56	198.58	7.85
	17520.38	0.06	10187.96	4699.39	1725.71	1867.86	158.08	0.42	157.71	6.94
	16392.00	0.01	8987.44	4429.18	1698.13	1839.16	149.81	0.15	145.40	6.42
	16221.74	0.00	6626.30	4166.97	1263.21	1385.24	81.71	0.03	101.17	2.25
	347.28	0.00	1443.84	11.89	428.84	310.27	38.93	0.08	38.34	0.01
	6582.96	0.01	3877.92	2830.02	1257.29	1609.18	121.23	0.23	51.72	1.56
	40455.46	0.08	19147.06	9989.59	1459.88	1629.30	232.88	0.72	208.56	11.55
	48349.60	0.10	19993.37	12757.23	4416.71	5492.97	856.17		438.55	24.25
d =	163566.72	0.38	80852.72	43768.24	14059.56	16523.76	1877.19	2.19	1340.03	60.83

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	ai{x(n-i+1)-x(i)}									
	213.59	0.40	147.85	110.65	65.97	74.44	27.05	1.00	21.20	4.68
	105.52	0.17	75.72	53.31	25.23	26.45	8.81	0.34	8.54	1.91
	36.46	0.03	27.38	20.87	13.36	14.47	4.05	0.09	3.36	0.66
	8.19	0.00	6.70	3.81	3.16	3.08	0.16	0.00	0.91	0.08
sum	363.75	0.60	257.64	188.65	107.72	118.43	40.07	1.43	34.01	7.32
sum ^ 2	132316.18	0.37	66380.45	35589.34	11603.24	14025.29	1605.48	2.05	1156.81	53.61

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)as CaCO3	ALKALINITY (mg/l)as CaCO3	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W=	0.809	0.957	0.821	0.813	0.825	0.849	0.855	0.936	0.863	0.881
(sum ^ 2/d)										
W [0.05]	0.842	0.842	0.842	0.818	0.842	0.842	0.842	0.818	0.842	0.842
W [0.02]	0.806	0.806	0.806	0.778	0.806	0.806	0.806	0.778	0.808	0.806
W [0.01]	0.781	0.781	0.781	0.749	0.781	0.781	0.781	0.749	0.781	0.781

Note : reject the normality at i% significance level if W < W [i]

Table C.3.3 Normality Test for Data from the Logan River Basin (SAPHIRO-WILK W TEST)

Table C.3.3(a) Station 145010

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	147.50	6.75	91.80	94.00	42.00	24.50	13.50	1.25	7.90	5.50
x2	340.83	7.66	233.28	197.17	108.00	89.50	24.00	1.37	18.50	15.00
x3	360.00	7.83	235.00	203.33	112.33	92.00	24.02	1.40	19.90	15.22
x4	382.50	7.90	248.05	214.50	116.33	97.17	25.00	1.40	20.73	15.67
x5	393.00	8.03	253.50	217.50	128.50	98.00	29.00	1.48	22.68	17.45
x6	426.00	8.05	274.72	240.40	146.20	103.00	31.17	1.48	25.58	19.60
x7	439.17	8.10	294.05	246.67	146.50	119.33	31.50	1.90	26.20	20.08
x	355.57	7.76	232.91	201.94	114.27	89.07	25.45	1.47	20.21	15.50

2. Computation of the Denominator [d]

$$d = \sum (x_i - \bar{x})^2$$

	$(x_i - \bar{x})^2$									
	43293.72	1.02	19913.38	11650.63	5222.47	4169.47	142.92	0.05	151.61	100.05
	217.21	0.01	0.14	22.77	39.27	0.18	2.12	0.01	2.93	0.25
	19.61	0.01	4.35	1.95	3.74	8.58	2.07	0.00	0.10	0.08
	725.15	0.02	229.08	157.80	4.27	65.53	0.21	0.00	0.27	0.03
	1400.90	0.07	423.75	242.17	202.59	79.72	12.57	0.00	6.06	3.79
	4960.18	0.08	1747.68	1479.32	1019.74	194.01	32.63	0.00	28.84	16.79
	6988.16	0.11	3737.52	2000.65	1038.99	915.78	36.54	0.19	35.84	20.99
d =	57604.94	1.33	26055.88	15555.28	7531.06	5433.27	229.05	0.25	225.66	141.98

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	$a_i \{x(n-i+1) - x(i)\}$									
	181.80	0.84	126.06	95.16	65.13	59.11	11.22	0.41	11.41	9.09
	25.81	0.12	12.56	13.10	11.58	4.09	2.17	0.04	2.15	1.39
	4.62	0.03	2.59	1.98	2.26	0.84	0.70	0.01	0.39	0.31
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	212.23	0.99	141.21	110.25	78.98	64.04	14.09	0.45	13.94	10.80
sum ^ 2	45042.91	0.98	19941.32	12154.16	6237.56	4101.99	196.52	0.20	194.38	116.57

YEAR	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W = (sum ^ 2/d)	0.782	0.734	0.765	0.781	0.828	0.755	0.867	0.803	0.881	0.821
W [0.05]	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803
W [0.02]	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760
W [0.01]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730

Note : reject the normality at i% significance level if W < W [i]

Table C.3.3(b) Station 145013

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	429.00	7.57	255.18	232.00	130.00	89.60	29.00	1.38	24.00	17.00
x2	432.50	7.74	266.70	238.00	131.75	100.00	30.25	1.60	24.00	17.50
x3	450.00	7.80	276.30	253.20	146.40	110.00	32.20	1.64	26.82	19.28
x4	494.00	7.90	327.30	261.00	152.40	129.00	38.00	1.83	27.70	20.20
x5	525.00	7.98	359.73	296.00	175.33	151.00	38.40	1.87	31.40	22.33
x6	541.00	8.00	363.38	297.00	176.40	155.33	39.20	1.96	33.33	23.80
x7	598.33	8.05	404.87	340.33	206.67	156.60	43.67	2.00	37.67	27.33
x	495.69	7.86	321.92	273.93	159.85	127.36	35.82	1.75	29.27	21.06

2. Computation of the Denominator [d]

$$d = \sum (x_i - \bar{x})^2$$

	$(x_i - \bar{x})^2$									
	4447.62	0.09	4454.61	1758.40	891.02	1425.96	46.47	0.14	27.82	16.51
	3993.04	0.01	3049.56	1291.20	789.61	748.67	30.99	0.02	27.82	12.70
	2087.62	0.00	2081.45	429.87	180.90	301.44	13.08	0.01	6.02	3.18
	2.86	0.00	28.91	167.27	55.50	2.68	4.77	0.01	2.48	0.75
	859.05	0.01	1429.63	486.94	239.73	558.76	6.67	0.01	4.52	1.61
	2052.95	0.02	1718.69	532.07	273.90	782.40	11.45	0.04	16.48	7.49
	10535.56	0.04	6879.68	4408.96	2191.80	854.87	61.62	0.06	70.43	39.31
d =	23978.69	0.18	19642.53	9074.72	4622.47	4674.78	175.04	0.30	155.56	81.55

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	$a_i \{x(n-i+1) - x(i)\}$									
	105.55	0.30	93.30	67.52	47.79	41.76	9.14	0.39	8.52	6.44
	32.89	0.08	29.30	17.88	13.53	16.77	2.71	0.11	2.83	1.91
	10.51	0.03	11.69	6.00	4.05	5.74	0.87	0.03	0.64	0.43
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	148.94	0.41	134.29	91.40	65.37	64.28	12.72	0.53	11.99	8.78
sum ^ 2	22182.92	0.16	18034.45	8354.57	4273.67	4131.50	161.88	0.28	143.74	77.05

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W = (sum ^ 2/d)	0.925	0.935	0.918	0.921	0.925	0.884	0.925	0.931	0.924	0.945
W [0.05]	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803
W [0.02]	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760	0.760
W [0.01]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730

Note : reject the normality at 1% significance level if W < W [i]

Table C.3.3(c) Station 145020

1. Rank of the Data from the Smallest Value

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
x1	402.50	7.70	262.30	227.50	98.75	83.25	42.75	1.88	19.75	12.05
x2	539.67	7.70	311.70	271.33	121.33	87.33	52.67	1.97	23.33	15.27
x3	571.25	7.73	350.45	305.00	132.25	89.80	59.75	2.25	24.50	17.25
x4	617.50	7.93	362.20	317.50	135.75	98.75	64.50	2.45	25.63	17.38
x5	677.00	8.08	396.42	356.00	152.80	103.50	71.00	2.48	29.40	19.24
x6	856.67	8.10	519.57	444.67	204.67	141.00	87.33	3.10	39.67	25.67
x	610.76	7.87	367.11	320.33	140.93	100.61	63.00	2.35	27.05	17.81

2. Computation of the Denominator [d]

$$d = \sum (x_i - x)^2$$

	(x _i - x) ^ 2									
	43373.85	0.03	10984.32	8618.03	1778.73	301.22	410.06	0.23	53.23	33.16
	5054.82	0.03	3069.84	2401.00	383.83	176.15	106.78	0.15	13.78	6.46
	1561.35	0.02	277.43	235.11	75.26	116.76	10.56	0.01	6.48	0.31
	45.38	0.00	24.07	8.03	26.78	3.44	2.25	0.01	2.02	0.19
	4387.22	0.04	859.30	1272.11	141.02	8.38	64.00	0.02	5.54	2.05
	60468.18	0.05	23244.22	15458.78	4063.00	1631.71	592.11	0.56	159.29	61.76
d =	114890.78	0.17	38459.18	27993.06	6468.62	2237.66	1185.76	0.97	240.34	103.92

3. Computation of the W values

$$w = [\sum a_i \{x(n-i+1) - x(i)\}]^2 / d$$

	a _i {x(n-i+1) - x(i)}									
	292.07	0.26	165.45	139.66	68.12	37.14	28.67	0.79	12.81	8.76
	38.54	0.11	23.77	23.76	8.83	4.54	5.14	0.14	1.70	1.11
	4.05	0.02	1.03	1.09	0.31	0.78	0.42	0.02	0.10	0.01
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	334.66	0.38	190.25	164.51	77.25	42.46	34.23	0.95	14.61	9.88
sum ^ 2	111995.44	0.14	36194.59	27063.90	5967.69	1802.73	1171.80	0.90	213.43	97.67

DATA #	CONDUCTIVITY @ 25C (mS/m)	PH	DISSOLVED IONS (mg/l)	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l) as CaCO ₃	ALKALINITY (mg/l) as CaCO ₃	NATRIUM (mg/l)	KALIUM (mg/l)	CALCIUM (mg/l)	MAGNESIUM (mg/l)
W = (sum ^ 2/d)	0.975	0.825	0.941	0.967	0.923	0.806	0.988	0.927	0.888	0.940
W [0.05]	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788	0.788
W [0.02]	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743
W [0.01]	0.713	0.713	0.713	0.713	0.713	0.713	0.713	0.713	0.713	0.713

Note : reject the normality at i% significance level if W < W [i]