ASSESSMENT OF NITRATE CONTAMINATION OF GROUNDWATER USING STATISTICAL METHODS

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ABSTRACT

Irrigation schemes have the potential to increase in the concentration of nitrate in shallow groundwater. Historically effects assessment has focused one of two approaches. For the near field assessment, aquifer parameters are assumed uniform and representative, with cumulative effects largely ignored. For far field assessments, bucket models are commonly used that rely on assumptions of inflows and outflows of water and conservative assumptions on contaminants to assess downstream concentrations.

This paper presents an approach where the variability and uncertainties in data and our understanding of the groundwater systems, land use practices, climate and other factors that may influence nitrate contamination are acknowledged. Through the use of Monte Carlo simulation techniques, realistic estimates of potential contamination are made.

The advantage of this methodology is that it acknowledges the occurrence of adverse events, that when combined may lead to high estimates in nitrate concentrations. The methodology is able to assign probabilities to these events, such that while they are possible, the significance or weight given to such predictions is realistic. The Central Plains Water Enhancement Scheme provides an example of the use of these techniques that focus on the magnitude of the expected change in nitrate concentrations across the plains.

KEYWORDS

Nitrate Assessment, Groundwater, Monte Carlo, Central Plains Water Enhancement.

1 INTRODUCTION

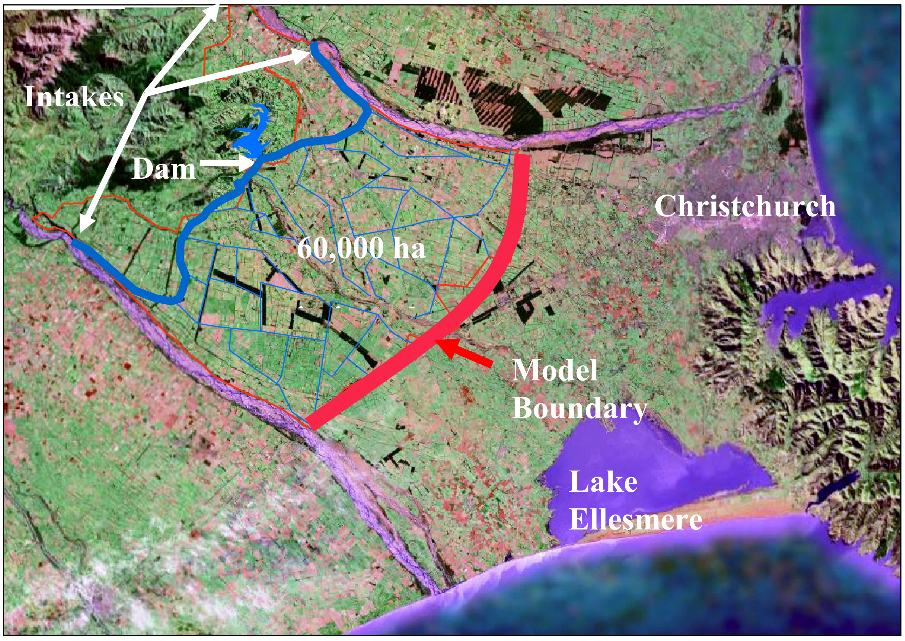
The Central Plains Water Enhancement Scheme, planned for the area between the Waimakariri and Rakaia Rivers, was a major project conceived to ensure there is a sustainable supply of water to the central plains utilising storage in the Waianiwaniwa Valley. This was to be filled from the Waimakariri River during periods of low demand and higher river flow. By harvesting all sources of water the scheme would have be able to irrigate 60,000 ha of farmland.

It is now a matter of public record, that through the resource consent hearing process, the Commissioners did not see favour in granting the resource consents nor recommending the designations required for the reservoir. In light of the advanced notice of the Commissioner's intention to decline such aspects, the Central Plains Water Enhancement Scheme is undergoing a major revision, considering the use of existing groundwater resources to provide the "stored water" required for sustainable agriculture.

Notwithstanding the above, the methodology used to assess the potential impacts of nitrate contamination from the proposed scheme, offers significant advantages to practitioners involved in environmental assessment. This paper therefore outlines that methodology, and presents an example of its use on the CPWES, prior to the demise of the Waianiwaniwa Reservoir concept.

The irrigated area of 60,000ha is within the central plains area of ~100,000 ha. The total area between the foothills, Rakaia and Waimakariri Rivers, the coast, Port Hills and Lake Ellesmere is approximately 200,000ha. The important boundary for this exercise is the lower one along the bottom end of the scheme which forms the line through which the groundwater flux and nitrate contamination from the scheme area is to be determined. This is shown on Figure 1.

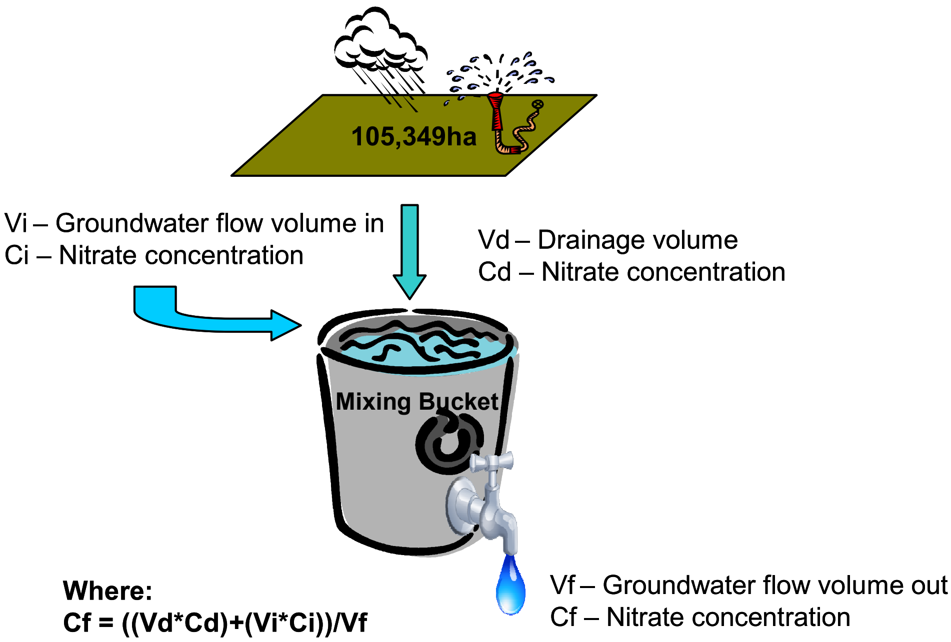
Figure 1 : Scheme and Model Boundaries



2 THE BASIC BUCKET MODEL CONSTRUCTION

The basic approach used for the nitrate contamination assessment can be simplified to a bucket model as outlined in Figure 2. The bucket model concept relates to the way in which water and nitrate flow together, become fully mixed (as if in a bucket) and a resulting final concentration of nitrate is estimated. The inflows and outflows are described in the following sections.

Figure 2: Bucket Model Concept



2.1 INPUT VARIABLES

The primary variables used in such a nitrate assessment are:

- Specific land use (type)
- Annual nitrate leaching commensurate with land use (kg NO_3-N/ha/yr)
- Area of land irrigated (ha)
- Annual volume of drainage water leached (m/yr)
- Annual volume of other inflows to groundwater system (m^3/yr)
- Background nitrate concentrations

An example calculation for nitrate concentrations downstream of a particular irrigated land use that demonstrates the limitations in methods commonly used in a resource consent application is outlined as follows:

1. Land use – dairy
2. Annual nitrate leaching – 46 kgN/ha/yr
3. Area of land – 5,659 ha
4. Volume of drainage water – 0.387m/yr = 60,000 m^3/d
5. Drainage water concentration of nitrate - 46,000gN/(0.387*10,000) = 12g/m^3
6. Annual volume of other inflows to groundwater system (based on 6000m wide farm) = 42,000 m^3/day
7. Background nitrate concentration – 5 g/m^3.
8. Mass Balance (bucket model) Calculation: (12*60,000 + 5*42,000)/(60,000 + 42,000) = 9.2 g/m^3, or an increase of ~ 4 g/m^3.

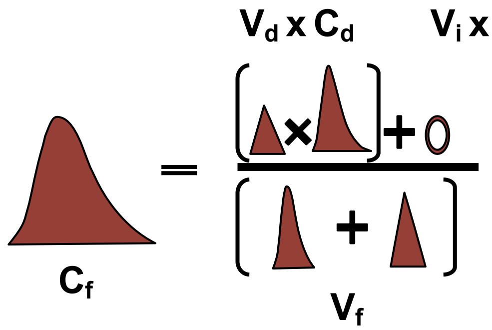
This example, used in a resource consent application, was claimed to be conservative, as it did not include other low nitrate concentration water entering the groundwater system, or the dispersion effects within the aquifer. It was acknowledged that there was a "degree of uncertainty" with this calculation and monitoring was recommended. The drawback of this type of calculation is that there are uncertainties that have not be quantified, both for the applicant and the regulator.

The method outlined in this paper, still uses the basic calculation sequence as above, but rather than taking single value estimates for each variable, includes a range for each of these that allows for the variability and uncertainty that exists. In this method, outcomes across the full range of best-case, expected and worst-case can all be represented, and the degree of conservatism becomes clearly evident.

2.2 THE CALCULATION

The mass balance calculation shown in Figure 2, ($C_f = ((V_d*C_d)+(V_i*C_i))/V_f$), can now be considered as the combination of a number of variables, each with their own level of uncertainty described by a probability distribution. Then the resultant answer, C_f, also will be a number that will vary, having its own probability distribution that represents the combination of the preceding distributions. Schematically this is represented in Figure 3:

Figure 3: Schematic representation of Mass Balance calculation using probability distributions.



The method used to undertake this calculation is a Monte Carlo simulation, using @RISK software. This undertakes individual calculations based on random samples taken from the statistical distributions of the quantities that are variable or uncertain and repeats it a large number of times, such that the distribution of the answers (C_f) does not change. We can then assume that the variability in our answer, represented by a probability distribution is representative of the variability or uncertainty in our input data. This provides the power and the simplicity to the methodology.

3 APPLICATION TO CENTRAL PLAINS WATER ENHANCEMENT SCHEME

To demonstrate the use of this methodology, the assessment of nitrate leaching from the Central Plains Water Enhancement Scheme is used. The following sections presents the uncertainty in each of the input variables as probability distributions and shows how the calculations produce the assessment of effects expected from this very large intensification of land use.

3.1.1 LAND USE

Land use within the developed scheme will be primarily crop or pasture. Of the 60,000 ha of land to be irrigated, the proportion that would be intensive pasture system was varied between 62.5% - 87.5% around a best guess estimate of 75% pasture. A triangular distribution was selected for land use variability.

3.1.2 NITRATE LEACHING

Nitrate leaching rates from cropping were selected such that they were representative of wheat, maize, barley and vegetable crops typically grown in Canterbury, and the differences in nitrate losses between each crop type were accounted for in the range of values used, as were the likely differences in soil types with deeper profile soils, on average having lower nitrate leaching losses than the shallower profile soils. Cropping loss distributions were selected based on an average of 44 kgN/ha/yr with a range of 17 – 81 kgN/ha/yr.

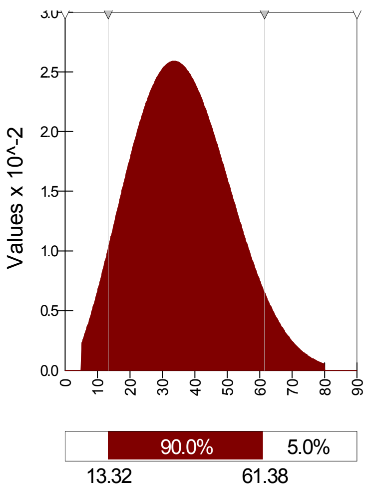
Nitrate leaching rates from pasture were representative of intensive pasture systems such as dairy, dairy support and intensive beef, all of which rely upon high (grass) dry matter yields and nitrogen recycling through mechanisms such as urine patches. Nitrate leaching distributions were selected primarily based upon research findings for dairy pasture. A major difficulty in selecting pasture nitrate leaching losses was the drainage expected under the CPWE scheme, being in the order of 670 mm/yr. Predictive tools such as OVERSEER© were typically calibrated on lower drainage rates, and were therefore operating outside their range of applicability. Judgement was applied to select nitrate leaching distributions that reflected results presented in scientific literature where drainage rates and intensity of the pastoral system were more representative of that expected in this scheme.

The distribution selected was based upon:

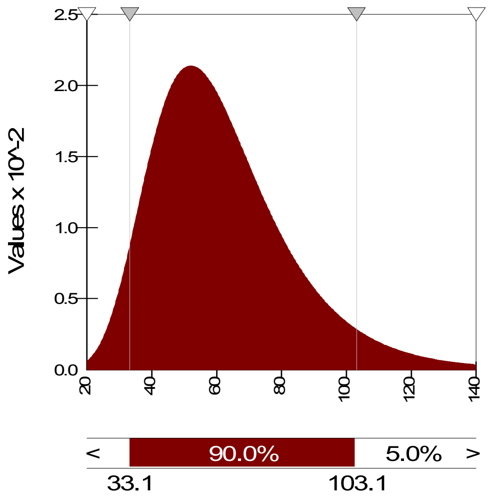
- The minimum loss of approximately 20 kgN/ha/yr
- The 10%ile loss of approximately 34.5 kgN/ha/yr
- The median loss of approximately 55 kgN/ha/yr
- The 90%ile loss of approximately 86.7 kgN/ha/yr
- The upper limit of approximately 140 kgN/ha/yr

Nitrate leaching distributions for cropping and pasture that were generated within @RISK are presented in Figure 4 below. These show the leaching loss along the x-axis in kgN/ha/yr, with the y-axis selected such that the area under the graph is equal to 1.

Figure 4: Typical Nitrate Leaching distributions for cropping and pasture within CPWES



Nitrate leaching for Cropping – 90mm PAW soils (kgN/ha/yr)



Nitrate leaching for Pasture – all sub-regions (kgN/ha/yr)

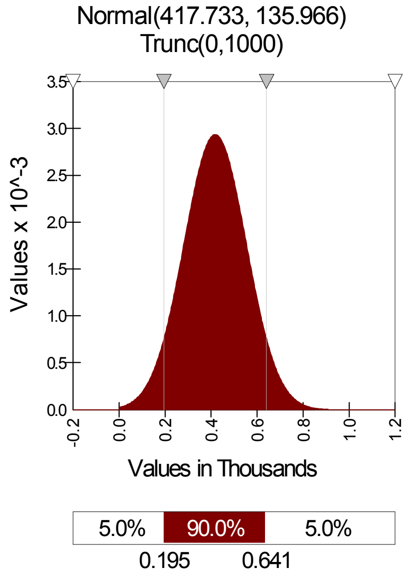
3.1.3 AREA OF LAND

The area of land under consideration was not varied in this assessment, as the maximum applied for volume of water was only sufficient to fully irrigate 60,000ha, and therefore this represented an upper bound to the assessment.

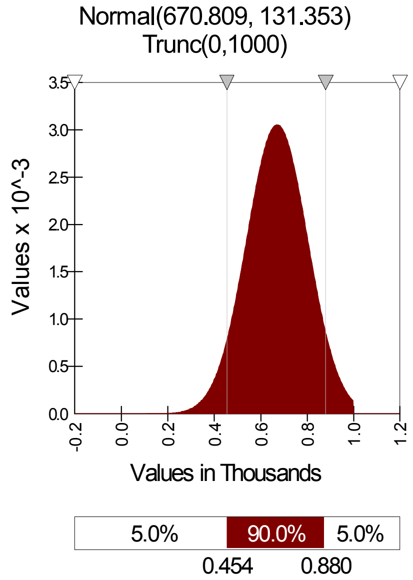
3.1.4 VOLUME OF DRAINAGE WATER

The volume of drainage water is dependant upon the depth of water applied by irrigation, the soil type, the land use, and the rainfall represented in separate climatic zones across the plains. Aqualinc Research assessed the volume of drainage water from the differing sub-regions within the scheme area using its Canterbury Plains Irrigation modelling software. From the modelled period of some 32 years, drainage volume distributions were developed for use in this assessment. There were 24 different scenarios modelled, based on climatic zone, soil type and land use. Two typical drainage distributions generated by @RISK are shown in Figure 5 following:

Figure 5: Drainage distributions used in the CPWES nitrate assessment



Drainage Darfield Irrigated Crop - 90mm soils (mm/yr)



Drainage Darfield Irrigated Pasture - 90mm soils (mm/yr)

3.1.5 ANNUAL VOLUME OF OTHER INFLOWS TO GROUNDWATER SYSTEM

The other volumes of water, excluding rainfall and irrigation induced drainage that enter the groundwater system, include inflows from the Rakaia and Waimakariri Rivers from seepage losses, the losses from the streams flowing from the upper catchment, primarily the tributaries to the Selwyn River, stock water races, headrace canal and distribution race losses and bywash to ground from the constructed irrigation system. These volumes are important in that they define the total volume of groundwater that nitrate from the scheme area will mix into. This is the "size of the bucket". These volumes were determined from the Aqualinc groundwater model (Aqualinc 2007) and were applicable to that portion of the central plains represented by the scheme area. Use of these data from the Aqualinc model ensured that mass was conserved within the mass balance calculation, such that water flowing into the model area, equalled that flowing out in the longer term, ignoring inter-seasonal storage effects due to higher or lower groundwater levels.

Volumes were calculated for Dry, Typical and Wet years, representing the differences that arise due to higher groundwater levels during wet periods and lower losses from the rivers as a consequence. 1967 was selected as representative of a dry year, and 1978 was selected as a wet year. A triangular distribution was assumed for the values contained in Table 1: following. Table 1 shows that inflow from the rivers is less in the wet years, that may seem counterintuitive, however this is due to elevated groundwater levels decreasing the hydraulic gradient away from the rivers, and therefore decreasing aquifer recharge.

Table 1: Low nitrate water sources to groundwater, post CPWE Scheme development

Water Source	Dry year (1967)	Typical Year	Wet year (1978)
Rakaia River	394 MCM/yr	358 MCM/yr	267 MCM/yr
Waimakariri River	136 MCM/yr	113 MCM/yr	16 MCM/yr
Upper catchment Streams	55.0 MCM/yr	118 MCM/yr	184 MCM/yr
Stock water races	62.8 MCM/yr	62.8 MCM/yr	62.8 MCM/yr
Headrace canal	31.5 MCM/yr	31.5 MCM/yr	31.5 MCM/yr
Distribution canal	32.1 MCM/yr	32.1 MCM/yr	32.1 MCM/yr
Bywash to ground	32.1 MCM/yr	32.1 MCM/yr	32.1 MCM/yr

3.1.6 BACKGROUND NITRATE CONCENTRATIONS

When undertaking a bucket model assessment, the concentration of nitrate in the incoming groundwater (refer C_i in Figure 2) is needed for the mass balance calculation. Because the model boundaries encompass the headwaters of the aquifer system, it has been assumed that the background nitrate concentration is zero. This is a valid assumption as the source of this water is that shown in Table 1 above, and for the purposes of this assessment can be assumed to be ~ 0. Other water entering the groundwater system, is by way of land drainage and this is accounted for in the drainage volumes as shown in Figure 5, representing irrigated and dryland areas.

In the CPWE Scheme situation, the above calculation is undertaken for 15 sub-regions making up the ~100,000ha in the scheme area. These sub-regions are defined by land use, soil type and climatic rainfall region, as contained in Table 2.

3.2 CALCULATION OF NITRATE LOSS AND GROUNDWATER UNDER EXISTING CONDITIONS

The land use distribution as in Table 2 with the areal nitrate loss data expressed as leaching distributions and the drainage volumes from the Aqualinc model represented by the drainage distributions in Appendix A, have been used to calculate the loss of nitrate to groundwater.

The process that @RISK uses is to firstly select an estimate of the areal leaching loss commensurate with the land use and soil type for the particular sub-region considered. It then calculates the concentration of nitrate in the drainage water using the drainage volume from the Aqualinc model, for an average year for that same sub-region. This groundwater is then further diluted (in the model) with the portion of the clean dilution water that is entering the groundwater system from the upland rivers. The clean water dilution volume was varied between the dry and wet year annual volumes contained in Table 1. The resulting concentration for that particular set of parameters is then collected by @RISK in an output file. @RISK repeats this calculation for each sub-region 5000 times. Therefore in total a matrix of 5000 x 25 (125,000 calculations for 15 irrigated land uses, plus 10 dryland options for 5000 model runs) is created for each simulation.

Table 2: Land use and Sub-Region Definition.

	Rainfall area	Title Area	Soil WHC	Land-use	Existing Land-use		Future Land-use		
Sub-region	**Region**	**Ha**	**mm**		**Irrigated**	**Dry land**	**87.5% Pasture**	**75.0% Pasture**	**62.5% Pasture**
1	Darfield	5,349	120	Pasture	1,000	4,349	3,500	2000	500
2	Homebush	63	90	Crop	0	63	-	2000	4000
3	TePirita	981	120	Crop	281	700	-	500	1000
4	Darfield	3064	90	Crop	750	2,314	2,000	4000	6000
5	Darfield	2,916	120	Crop	583	2,333	2,000	3500	5000
6	Homebush	7,648	120	Crop	2,000	5,648	3,500	4500	5000
7	TePirita	12,538	90	Pasture	7,675	4,863	8,500	8,000	7,000
8	Homebush	14,610	90	Pasture	1,000	13,610	6,000	4000	2000
9	TePirita	821	90	Crop	0	821	-	500	1500
10	TePirita	9,023	60	Pasture	3,837	5,186	6,500	6,500	6,500
11	TePirita	1,372	120	Pasture	0	1,372	1,000	500	0
12	Darfield	14752	60	Pasture	1,000	13,752	9,000	9,000	9,000
13	Homebush	8,873	60	Pasture	1,000	7,873	4,000	4,000	4,000
14	Darfield	19,389	90	Pasture	4,000	15,389	12,500	10500	8500
15	Homebush	3,950	120	Pasture	874	3,076	1,500	500	0
	Total Area	**105,349**			**24,000**	**81,349**	**60,000**	**60,000**	**60,000**

The data in this matrix is used to generate the cumulative frequency distribution of nitrate concentrations shown in Figure 5. However not all data points are used, as each sub-region has a different area or size and therefore the relative impact it may have on the nitrate concentrations within the whole model area is dependant upon that size. The data is therefore randomly selected in proportion to the land area of each sub-region. Thus for the largest sub-region, all 5000 data points are used, but for a sub-region of half that area, only 2500 data points are used. The resulting data set therefore adequately reflects the mix of land use and land areas across the plains.

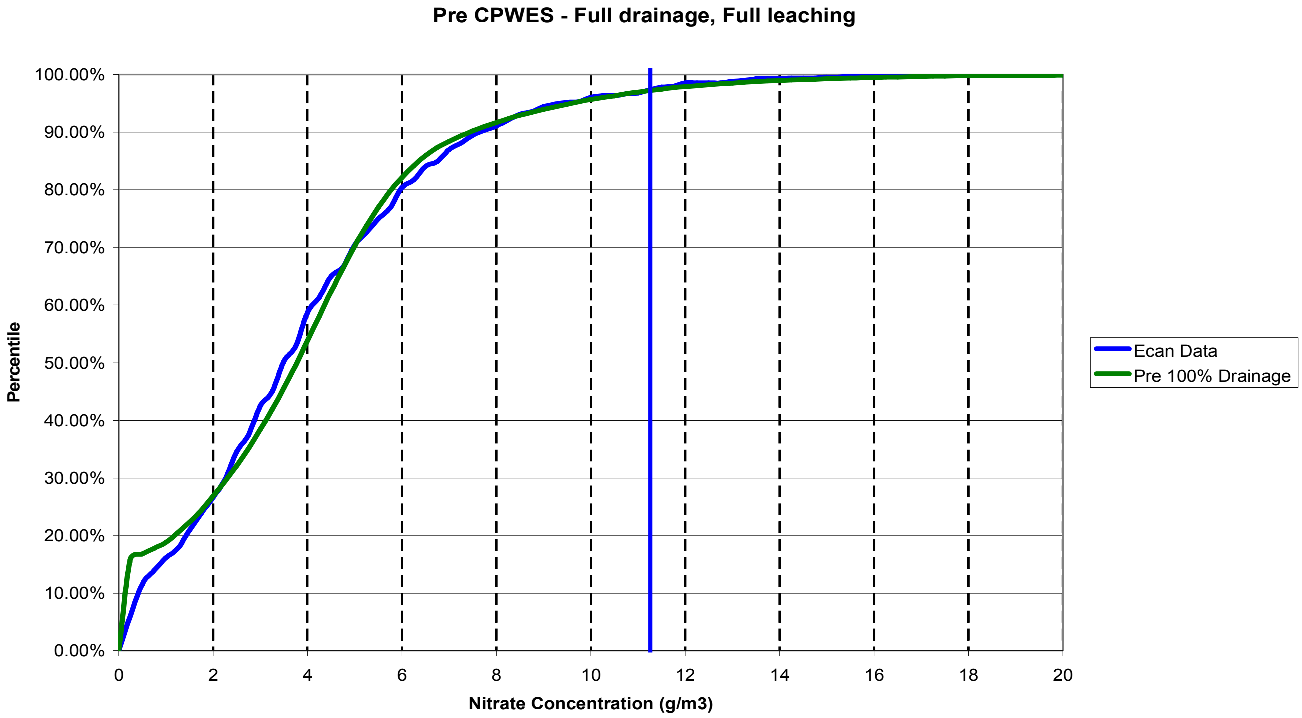
3.2.1 COMPARISON WITH EXISTING DATA

Figure 5 shows the modelled results of the existing land use scenario with the full nitrate concentration data set for the Central Plains area obtained from ECan. This figure shows that modelled cumulative frequency distribution curve is very close to that of the full existing data set and therefore provides a good basis upon which to conduct this evaluation.

The close fit between the modelled data set and the actual monitoring data, is not to be interpreted as providing a validation of the modelling output. Rather it is a demonstration of the calibration of the model, such that when it is used to predict the magnitude of the change resulting from the land use intensification, that change can be assessed against what is currently represented as the existing environment.

It can be argued reasonably that the existing data set under-represents the future steady state based on existing land use, as there is an expected time delay between land use change and this being reflected in the monitoring data. As the modelling is more appropriately considering changes between before and after CPWES, allowing for future increases should they occur is not strictly required. If the results of the modelling presented below are examined, it is evident that changes to groundwater quality in excess of the MAV are not expected, and therefore at the top end of the data range, the potential for change is less.

Figure 5: Actual nitrate data compared to modelled data (Existing land-use)



3.3 FUTURE GROUNDWATER NITRATE CONCENTRATIONS

The estimation of future groundwater nitrate concentrations follows a number of sequential steps as follows:

- Future land use scenario is selected
- Nitrate leaching from that land use is selected
- Drainage volume from that land use is selected
- Nitrate concentration in the drainage water is calculated
- Clean dilution water from the rivers is added to the bucket
- Resultant concentration in groundwater nitrate is calculated

These steps are described below.

3.3.1 FUTURE LAND USE SCENARIO IS SELECTED

The future land use for each of the 15 sub-regions is selected by @RISK through reference to Table 2. It is assumed that a triangular distribution for the proportion of pasture to dry land farming exists for each of the sub-regions. For example, for sub-region 1 – Darfield, it has been assumed that at a minimum there will be 500 ha of pasture, with a most likely area of 2000 ha and a maximum area of 3500 ha. The triangular distribution therefore has its peak at 2000ha, and reduces to zero probability below 500 and above 3,500ha. The area for each land use category as selected by @RISK is then used in the calculation of drainage volume and leaching concentration.

3.3.2 NITRATE LEACHING FROM THAT LAND USE IS SELECTED

An estimate of the nitrate loss (kgN/ha) is then selected for each of the sub-regions by @RISK, based on the land use and sub-region assumed. This is sampled from the leaching distributions as shown in Appendix A.

3.3.3 DRAINAGE VOLUME FROM THAT LAND USE IS SELECTED

The annual drainage volume for each of the sub-regions is selected by @RISK from a frequency distribution generated from the output from the Aqualinc model. These distributions are as shown in Appendix A.

3.3.4 NITRATE CONCENTRATION IN THE DRAINAGE WATER IS CALCULATED

The annual drainage volume and areal nitrate loss is used to estimate the drainage water's concentration of nitrate before it mixes with any diluting clean water within the aquifer system.

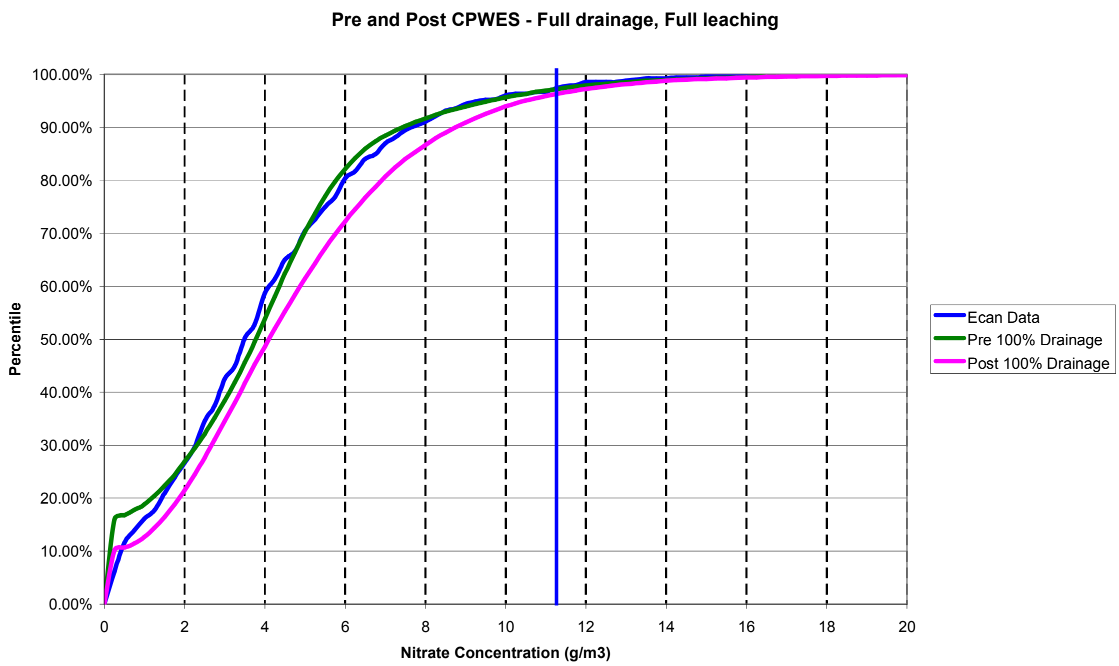
3.3.5 CLEAN DILUTION WATER FROM THE RIVERS IS ADDED TO THE BUCKET

A volume of clean dilution water is added to the drainage volume. For these scenarios, the clean water from the upper catchment streams, the headrace canal, and distribution systems is used to dilute the leached concentrations. No water from the Rakaia River or Waimakariri River has been used in this model to increase the availability of water to dilute groundwater concentrations. The clean water volume is also selected from a distribution reflecting wet, dry and typical years. The water from the races and distribution systems is widely distributed across the plains and, therefore, will act as an effective dilution source for all drainage. Nevertheless the conservative assumption of ignoring the contributions from the Waimakariri and Rakaia Rivers has been maintained for modelling purposes.

3.3.6 RESULTANT CONCENTRATION IN GROUNDWATER NITRATE IS CALCULATED

The resultant groundwater nitrate concentration is calculated and for each sub-region. @RISK repeats the calculation 5000 times. As previously, not all of these data are used to generate the predicted frequency distribution. The data are randomly selected in proportion to the area of each sub-region, so that the largest sub-region contributes 5000 data points to the combined data set and other areas contribute proportionally fewer data points. The resultant distribution is plotted on Figure 6.

Figure 6: Future scenario compared to existing land use and actual data



4 DISCUSSION OF RESULTS FROM GROUNDWATER NITRATE PREDICTIONS

The comparison of the model predictions for the existing land use scenario with the actual nitrate data set for the Central Plains is sufficiently close to establish the useful nature of this methodology. It also establishes parameters suitable for the future land use scenario modelling.

The future scenario modelling does not indicate any significant increase in groundwater nitrate concentrations. The modelling shows that for less than the 40%ile values, the nitrate concentrations will increase, but because they are generally less than 3 g/m^3 they are of no consequence. Over the portion of the distribution from 30 –

95%ile, there is a slight increase in nitrate concentrations predicted. Over the 95%ile range, there is no change in the predicted nitrate concentration, In general it is concluded that there is very little difference between the existing situation and the future predictions.

This conclusion may seem counter intuitive; however there is a reasonable explanation. Current experience with land use intensification across the central plains has resulted in an increase in groundwater nitrate concentrations. This has occurred as a result of groundwater being taken for irrigation, and as a result more nitrate being flushed into the groundwater system. At the same time irrigation has decreased the groundwater volume. The combination of increased nitrate leaching and reduced groundwater volumes leads to an inevitable increase in groundwater nitrate concentrations. Point source impacts are ignored in this discussion. This leads to a reasoned position that land use intensification will result in increased groundwater nitrate concentrations.

The CPWES is different in this regard. Any increase in the mass of nitrate from land use intensification is accompanied by an increase in clean water dilution. The increase in groundwater dilution from the headrace canal and the distribution network is significant. This can be seen from examining the data in Table 1, where the additional clean water entering the groundwater system is of a similar order to the existing inflows from the upper catchment streams. Therefore while there is an increased mass of nitrate entering the groundwater system, so too has the volume of groundwater increased, off-setting the potential increasing trend in nitrate contamination.

While the comparison between the existing situation and the future scenario shows that the future scenario may slightly reduce the median concentration of nitrate in groundwater, it would be dangerous to assume this was definitive. Due to the statistical approach adopted, there are anomalies in the output data around the near zero values. This is a consequence of the probability distributions chosen for dryland options. While the low nitrate concentration data points are of no environmental or health concern, they could skew the output data set slightly. However this is of no concern as the concentrations are well below the MAV.

It is particularly encouraging to see the higher values in the frequency distribution decrease. This can be explained by the extra benefit that higher concentration groundwater receives from the dilution water. Further the change to a predominantly pastoral land based management regime, limits the extent of very high nitrate concentrations that can be observed from irrigated crops. Thus the future scenario includes a higher proportion of pastoral land use that does not have significantly high leaching concentrations in the distributions provided in Appendix A.

4.1 SPATIAL EFFECTS ACROSS THE CENTRAL PLAINS

There is a spatial component to the nitrate concentrations across the plains where there is a predominance of wells with less that 1/3 of the MAV (Maximum allowable value – Drinking water standard of 11.3 g/m^3) close to the Waimakariri and Rakaia Rivers on the lower plains. Wells where the maximum value exceeds the MAV are more centrally located to the area between the Selwyn River and Christchurch City. This model does not attempt to simulate spatial effects.

The variability in the data due to location is reflected in the full data set of existing nitrate concentrations. The bucket model assumed will over estimate low concentrations and under estimate higher concentrations, depending upon the additional low nitrate water that is available to provide dilution. In modelling the existing situation, it is more important to reflect the higher concentration portion of the data set than the lower portion.

4.2 TEMPORAL EFFECTS

Groundwater flow times are very large, with flow times of between 10 – 100 years being realistic for an aquifer system such as the Central Plains area. Therefore there will be very large time constants involved in any model, with long time lags between land use change and the effects being noticeable. The issue here is that today's groundwater is the result of past land use practice and groundwater quality has not caught up with current practices. Hanson (2002) reports on an increasing trend in groundwater concentrations of nitrate, while at the same time there are also decreasing trends. Therefore the question is that if the increasing trend is real then what might the future steady state become, given no change in land use practices.

The important aspect here is that the increasing trend cannot be linear as the driving force for the change is a limited concentration of nitrate in the drainage water and therefore the future concentrations cannot exceed the drainage concentration. The leaching data presented above indicates an average drainage concentration in the order of 12 g/m^3. This represents an upper-bound of what could be seen within the groundwater system from the point of view of assessing the cumulative effects of CPWE Scheme. The future scenario modelling shows that a significant increase at the high end of the nitrate distribution is unlikely. Even if there is an increasing trend in existing groundwater nitrate concentrations, the CPWE Scheme will not exacerbate these concentrations. The possible increasing trend in background nitrate concentrations can therefore be disregarded in this assessment.

4.3 SENSITIVITY TO ASSUMPTIONS AND INPUT DATA

The four major assumptions used in this modelling are:

- Nitrate leaching losses for pasture – kgN/ha/yr
- Drainage volumes under irrigation – mm/yr
- That the scheme has an open race distribution system
- That the aquifer is completely mixed

The significance of the first two points is that if the areal leaching loss is too low and/or the drainage volumes are too high, then the resulting concentration of nitrate leached will be too low and therefore the predictions would not be conservative.

The significance of the open race distribution system is that losses to groundwater from that source are used to dilute the leached nitrate concentrations within the aquifer system. Loss of this dilution water would increase groundwater nitrate concentrations.

The significance of the complete mixing is that all clean water sources are assumed to contribute to dilution of the drainage water across the plains, where as for example the head race leakage may travel to deeper depths and not be available to dilute the drainage from areas lower down the scheme.

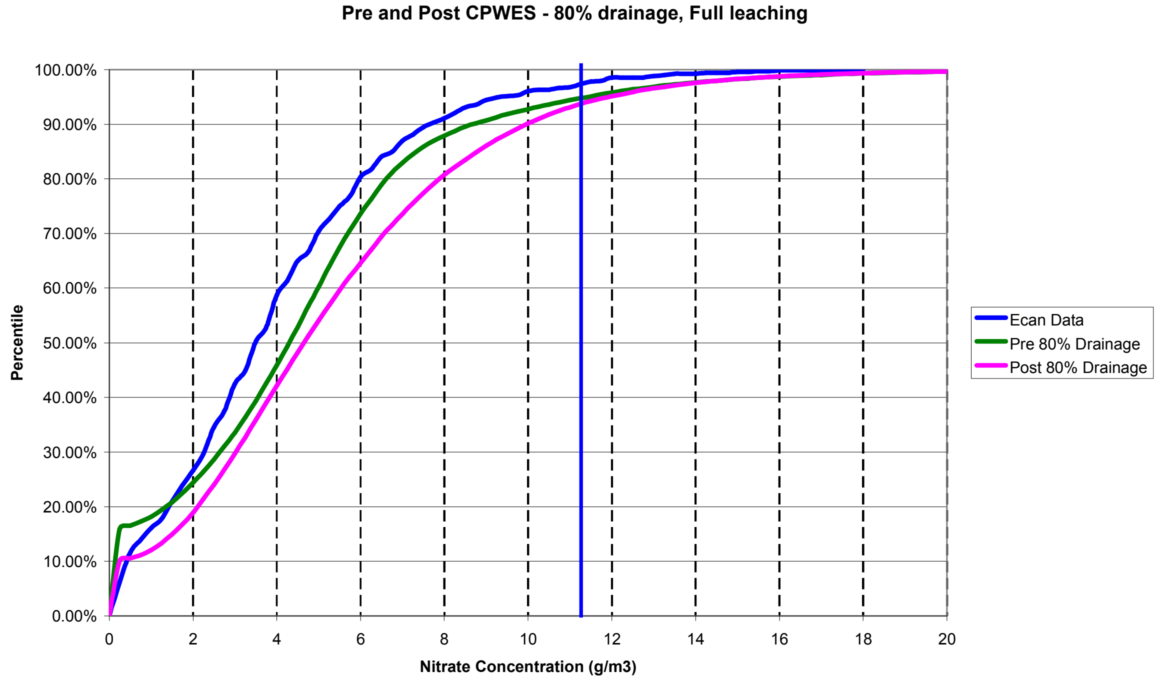
To test the significance of the principal assumptions, the annual drainage has been reduced by 20% which would bring predictions from OVERSEER© more into line with the drainage values used here. In addition to the modelling runs with the full areal nitrate leaching losses assumed above with only 80% drainage, additional runs were undertaken where the areal leaching losses more commensurate with the 80% drainage assumptions.

A modelling run without the losses from the distribution races has also been included as this would represent a situation where the distribution system was piped. The results from these runs are depicted below.

4.3.1 REDUCED DRAINAGE VOLUME

Figure 7 depicts the results with the irrigation induced drainage reduced by 20%. There has been no change to the nitrate leaching losses used in the previous assessment. Figure 7 illustrates that both the before and after scenarios predict higher concentrations than that of the existing data set. It also shows that there is very little change at the median concentration level and no change to nitrate concentrations at or above the MAV. There is an increase over the 60 – 90%ile range where the impact of the increased pastoral land use is evident.

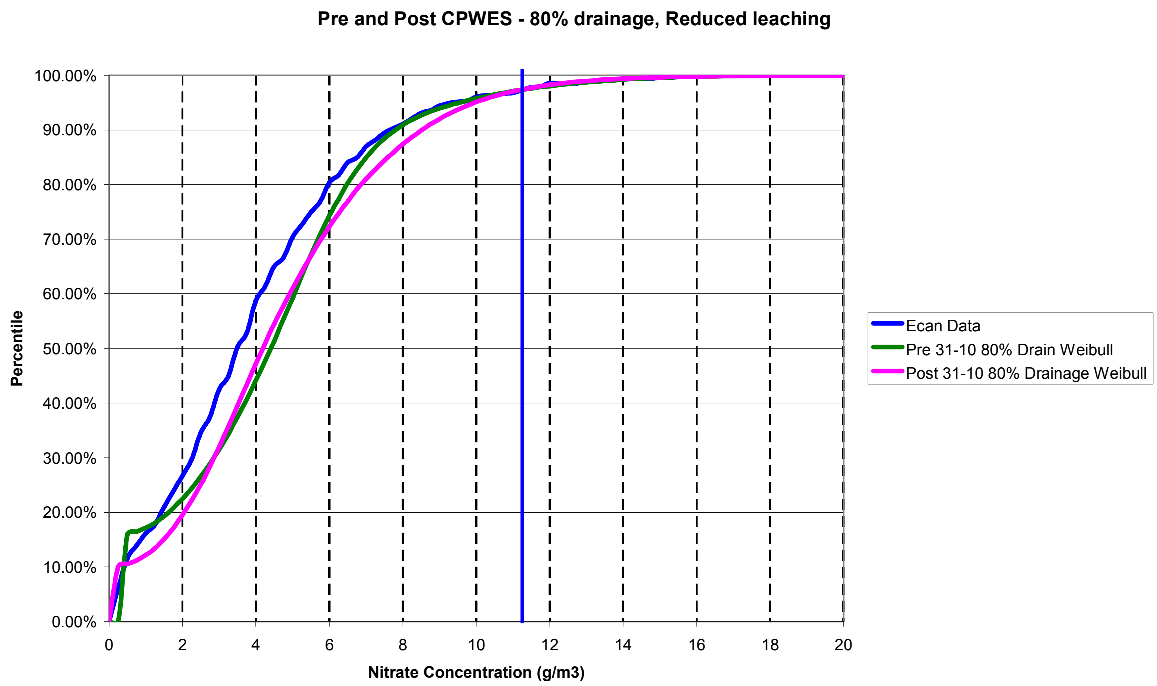
Figure 7: Nitrate concentrations under reduced drainage



4.3.2 REDUCED DRAINAGE AND REDUCED LEACHING

As for the scenario above, the drainage has been reduced by 20%, which brings the drainage volumes more into line with those used within OVERSEER©. Therefore a nitrate areal distribution loss commensurate with that predicted by OVERSEER© has been used with the reduced drainage. The consequence of this is that the before and after predictions revert closer to the existing data series. This is depicted in Figure 8 following.

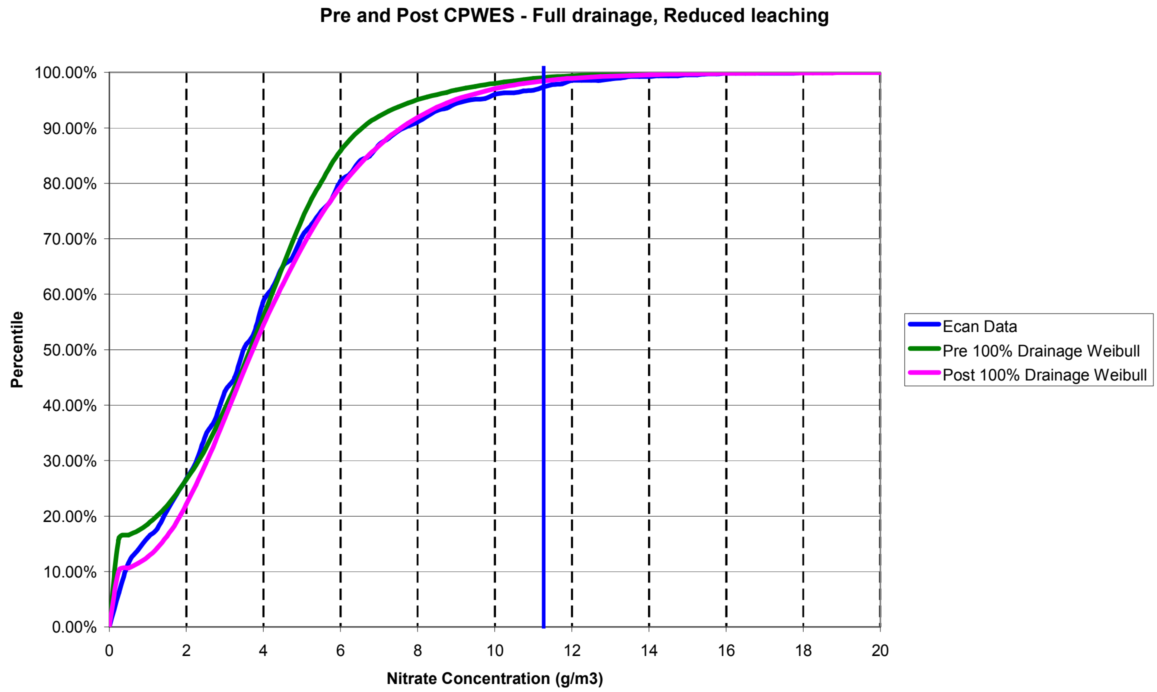
Figure 8: Nitrate concentrations under reduced drainage and reduced leaching



4.3.3 FULL DRAINAGE AND REDUCED LEACHING

Figure 9 depicts the results of reduced nitrate leaching and full drainage. The change from Figure 8 above is that the before and after predictions move to the left and there is even less change than that predicted when considering the full leaching losses.

Figure 9: Nitrate concentrations under full drainage and reduced leaching



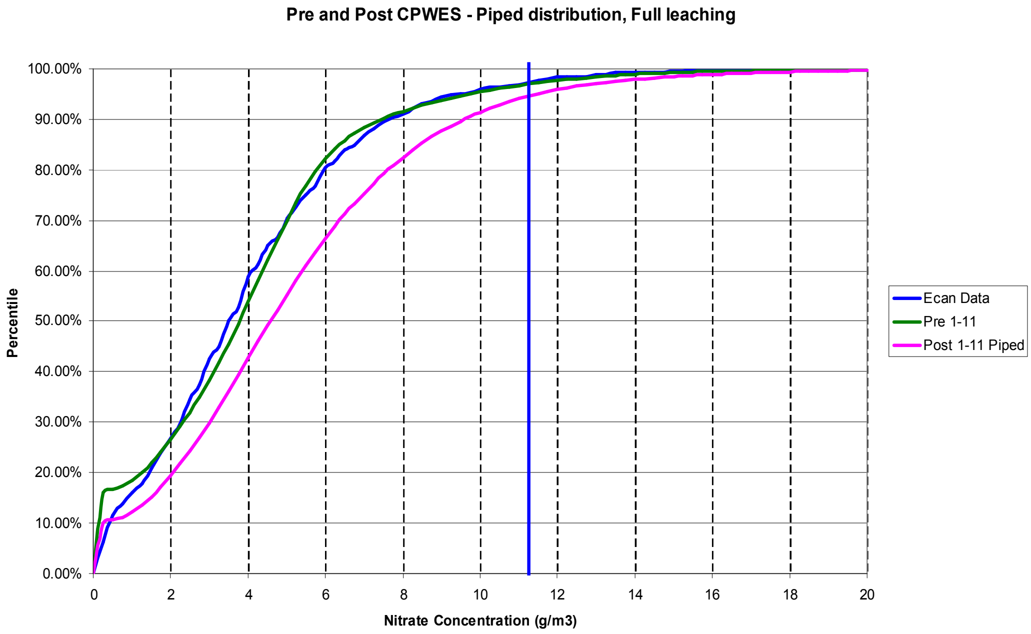
4.3.4 PIPED DISTRIBUTION NETWORK

The base scheme proposed is for the distribution system to be by open canals and races. This distribution system will introduce clean water into the aquifers through seepage and bywash. The total volume of this water has been estimated at 10% of the total on-farm demand. If a piped distribution system was to be selected for implementation, then this clean water would not be available for aquifer recharge and dilution of leached nitrate. Table 3 shows the volumes of clean water available during a typical year for dilution. This shows that there would be a reduction from 302.8 MCM/yr to 212.3 MCM/yr if the scheme was piped. This reduction will have a consequential change as depicted in Figure 10. This shows that median concentration will increase by ~ 0.75 g/m^3 and at the MAV of 11.3 g/m^3 there would be a 7% exceedence rate, compared to an existing exceedence rate of 5%. (A shift from the 97%ile to 95ile).

Table 3: Reduction in dilution water for piped scheme

Water Source	Canals	Piped
Upper catchment Streams	118 MCM/yr	118 MCM/yr
Stock water races	62.8 MCM/yr	62.8 MCM/yr
Headrace canal	31.5 MCM/yr	31.5 MCM/yr
Distribution canal	32.1 MCM/yr	-
Bywash to ground	32.1 MCM/yr	-
Total available for dilution	276.5 MCM/yr	212.3 MCM/yr

Figure 10: Nitrate concentrations under piped distribution



4.3.5 FULL MIXING WITHIN THE BUCKET

The assumption that all the clean water from the upper catchments and head race is available to dilute all drainage water does not account for the large spatial separation between these sources and the lower end of the scheme. For example the leakage from the headrace, which is at the upper end of the scheme area, may follow flow paths to the deeper aquifers and not mix with drainage water from the lower areas of the scheme. The streams do at times flow continuously into the Selwyn River and down to Lake Ellesmere, so this assumption is not so significant in relation to those sources.

There are two considerations in relation to this. Firstly the headrace leakage is only 17% of the total clean water entering the bucket and therefore even if all of this is not available for the complete mixing assumption, the effect will be small. Secondly if this is the case, then the impacts on the deeper aquifers will be less than assumed in this assessment.

On balance, it is contended that this assumption does not invalidate the conclusions reached in this assessment.

5 CONCLUSIONS

This paper has outlined a methodology for accounting for the uncertainty and variability in data used in the assessment of nitrate contamination of groundwater. The rigorous statistical process that has been used, will more accurately represent what happens in the real life situation than the single value assessments often provided in resource consent hearings. This approach acknowledges the variability and uncertainty in the data used to predict a range of outcomes that more accurately reflects that which can be expected in nature.

In the practical example used to demonstrate the effectiveness of this approach, it has been concluded that there will be no significant change in nitrate concentrations in the groundwater across the central Canterbury Plains should a water enhancement scheme such as CPWE be implemented. This is simply an artefact of using low nitrate concentration water for irrigation as well as having significant recharge of the aquifer system across the plains from leakage from the distribution system. This low nitrate drainage water is effective in diluting the soil moisture that drains through the soil profile, carrying with it nitrate that is lost from the agricultural system.

The outcome is that we would expect to see little change in the distribution of nitrate concentrations across the plains. There would still be a similar number of wells with high, medium and low concentrations of nitrate respectively, to what currently exists. It can not be concluded from this assessment, that the Central Plains Water Enhancement Scheme poses a significant risk to groundwater quality.

ACKNOWLEDGEMENTS

The author would like to acknowledge the input from Aqualinc Research Ltd for its drainage and groundwater modelling, which provided essential data for the statistical approach adopted.

Also Central Plains Water Ltd is thanked for its consent to publish this paper.

REFERENCES

Aqualinc (2007): 'Canterbury Groundwater Model 2'. *Report No. L07079/1,* July 2007. Aqualinc Research Ltd.

Tipler CJM., Lewthwaite WJ. (2007) 'Water sources for Central Plains Water Enhancement Scheme, Canterbury'. *NZWWA 49th Annual Conference & Expo*, 19 – 21 September 2007.

Hanson CR (2002): '*Nitrate concentrations in Canterbury groundwater – a review of existing data'.* Report No. R02/17, ISBN 1-86937-457-6, Environment Canterbury.

6 APPENDIX A

A.1 Nitrate leaching losses

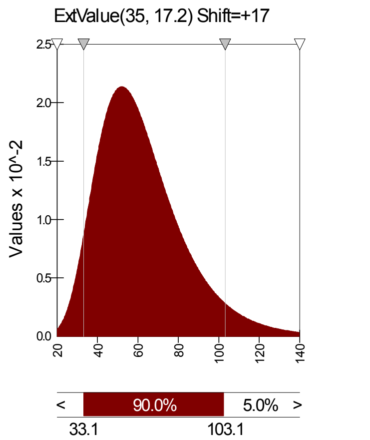


Figure A-1 : Nitrate leaching for Pasture – all sub-regions – Full leaching (kgN/ha/yr)

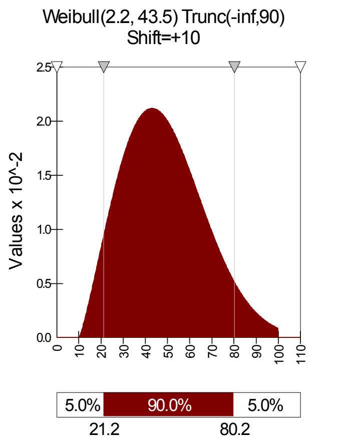


Figure A-2 : Nitrate leaching for Pasture – all sub-regions Reduced leaching (kgN/ha/yr)

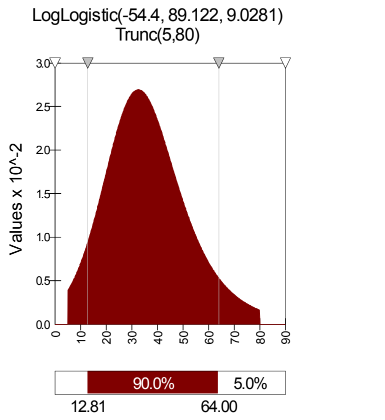


Figure A-3 : Nitrate leaching for Cropping – Homebush - 90mm soils (kgN/ha/yr)

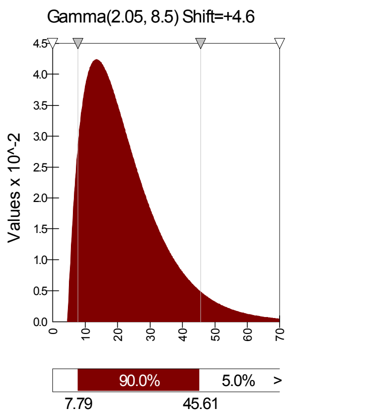


Figure A-4 : Nitrate leaching for Cropping – Homebush 120mm soils (kgN/ha/yr)

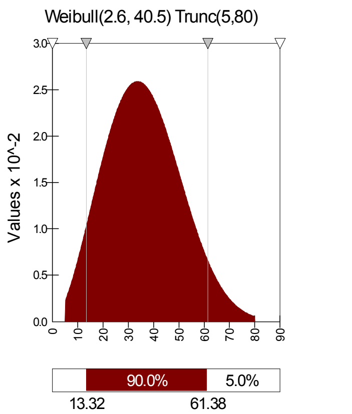


Figure A-5 : Nitrate leaching for Cropping – Darfield 90mm soils (kgN/ha/yr)

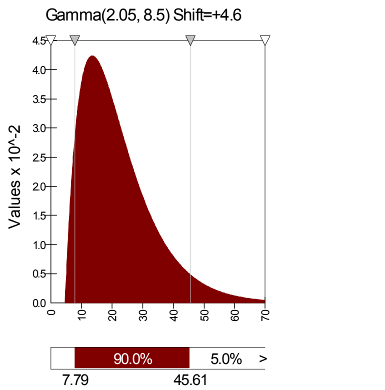


Figure A-6 : Nitrate leaching for Cropping – Darfield 120mm soils (kgN/ha/yr)

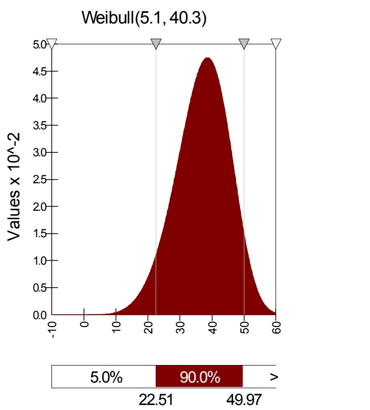


Figure A-7 : Nitrate leaching for Cropping – TePirita 90mm soils (kgN/ha/yr)

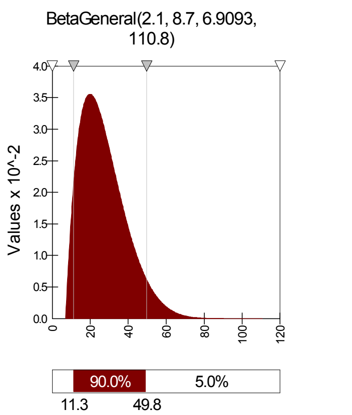


Figure A-8 : Nitrate leaching for Cropping – TePirita 120mm soils (kgN/ha/yr)

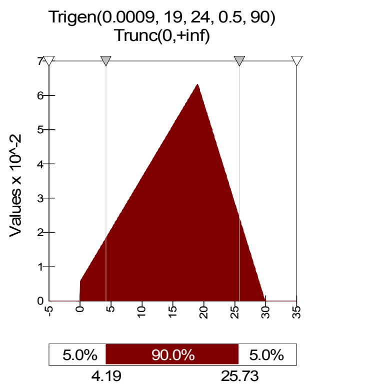


Figure A-9 : Nitrate leaching for Dryland - all sub-regions (kgN/ha/yr)

A.2 Drainage

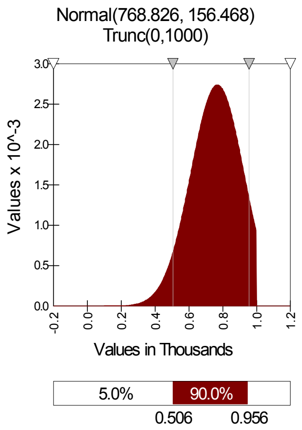


Figure A-10 : Drainage Homebush Irrigated Pasture - 60mm soils (mm/yr)

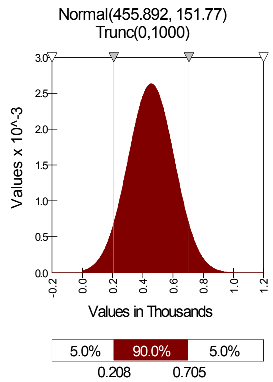


Figure A-11 : Drainage Homebush Irrigated Crop - 90mm soils (mm/yr)

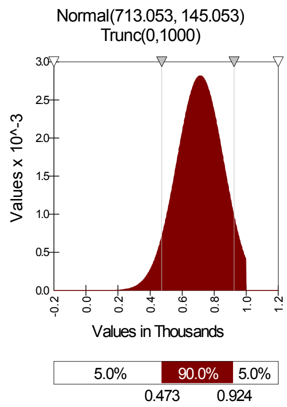


Figure A-12 : Drainage Homebush Irrigated Pasture - 90mm soils (mm/yr)

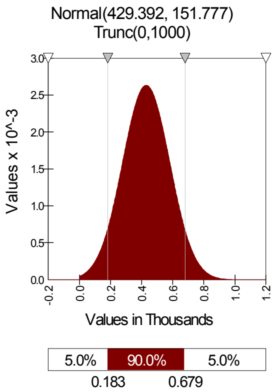


Figure A-13 : Drainage Homebush Irrigated Crop 120mm soils (mm/yr)

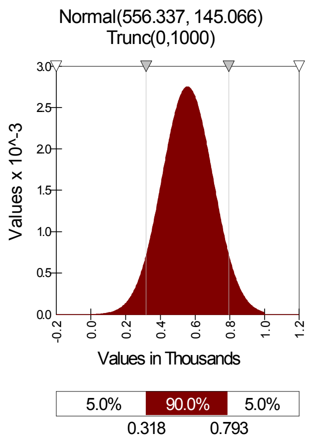


Figure A-14 : Drainage Homebush Irrigated Pasture 120mm soils (mm/yr)

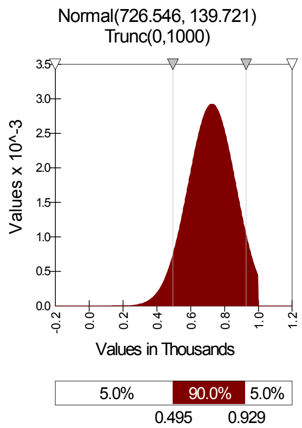
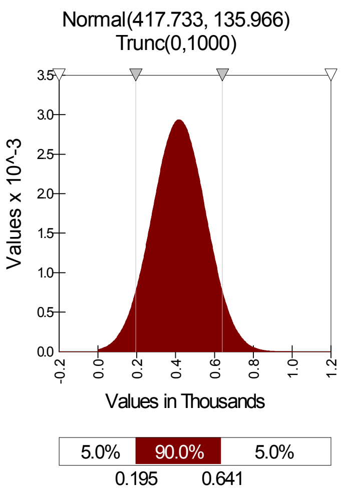
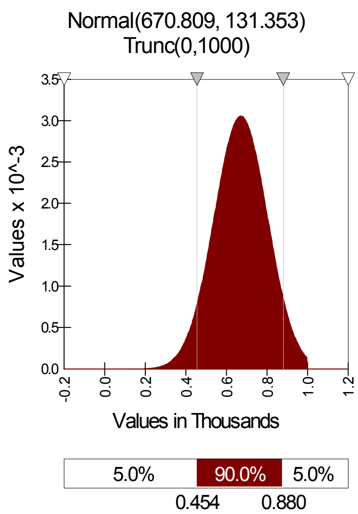


Figure A-15 : Drainage Darfield Irrigated Pasture - 60mm soils (mm/yr)





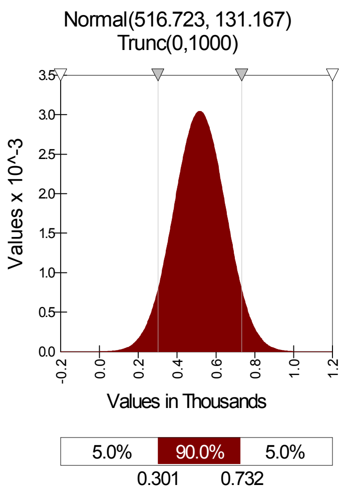


Figure A-16 : Drainage Darfield Irrigated Crop - 90mm soils (mm/yr)

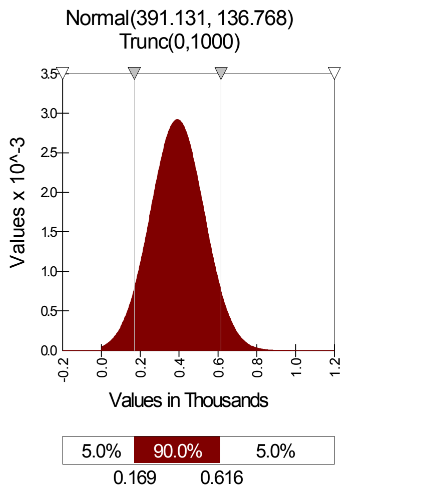


Figure A-17 : Drainage Darfield Irrigated Pasture - 90mm soils (mm/yr)

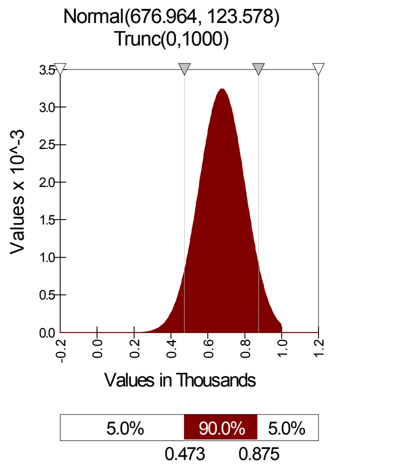


Figure A-18 : Drainage Darfield Irrigated Pasture - 120mm soils (mm/yr)

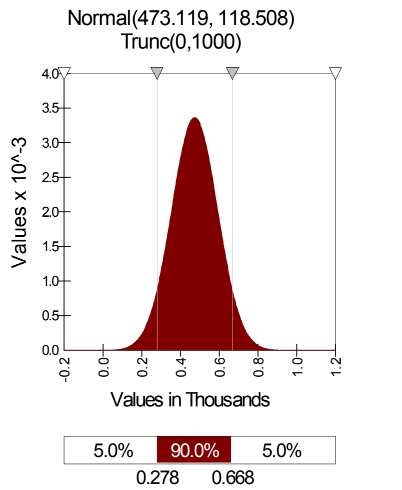


Figure A-19 : Drainage Darfield Irrigated Crop - 120mm soils (mm/yr)

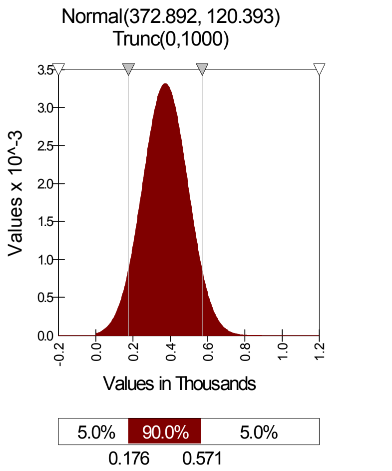


Figure A-20 : Drainage TePirita Irrigated Pasture 60mm soils (mm/yr)

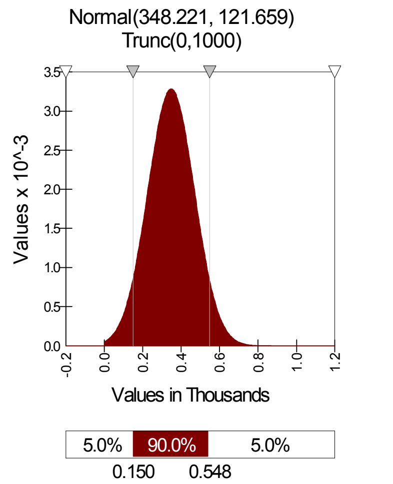


Figure A-21 : Drainage TePirita Irrigated Pasture 90mm soils (mm/yr)

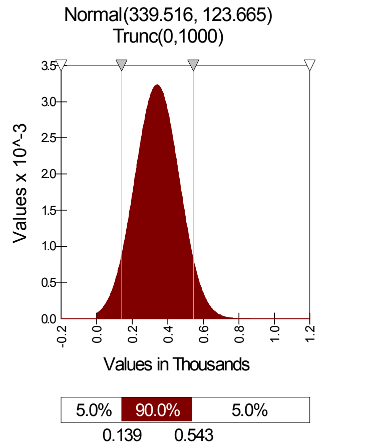


Figure A-22 : Drainage TePirita Irrigated Crop 90mm soils (mm/yr)

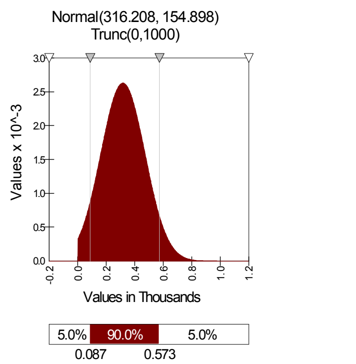


Figure A-23 : Drainage TePirita Irrigated Crop 120mm soils (mm/yr)

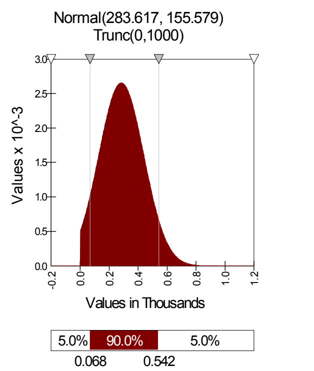


Figure A-24 : Drainage TePirita Irrigated Pasture 120mm soils (mm/yr)

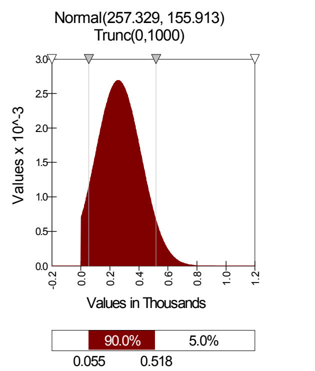


Figure A-25 : Drainage Homebush Dryland Pasture 60mm soils (mm/yr)

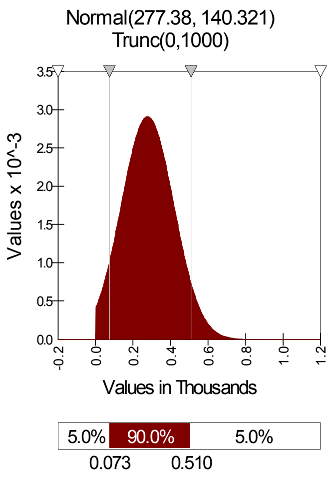


Figure A-26 : Drainage Homebush Dryland Pasture 90mm soils (mm/yr)

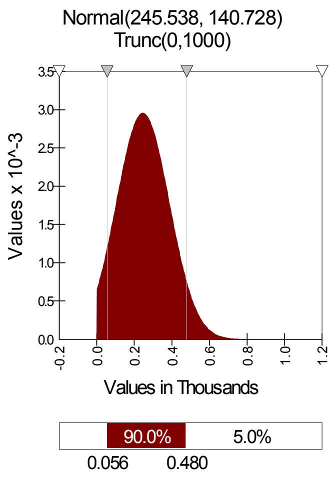


Figure A-27 : Drainage Homebush Dryland Pasture 120mm soils (mm/yr)

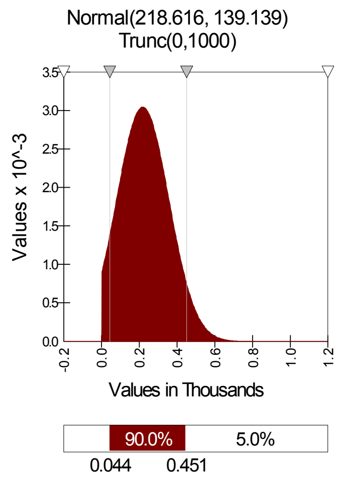


Figure A-28 : Drainage Darfield Dryland Pasture 60mm soils (mm/yr)

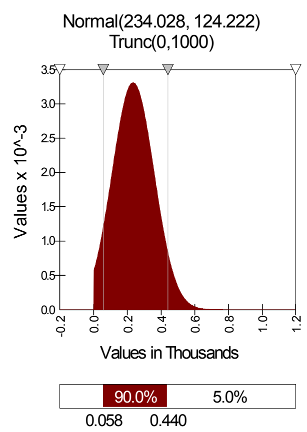


Figure A-29 : Drainage Darfield Dryland Pasture 90mm soils (mm/yr)

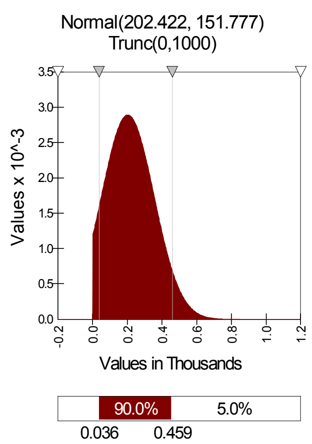


Figure A-30 : Drainage Darfield Dryland Pasture 120mm soils (mm/yr)

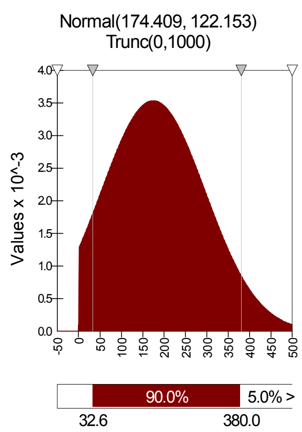


Figure A-31 : Drainage TePirita Dryland Pasture 60mm soils (mm/yr)

Figure A-32 : Drainage TePirita Dryland Pasture 90mm soils (mm/yr)

Figure A-33 : Drainage TePirita Dryland Pasture 120mm soils (mm/yr)