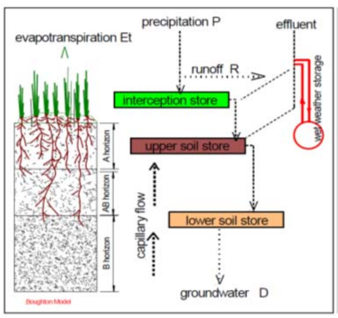
On-site Wastewater Management Training Course

Irrigation Systems; Sizing by Water Balance

Water Balance

- A water balance considers wastewater generation and assimilation of that wastewater load and any other water introduced into the soil, for example by rainfall, by the processes of evaporation, transpiration and seepage

Elements of a Water Balance



Wet Weather Storage

- Some storage of excess effluent may be required

Two types of wet weather storage can be used:

- **Constructed storage**, such as a tank or pond, or
- **In-soil storage** below ground in trenches or beds

Water Balance

- A simplistic water balance is described by the following equation:

wastewater + precipitation = evapotranspiration + drainage + storage *Equation 1*

- Which can be rearranged as follows:

(wastewater + precipitation) – (evapotranspiration + drainage) = storage required *Equation 2*

Wastewater Flow Calculation

- Based on peak occupancy and per person design flows
- Typically calculated by:

Number of persons (2 persons for each of the first two bedrooms, then 1 person for each other bedroom) x per person rate as per AS/NZS 1547:2012 (2+2+1…)

i.e. 3 bedroom, 5 person house

Domestic Wastewater Flow Allowance AS/NZS1547:2012

Source	Onsite roof water – tank supply (Litres/person/day)	Reticulated water supply (Litres/person/day)
Residential premises	120	150

CALCULATION 1 (Wastewater generation) – use a month of 30 days and reticulated water supply

Method	No. of bedrooms	No. of persons	Rate (L/day)	Wastewater (L/day)	Monthly wastewater (L)
2+2+1..	4				

CALCULATION 1 (Wastewater generation) – use a month of 30 days and reticulated water supply

Method	No. of bedrooms	No. of persons	Rate (L/day)	Wastewater (L/day)	Monthly wastewater (L)
2+2+1..	4	6	150	900	27000

Precipitation (Rainfall) (R)

- The value used for the rainfall (R) will depend upon the level of security you wish to include in the calculation
- BoM website offers mean (average), Decile 1 (10th percentile), Decile 5 (median/50th percentile) and Decile 9 (90th percentile) data

Which Precipitation (Rainfall) data to use?

- Mean and median are similar
- Median (50th percentile) values design for failure approximately 7 years in 10
- Mean values design for failure approximately 1 year in 2 (5 years in 10)
- 70th percentile values design for failure approximately 2 years in 10, which is more acceptable and suitably conservative

Precipitation (Rainfall) (R)

- The summation of the 70th percentile monthly rainfall closely resembles the actual 70th percentile annual rainfall
- The use of 90th percentile monthly rainfall, the summation of which gives an annual rainfall value higher than the most extreme annual rainfall ever received, is unrealistic and unnecessarily conservative

Precipitation (Rainfall) (R)

- The use of the 70th percentile is suitably conservative, and more likely to lower the risk of failure compared with median (50th percentile) or average (mean) monthly values
- Access data from SILO

https://www.longpaddock.qld.gov.au/silo/

Retained Rainfall (RR)

- Retained rainfall - the amount of rainfall that is likely to infiltrate into the surface and reduce the volume of wastewater than can be discharged to the ground

Retained Rainfall (RR)

- Runoff Coefficient (r) - the proportion of water that runs off in any event
  - 1 for impervious surfaces (e.g. roofs, paved surfaces), and
  - around 0.25 for grassed areas
- Rainfall Runoff Factor (RF) = (1-r) and is used in Water Balance calculations
- Select an appropriate value, usually between 0.75 and 1.0

Evapotranspiration (ET)

- Not all BoM stations measure open pan evaporation (E)
- May need to use data from a carefully selected station nearby with similar climate, topography (altitude and landform) and proximity to the ocean or very large lakes etc.
- Alternatively use SILO data

Evapotranspiration (ET)

- The open pan evaporation (E) needs to be modified to represent the evapotranspiration (ET) from various types of vegetation by applying a “crop factor” (C)
- Crop factor (<1) varies with season, crop, crop height, exposure to winds, sunlight and many other influences. It is usual to use 0.7 for grass

CALCULATION 2 (Evapotranspiration)

Month	No. days	Daily E	Monthly E	Crop Factor C	Monthly ET
March		5.5		0.7	
April		3.6		0.7	
May		2.2		0.7	

CALCULATION 2 (Evapotranspiration)

Month	No. days	Daily E	Monthly E	Crop Factor C	Monthly ET
March	31	5.5		0.7	
April	30	3.6		0.7	
May	31	2.2		0.7	

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CALCULATION 2 (Evapotranspiration)

Month	No. days	Daily E	Monthly E	Crop Factor C	Monthly ET
March	31	5.5	170.5	0.7	
April	30	3.6	108	0.7	
May	31	2.2	68.2	0.7	

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CALCULATION 2 (Evapotranspiration)

Month	No. days	Daily E	Monthly E	Crop Factor C	Monthly ET
March	31	5.5	170.5	0.7	119.35
April	30	3.6	108	0.7	75.60
May	31	2.2	68.2	0.7	47.74

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Drainage (absorption, seepage, percolation) (B)

- Determine the Design Irrigation Rate (DIR) for the soil
- Select for appropriate field texture and structure using Table M1 (AS/NZS 1547:2012)
- The soil horizon chosen for the design is that which has the lowest permeability (limiting layer) – this is conservative

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Drainage (absorption, seepage, percolation) (B)

- Alternatively, the hydraulic conductivity can be determined using a constant head permeameter
- Do not use the old “percolation test” which is unreliable

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CALCULATION 3 (Drainage/Percolation) (B)

Month	No. days	Daily drainage (mm)	Monthly drainage (mm)
March		4	
April		4	
May		4	

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CALCULATION 3 (Drainage/Percolation) (B)

Month	No. days	DIR (mm)	Monthly drainage (mm)
March	31	4	124
April	30	4	120
May	31	4	124

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Storage (S)

- Calculated using *Equation 2*, a simple arithmetic calculation for each month
- Some months may have a negative value in which the sum of evaporation (ET) and drainage (B) exceeds the sum of the wastewater (W) and precipitation (R) (excess losses)
- Others may be positive, that is W + R exceeds ET + B (too much water)

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EXAMPLE

- Four bedroom (six person) house with a flow design allowance of 900L/day
- For the months of March, April and May the following monthly rainfall and daily evaporation rates apply:
  - Monthly retained rainfall: (52, 48, 46mm)
  - Daily evaporation: (5.5, 3.6, 2.2mm)

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EXAMPLE

- Crop factor is 0.7.
- Soil is a well-structured loam, with a DIR of 4mm/day (4L/m^2/day)
- Irrigation area is 200m^2 of lawn

- Calculate the wet weather storage required for each of the three months

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CALCULATION 4 – (Storage of effluent) (S)

Month	Wastewater W Calc^n 1 (mm)	Retained Rainfall RR = R x RF (mm)	Evapotranspiration ET = E x C Calc^n 2 (mm)	Drainage Calc^n 3 (mm)	Storage In - Out (mm)	Storage Volume depth x area (L)
March		52				
April		48				
May		46				
Totals						

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CALCULATION 4 – (Storage of effluent) (S)

Month	Wastewater W Calc^n 1 (mm)	Retained Rainfall RR = R x RF (mm)	Evapotranspiration ET = E x C Calc^n 2 (mm)	Drainage Calc^n 3 (mm)	Storage In - Out (mm)	Storage Volume depth x area (L)
March#	139.5	52	119.35			
April#	135	48	75.60			
May#	139.5	46	47.74			
Totals						

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CALCULATION 4 – (Storage of effluent) (S)

Month	Wastewater W Calc^{n} 1 (mm)	Retained Rainfall RR = R x RF (mm)	Evapotranspiration ET = E x C Calc^{n} 2 (mm)	Drainage Calc^{n} 3 (mm)	Storage In - Out (mm)	Storage Volume depth x area (L)
March#	139.5	52	119.35	124		
April#	135	48	75.60	120		
May#	139.5	46	47.74	124		
Totals						

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CALCULATION 4 – (Storage of effluent) (S)

Month	Wastewater W Calc^{n} 1 (mm)	Retained Rainfall RR = R x RF (mm)	Evapotranspiration ET = E x C Calc^{n} 2 (mm)	Drainage Calc^{n} 3 (mm)	Storage In - Out (mm)	Storage Volume depth x area (L)
March#	139.5	52	119.35	124	-51.85	-10370
April#	135	48	75.60	120	-12.60	-2520
May#	139.5	46	47.74	124	13.76	2752
Totals					-50.69	-10138

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Cumulative Storage (M)

- The storage requirement accumulates each month and over an extended period of positive inputs
- There is no opportunity to irrigate the stored water onto the land during these months where total inputs exceed total outputs

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Cumulative Storage (M)

- This storage component then becomes part of the wastewater load
- There are many operational difficulties in accounting for the stored effluent, which must be disposed of to the land application area at the first available opportunity (months when outputs exceed inputs) to free up the storage space

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Cumulative Storage

- In Calculation 4, the total depth of stored water is for three months. In this case the value is negative, but it is quite possible that it can be positive (excess)
- A similar calculation would be required for at least a full year, preferably longer, and the maximum cumulative storage is the volume between zero storages in the annual cycle

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Cumulative Storage

- If the volume is TOO large, then either the wastewater load will have to be reduced or the irrigation area increased
- In some wet climates it is not possible to dispose of the excess storage by simply increasing the size of the disposal area

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Cumulative Storage

- Separate wet weather storage might be inevitable
- In any full year, the cumulative total must return to zero for the system to be sustainable

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Modelling for In-ground Storage

- *Equation 1* may be rearranged to calculate the annual wastewater depth that can be applied to a particular area, with all measurements in millimetres

Wastewater Application = Evapotranspiration + Drainage - Design Precipitation   Equation 3

- However, this equation does not account for the ability to store water in the soil

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Minimum Area Method

- Can take account of the potential for storing water in the pore space in the soil
- This method is known as the Minimum Area Method

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Minimum Area Method

- In most aggregates and natural soils, the void space ratio is in the order of 30% of the total volume
- Typically each 1mm of Cumulative Storage would saturate 3mm depth of otherwise unsaturated soil
- Can therefore assess the potential depth of saturation at any time

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Minimum Area Method

- Start with the calculation in *Equation 3*
- In the modelling exercise, this is further refined in *Equation 4*
- The selection of the appropriate monthly percentile value will have a significant bearing on the outcome, as will the daily wastewater generation rate

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Minimum Area Method

Wastewater + Precipitation – Evapotranspiration – Drainage ± In-ground Storage = 0   Equation 4

- When the in-ground storage value is negative, the value has to be reset to zero, since it is not possible to have less water than none

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CALCULATION 5 - TRIAL AREA = 200m^2 (same as above to avoid recalculations)

Month	Application rate W + R (mm)	Disposal rate ET + B (mm)	Result (mm)	Change in depth (mm)	Depth for month (mm)	Cumulative depth for month (mm)
March						
April						
May						

CALCULATION 5 - TRIAL AREA = 200m^2 (same as above to avoid recalculations)

Month	Application rate W + R (mm)	Disposal rate ET + B (mm)	Result (mm)	Change in depth (mm)	Depth for month (mm)	Cumulative depth for month (mm)
March	191.5	243.35	-51.85			
April	183	195.60	-12.60			
May	185.5	171.74	13.76			

CALCULATION 5 - TRIAL AREA = 200m^2 (same as above to avoid recalculations)

Month	Application rate W + R (mm)	Disposal rate ET + B (mm)	Result (mm)	Change in depth (mm) Divide by 0.3	Depth for month (mm)	Cumulative depth for month (mm)
March	191.5	243.35	-51.85	-172.83		
April	183	195.60	-12.60	-42.00		
May	185.5	171.74	13.76	45.87		

CALCULATION 5 - TRIAL AREA = 200m^2 (same as above to avoid recalculations)

Month	Application rate W + R (mm)	Disposal rate ET + B (mm)	Result (mm)	Change in depth (mm) Divide by 0.3	Depth for month (mm)	Cumulative depth for month (mm)
March	238	243.35	-51.85	-172.83	0	0
April	228	195.60	-12.60	-42.00	0	0
May	232	171.74	13.76	45.87	45.87	45.87

Minimum Area Method

- Complete calculations for a whole year
- For surface and subsurface irrigation, the computed depth must be kept close to ZERO at all times so that the surface soil is never saturated
- Clearly the soils must be free draining and have adequate unsaturated depth to accommodate irrigated effluent

Spreadsheet Model

- The 1994 version of Australian Standard AS1547 included a water balance model which has not been reproduced in the 2000 and 2012 versions of the Standard, yet is every bit as useful and appropriate now as it was in 1994!

Conclusion

- The water balance model assesses the sensitivity of the design to the various input and output characteristics
- Avoid choosing too small an area with the risk of having a saturated soil for long periods
- Having too large an application area may result in poor dispersal and vegetation die-off

Conclusion

- Templates for both Minimum Area and Nominated Area water balances follow in these notes
- Also included is a completed example of the Minimum Area water balance
- Designers and regulators should do the first one (few) longhand with pencil, paper and calculator – then set up an Excel spreadsheet!

Minimum Area Method Water Balance and Wet Weather Storage Calculations

Site Address:

Date: **Assessor:**

INPUT DATA

Design Wastewater Flow	Q		L/day	Based on maximum potential occupancy and derived from Appendix H, AS/NZS1547:2012
Design Irrigation Rate	DIR		mm/day	Based on soil texture class/permeability and derived from Table M1, AS/NZS1547:2012
Nominated Land Application Area	L		m^2	[1]
Crop Factor	C	0.6-0.8	unitless	Estimates evapotranspiration as a fraction of pan evaporation; varies with season and crop type[2]
Rainfall Runoff Factor	RF		unitless	Proportion of rainfall that remains onsite and infiltrates, allowing for any runoff
Mean Monthly Rainfall Data				BoM Station and number
Mean Monthly Pan Evaporation Data				BoM Station and number

Parameter	Symbol	Formula	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Days in month	D		days	31	28	31	30	31	30	31	31	30	31	30	31	**365**
Rainfall	R		mm/month													
Evaporation	E		mm/month													
Crop Factor	C		unitless	0.80	0.80	0.70	0.70	0.60	0.60	0.60	0.60	0.70	0.80	0.80	0.80	
OUTPUTS																
Evapotranspiration	ET	ExC	mm/month													
Percolation	B	DIRxD	mm/month													
Outputs		ET+B	mm/month													
INPUTS																
Retained Rainfall	RR	RxRF	mm/month													
Possible Effluent Irrigation	W	(ET+B)-RR	mm/month													
Actual Effluent Production	I	H/12	mm/month													
Inputs		RR+I	mm/month													
STORAGE CALCULATION																
Storage for the month	S	(RR+I)-(ET+B)	mm/month													
Cumulative Storage	M		mm													
LAND AREA REQUIRED																
Irrigation Area	L	(365xQ)/H	m^2			H = Sum of W										
STORAGE																
Storage	V	largest M	mm			Cumulative Storage is calculated by adding residual storage from previous month to current month										
		(VxL)/1000	m^3			Cumulative storage cannot be less than zero										

CELLS

(blue)	Please enter data in blue cells
XX	Data in yellow cells is calculated by the spreadsheet, DO NOT ALTER THESE CELLS

NOTES

[1] This value should be the largest of the following: land application area required based on the most limiting nutrient balance or minimum area required for zero storage

[2] Values selected are suitable for pasture grass

Nominated Area Method Water Balance and Wet Weather Storage Calculations

Site Address:

Date: **Assessor:**

INPUT DATA

Design Wastewater Flow	Q		L/day	Based on maximum potential occupancy and derived from Appendix H, AS/NZS1547:2012
Design Irrigation Rate	DIR		mm/day	Based on soil texture class/permeability and derived from Table M1, AS/NZS1547:2012
Nominated Land Application Area	L		m^2	[1]
Crop Factor	C	0.6-0.8	unitless	Estimates evapotranspiration as a fraction of pan evaporation; varies with season and crop type[2]
Rainfall Runoff Factor	RF		unitless	Proportion of rainfall that remains onsite and infiltrates, allowing for any runoff
Mean Monthly Rainfall Data				BoM Station and number
Mean Monthly Pan Evaporation Data				BoM Station and number

Parameter	Symbol	Formula	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Days in month	D		days	31	28	31	30	31	30	31	31	30	31	30	31	**365**
Rainfall	R		mm/month													**0**
Evaporation	E		mm/month													**0**
Crop Factor	C		unitless	0.80	0.80	0.70	0.70	0.60	0.60	0.60	0.60	0.70	0.80	0.80	0.80	
OUTPUTS																
Evapotranspiration	ET	ExC	mm/month													
Percolation	B	DIRxD	mm/month													
Outputs		ET+B	mm/month													
INPUTS																
Retained Rainfall	RR	RxRF	mm/month													
Effluent Irrigation	W	(QxD)/L	mm/month													
Inputs		RR+I	mm/month													
STORAGE CALCULATION																
Storage for the month	S	(RR+I)-(ET+B)	mm/month													
Cumulative Storage	M		mm													
LAND AREA REQUIRED																
Irrigation Area	L		m^2													
STORAGE																
Storage	V	largest M	mm			Cumulative Storage is calculated by adding residual storage from previous month to current month										
		(VxL)/1000	m^3			Cumulative storage cannot be less than zero										

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NOTES

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[2] Values selected are suitable for pasture grass

IRRIGATION AREA SIZING BY WATER BALANCE WORKSHOP SESSION

Calculation of irrigation area size by use of a water balance.

In ideal circumstances, all effluent applied to an irrigation area would be assimilated by seepage into the soil and/or evapotranspiration. This may not be possible at all times of the year, particularly if the soil has a low hydraulic conductivity i.e. a low Design Irrigation Rate (DIR) and/or during or following a succession of wet months.

A water balance can be used to assess how the various parameters such as the daily hydraulic load, rainfall, evapotranspiration, DIR, crop factor and rainfall runoff factor contribute to the performance of an irrigation area throughout the annual climatic cycle.

We will use the following climatic data to calculate the minimum irrigation area size required for a three bedroom / five person dwelling.

Bureau of Meteorology rainfall and pan evaporation data for the nearest station (Perth Airport) is provided below.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
DAILY PAN EVAPORATION (mm)	10.2	9.6	7.7	5.0	3.0	2.2	2.1	2.6	3.7	5.4	7.5	9.1
MEAN MONTHLY RAINFALL (mm)	11.1	14.9	16.0	40.0	97.4	155.7	156	119.0	72.7	43.2	25.6	11.3

The soils in the proposed irrigation area are 475mm of weakly structured clay loam overlying moderately structured light clay to a depth of 2000mm. Use the recommended design loading rate derived from Table M1 of AS/NZS 1547:2012 (see the Field Workshop and Design Exercise section of these Course Notes).

Calculate the irrigation area size using the worksheet provided on the following page.

Questions

What makes up the load applied to the soil?

For how many months of the year is storage required?

What is the maximum storage requirement indicated by the water balance?

Whilst flow balancing (wet weather storage for later discharge) is an option, it is rarely used in domestic wastewater systems.

What are the alternatives for managing the daily hydraulic load?

Which of the variable parameters can be changed to result in advantageous outcomes?

Minimum Area Method Water Balance and Wet Weather Storage Calculations

Site Address:

Date: **Assessor:**

INPUT DATA

Design Wastewater Flow	Q	750	L/day	Based on maximum potential occupancy and derived from Appendix H, AS/NZS1547:2012
Design Irrigation Rate	DIR	3.0	mm/day	Based on soil texture class/permeability and derived from Table M1, AS/NZS1547:2012
Nominated Land Application Area	L		m^2	[1]
Crop Factor	C	0.6-0.8	unitless	Estimates evapotranspiration as a fraction of pan evaporation; varies with season and crop type[2]
Rainfall Runoff Factor	RF	1.0	unitless	Proportion of rainfall that remains onsite and infiltrates, allowing for any runoff
Mean Monthly Rainfall Data		Perth Airport (009021)		BoM Station and number
Mean Monthly Pan Evaporation Data		Perth Airport (009021)		BoM Station and number

Parameter	Symbol	Formula	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Days in month	D		days	31	28	31	30	31	30	31	31	30	31	30	31	**365**
Rainfall	R		mm/month	11.1	14.9	16	40	97.4	155.7	156	119	72.7	43.2	25.6	11.3	**762.9**
Evaporation	E		mm/month	316.2	268.8	238.7	150	93	66	65.1	80.6	111	167.4	225	282.1	**2063.9**
Crop Factor	C		unitless	0.80	0.80	0.70	0.70	0.60	0.60	0.60	0.60	0.70	0.80	0.80	0.80	
OUTPUTS																
Evapotranspiration	ET	ExC	mm/month	253.0	215.0	167.1	105.0	55.8	39.6	39.1	48.4	77.7	133.9	180.0	225.7	**1540.2**
Percolation	B	DIRxD	mm/month	93.0	84.0	93.0	90.0	93.0	90.0	93.0	93.0	90.0	93.0	90.0	93.0	**1095.0**
Outputs		ET+B	mm/month	346.0	299.0	260.1	195.0	148.8	129.6	132.1	141.4	167.7	226.9	270.0	318.7	**2635.2**
INPUTS																
Retained Rainfall	RR	RxRF	mm/month	11.1	14.9	16.0	40.0	97.4	155.7	156.0	119.0	72.7	43.2	25.6	11.3	**762.9**
Possible Effluent Irrigation	W	(ET+B)-RR	mm/month	334.9	284.1	244.1	155.0	51.4	-26.1	-23.9	22.4	95.0	183.7	244.4	307.4	**1872.3**
Actual Effluent Production	I	H/12	mm/month	156.0	156.0	156.0	156.0	156.0	156.0	156.0	156.0	156.0	156.0	156.0	156.0	**1872.3**
Inputs		RR+I	mm/month	167.1	170.9	172.0	196.0	253.4	311.7	312.0	275.0	228.7	199.2	181.6	167.3	**2635.2**
STORAGE CALCULATION																
Storage for the month	S	(RR+I)-(ET+B)	mm/month	-178.8	-128.1	-88.1	1.0	104.6	182.1	180.0	133.7	61.0	-27.7	-88.4	-151.4	
Cumulative Storage	M		mm	0.0	0.0	0.0	1.0	105.7	287.8	467.7	601.4	662.4	634.7	546.4	395.0	
LAND AREA REQUIRED																
Irrigation Area	L	(365xQ)/H	m^2	**146**		H = Sum of W										
STORAGE																
Storage	V	largest M	mm	**662**		Cumulative Storage is calculated by adding residual storage from previous month to current month										
		(VxL)/1000	m^3	**97**		Cumulative storage cannot be less than zero										

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NOTES

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[2] Values selected are suitable for pasture grass