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GLADSTONE AREA WATER BOARD

Augmentation Triggers For Drought Review Of Dam Hydrology

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GLADSTONE AREA WATER BOARD

AUGMENTATION TRIGGERS FOR DROUGHT REVIEW OF DAM HYDROLOGY

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EXECUTIVE SUMMARY

Gladstone Area Water Board (GAWB) has developed a water balance model (AWSIM-D) for prediction of restriction and augmentation triggers for Awoonga Dam. This model is used in conjunction with GAWB's Drought Management Plan to mitigate the effects of drought on the Gladstone Area water supply. The Drought Management Plan is currently being revised and a worst-3-year, more conservative, inflow assumption for the model is being introduced.

GAWB's recent specialist advice has indicated that a worst-3-year inflow assumption is suitably conservative for restriction trigger modelling when balancing the risks and impacts involved with overestimation or underestimation of the inflow. This inflow assumption has been extended for use with augmentation trigger modelling in the proposed updated Drought Management Plan, as augmentation triggering coincides with first level Supply Restrictions.

Stochastic modelling has recently been carried out by GAWB to investigate the probability of various low inflow assumptions for input into their Drought Model (AWSIM-D).

Cardno has been commissioned to review the assumptions involved in GAWB's proposals for determining augmentation triggers. This report presents discussion of the worst-3-year inflow assumption and suggests alternatives, reviews GAWB's stochastic modelling and presents results of further stochastic modelling and investigates deferral of failure and possible deferral augmentation triggering for different augmentation options.

The worst-3-year inflow assumption is considered very conservative for use in the Drought Model even with regard to the unquantifiable effect of climate variability. The 1 percentile worst-4-year inflow is suggested as a more appropriate assumption for modelling of restrictions triggering. If augmentation triggering is not required to coincide with first level Supply Restrictions, then a separate inflow assumption of the worst-5-year inflow is suggested for modelling augmentation trigger volumes. If augmentation triggering is to be deferred significantly beyond the time of first level Supply Restrictions, then a more conservative inflow assumption would be required and the worst-3-year inflow assumption may be suitable in this case.

Use of the GAWB Drought model with different inflow and rainfall assumptions indicated that augmentation would defer failure for significant periods and a 30,000 ML/a capacity of Gladstone-Fitzroy pipeline would be required to defer failure at least 2 years using suggested inflow assumptions. Also augmentation triggering could be deferred by approximately 2 years while maintaining at least 2 years deferral of failure and reducing buffer time.

Review of evaporation and seepage loss assumptions discussed in provided documentation indicated that acceptable methods were used for estimating these losses and that assumptions were similar those used in other dam water balance studies.

1. INTRODUCTION

Gladstone Area Water Board (GAWB) has developed a model of Awoonga Dam to estimate available water supply in a drought situation for a range of inputs. This model, AWSIM-D, is a simple water balance model for simulating the water level in Awoonga Dam based on user definable assumptions of dam starting level, simulation start date, inflows, rainfall, demand, supply restrictions and system augmentation. It is currently used to estimate "Time Frame from Failure" for GAWB's Drought Management Plan to calculate trigger volumes for alerts, restrictions and augmentation. GAWB amended its Drought Management Plan (GAWB, 2007) to adopt a worst-3-year inflow assumption. Assumptions of the Drought Management Plan have been reviewed by Synergies, and GAWB's recent submission to the QCA and updated Drought Management Plan have made reference to this advice.

Queensland Competition Authority (QCA) have commissioned Cardno to review and provide independent advice regarding assumptions incorporated into GAWB's proposals for determining augmentation triggers.

This report discusses the worst-3-year inflow assumption and the appropriateness for its use in modelling longer durations and investigates alternatives to this assumption. There is a focus on the model's use for calculating augmentation trigger volume. The report discusses stochastic modelling and its use in determining the probability of various inflows for use in the drought model. This report also presents the results of further stochastic modelling and investigates the benefits of various augmentation options (sizes of Gladstone-Fitzroy pipeline) in terms of deferral of failure or deferral of triggering augmentation.

This report also includes comment on GAWB's assumptions regarding water evaporation and seepage losses.

2. INFLOW ASSUMPTION FOR DROUGHT MODELLING

2.1 Background

Selection of an inflow sequence for input to the drought model is an exercise in risk management. The investigation must include not only an assessment of the likelihood of various inflow volumes, but also the impacts of overestimation or underestimation.

Synergies Economic Consulting (Synergies) have reviewed inflow assumptions of the Drought Management Plan in May 2007 (Synergies, 2007). Their review considered the balance between the risk of failure of the system resulting from overestimation of the inflows versus the risk of disruption of customers through unnecessary restrictions resulting from underestimation of the inflow. They concluded that the relatively conservative assumption of a worst-3-year inflow using the average of the past 3 years of inflow (2004-2007) was appropriate for determining the trigger volumes for water restrictions. This conclusion was not made in relation to determining the augmentation trigger volume. Among their reasons for recommending a worst-3-year inflow was that, with the low supply alert at 48 months timeframe to failure, it allows a 3 year reserve volume (supply volume assuming zero inflow) and this provides a window to trigger augmentation. They go on to say “This is not meant to suggest that a 3 year trigger point for supply augmentation is required…”.

Supply augmentation carries with it the further consequence of increase in water cost. In its Part (A) Final Report (December 2007) the QCA indicated that with the current proposal of a 30,000 ML/a Gladstone-Fitzroy pipeline at an estimated cost of $345 million would be likely to have a substantial impact on prices. The QCA estimated that raw water prices would need to increase by between $310 and $410 per ML more than double the current price.

In GAWB’s “Submission to the Queensland Competition Authority Fitzroy River Contingency Infrastructure Part (b) - Augmentation Triggers” (GAWB, 2007b) they refer to the Synergies paper when discussing their decision to use the worst-3-year inflow assumption to select the trigger point for augmentation.

GAWB’s revised Drought Management Plan (GAWB, 2007) states that the worst-3-year inflow assumption for the drought model was made with due acknowledgement of the unquantifiable effect of climate variability. This was probably in light of the earlier May 2007 draft of the Synergies paper with reference to modelling restriction trigger volumes.

Currently the Drought Management Plan sets a Low Supply Alert with 60 months Time Frame from Failure, first level Supply Restrictions at 48 months Time Frame from Failure and Emergency Restrictions at 6 months Time Frame from Failure. Trigger of Supply Augmentation with the construction of the Gladstone-Fitzroy pipeline is set to coincide with first level Supply Restrictions with 48 months Time Frame from Failure and supply augmentation is expected to be completed within a further 24 months. Due to the coincidence of Supply Augmentation trigger with Supply Restriction, the Drought Management Plan uses the same inflow assumption for augmentation as has been recommended by Synergies for restrictions only. GAWB did not address the possibility of using different inflow assumptions for triggering augmentation or the possibility of deferring the time of augmentation triggering within the requirements of their drought mitigation objective of extending the time of dam failure by 2 years.

2.2 Low Inflow Period versus Model Duration

In an earlier version of the Drought Management Plan a worst-10-year inflow assumption has been used to determine restriction triggers using the GAWB Drought Model. Synergies discussed this and other potential worst inflow durations and their appropriateness for use in the Drought Model. They considered the worst-10-year inflow assumption to be inappropriate for use as, due to the Low Supply Alert being triggered at 60 months Time Frame from Failure, the Model will be run for at most 5 years duration. (It is understood that the critical time the model would be run is at a time close to when restrictions are expected to be imposed).

The GAWB Drought Model is a simple water balance model of various inflows and outflows of water to and from Awoonga Dam. During a typical modelled failure period the important quantities are the total inflows and total outflows. Consequently an averaged inflow is adequate for use so long as it is averaged over at least the duration of the model.

Using an averaged inflow sequence of greater than 5 years (the duration of the model) is considered to be inappropriate due to the variability of the annual inflow. If failure can occur in 5 years, the actual average inflow over the first 5 years may be less than the average flow over a longer period.

2.3 Stochastic Modelling

2.3.1 A Simple Explanation of Stochastic Modelling

A model relies heavily on its inputs and a very significant part of the inputs to the GAWB Drought Model is hydrologic and meteorological data. Importantly, the more recorded data there is, the more reliable the input will be. In most parts of Australia meteorological information has only been recorded for less than 120 years. This may seem like a lot of data but is very little when considering the duration and variability of droughts that may be experienced.

Very often models are run using historical data and provide such outputs as “historic no failure yield” of dams etc. These outputs have their uses, but in a sense assume that the next 100 or so years will be just like the last 100 or so years. When modelling something which has higher risks or more severe consequences it is prudent to use Stochastic Modelling.

Stochastic Modelling is a way of creating more information from the data you have got. It uses the statistical properties of your data to create more data with the same statistical properties. It can be used to estimate the probability of a certain flow occurring. For instance, the lowest annual flow in a 100 year historical sequence might seem to have a 1% probability of non-exceedance (or 1 in 100 chance that the annual flow will be less than or equal to that value) when compared to that historical sequence, but when you create 500 further data sets of 100 years flow that same low flow may have much more or less than 1% probability of non-exceedance.

There are a number of different ways of generating stochastic data, each of them preserving statistical properties and using a random number generator. One such method is the Annual Markov Model which preserves the mean, standard deviation and skew and may also preserve the lag-1 autocorrelation (a measure of how flow one year may be similar to the flow the previous year).

2.3.2 Review of GAWB's Stochastic Modelling

In GAWB's report "2007 Update of GAWB's Drought Model: AWSIM-D Documentation of Review Process" (GAWB 2007c) the Annual Markov Model is described and has been used to generate data for stochastic modelling. As well as mean and standard deviation, GAWB use sample corrected skew and lag-1 autocorrelation. The Annual Markov Model has a deterministic component and a random component. The deterministic component is dominated by the lag-1 autocorrelation and the random component is dominated by the 'like-gamma variate' which uses the sample corrected skew and a normally distributed random number.

In order to provide more stochastic analysis results with similar data as had been used in GAWB's analysis, the formulae from GAWB's Drought Model Update Report were used to generate more data independently, however errors were found in the published formulae. These errors were corrected using information from "River and Reservoir Yield" (Mein and McMahon, 1986). Generation of data using the corrected formulae resulted in a significant quantity of negative flow data. Simple removal of these negative flows by replacing with zero flows resulted in an unacceptable increase in the mean and zero flows in the low percentile range. The GAWB Drought Model Update Report did not discuss the negative flow correction used in their stochastic analysis.

GAWB used a truncated historical flow sequence to generate stochastic data. Flows for the Boyne River have been recorded since 1939. Data prior to 1939 were identified by GAWB as unreliable as they had been generated by a rainfall/runoff model which was overestimating the flows due to limited streamflow information for calibration. Data from 1939 was considered to have a significant downward trend and the Annual Markov Model requires stationary data. A sub-set of the data from 1984 was used for GAWB's stochastic analysis.

For this stochastic analysis the historic data set from 1939 to 2007 was used. The evidence showing that pre-1939 flow data was unreliable (Hydro Tasmania Consulting, 2006) was considered acceptable. Further truncating the data was not considered beneficial as stochastic analysis relies heavily on statistical properties. The benefits of a data set which is apparently more stationary was considered to be outweighed by the benefits of a large data set to obtain more reliable statistical properties. Truncating the data set from 68 years to 23 years reduced the mean from 325,850 ML/a to 142,892 ML/a, a 56% reduction in the mean.

Initially the Annual Markov Method was used to generate data, but as described above, there was a problem with generation of too many negative flows. This was the result of a high standard deviation compared to the mean and occurred for both 1939 to 2006 and 1984 to 2006 historic data sets. Zero flow correction and moment transformation equations (Mein and McMahon, 1986) were used to try to generate more realistic data, but the mean of the generated data was unacceptably increased (15%).

Finally, flow data was generated using a program called Syngen2h (also known as WT89) written by Kev Tickle of NR&W. Syngen2h is suitable for generating monthly data for a number of stations and uses the residual approach, described in "River and Reservoir Yield" (Mein and McMahon, 1986) and also in the NR&W program manual (Tickle 1985). For this analysis, the program has been used to generate annual flow volumes for a single station. The residual approach involves logarithmically transforming the data and then the mean, standard deviation, skew and lag-1 serial correlation (autocorrelation) of the transformed data are used to generate the stochastic data. The random component of the data generation includes a randomly generated number (random normal (0,1) deviate). Syngen2h provides a number of distribution options for data transformation, from which the log-Pearson III distribution was chosen because the historical and generated data distributions matched better than other distribution options for the low flow range keeping in mind the stochastic data is being used to analyse low (drought) flows. There was no correction for negative flows for this option but the log-Pearson III distribution did not produce any negative flows.

The historical data used for flow generation was amended to exclude data in the period October 1964 to August 1966. Zero flow data in this period was found to be inconsistent with the rainfall data for that period. Streamflow Data Quality codes were obtained for the daily flow data and much of the assumed zero flows were erroneously labelled "below threshold" and some of it was, probably correctly, labelled "missing".

Further data was provided up to February 2008, so the period was also amended to include this data.

Two sets of stochastically generated data each comprising 500 sequences of annual flow volumes of length equal to the historical data set were generated using Syngen2h for different water years. One set of stochastic data for water years from October to September (GAWB's previous water year) was generated from the data for the period 1938/39 to 2006/07 less the years 1964/65 and 1965/66 (67 years). A second set of stochastic data for the water year from May to April (GAWB's current water year) was generated from the data for the period 1939/40 to 2006/07 less the years 1964/65, 1965/66, and 1966/67 (65 years). Figures 1 and 2 show plots comparing the frequency distributions of the historical and generated annual flow data for October to September and May to April water years respectively.

The principal differences between the GAWB's and Cardno's stochastic data generation methods is the transformation process which is part of the residual approach The transformation using the log-Pearson III distribution addressed the negative flow generation problems and produced acceptable statistics in the low flow range. It is possible that the distribution chosen better suited the historical data set from 1939 to 2007. Both the gamma distribution used in the GAWB analysis and the log-Pearson III distribution used in the Cardno analysis are commonly used for fitting hydrologic data. Without knowing how the negative and low flows were treated in the GAWB analysis it is not possible to compare the performance of the two methods for the low range of flows.

Information and advice on stochastic data generation was provided by G. Hausler of EHA Pty Ltd.

2.3.3 Stochastic Modelling Results

Stochastic Modelling was carried out to check the probability of various average flows occurring over different durations, particularly the worst-3-year average flow which is currently used in modelling. Only the May to April stochastic modelling results are shown, as this is the most recently adopted water year. The results are presented in Tables 1 and 2.

Table 1 Stochastic Modelling Results – Probability of Average Inflows (May to April Water Year)

Flow Duration	Historically Worst Flow Period	HistoricallyLowest Average Flow (ML/a)	Probability of Non-Exceedance (%) (based on stochastically generated flows)						
			For 1 year	For 3 years	For 4 years	For 5 years	For 6 years	For 7 years	For 8 years
3 year*	2005 to 2007	23,633	7.21	0.50	0.15	0.05	0.01	0.002	<0.0001
3 year	2005 to 2007	24,161	7.45	0.53	0.16	0.05	0.01	0.002	<0.0001
4 year	1999 to 2002	46,433	16.8	3.43	1.63	0.83	0.43	0.23	0.14
5 year	1998 to 2002	42,994	15.4	2.78	1.28	0.64	0.31	0.16	0.10
6 year	1997 to 2002	52,055	19.0	4.44	2.28	1.21	0.68	0.40	0.25
7 year	1995 to 2001	80,722	29.0	11.0	7.16	4.69	3.19	2.25	1.57
8 year	1995 to 2002	73,660	26.6	10.8	7.06	3.57	2.32	2.09	1.09

- Currently proposed for model based on calculated flows for 2007

Table 2 Stochastic Modelling Results – Percentile Average Flows (ML/a) (May to April Water Year)

Percentile	5%	2%	1%	0.5%	0.1%	0.015%
Approx. Frequency	**1 in 20 years**	**1 in 50 years**	**1 in 100 years**	**1 in 200 years**	**1 in 1000 years**	**1 in 2000 years**
Flow Duration						
3 year	55,176	38,189	29,750	23,683	14,667	12,216
4 year	69,454	50,210	39,896	33,746	21,404	16,538
5 year	82,654	60,209	49,470	40,310	28,304	23,688

2.4 Climate Variability

The Drought Management Plan justifies the worst-3-year inflow assumption in the Drought Model (which runs for 5 years) due to the unquantifiable effect of climate variability. The term “climate variability” has been used in preference to “climate change” in this context because, particularly in Australia where there is limited history of meteorological information, there is not enough evidence at Awoonga Dam to determine if recent low flows are a result of larger than expected rate of global climate change or natural (although large) variation in Australian climate. “Climate change” implies a longer term continual trend. Australia experiences a wide range in climate conditions and long periods of low rainfall have occurred in the past even within our short historical information period. The degree to which recent climate variability is caused by climate change is not a subject of this study.

In past hydrologic studies, climate variability has been accounted for by conservative assumption of lower flow to accommodate a worst case scenario, such as a percent reduction in inflow. It may be more suitable to model an increase in average duration between major inflow events.

The historical data at Awoonga Dam shows higher average flows over 4 years than 5 years and 7 years than 8 years. This indicates that large events occur more frequently 4 and 7 years apart. This apparent periodicity may be due more to the characteristics of the short period of record used to obtain the statistics. Climate variability may increase this periodicity of large events beyond the 5 years of the model and effectively reduce worst average flows for 4 and 5 years.

The stochastically generated data does not have the quality of an average periodicity of events. This is evidenced by the non-exceedance probability of the flows for the duration they occur. The worst flows for most periods have approximately 0.5 to 0.6% non-exceedance, but 4 and 7 years have 1.6% and 2.2% respectively.

To account for climate variability in a model that runs for 5 years it would be advisable to either choose a worst average flow for a period less than 4 years (i.e. 3 years) or choose the 1 percentile flow (of stochastic data) for 4 years. The former is more conservative than the latter and does not require regular generation of new stochastic data. Low percentiles of stochastic data are sensitive to prolonged years of low flow such as that occurring during a drought.

2.5 Appropriate Inflow Assumption

2.5.1 Water Restriction Trigger Modelling

When modelling restriction triggers, the worst-3-year inflow assumption proposed for use in the GAWB drought model (23,633 ML/a) is considered conservative even with regard to accounting for climate variability. Stochastic modelling indicates that there is a 0.5% (1 in 200 year event) chance that the average inflow will be less than this in 3 years. Stochastic modelling also indicates that there is a 0.05% (1 in 2,000 year event) chance that the average inflow will be less that this in 5 years. This indicates a very conservative assumption for use in a model which runs for 5 years.

Accounting for climate variability, a worst inflow period of 5 years or less should be used, however use of the worst-4-year average flow should be avoided due to the peak of average inflow for this period. Also this peak may change period due to climate variability.

An inflow assumption of the 1 percentile of average 4 year flow would be suitably conservative and would also avoid overestimation of the inflow due to periodicity of large events. This percentile is based on stochastic data. If this inflow assumption is used, new stochastic data should be generated every few years, particularly if the worst-4-year inflow decreases. Stochastic data generation should aim to preserve the low percentiles.

The 1 percentile worst-4-year inflow is **39,896 ML/a** for the May to April water year.

2.5.2 Augmentation Trigger Modelling

Due to the added impact of increased water costs resulting from augmentation triggering, a less conservative inflow assumption should be used. Currently the Drought Management Plan indicates that augmentation would be triggered at the same time as first level Supply Restrictions at 48 months Time Frame from Failure. Augmentation would require 2 years for construction. The resulting model duration would be 5 years including 2 years buffer. If it is not required that augmentation triggering coincide with first level restrictions, a worst-5-year or 1 percentile 5 year (whatever is lower) inflow would be a more suitable assumption than the worst-3-year assumption proposed.

Queensland Competition Authority have asked Cardno to consider scenarios of maximum augmentation trigger deferral which will meet GAWB's objective of deferring dam failure by at least 2 years. If augmentation triggering is deferred significantly beyond the time of first level restrictions, then a more conservative inflow assumption should be used. The duration of this model would be a minimum of 4 years including 2 years failure deferral and 2 years construction time. A 1 percentile of average 4 year flow assumption would be suitable in this case.

3. BENEFITS OF AUGMENTATION OPTIONS

3.1 Background

Queensland Competition Authority would like to present a range of augmentation options along with a measure of their risk to the customers for consideration. Currently a 30,000 ML/a Gladstone-Fitzroy pipeline is the preferred augmentation option. Larger pipelines would defer failure for longer or may be triggered later, but would cost more. Smaller pipelines would defer failure for a lesser time or would be triggered earlier, but would cost less.

The GAWB Drought Model was used to estimate failure and triggering deferral times using different inflow assumptions and augmentation options. For the purpose of this exercise, failure was defined as the time when Emergency Restrictions are imposed, as this is considered failure by high priority users.

For the modelling, an initial dam elevation of 33.75m (recorded 12 May 2008) was assumed and the start date set to May 2008. The demands were also updated to those provided by QCA in an email of 29 April 2008 and are shown in Table 3 below.

Table 3 GAWB - Hydrology Model Inputs - Demand Scenarios

Year	Low	High
2007	50,966	53,337
2008	51,024	52,775
2009	51,208	53,682
2010	57,143	63,260
2011	57,448	78,655
2012	61,576	80,467
2013	64,129	82,340
2014	65,230	85,139
2015	65,535	88,036
2016	65,846	91,031
2017	71,162	94,128
2018	71,484	97,334
2019	72,311	100,648
2020	72,644	104,079
2021	72,983	107,625
2022	70,827	111,294
2023	71,178	115,090
2024	71,535	119,016
2025	71,899	123,078
2026	72,269	127,140

3.2 Deferral of Failure

The current proposal is to trigger augmentation in conjunction with first level Supply Restrictions. Augmentation implementation was assumed to be exactly 2 years from first level Supply Restrictions to account for the construction period. A water year of May to April was used for the inflows. Rainfall for the 1 percentile 4 year inflow was assumed to be the worst-4-year inflow rainfall proportioned approximately according to the inflow ratio (85%). Table 4 presents the results from the GAWB Drought Model of failure deferral for a range of Gladstone-Fitzroy pipeline capacities based GAWB's approach of a common trigger date for restrictions and construction. A range of possible deferrals are shown for the range of projected demands.

Table 4 Failure Deferral Time (Years)

Inflow Assumption (May-Apr water years)	Inflow (ML/a)	Gladstone-Fitzroy Pipeline Capacity (ML/a)			
		20,000	30,000	46,000	60,000
Worst-3-year average	24,161	0.58 – 1.33	1.41 – 3.17	3.41 - No failure within simulation period	6.41 - No failure within simulation period
Worst-4-year average	46,432	1.08 – 4.0	2.92 - No failure within simulation period	6.92 - No failure within simulation period	10.92 - No failure within simulation period
Worst-5-year average	42,994	1.16 – 3.25	2.33 - No failure within simulation period	6.16 - No failure within simulation period	10.16 - No failure within simulation period
1 percentile of 4 year average	39,896	1.00 – 2.91	2.67 – 7.0	5.67 - No failure within simulation period	8.83 - No failure within simulation period

3.3 Deferral of Triggering Augmentation

Queensland Competition Authority wishes to consider deferral of augmentation trigger time such that there is a greater chance of higher inflows occurring and preventing the need for augmentation. Modelling was carried out to calculate the minimum timing for triggering construction to meet GAWB's objective of deferring dam failure by at least 2 years.

Table 5 presents the results from the GAWB Drought Model of augmentation trigger deferral for a range of Gladstone-Fitzroy pipeline capacities. Also, a range of possible deferrals are shown for the range of projected demands. Augmentation deferral is expressed as both years deferral and months Time Frame from Failure. Note that the projected failure time is calculated based on restricted demands and actual failure (reaching dead storage not time of implementation of Emergency Restrictions). Also, in some cases deferral of dam failure was significantly more than 2 years.

Table 5 Augmentation Trigger Deferral Time

Inflow Assumption (May-Apr water years)	Inflow (ML/a)	Gladstone-Fitzroy Pipeline Capacity (ML/a)							
		20,000		30,000		46,000		60,000	
		Years	Months from Failure	Years	Months from Failure	Years	Months from Failure	Years	Months from Failure
Worst-3-year average	24,161	Not possible to defer failure 2 years		1.25 (max)*	40 (min)*	1.42 – 2.25**	37 – 28**	2.34 - 2.25**	26 – 28**
Worst-4-year average	46,432	1.83 (max)*	30 (min)*	1.08 – 2.25**	39 – 25**	2.17*** – 2.34**	26***- 24**	2.25*** – 2.34**	25*** – 24**
Worst-5-year average	42,994	1.50 (max)*	41 (min)*	1.08 – 2.58**	44 – 28**	2.41*** – 2.83**	28*** - 25**	2.58*** - 2.92**	26*** – 24**
1 percentile of 4 year average	39,896	1.25 (max)*	43 (min)*	0.25 – 2.58***	49 – 27***	2.17 – 2.75**	26 – 25**	2.25*** – 2.75**	25*** – 25**

* Not possible to defer failure 2 years for high demand
** No failure within simulation period for low demand
*** Defers failure significantly longer than 2 years

4. EVAPORATION AND SEEPAGE LOSS ASSUMPTION

GAWB's Drought Model, AWSIM-D, includes evaporation loss and seepage assumptions based on advice provided by Hydro Tasmania Consulting in their report of January 2006 (Hydro Tasmania Consulting, 2006). The report describes a review of dam levels during 7 zero inflow months within the period 2000 to 2005. SILO Data Drill data was used for pan evaporation values, and based on the dam levels during the 7 suitable months a Pan Factor of 0.8 and seepage of 1mm per day was estimated.

Connell Wagner letter to GAWB of 14 May 2007 (Comments on Evaporation from Lake Awoonga and Implications for Water Restrictions) reports that in drought conditions total loss due to evaporation and seepage is approximately 100% of the current (2005/2006) demand when the dam level is at about 32m.

It is important to estimate evaporation and seepage loss reliably in the model as it accounts for a large portion of the outflow from the dam. Use of SILO data for evaporation is common for dam water balance studies and is considered acceptable. Estimating Pan Factor and seepage from zero flow months is a suitable approach. Estimating 1mm per day seepage is also common for dam water balance studies and is considered acceptable. The model actually uses 30mm per month which is close to 1mm per day.

5. REFERENCES

GAWB (2007)	*Drought Management Plan.* Gladstone Area Water Board, 12 September 2007
GAWB (2007b)	*Submission to the Queensland Competition Authority Fitzroy River Contingency Infrastructure Part (b) - Augmentation Triggers.* Gladstone Area Water Board, 21 December 2007
GAWB (2007c)	*2007 Update of GAWB's Drought Model: AWSIM-D Documentation of Review Process, Version 2*. Gladstone Area Water Board, 14 June 2007
Hydro Tasmania Consulting (2006)	*GAWB System Optimisation Development of Inflows to Awoonga Dam.* Hydro Tasmania Consulting, 30 January 2006
Mein and McMahon (1986)	*River and Reservoir Yield.* Mein and Mc Mahon, 1986
Synergies (2007)	*Gladstone Area Water Board Review of Inflow Assumptions Drought Management Plan*, Synergies Economic Consulting, May and December 2007
Tickle (1985)	*Computer Program WT89 – Synthetic Streamflow Generation by the Method of Fragments – Program Manual.* Tickle, 1985

FIGURES

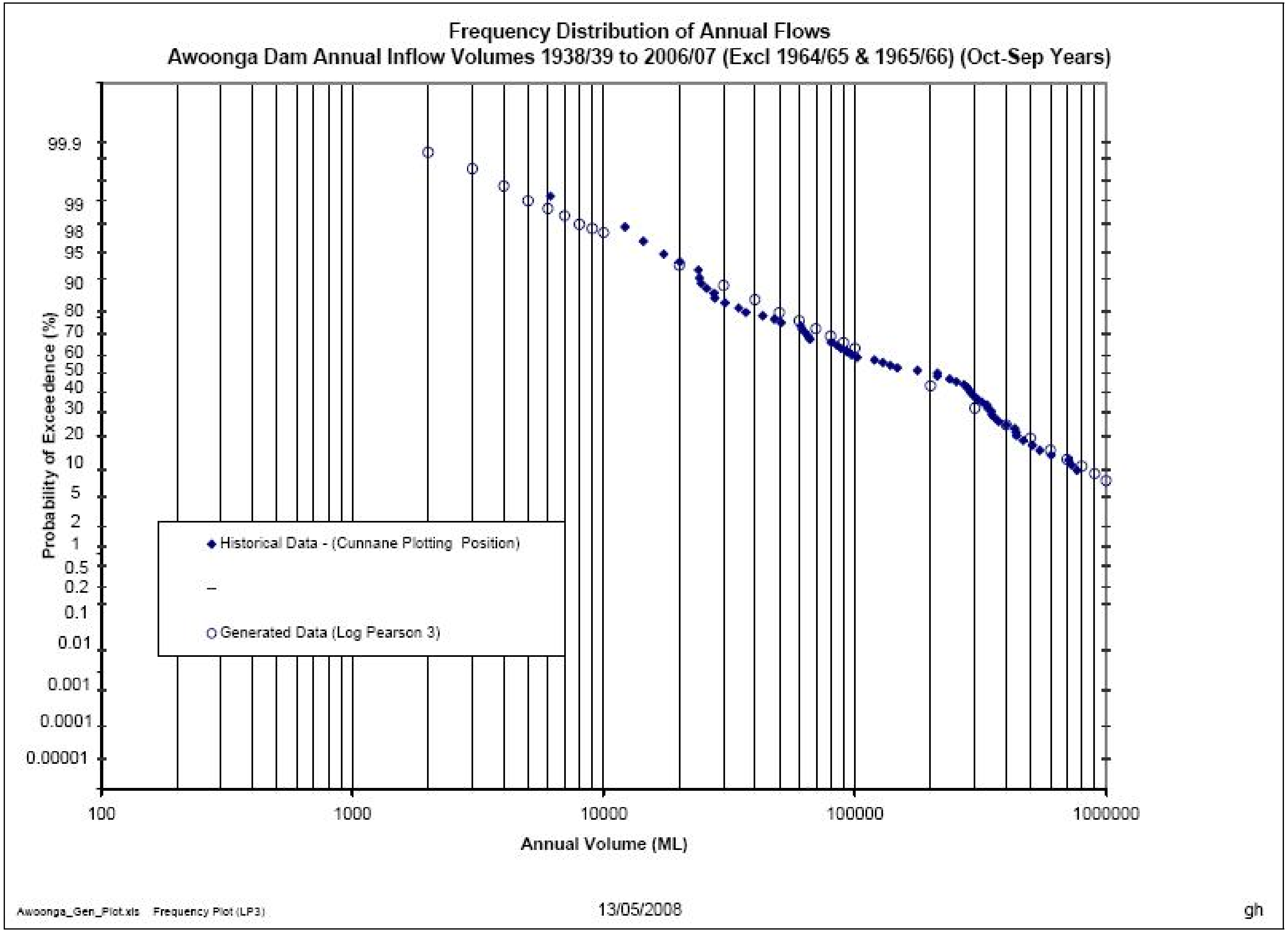

Figure 1 Frequency Distribution of Annual Flows – October to September water years

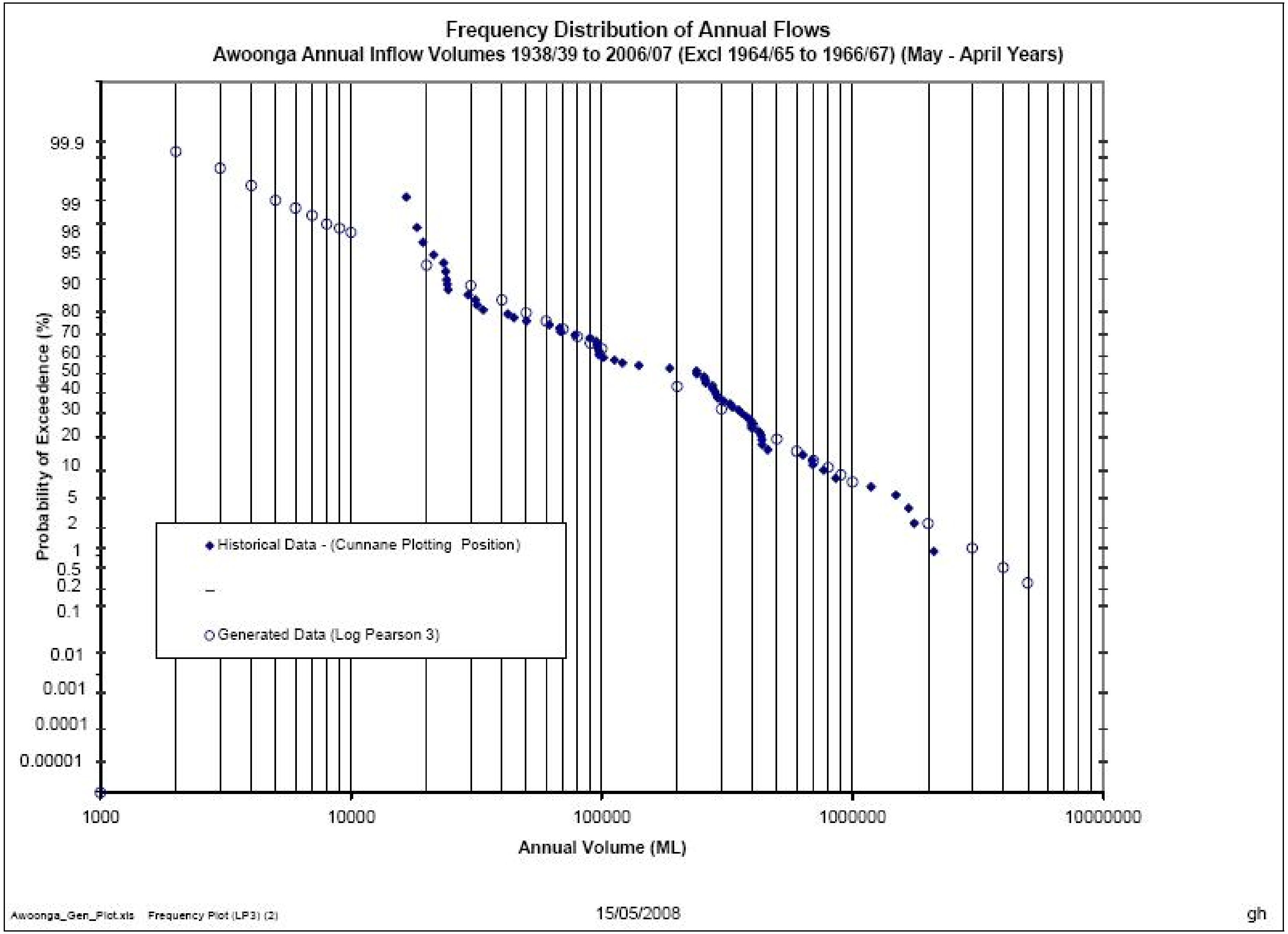

Figure 2 Frequency Distribution of Annual Flows – May to April water years