INTRODUCTION

This Excel spreadsheet has been prepared to assist the sizing of water distribution storages using a stochastic methodology. It is based on three papers published in 2018 in the Australian Water Association e-journal:

- *Water Supply Peaking Factor Stochastics* (Vol 3, No. 3)
- *Water Supply Risk Assessments Using Stochastic Peaking Factors* (Vol 3, No. 3)
- *Sizing Water Supply Distribution Storages for Persistence and Emergency Demands* (Vol 3, No. 4)

The spreadsheet includes three worksheets:

- Worksheet 1, *Reservoir Storage*
- Worksheet 2, *Failure Persistence Storage*
- Worksheet 3, *South East Queensland Peaking Factors*
- Worksheet 4, *Example Layout*

Worksheets 1 and 2 are protected apart from their data input areas. The protection password is "Universal". Those data input areas are all highlighted in a pink colour. Guidance about the worksheet inputs and outputs follows.

RESERVOIR STORAGE WORKSHEET

Inputs

- Residential (Cell J19) and non - residential (Cell J20) equivalent person numbers served by the distribution storage.
- Equivalent person per capita daily demand including non-revenue water (Cell J21).
- Inflow in ML per day to distribution system storage (Cell J34).
- Storage diameter in metres (Cell J38). An equivalent diameter is used if the storage is not circular in plan area.
- Dead water allowance depth in mm (Cell J39). A dead water allowance of 300 to 500 mm is often adopted by operators.

Outputs

- Average Day (AD) demand (Cell J23). Calculated as:

$$AD = (Residential\ EP + Non - residential\ EP)\ \times EP\ per\ capita\ demand \tag{1}$$

- Level of Service (LOS) (Cell J26). Calculated as:

$$LOS = 10 + AD\ /\ 6 \tag{2}$$

- Maximum Day (MD) peaking factor (Cell J29). Determined by interpolation from 100 percentile section Worksheet 3 using AD and LOS values.
- 30 Day peaking factor (Cell J30). Determined by interpolation from 100 percentile section of Worksheet 3 using AD and LOS values.
- Daily fluctuation storage (Cell J33). Calculated as:

$$Daily\ fluctuation\ storage = 4/24 \times 2 \times AD \tag{3}$$

- Inflow/AD ratio (Cell J35). Calculated as:

$$Ìnflow/AD\ ratio = \frac{Inflow}{AD} \tag{4}$$

- No failure persistence storage (Cell J36). Calculated as:

$$No\ failure\ persistence\ storage = \left(MD \times Critical\ Persistence\ Period^{(1+b)} - Critical\ Persistence\ Period\ \times\ \frac{Inflow}{AD}\right) \times AD \qquad (5)$$

Where $Critical\ Persistence\ Period = \left[\dfrac{Inflow/AD}{MD\ Peaking\ Factor\ \times\ (1+b)}\right]^{(1/b)}$ \qquad (6)

and $b = Log_{10}$ (30 Day Peaking Factor / MD Peaking Factor) / Log_{10} (30) \qquad (7)

- Failure persistence storage (Cell J37). Calculated in Worksheet 2 (Cell Z3).
- Dead water storage (Cell J40). Calculated as:

$$Dead\ water\ storage\ =\ \pi \times \frac{Storage\ diameter^2}{4,000} \times \frac{Dead\ water\ depth}{1,000} \qquad (8)$$

- Total minimum required storage (Cell J41). Calculated as:

$Total\ minimum\ required\ storage = Daily\ fluctuation\ storage + Maximum\ (No\ failure\ persistence\ storage, Failure\ persistence\ storage) + Dead\ water\ storage$ \qquad (9)

FAILURE PERSISTENCE STORAGE WORKSHEET

INPUTS

INPUT SEGMENTS - Supply system details (Cells C38 to L377):

Figure 1 below shows a typical supply system with a source which has a LOS much in excess of that required for the Figure 1 water supply area (calculated in Worksheet 1 in Cell J26).
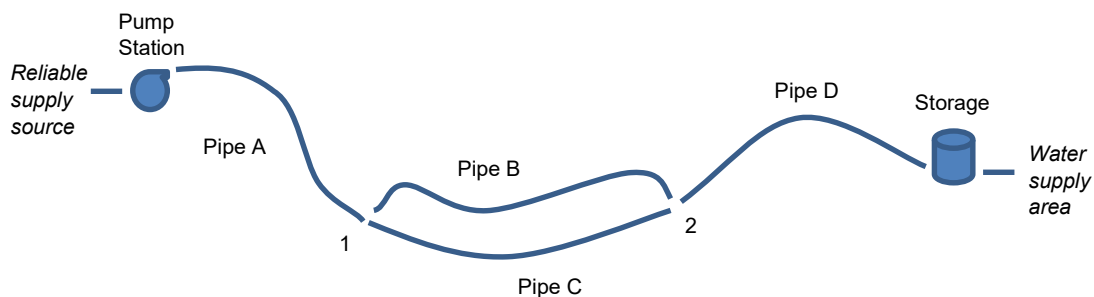
Figure 1   Typical Supply System

For this illustration, the pipeline from the Reliable Supply Source to the Pump Station, the duty pump, and its power supply have been entered in the Example worksheet as shown below:

Failure Investigation Year	2036		FAILURE PROBABILITIES AND OUTAGE TIMES							
Failure Scenario	Failure Type	Failure Extent	Diameter	Length	Material	Age	Failure Event Probability	5% Outage Time	50% Outage Time	95% Outage Time
		Full-Part	*mm*	*Lm*	*#*	*Years*	*#*	*Hours*	*Hours*	*Hours*
INPUT SEGMENTS										
Pipe from reliable supply to pump station										
1	Pipe	Full	400	15.118	MS	89	0.00028	4.61	10.46	16.75
2	Pipe	Full	400	45.199	MS	89	0.00083	4.61	10.46	16.75
3	Pipe	Full	400	15.407	MS	58	0.00019	4.61	10.46	16.75
Combination of elements		Full								
Pump Station Duty Pump										
Duty pump	Pump	Part					0.05000	3.00	10.00	240.00
Duty pump motor	Pump	Part					0.08240	8.00	15.00	22.00
Duty pump reflux valve	Pump	Part					0.00570	2.00	8.00	16.00
Swichboard duty pump circuit breaker	Pump	Part					0.00420	2.00	4.70	7.40
Swichboard duty pump starter	Pump	Part					0.01752	8.00	39.00	70.00
Duty pump cable	Pump	Part					0.00923	4.00	8.90	13.80
Combination of elements		Part								
Pump Station Power Supply										
Power Supply	Power	Full					2.20000	1.00	2.00	7.00
Swichboard power supply cable	Power	Full					0.00388	8.00	15.00	22.00
Swichboard cable terminations	Power	Full					0.00013	2.00	4.00	6.00
Swichboard bus	Power	Full					0.00080	8.00	27.00	46.00
PLC/Telemetry control	Power	Full					0.00820	3.00	6.00	9.00
Combination of elements		Full								

Descriptions of the inputs to this figure follow:

- Failure Investigation Year (Cell C38) - Data description only and does not affect subsequent calculations. However, in the Example worksheet the pipe ages are linked to this cell to allow the impact of system aging to be assessed.
- Failure Scenario Column - Data description only and does not affect subsequent calculations.
- Failure Type Column – Data description only and does not affect subsequent calculations. However, in the Example worksheet the algorithm for calculating the Failure Event Probability is linked to the Failure Type being a "Pipe" or "Valve".
- Failure Extent Column – Apart from the column remaining blank, only the words "Full" or "Part" are entered in this column. No subsequent failure and outage calculations for the represented element are undertaken if the column is left blank. If the word "Part" is inserted, subsequent failure and outage calculations are undertaken but the results are not included when calculating the storage required to accommodate the element failure. If the word "Full" is inserted, subsequent failure and outage calculations are undertaken, and the results are incorporated when calculating the storage required to accommodate the element failure.

- Diameter Column – Data description only and does not affect subsequent calculations. However, in the Example worksheet the algorithm for calculating the Failure Event Probability for Pipes and Valves is linked to the Diameter of the element.

- Length Column – Data description only and does not affect subsequent calculations. However, in the Example worksheet the algorithm for calculating the Failure Event Probability for Pipes is linked to the Length of the element.

- Material Column – Data description only and does not affect subsequent calculations. However, in the Example worksheet the algorithm for calculating the Failure Event Probability for Pipes is linked to the Material of the element.

- Age Column – Data description only and does not affect subsequent calculations. However, in the Example worksheet the algorithm for calculating the Failure Event Probability for Pipes is linked to the Age of the element.

- Failure Event Probability Column – This is the average failure rate of the element and influences subsequent calculations in the worksheet. It is inserted by the User based on known historical failure rates. However, in the Example worksheet, an algorithm has been provided which calculates the failure rate of the element based on whether it is a Pipe or Valve, and its diameter for a Valve and its diameter, length, material and age for a Pipe. Failure rates have also been provided for pump and switchboard components based on published values but the power supply failure rates are site specific and need to be sourced from local historical records.

- 5% Outage Time Column – This is the 5 percentile outage time for the element failure. The outage time is the total time from failure to reinstatement and includes the time for its identification, repair and reinstatement. It is by the User based on known historical outage times. However, in the Example worksheet, an algorithm has been provided which calculates the outage time of the element based on whether it is a Pipe or Valve, and its diameter. Outage times have also been provided for pump and switchboard components based on published values but the power supply outage times are site specific and need to be sourced from local historical records.

- 50% Outage Time Column – As for the 5 percentile outage, this is the 50 percentile outage time for the element failure.

- 95% Outage Time Column - As for the 5 percentile outage, this is the 95 percentile outage time for the element failure.

COMBINATIONS - Supply system details (Cells B380 to L598). Three combination options have been provided. Other element combinations can be achieved by using multiples of these options:

- Dual Parallel Combination – This combination allows for two parallel segments to be combined. The parallel segments are identified by their Excel worksheet row numbers which are input in Column L. The inputs to Column B are data descriptions and do not affect subsequent calculations. As an illustration, the figure below is copied from the Example worksheet and shows the combination of the duty and standby pumps in the pump station.

Pump Station (Dual Parallel Combination)					
Duty pump		Part		Row Number	66
Standby pump		Part		Row Number	66
Combination of elements		Full			

- Triple Parallel Combination – This combination allows for three parallel segments to be combined. The parallel segments are identified by their Excel worksheet row numbers which are input in Column L. The inputs to Column B are data descriptions and do not affect subsequent calculations.

• Summation Combination – This combination allows for up to ten elements to be combined in a single series. The segments are identified by their Excel worksheet row numbers which are input in Column L. The inputs to Column B are data descriptions and do not affect subsequent calculations. As an illustration, the figure below is copied from the Example worksheet and shows the combination of all the elements in the Figure 1 supply system including the combined parallel segments.

| Summation combination of all segments					
Pipe from reliable supply to pump station		Full		Row Number	54
Duty and standby pumps		Full		Row Number	383
Power supply		Full		Row Number	78
Pipes B & C		Full		Row Number	387
Pipe A, 1		Full		Row Number	90
Pipe A, 2		Full		Row Number	102
Pipe D		Full		Row Number	138
				Row Number	
				Row Number	
				Row Number	
Combination of elements		Full			

FAILURE ENVELOPE CURVE

• Failure Envelope Curve Coefficient K (Cell T2) – K coefficient for envelope curve.
• Failure Envelope Curve Coefficient a (Cell T3) - a coefficient for envelope curve.

Coefficients K and a are adjusted by trial and error to obtain a failure envelope which best fits the generated Outage versus Failure Return Period data points.

OUTPUTS FOR ELEMENTS

• Failure Rate (Cells AB44 to AB378 , AF45 to AF378, etc) –A failure rate is calculated for each completed failure scenario element and for failure percentiles ranging from 2% to 98% at 2% increments. (The failure percentiles are shown in Cells AB37, AF37, etc). As an illustration, **Figure 2** shows a typical failure percentile versus outage time plot.
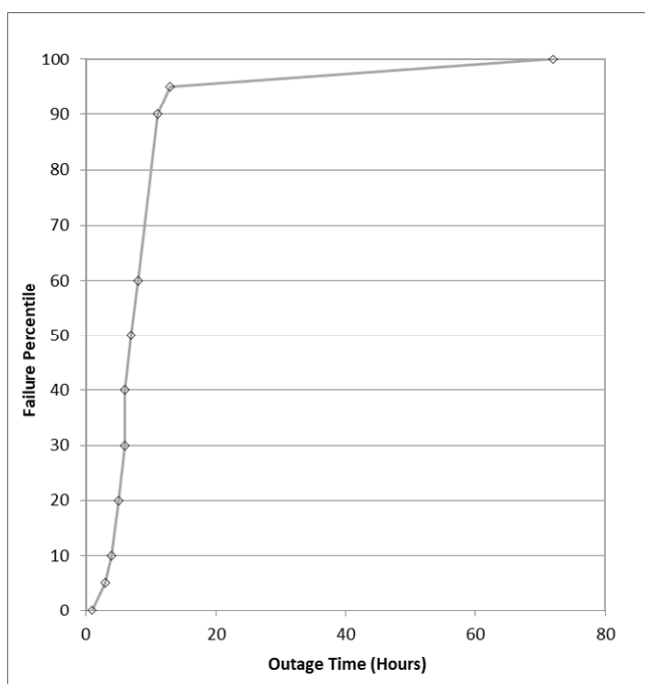
Figure 2   Typical Failure Percentile Outage Plot

The outage time for the 10 percentile failure rate on Figure 2 is about 3 hours but is interpreted as **90 percent** of the failures having outages of less than or equal to 3 hours where the 100% failure percentile equals the Failure Event Probability. The failure rate is therefore calculated as:

$$Failure\ Rate = (100 - Failure\ Percentile) \times Failure\ Event\ Probability \tag{10}$$

And $Failure\ Rate\ (Years) = \frac{1}{Failure\ Rate}$ (11)

- Unavailability (Columns AD, etc to HN) – Unavailability is the average number of hours per annum that an element has failed and is calculated as:

$$Unavailability = \frac{Outage}{Failure\ Rate\ (Years)} \tag{12}$$

Where the Outage is calculated by interpolating between and extrapolating from the provided 5% and 50% Outage Times up to the 90% failure percentile. Outages for greater failure percentiles are calculated by interpolating between and extrapolating from the so calculated 90% failure percentile outage time and the provided 95% Outage Time.

- Outage (Columns AE, etc to HO) – Calculated as:

$$Outage = Unavailability \times Failure\ Rate\ (Years) \tag{13}$$

OUTPUTS FOR COMBINATIONS OF ELEMENTS

Three types of element combinations are provided for by Worksheet 2, i.e. Dual Parallel Combination, Triple Parallel Combination and Summation Combination. The Failure Rate, Unavailability and Outage outputs for these combinations follow:

Dual Parallel Combination

- Failure Rate – Calculated for two parallel elements A and B as:

$$Failure\ Rate\ =\ Failure\ Rate\ (Element\ A) \times Failure\ Rate\ (Element\ B) \tag{14}$$

And Failure Rate (Years) is calculated using Equation (11).

- Unavailability – Calculated for two parallel elements A and B as:

$$Unavailability = Minimum\ \left(\frac{Unavailability\ (Element\ A)}{Failure\ Rate\ (Element\ A)}, \frac{Unavailability\ (Element\ B)}{Failure\ Rate\ (Element\ B)}\right) \times$$
$$Failure\ Rate\ (Element\ A) \times Failure\ Rate\ (Element\ B) \tag{15}$$

- Outage – Calculated for two parallel elements A and B using Equation (13) where the Failure Rate and Unavailability have been calculated using Equations (14) and (15).

Triple Parallel Combination

- Failure Rate – Calculated for three parallel elements A, B and C as:

$$Failure\ Rate\ =\ Failure\ Rate\ (Element\ A) \times Failure\ Rate\ (Element\ B) \times$$
$$Failure\ Rate\ (Element\ C) \tag{16}$$

And Failure Rate (Years) is calculated using Equation (11).

- Unavailability – Calculated for two parallel elements A and B as:

$$Unavailability = Minimum\left(\frac{Unavailability\ (Element\ A)}{Failure\ Rate\ (Element\ A)}, \frac{Unavailability\ (Element\ B)}{Failure\ Rate\ (Element\ B)}, \frac{Unavailability\ (Element\ C)}{Failure\ Rate\ (Element\ C)}\right) \times$$
$$Failure\ Rate\ (Element\ A) \times Failure\ Rate\ (Element\ B) \times Failure\ Rate\ (Element\ C) \qquad (17)$$

- Outage – Calculated for three parallel elements A, B and C using Equation (13) where the Failure Rate and Unavailability have been calculated using Equations (16) and (17).

Summation Combination

- Failure Rate – Calculated for up to ten elements in series as:

$$Failure\ Rate\ =\ Failure\ Rate\ (Element\ 1) +$$
$$Failure\ Rate\ (Element\ 2) + \ldots\ldots + Failure\ Rate\ (Element\ 10) \qquad (18)$$

   And Failure Rate (Years) is calculated using Equation (11).

- Unavailability – Calculated for up to ten elements in series as:

$$Unavailability\ =\ Unavailability\ (Element\ 1) +$$
$$Unavailability\ (Element\ 2) \ldots\ldots + Unavailability\ (Element\ 10) \qquad (19)$$

- Outage – Calculated for up to ten elements in series using Equation (13) where the Failure Rate and Unavailability are calculated using Equations (18) and (19).

MAXIMUM FAILURE PERSISTENCE STORAGE

The full failure outages and their respective failure rates (Years) generated by these calculations are automatically tabulated in Cells HQ44 to LJ599 and plotted on **Figure C**. The outputs which make up those tabulations follow.

- AD Column – AD value copied from Worksheet 1 (Cell J23)
- LOS Column – LOS value copied from Worksheet 1 (Cell J25)
- Failure Rate Column – Failure Rate (Years) generated from 1, 2 and 4 years at intervals of 0.5, 1 and 2 years respectively for LOS values of <=15, <=30 and >30.
- Outage Column – Outage times calculated as:

$$Outage\ =\ K \times Failure\ Rate\ ^{a}\text{for fitting failure envelope curve to Figure C.}$$

   Where coefficients *K* and *a* (Worksheet 2, Cells T2 and T3) are user inputs .

- Demand Percentile – Calculated as follows:

$$Demand\ Percentile = 1 - \left(1 - \frac{1}{Failure\ Rate}\right)^{Level\ of\ Service} \qquad (20)$$

   Where the Failure Rate is the Failure Rate Column value and the Level of Service is the LOS Column value.

- MD Peaking Factor Column - Determined by interpolation from Worksheet 3 using AD Column, LOS Column and Demand Percentile Column values.
- 30 Day Peaking Factor Column - Determined by interpolation from Worksheet 3 using AD Column, LOS Column and Demand Percentile Column values.
- *b* Column – Calculated using Equation (7).
- Inflow Column - Inflow value copied from Worksheet 1 (Cell J34)

- Critical Persistence Period Column – Calculated using Equation (6).
- Inflow/AD Ratio Column - Inflow value copied from Worksheet 1 (Cell J35)
- Full Failure Storage Column – Calculated as follows:

$$Emergency\ Persistence\ Storage = \Big(MD\ Peaking\ Factor \times$$
$$Critical\ \ Persistence\ Period^{(1+b)} - (Critical\ Persistence\ Period - Outage) \times$$
$$\frac{Inflow}{AD}\ Ratio\Big) \times AD \qquad\qquad (19)$$

Where the Critical Persistence Period cannot be less than the Outage time, and the MD Peaking Factor, Critical Persistence Period, Outage, Inflow/AD and AD values are taken from their respective columns.

- Maximum Failure Persistence Storage (Cell Z3) – Calculated as the maximum of the Full Failure Storage Column values.

EXAMPLE LAYOUT WORKSHEET

An example layout is shown on this worksheet. The model file which this user guidance relates to is Example Risk Tree (E-Journal Paper).

The example model is for a simple hypothetical pumped supply from a reliable source to a storage tank. The tank serves a total supply area of 36,700 EP.

The example shows that the storage tank needs to hold a minimum of 10.56 ML. That volume is the sum of the tank's dead water daily fluctuation storage volume plus the greater of the no failure and failure persistence storages (Worksheet 1, Cells J36 and J37). In this example the failure persistence storage is the greater.

Figure C and the adjacent failure persistence storage table on Worksheet 2 shows that the maximum failure persistence storage is required for a failure which has a failure rate of only once in two years. Such failures, for this example, are caused by relatively frequent but short duration power outages.