Assets Planning and Delivery Group
Engineering

DESIGN GUIDELINE DS231

Evaporation ponds

VERSION 1
REVISION 1

NOVEMBER 2022

FOREWORD

The intent of Design Standards and Design Guidelines is to specify requirements that assure effective design and delivery of fit for purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation safety and service standards. Design standards and guidelines are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards and Guidelines draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction, and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of the Western Australia's Work Health and Safety (General) Regulations 2022 to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

Overview of Western Australia’s Work Health and Safety (General) Regulations 2022 (dmirs.wa.gov.au)

Enquiries relating to the technical content of a Design Standard or Design Guideline should be directed to the Senior Principal Engineer, Water Resource Recovery, Engineering. Future Design Standard and Guideline changes, if any, will be issued to registered Design Standard and Guideline users as and when published.

Head of Engineering

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

Users should use and reference the current version of this document.

DISCLAIMER

This Guideline is provided for use only by a suitably qualified professional design engineer who shall apply the skill, knowledge and experience necessary to understand the risks involved and undertake all infrastructure design and installation specification preparation work.

Water Corporation accepts no liability for any loss or damage that arises from anything in the Standards/Specifications including any loss or damage that may arise due to the errors and omissions of any person. Any person or entity which relies upon the Standards/Specifications from the Water Corporation website does so that their own risk and without any right of recourse to the Water Corporation, including, but not limited to, using the Standards/Specification for works other than for or on behalf of the Water Corporation.

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Any interpretation of anything in the Standards/Specifications that deviates from specific Water Corporation Project requirements must be referred to, and resolved by, reference to and for determination by the Water Corporation's project manager and/or designer for that particular Project.

REVISION STATUS

This Guideline was developed by Derek Wilson (EBU-ADV-WRR)

The revision status of this Guideline is shown section by section in the table below.

REVISION STATUS

SECT.	VER. /REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	REVIEWED	APPROVED
1	1/0	10/08/22	All	New Version/Revision	Derek Wilson	Derek Wilson
2	1/0	10/08/22	All	New Version/Revision	Derek Wilson	Derek Wilson
3	1/0	10/08/22	All	New Version/Revision	Derek Wilson	Derek Wilson
4	1/0	10/08/22	All	New Version/Revision	Derek Wilson	Derek Wilson
4	1/1	08/11/22	14	Link to Evaporation Ponds Sizing spreadsheet added to section 4.2	Derek Wilson	Derek Wilson

DESIGN GUIDELINE DS231

EVAPORATION PONDS

CONTENTS

Section *Page*

1 SCOPE AND GENERAL

1.1 Purpose

The Corporation has developed a suite of Design Standards and Guidelines. Designers shall comply with these Standards and Guidelines for the definition, design and specification of water services assets being acquired for the Corporation.

The purpose of the Design Standards and Guidelines is to provide:

a) Standards and guidelines applicable in the design of Corporation assets,

b) Explanatory or specific design information, and

c) Information relating to the Corporation preferences and practices which have evolved from more than 100 years of water industry experience.

1.2 Scope

This Design Guideline is focussed on the design of Evaporation Ponds for the disposal of treated water from municipal Activated Sludge plants as well as Waste Stabilisation Ponds (WSPs). It also includes information on slow infiltration in combination with evaporation. Rapid Infiltration Basins are not covered in this document and are covered by a separate design guideline

The intent and approach of this Guideline is to provide a clear design approach to sizing of evaporation ponds. More information on the practical aspects of pond design as such can be found in DS230 Design of Waste Stabilisation Ponds.

1.3 Design Process

The design process to be followed by Designers is documented in the Corporation's Engineering Design Process and applicable Design Standards.

1.4 Standards

All materials and workmanship shall comply with latest revisions of the relevant codes and standards.

Water Corporation Strategic Product Specifications (SPS), or in their absence the latest editions of Australian Standards, or Water Services Association Australia (WSAA) Codes, shall be referenced for design and specification. In the absence of relevant Australian or WSAA Codes, relevant international or industry standards shall be referenced

In the event of conflict between standards or codes, the following hierarchy shall be used:

1. Statutory requirements of Australia and the State of Western Australia.
2. Water Corporation Strategic Product Specifications, design and construction standards.
3. Australian Standards and Codes of Practice, or Water Services Association Australia (WSAA) Codes.
4. Other international standards or codes acceptable to Australian statutory authorities.
5. Alliance preferred alternative international standards or codes acceptable to Australian statutory authorities as described above.
6. Original Equipment Manufacturers (OEM) design standards.

1.5 Referenced Documents

Documents referred to in this Design Guideline are listed in Appendix A of this Guideline.

For Corporation Standards refer to Section 7 of DS30-01 Glossary - Mechanical.

For Australian and International Standards refer to Section 8 of DS30-01 Glossary - Mechanical.

1.6 Mandatory Requirements

The use of the imperative “shall” denotes a mandatory requirement. Use of verbs other than “shall” such as “will”, “should”, “may” indicates recommended practice.

1.7 Nomenclature

The symbols listed below relate specifically to design calculations for evaporation ponds.

AEP	annual exceedance probability
BoM	bureau of meteorology
BWL	bottom water level
E	Evaporation
EP	equivalent persons
IFD	Intensity-Frequency-Duration
P	precipitation (rainfall)
PWWF	peak wet weather flow
Q	Flow
SS	suspended solids
TSS	total suspended solids
TWL	top water level
WSP	waste stabilisation pond
WRRF	Water Resource Recovery Facility
WWTP	wastewater treatment plant

1.8 Glossary of Terms

The terms listed below relate specifically to design calculations for evaporation ponds.

annual exceedance probability	(Abbreviated AEP) is the probability that a value will exceed a specified value in a time period. AEPs are to be expressed as an exceedance probability using percentage probability; for example a design rainfall will be described as having a 1% AEP.
average annual daily flow	(Abbreviated AADF) This is the total annual flow reaching the WWTP in a calendar year divided by 365. It is useful for understanding annual plant throughput but should not be used as a basis for process design as it includes flows from wet weather events. For process design purposes the ADWF and PDWF should be used.
average dry weather flow	(Abbreviated as ADWF.) This is the average flow of incoming wastewater measured in the three driest (non-rainfall) months of the year.

class A evaporation pan	The Class A Evaporation Pan is a standard device for manual measurement of evaporation (Australian Bureau of Meteorology Class A type). The pan represents an open body of water. It is filled with water and exposed on a flat plateau. Size: Height: 255 mm; Diameter: 1225 mm
Intensity-Frequency-Duration	(Abbreviated IFD) IFDs are Intensity-Frequency-Duration design rainfall intensities (mm/h) or design rainfall depths (mm) corresponding to selected Annual Exceedance Probabilities (AEPs), based on the statistical analysis of historical rainfall.
peak dry weather flow	(Abbreviated as PDWF) This applies to the daily diurnal flow pattern. As a factor, it is the ratio of the peak hourly flow (usually late morning) to the ADWF measured in the three driest (non-rainfall) months of the year. (Usual range is 1.5 to 2.0)
pan evaporation	Evaporation is the amount of water which evaporates from an open pan called a class A evaporation pan. The rate of evaporation depends on factors such as cloudiness, air temperature and wind speed.
peak flow	Maximum flow able to reach the WWTP. In pumped systems this is the combined flow of all pump stations able to deliver wastewater to the WWTP when pumping at the same time. To be used for hydraulic design.
peak wet weather flow	(Abbreviated as PWWF) Usually caused by ingress of water into the collector system during rainfall events. It can be of short (one hour) or long (days) duration. As a design factor it is the ratio of the peak hour flow reaching the plant to the ADWF. (Usual range is 2.0 to 3.0, but could be as high as 5.0). To be used for hydraulic design.

2 INTRODUCTION

2.1 Purpose

Where no other method for management of treated water from a waste stabilisation pond (WSP) or Activated Sludge plant is available, making use of wood-lots, evaporation or infiltration or a combination of these may be the only remaining options.

This document provides a simple design guideline for Evaporation Ponds used for the management of treated water from wastewater treatment plants. If limited infiltration forms part of the method, this guideline provides information on how infiltration can be integrated as part of the evaporation pond design.

2.2 Background Information

In semi-arid regions, which includes much of Western Australia, evaporation ponds are a suitable means of managing treated water if no alternative method is available. Evaporation ponds refer to lined retention facilities designed to hold treated water whilst allowing evaporation to take place. Successful use of evaporation for treated water management requires that evaporation is equal to or exceeds the total water input to the system, including precipitation. The net evaporation may be defined as the difference between the evaporation and precipitation during any time period – usually an annual cycle.

Evaporation rates are largely dependent upon the characteristics of the water body. Evaporation from relatively small shallow ponds, (as covered by this guideline) is usually considered to be quite different from that of large lakes mainly due to different rates of heating and cooling because of size and depth differences. In semi-arid regions, hot dry air moving from a land surface over a water body will result in higher evaporation rates for smaller water bodies. Where saline water is to be evaporated, the evaporation rate of the solution will decrease as the solids and chemical composition increase. This must be considered in design, and some guidance is given. A detailed consideration of contaminants and the impact is beyond the scope of this guideline.

This guideline recommends that designers of evaporation ponds should size the ponds for average conditions as a base case. With a base case established consideration must be given to dealing with flows from wet events (typically a 10% AEP 72-hour event) which includes rainfall on the evaporation ponds as well as upstream processes *and* increased flows from the sewer collection system, all of which end up in the evaporation pond. Pan evaporation data is the most common means for defining free water evaporation and is the most commonly available data to use as a basis for design. Unfortunately, the density of evaporation pan stations is much less than that of weather stations, so the designer needs to make judgement calls on the basis of isopleths. Note that it is not good enough to simply take the nearest weather station that has evaporation data available.

Several methods of estimating pond evaporation rates have emerged over the years (Blaney-Criddle, Stewart-Roe, de Bruin, Penman-Monteith). For the purpose of this guideline, however, information from the BoM website for pan evaporation, and recommended regional adjustments to that information from the Department of Agriculture on Lake:Pan evaporation ratios are accepted as the basis for design.

2.3 Design Considerations

This Guideline assumes that the user has an understanding of general process design for waste stabilisation ponds and is able to determine the impact of rainfall and evaporation on the treatment system upstream of the evaporation ponds.

Evaporation ponds cover large areas relative to their depth. The impact of sloping embankments can therefore be ignored in most cases and is not accounted for in the method developed below. The designer should however consider each case and account for varying embankment conditions if warranted. When considering rainfall on upstream processes, the area used for rainfall should be at the top of the embankment and evaporation at the TWL.

3 EVAPORATION PONDS - DESIGN INPUTS

3.1 Water Balance

Evaporation ponds refer to lined retention facilities. Successful return of treated water to the water cycle by evaporation requires that *annual evaporation* (E) is equal to or exceeds the *annual total water inflow* (Qi) to the system, plus *annual precipitation* (P).

$$\Sigma Q_E \geq \Sigma Q_i + \Sigma Q_P$$

Rearranging, the net evaporation may be defined as the difference between the evaporation and precipitation over the period of one year. Assuming a pond of area A,

$$Net\ annual\ evaporation\ = (\Sigma Q_E - \Sigma Q_P) = \Sigma A(E - P)\ must\ be > \Sigma Q_i$$

The method presented in this document is a water balance calculation aiming to size a pond which *optimises area (A) and depth (d)* to achieve an annual cycle in which *(on average)* the pond is emptied at least once a year and retains inflow for the balance of the year.

For much of Western Australia, roughly north of a line from Geraldton to Esperance, average evaporation exceeds rainfall each month of the year, making it ideal for the use of evaporation ponds. In the south west corner of the state where average rainfall can exceed evaporation for up to 6 months of the year, evaporation ponds become challenging, covering very large areas to be successful, and may not be viable. Similarly, in the north eastern corner of WA high rainfall (particularly in February) has a significant impact on the sizing of evaporation ponds. The use of evaporation ponds is not recommended in these areas, unless combined with infiltration, and should be tested on a case-by-case basis. Figures 3-1 and 3-2 show annual average evaporation and precipitation across Australia which help to illustrate this point.

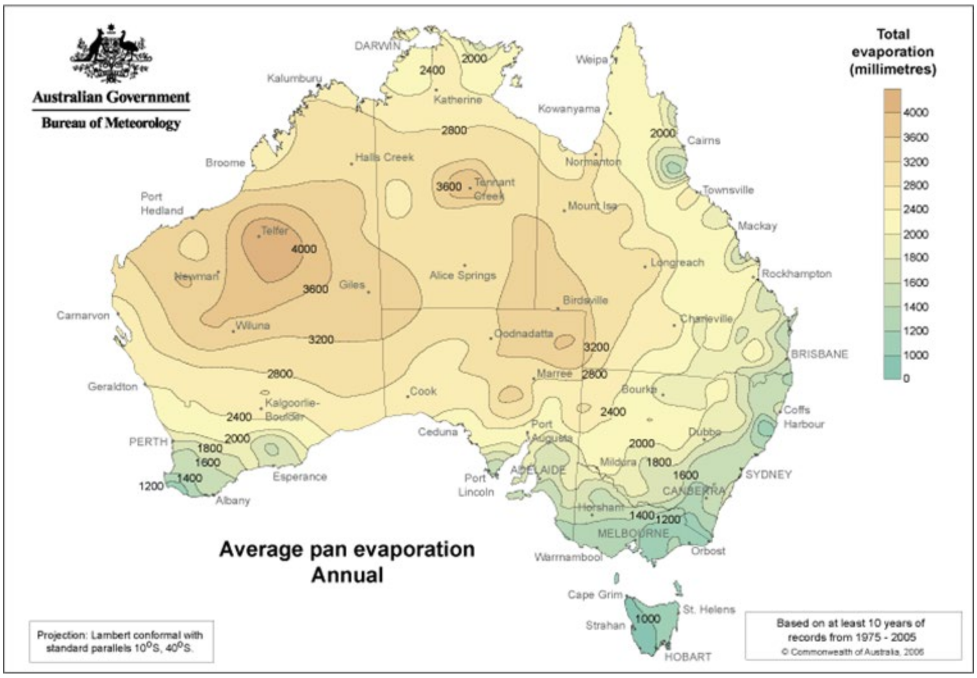


Figure 3-1: Average evaporation across Australia (Courtesy: Bureau of Meteorology)

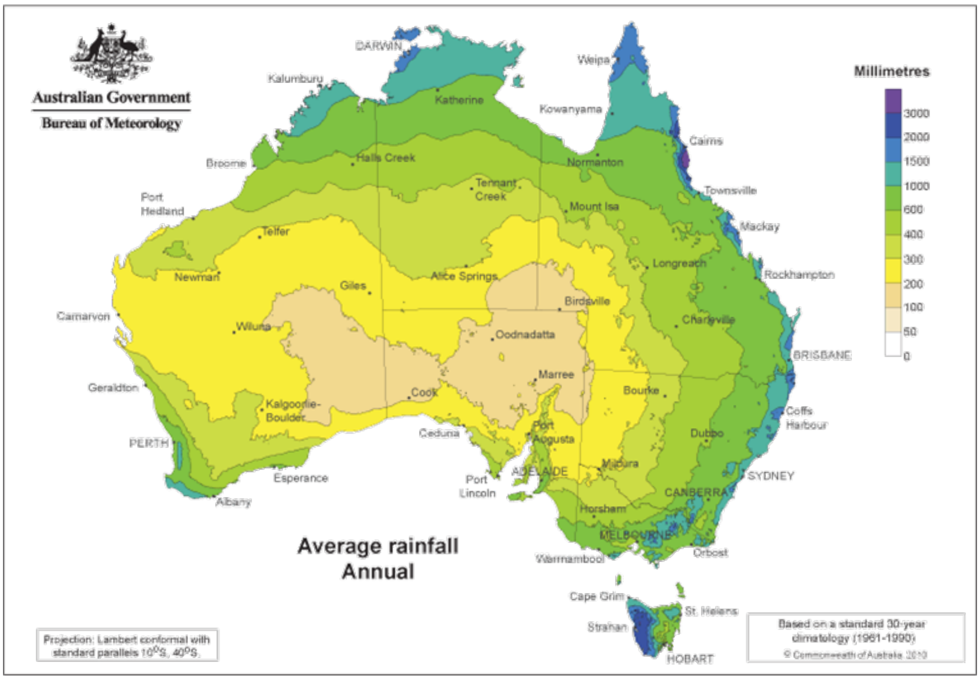


Figure 3-2: Average rainfall across Australia (Courtesy: Bureau of Meteorology)

3.2 Information sources

The Bureau of Meteorology (BoM) provides climate data useful for design.

See: http://www.bom.gov.au/climate/data/ for general climate data

See: http://www.bom.gov.au/water/designRainfalls/revised-ifd/ for IFD data

The WA Department of Agriculture provides Evaporation data for Western Australia as well as Lake:Pan ratios which should be used for estimating evaporation rates from evaporation ponds.

See: https://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1058&context=rmtr

3.3 Factors affecting evaporation, and data manipulation

Evaporation rates are dependent upon a number of factors, including:

- The characteristics of the water body. Evaporation from small shallow ponds is different to that from large lakes due to differences in the rates of heating and cooling of the water bodies.
- Arid regions. Hot dry air moving from a land surface over a water body will result in higher evaporation rates for smaller water bodies.
- Contaminants in the water decrease evaporation rates compared to fresh water rates.
- Salinity. Reduces the rate of evaporation.
- Extent of the evaporation pond. Very large evaporation ponds (typically covering several hectares), particularly in conditions of little wind, develop their own micro-climatic conditions towards the centre of the pond where humidity increases, and evaporation is inhibited. The size of evaporation ponds covered by this document is considered to be small, and design for these conditions is not covered.

Guidance for the manipulation of pan evaporation data is as follows:

- Lake:Pan evaporation ratio: 0.70 to 0.85 (see Dept of Agriculture link in 3.2 above)
- Reduction for salinity:
  - Roughly 0.98 for 2% NaCl solution
  - Roughly 0.97 for 5% NaCl solution
- Allowance for embankments: 1.05 to 1.2

NOTE: Evaporation ponds described in this guideline are generally shallow, with water depths typically varying between 0 and 600mm over an average annual cycle which means that evaporation rates are likely to be closer to pan evaporation rates for clean water, drawing into question the need for the Dept of Agriculture conversion. Lake:pan evaporation ratios provided by the Department of Agriculture have been based on research on shallow farm dams less than 4m deep where turbidity also has an influence on the result. WSP effluent does contain suspended solids in the form of algae and the associated turbidity with reduced light penetration for heating can reduce evaporation rates by as much as 20%. Using the lake:pan evaporation ratio as provided by the department of agriculture is therefore imminently applicable to evaporation ponds for WSP effluent.

4 THEORY DEVELOPMENT

4.1 General Design Method for Volume Equalisation (Rippl diagram)

The Rippl diagram is an industry recognised approach to sizing of balancing storages of various types.

The objective is to size a balancing storage which will reduce variations in an influent flow pattern to provide a constant outflow. Flow equalisation is achieved by storing influent flows above the average daily flow, and discharging the stored volume during periods of low flow. Various methods can be employed to achieve this, but the Rippl mass flow diagram is simple to use, and eminently suitable to our requirement. See **Figure 4-1** which illustrates the method.

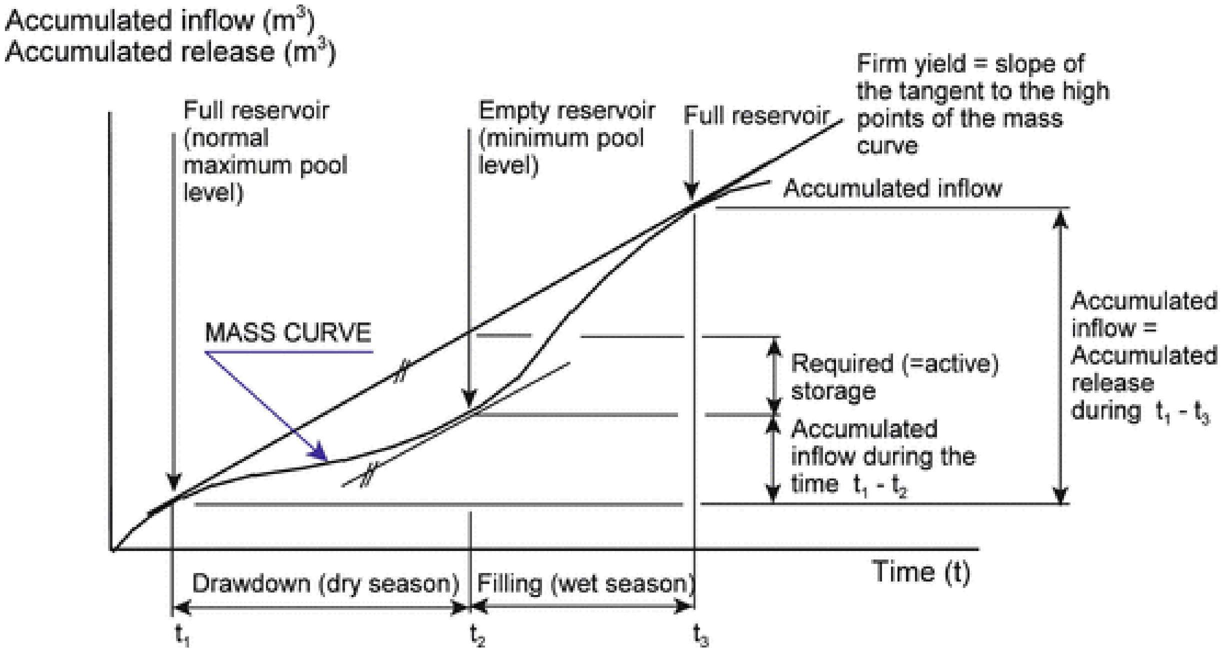


Figure 4-1: Rippl mass flow diagram to determine the size of a balancing storage

By the Rippl method, the diurnal flow pattern is first determined (daily, weekly, monthly etc). In the case of evaporation ponds the annual inflow diurnal flow pattern is first determined. From the diurnal flow pattern, a hydrograph is constructed by plotting the *cumulative volume* of the influent flow (usually taking monthly increments) to give the *mass flow curve*. Now join the start and end points of the mass flow curve, and then draw parallel lines tangential to the peak and trough of the mass curve. The vertical distance (maximum ordinate) between the two lines represents the balancing volume required. Also see **Figure 4-2**.

4.2 Application to evaporation ponds

For sizing evaporation ponds using the Rippl diagram, a mass inflow curve is developed as shown in **Figure 4-2**, and

$$Mass\ inflow\ curve\ \equiv Annual\ inflow = \sum_{Jan}^{Dec} Q_i$$

If a Rippl diagram can be developed for the *inflow* to a pond, then equally a theoretical Rippl diagram can be developed for net rainfall and evaporation using monthly average rainfall minus evaporation multiplied by the pond area (A). As long as the annual evaporation exceeds the annual rainfall, the Rippl diagram will fall below the x-axis. [NOTE that the area (A) is unknown at this stage]. See **Figure 4-3**.

$$Precipitation - \ evaporation\ \equiv Annual\ net\ evaporation = \sum_{Jan}^{Dec} (P-E).A$$

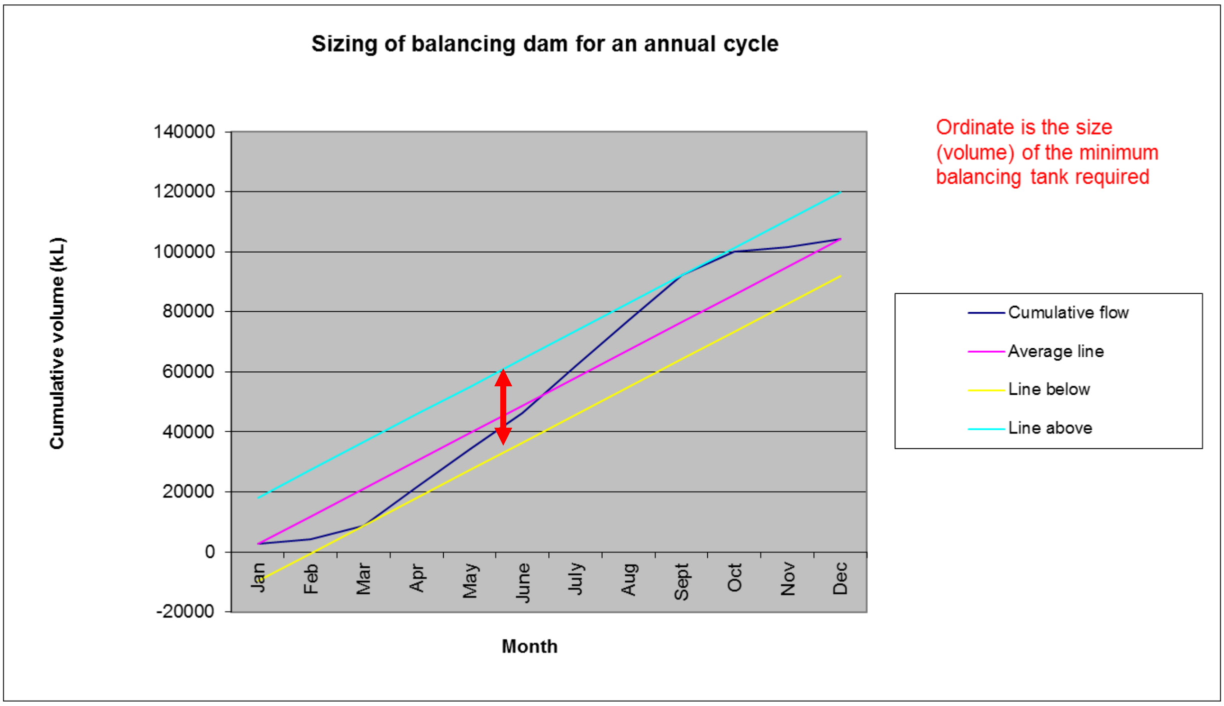


Figure 4-2: Rippl Curve for balancing pond inflow

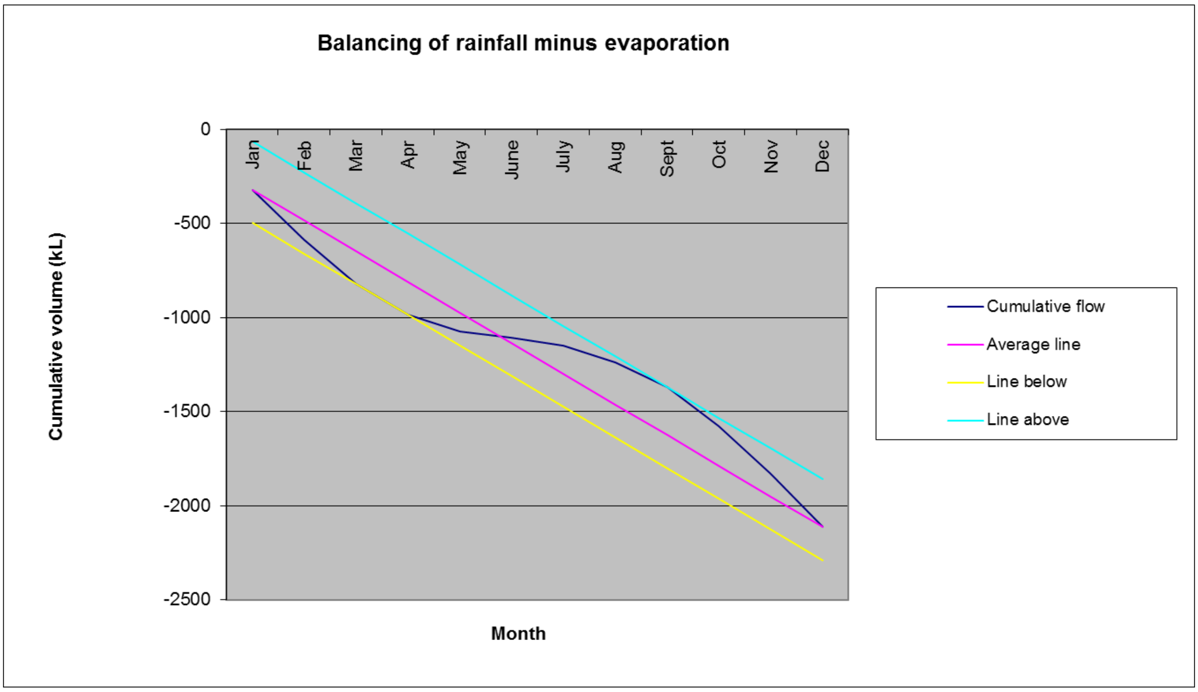


Figure 4-3: Rippl curve for balancing evaporation minus rainfall

Adding these two mass curves together, the aim is to achieve:

$$\textit{The mass curve:} \quad \sum_{Jan}^{Dec}(P-E)A + \sum_{Jan}^{Dec} Q_i \leq 0\,, \quad but \sum_{Jan}^{Dec}\frac{Q_i}{A} = \sum_{Jan}^{Dec} d \qquad [d = pond\ depth]$$

$$\textit{The aim is therefore to achieve:} \quad \sum_{Jan}^{Dec}(P-E) + \sum_{Jan}^{Dec}\frac{Q_i}{A} \leq 0 \qquad (4.1)$$

The advantage of using equation 4.1 in this form is that the first term remains unchanged as it is independent of area, and calculations can proceed with a depth cycle, rather than varying mass. The designer must now determine the area (A) which will make the equality true. The final solution will then be the pond depth variation through the year. Knowing the depth cycle is more useful as an item of design information.

An Evaporation Ponds Sizing calculation spreadsheet has been prepared as a guide. This spreadsheet should be used in line with the instructions of this guideline. Please email engineering.standardsenquiries@watercorporation.com.au to request a copy of the spreadsheet if you are accessing this document externally.

5 WORKED EXAMPLE 1

5.1 Step 1: Sizing for average conditions

In equation 4.1 the only unknown is the pond area A. The solution is found by estimating a value for A and adding the 2 curves together. See the green line in figure 5-1. A balanced curve would be achieved once the start and end points of the green line are equal to zero. Calculations are shown in table 5-1.

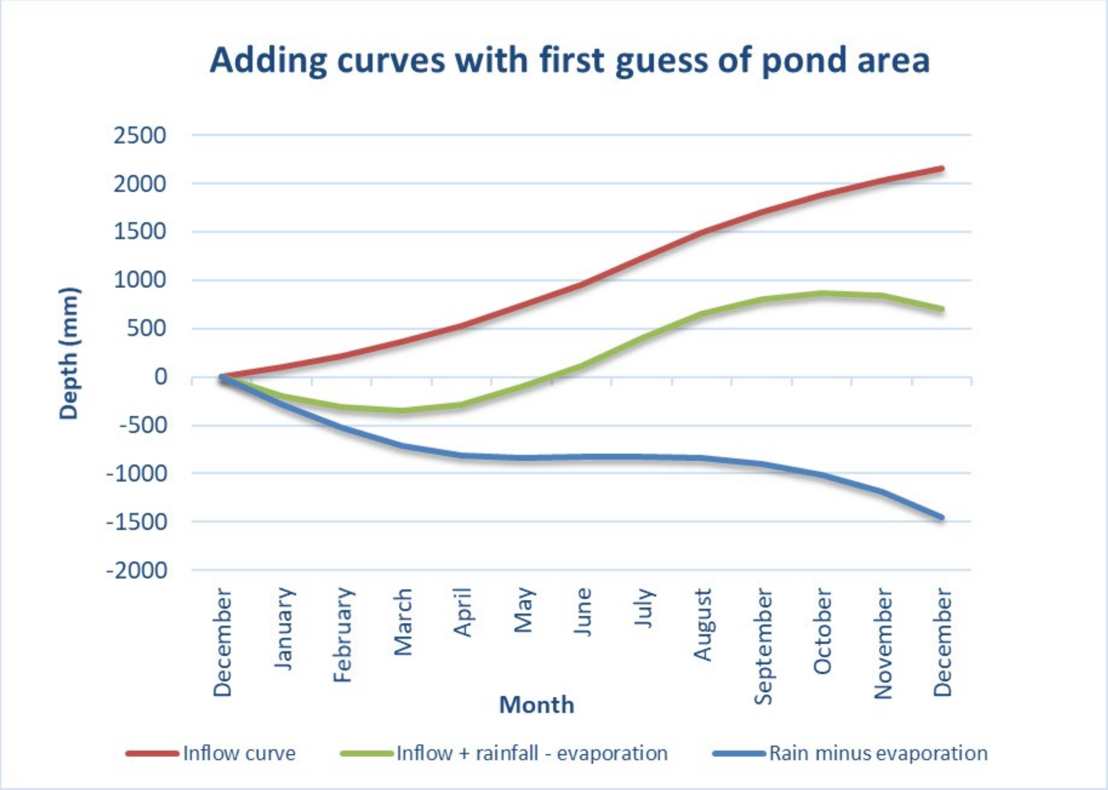
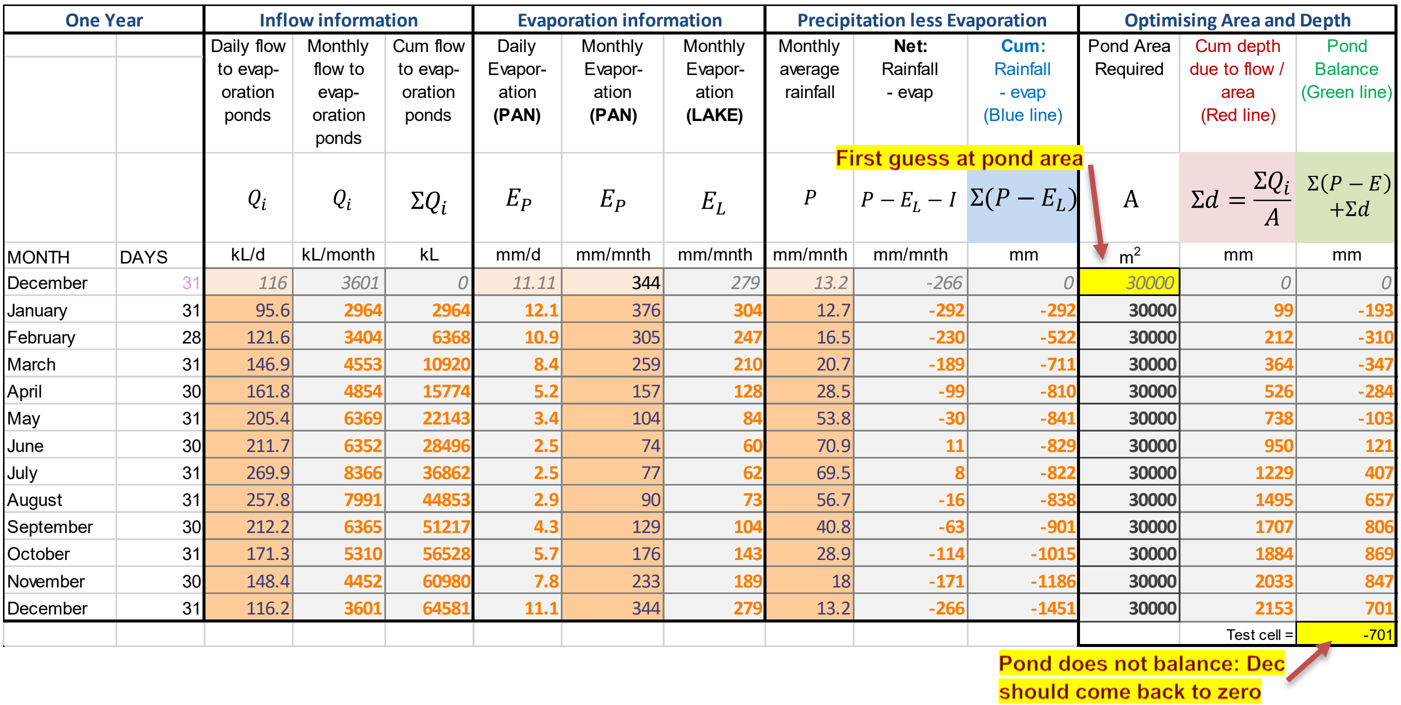


Figure 5-1: Initial curve with first guess of pond area A

A spreadsheet is very useful for finding the final solution. In this example, the Lake:Pan evaporation ratio is taken as 0.81 ($E_L = 0.81E_P$)



One Year		Inflow information			Evaporation information			Precipitation less Evaporation			Optimising Area and Depth		
		Daily flow to evap-oration ponds	Monthly flow to evap-oration ponds	Cum flow to evap-oration ponds	Daily Evapor-ation **(PAN)**	Monthly Evapor-ation **(PAN)**	Monthly Evapor-ation **(LAKE)**	Monthly average rainfall	**Net:** Rainfall - evap	**Cum:** Rainfall - evap (Blue line)	Pond Area Required	Cum depth due to flow / area (Red line)	Pond Balance (Green line)
		Q_i	Q_i	ΣQ_i	E_P	E_P	E_L	P	$P - E_L - I$	$\Sigma(P - E_L)$	A	$\Sigma d = \frac{\Sigma Q_i}{A}$	$\Sigma(P-E) + \Sigma d$
MONTH	DAYS	kL/d	kL/month	kL	mm/d	mm/mnth	mm/mnth	mm/mnth	mm/mnth	mm	m^2	mm	mm
December	31	*116*	*3601*	*0*	*11.11*	344	*279*	*13.2*	*-266*	*0*	*30000*	*0*	*0*
January	31	95.6	2964	2964	12.1	376	304	12.7	-292	-292	30000	99	-193
February	28	121.6	3404	6368	10.9	305	247	16.5	-230	-522	30000	212	-310
March	31	146.9	4553	10920	8.4	259	210	20.7	-189	-711	30000	364	-347
April	30	161.8	4854	15774	5.2	157	128	28.5	-99	-810	30000	526	-284
May	31	205.4	6369	22143	3.4	104	84	53.8	-30	-841	30000	738	-103
June	30	211.7	6352	28496	2.5	74	60	70.9	11	-829	30000	950	121
July	31	269.9	8366	36862	2.5	77	62	69.5	8	-822	30000	1229	407
August	31	257.8	7991	44853	2.9	90	73	56.7	-16	-838	30000	1495	657
September	30	212.2	6365	51217	4.3	129	104	40.8	-63	-901	30000	1707	806
October	31	171.3	5310	56528	5.7	176	143	28.9	-114	-1015	30000	1884	869
November	30	148.4	4452	60980	7.8	233	189	18	-171	-1186	30000	2033	847
December	31	116.2	3601	64581	11.1	344	279	13.2	-266	-1451	30000	2153	701
												Test cell =	-701

First guess at pond area

Pond does not balance: Dec should come back to zero

Table 5-1: Data input and first guess at pond area

By iteratively adjusting the area (A) a balanced position is reached (start and end points of green line = zero). See figure 5-2. The maximum pond depth can now be determined from the green line. In the spreadsheet, the test cell is previous Dec value (zero) minus new Dec value (-701) which needs to be equal to zero.

In the spreadsheet, use "goal seek" to set the test cell = 0 by changing the area.

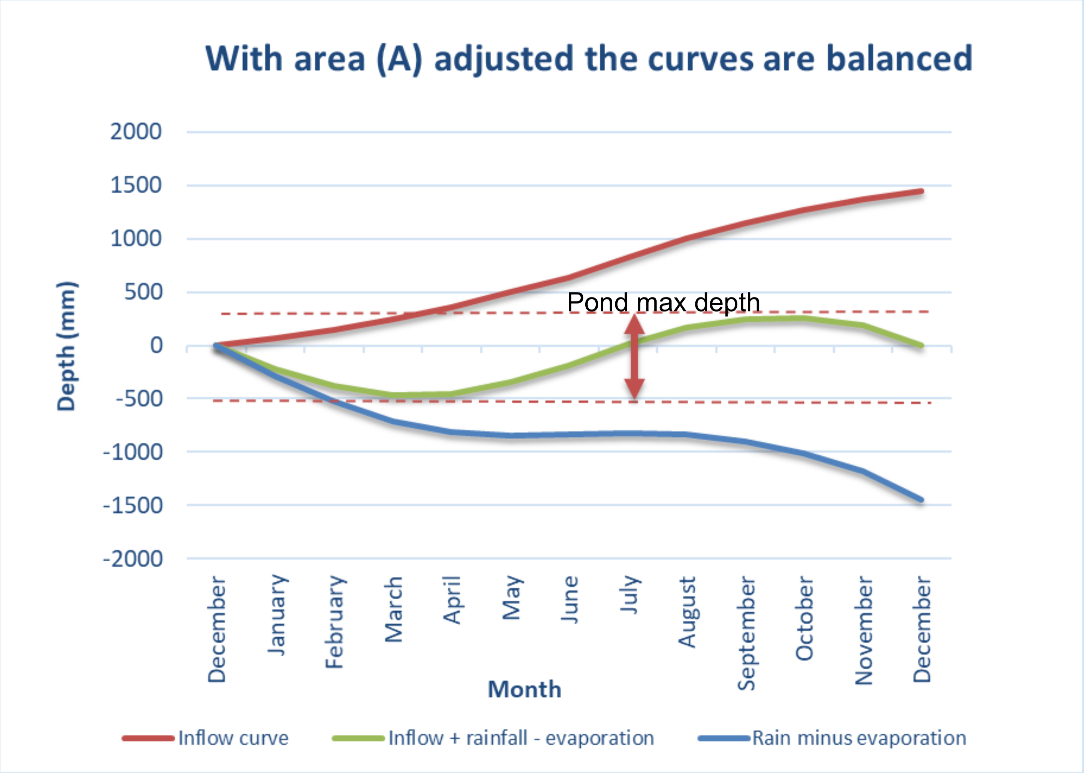
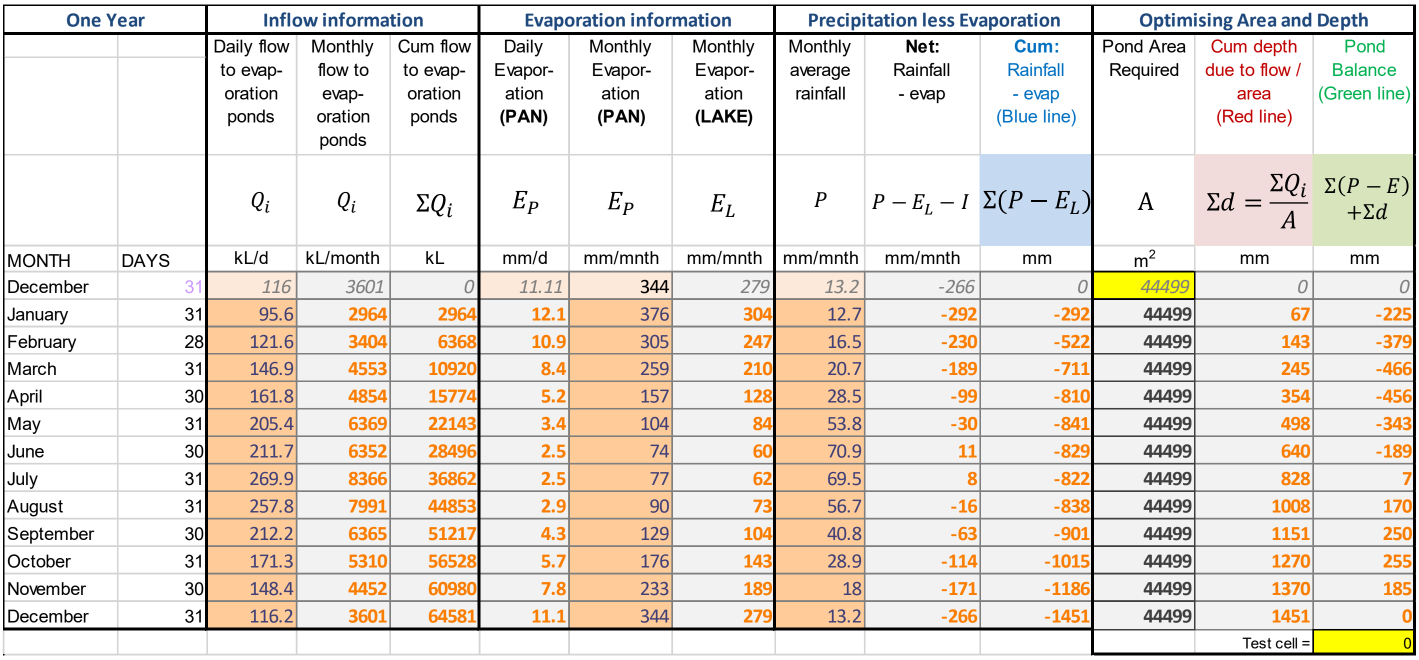


Figure 5-2: Balanced curves following determination of optimum pond area (A)



One Year		Inflow information			Evaporation information			Precipitation less Evaporation			Optimising Area and Depth		
		Daily flow to evaporation ponds	Monthly flow to evaporation ponds	Cum flow to evaporation ponds	Daily Evaporation **(PAN)**	Monthly Evaporation **(PAN)**	Monthly Evaporation **(LAKE)**	Monthly average rainfall	**Net:** Rainfall - evap	**Cum:** Rainfall - evap (Blue line)	Pond Area Required	Cum depth due to flow / area (Red line)	Pond Balance (Green line)
		Q_i	Q_i	ΣQ_i	E_P	E_P	E_L	P	$P - E_L - I$	$\Sigma(P - E_L)$	A	$\Sigma d = \frac{\Sigma Q_i}{A}$	$\Sigma(P - E) + \Sigma d$
MONTH	DAYS	kL/d	kL/month	kL	mm/d	mm/mnth	mm/mnth	mm/mnth	mm/mnth	mm	m^2	mm	mm
December	31	*116*	*3601*	*0*	*11.11*	344	*279*	*13.2*	*-266*	*0*	*44499*	*0*	*0*
January	31	95.6	2964	2964	12.1	376	304	12.7	-292	-292	44499	67	-225
February	28	121.6	3404	6368	10.9	305	247	16.5	-230	-522	44499	143	-379
March	31	146.9	4553	10920	8.4	259	210	20.7	-189	-711	44499	245	-466
April	30	161.8	4854	15774	5.2	157	128	28.5	-99	-810	44499	354	-456
May	31	205.4	6369	22143	3.4	104	84	53.8	-30	-841	44499	498	-343
June	30	211.7	6352	28496	2.5	74	60	70.9	11	-829	44499	640	-189
July	31	269.9	8366	36862	2.5	77	62	69.5	8	-822	44499	828	7
August	31	257.8	7991	44853	2.9	90	73	56.7	-16	-838	44499	1008	170
September	30	212.2	6365	51217	4.3	129	104	40.8	-63	-901	44499	1151	250
October	31	171.3	5310	56528	5.7	176	143	28.9	-114	-1015	44499	1270	255
November	30	148.4	4452	60980	7.8	233	189	18	-171	-1186	44499	1370	185
December	31	116.2	3601	64581	11.1	344	279	13.2	-266	-1451	44499	1451	0
												Test cell =	0

Table 5-2: Balanced Pond with pond area now calculated

Table 5-2 corresponds with figure 5-2. The values in the "pond balance" column represent the variance around an average of zero in keeping with the Rippl diagram principles. The maximum pond depth can now be determined by taking the difference between the maximum and minimum in the last column of the spreadsheet i.e. (255-(-466) = 721mm) gives the maximum pond depth for average conditions.

In figure 5-2 the green line is a theoretical curve showing the balanced pond. By transposing this curve upwards so that the minimum point on the curve forms a tangent with the x-axis, the resulting curve shows the pond depth variation through the year. See purple line in figure 5-3. See also the added column in table 5-3.

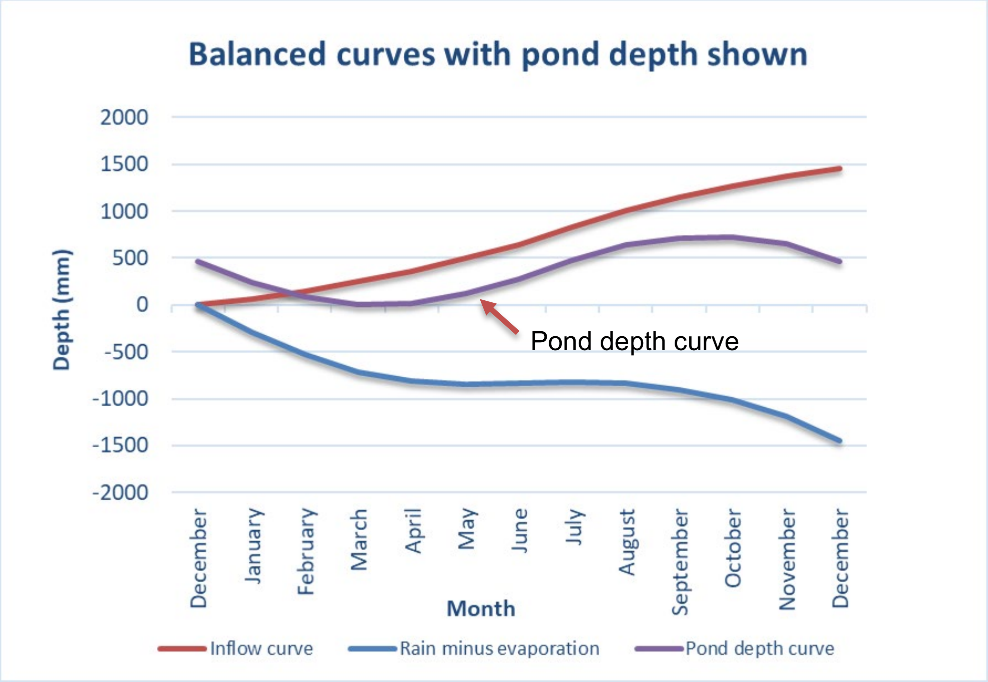


Figure 5-3: Balanced curves with pond depth curve

Transposing the values in the pond *balance column* is simply shifting the green line in figure 5-2 upwards, and the ***pond depth*** through the year is determined. Purple line in figure 5-3, and last column in table 5-3.

One Year		Inflow information			Evaporation information			Precipitation less Evaporation			Optimising Area and Depth			Transposed
		Daily flow to evap-oration ponds	Monthly flow to evap-oration ponds	Cum flow to evap-oration ponds	Daily Evapor-ation **(PAN)**	Monthly Evapor-ation **(PAN)**	Monthly Evapor-ation **(LAKE)**	Monthly average rainfall	**Net:** Rainfall - evap	**Cum:** Rainfall - evap (Blue line)	Pond Area Required	Cum depth due to flow / area (Red line)	Pond Balance (Green line)	Pond depth require-ment (Purple line)
		Q_i	Q_i	ΣQ_i	E_P	E_P	E_L	P	$P - E_L - I$	$\Sigma(P - E_L)$	A	$\Sigma d = \frac{\Sigma Q_i}{A}$	$\Sigma(P - E) + \Sigma d$	d
MONTH	DAYS	kL/d	kL/month	kL	mm/d	mm/mnth	mm/mnth	mm/mnth	mm/mnth	mm	m^2	mm	mm	mm
December	31	*116*	*3601*	*0*	*11.11*	344	*279*	*13.2*	*-266*	*0*	*44499*	*0*	*0*	*466*
January	31	95.6	2964	2964	12.1	376	304	12.7	-292	-292	44499	67	-225	241
February	28	121.6	3404	6368	10.9	305	247	16.5	-230	-522	44499	143	-379	87
March	31	146.9	4553	10920	8.4	259	210	20.7	-189	-711	44499	245	-466	0
April	30	161.8	4854	15774	5.2	157	128	28.5	-99	-810	44499	354	-456	10
May	31	205.4	6369	22143	3.4	104	84	53.8	-30	-841	44499	498	-343	123
June	30	211.7	6352	28496	2.5	74	60	70.9	11	-829	44499	640	-189	277
July	31	269.9	8366	36862	2.5	77	62	69.5	8	-822	44499	828	7	472
August	31	257.8	7991	44853	2.9	90	73	56.7	-16	-838	44499	1008	170	636
September	30	212.2	6365	51217	4.3	129	104	40.8	-63	-901	44499	1151	250	716
October	31	171.3	5310	56528	5.7	176	143	28.9	-114	-1015	44499	1270	255	721
November	30	148.4	4452	60980	7.8	233	189	18	-171	-1186	44499	1370	185	651
December	31	116.2	3601	64581	11.1	344	279	13.2	-266	-1451	44499	1451	0	466
												Test cell =	0	721

Table 5-3: Transposing pond balance to show pond depth variation column added

Interesting Result:

The result here is that the area and depth of the evaporation pond have been optimised for an average year. If therefore average conditions were to prevail year on year, a pond with area 44,499m^2 would cycle through being empty in March each year and reaching a maximum water depth of 721mm in October each year.

NOTE: The calculation above sets the area of the pond. DO NOT increase the area for wet events as this simply increases the catchment. Cater for wet events by increasing the pond depth.

5.2 Step 2: Accounting for wet weather events

In addition to retaining average flows in the evaporation ponds, it is also necessary to retain flows from wet weather events with Annual Exceedance Probabilities (AEP) as set by the Regulator.

The Bureau of Meteorology provides information on IFDs or Intensity-Frequency-Duration design rainfall intensities (mm/h) or design rainfall depths (mm) corresponding to selected Annual Exceedance Probabilities (AEPs), based on the statistical analysis of historical rainfall. ***The information can be found on the BoM web site for which the link is provided in section 3.2 of this document.*** An example is provided in Table 5.4 and corresponds with the site used in this worked example.

Information in the chart is provided as an AEP (%) whereas the Regulator will normally refer to an AEP (1 in x). To understand the difference, a 1:20 AEP corresponds with a 5% AEP $\left(\frac{1}{20} \times 100 = 5\%AEP\right)$ or a 1:2 AEP corresponds with $\frac{1}{2} \times 100 = 50\%AEP$.

The more commonly used AEP for evaporation ponds in WA is the 1:10 AEP 72 h event. This corresponds with a 10% AEP. Referring to the BoM information for this example (see Table 5-4), the 10% AEP 72 h event predicts 83.7mm of rainfall.

The additional depth required for the evaporation pond determined in the example consists of 3 components:

1. Rainfall directly onto the evaporation pond.

2. Rainfall on the process plant upstream of the evaporation pond.
3. Higher inflow to the plant due to infiltration in the upstream network.

Rainfall directly onto the evaporation pond

During high rainfall events, evaporation drops significantly, and for practical purposes can be considered as zero. This may not be a big factor if such an event were to occur during winter months, but in summer months in hot climates, this could be significant.

The total impact directly on the evaporation pond is thus:

1. Direct rainfall
2. Evaporation *that did not take place*.

With respect to the example the greatest impact would be if the wet event occurred when the pond is at its maximum depth in the month of October. The evaporation for 3 days must therefore be added to the rainfall event ie. 5.7mm/d. [5.7mm/d is the average daily evaporation for the month of October – See table 5.3]

The water depth added over the 3 days is therefore:

Rainfall:	83.7mm
Non- evaporation: (3×5.7)	17.1mm
Total direct depth impact:	**100.8mm**

Rainfall on upstream treatment ponds

The impact of rainfall and evaporation on upstream ponds in terms of depth is the same as for the evaporation ponds i.e. the impact is 100.8mm over the 3 day event. The water falling on the upstream ponds will end up in the evaporation pond, increasing its depth further and must be added proportionately. [Note that we have calculated the evaporation pond area to be 44,499m^2]

With respect to the example if the upstream ponds have a total area of 7,300m^2 then the impact on the evaporation pond is:

$$\frac{7{,}300}{44{,}499} \times 100.8 = 16.5mm$$

Higher inflow to the plant due to infiltration

Infiltration into the sewer system can result from:

1. Old pipes allowing ingress of water as rain percolates through the ground, and/or as the water table rises.
2. Direct inflow through access chambers that are not properly sealed.
3. Illegal diversion of runoff from private properties into the sewer system.

Using local data, the designer must, as far as possible, assess what is likely to occur in the catchment.

1. If it is a pumped system the maximum rate of delivery is what the upstream pumps can deliver. This is not necessarily continuous for the wet event although in some areas it can be continuous after the first few hours of the event. The designer shall source and assess this information.
2. In gravity systems the maximum flow is a bit more difficult to determine but a combination of hydraulic assessments of the system and historical data should give the designer a good indication of what is likely.

With respect to the example, it is assumed that the combined impact of an upstream pumping system will generate a flow of 6L/s. The increased flow is likely to be some form of bell curve, which will build for 6 to 12 hours at the start of the event and continue for as much as 24 to 48 hours after the wet event. For the purpose of this example the increased rate of flow is assumed to be for 60% of the maximum flow rate for a period of 3 days. The volume associated with this flow is therefore:

$$0.6 \times 6 \times 3 \times 24 \times 3.6 = 933kL$$

The 933kL also arrives in the evaporation pond and increases the depth by:

$$\frac{933 \times 1{,}000}{44{,}499} = 21.0mm$$

Total pond depth increase:

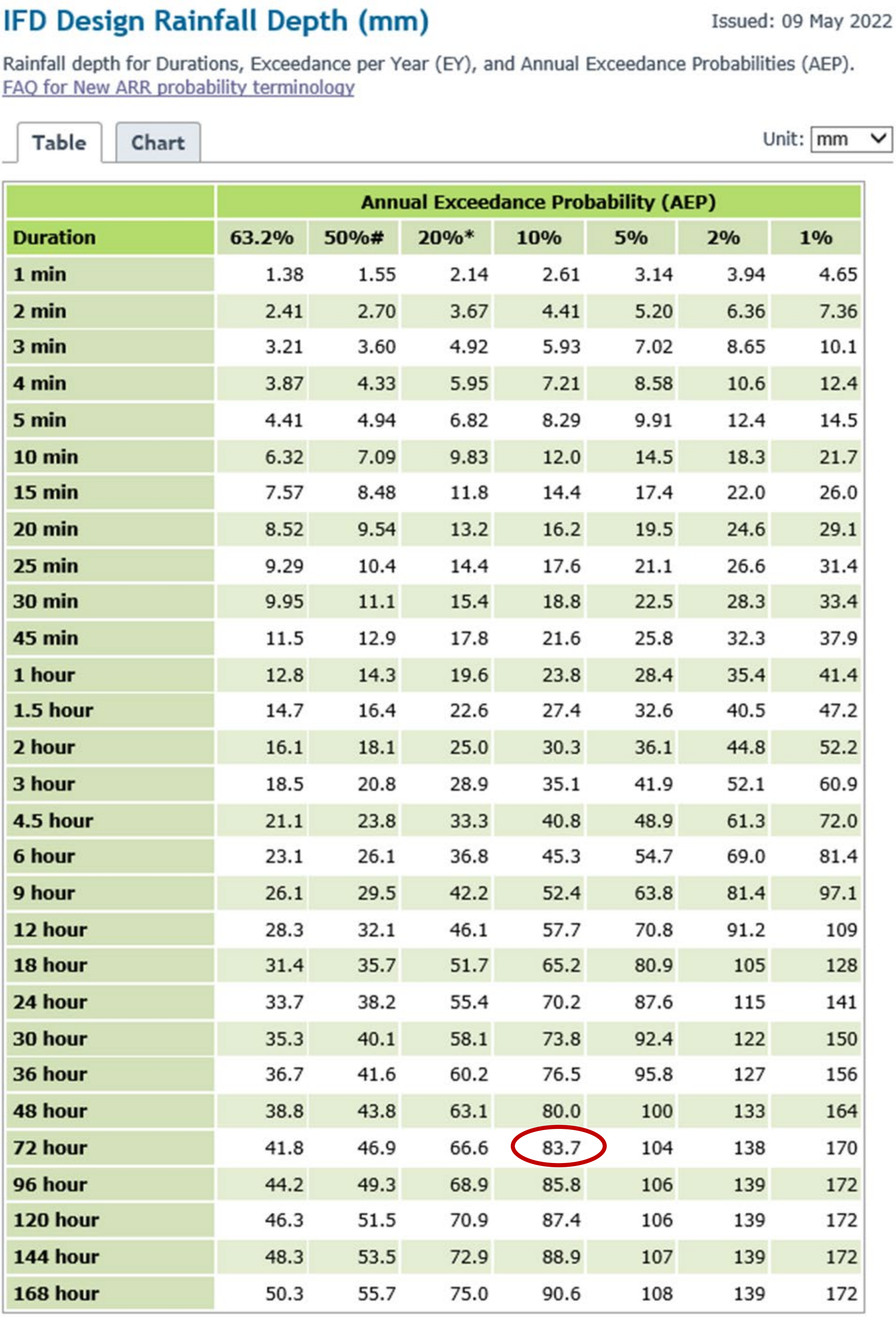
Combining these flows with the maximum depth of the pond in an average year gives:

Pond depth (average year):	721mm
Direct rainfall:	100.8mm
Upstream ponds:	16.5mm
Collection system:	21.0mm
Max depth of pond:	**859.3mm (say 860mm)**

Allowance must therefore be made in the design for a contained depth of at least 860mm. Note that the pond area remains 44,499m^2.

As this is not a normal event, it is suggested that a freeboard of 300mm above this level should be allowed before the pond spills into the environment. A total depth of 860+300=1,160mm, say 1,200mm, from the floor to the top of the embankment should be allowed.

Example 1: Intensity – Frequency – Duration table from BoM



IFD Design Rainfall Depth (mm)

Issued: 09 May 2022

Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).
FAQ for New ARR probability terminology

	Annual Exceedance Probability (AEP)						
Duration	63.2%	50%#	20%*	10%	5%	2%	1%
1 min	1.38	1.55	2.14	2.61	3.14	3.94	4.65
2 min	2.41	2.70	3.67	4.41	5.20	6.36	7.36
3 min	3.21	3.60	4.92	5.93	7.02	8.65	10.1
4 min	3.87	4.33	5.95	7.21	8.58	10.6	12.4
5 min	4.41	4.94	6.82	8.29	9.91	12.4	14.5
10 min	6.32	7.09	9.83	12.0	14.5	18.3	21.7
15 min	7.57	8.48	11.8	14.4	17.4	22.0	26.0
20 min	8.52	9.54	13.2	16.2	19.5	24.6	29.1
25 min	9.29	10.4	14.4	17.6	21.1	26.6	31.4
30 min	9.95	11.1	15.4	18.8	22.5	28.3	33.4
45 min	11.5	12.9	17.8	21.6	25.8	32.3	37.9
1 hour	12.8	14.3	19.6	23.8	28.4	35.4	41.4
1.5 hour	14.7	16.4	22.6	27.4	32.6	40.5	47.2
2 hour	16.1	18.1	25.0	30.3	36.1	44.8	52.2
3 hour	18.5	20.8	28.9	35.1	41.9	52.1	60.9
4.5 hour	21.1	23.8	33.3	40.8	48.9	61.3	72.0
6 hour	23.1	26.1	36.8	45.3	54.7	69.0	81.4
9 hour	26.1	29.5	42.2	52.4	63.8	81.4	97.1
12 hour	28.3	32.1	46.1	57.7	70.8	91.2	109
18 hour	31.4	35.7	51.7	65.2	80.9	105	128
24 hour	33.7	38.2	55.4	70.2	87.6	115	141
30 hour	35.3	40.1	58.1	73.8	92.4	122	150
36 hour	36.7	41.6	60.2	76.5	95.8	127	156
48 hour	38.8	43.8	63.1	80.0	100	133	164
72 hour	41.8	46.9	66.6	83.7	104	138	170
96 hour	44.2	49.3	68.9	85.8	106	139	172
120 hour	46.3	51.5	70.9	87.4	106	139	172
144 hour	48.3	53.5	72.9	88.9	107	139	172
168 hour	50.3	55.7	75.0	90.6	108	139	172

Table 5-4: AFP information obtained from the BoM web site for the particular infiltration pond location

6 ADDING INFILTRATION

A discussion on how infiltration should be determined is outside the scope of this document. However, the infiltration rate selected for design after site testing must be conservative and based on the advice of experienced Geotechnical Engineers. The floors of infiltration ponds tend to blind due to residual suspended solids in the treated water and the resultant long term infiltration rate is often much less, as little as 4 to 10% of the rate determined by a constant head permeability test.

Expanding the method developed above, with the infiltration rate (I) known, equation 4.1 becomes

$$\sum_{Jan}^{Dec}(P - E - I) + \sum_{Jan}^{Dec}\frac{Q_i}{A} \leq 0 \qquad eq\ 6.1$$

and the method of sizing of the evaporation / infiltration pond proceeds exactly as previously described.

7 WORKED EXAMPLE 2

Taking the information from example 1, and assuming a sustainable infiltration rate of 5mm per day, the result will be as per table 7-1 and figure 7-1. The detail of how this is developed is identical to example 1 and not repeated here.

The results show that the evaporation / infiltration pond area is reduced to 19,712m^2 but the depth increases to 943mm for an average year. Wet events are added as before.

One Year		Inflow information			Evaporation information			Precipitation less Evaporation			Optimising Area and Depth			Transposed
		Daily flow to evap-oration ponds	Monthly flow to evap-oration ponds	Cum flow to evap-oration ponds	Daily Evapor-ation **(PAN)**	Monthly Evapor-ation **(PAN)**	Monthly Evapor-ation **(LAKE)**	Monthly average rainfall	**Net:** Rainfall - evap - infiltration	**Cum:** Rainfall - evap -infiltration	Pond Area Required	Cum depth due to flow / area	Pond Balance	Pond depth require-ment
		Q_i	Q_i	ΣQ_i	E_P	E_P	E_L	P	$P - E_L - I$	$\Sigma(P - E_L - I)$	A	$\Sigma d = \frac{\Sigma Q_i}{A}$	$\Sigma(P - E - I) + \Sigma d$	d
MONTH	DAYS	kL/d	kL/month	kL	mm/d	mm/mnth	mm/mnth	mm/mnth	mm/mnth	mm	m^2	mm	mm	mm
December	31	116	3601	0	11.11	344	279	13.2	-421	0	19712	0	0	610
January	31	95.6	2964	2964	12.1	376	304	12.7	-447	-447	19712	150	-296	314
February	28	121.6	3404	6368	10.9	305	247	16.5	-370	-817	19712	323	-494	116
March	31	146.9	4553	10920	8.4	259	210	20.7	-344	-1161	19712	554	-607	3
April	30	161.8	4854	15774	5.2	157	128	28.5	-249	-1410	19712	800	-610	0
May	31	205.4	6369	22143	3.4	104	84	53.8	-185	-1596	19712	1123	-472	138
June	30	211.7	6352	28496	2.5	74	60	70.9	-139	-1734	19712	1446	-289	321
July	31	269.9	8366	36862	2.5	77	62	69.5	-147	-1882	19712	1870	-12	598
August	31	257.8	7991	44853	2.9	90	73	56.7	-171	-2053	19712	2275	223	833
September	30	212.2	6365	51217	4.3	129	104	40.8	-213	-2266	19712	2598	332	942
October	31	171.3	5310	56528	5.7	176	143	28.9	-269	-2535	19712	2868	333	943
November	30	148.4	4452	60980	7.8	233	189	18	-321	-2856	19712	3094	238	848
December	31	116.2	3601	64581	11.1	344	279	13.2	-421	-3276	19712	3276	0	610
												Test cell =	0	943

Table 7-1: Balanced pond including infiltration

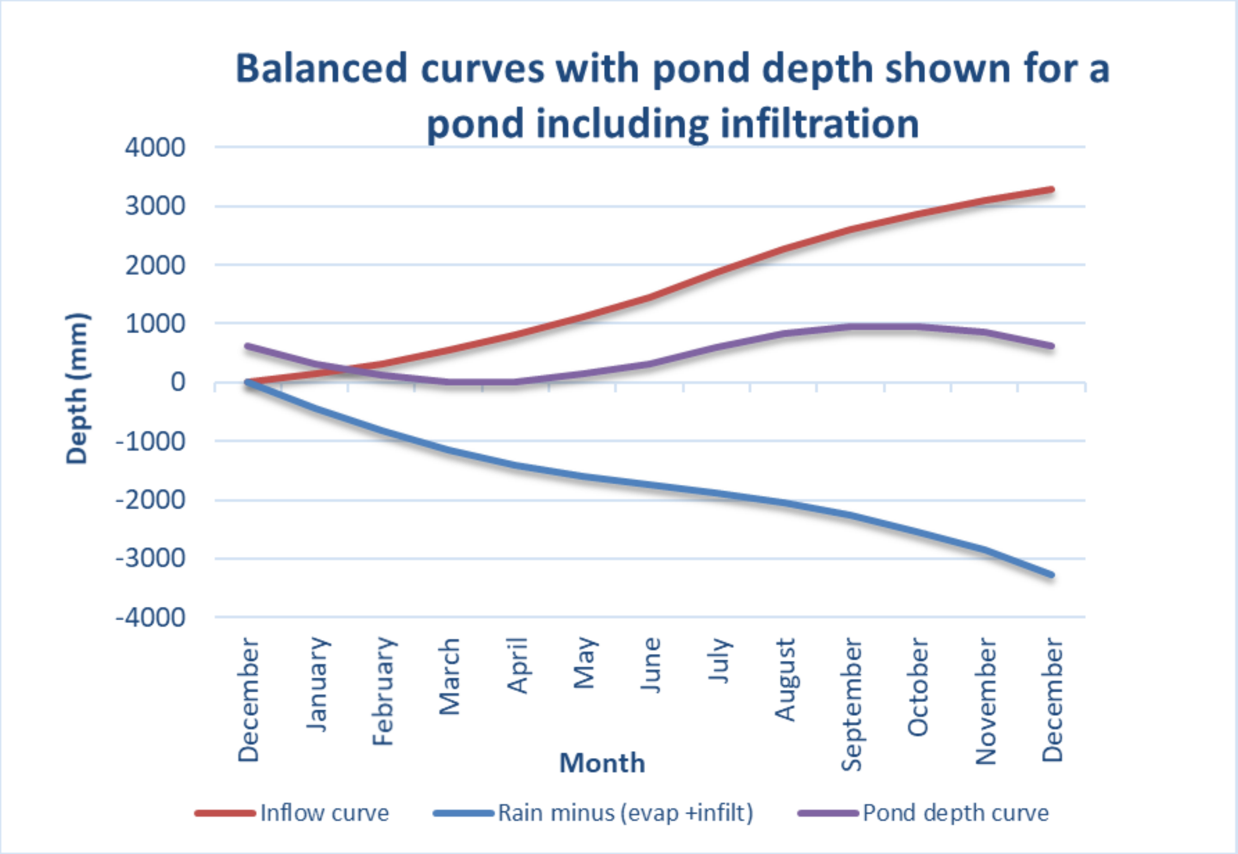


Figure 7-1: Graphical representation of pond operation including infiltration

8 APPENDIX A

Referenced Resources and Documents

Finch, JW and Hall, RL (2001) Estimation of open water evaporation: A review of methods: R&D Technical Report W6-043/TR

Bose, D. and Doombos, M. (2002) Evaporation Pond Sizing with Water Balance and Make-up Water: CH_2MHill on behalf of Idaho National Engineering and Environmental Laboratory (INEEL)

Zan, G. and Lin Shelp, M. (2009) Modified Blaney-Criddle method — an empirical approach to estimate potential evaporation using air temperature: Australian Centre for Geomechanics, Perth, ISBN 978-0-9804185-9-0; https://papers.acg.uwa.edu.au/p/908_35_Zhan/

9 APPENDIX B

Preferred Terminology

The table below contains preferred terms for use by the Designer in Corporation mechanical designs.

Preferred Terminology Units	Non-preferred
Bend	Elbow
Discharge (pump)	Delivery, outlet
Drinking water	Potable water
Ejector	Injector
GRP	FRP
Impeller	Impellor
L/s	l/s
MLD	ML/d, Ml/d
Nominal diameter - DN	ND
Non return valve	Check valve
Pumpset	Pump unit, pumping unit
Pump station	Pumping station
Sewage pump station	Wastewater pump station
Suction (pump)	Inlet, intake

10 APPENDIX C

Abbreviations, acronyms and symbols

The table below contains terms and symbols used in this Guideline and more generally in the water industry.

Term	Description
AADF	Average Annual Daily Flow = the total annual flow reaching the WWTP in a calendar year divided by 365. It is useful for understanding annual plant throughput but should not be used as a basis for process design as it includes flows from wet weather events. For process design purposes ADWF and PDWF should be used.
ADWF	Average Dry Weather Flow = the average flow of incoming used water measured in the three driest (non-rainfall) months of the year.
ABS	Acrylonitrile – Butadiene – Styrene (pipe and fittings)
AHD	Australian Height Datum
AISI	American Iron and Steel Institute
ANSI	American national Standards Institute
API	American Petroleum Institute
AS	Australian Standards
ASM	American Society of Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for testing and Materials
AWS	American Welding Society
BEP	Best Efficiency Point
BFJ	Butt-fusion joint
BJ	Butt joint (plain ends)
BOD	Biochemical oxygen demand
BS	British Standard
BSP	British Standard Pipe
BSI	British Standards Institute
BWL	Bottom Water Level
CI	cast Iron
CIP	Clean-in-place
CML	Cement mortar lined
COD	Chemical oxygen demand
CS	Carbon steel (pipe)
CSA	Canadian Standards Association

Term	Description
©	Copyrighted
Cv	Flow coefficient, flow factor or valve coefficient (imperial)
dBA	Decibel – A weighted scale
DI	Ductile Iron (pipe and fittings)
DICL	Ductile iron cement lined
DIN	Deutsches Institut fur Normung (Germany)
°C	Degrees Celsius
DN	Nominal diameter
EAS	Excess activated sludge
EFJ	Electro-fusion joint
EPDM	Ethylene propylene diene monomer rubber
ESJ	Elastomeric seal joint
FAD	Free air delivered
FBE	Fusion bonded epoxy
FJ	Flange joint (bolted)
FRP	Fibreglass reinforced plastic
g	Acceleration due to gravity – 9.81 m/s^2
GDA	Geocentric datum of Australia
GL	Gigalitres
GRP	Glass reinforced plastic (pipe)
HBW	Brinell hardness number
HDPE	High density polyethylene
HGL	Hydraulic Grade Line
H	Head of water in m
Hz	Hertz (cycles per second)
h	Hour
HRB	Rockwell B (hardness)
HRC	Rockwell C (hardness)
IEC	International Electrotechnical Commission
IFJ	Flush joint
I/O	Input/Output
IRHD	International rubber hardness degree

Term	Description
ISO	International Standards Organisation
JIS	Japanese Industrial Standard
k	Absolute pipe roughness in mm
K	Resistance coeeficient
kg	Kilogram
kL	Kilolitre
kN	Kilonewton
kPa	Kilopascal
Kv	Flow coefficient, flow factor or valve coefficient (metric)
kW	Kilowatt
L	Litre
L/s	Litres per second
m	Metre
m^2	Square metres
m^3	Cubic metres
mm	Millimetre
m/s	metres per second
MDPE	Medium density polyethylene
ML	Megalitre
MLD	Megalitres per day
MLSS	Mixed liquor suspended solids
MSCL	Mild steel cement lined (pipe and fittings)
N	Speed in revolutions per minute
NACE	National Association of Corrosion Engineers
NATA	National Association of Testing Authorities
NDT	Non-destructive testing
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
Nm	Newton metres
NPSH	Net positive suction head
NPSHa	Net positive suction head available
NPSHr	Net positive suction head required

Term	Description
NZS	New Zealand Standards
OEM	Original equipment manufacturer
OH&S	Occupational health and safety
O&M	Operations and maintenance
PE	Polyethylene (pipe)
PDWF	Peak Dry Weather Flow applies to the daily diurnal flow pattern. As a factor, it is the ratio of the peak hourly flow (usually late morning) to the ADWF measured in the three driest (non-rainfall) months of the year (Usual range is 1.5 to 2.0).
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
pH	Measure of acidity/alkalinity (from German *potenz* = power, and *H*; the symbol for hydrogen). A logarithmic index for the hydrogen ion concentration in an aqueous solution.
PLC	Programmable logic controller
PN	Nominal pressure
ppm	Parts per million
PU	Polyurethane
PVC	Polyvinyl chloride
PWWF	Peak Wet Weather Flow is usually caused by infiltration of water into the collector system during rainfall events. It can be of short (one hour) or long (days) duration. As a design factor it is the ratio of the peak hour flow reaching the plant to the ADWF. (Usual range is 1.9 to 2.2 for Metro plants). To be used for hydraulic design.
Q	Flowrate, capacity or discharge rate
®	Registered
RCD	Residual current joint
Re	Reynolds number
rpm	Revolutions per minute
RPS	Raw primary sludge
RPZD	Reduced pressure zone device
RRJ	Rubber ring joint
s	Second
RST	Rotary screw thickener
SANZ	Standards New Zealand
SCADA	Supervisory control and automated data acquisition

Term	Description
SI	Systems International d' Unites
SLR	Solids loading rate
SPS	Strategic Product Specification
SS	Stainless steel
SSJ	Spherical slip-in welded joint
SWJ	Solvent welded joint
TDH	Total developed head in metres
TEAS	Thickened excess activated sludge (= TWAS)
™	Trademark
TOC	Total organic carbon
TSS	Total suspended solids
TWL	Top Water Level
uPVC	Unplasticized Polyvinyl Chloride (pipe and fittings)
UV	Ultraviolet
V	Volts
VSD	Variable speed drive
VVVF	Variable voltage variable frequency drive (= VSD)
WLL	Working load limit (replaces SWL)
WAS	Waste activated sludge (= EAS)
WSAA	Water Services Association of Australia
WTIA	Welding Technology Institute of Australia
WRRF	Water Resource Recovery Facility
WWTP	Wastewater Treatment Plant

11 APPENDIX D

The table below contains standard units and relationships used by the Corporation.

Quantity	Unit	Relationship
Flow	L/s	Rate of flow
	MLD	L/s x 86.4
Volume	L	Amount of volume
	kL	L / 10^3
	ML	L / 10^6
	GL	L / 10^9
Length	mm	Linear dimension
	m	mm / 10^3
Area	m^2	Areal measure
	ha	m^2 / 10^4

The table below lists SI unit prefixes and symbols for reference.

Fraction or Multiple	Prefix	Symbol
10^{-1}	Deci	d
10^{-2}	Centi	c
10^{-3}	Milli	m
10^{-6}	Micro	µ
10^{-9}	Nano	n
10^{-12}	Pico	p
10	Deca	da
10^2	Hecta	h
10^3	Kilo	k
10^6	Mega	M
10^9	Giga	G
10^{12}	Terra	T

END OF DOCUMENT