Submission No 286

INQUIRY INTO COAL SEAM GAS

Organisation: Upper Hunter Waterkeepers Alliance

Date received: 7/09/2011

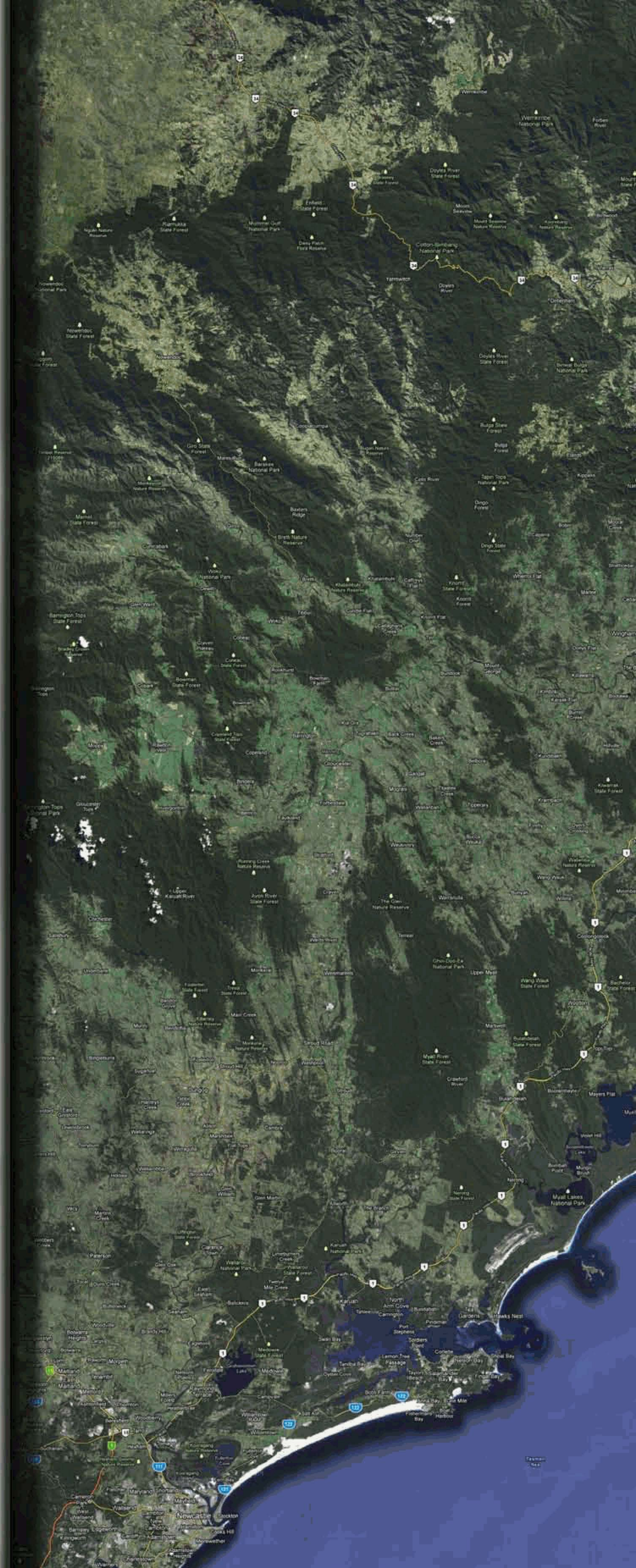
This report examines the state of baseline water datasets and the status of water resources in the Upper Hunter Local Government Region. The report makes recommendations on how to improve baseline water datasets, and how to improve certainty for landowners, governments and mining companies.

The report was prepared by FrOG Tech on behalf of the Upper Hunter Waterkeepers Alliance.

Risks of Coal Seam Gas in the Upper Hunter

September, 2011

Commissioned by
The Upper Hunter Waterkeepers Alliance



HUN802

From Oil to Groundwater
FrOG Tech®

Evaluation of the Risks of Coal Seam Gas in the Upper Hunter Local Government Area

Submission to the NSW Coal Seam Gas Inquiry

September 2011

FrOG Tech Project Code:
HUN802

Author:

S Hostetler, BSc (Hon) shostetler@frogtech.com.au

FrOG Tech Project Team:
www.frogtech.com.au

Jane Blevin, PhD
Donna Cathro, PhD
James Chapman, MA
Karen Connors, PhD
Marina den Hartog, MSc
Nick Direen, PhD
Fiona Farquharson, CA
Meredith Guy-Villon, DipFA
Philip Henley
Stephen Hostetler, BSc (Hons)
Cedric Jorand, PhD
Andrew Krassay, PhD
Tom Loutit, PhD
Allan Mills, BE
Usha Morar, BSc Post Grad
Christopher Pietrucha, BSc Env
Yvette Poudjom Djomani, PhD
Lynn Pryer, PhD
Michael Robinson, PhD
Karen Romine, PhD
Zhiqun Shi, PhD
Silvano Sommacal, PhD
John Vizy, DipGS

Stephen Hostetler
Hydrogeologist

Michael Robinson
Chief Executive Officer

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Summary

This project examines some of the potential risks to water resources due to coal seam gas mining in the Upper Hunter Local Government Area.

Lack of baseline hydrological datasets
There is a lack of long term surface water and groundwater monitoring for the Upper Hunter Local Government Area (LGA). Without adequate baseline datasets, the effects of Coal Seam Gas (CSG) mining cannot be adequately measured or modelled.

Surface Water (***pages 29-39)***

There is sufficient data for analysing trends from 7 gauges in the Upper Hunter LGA. In addition (**page 30)**, most of the available streamflow monitoring is located in the eastern part of the Upper Hunter LGA. However, the primary focus of CSG exploration thus far is in the Gunnedah Basin (west of the New England Highway).

Groundwater (***pages 40-52****)*

There is no continuous monitoring of groundwater levels or groundwater quality in the Upper Hunter. Where groundwater monitoring exists, measurement intervals are sparse and infrequent. With a median of 5 measurements over a 20-30 years time period.

Recommendation 1

Before CSG exploration or production starts, there needs to be established:

- a network of surface water gauges in affected catchments with a baseline establishment period of at least 10 years;
- a network of continuously monitored, telemetered, nested piezometers throughout the Upper Hunter to provide calibration and baseline data on groundwater at various depths. Such a network will also help to understand the relationship between potable aquifers and the targeted coal seams; and
- a program of groundwater quality sampling in the Upper Hunter to establish both baseline data, but also to allow for early warning on potential contamination from CSG mining. Samples to be taken from both groundwater bores under use and from the piezometer network described above. Water samples should be analysed for major and minor chemistry, as well as BTEX chemicals and other volatile compounds.

Highly stressed system
While rainfall in the Upper Hunter has remained near normal (**pages 6-28)**, streamflow and groundwater levels have decreased.

Most gauged rivers in the Upper Hunter LGA (the Hunter River, Kingdon Ponds Creek, Moonan Brook, Pages River and Rouchel Brook) are highly utilised (**page 54**) and show a decrease in streamflow compared to "natural" conditions. In addition, all rivers (**pages 55-56**) are rated as having a high level hydrologic stress, with the exception being Stewarts Brook (which is rated as having a medium level of hydrologic stress).

In addition, groundwater levels across the Upper Hunter have declined over the last 30 years (**pages 46-51**).

Rivers in the Upper Hunter also have a high level of baseflow (groundwater component) so any decrease in groundwater levels will result in a decreased volume of water in the rivers as well (**page 32**).

Co-produced water (page 51)
Long term average water production from the CSG in Australia is estimated to be about 200-400 ML/PJ. Exploration for CSG in the Gunnedah Basin is relatively recent so the total reserves of natural gas is not known, but current estimates are at least 336 PJ. The geologically similar, Bowen Basin has over 5000 PJ of natural gas.

This suggests that from 1000-2000 GL of water could be co-produced the Gunnedah Basin. Assuming a 20 year lifespan of a CSG field, this equates to ~50-100 GL/yr of co-produced water. As a comparison, the total local water utilities licenses (28 licenses) in the NSW Great Artesian Basin is 5.8 GL/yr
(http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_nsw_gab_background.pdf.aspx).

Salt/heavy metals from co-produced water (page 52)
Co-produced water is usually saline and contains significant amounts of heavy metals. Over the life of CSG production in the Gunnedah Basin over 1.3 million tons of salt will be extracted. In addition, 4.4 tones of lead, 5.6 tons of chromium and 2.5 tons of arsenic will be brought to the surface.

In comparison total annual salt load in the Namoi River is estimated to be ~135,000 tons/yr
(www.water.nsw.gov.au/.../34/quality_iqqm_mbd_**namoi**.pdf.aspx), while the Macquarie River at Narromine is estimated to be 224,100 tons/yr
(*www.water.nsw.gov.au/.../34/quality_iqqm_mbd_**macquarie**.pdf.aspx).*

Recommendation 2
The preferred method of disposal of co-produced water should be re-injection of the water back into the original coal seam as soon as possible.

Such a policy will not only dispose of the salt and water safely, but it will act to re-pressurise the coal seam, limiting potential negative effects on groundwater and surface water levels.

Groundwater modelling (page 58)
Any groundwater models produced by CSG companies will be inadequate to measure the water impacts at the local scale or even regionally because of the lack of data. Much like a digital picture is made of pixels, a groundwater model is made of cells. The resolution of the groundwater model is only as good as the available data (typically wells, seismic data, groundwater modelling etc.). As noted above there is no continuous groundwater monitoring. There are only a handful of CSG/petroleum wells that are ~30km apart and there are only a few seismic lines dating from the 1960s. The CSG companies can't possibly understand the effects of their wells, let alone the cumulative effects of multiple wells from multiple companies producing CSG at the same time.

Recommendation 3
In order to measure the effects of not just a single CSG scheme, but the cumulative effects throughout the region/state, a master groundwater model of the Upper Hunter (and indeed NSW) should be built and maintained by an independent group.

Data resolution can be enhanced through incorporation of data from the groundwater and surface water baseline datasets, and through extensive, longterm (1-3 months) pump tests in strategic locations, so that the groundwater model is based on the best available information.

As part of maintaining the groundwater model, the independent group will be able to advise the NSW Government, CSG companies and landholders if there is enough data in an area to give certainty about the effects of CSG mining.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Summary continued

Other stresses (page 66)
A carbon price could change the landuse balance in the Upper Hunter from predominantly pasture/grazing to forestry. A 10% change from grazing to forests will decrease surface water runoff by 0.6%. Coupled with the modelled 10% decrease in surface water runoff due to climate change, further stress of the river systems in the Upper Hunter could be expected.

Recommendation 4
In order to understand and manage these risks, it is recommended that the NSW Government in partnership with the local government, industries and people from the Upper Hunter, develop a comprehensive, whole of region plan. Such a plan should include an assessment of known and unknown information, potential risks and strategies to limit/manage risks.

Introduction and Aims

This project examines some of the potential risks to water resources due to coal seam gas mining in the Upper Hunter Local Government Area. The project was commissioned by the Upper Hunter Waterkeepers Alliance in response to the call by the New South Wales Government for an inquiry into Coal Seam Gas (http://www.parliament.nsw.gov.au/prod/parlment/committee.nsf/0/29AE48525CFAEA7CCA2578E3001ABD1C).

This report is to designed to accompany testimony given by FrOG Tech on 5 September 2011 at Scone, NSW.

The report sets out in more detail than will be possible during the inquiry the following information:

- background information on the areas of interest for coal seam gas;
- the status and type of baseline climatic, surface water and groundwater datasets;
- analysis of surface water resources including consumptive use, the level of hydrologic stress and the volume of groundwater contribution to streamflow;
- analysis of groundwater trends;
- estimates of the volume of co-produced water due to coal seam gas mining, along with the risks of mobilising salt and heavy metals;
- a description of the major aquifers from the surface to the target coal seams;
- the ability of groundwater modelling to answer questions on the effects of coal seam gas mining;
- a description of the geology of the region and the target coal seams, as well as the location of coal seam gas exploration;
- a description of current landuse;
- an analysis of other risks to the water resource; and
- recommendations for safeguarding water supplies in the Upper Hunter.

This report is not a comprehensive look into the full effects of coal seam gas mining on water resources in the Upper Hunter, nor an analysis of all water resources/uses in the region. Should more information be sought, please contact the FrOG Tech.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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F: +61 2 6283 4801
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Petroleum Exploration Licenses

Location of Exploration Permits

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
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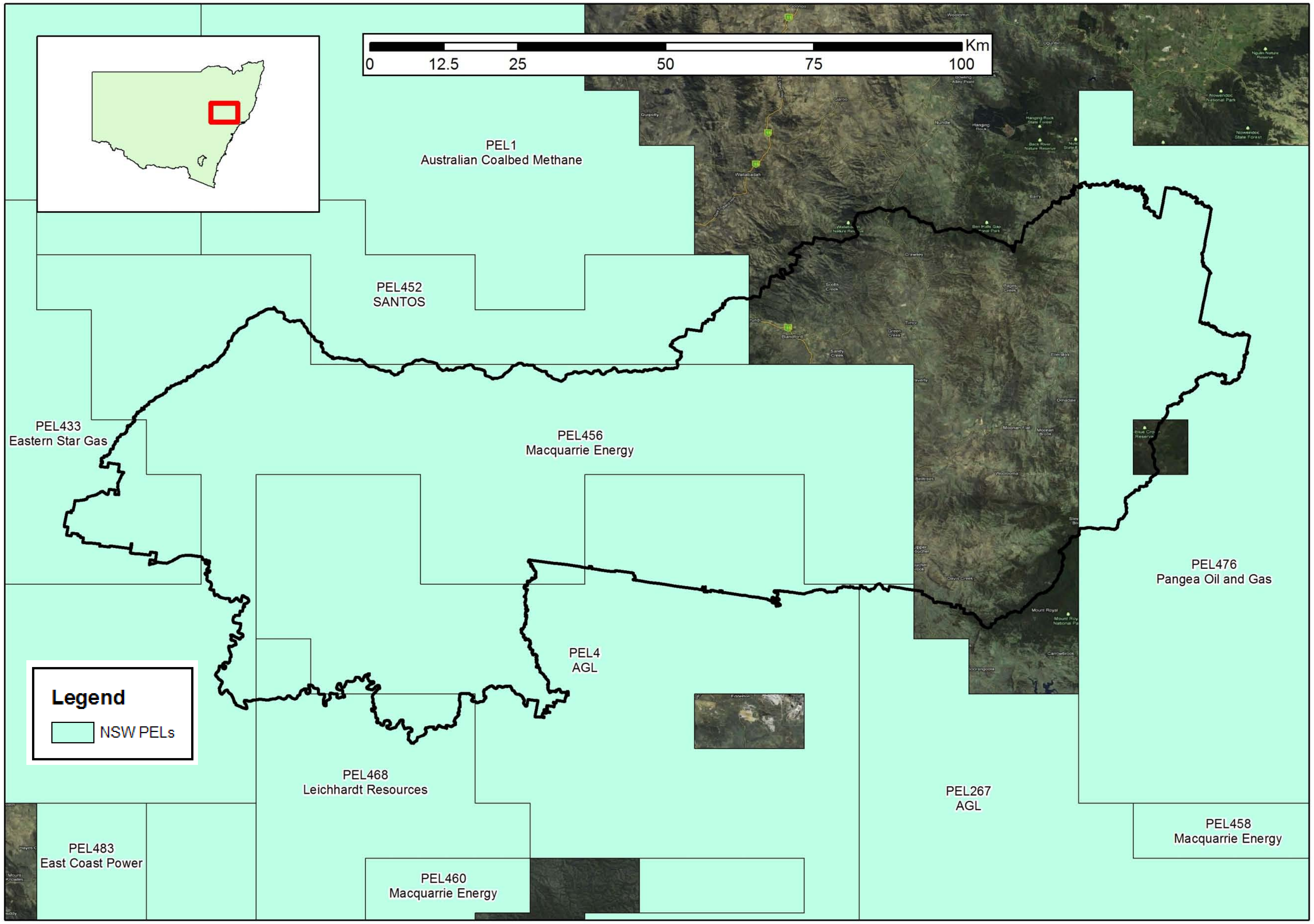
Upper Hunter Region Petroleum Licenses



The Upper Hunter LGA is covered by 7 partial Petroleum Exploration Licenses (PEL) granted by the NSW government.

The image to the **left** shows the extent of the PELs and the name of the licensed operator.

As can be seen, the primary focus of CSG exploration is in the western part of the Upper Hunter LGA, which geologically, is part of the Gunnedah Basin (see **pages 59-62**).

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
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CANBERRA, AUSTRALIA

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Climate Analysis

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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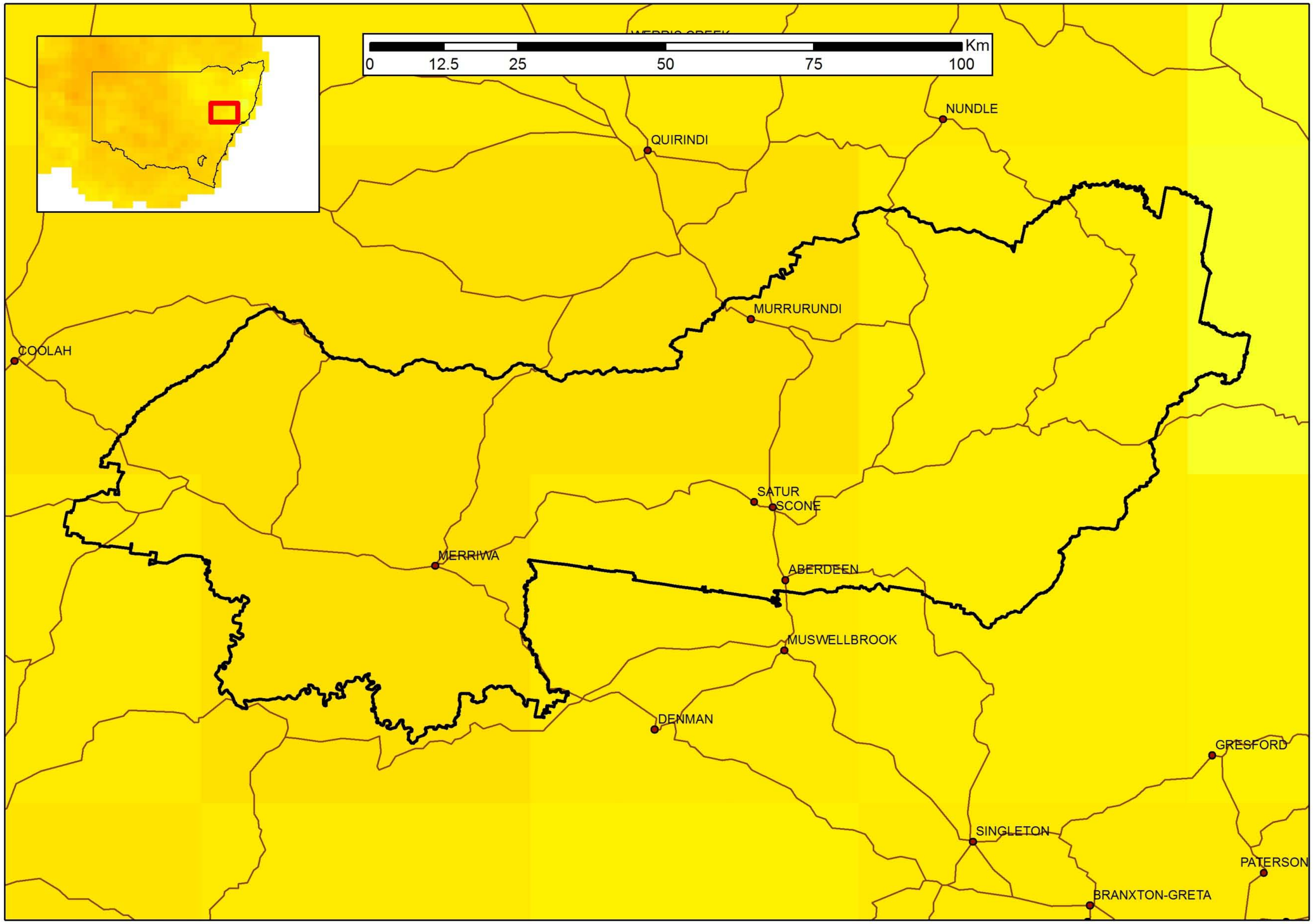
Upper Hunter Region Climate: Comparison of recent to longterm

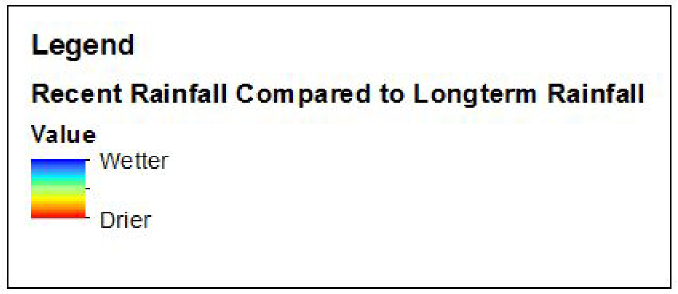


Recent rainfall (2001-2010) in the Hunter region has been generally at or above the longterm average (1900-2010). Data is from ftp://ftp-anon.dwd.de/pub/data/gpcc/PDF/GPCC_intro_products_2008.pdf.

Rainfall in the eastern part of the Upper Hunter LGA is approximately equal to the longterm average, while in the west, rainfall during 2001-2010 was ~7% below average. There has also been an over all decrease in streamflow in the key gauges in the Upper Hunter (see **page 31**).

This relationship is reflected in the analysis of the individual Bureau of meteorology weather stations seen on **pages 9-29**. Annual average rainfall is variable ranging from 5-10% lower to ~5% higher over the last 20 years compared to the longterm record.

Climate change is forecast to decrease rainfall by ~3% which equates to a decrease of runoff of ~10% (CSIRO 2007).



Above: Relative change in rainfall between 2001-10 compared to 1900-2010 (yearly rainfall data from ftp://ftp-anon.dwd.de/pub/data/gpcc/PDF/GPCC_intro_products_2008.pdf.

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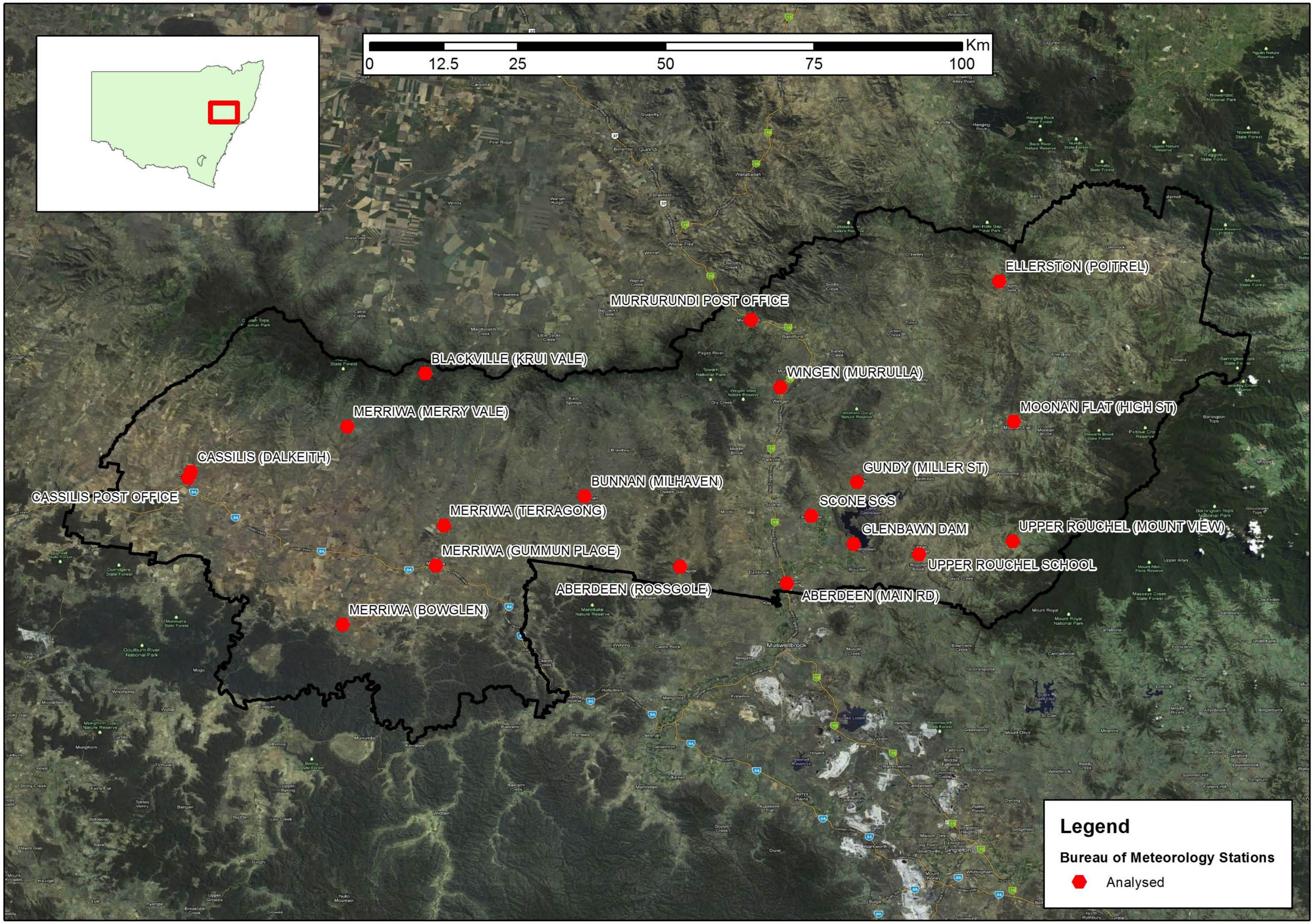
Location of Bureau of Meteorology rain gauges with long records



(Image from Google Maps)

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PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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Aberdeen (Main Road) 61000 (Analysis Explained)

Name and BOM serial number of the site. Data from http://www.bom.gov.au/climate/data/

Rainfall statistics (**right**). Monthly and annual rainfall statistics for the entire record and for the last 20 years. The coloured box, indicates whether annual rainfall during the last 20 years is higher (**green**) or lower (**red**) than the longterm average.

Visual representation (**below**) of the same rainfall statistics. Solid lines represent whole of record values, while dashed lines represent the values for the last 20 years.

Aberdeen (Main Road) entire record: 114 years of data (1894 to 2007)

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	0	0	0	0	1	0	0	0	0	1	0	283
Average	73	62	51	41	42	45	41	37	39	49	51	66	592
Max	232	433	198	175	228	225	199	179	162	160	171	201	1188
10%ile	17	7	5	3	4	9	7	8	8	11	8	20	374
50%ile	63	40	38	31	27	34	31	28	32	43	45	57	599
90%ile	148	138	114	91	92	96	85	70	75	98	99	130	790

Aberdeen (Main Road) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	4	0	3	0	0	6	3	1	2	0	6	31	283
Average	67	69	51	38	43	38	41	37	40	40	52	82	575
Max	140	203	173	124	118	99	134	111	84	127	142	174	874
10%ile	21	10	6	1	8	19	10	7	8	5	12	38	354
50%ile	68	59	37	18	42	33	36	33	44	38	50	69	608
90%ile	121	147	119	93	74	77	73	88	70	76	84	141	780

Size of rainfall events (mm) for various return intervals

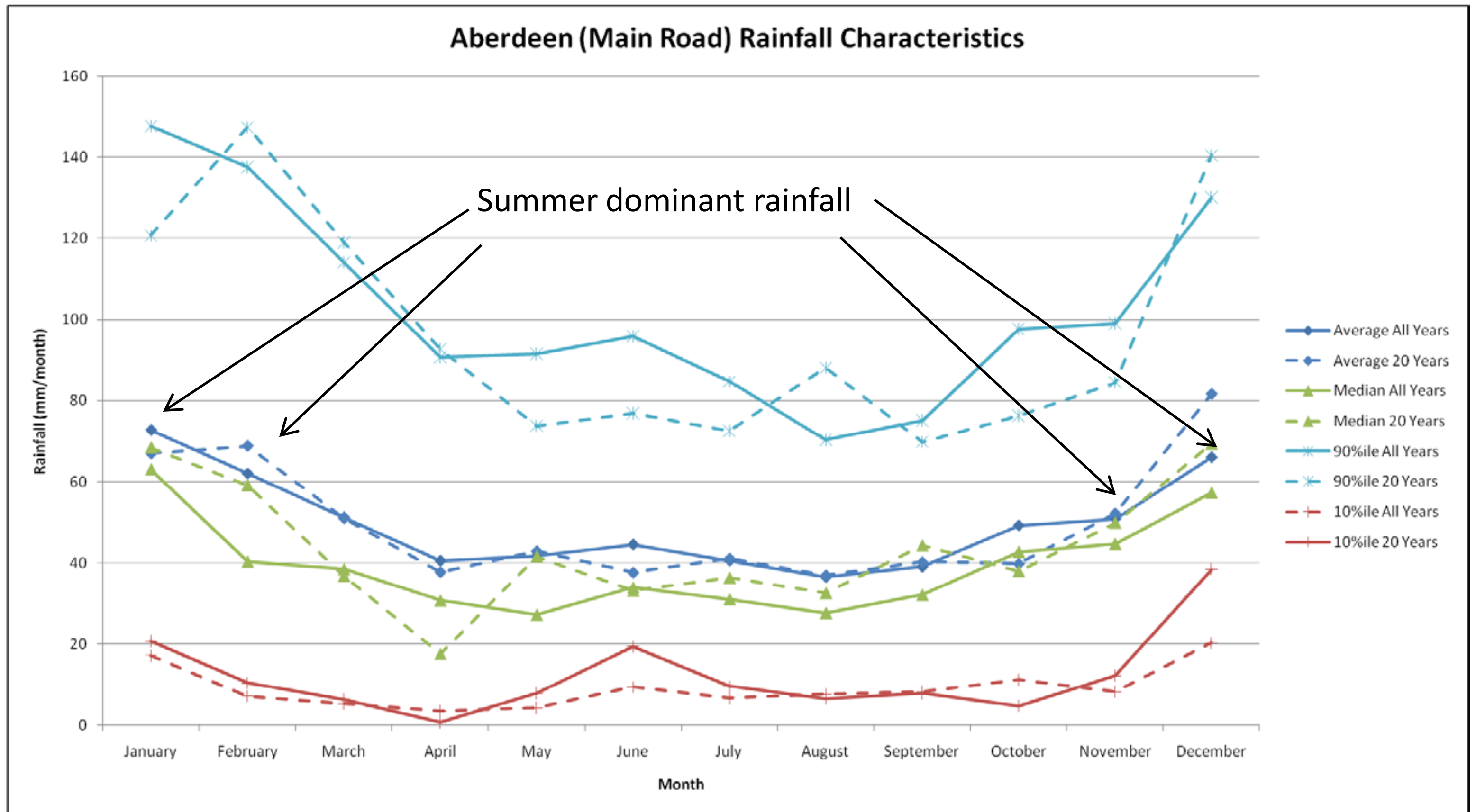
Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	64	51	44	35	35	38	35	31	34	44	45	59	577
5	110	108	85	66	72	72	67	59	61	74	79	98	728
10	140	146	112	87	97	95	89	76	78	94	101	124	816
20	169	182	138	107	121	117	110	94	95	113	123	149	893
25	178	194	146	113	129	124	116	99	100	119	129	157	916
50	207	229	171	132	152	145	136	116	117	138	151	181	984
100	235	264	197	152	175	166	156	133	133	157	172	205	1047
500	300	346	255	196	229	214	203	171	171	200	220	261	1182

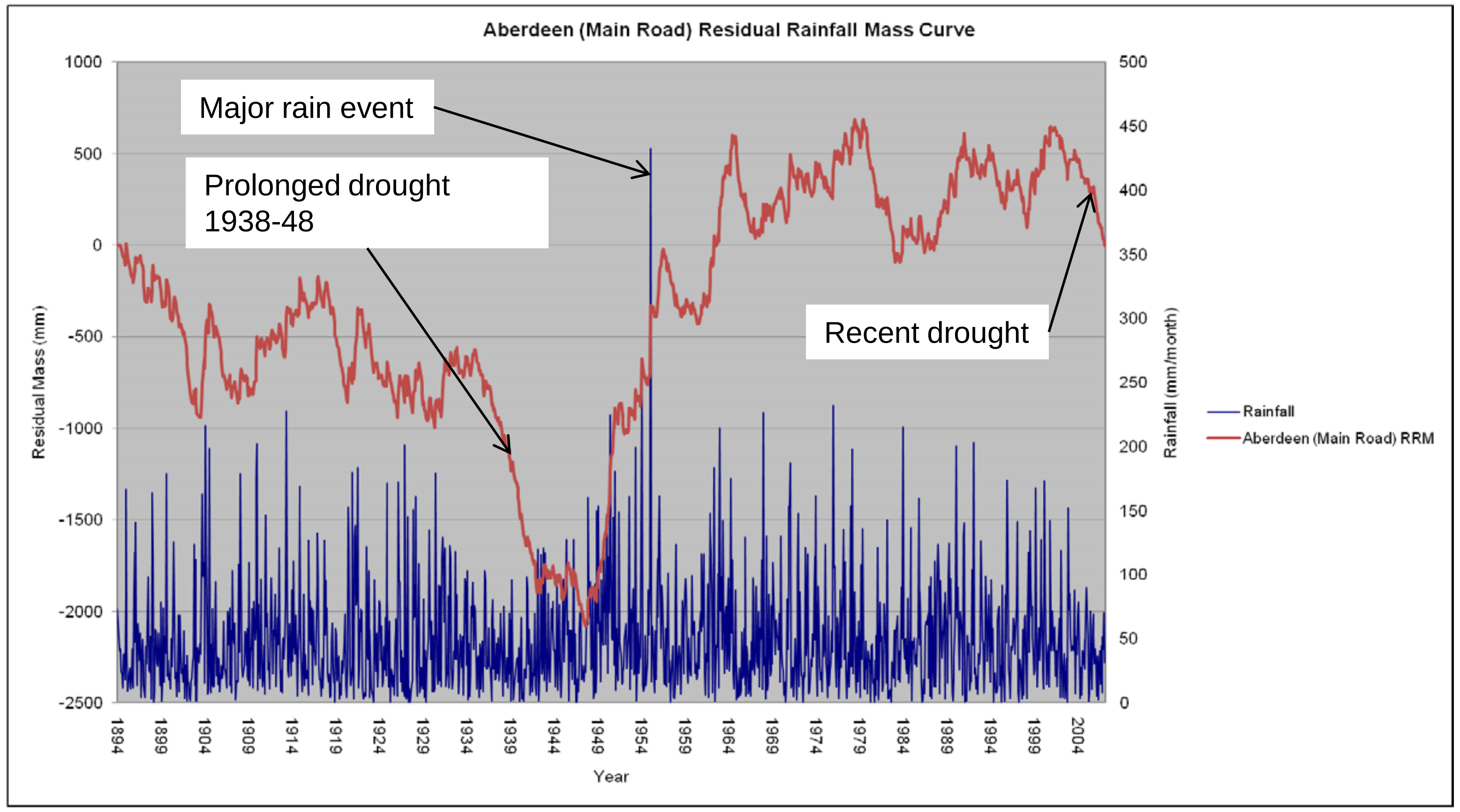
Residual Rainfall Mass (**below**). The **blue** lines represents actual monthly rainfall during for the site.

The **red** line is a running average of actual monthly rainfall (known as a Residual Rainfall Mass Curve or RRM) against the longterm average rainfall. A decrease in the **red** line means that actual rainfall was less than average rainfall for that month. While a rise in the **red** line indicated that actual rainfall was above average.

Droughts then are represented by a significant downwards trends, and "good" periods by upwards trends.

Where data is missing, average values were substituted, which results in no change to the RRM.





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PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
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Aberdeen (Main Road) 61000

Aberdeen (Main Road) entire record: 114 years of data (1894 to 2007)

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Max	232	433	198	175	228	225	199	179	162	160	171	201	1188
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Size of rainfall events (mm) for various return intervals

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5	110	108	85	66	72	72	67	59	61	74	79	98	728
10	140	146	112	87	97	95	89	76	78	94	101	124	816
20	169	182	138	107	121	117	110	94	95	113	123	149	893
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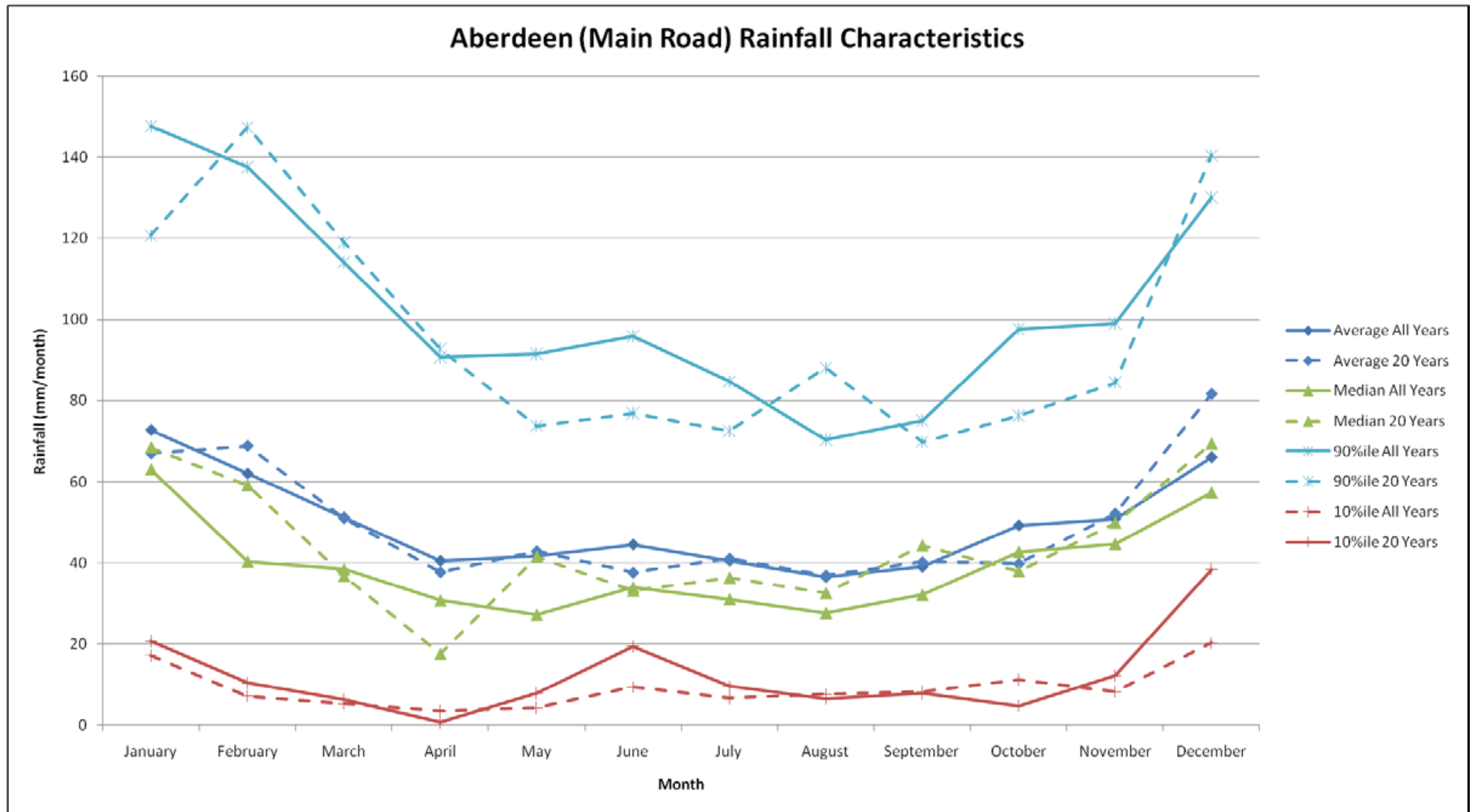

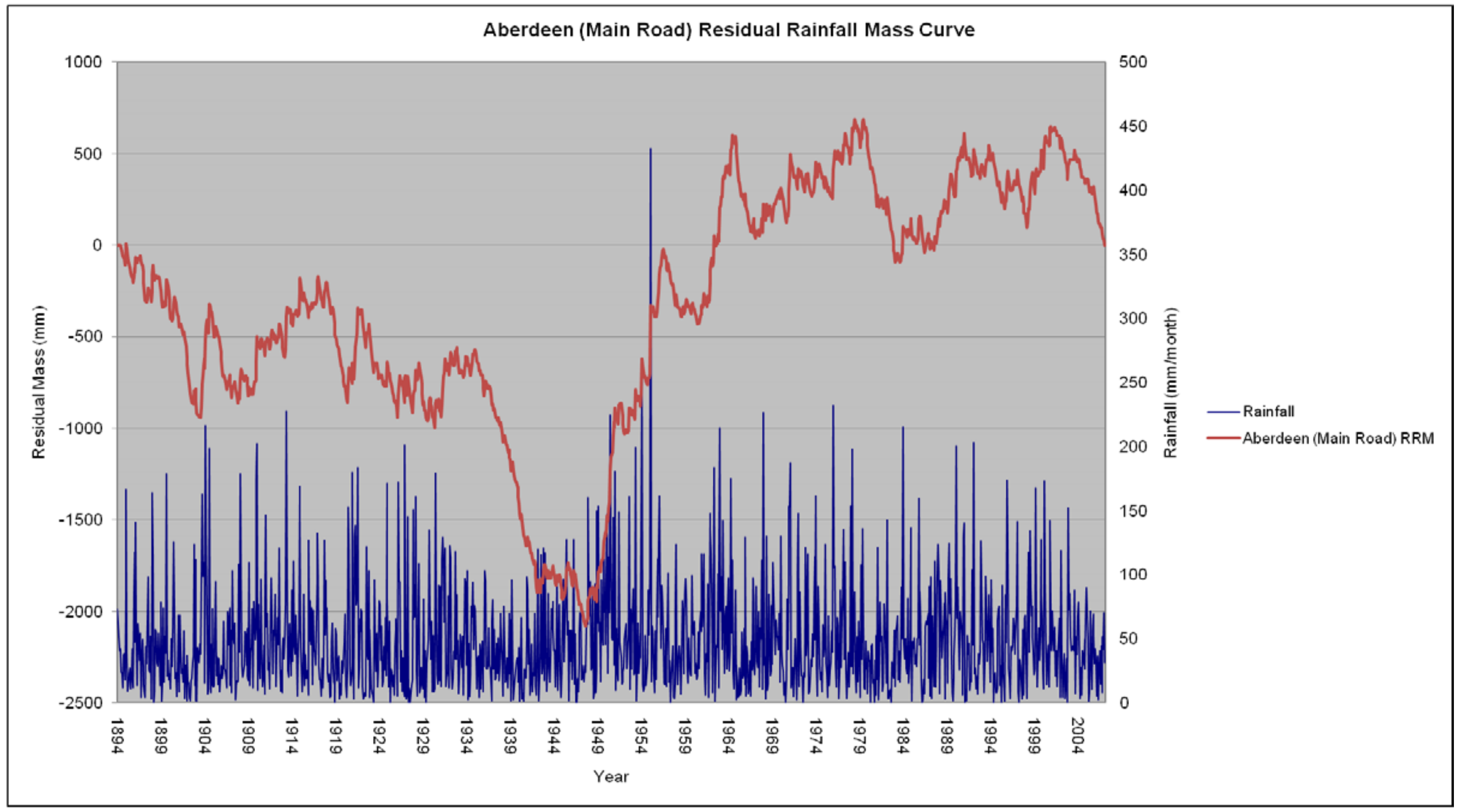

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
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W: www.frogtech.com.au
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Aberdeen (Rossgole) 61065

Aberdeen (Rossgole) entire record: 86 years of data (1926 to 2011)

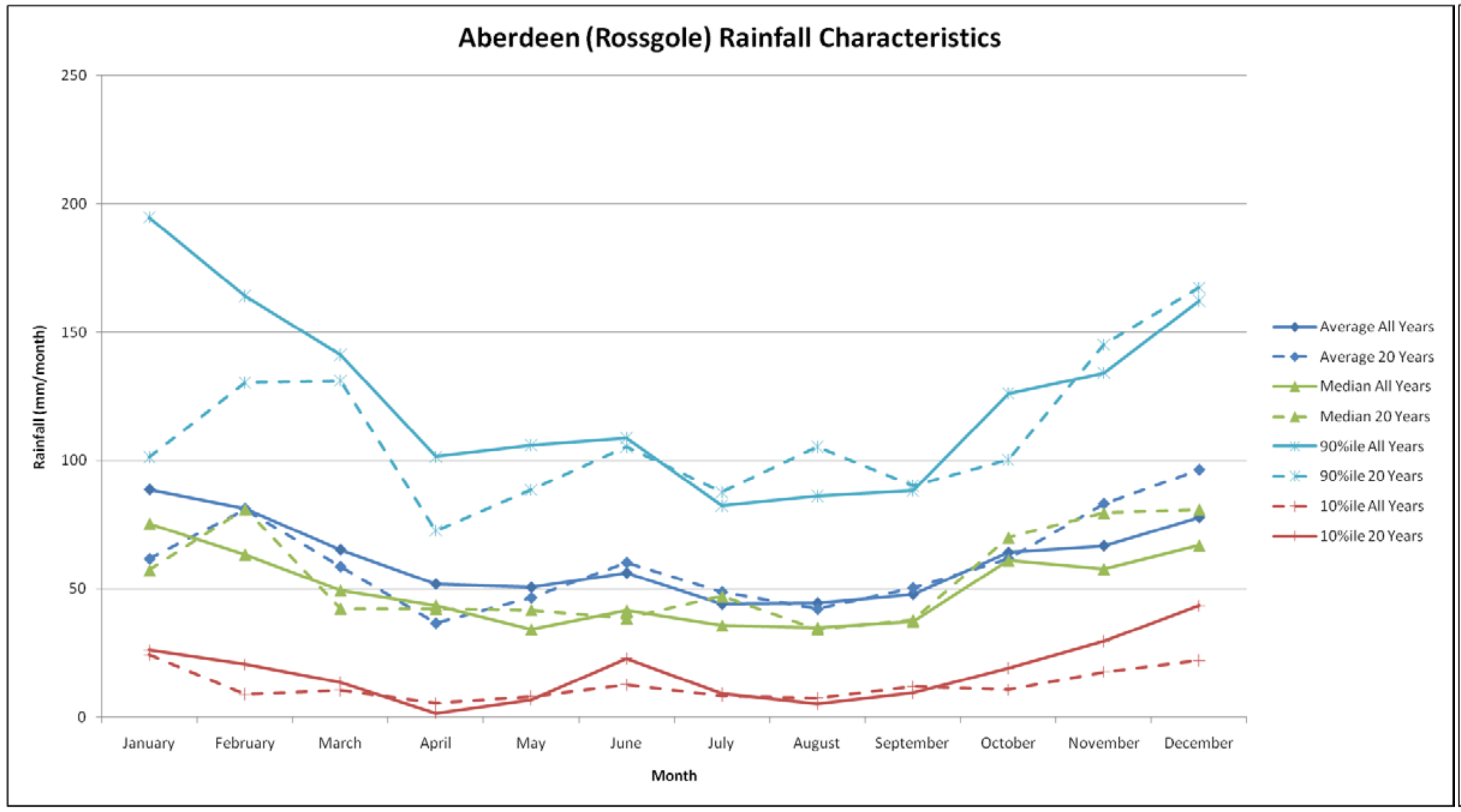
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	0	0	0	0	0	0	0	0	0	2	5	378
Average	89	81	65	52	51	56	44	44	48	64	67	78	738
Max	304	413	234	194	239	287	173	189	145	209	206	245	1417
10%ile	24	9	11	5	8	13	8	7	12	11	18	22	514
50%ile	75	63	49	44	34	42	36	35	37	61	58	67	731
90%ile	195	164	141	102	106	109	83	86	88	126	134	162	939

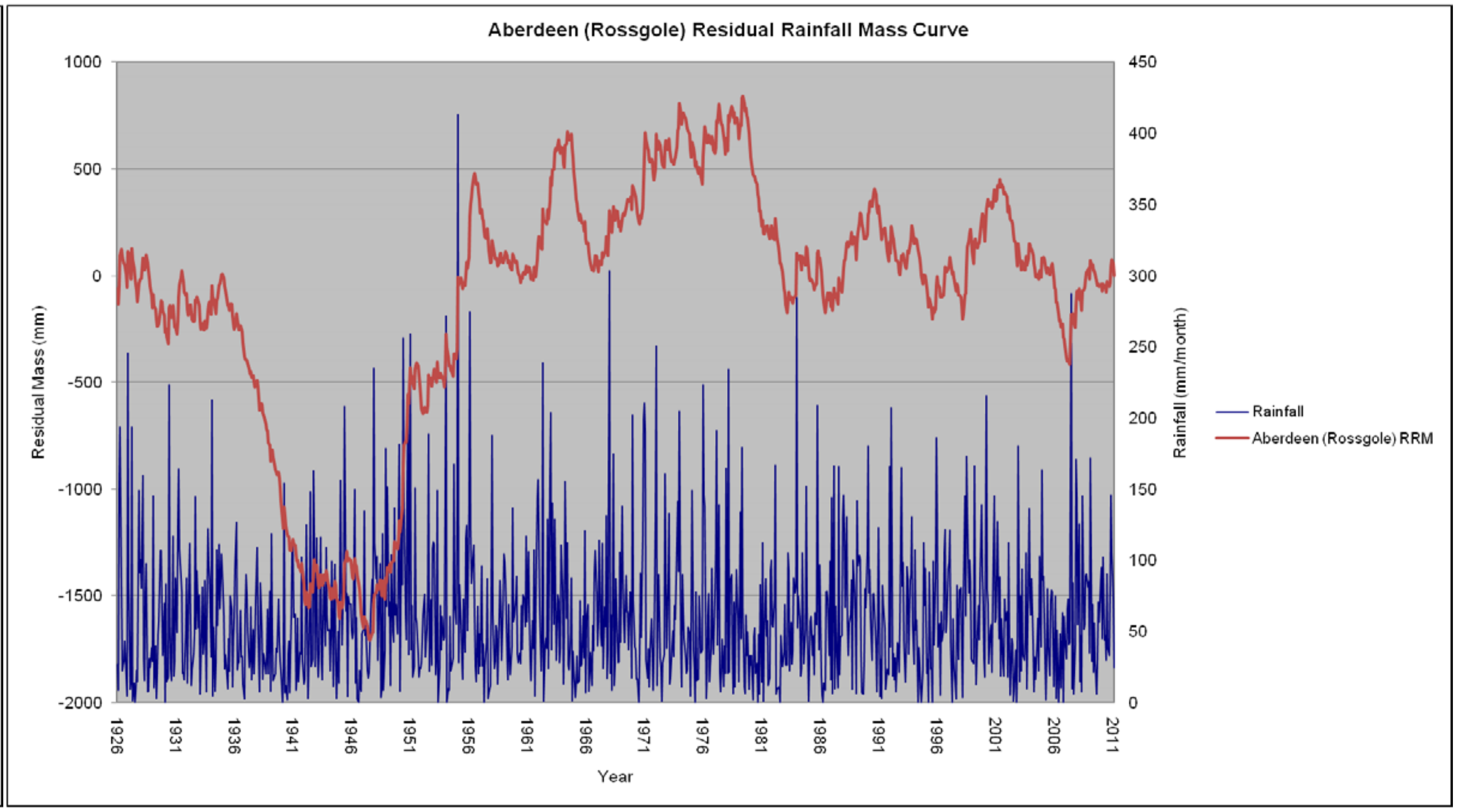
Aberdeen (Rossgole) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	15	4	3	0	0	16	1	0	0	0	20	12	421
Average	62	81	59	37	47	60	49	42	50	62	83	96	723
Max	133	207	215	94	145	287	173	132	122	139	171	186	1000
10%ile	26	21	13	2	7	23	9	5	10	19	30	43	521
50%ile	57	81	42	42	42	39	47	34	38	70	80	81	711
90%ile	101	130	131	73	89	105	88	105	90	100	145	167	872

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	78	70	56	44	43	47	38	39	42	57	59	69	726
5	136	132	104	84	84	95	68	70	71	96	99	116	887
10	174	174	136	110	111	126	88	91	91	123	124	147	977
20	211	214	166	135	137	156	107	111	109	148	149	177	1056
25	223	227	176	143	145	166	114	118	115	156	157	186	1079
50	259	266	206	167	171	195	132	137	133	181	181	215	1147
100	294	304	235	192	196	224	151	157	151	205	205	244	1209
500	377	394	303	248	254	292	193	202	192	262	261	310	1339





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Blackville (Krui Vale) 61002

Blackville (Krui Vale) entire record: 127 years of data (1885 to 2011)

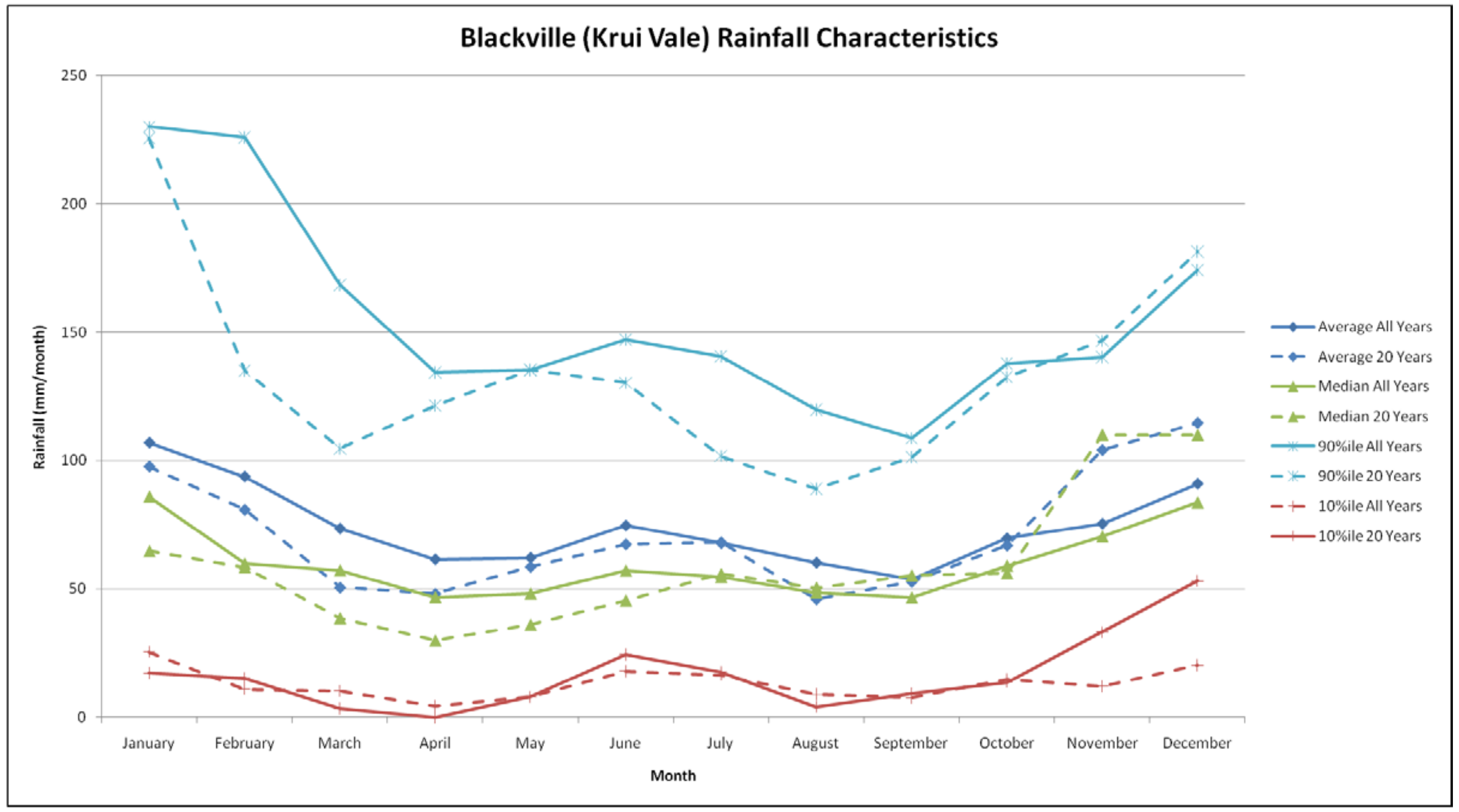
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	8	0	0	0	0	6	3	0	0	0	0	0	389
Average	107	94	74	62	62	75	68	60	54	70	75	91	877
Max	369	452	340	234	311	379	275	202	230	235	260	307	1787
10%ile	25	11	10	4	8	18	17	9	8	15	12	20	561
50%ile	86	60	57	47	48	57	55	49	47	59	70	84	888
90%ile	230	226	168	134	135	147	141	120	109	138	140	174	1164

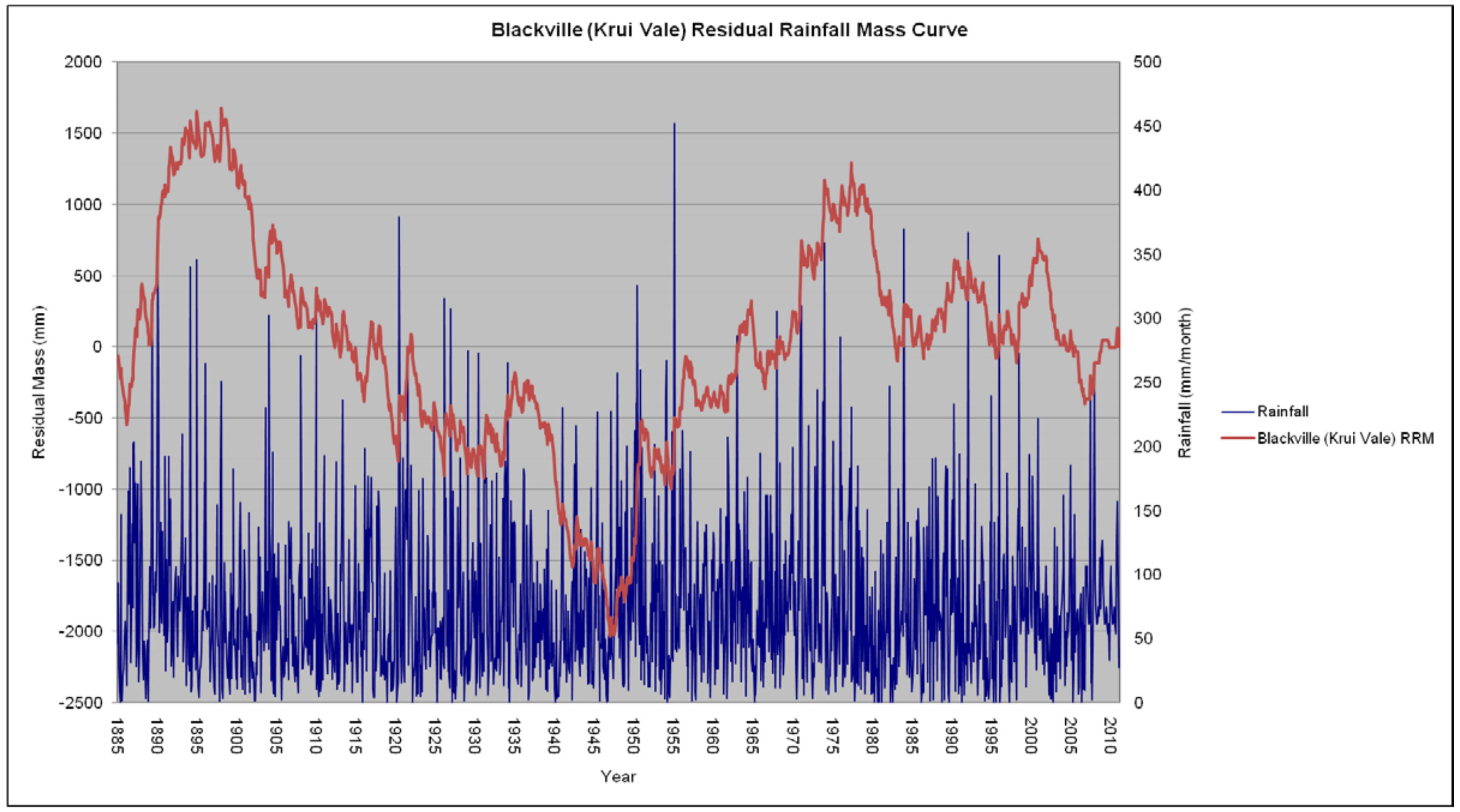
Blackville (Krui Vale) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	13	0	2	0	0	15	3	0	2	0	30	6	389
Average	98	81	51	48	59	67	68	46	53	67	104	115	753
Max	349	367	177	130	151	239	273	116	114	194	222	262	1083
10%ile	17	15	3	0	8	24	18	4	9	14	33	53	466
50%ile	65	58	39	30	36	45	56	50	55	56	110	110	836
90%ile	226	135	105	121	135	130	102	89	101	132	147	181	1060

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	93	79	62	53	53	64	59	53	47	61	67	81	857
5	167	159	122	100	102	121	106	94	83	106	114	135	1084
10	216	212	161	132	135	158	138	121	107	136	145	171	1214
20	263	262	199	162	167	194	168	147	131	164	175	205	1326
25	278	278	211	172	177	205	177	155	138	173	184	216	1359
50	323	328	248	201	207	240	207	181	160	201	213	249	1457
100	369	377	284	231	238	275	236	206	183	228	242	283	1546
500	474	491	369	299	308	355	304	265	235	292	309	359	1732





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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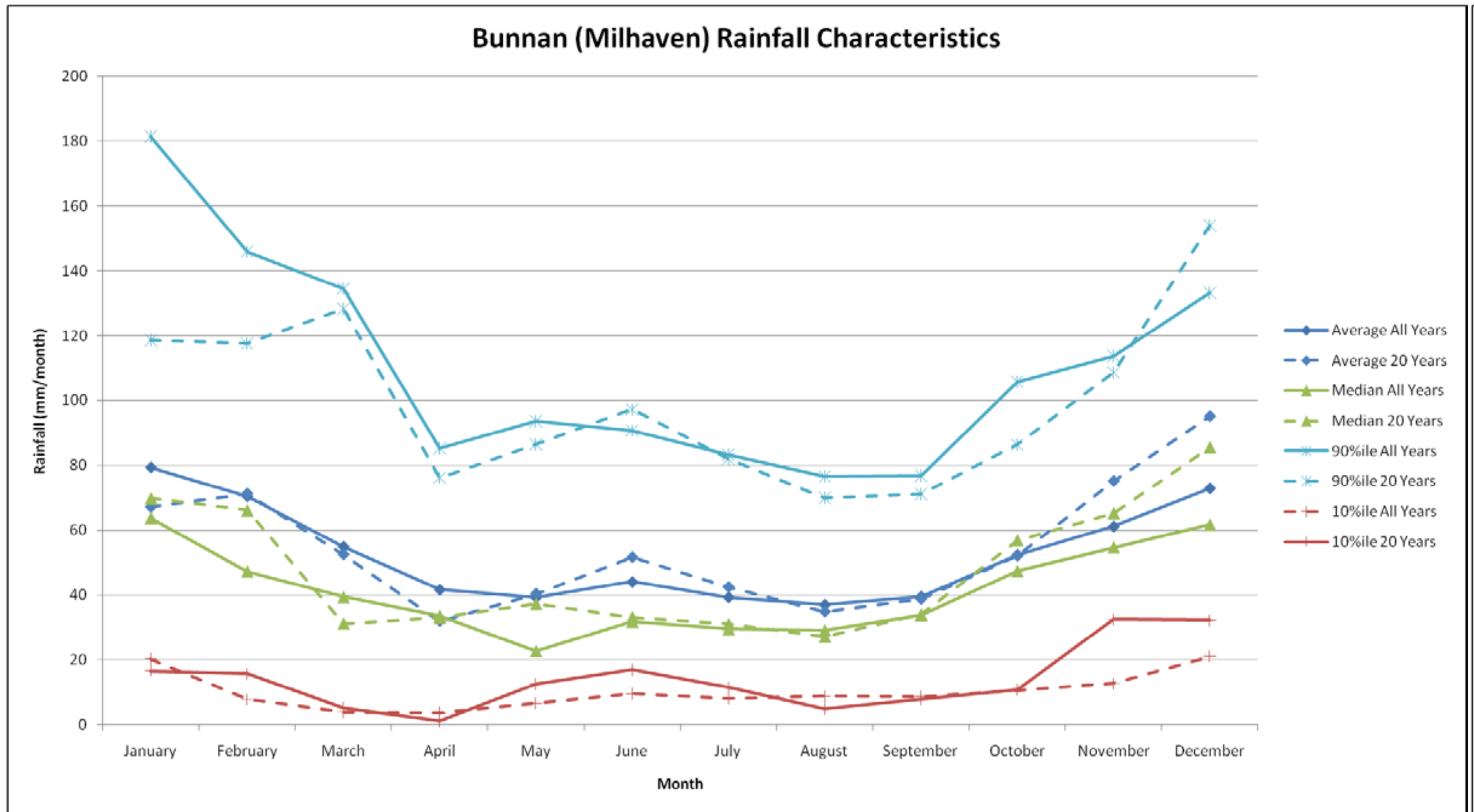
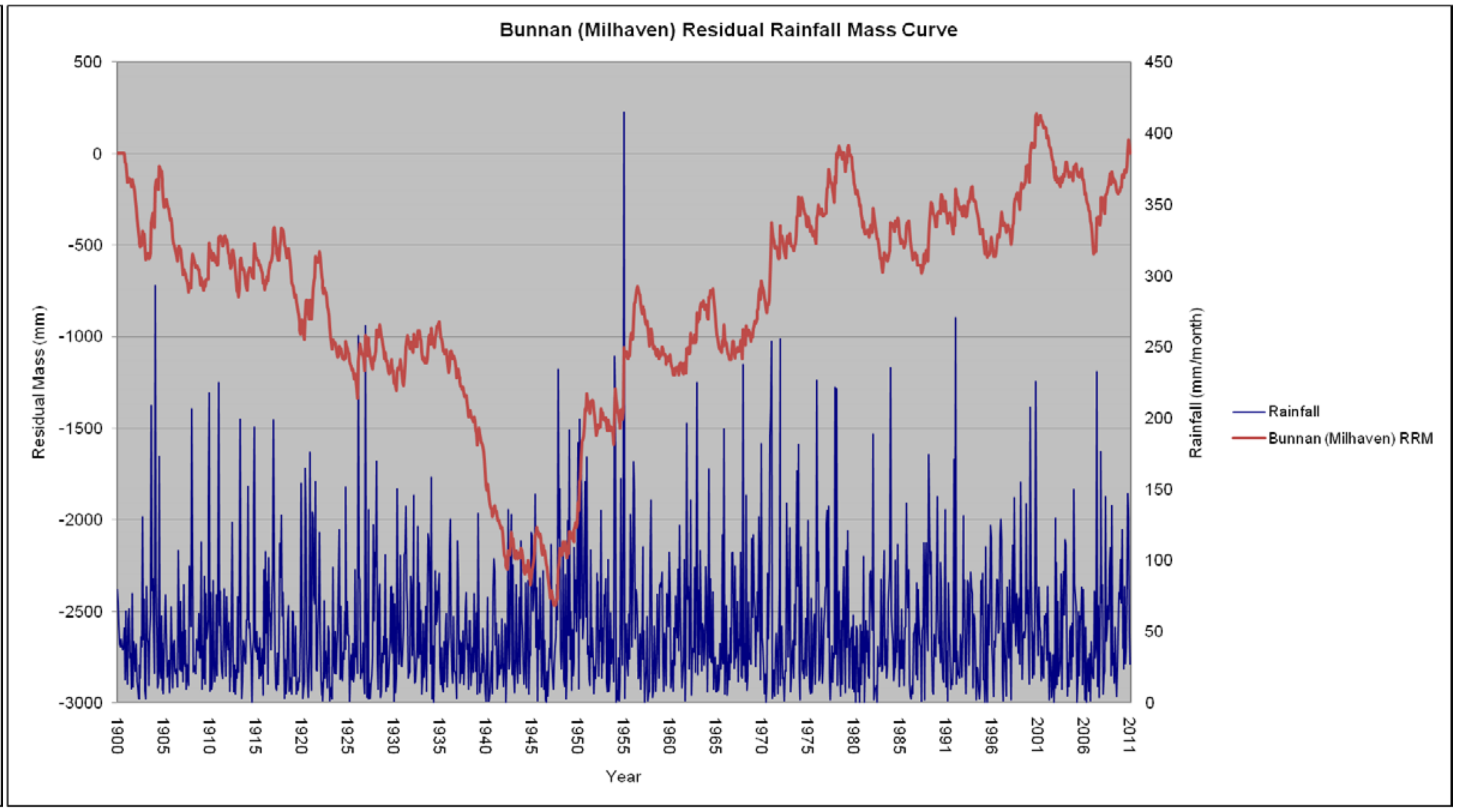
Bunnan (Milhaven) 61007

Bunnan (Milhaven) entire record: 111 years of data (1900 to 2011)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	6	1	0	0	0	1	0	0	0	0	3	6	258
Average	79	70	55	42	39	44	39	37	40	52	61	73	628
Max	255	415	258	199	199	233	173	135	209	157	225	265	1264
10%ile	20	8	4	4	7	10	8	9	9	11	13	21	404
50%ile	64	47	39	34	23	32	30	29	34	47	55	62	628
90%ile	181	146	135	85	94	91	83	77	77	106	114	133	822

Bunnan (Milhaven) rainfall during the last 20 years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	10	11	2	0	0	11	4	0	3	0	22	13	258
Average	67	71	52	32	40	52	42	35	39	52	75	95	635
Max	135	271	207	89	111	233	144	91	86	139	225	177	912
10%ile	17	16	5	1	13	17	12	5	8	11	33	32	418
50%ile	70	66	31	33	37	33	31	27	34	57	65	86	627
90%ile	119	118	128	76	87	97	82	70	71	86	109	154	833

Size of rainfall events (mm) for various return intervals — Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	69	59	46	36	33	37	34	33	34	46	54	64	615
5	124	120	94	68	67	73	65	56	62	79	92	110	774
10	159	160	126	90	90	97	85	71	80	101	118	141	865
20	194	199	157	111	112	120	105	86	97	122	142	170	942
25	205	211	166	117	119	127	111	91	103	128	150	179	965
50	238	249	196	137	140	149	131	105	120	149	173	207	1032
100	272	287	226	157	161	171	150	120	137	169	197	235	1094
500	349	374	295	204	210	222	194	153	175	216	251	301	1220





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Cassilis (Dalkeith) 62009

Cassilis (Dalkeith) rainfall during entire record: 134 years of data (1874 to 2011) some years missing

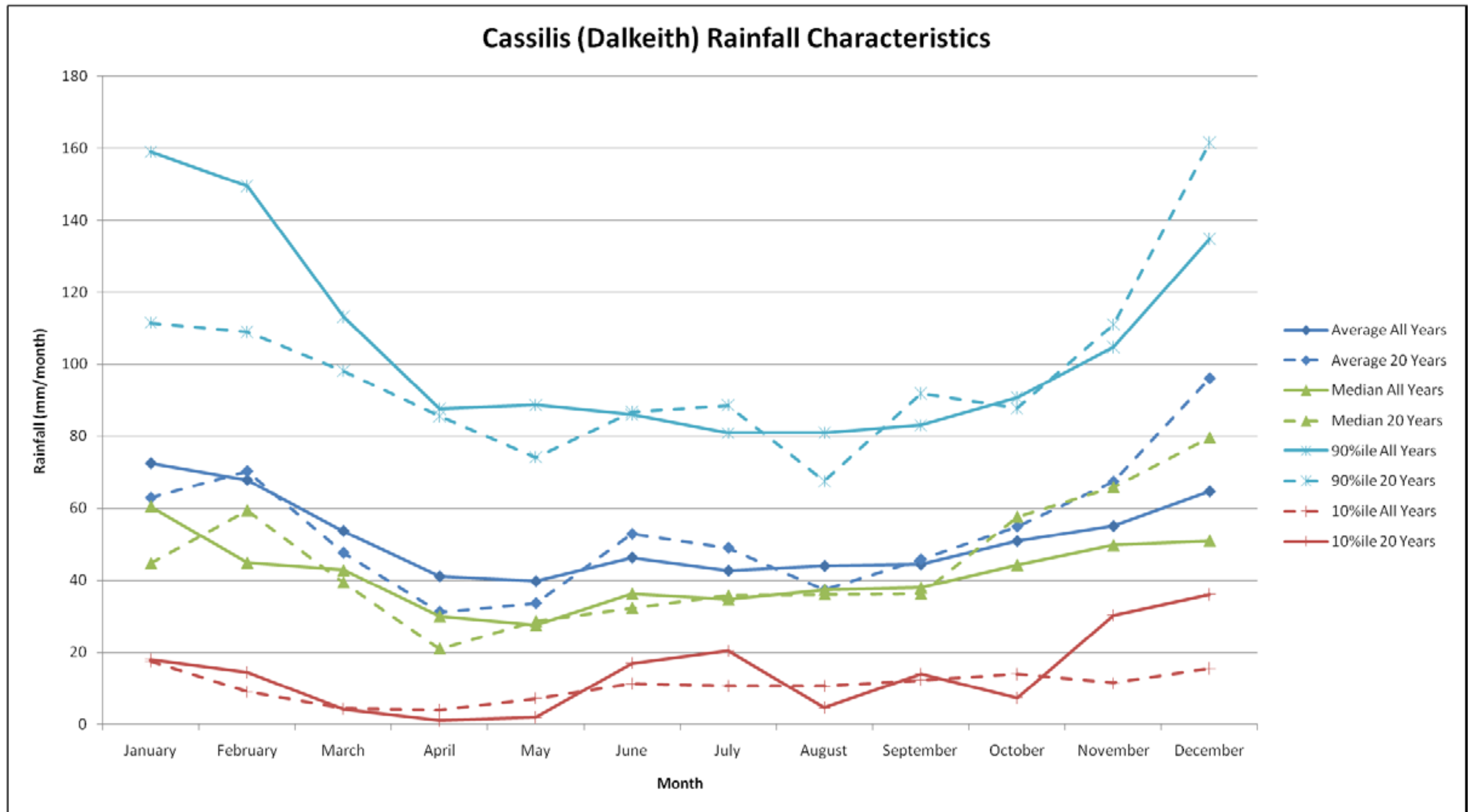
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	1	2	0	0	0	0	0	276
Average	72	68	54	41	40	46	43	44	44	51	55	65	622
Max	252	338	273	175	202	273	182	145	181	171	231	232	1256
10%ile	17	9	4	4	7	11	11	11	12	14	11	16	403
50%ile	60	45	43	30	28	36	35	37	38	44	50	51	614
90%ile	159	150	113	88	89	86	81	81	83	91	105	135	846

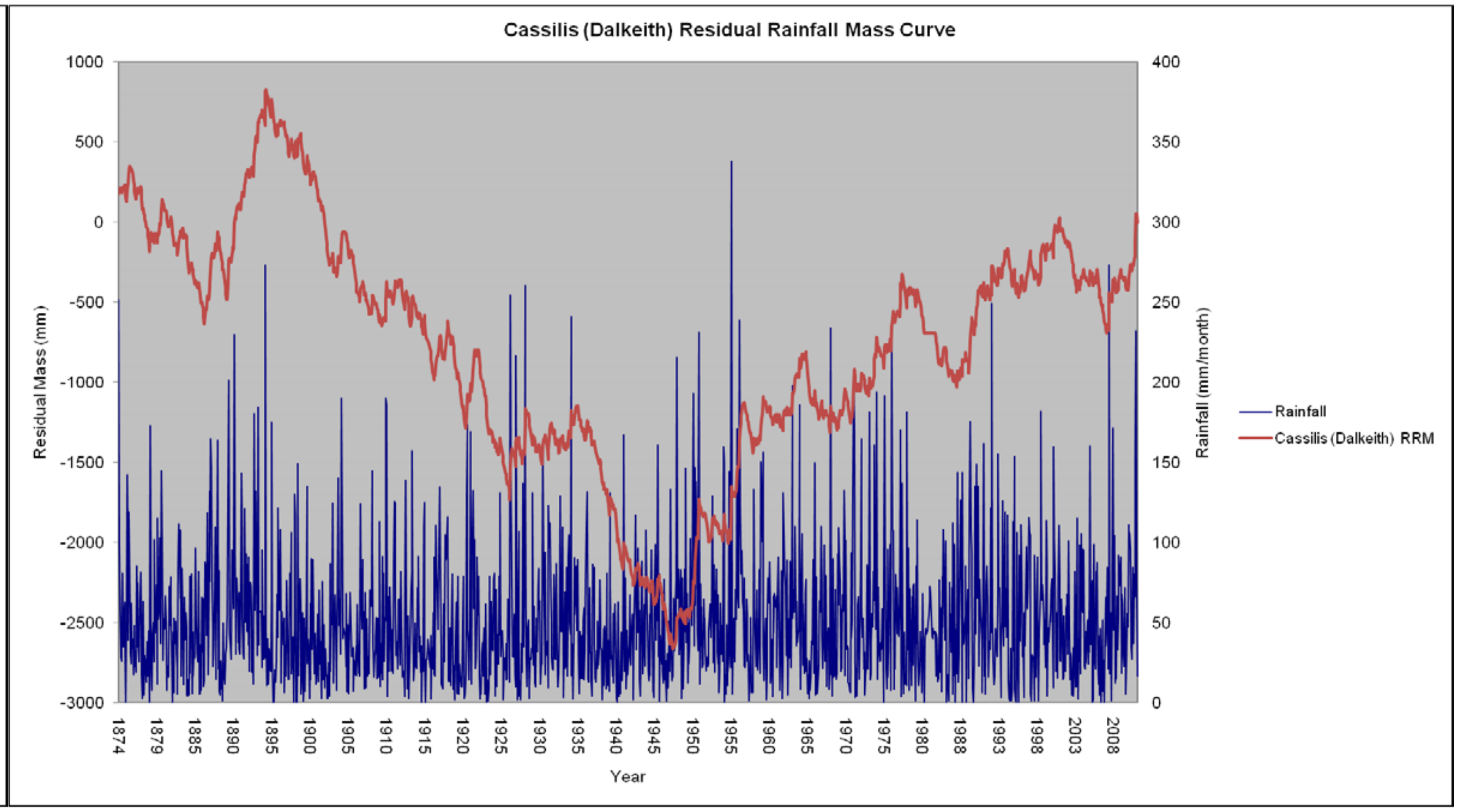
Cassilis (Dalkeith) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	10	8	1	0	0	1	5	0	1	0	16	25	322
Average	63	70	48	31	34	53	49	37	46	55	67	96	639
Max	162	249	160	115	106	273	182	98	92	119	154	232	1052
10%ile	18	14	4	1	2	17	20	5	14	7	30	36	425
50%ile	45	59	39	21	29	32	36	36	36	58	66	80	660
90%ile	112	109	98	86	74	87	89	68	92	88	111	162	806

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	64	57	46	35	34	40	37	39	39	45	49	56	606
5	111	115	89	67	65	74	66	66	66	75	83	100	765
10	142	153	118	88	86	97	85	84	84	94	105	129	857
20	172	190	145	109	106	118	103	102	101	113	126	157	937
25	181	202	154	115	113	125	109	107	107	119	133	166	962
50	211	238	181	135	132	146	127	124	123	137	154	193	1032
100	240	274	207	155	152	167	145	141	140	155	175	220	1098
500	307	356	269	200	196	216	186	180	178	197	223	282	1237





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Cassilis Post Office 62005

Cassilis Post Office rainfall during entire record: 139 years of data (1870 to 2011) some years missing

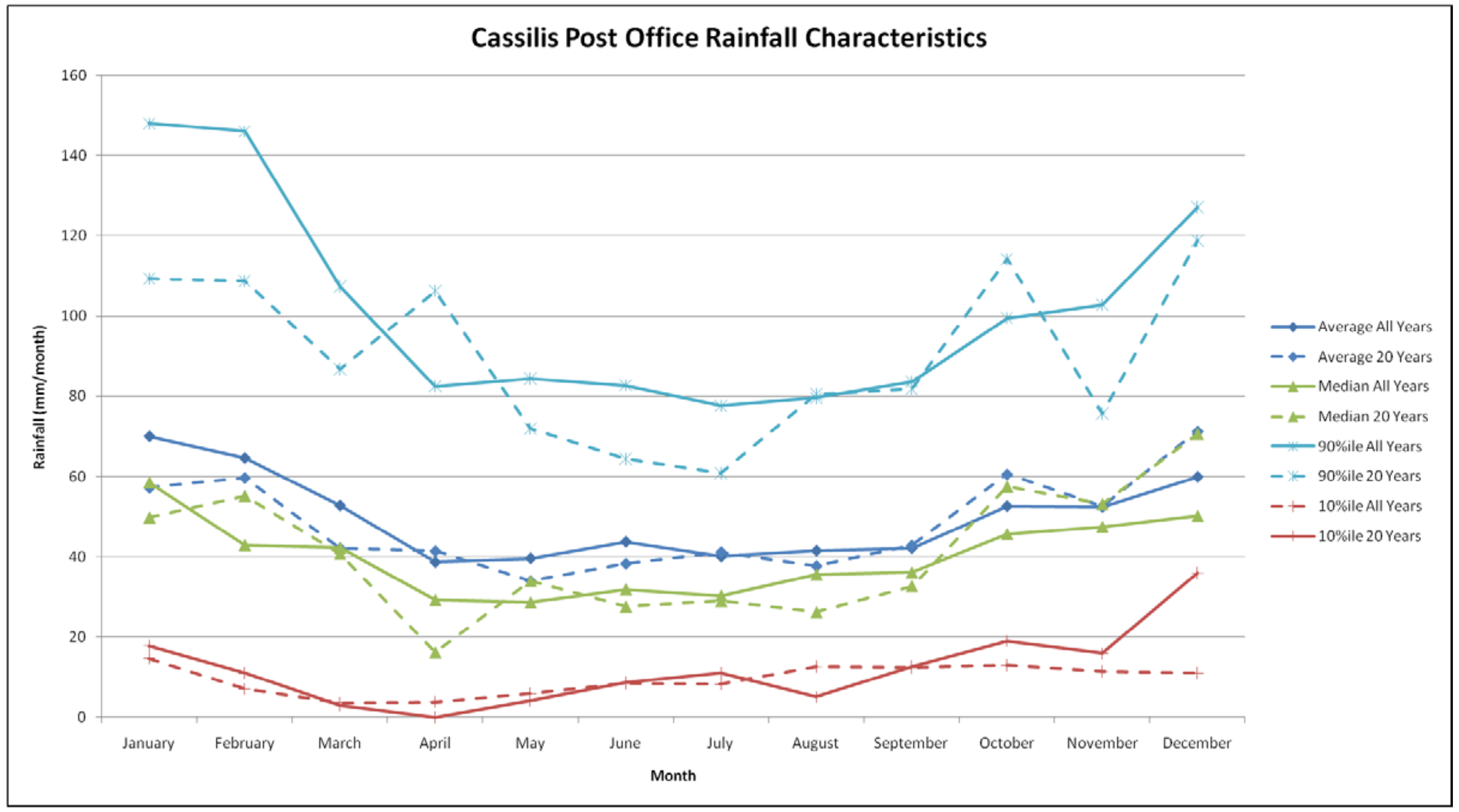
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	2	0	0	0	3	0	0	238
Average	70	65	53	39	40	44	40	41	42	53	52	60	592
Max	229	352	278	154	199	242	200	148	190	164	248	235	1281
10%ile	15	7	4	4	6	8	8	13	12	13	11	11	383
50%ile	59	43	42	29	29	32	30	36	36	46	48	50	592
90%ile	148	146	107	83	84	83	78	80	84	100	103	127	787

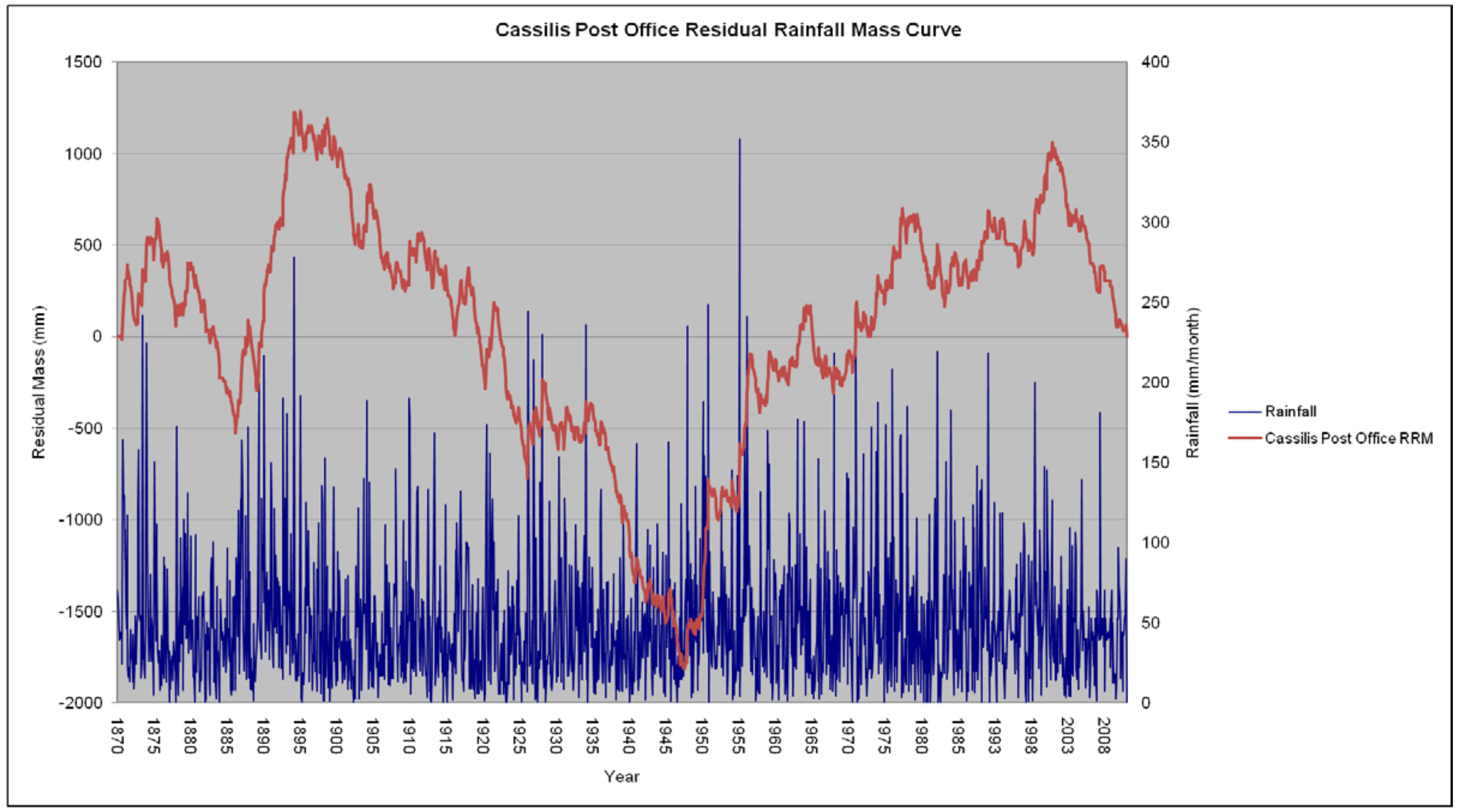
Cassilis Post Office rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	3	7	0	0	3	3	5	1	10	3	13	1	238
Average	57	60	42	41	34	38	41	38	43	61	53	71	545
Max	133	218	145	139	79	181	200	98	92	147	127	139	840
10%ile	18	11	3	0	4	9	11	5	13	19	16	36	290
50%ile	50	55	41	16	34	28	29	26	33	58	53	71	560
90%ile	109	109	87	106	72	64	61	80	82	114	76	119	730

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	61	54	45	33	34	37	34	36	37	47	46	52	581
5	108	110	88	62	66	72	64	64	64	78	80	93	732
10	138	147	116	82	87	95	84	82	82	99	103	121	817
20	168	183	144	100	107	116	103	99	99	120	124	147	889
25	177	194	152	106	114	123	109	104	104	126	131	155	910
50	206	229	179	124	134	145	128	121	121	146	152	181	971
100	234	264	205	142	153	166	146	138	137	165	173	206	1026
500	300	343	267	184	199	215	189	177	176	210	222	265	1137





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Ellerston (Poitrel) 61196

Ellerston (Poitrel) entire record: 52 years of data (1960 to 2011)

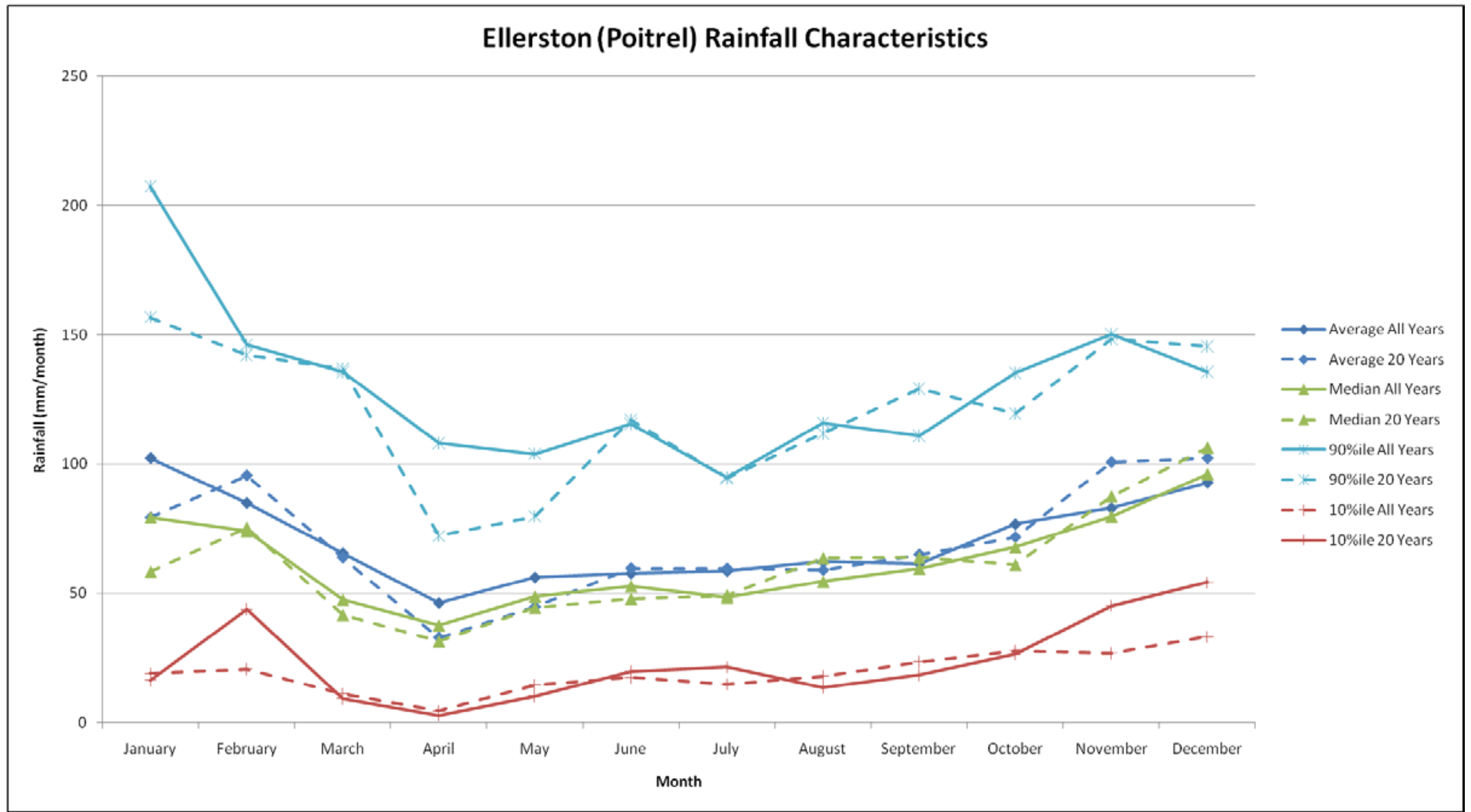
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	13	4	0	0	0	2	3	0	1	3	4	9	406
Average	102	85	66	46	56	58	59	62	61	77	83	93	834
Max	312	319	236	150	189	154	203	158	135	222	238	209	1194
10%ile	19	21	11	4	15	18	15	18	24	28	27	33	535
50%ile	79	74	48	38	49	53	48	55	60	68	80	96	849
90%ile	207	146	136	108	104	116	95	116	111	135	150	136	1063

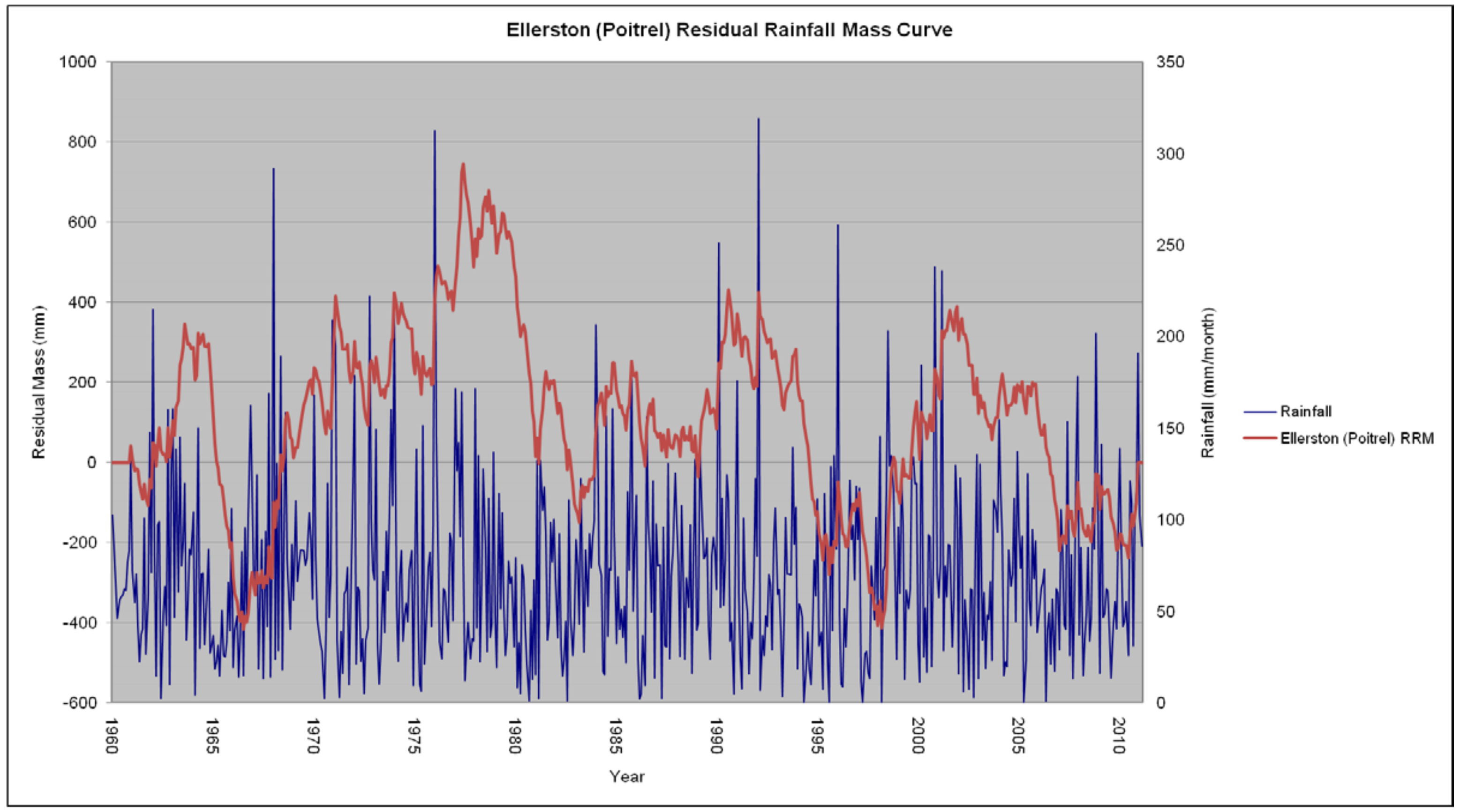
Ellerston (Poitrel) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	13	11	0	0	0	17	7	0	10	3	40	23	406
Average	79	96	64	33	45	60	60	59	65	72	101	102	801
Max	261	319	236	98	114	154	203	129	135	139	238	191	1137
10%ile	16	44	9	3	10	20	21	14	19	26	45	54	487
50%ile	58	75	42	31	44	48	49	64	64	61	88	106	814
90%ile	157	142	137	72	80	117	95	112	129	119	148	145	1063

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	90	75	57	40	49	52	52	56	56	69	75	86	848
5	157	129	102	74	86	85	89	90	86	109	119	123	1005
10	201	165	132	97	111	106	113	112	106	136	148	148	1074
20	243	200	161	119	134	127	136	134	125	162	175	172	1124
25	257	211	170	126	141	134	144	140	131	170	184	180	1136
50	298	245	198	148	164	154	167	161	149	195	211	203	1170
100	339	278	226	169	187	175	189	182	168	219	238	227	1196
500	434	356	290	218	240	222	242	230	211	277	301	280	1235





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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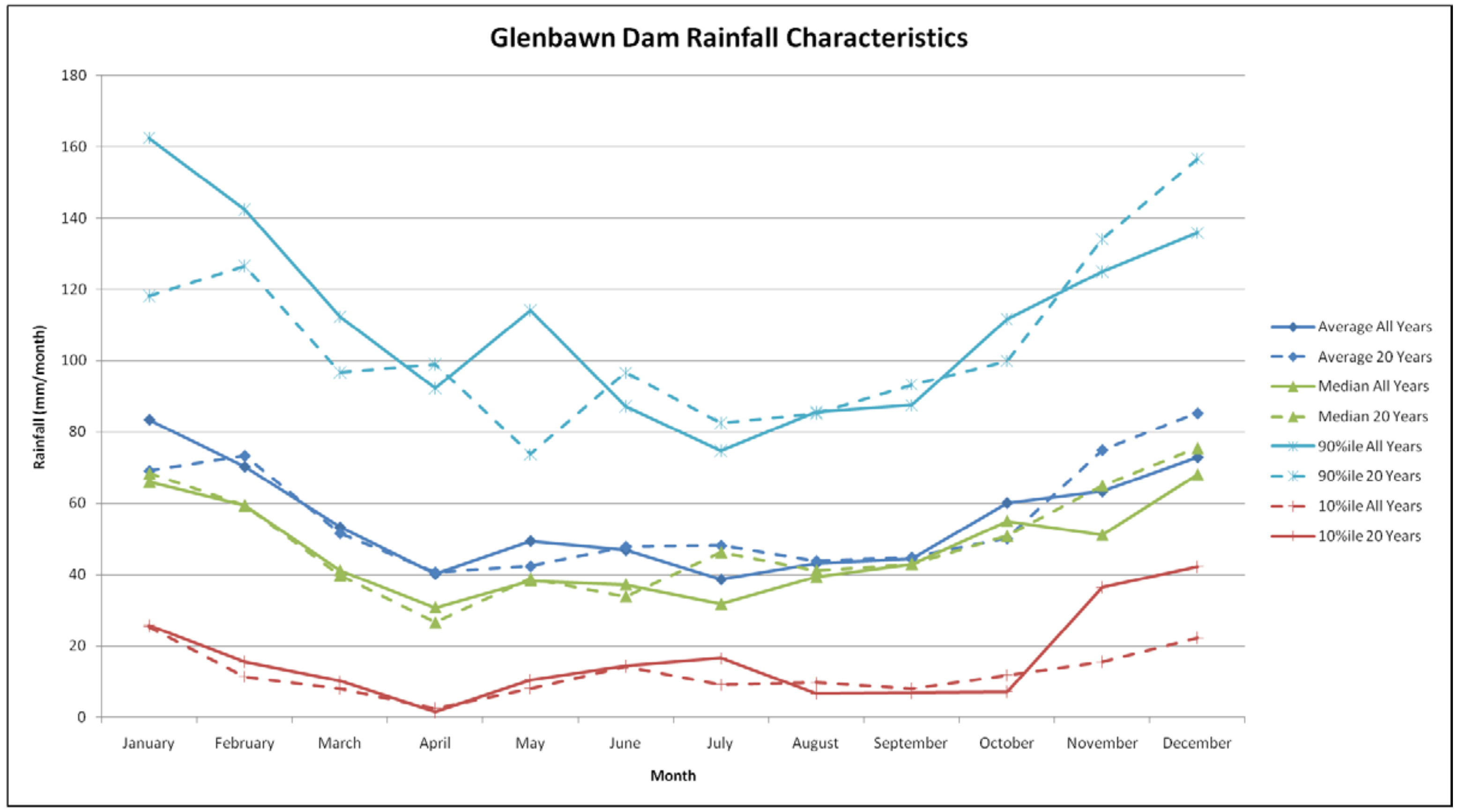
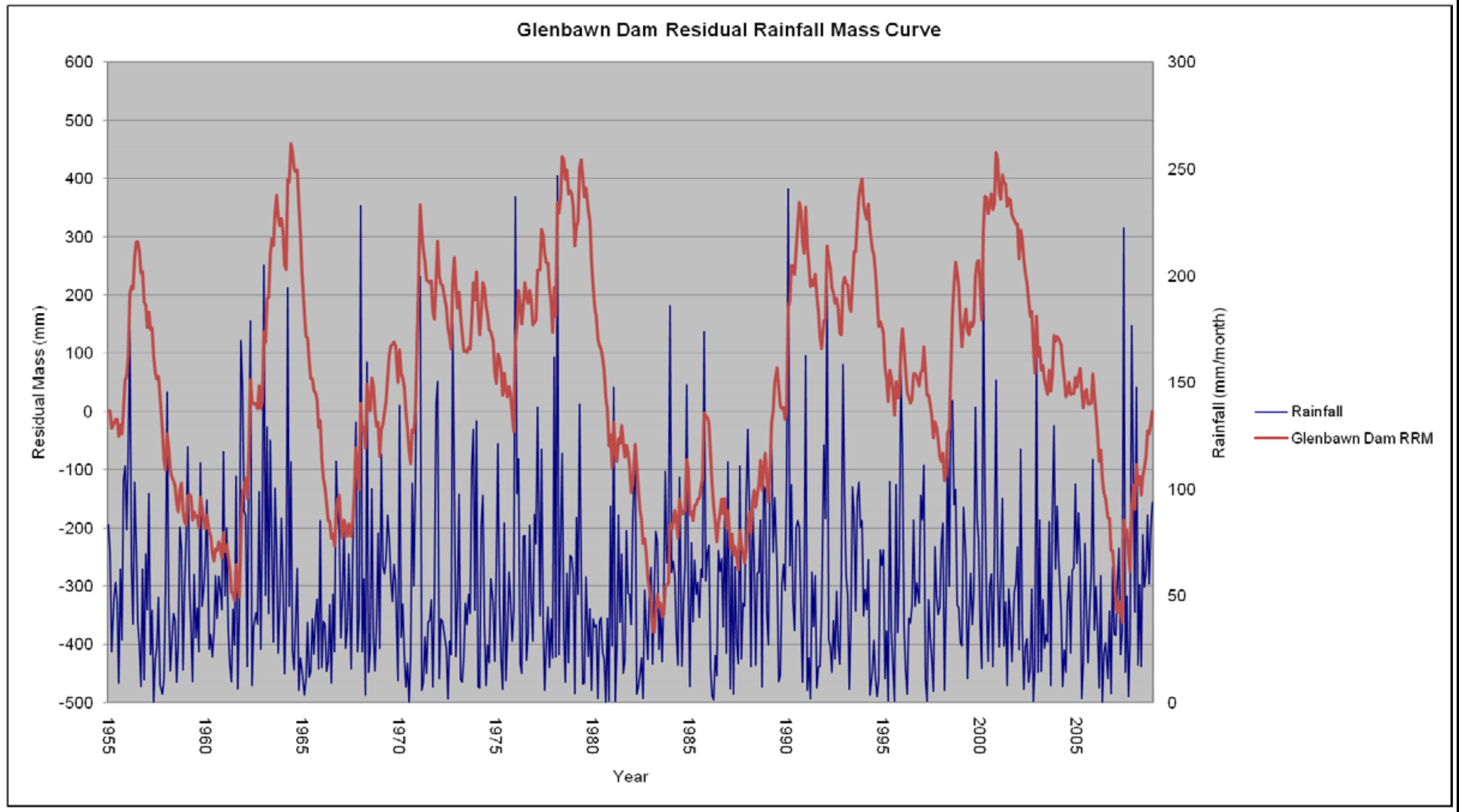
Glenbawn Dam 61094

Glenbawn Dam entire record: 54 years of data (1955 to 2008)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	8	4	1	0	0	8	0	0	0	1	1	6	345
Average	83	70	53	40	49	47	39	43	44	60	63	73	659
Max	237	241	247	194	179	222	138	141	103	177	177	180	982
10%ile	25	11	8	2	8	14	9	10	8	12	16	22	460
50%ile	66	59	41	31	38	37	32	39	43	55	51	68	648
90%ile	162	142	112	92	114	87	75	86	88	112	125	136	849

Glenbawn Dam rainfall during the last 20 years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	14	6	6	0	0	8	10	0	3	1	9	32	361
Average	69	73	52	41	42	48	48	44	45	50	75	85	662
Max	163	241	208	122	122	222	138	141	102	138	177	170	953
10%ile	26	16	10	2	10	14	17	7	7	7	36	42	475
50%ile	68	59	40	27	39	34	46	41	43	51	65	76	627
90%ile	118	127	97	99	74	97	83	85	93	100	134	157	859

Size of rainfall events (mm) for various return intervals — Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	74	61	45	34	42	41	34	38	40	53	56	66	655
5	125	110	89	68	80	74	59	66	65	90	94	103	796
10	160	142	117	90	105	95	75	84	82	114	119	127	870
20	192	173	145	111	128	116	91	102	98	138	143	150	930
25	203	183	153	118	136	123	96	108	103	145	150	158	948
50	235	213	180	139	159	143	111	125	119	168	174	180	997
100	267	243	207	160	182	164	126	142	135	191	197	203	1040
500	340	312	269	208	235	211	162	182	171	243	250	255	1123





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
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W: www.frogtech.com.au
E: info@frogtech.com.au
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Gundy (Miller Street) 61026

Gundy (Miller Street) rainfall during entire record: 119 years of data (1887 to 2011) some years missing

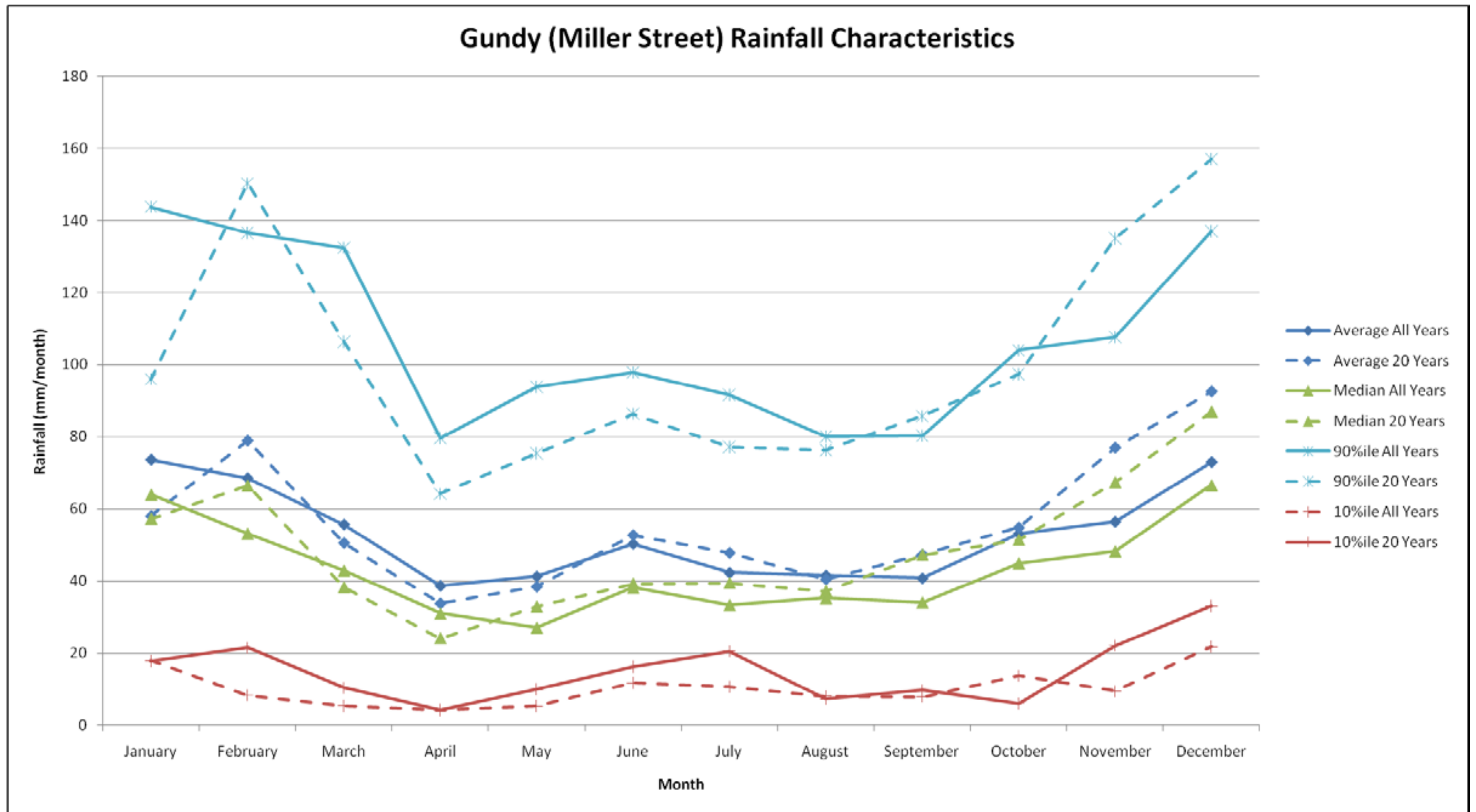
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	0	0	0	274
Average	74	69	56	39	41	50	42	42	41	53	56	73	625
Max	243	403	209	187	194	220	177	171	170	159	212	207	1053
10%ile	18	8	5	4	5	12	11	8	8	14	9	22	399
50%ile	64	53	43	31	27	38	33	35	34	45	48	67	637
90%ile	144	137	132	80	94	98	92	80	80	104	108	137	851

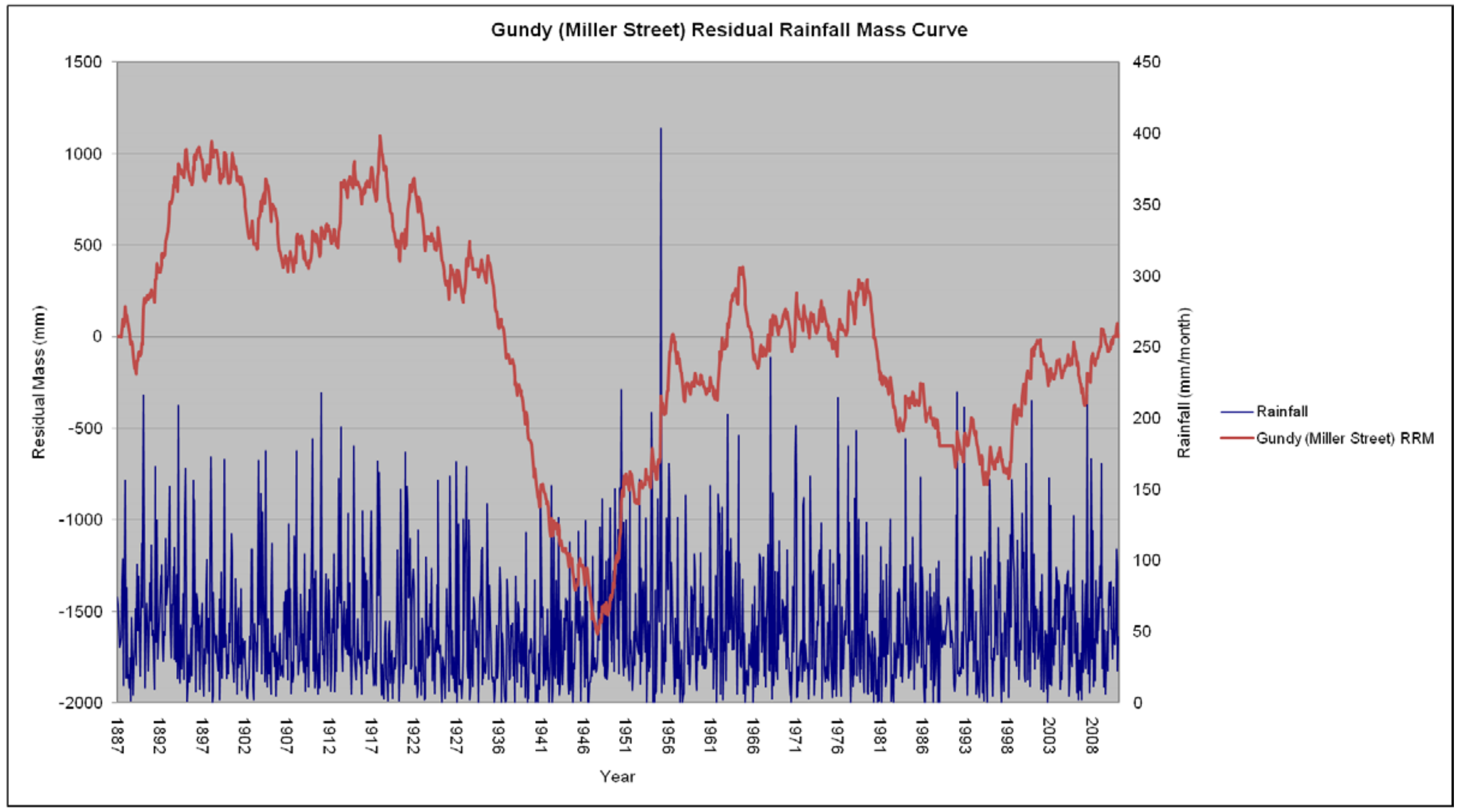
Gundy (Miller Street) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	9	7	4	0	2	14	16	0	3	0	15	21	372
Average	58	79	51	34	38	53	48	41	47	55	77	92	631
Max	128	218	168	91	118	216	157	134	102	133	212	207	966
10%ile	18	21	10	4	10	16	21	7	10	6	22	33	429
50%ile	57	66	38	24	33	39	39	37	47	51	67	87	628
90%ile	96	150	106	64	75	86	77	76	86	97	135	157	807

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	65	59	48	33	35	43	37	36	35	47	50	66	617
5	112	111	91	63	68	81	66	65	65	78	87	105	771
10	143	146	121	84	90	105	86	83	84	99	112	132	853
20	172	179	148	103	111	129	104	101	103	118	135	157	920
25	182	189	157	109	118	136	110	107	109	124	143	165	940
50	211	222	185	128	138	159	128	125	127	144	166	190	996
100	239	254	212	147	158	182	146	142	145	163	189	214	1045
500	306	328	274	190	205	235	188	183	186	206	242	271	1140





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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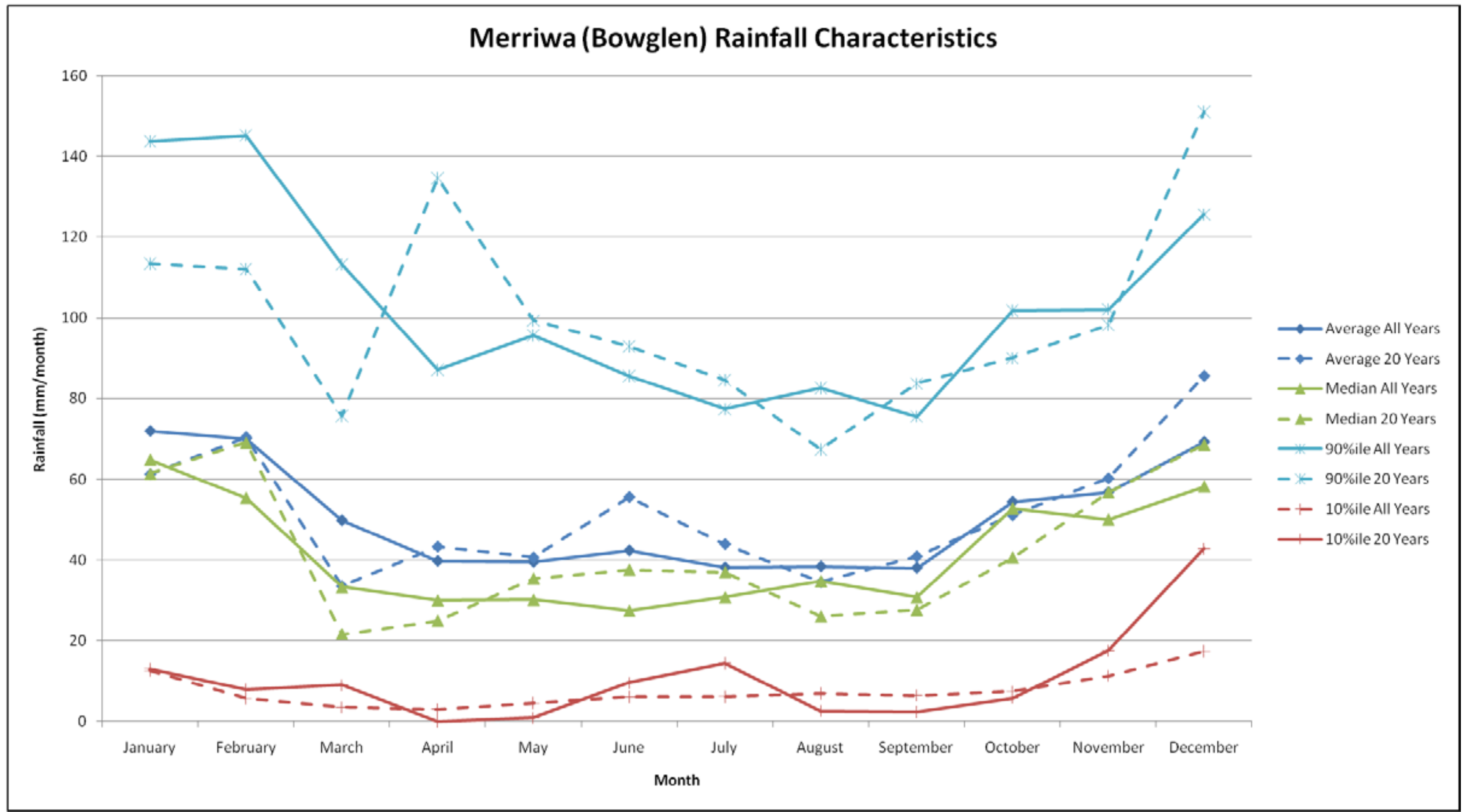
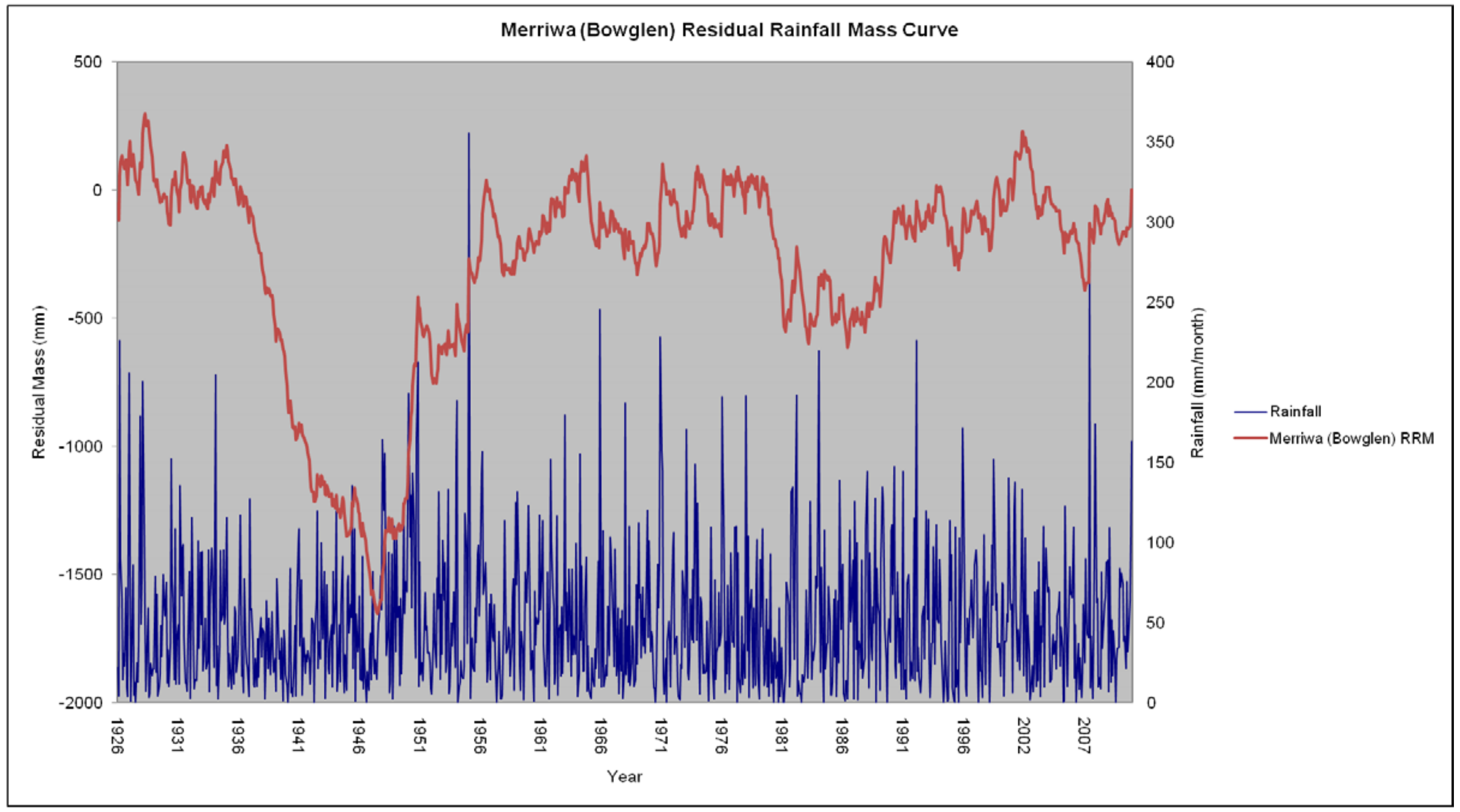
Merriwa (Bowglen) 61075

Merriwa (Bowglen) entire record: 84 years of data (1926 to 2010)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	3	0	0	0	0	0	0	0	0	0	3	1	298
Average	72	70	50	40	39	42	38	38	38	54	57	69	603
Max	220	356	226	155	133	276	152	132	128	166	213	246	1333
10%ile	13	6	3	3	5	6	6	7	6	7	11	17	421
50%ile	65	55	33	30	30	28	31	35	31	53	50	58	607
90%ile	144	145	113	87	96	86	77	83	76	102	102	126	765

Merriwa (Bowglen) rainfall during the last 20 years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	7	6	0	0	0	6	2	0	0	2	8	37	298
Average	61	70	34	43	41	56	44	35	41	51	60	86	600
Max	145	226	121	147	126	276	152	110	105	140	133	174	892
10%ile	13	8	9	0	1	10	14	3	2	6	18	43	423
50%ile	61	69	22	25	35	38	37	26	28	41	57	69	638
90%ile	113	112	76	135	99	93	85	67	84	90	98	151	760

Size of rainfall events (mm) for various return intervals — Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	64	59	42	34	34	35	33	34	33	48	50	61	587
5	109	116	83	66	64	73	60	59	58	82	87	106	731
10	138	154	111	88	84	99	79	76	75	105	111	136	816
20	167	190	137	108	103	123	96	93	91	126	134	164	891
25	176	201	145	115	109	131	102	98	96	133	142	173	914
50	204	236	171	135	128	154	119	114	111	154	164	201	983
100	232	271	196	155	146	178	136	129	127	175	187	229	1047
500	296	352	255	201	189	232	175	166	162	224	239	293	1187





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Merriwa (Gummun Place) 61040

Merriwa (Gummun Place) entire record: 129 years of data (1882 to 2011)

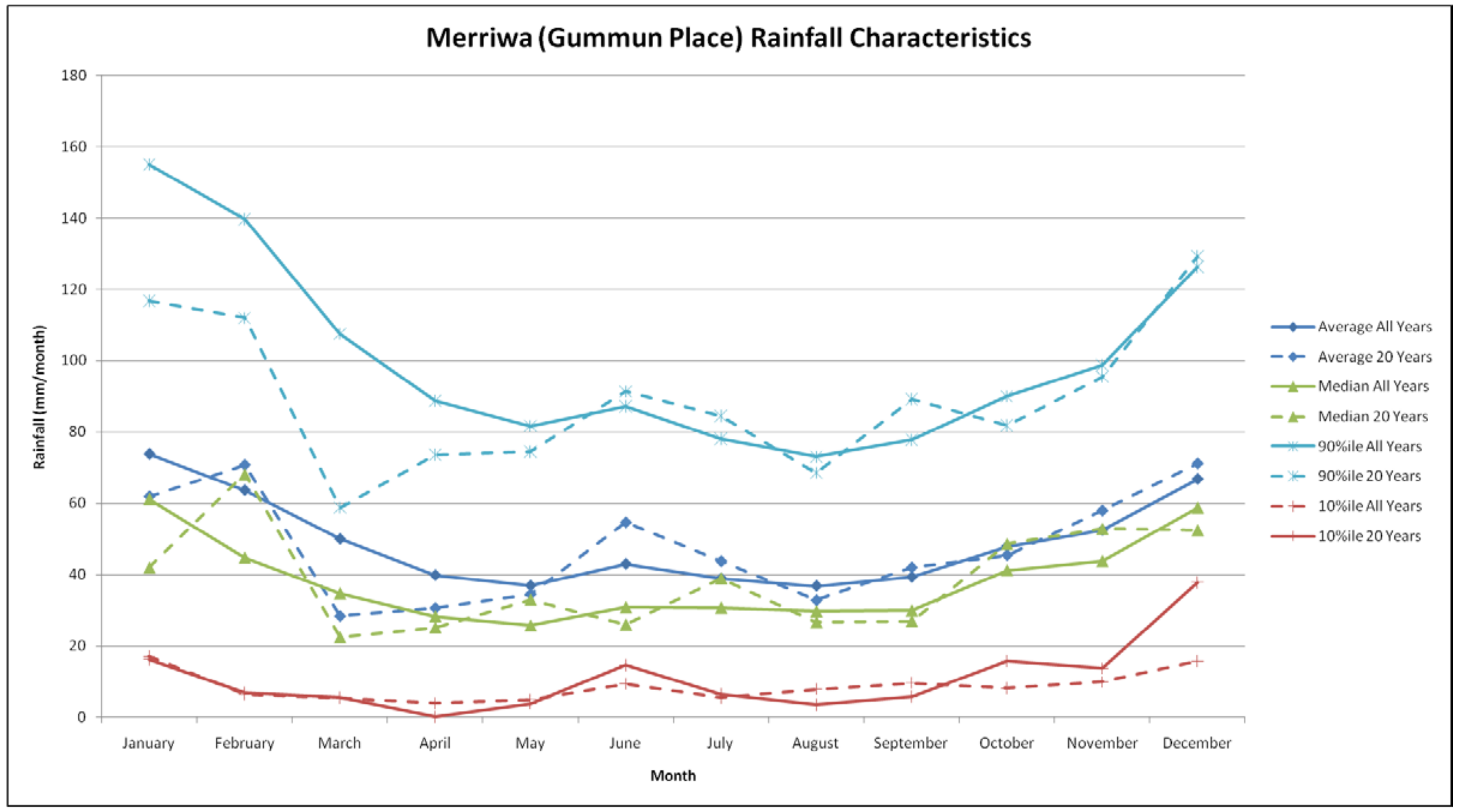
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	0	0	0	164
Average	74	64	50	40	37	43	39	37	39	48	52	67	586
Max	275	318	259	150	188	284	176	138	192	176	189	217	1155
10%ile	17	6	5	4	5	9	5	8	10	8	10	16	370
50%ile	61	45	35	28	26	31	31	30	30	41	44	59	601
90%ile	155	140	107	89	82	87	78	73	78	90	99	126	778

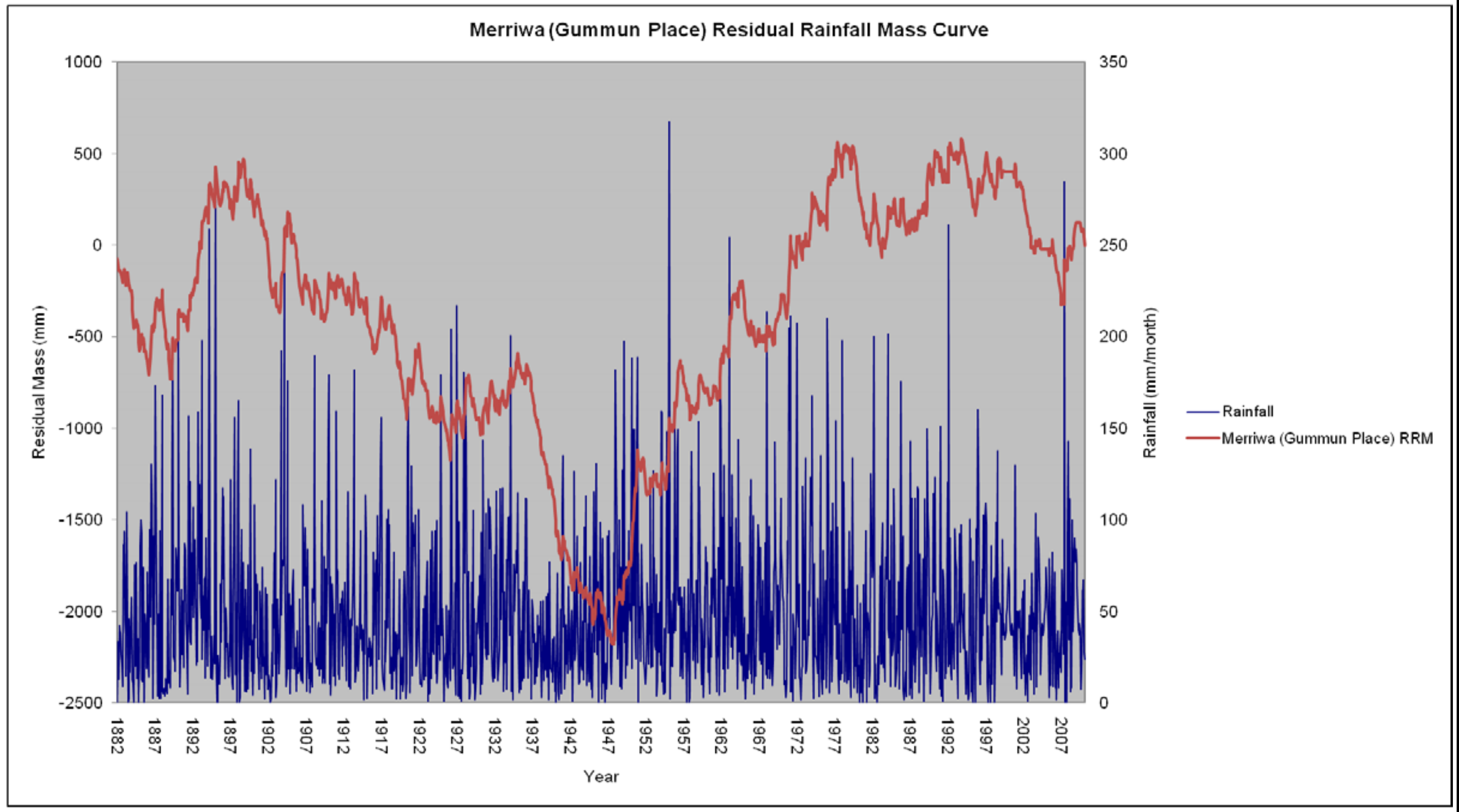
Merriwa (Gummun Place) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	12	4	0	0	2	12	0	0	0	4	8	9	249
Average	62	71	28	31	35	55	44	33	42	45	58	71	548
Max	151	261	89	123	99	284	138	103	102	97	130	160	844
10%ile	16	7	6	0	4	15	6	4	6	16	14	38	353
50%ile	42	68	22	25	33	26	39	27	27	49	53	53	577
90%ile	117	112	59	74	75	91	84	69	89	82	96	129	716

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	65	53	42	34	31	36	33	32	34	42	46	59	582
5	114	108	84	65	62	72	64	57	62	73	81	100	733
10	146	144	112	85	83	95	85	73	81	94	103	127	810
20	177	179	139	105	103	118	104	89	98	114	125	153	871
25	187	190	148	111	109	125	111	94	104	120	132	161	889
50	217	224	174	130	129	147	130	109	121	139	154	186	937
100	247	257	200	149	148	169	149	125	138	159	175	212	979
500	317	335	260	192	193	219	193	160	178	203	224	270	1056





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Merriwa (Merry Vale) 62015

Merriwa (Merry Vale) entire record: 119 years of data (1890 to 2008)

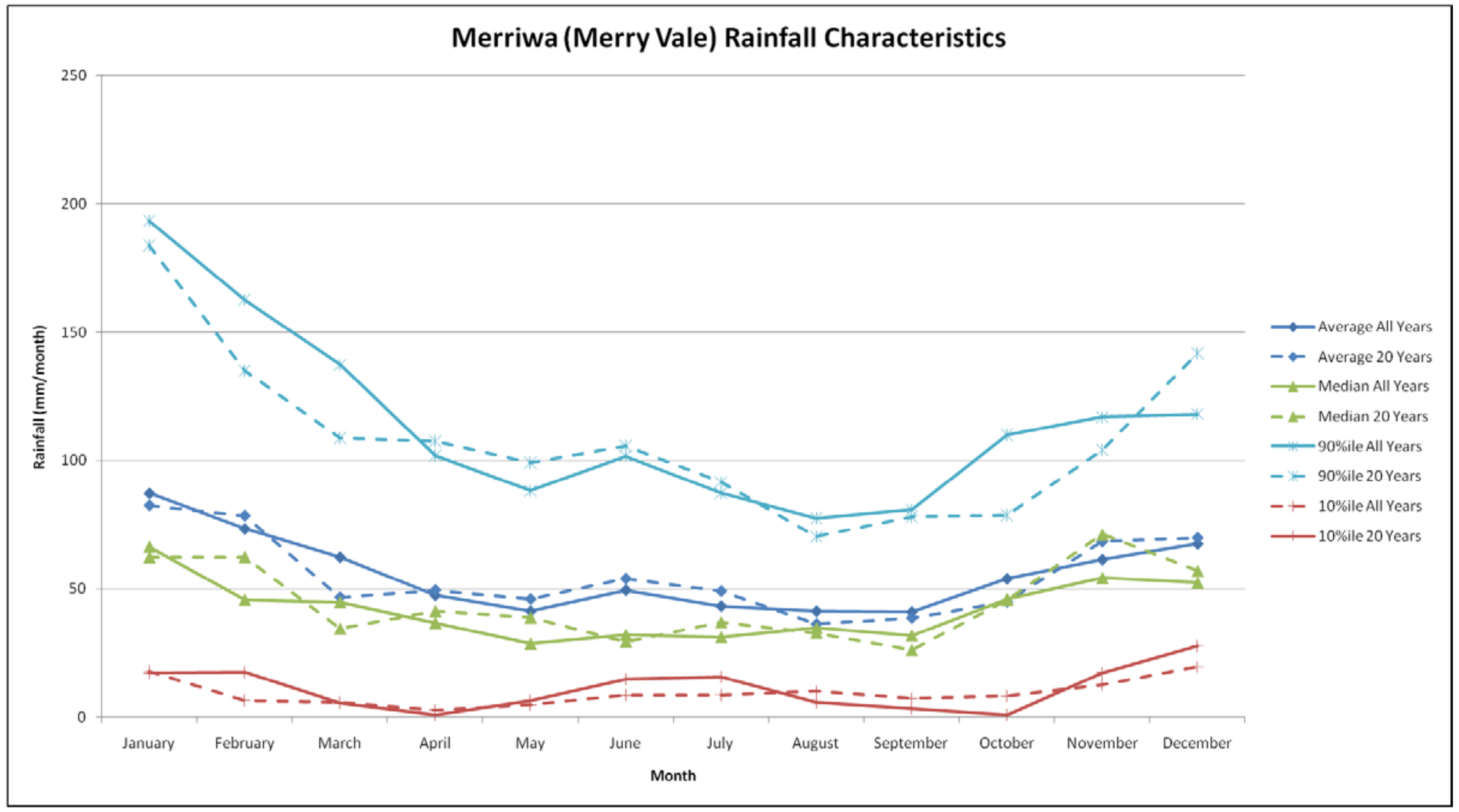
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	0	0	0	184
Average	87	73	62	47	41	50	43	41	41	54	61	68	657
Max	302	417	311	196	224	256	232	164	197	184	250	302	1488
10%ile	18	7	6	3	5	9	9	10	7	8	13	20	421
50%ile	66	46	45	37	29	32	31	35	32	46	54	52	678
90%ile	193	163	137	102	88	102	87	78	81	110	117	118	881

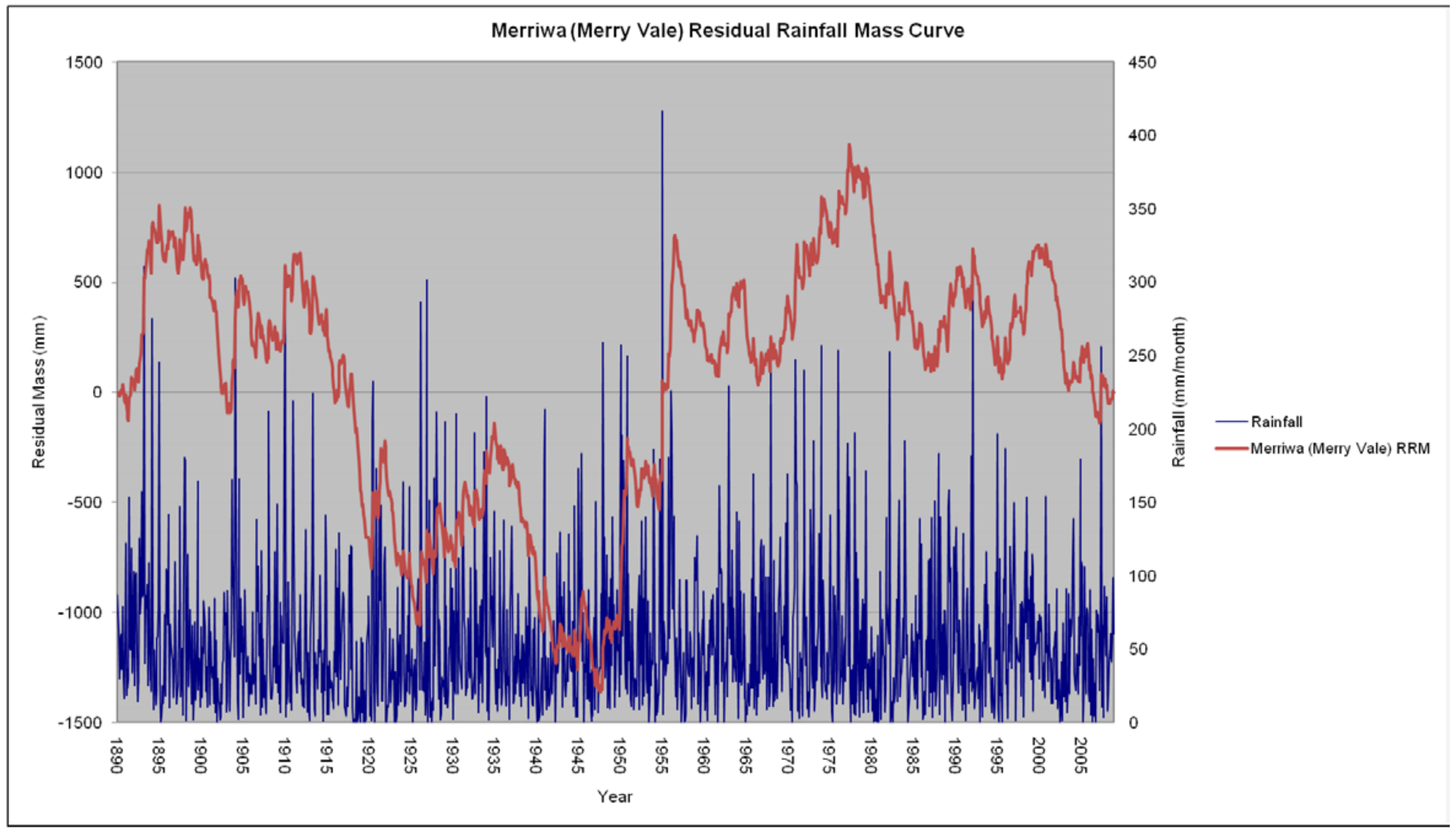
Merriwa (Merry Vale) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	14	10	4	0	0	10	0	0	1	0	8	0	194
Average	83	79	47	50	46	54	49	36	39	45	68	70	618
Max	197	303	147	158	116	256	154	120	92	116	154	182	910
10%ile	17	18	6	1	7	15	16	6	3	1	17	28	375
50%ile	62	63	35	41	39	29	37	33	26	46	71	57	676
90%ile	184	135	109	107	99	106	92	70	78	79	104	142	812

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	76	61	52	41	35	42	37	36	35	47	54	59	656
5	136	127	106	77	70	83	72	65	65	83	93	107	831
10	175	171	142	101	94	111	95	84	85	106	118	139	916
20	213	213	177	124	117	137	118	103	104	129	142	169	982
25	225	227	188	131	124	146	125	109	110	136	150	179	1000
50	262	268	221	154	146	172	147	127	129	158	174	209	1050
100	299	308	255	176	168	197	168	144	147	180	197	239	1090
500	384	403	332	227	219	257	218	186	190	231	252	307	1161





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Merriwa (Terragong) 62073

Merriwa (Terragong) rainfall during entire record: 113 years of data (1890 to 2010) some years missing

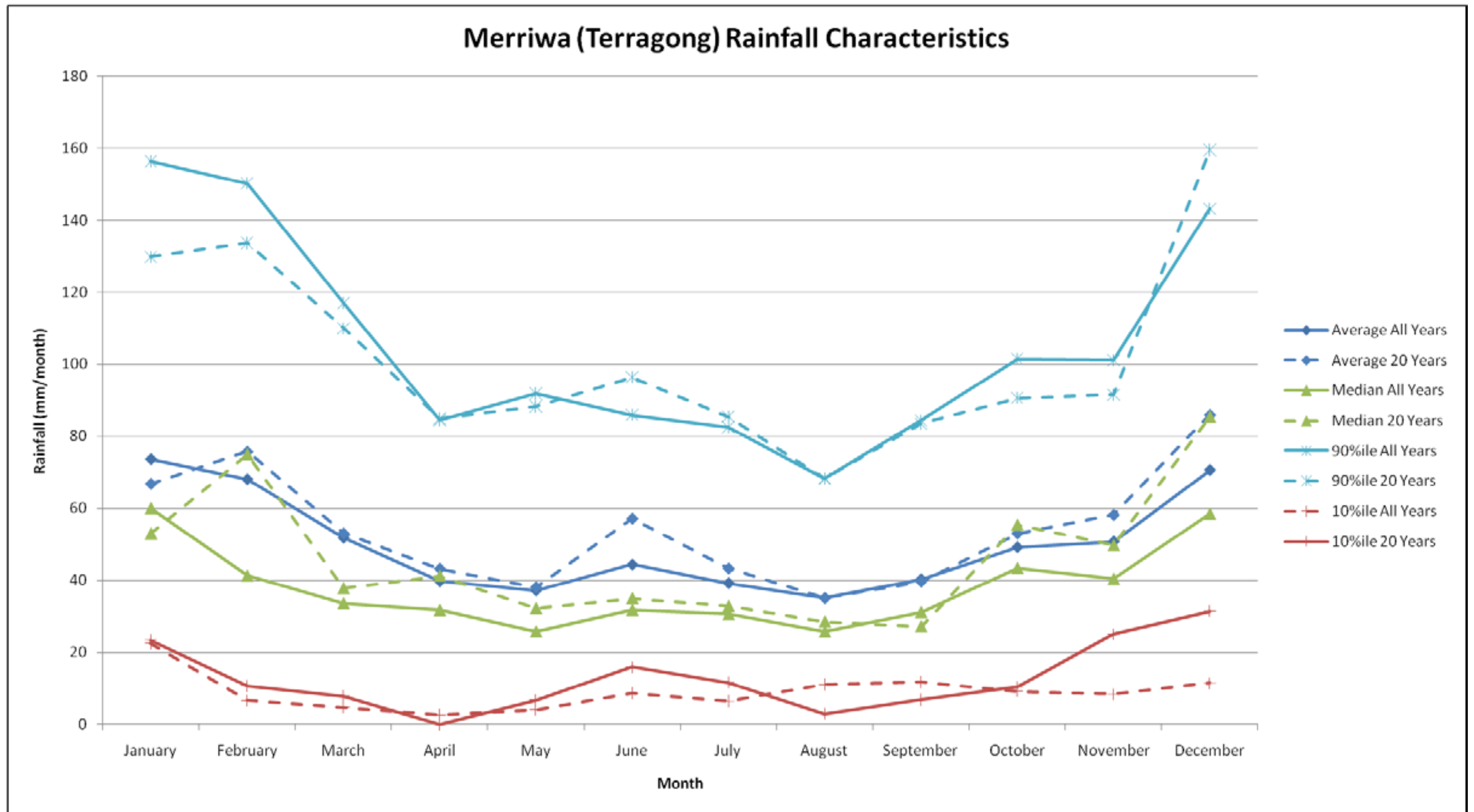
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	4	0	0	0	0	0	0	0	0	2	0	0	282
Average	74	68	52	40	37	44	39	35	40	49	51	71	592
Max	311	377	286	174	181	277	184	134	172	157	181	278	1035
10%ile	23	7	5	3	4	9	6	11	12	9	8	11	373
50%ile	60	41	34	32	26	32	31	26	31	43	40	58	595
90%ile	156	150	117	85	92	86	82	68	84	101	101	143	811

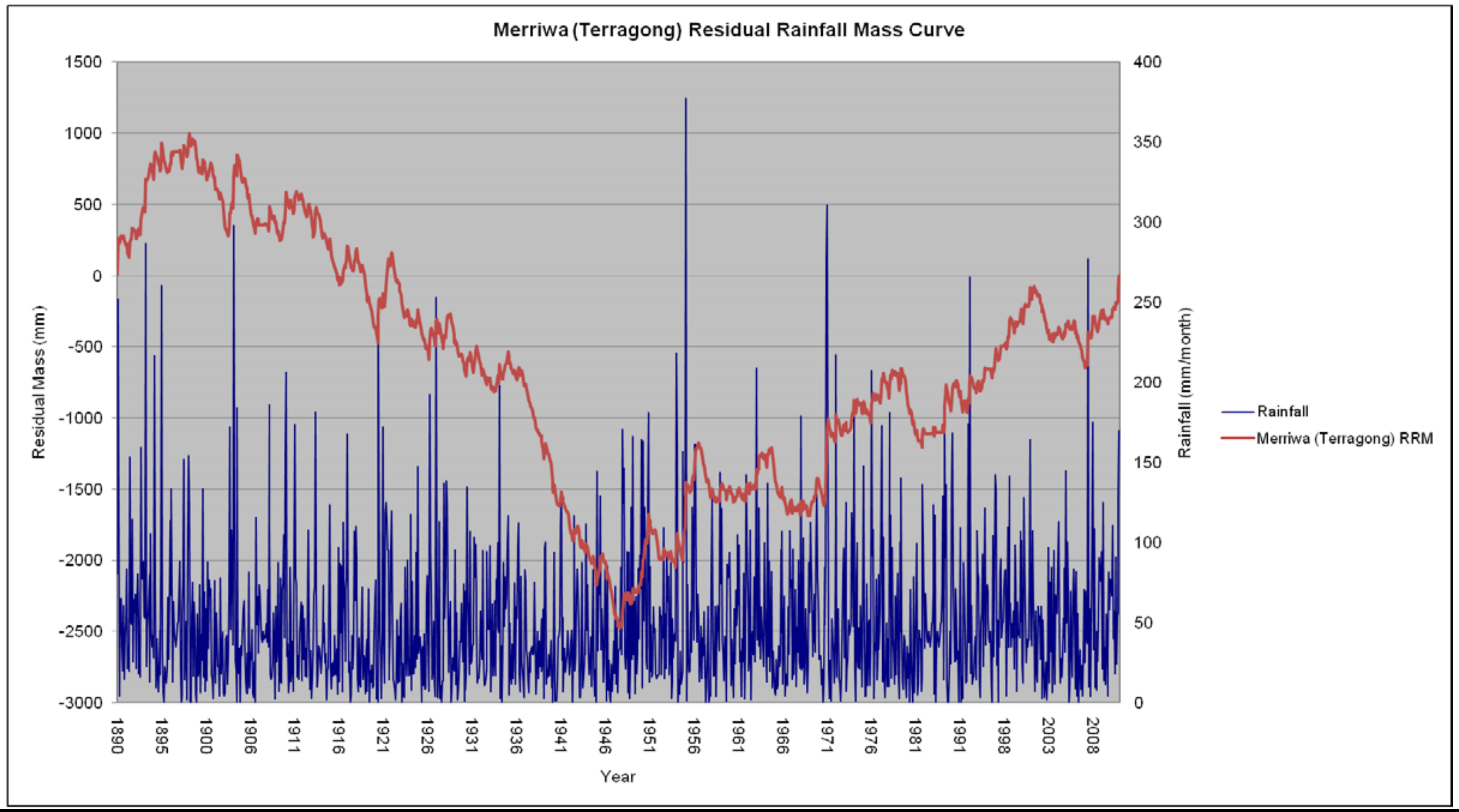
Merriwa (Terragong) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	12	0	4	0	0	7	3	0	0	2	0	9	311
Average	67	76	53	43	38	57	43	35	40	53	58	86	605
Max	136	266	128	174	110	277	142	95	105	122	164	175	873
10%ile	23	11	8	0	7	16	12	3	7	10	25	31	455
50%ile	53	75	38	41	32	35	33	29	27	55	50	86	608
90%ile	130	134	110	85	88	96	86	68	84	91	92	160	751

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	64	57	43	34	31	37	34	31	35	43	44	62	581
5	115	117	89	65	63	76	64	54	63	74	79	109	729
10	149	157	119	86	83	103	84	70	82	95	102	140	811
20	181	195	148	106	103	128	104	84	99	114	123	170	882
25	192	207	157	113	110	136	110	89	105	120	130	179	902
50	223	244	185	132	129	160	129	104	122	139	152	208	962
100	255	281	213	152	148	184	147	118	139	158	173	237	1016
500	327	367	278	197	193	240	191	151	179	202	222	304	1126





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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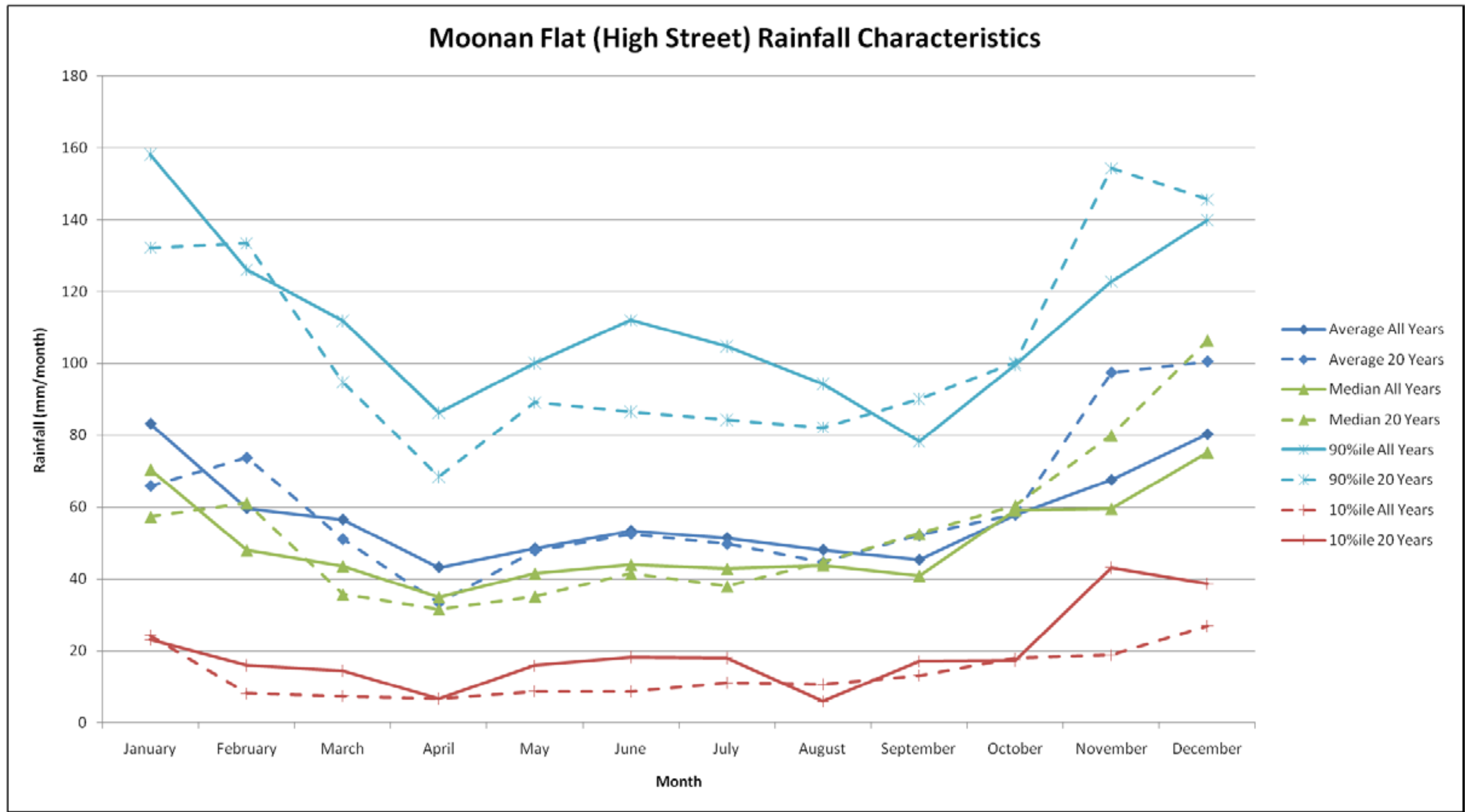
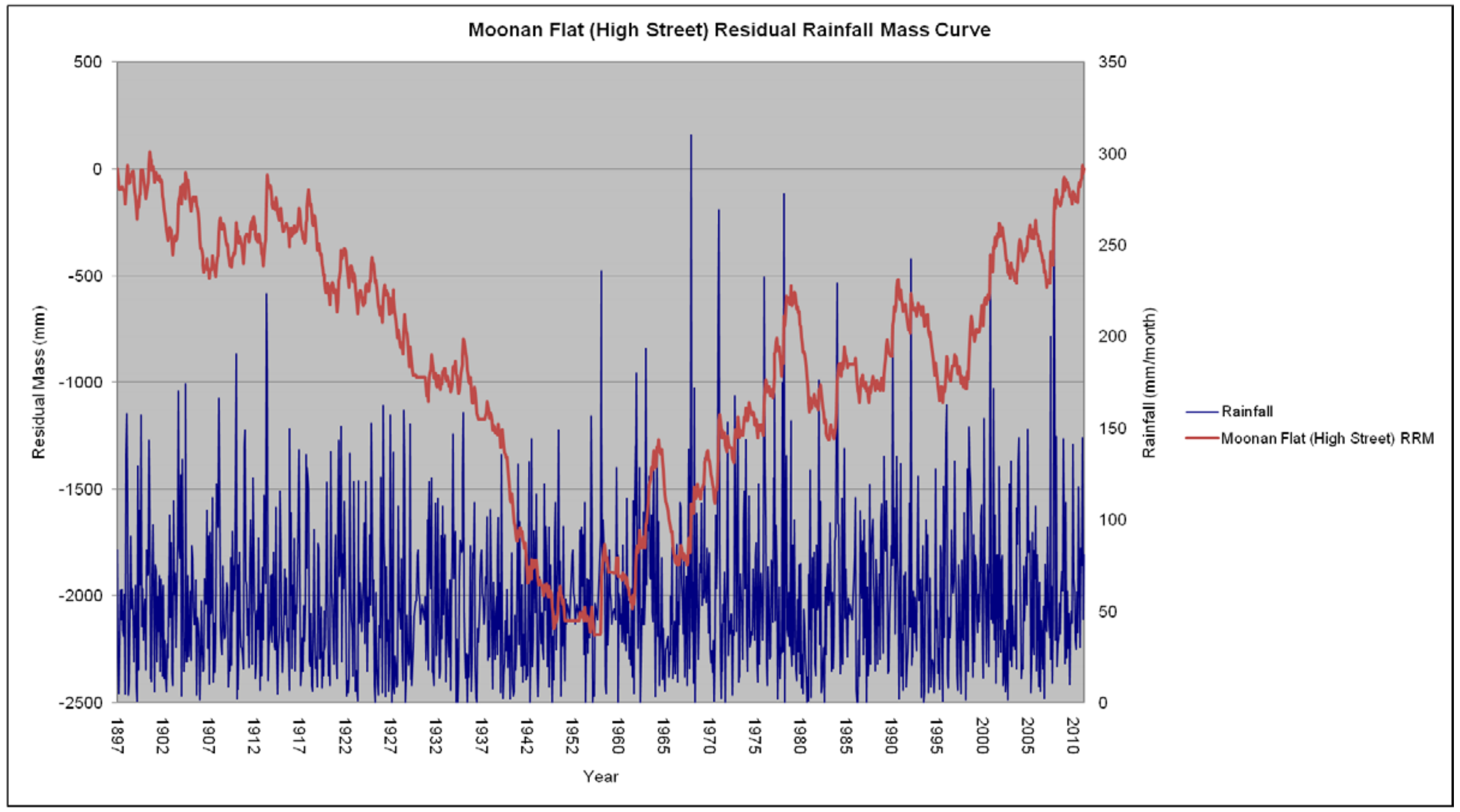
Moonan Flat (High Street) 61097

Moonan Flat (High Street) rainfall during entire record: 107 years of data (1897 to 2011) some years missing	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	0	1	9	332
Average	83	60	57	43	48	53	51	48	45	58	68	80	689
Max	310	242	278	143	223	200	174	157	170	168	275	207	1147
10%ile	24	8	7	7	9	9	11	11	13	18	19	27	474
50%ile	71	48	44	35	42	44	43	44	41	59	60	75	692
90%ile	158	126	112	86	100	112	105	94	78	100	123	140	900

Moonan Flat (High Street) rainfall during the last 20 years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	6	14	1	3	6	10	0	1	5	2	34	14	430
Average	66	74	51	33	48	53	50	45	52	58	97	101	722
Max	163	242	171	76	128	200	151	129	121	107	275	188	1073
10%ile	23	16	14	7	16	18	18	6	17	17	43	39	482
50%ile	57	61	36	32	35	42	38	45	53	60	80	106	756
90%ile	132	133	95	68	89	87	84	82	90	100	154	146	898

Size of rainfall events (mm) for various return intervals — Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	74	51	48	38	42	46	45	43	40	52	60	73	678
5	125	96	92	68	77	84	78	72	67	81	101	112	830
10	158	126	121	88	100	109	100	91	85	101	129	138	915
20	191	154	149	107	121	133	121	109	102	119	156	163	987
25	201	164	157	113	128	141	127	115	107	125	164	171	1009
50	233	191	185	132	150	164	148	133	124	143	190	195	1071
100	264	219	211	150	171	187	168	151	140	161	215	219	1127
500	337	283	274	193	220	241	215	192	178	202	275	274	1243





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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Murrurundi Post Office (61051)

Murrurundi Post Office entire record: 142 years of data (1870 to 2011)

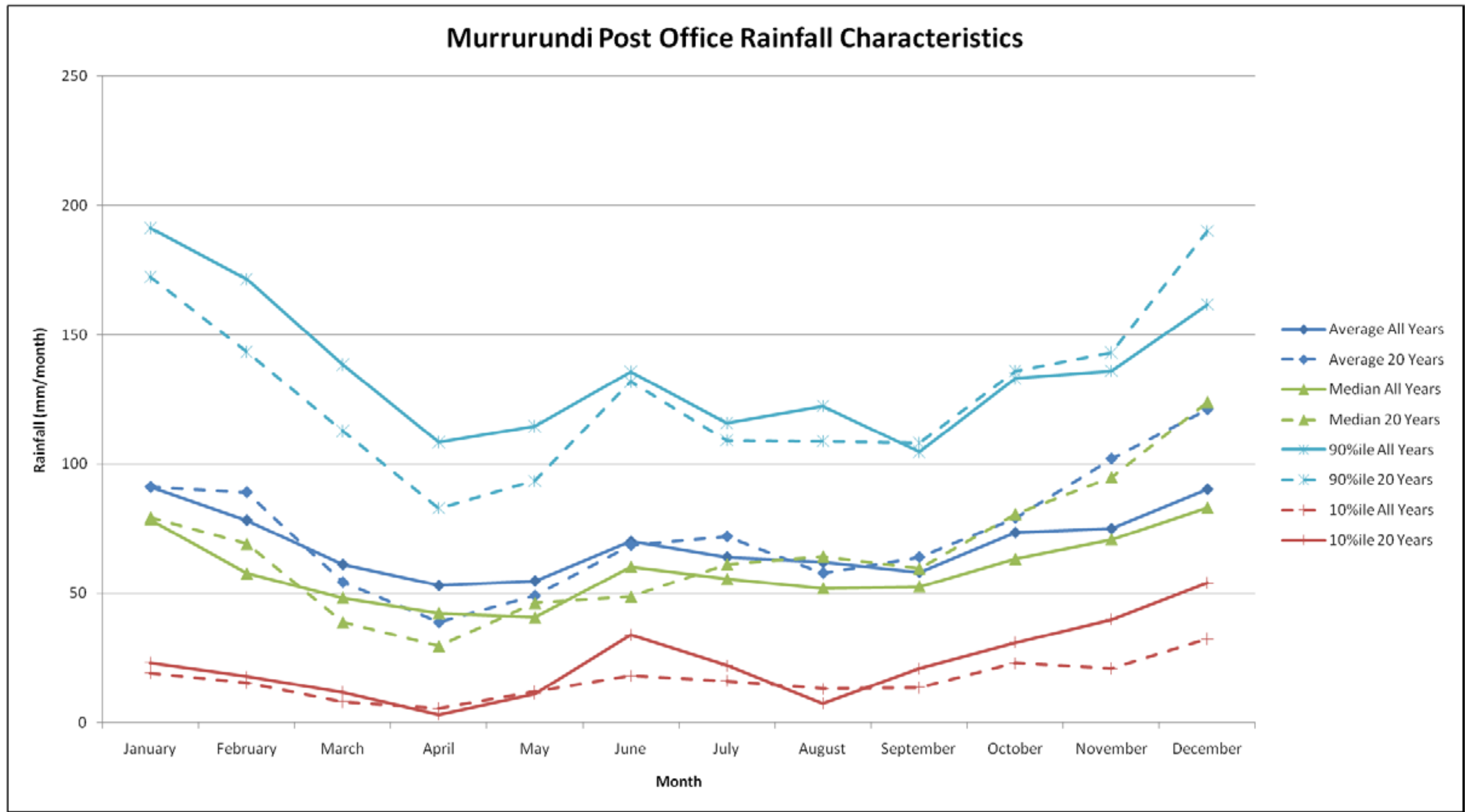
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	2	1	0	1	4	3	0	0	0	1	6	377
Average	91	78	61	53	55	70	64	62	58	73	75	90	826
Max	397	433	259	210	269	357	268	209	162	240	348	234	1413
10%ile	19	15	8	6	12	18	16	13	14	23	21	32	544
50%ile	79	58	48	42	41	60	55	52	53	63	71	83	815
90%ile	191	171	138	108	115	136	116	122	105	133	136	162	1077

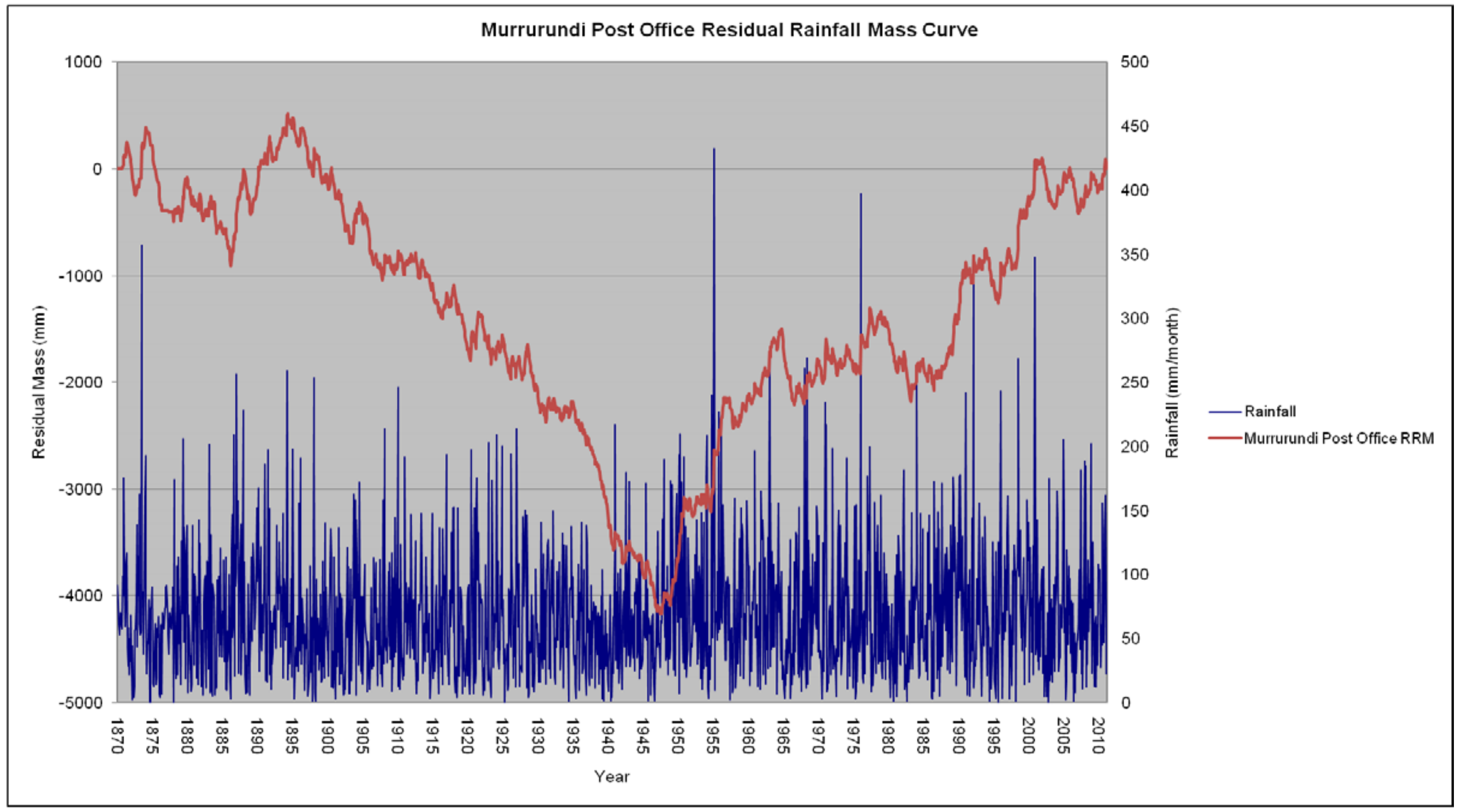
Murrurundi Post Office rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	17	16	1	2	1	22	5	0	11	0	30	39	507
Average	91	89	54	39	49	69	72	58	64	79	102	121	886
Max	243	338	143	113	118	182	268	122	125	158	348	233	1311
10%ile	23	18	12	3	11	34	22	8	21	31	40	54	540
50%ile	79	69	39	30	46	49	61	64	60	81	95	124	890
90%ile	172	143	113	83	93	132	109	109	108	136	143	190	1136

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	80	67	53	46	47	62	57	55	52	66	67	81	812
5	141	127	97	83	88	107	96	92	84	106	110	128	998
10	181	167	125	107	115	137	121	116	106	133	138	160	1103
20	220	206	153	130	141	165	146	140	126	158	165	190	1192
25	233	218	162	137	149	174	154	147	133	166	174	199	1219
50	270	255	189	159	174	202	178	170	153	191	201	228	1296
100	308	292	216	182	199	230	202	193	173	216	227	257	1366
500	395	378	278	233	257	294	257	245	218	273	288	324	1511





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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Scone SCS 61089

Scone SCS entire record: 62 years of data (1950 to 2011)

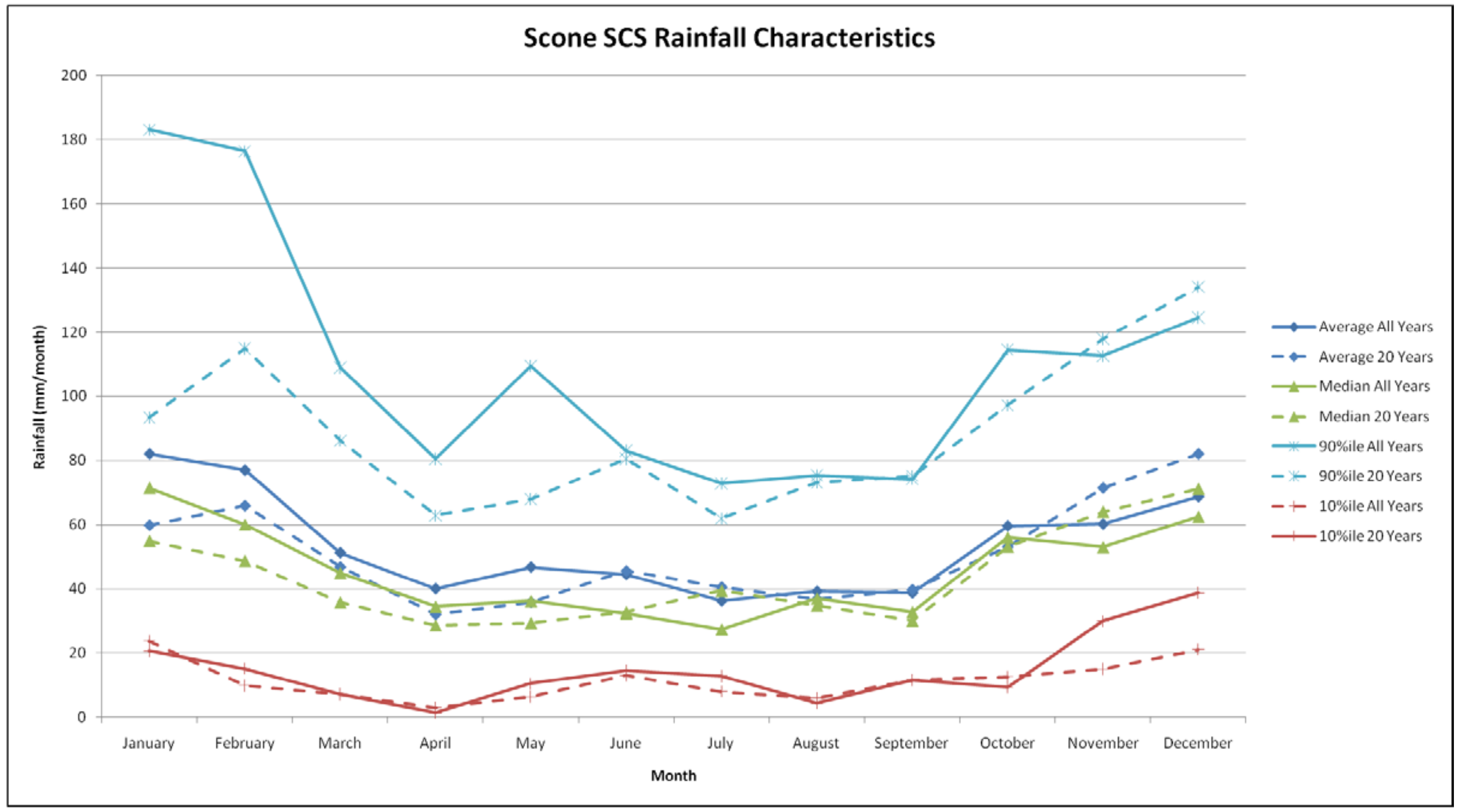
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	5	4	0	0	0	2	1	0	0	0	2	5	319
Average	82	77	51	40	47	44	36	39	39	60	60	69	646
Max	237	417	220	188	163	210	140	110	89	163	182	168	1055
10%ile	24	10	7	3	6	13	8	6	12	13	15	21	416
50%ile	72	60	45	35	36	32	27	37	33	56	53	63	654
90%ile	183	176	109	81	109	83	73	75	74	115	113	125	817

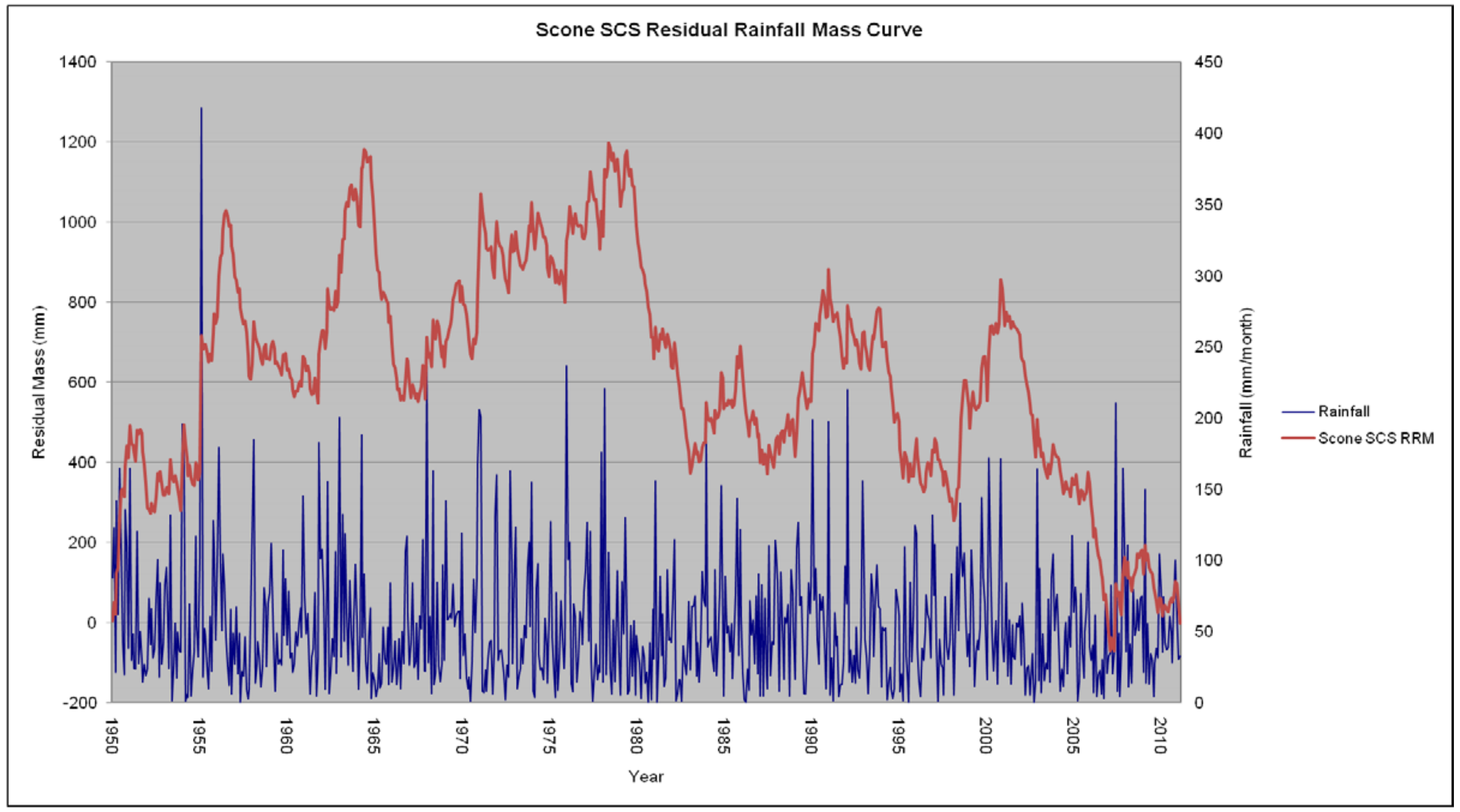
Scone SCS rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	11	5	5	1	2	12	5	0	3	0	15	21	319
Average	60	66	47	32	36	46	41	37	40	53	72	82	611
Max	198	220	172	105	109	210	140	107	89	144	171	164	911
10%ile	21	15	7	1	11	15	13	4	12	9	30	39	428
50%ile	55	49	36	29	30	33	39	35	30	53	64	71	605
90%ile	93	115	86	63	68	81	62	73	75	97	118	134	788

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	72	65	44	34	40	38	32	35	35	53	53	62	644
5	125	128	83	67	76	71	56	59	56	89	91	97	785
10	160	170	109	89	100	93	73	74	70	112	116	121	857
20	194	210	134	109	123	114	88	89	84	135	139	143	914
25	205	223	141	116	131	121	93	94	88	142	147	150	930
50	238	262	166	136	153	141	109	109	101	165	170	172	975
100	270	301	190	157	175	162	124	124	114	187	193	194	1013
500	346	391	245	204	227	209	159	158	144	238	247	244	1084





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Upper Rouchel (Mount View) 61135

Upper Rouchel (Mount View) entire record: 51 years of data (1961 to 2011)

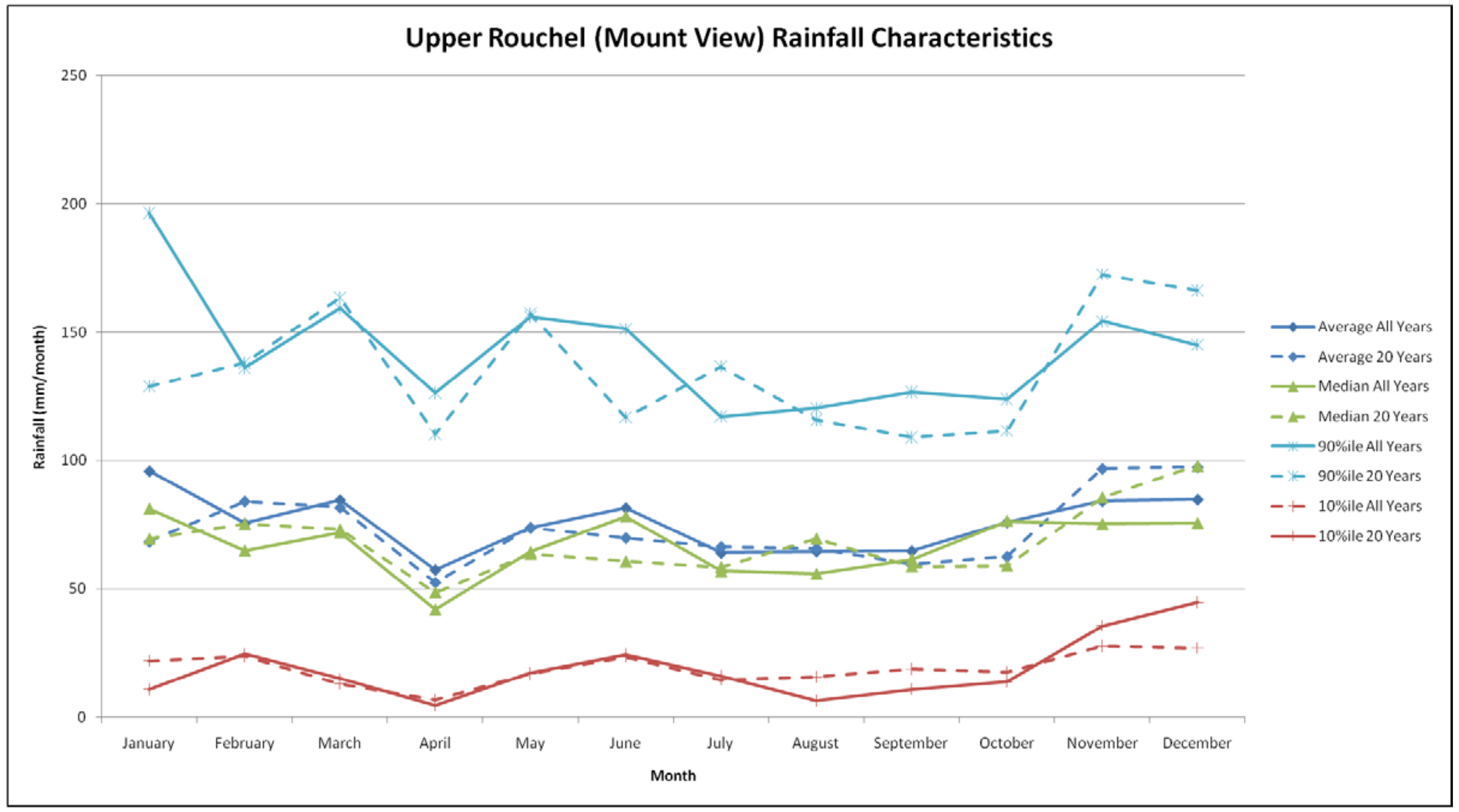
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	4	0	2	3	8	2	0	0	3	5	8	429
Average	96	76	85	58	74	82	64	65	65	76	84	85	877
Max	299	266	409	202	214	232	169	223	147	214	245	217	1348
10%ile	22	24	13	7	17	24	15	16	19	18	28	27	575
50%ile	81	65	72	42	64	78	57	56	62	76	75	76	888
90%ile	196	136	159	126	156	151	117	120	127	124	154	145	1158

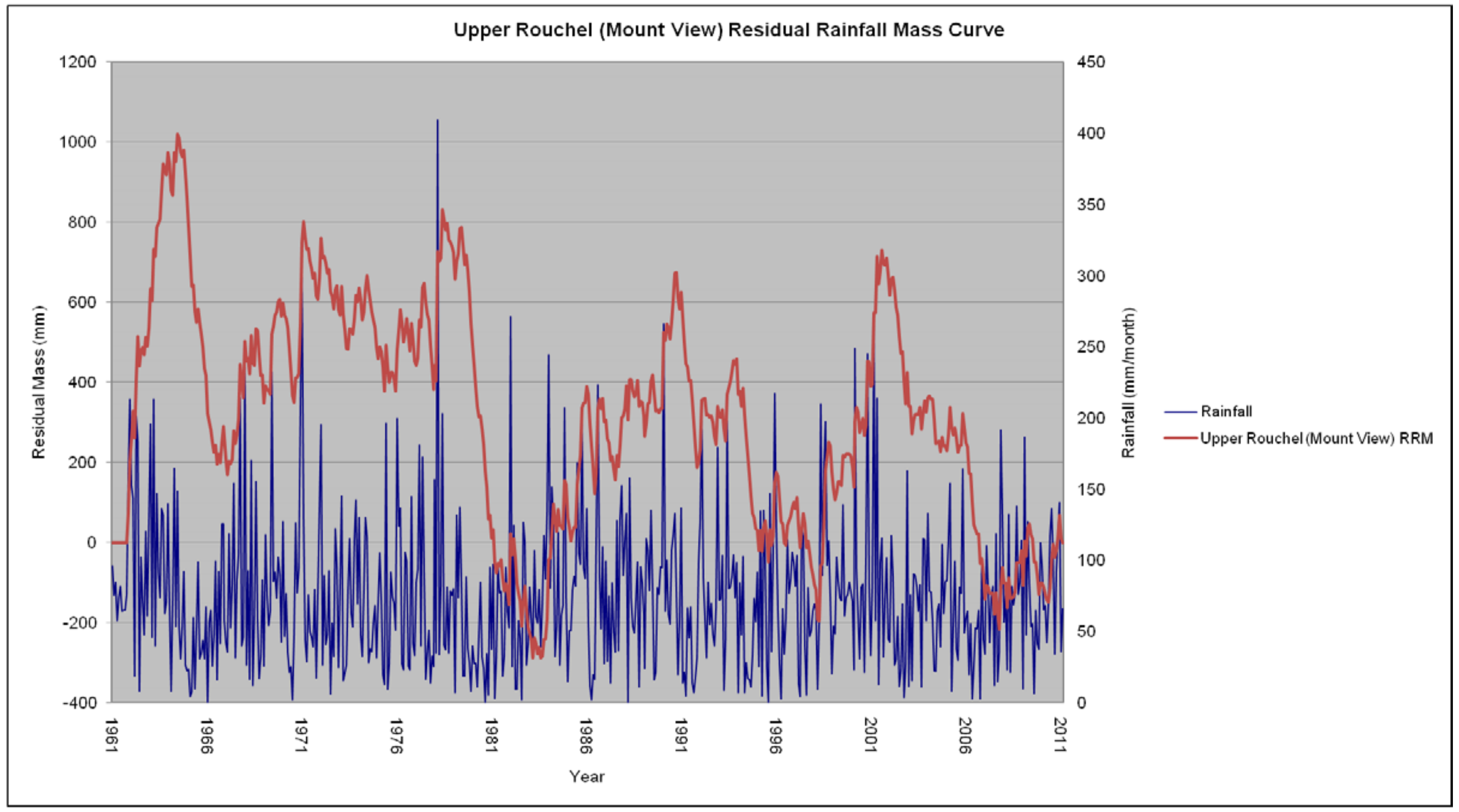
Upper Rouchel (Mount View) rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	7	14	9	3	3	12	11	0	7	3	27	20	476
Average	68	84	82	53	74	70	66	66	59	63	97	97	814
Max	137	199	265	133	214	199	163	197	147	115	245	217	1164
10%ile	11	25	15	5	17	24	16	6	11	14	36	45	520
50%ile	70	75	73	49	64	61	59	70	59	59	86	98	766
90%ile	129	138	163	110	157	117	137	116	109	112	172	166	1076

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	84	67	72	50	65	73	57	56	58	68	76	76	875
5	147	114	141	92	113	120	94	100	92	110	121	122	1072
10	189	146	186	121	145	151	119	130	115	138	151	152	1173
20	228	176	230	148	175	181	142	158	136	165	180	181	1253
25	241	186	244	156	185	191	150	166	143	173	189	190	1275
50	280	216	287	183	215	220	173	194	164	199	217	219	1338
100	319	245	329	209	245	249	195	221	185	225	245	247	1392
500	408	313	428	270	313	316	248	284	233	285	310	312	1493





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Upper Rouchel School 61067

Upper Rouchel School rainfall during entire record: 66 years of data (1926 to 2005) some years missing

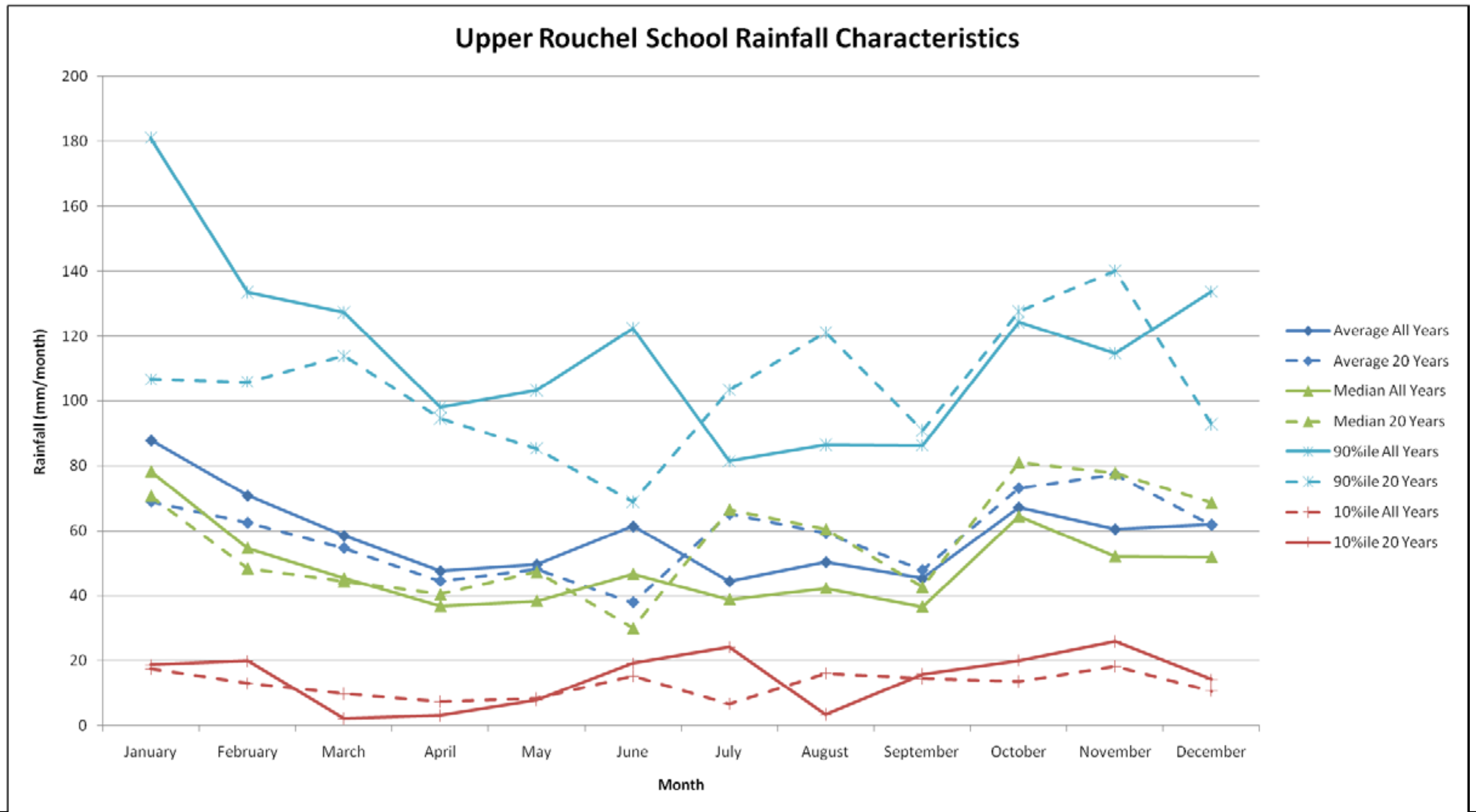
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	6	3	0	1	0	1	1	0	0	3	2	0	268
Average	88	71	59	48	50	61	45	50	45	67	61	62	703
Max	250	324	206	237	162	298	135	194	123	191	215	205	1198
10%ile	17	13	10	7	8	15	7	16	15	14	18	11	488
50%ile	78	55	45	37	38	47	39	42	37	65	52	52	712
90%ile	181	133	127	98	103	122	81	86	86	124	115	134	939

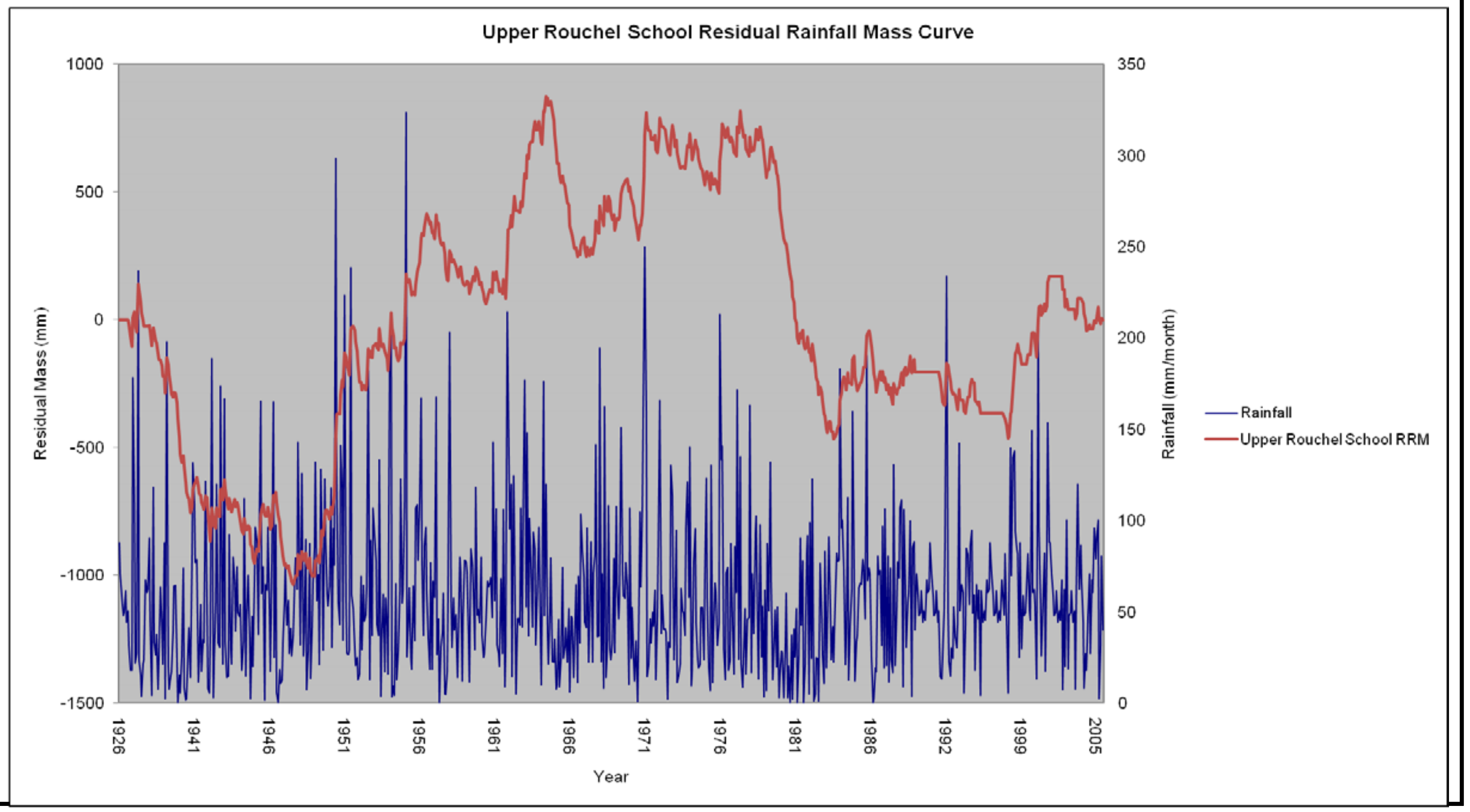
Upper Rouchel School rainfall during the last 20 years

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	12	13	0	1	4	17	17	0	8	4	7	5	462
Average	69	62	55	44	48	38	65	59	48	73	77	62	709
Max	183	234	206	106	140	85	135	138	100	191	160	142	972
10%ile	19	20	2	3	8	19	24	3	16	20	26	14	494
50%ile	71	49	45	41	47	30	67	61	43	81	78	69	683
90%ile	107	106	114	95	85	69	103	121	91	128	140	93	950

Size of rainfall events (mm) for various return intervals

Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	78	61	50	40	43	52	39	45	41	60	54	54	704
5	131	115	95	81	79	101	69	76	66	99	90	96	859
10	166	150	124	107	102	132	88	97	83	125	114	124	936
20	200	184	152	133	125	163	107	118	99	150	136	151	996
25	211	195	161	141	132	173	113	124	104	158	144	159	1013
50	243	228	188	166	154	202	131	144	120	183	166	185	1060
100	276	261	216	191	176	232	149	163	136	207	188	211	1099
500	352	338	279	249	227	300	191	209	172	263	239	271	1169





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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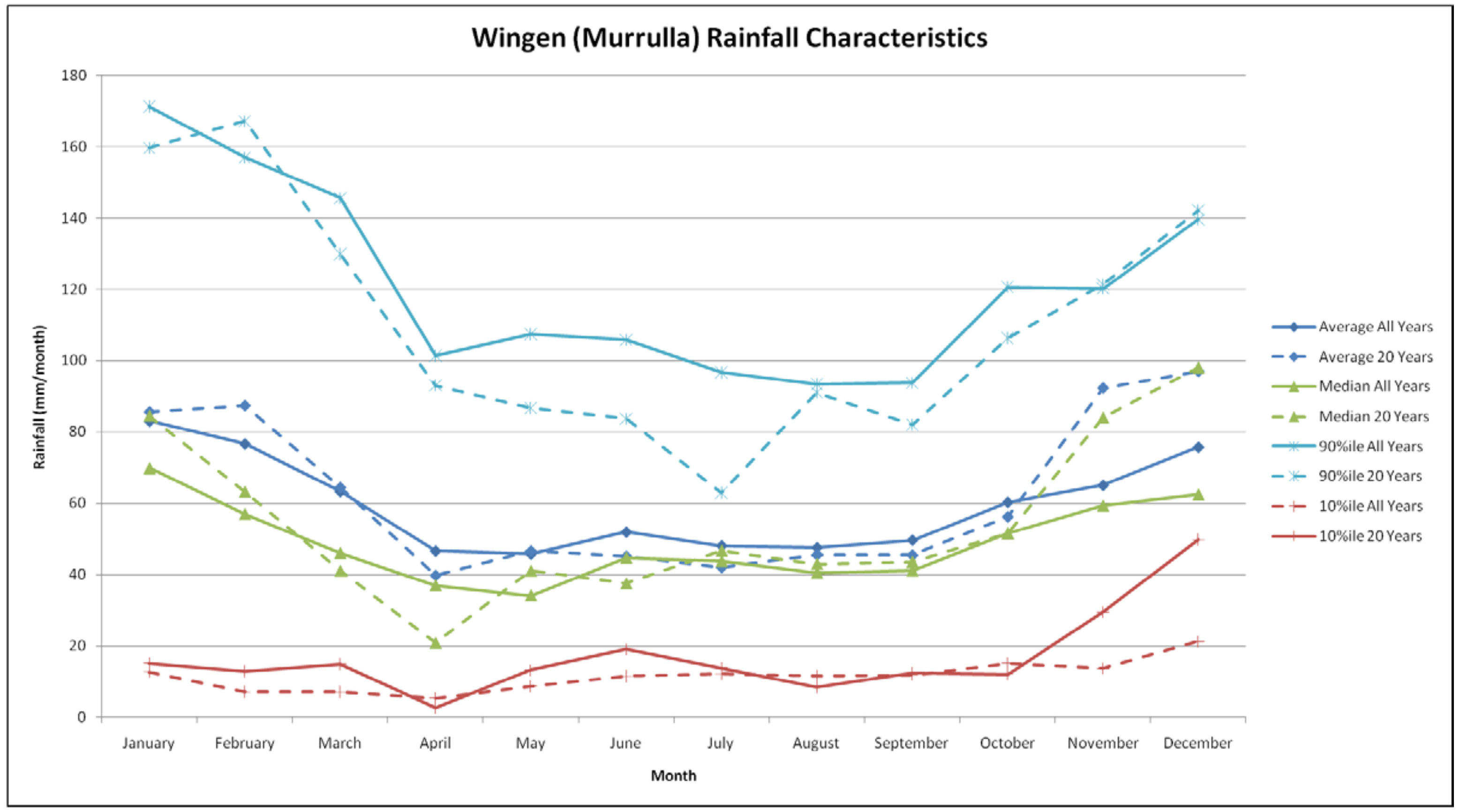
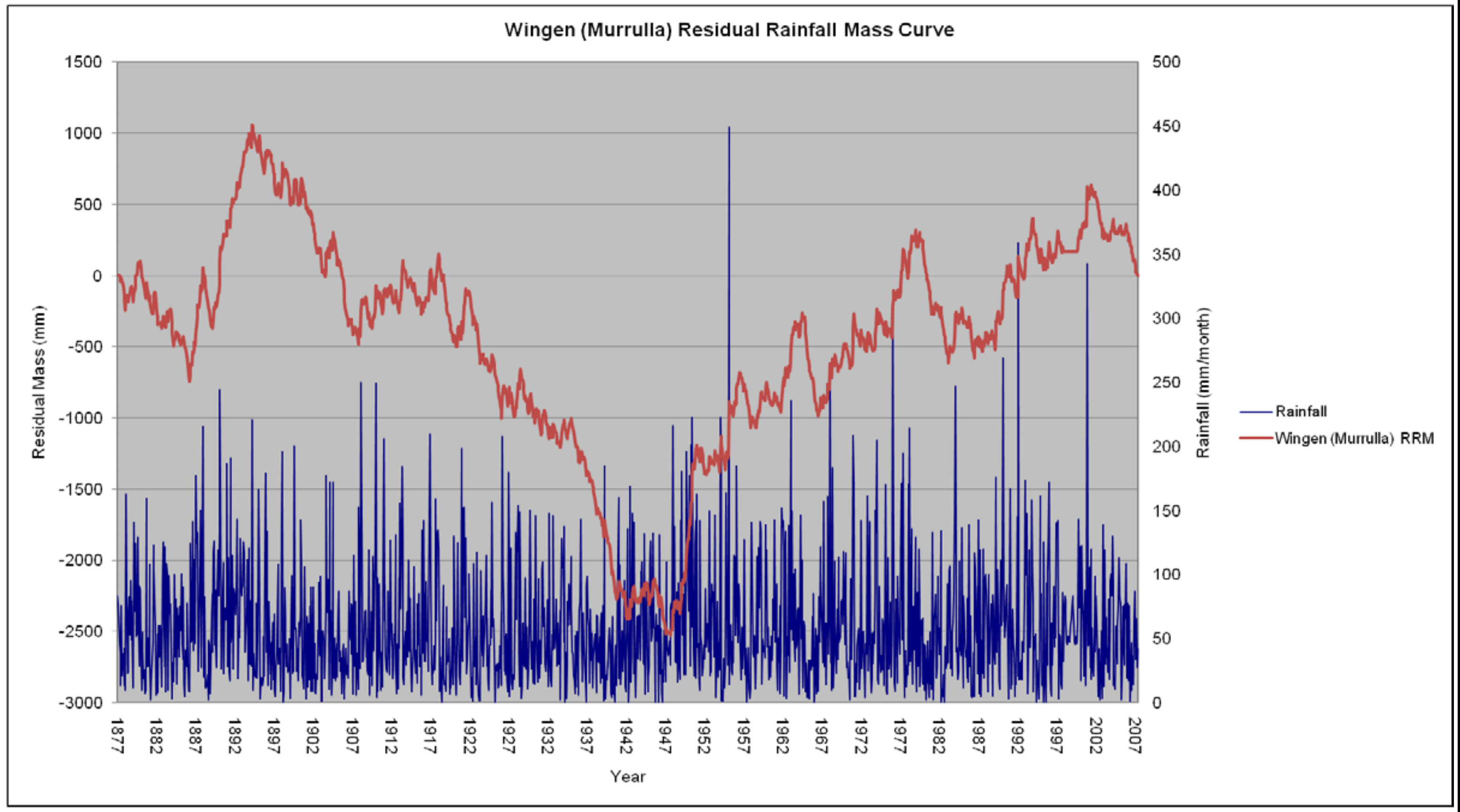
Wingen (Murrulla) 61079

Wingen (Murrulla) entire record: 131 years of data (1877 to 2007)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	3	1	3	275
Average	83	77	63	47	46	52	48	48	50	60	65	76	707
Max	310	449	221	201	195	222	172	200	196	164	343	217	1295
10%ile	13	7	7	5	9	11	12	12	12	15	14	21	440
50%ile	70	57	46	37	34	45	44	41	41	52	59	63	699
90%ile	171	157	146	101	107	106	97	93	94	121	120	140	931

Wingen (Murrulla) rainfall during the last 20 years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	8	7	8	0	0	10	2	0	3	3	3	19	408
Average	86	87	64	40	47	45	42	46	45	56	92	97	712
Max	172	359	176	138	125	119	83	120	93	158	343	174	1019
10%ile	15	13	15	3	13	19	14	8	12	12	29	50	511
50%ile	85	63	41	21	41	38	47	43	44	52	84	98	683
90%ile	160	167	130	93	87	84	63	91	82	106	121	142	930

Size of rainfall events (mm) for various return intervals — Return Interval (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2	73	65	55	40	39	45	42	42	44	54	57	68	700
5	129	129	101	75	75	81	73	74	76	88	99	112	873
10	167	171	132	98	99	104	93	95	98	110	126	141	965
20	203	211	162	120	121	127	112	115	119	131	153	170	1040
25	214	224	172	127	129	134	119	122	126	138	161	179	1061
50	249	263	201	148	151	156	137	141	146	159	187	206	1122
100	284	303	230	170	173	178	156	161	167	180	213	234	1175
500	365	393	296	219	224	229	200	207	213	228	272	297	1277





FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Streamflow Analysis

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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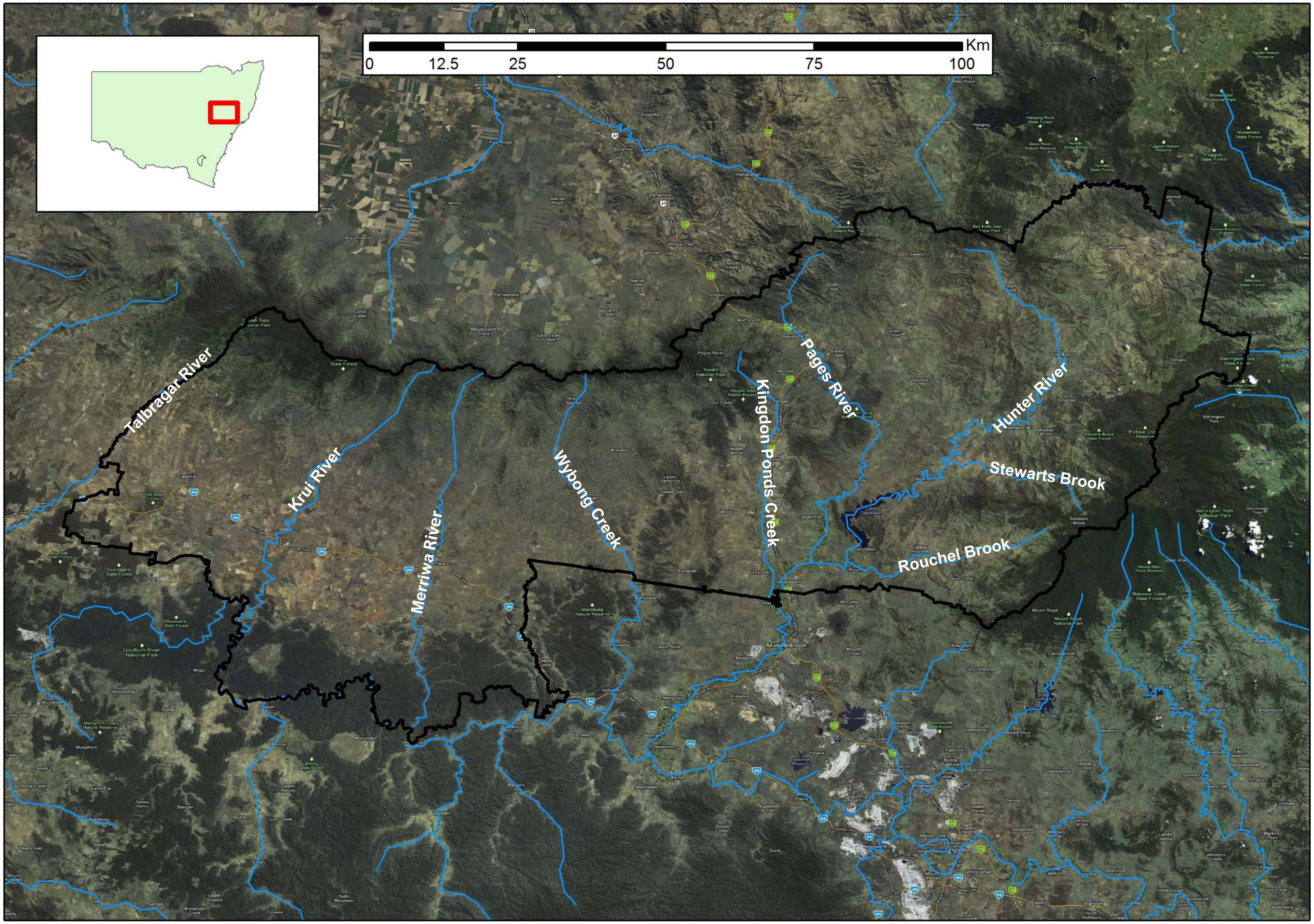
Location and names of major river in the Upper Hunter



(Image from Google Maps)

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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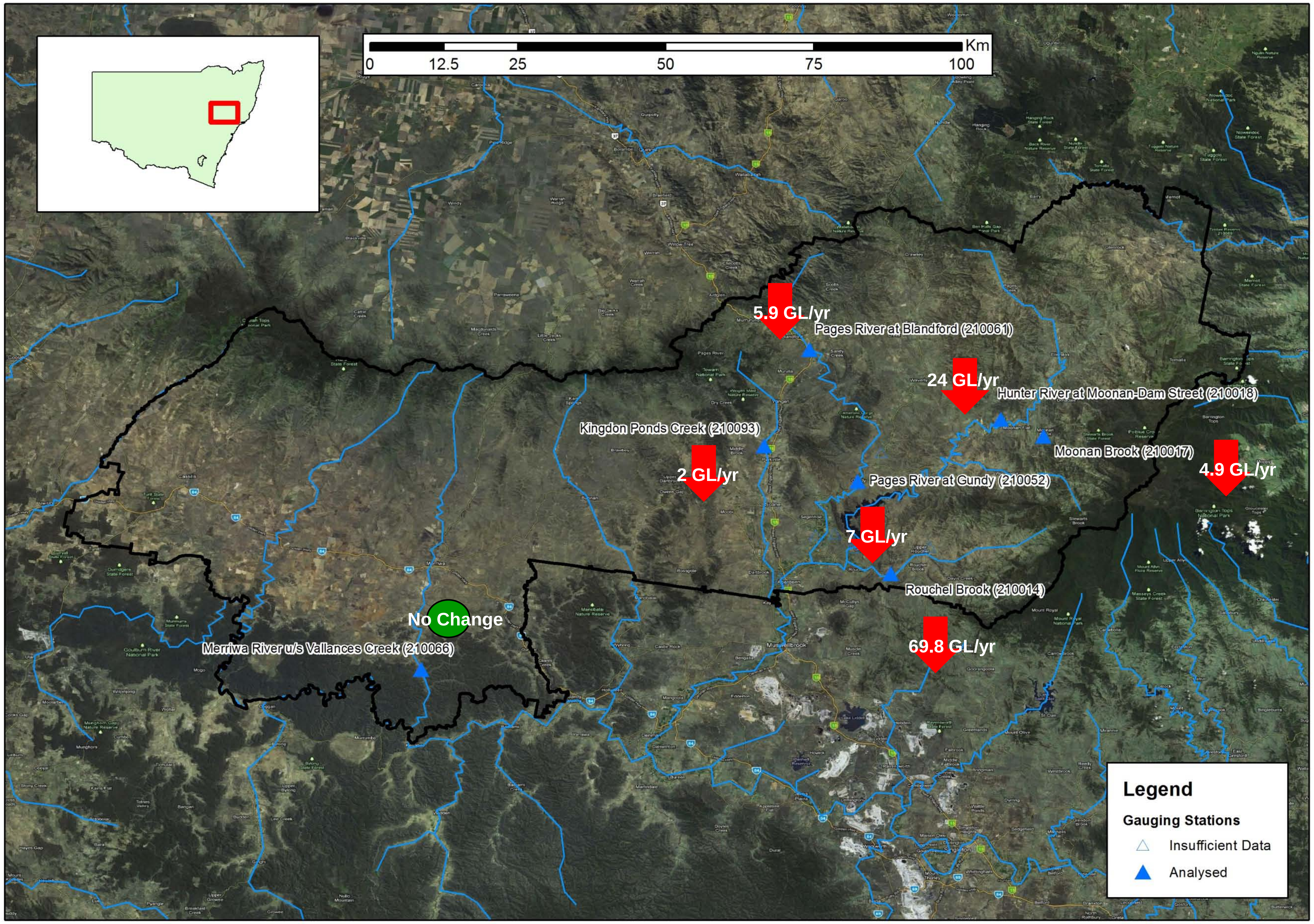
Location of stream gauges analysed and water used per year (as modelled)



(Image from Google Maps)

Double mass curve modelling (see **pages 33-39 & 68-69**) reveals that the most of the gauged rivers in the Upper Hunter LGA have a high level of use. The exception being the Merriwa River u/s of Vallances Creek, which shows no change (although there is period from 1992-2002 in which there is no data, which may obscure the double mass analysis).

There are also six existing gauging station with not yet sufficient datasets to identify longterm trends (Dart Brook at Yarrandi Bridge – 17 years of data, Foy Brook at Downstream Bowmans Creek Bridge – 18 years of data, Hunter River at Upstream Bayswater Creek – 17 years of data, Hunter River at Belltrees – 11 years of data, Hunter River at Upstream Foy Brook – 18 years of data and Isis River at Stick-Me-Up Bridge – 7 years of data). Ideally, so as to ensure that a broad range of climate and use conditions are represented in the record, at least 30 years of data should be present.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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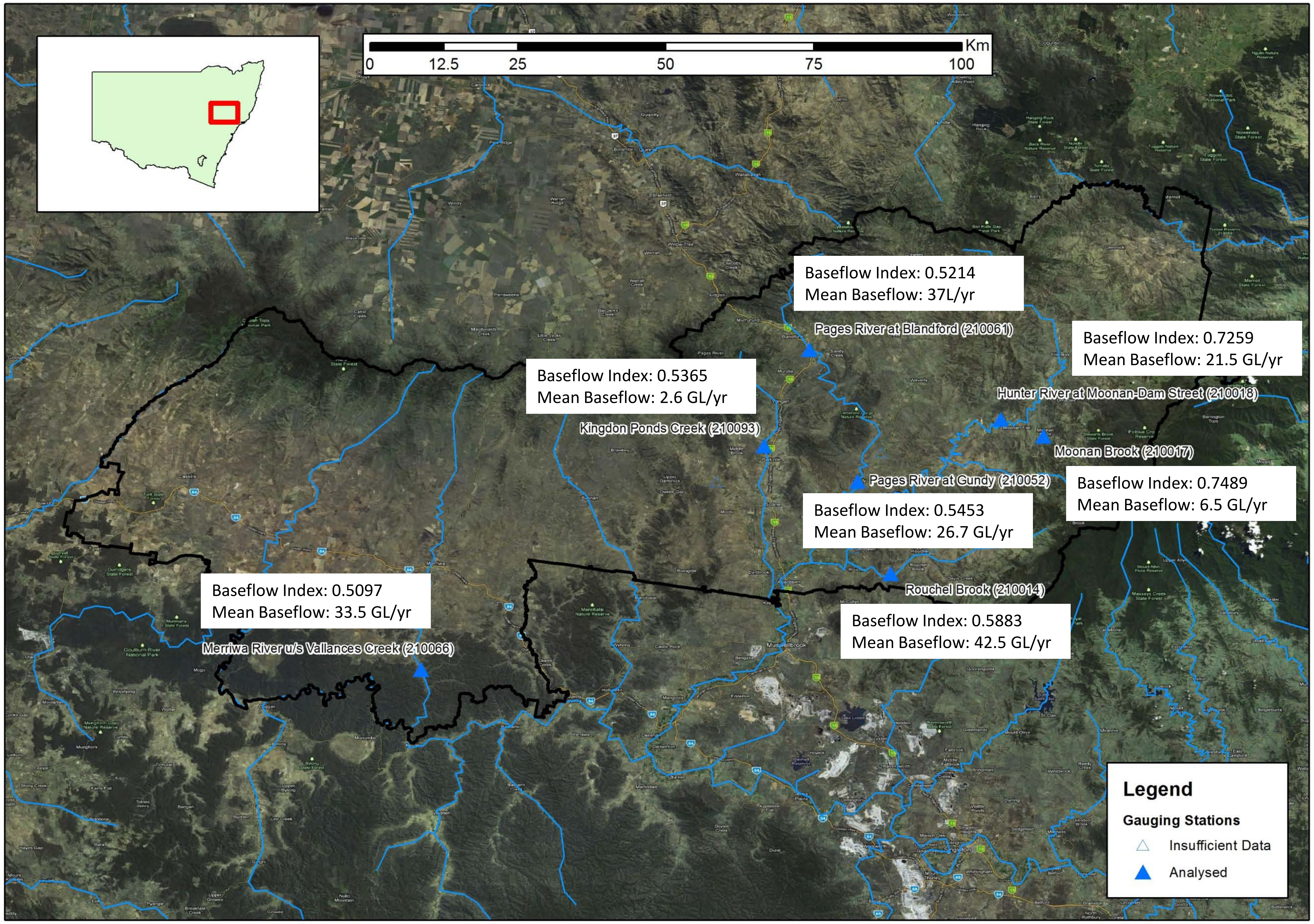
Location of stream gauges analysed and baseflow



(Image from Google Maps)

Baseflow is the longer-term discharge into a stream from natural storages, which act to sustain streamflow and support ecosystems in between periods with no rainfall. There may be a number of potential natural storages in a catchment, but one of the most critical is groundwater seepage into a stream (http://connectedwater.gov.au/processes/baseflow.html).

There are a number of tools to analyse the baseflow component of streamflow, but the most common is the use of a baseflow index (http://connectedwater.gov.au/documents/assessment/Baseflow_Separation.doc).

Analysis of streamflow data from the Upper Hunter shows that all gauged rivers are highly dependent on baseflow, probably from groundwater sources.

Falling groundwater levels in the region could change this relationship, decreasing the volume of baseflow and in some cases, even reversing the gradient so that the streams will feed the groundwater system.

Therefore it is important that anything that could cause a fall in groundwater levels be carefully considered.

The image to the **left** shows, the baseflow index and modelled annual baseflow contribution for each gauge.

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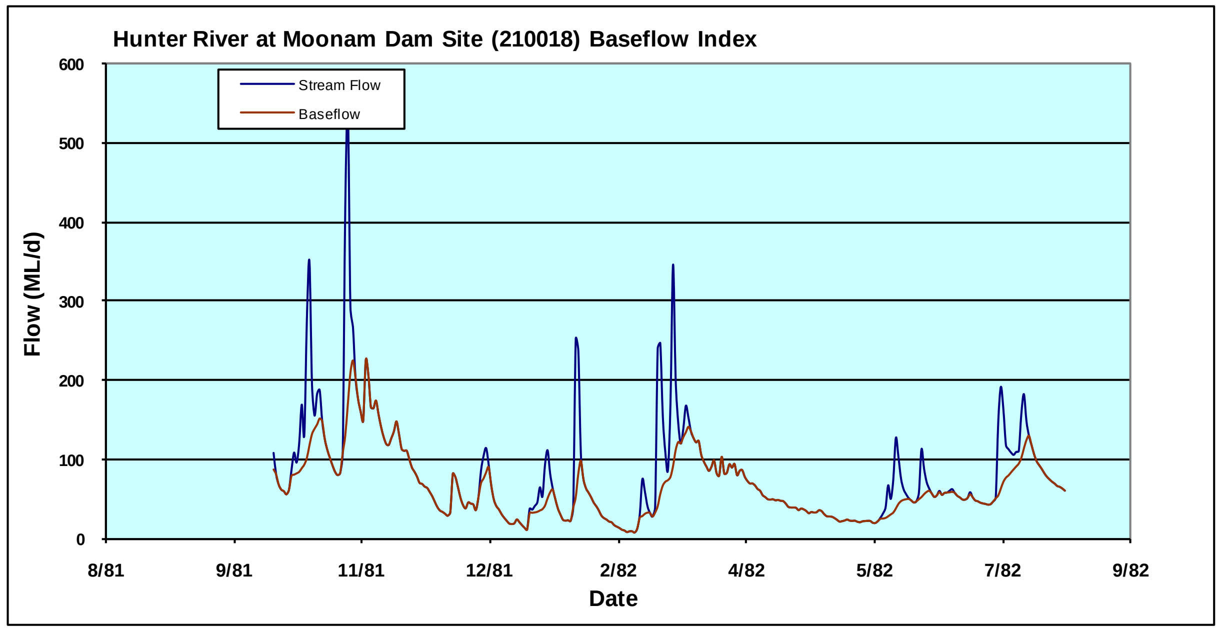
Hunter River at Moonam Dam Site (210018)

Hunter River at Moonam Dam Site (210018) Flow Statistics (ML/month) from 1940 to 2011													
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	2	1	4	5	6	7	8	9	10	11	12	16,608
Average	7,999	5,783	6,940	5,812	7,217	10,646	11,263	12,542	10,472	7,990	8,153	7,254	102,810
Max	45,514	39,241	72,618	29,835	45,961	41,169	44,919	62,087	52,735	26,942	40,405	52,169	279,887
5%ile	263	396	139	168	556	1,238	1,696	1,489	1,122	631	464	233	21,766
10%ile	619	736	289	413	810	1,640	2,107	2,103	2,141	1,397	1,313	921	30,445
20%ile	1,573	1,380	1,131	1,231	1,899	3,394	4,496	3,062	3,420	3,698	2,776	1,940	49,900
30%ile	2,144	2,078	2,152	1,747	2,407	4,166	5,124	4,903	5,218	4,372	3,930	3,072	65,045
40%ile	2,545	2,777	3,168	2,230	3,771	6,185	6,005	6,149	6,669	5,481	5,277	4,143	70,905
50%ile	3,102	3,399	3,942	3,136	4,519	6,999	7,992	7,875	7,820	6,312	6,648	5,228	89,642
60%ile	4,242	4,260	4,861	4,175	5,098	8,600	11,140	10,015	9,034	7,189	7,440	5,825	112,456
70%ile	5,534	6,185	5,592	6,587	6,432	11,446	13,727	12,759	11,348	9,854	9,075	7,061	129,679
80%ile	9,878	7,546	7,500	9,018	8,852	17,364	17,268	16,277	16,179	13,308	11,704	10,424	150,968
90%ile	26,140	11,529	12,539	14,655	17,394	27,336	22,766	24,414	19,848	15,977	16,018	13,029	178,381
95%ile	39,712	21,539	19,837	18,816	22,582	31,143	28,376	44,761	30,067	17,170	21,032	20,821	210,678

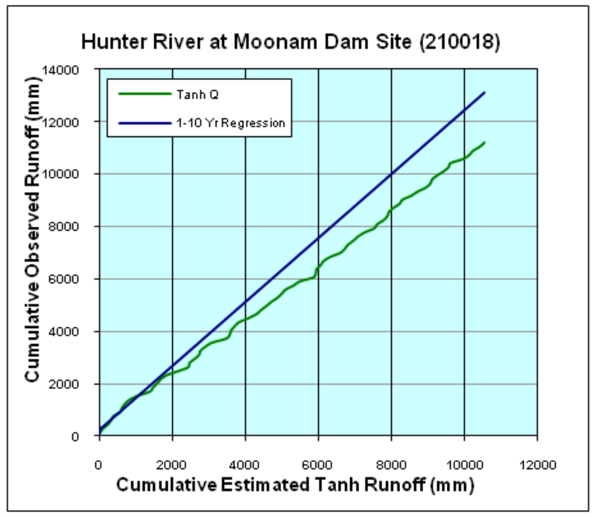
Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

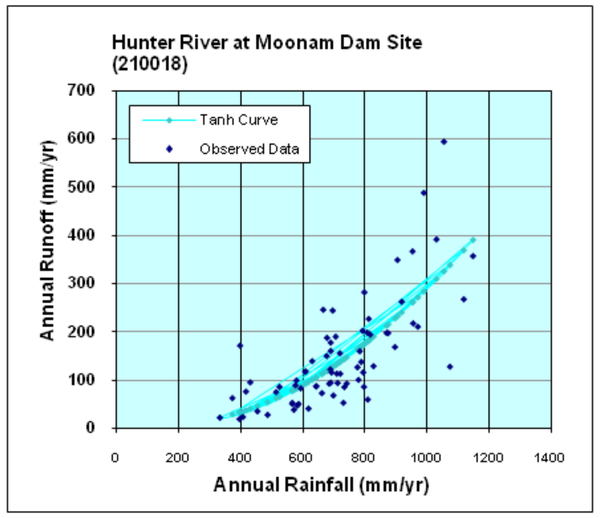


Catchment Information

Area:	764 km2
Baseflow Index:	0.7259
Mean Baseflow:	59 ML/day
Total volume of water less than modelled:	1461.8 GL
Average decrease in streamflow[1] per year:	24 GL
Average decrease in streamflow[1] per day:	65.7 ML

[1] **Wateruse modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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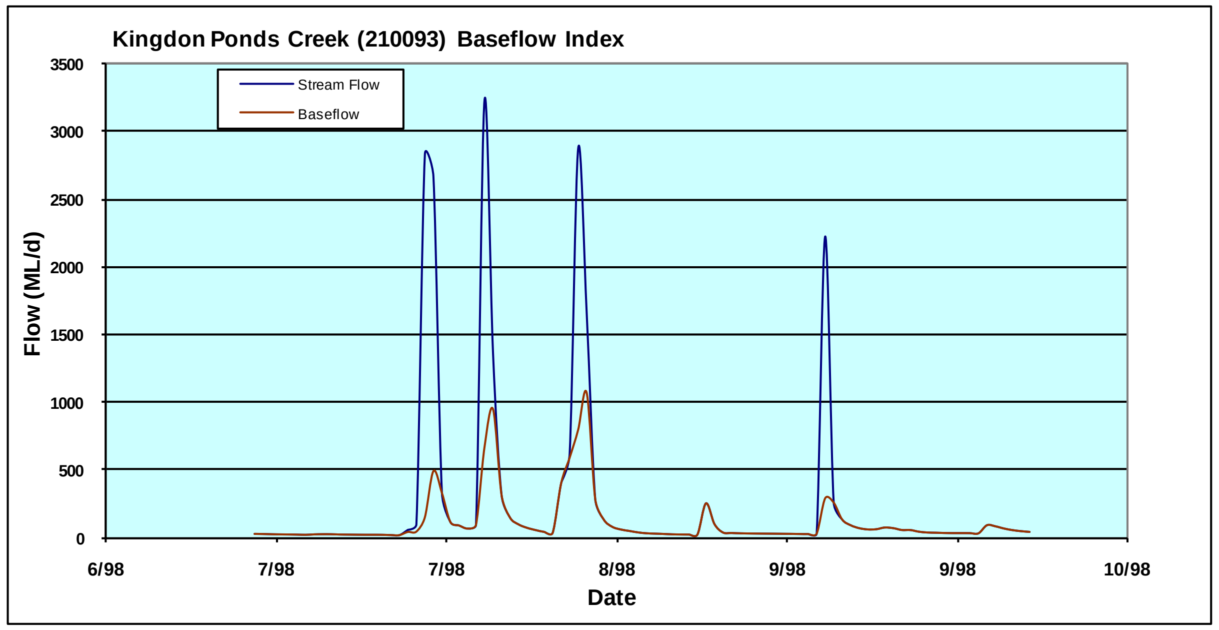
Kingdon Ponds Creek (210093)

Kingdon Ponds Creek (210093) Flow Statistics (ML/month) from 1972 to 2011													
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	1,964	744	1,203	229	768	831	863	557	432	389	856	385	8,862
Max	32,648	12,943	24,982	1,213	10,887	11,401	11,730	7,174	3,881	1,541	15,049	4,775	45,443
5%ile	0	0	0	0	0	1	2	2	1	0	0	0	35
10%ile	0	1	3	0	1	19	18	16	11	6	1	3	569
20%ile	16	21	23	10	37	42	45	47	45	26	36	43	1,212
30%ile	56	72	76	53	80	98	76	80	63	110	111	100	2,020
40%ile	109	111	111	100	123	123	118	117	130	177	167	132	2,130
50%ile	130	157	135	120	159	210	151	235	245	239	190	163	3,501
60%ile	182	180	161	155	264	252	318	325	351	269	269	243	4,941
70%ile	296	267	235	267	290	373	492	587	397	352	474	365	6,695
80%ile	340	569	418	353	416	989	883	631	481	428	711	523	13,932
90%ile	1,890	1,094	1,120	510	934	1,915	1,797	767	919	1,301	1,115	642	29,333
95%ile	10,579	2,453	4,315	876	3,699	3,120	3,587	1,886	1,549	1,404	2,184	699	35,116

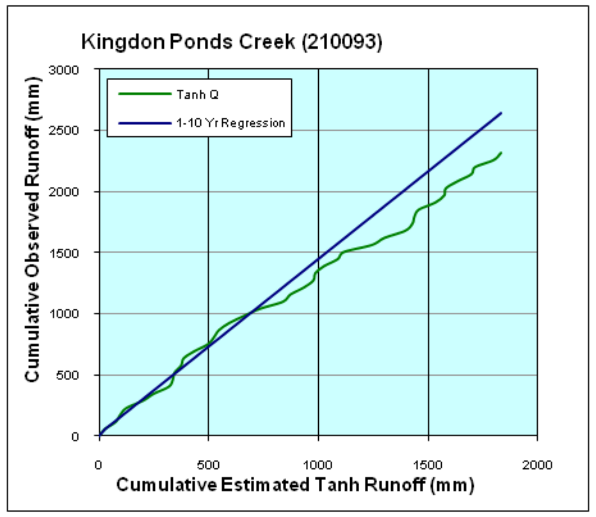
Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

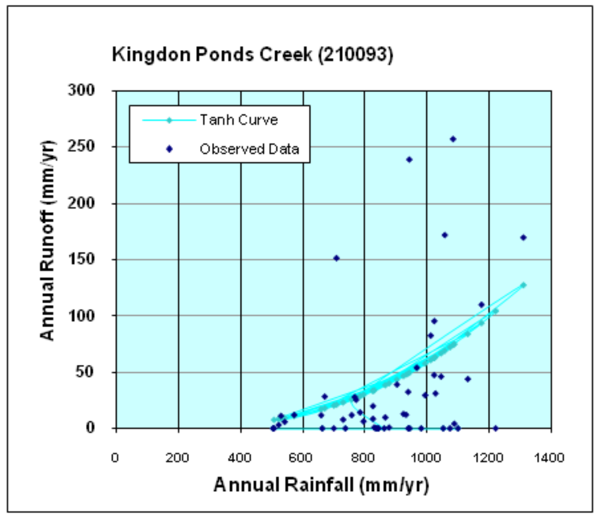


Catchment Information

Area:	177 km2
Baseflow Index:	0.5365
Mean Baseflow:	7.1 ML/day
Total volume of water less than modelled:	57.6 GL
Average decrease in streamflow[1] per year:	2 GL
Average decrease in streamflow[1] per day:	5.4 ML

[1] **Wateruse ("lost") modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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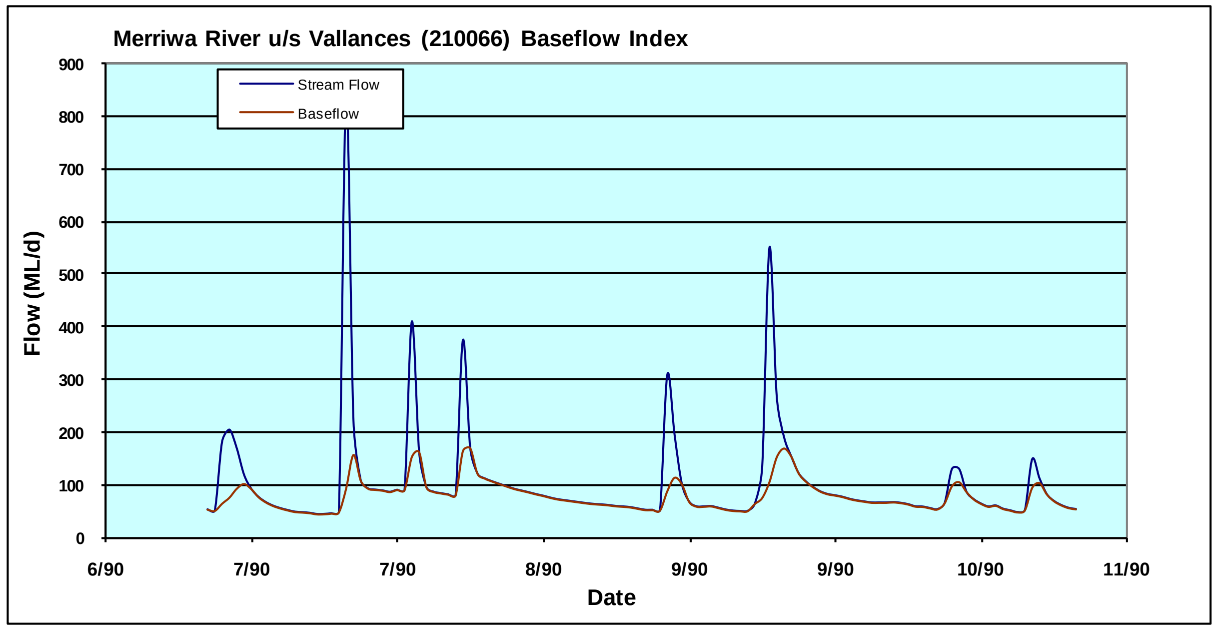
Merriwa River u/s Vallances (210066)

Merriwa River u/s Vallances (210066) Flow Statistics (ML/month) from 1963 to 2011													
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	1	1	0	2	3	7	8	9	7	1	1	168
Average	2,727	1,198	1,872	2,561	1,550	2,338	1,084	1,059	1,032	863	2,238	2,067	20,978
Max	32,464	9,362	34,586	52,146	16,076	27,856	4,023	4,580	6,982	7,784	43,247	29,945	67,679
5%ile	1	2	1	2	8	19	88	48	24	10	5	3	1,032
10%ile	2	2	4	4	17	57	109	83	34	12	10	6	1,391
20%ile	20	14	32	22	39	116	152	135	115	109	75	22	4,069
30%ile	57	59	85	68	127	191	192	242	146	209	101	47	5,247
40%ile	155	236	207	177	179	249	268	504	242	320	180	98	7,464
50%ile	229	444	349	237	276	368	427	619	445	506	216	205	13,571
60%ile	310	480	405	328	419	714	588	847	656	567	436	280	20,947
70%ile	530	1,129	672	823	1,005	1,066	1,103	1,216	864	745	538	483	27,475
80%ile	1,946	1,499	902	1,185	1,690	1,770	2,354	1,930	1,334	876	756	830	43,294
90%ile	8,454	2,343	2,069	2,290	5,041	5,390	3,362	2,639	2,937	1,873	1,418	2,671	51,158
95%ile	15,812	6,229	8,141	10,977	6,994	9,996	3,882	3,515	4,525	2,556	7,906	9,134	62,980

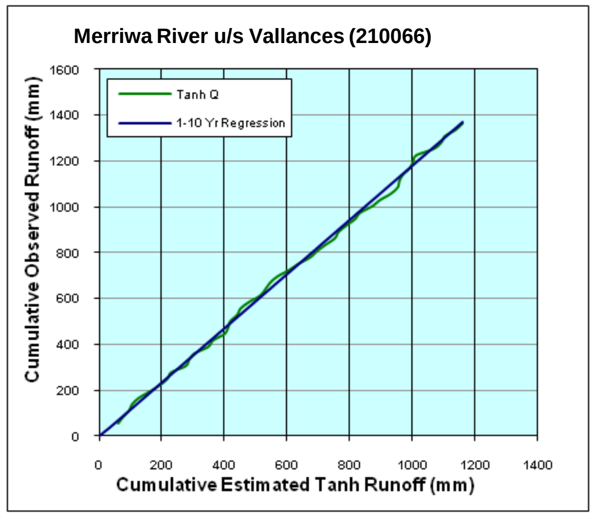
Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

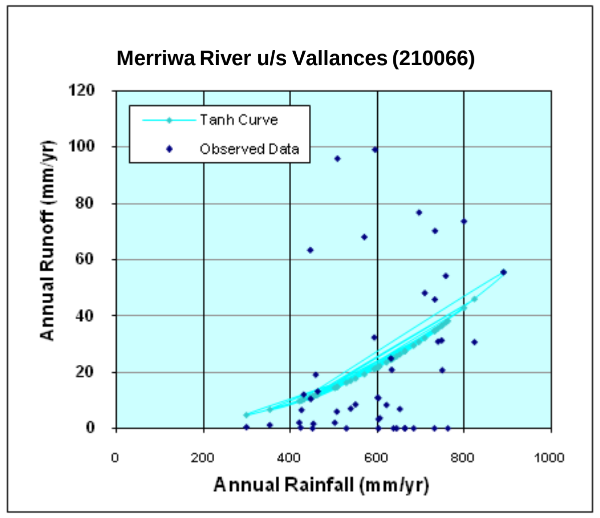


Catchment Information

Area:	684 km^2
Baseflow Index:	0.5097
Mean Baseflow:	91.9 ML/day
Total volume of water less than modelled:	3.1 GL
Average decrease in streamflow[1] per year:	0.1 GL
Average decrease in streamflow[1] per day:	0.2 ML

[1] **Wateruse ("lost") modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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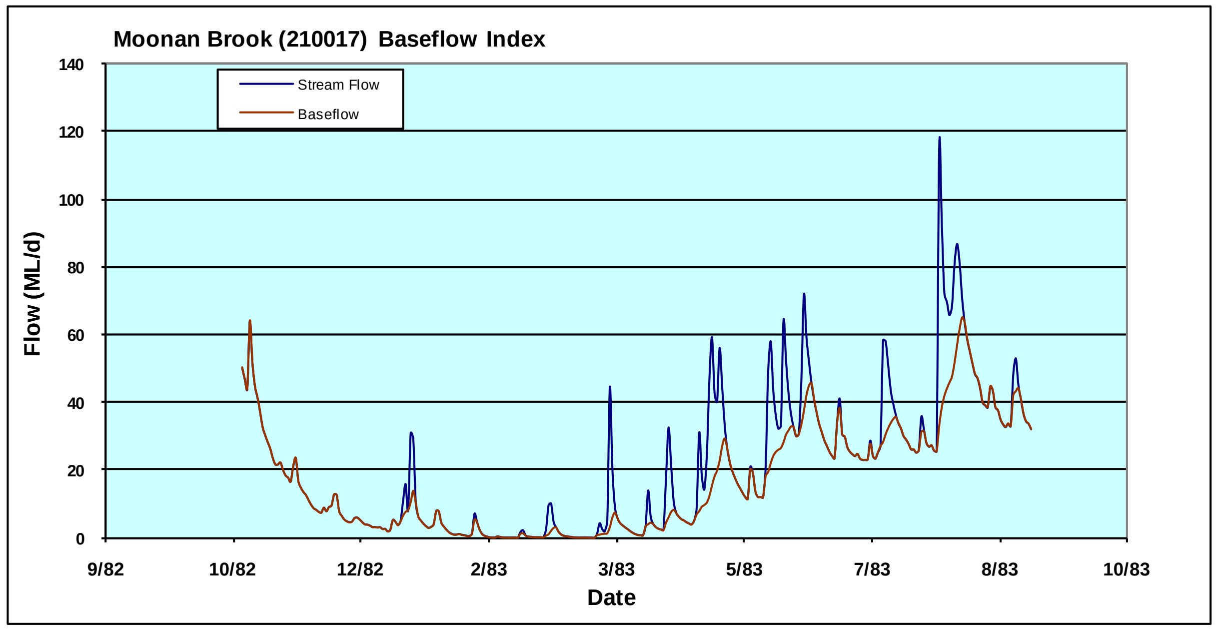
Moonan Brook (210017)

Moonan Brook (210017) Flow Statistics (ML/month) from 1940 to 2011	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	2	3	4	5	6	7	8	9	10	11	12	5,331
Average	1,587	1,412	1,595	1,726	2,296	3,373	3,410	3,443	2,888	2,156	1,809	1,735	27,406
Max	8,256	11,717	8,209	8,963	14,215	13,332	12,332	21,985	9,408	9,516	7,468	5,974	59,610
5%ile	111	122	78	78	248	338	542	419	311	213	53	131	7,205
10%ile	123	271	116	178	333	796	876	769	564	389	259	206	12,530
20%ile	314	446	287	260	489	1,067	1,612	909	998	908	523	410	13,878
30%ile	456	547	547	384	852	1,378	1,763	1,496	1,266	1,313	987	645	16,692
40%ile	538	594	802	654	1,065	1,914	2,303	1,819	1,719	1,638	1,314	1,118	20,926
50%ile	845	672	995	847	1,323	2,551	2,602	2,292	2,046	1,812	1,470	1,297	24,352
60%ile	1,212	953	1,337	997	1,739	3,496	3,136	3,096	2,534	2,144	2,002	1,750	29,428
70%ile	1,709	1,330	1,522	1,989	2,421	4,253	4,049	3,895	3,927	2,405	2,173	2,085	33,837
80%ile	2,337	2,118	2,427	2,402	2,837	5,043	5,753	4,757	5,071	2,692	2,404	2,401	41,513
90%ile	4,677	2,951	4,113	4,733	5,491	7,082	6,609	6,984	5,869	4,022	3,532	4,047	49,433
95%ile	4,930	3,337	4,727	5,661	7,420	8,913	7,354	9,132	7,251	4,625	5,062	5,144	54,096

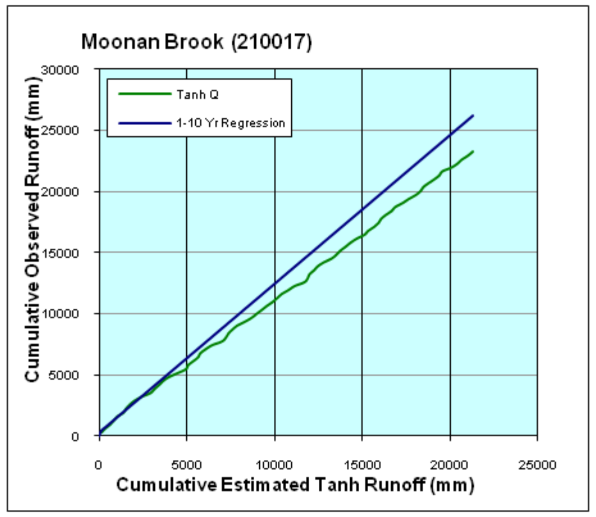
Table above:: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

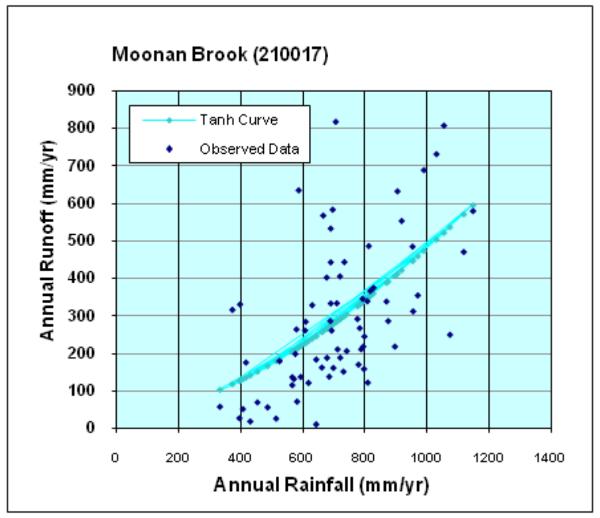


Catchment Information

Area:	103 km2
Baseflow Index:	0.7489
Mean Baseflow:	17.9 ML/day
Total volume of water	less than modelled: 296.3 GL
Average decrease in streamflow[1] per year:	4.9 GL
Average decrease in streamflow[1] per day:	13.3 ML

[1] **Wateruse ("lost") modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

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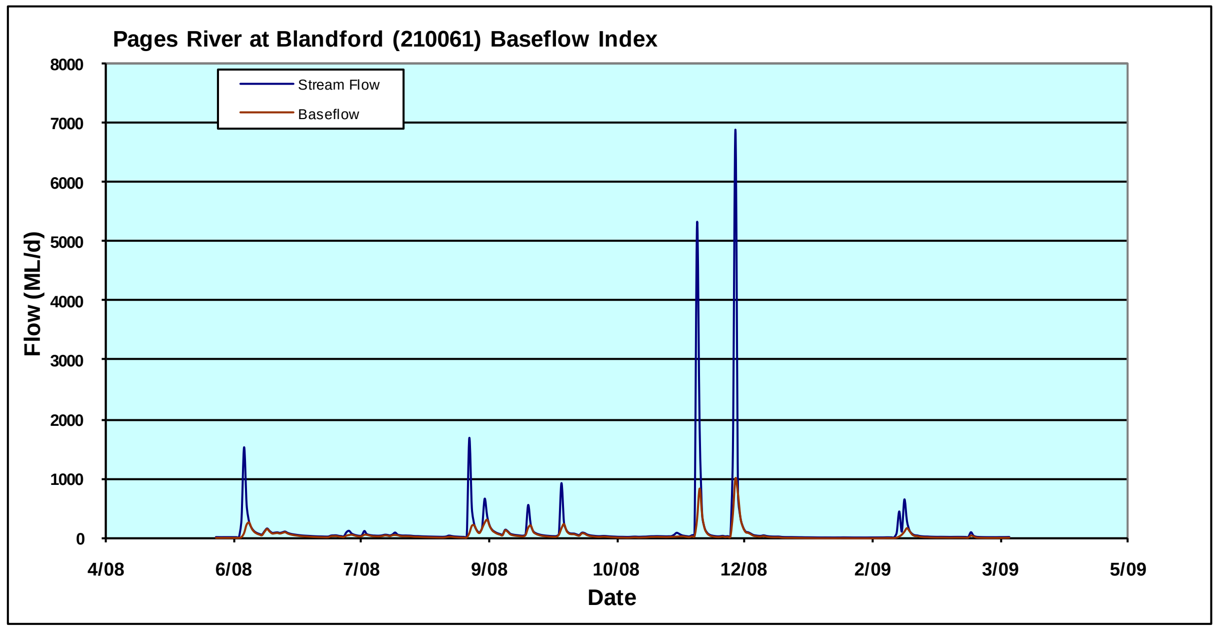
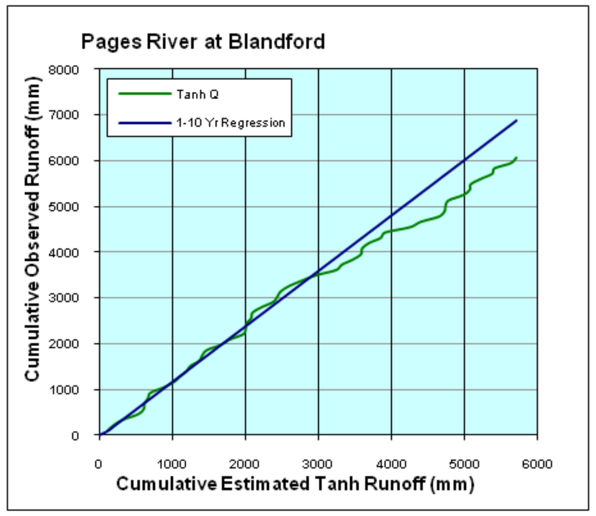
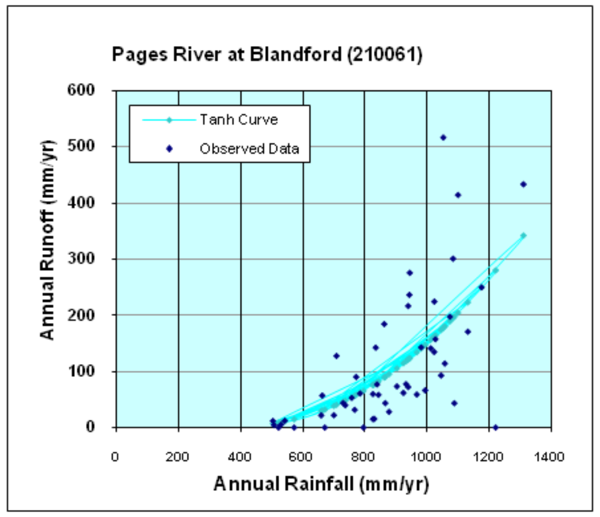
Pages River at Blandford (210061)

Pages River at Blandford (210061) Flow Statistics (ML/month) from 1960 to 2011	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	1	2	3	4	5	6	7	0	9	10	11	10	1,300
Average	7,214	2,569	1,833	1,232	2,558	2,490	4,062	4,356	2,652	3,408	3,414	2,635	36,865
Max	62,329	33,122	23,871	17,520	25,803	25,887	63,699	36,206	12,859	34,023	52,236	39,729	139,305
5%ile	62	49	81	47	76	45	50	91	98	100	69	70	3,568
10%ile	123	96	105	97	103	68	137	166	171	185	169	175	6,573
20%ile	196	154	148	118	120	198	331	301	390	379	223	320	11,999
30%ile	231	167	180	159	194	313	668	730	842	1,044	528	384	15,968
40%ile	306	248	459	225	216	431	946	1,459	1,136	1,255	914	512	17,809
50%ile	540	430	634	337	326	555	1,500	2,710	1,528	1,430	1,316	617	21,802
60%ile	813	1,281	856	415	463	845	2,091	4,058	1,994	1,867	1,515	996	30,622
70%ile	1,869	2,460	1,470	740	828	1,169	2,879	4,665	3,099	2,695	2,046	1,463	41,887
80%ile	6,876	3,270	2,438	1,502	2,825	3,359	4,137	5,456	3,806	4,977	3,230	2,344	58,002
90%ile	27,142	4,004	3,484	2,678	8,939	6,018	7,185	8,150	6,594	8,235	7,006	4,877	83,250
95%ile	37,549	10,172	4,514	3,869	12,391	12,048	11,700	14,646	9,833	9,860	11,153	10,400	125,135

Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.







Catchment Information

Area:	302 km^2
Baseflow Index:	0.5214
Mean Baseflow:	101.5 ML/day
Total volume of water less than modelled:	243.7 GL
Average decrease in streamflow[1] per year:	5.9 GL
Average decrease in streamflow[1] per day:	16.3 ML

[1] **Wateruse ("lost") modelled from Tanh curve**

Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

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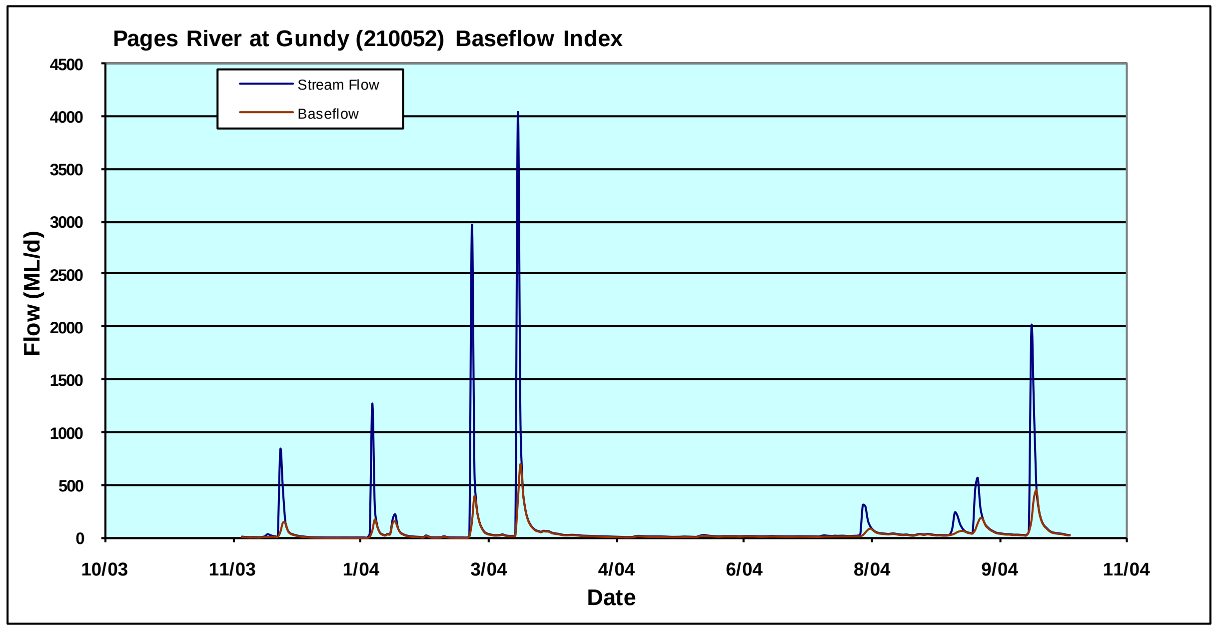
Pages River at Gundy (210052)

Pages River at Gundy (210052) Flow Statistics (ML/month) from 1958 to 2011	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	2	2	1	1	0	7	8	9	10	11	2	459
Average	10,367	7,141	3,640	3,139	4,817	4,745	8,250	7,670	5,811	4,307	3,531	3,408	61,388
Max	119,607	108,728	62,040	33,425	53,668	35,631	81,759	53,316	35,658	19,831	27,162	21,831	256,087
5%ile	4	7	13	4	5	52	130	161	130	41	55	35	4,979
10%ile	45	50	25	6	6	239	367	259	190	163	117	145	8,706
20%ile	202	226	154	97	159	328	686	756	472	332	447	345	17,253
30%ile	319	450	327	233	286	746	1,319	1,364	936	1,490	1,292	709	25,673
40%ile	602	797	630	453	359	988	2,177	2,160	2,357	1,631	2,027	970	29,320
50%ile	1,078	1,066	887	621	701	1,415	2,977	4,143	3,608	2,399	2,430	1,645	37,217
60%ile	1,997	2,195	1,221	812	1,044	2,135	3,624	5,972	4,527	3,376	2,855	2,089	49,126
70%ile	2,583	3,625	2,532	1,036	2,097	3,368	7,023	7,663	5,815	5,582	4,235	2,545	65,521
80%ile	7,370	4,498	4,702	3,833	3,709	7,184	12,356	10,279	9,757	7,827	4,618	4,305	97,725
90%ile	39,145	14,456	6,863	8,599	12,377	12,305	19,155	16,764	12,505	9,581	6,212	8,481	146,098
95%ile	42,389	38,112	11,253	10,759	31,736	20,559	31,263	28,910	18,307	13,762	7,457	16,349	193,754

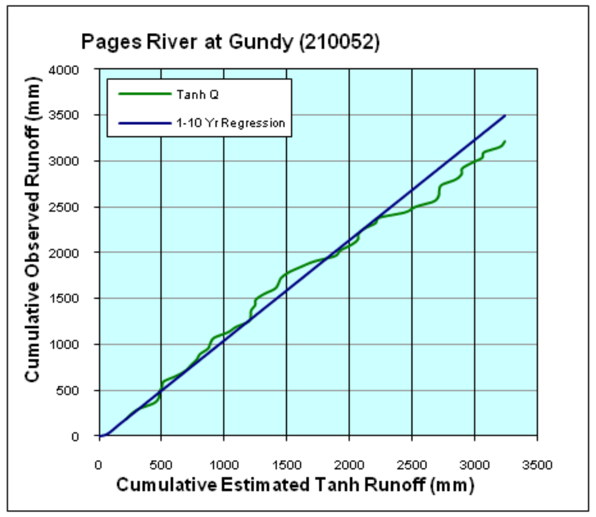
Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

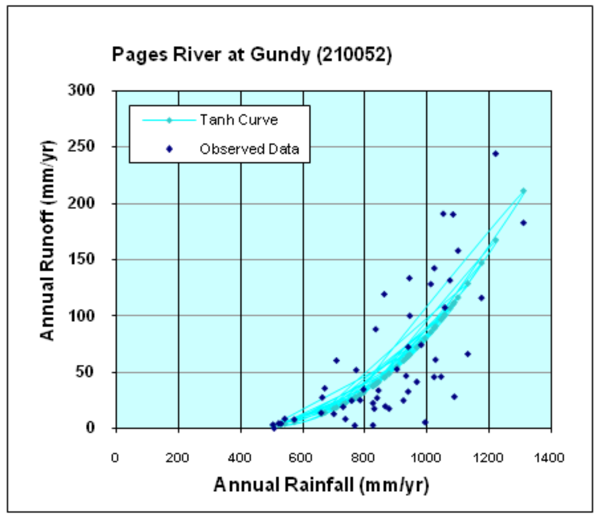


Catchment Information

Area:	1050 km^2
Baseflow Index:	0.5453
Mean Baseflow:	73.1 ML/day
Total volume of water less than modelled:	302.5 GL
Average decrease in streamflow[1] per year:	7 GL
Average decrease in streamflow[1] per day:	19.3 ML

[1] **Wateruse ("lost") modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
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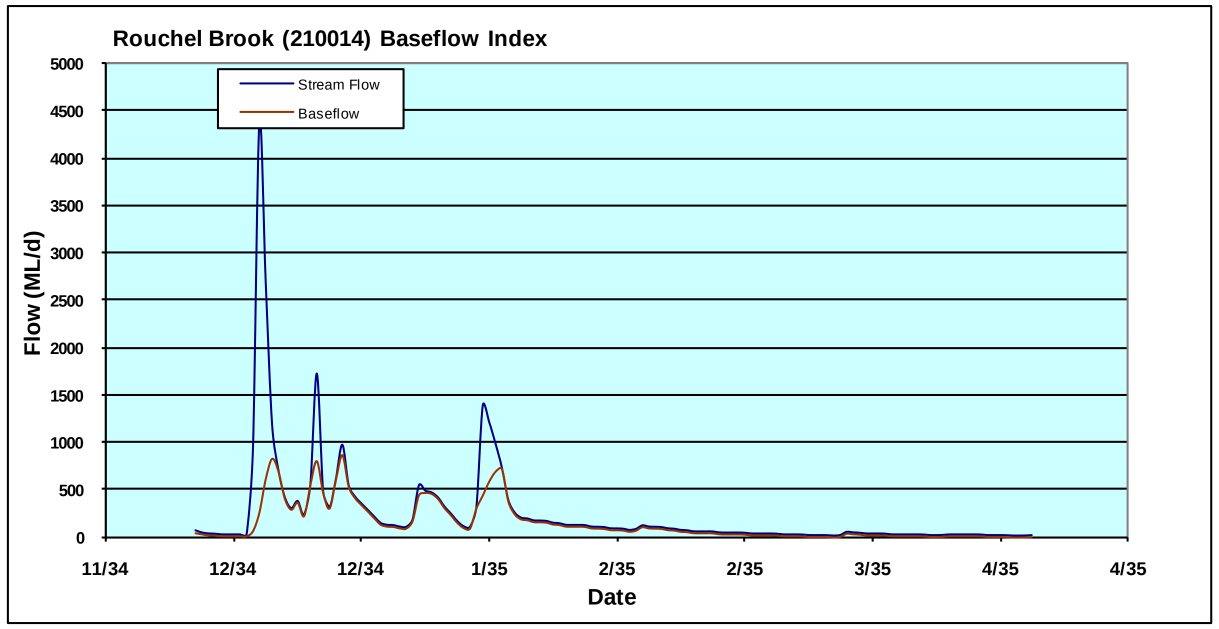
Rouchel Brook (210014)

Rouchel Brook (210014) Flow Statistics (ML/month) from 1934 to 2011													
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Min	0	0	0	0	1	6	7	8	9	9	2	0	2,047
Average	4,104	2,730	4,984	3,926	4,261	6,835	5,245	5,486	4,710	3,780	3,137	2,525	52,055
Max	40,766	28,807	66,746	39,831	40,412	43,193	29,407	58,784	34,109	36,160	36,423	21,579	170,784
5%ile	1	1	1	2	22	150	217	203	47	18	7	9	4,341
10%ile	18	15	8	10	117	269	461	325	389	285	93	19	6,337
20%ile	59	135	240	76	272	748	778	566	594	639	378	82	11,984
30%ile	191	501	403	144	579	1,314	1,587	946	979	879	769	261	22,235
40%ile	269	594	835	512	678	2,252	2,280	1,331	1,740	1,623	1,252	682	29,733
50%ile	490	922	1,383	622	1,096	3,665	2,753	2,825	2,468	2,087	1,501	934	35,114
60%ile	830	1,323	2,433	1,292	2,031	5,203	3,814	3,614	2,937	2,384	1,931	1,729	51,295
70%ile	1,864	1,932	3,145	2,942	2,763	6,603	5,527	5,541	3,560	2,811	2,745	2,020	63,972
80%ile	7,262	2,908	4,566	6,984	5,321	9,498	8,695	7,188	5,803	3,798	3,759	3,705	88,950
90%ile	11,628	7,386	13,401	11,006	11,568	16,658	12,896	10,491	11,239	7,157	6,990	6,491	110,609
95%ile	19,971	10,408	20,121	14,642	21,212	26,034	16,067	17,546	18,981	9,585	10,159	8,254	139,622

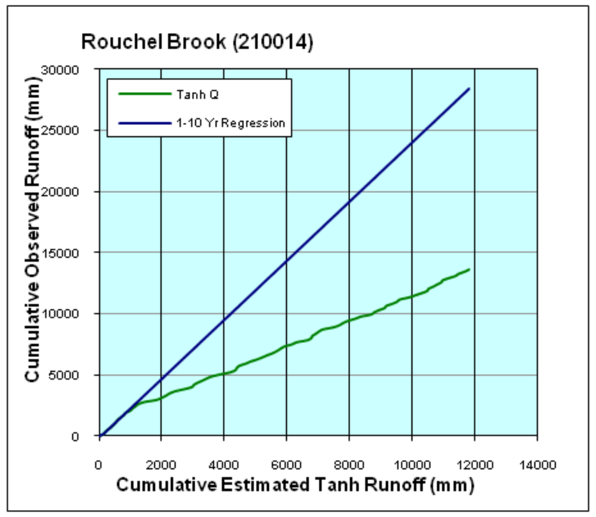
Table above: Monthly and annual streamflow statistics for various percentiles. Data from http://waterinfo.nsw.gov.au/water.shtml?ppbm=SURFACE_WATER&rs&3&rskm_url. Gauge name and number shown above.

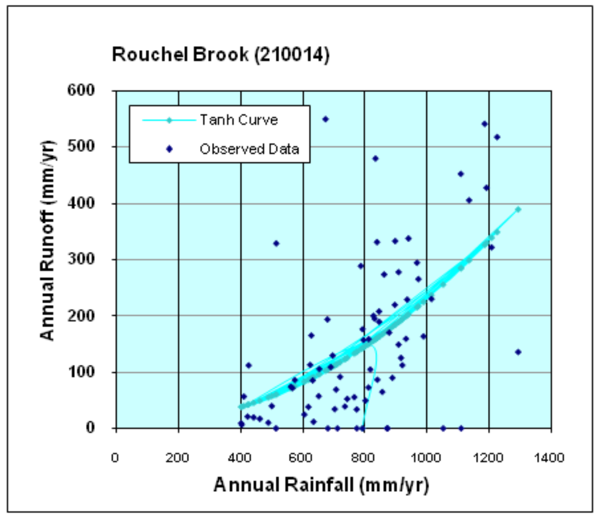


Catchment Information

Area:	315 km^2
Baseflow Index:	0.5883
Mean Baseflow:	116.4 ML/day
Total volume of water less than modelled:	4667 GL
Average decrease in streamflow[1] per year:	69.8 GL
Average decrease in streamflow[1] per day:	191.3 ML

[1] **Wateruse ("lost") modelled from Tanh curve**





Top left: Detail of a baseflow curve based on the baseflow index

Lower left: Tanh double mass curve (see Appendix for details)

Lower right: Tanh curve data fit

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Groundwater Analysis

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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E: info@frogtech.com.au
ABN: 29 129 411 981

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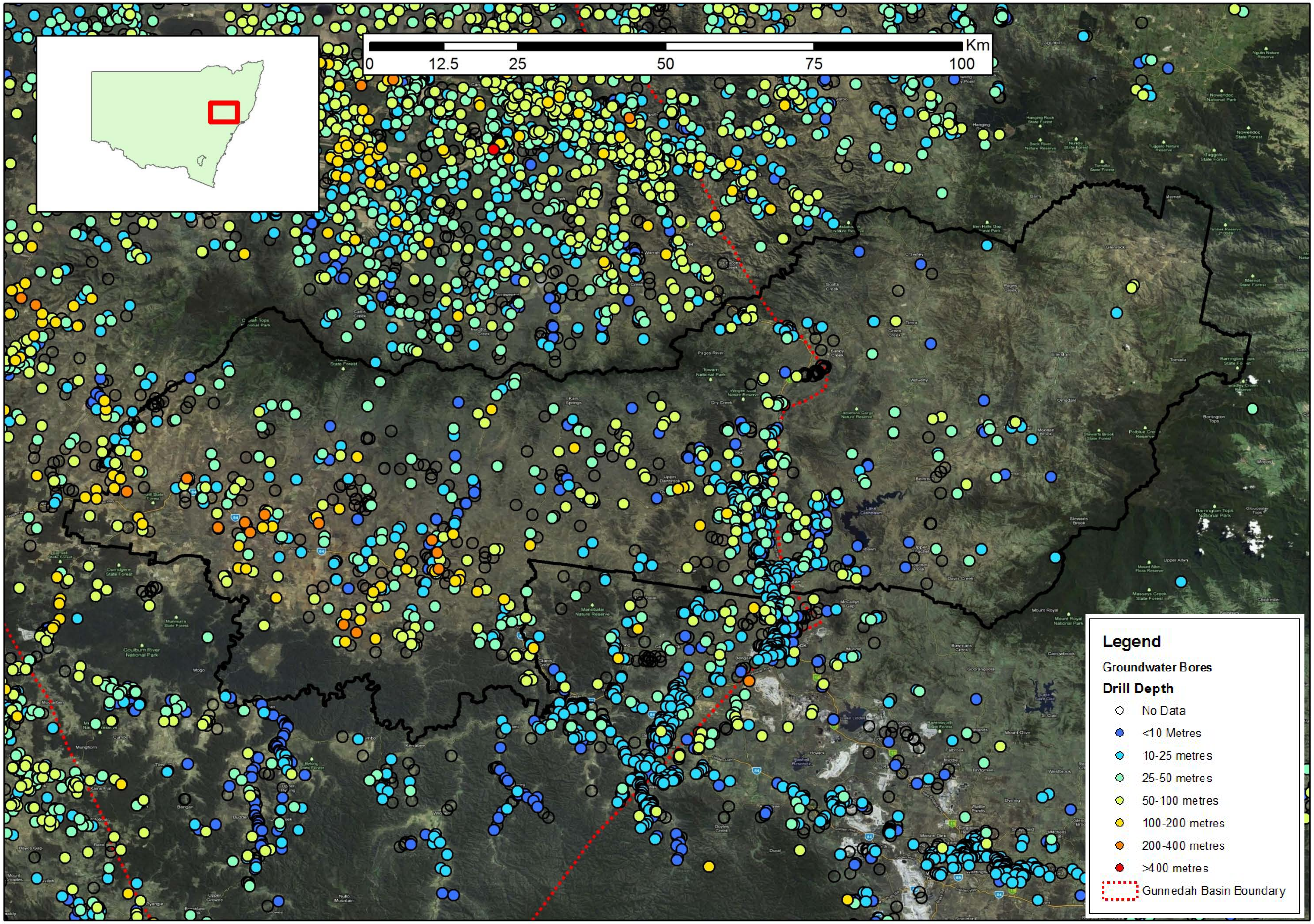
Location and depth of groundwater bores



(Image from Google Maps)

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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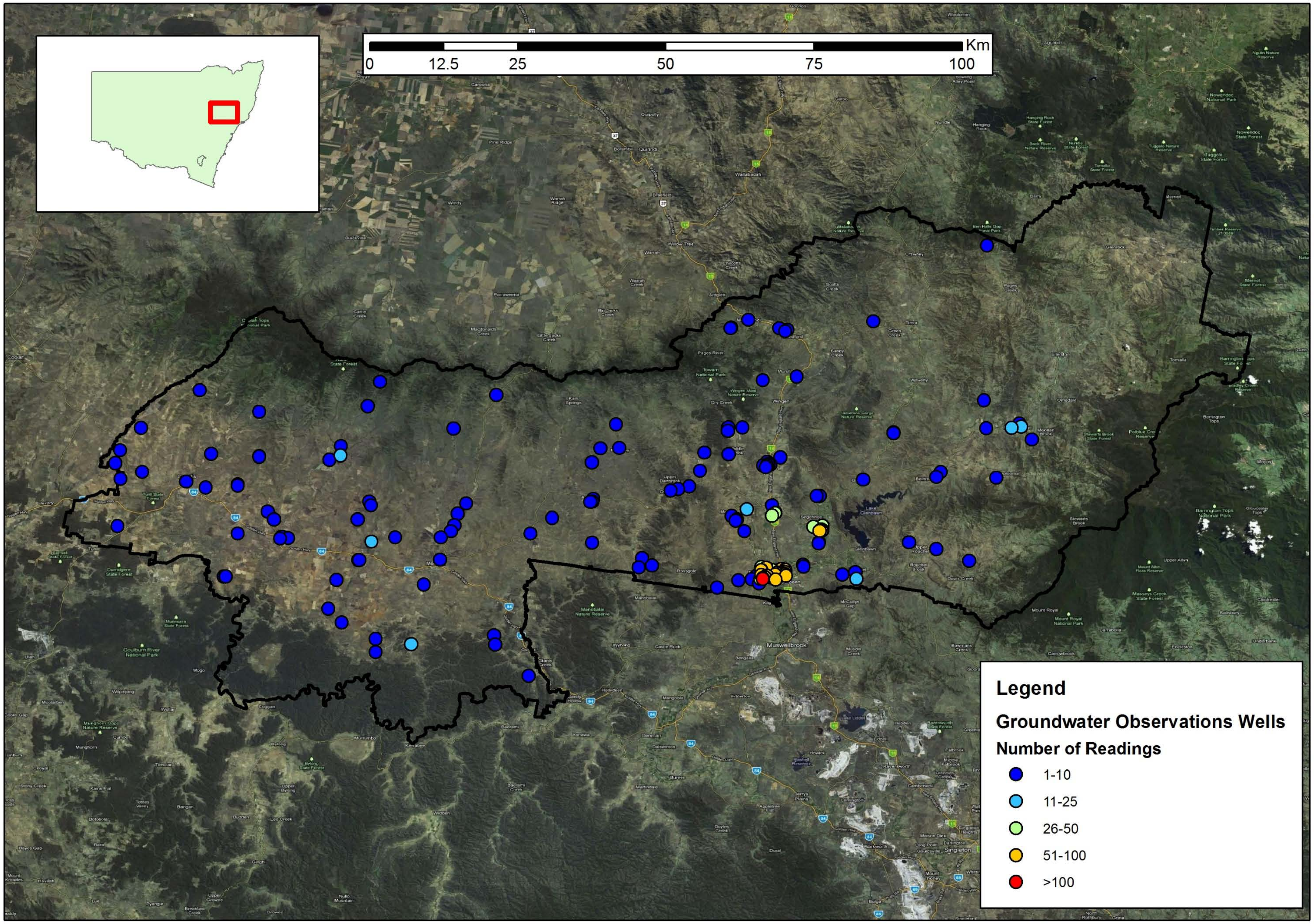
Location of groundwater monitoring bores



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Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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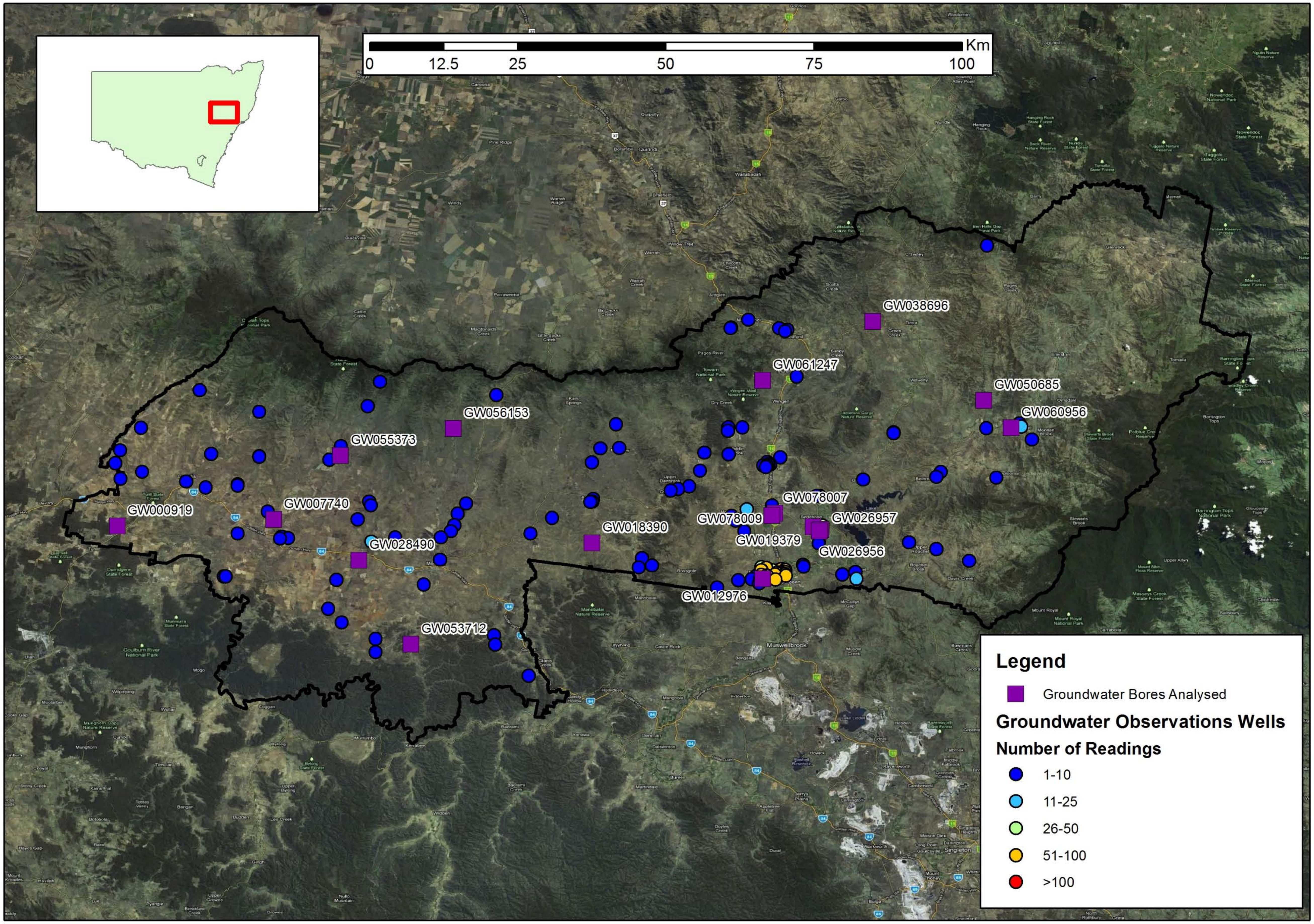
Groundwater monitoring bores analysed



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FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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There are about 1300 groundwater bores (**Table 2**) located in the Upper Hunter LGA with an average depth of 33.9 metres and with a maximum depth of 302 metres (NSW Groundwater Database).

Of these ~1300 groundwater bores (see **page 41**), 182 groundwater bores (**page 38**) are listed in the NSW Groundwater Borehole database as having groundwater monitoring information. The average number of readings per well is ~17 while the median number of readings is 5. Typically groundwater monitoring spans 20-30 years.

While some groundwater bores have in excess of 100 readings, most of these bores have not been actively monitored since the mid 1990s (see GW012976, GW026956 and GW026957 **below**).

Pages 46-51 show a sampling of groundwater level monitoring across the region.

Because of the low number of readings across the region, only general statements can be made. A sampling of 18 wells (see **page 43** for locations) are shown **below**.

Observations

- While there is variability due to climate (see Climate Section), the general trend in all of the groundwater bores examined is down, indicating falling groundwater levels across the Upper Hunter due to water use.
- Where sufficient data exists, groundwater levels generally follow climatic trends (see GW012976, GW026956 and GW026957). Therefore if the volume of groundwater recharge decreases due to climate or landuse change, then groundwater levels will also fall.
- Rivers in the Upper Hunter are highly connected to the groundwater system (see Surface Water Section), therefore any decrease in groundwater levels will also affect the volume of water available in rivers and streams in the region. Potential changes include a decrease in river baseflow (and the commensurate impact on ecosystems during periods of low flow) and an increase loss of water from rivers into the groundwater system.

Recommendations

In order to assess the impacts of CSG exploration/production in the Upper Hunter region, a network of groundwater monitoring bores needs to be established across the region prior to commencement of CSG production.

- Groundwater monitoring bores should consist of nested piezometers at a range of depth from the coal seams to the surface.
- Rather than relying on sporadic measurement, these groundwater monitoring bores should be fitted with telemetered data-loggers.
- In order to assess longterm trends due to climate and consumptive use, groundwater information should be collected for at least 10 years.
- Groundwater bores should be monitored for groundwater level and salinity.
- In addition, the bores should be sampled at least quarterly for the full range of major and minor chemistry, as well as for the presence of BTEX chemicals and other volatile compounds.

	Upper Hunter LGA	Gunnedah Basin Portion of Upper Junter LGA
<10 metres	184	140
10-25 metres	328	283
25-50 metres	172	138
50-100 metres	112	96
100-200 metres	38	38
200-400 metres	12	12
>400 metres	0	0
Total	**846**	**707**

Table 2: Depth (where known) of groundwater bores in the Upper Hunter LGA and within the Gunnedah Basin portion (most likely to be exploited for CSG) of the Upper Hunter LGA (source NSW Groundwater Borehole database). Note ~400 groundwater bores have no depth information.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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The major aquifers in the Upper Hunter LGA are:

Quaternary alluvium: Fluvial sediments associated with the present day river system

Tertiary Volcanics: Basalts and dolerites from the Liverpool Ranges

Digby Formation: Consisting of 3 sub-units, a lower lithic conglomerate unit, a middle lithic unit and an upper quartzose sandstone (Tardos 1993).

Unlike the Surat Basin, there is no aquitard separating the target coal seams in the Black Jack Formation from the aquifer system (see **pages 60-62**). Therefore it should be assumed that the Digby Formation, Tertiary Volcanic and alluvial aquifers are in hydrodynamic contact the Black Jack Formation.

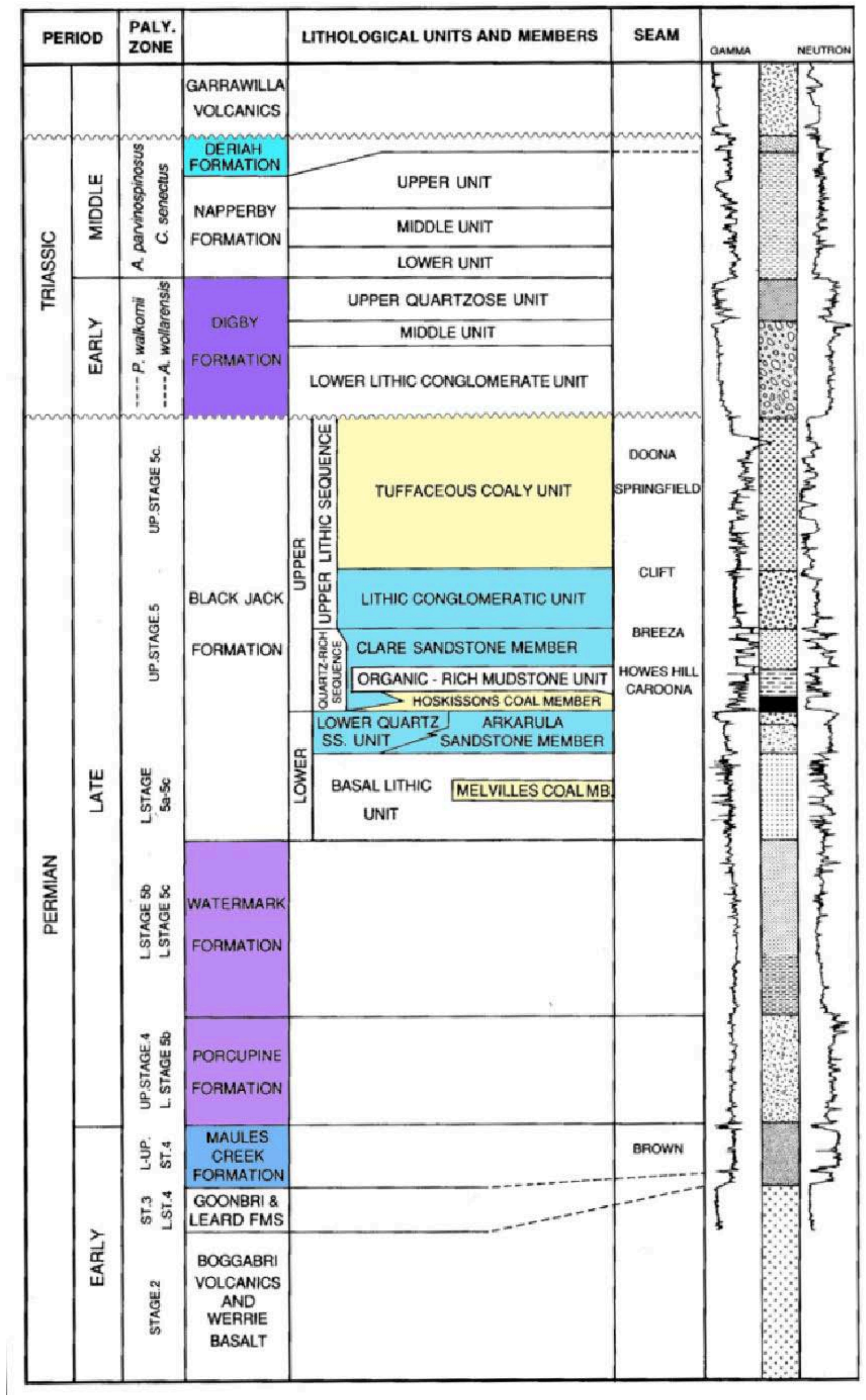
GW080102	0	0.6	Soil
GW080102	0.6	5.5	Clay, brown
GW080102	5.5	7	Basalt, decomposed
GW080102	7	14.9	Basalt, very weathered
GW080102	14.9	16.2	Shale, very soft
GW080102	16.2	22.6	Shale, firm
GW080102	22.6	38	Basalt, hard, blue
GW080102	38	39	Mudstone
GW080102	39	39.6	Sand
GW080102	39.6	48.5	Clay, pebbly, white
GW080102	48.5	50.1	Shale, grey
GW080102	50.1	67	Sandstone, soft, clayey
GW080102	67	87.8	Conglomerate, grey, hard, broken
GW080102	87.8	133.8	Mudstone, grey, firm
GW080102	133.8	148.4	Sandstone with shale layers
GW080102	148.4	151.2	Mudstone, grey
GW080102	151.2	171.3	Sandstone, white
GW080102	171.3	182	Mudstone
GW080102	182	212.9	Sandstone with shale layers
GW080102	212.9	216.1	Sandstone, muddy
GW080102	216.1	227.7	Shale, grey, sandy
GW080102	227.7	229.8	Sandstone, soft, coarse, free
GW080102	229.8	234	Sandstone shale, tight, cemented
GW080102	234	244.1	Sandstone, soft, coarse, free
GW080102	244.1	255.7	Sandstone, cream, sandstone, tight
GW080102	255.7	265.8	Sandstone, fine grained, free
GW080102	265.8	269.7	Sandstone with mudstone layers
GW080102	269.7	302	Sandstone, fine grained, tight

Alluvium

Tertiary Volcanics

Digby Formation

Above: Drillers log from the deepest groundwater bores in the Upper Hunter LGA. Aquifers are shown. There are no apparent aquitards, although the bore is not deep enough to penetrate the Black Jack Formation coal seams.



Above: Generalised Gunnedah Basin stratigraphic column, Potential CSG targets are shown in yellow, while potential aquifers are shown in shades of blue. Modified from Othman 2003

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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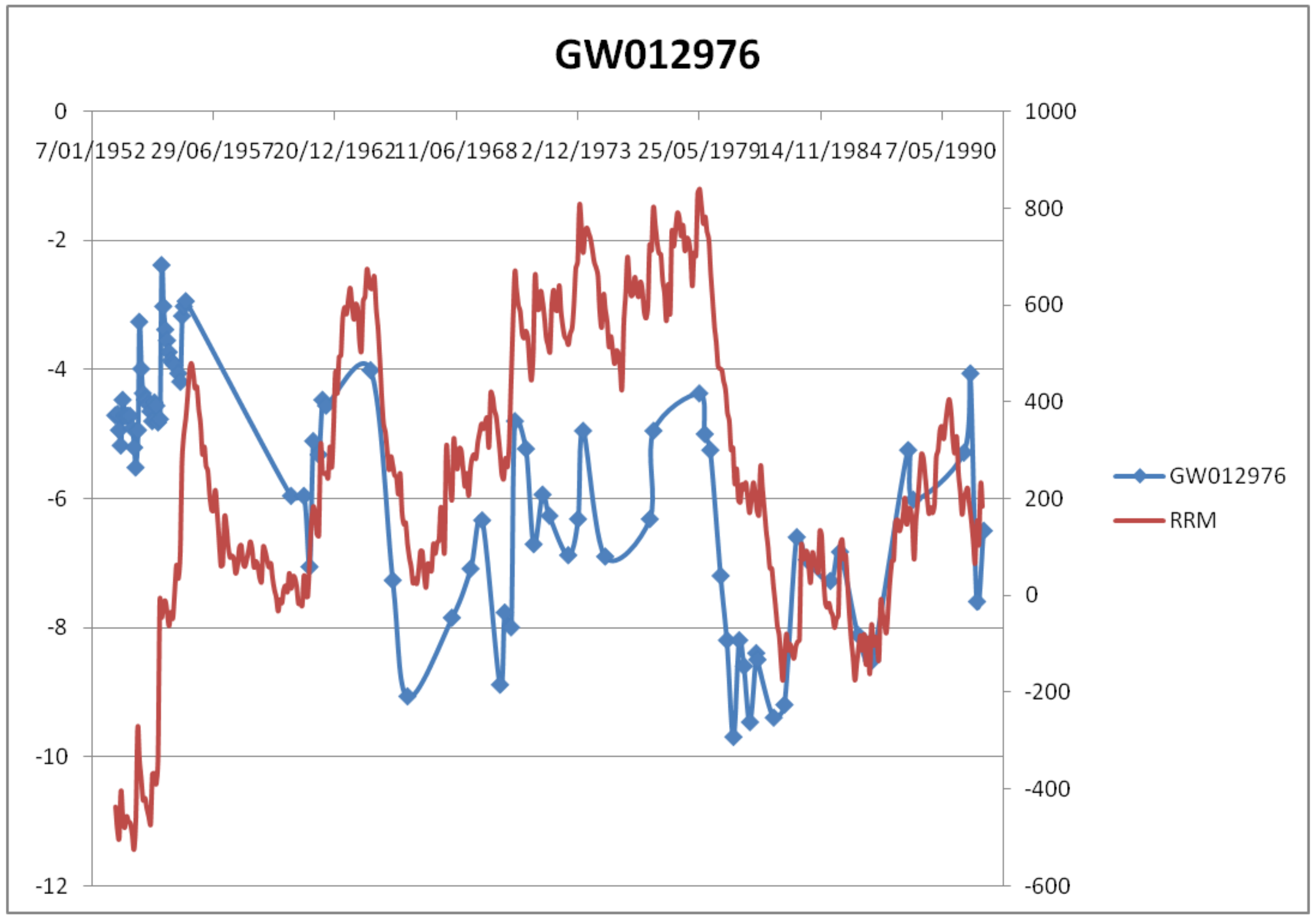
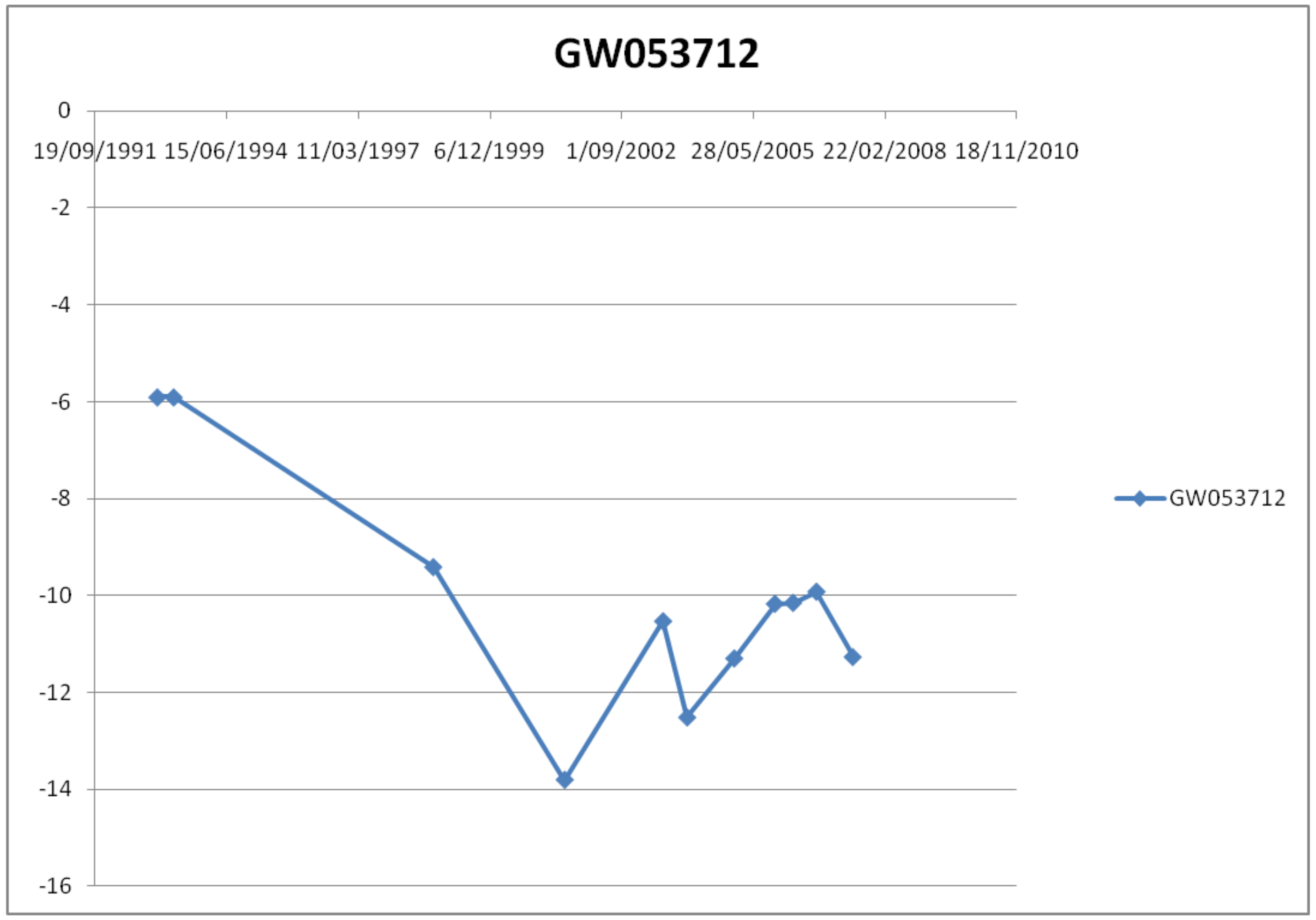


High Data: Groundwater standing water level is shown in the graph to the **left** in **blue**, with actual measurement shown by the markers.

In this case, the residual rainfall mass curve (see **page 9**) for the same time period (shown in **brown**) is included to demonstrate the strong correlation between climate (drought and flood) and standing water levels in the Upper Hunter.



Low Data: Groundwater standing water level is shown in the graph to the **left** in **blue**, with actual measurement shown by the markers.

In this case, there are only 11 measurements covering about 16 years. Some of the climate variation seen **above** is apparent, but since less data is available for analysis, the overall downwards trend in water level is more obvious.

Pages 47-51 represent a range of groundwater monitoring bores across the Upper Hunter.

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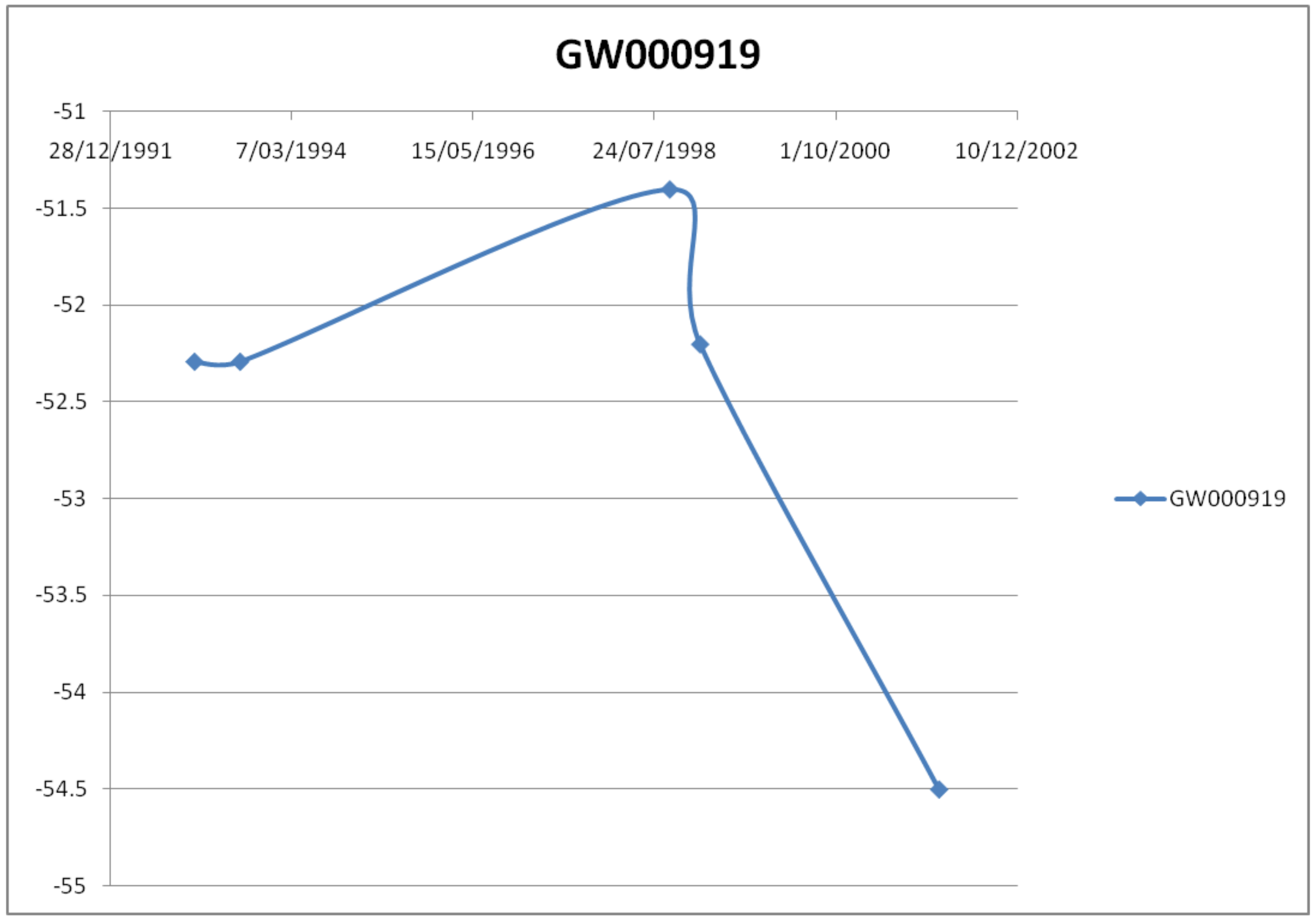
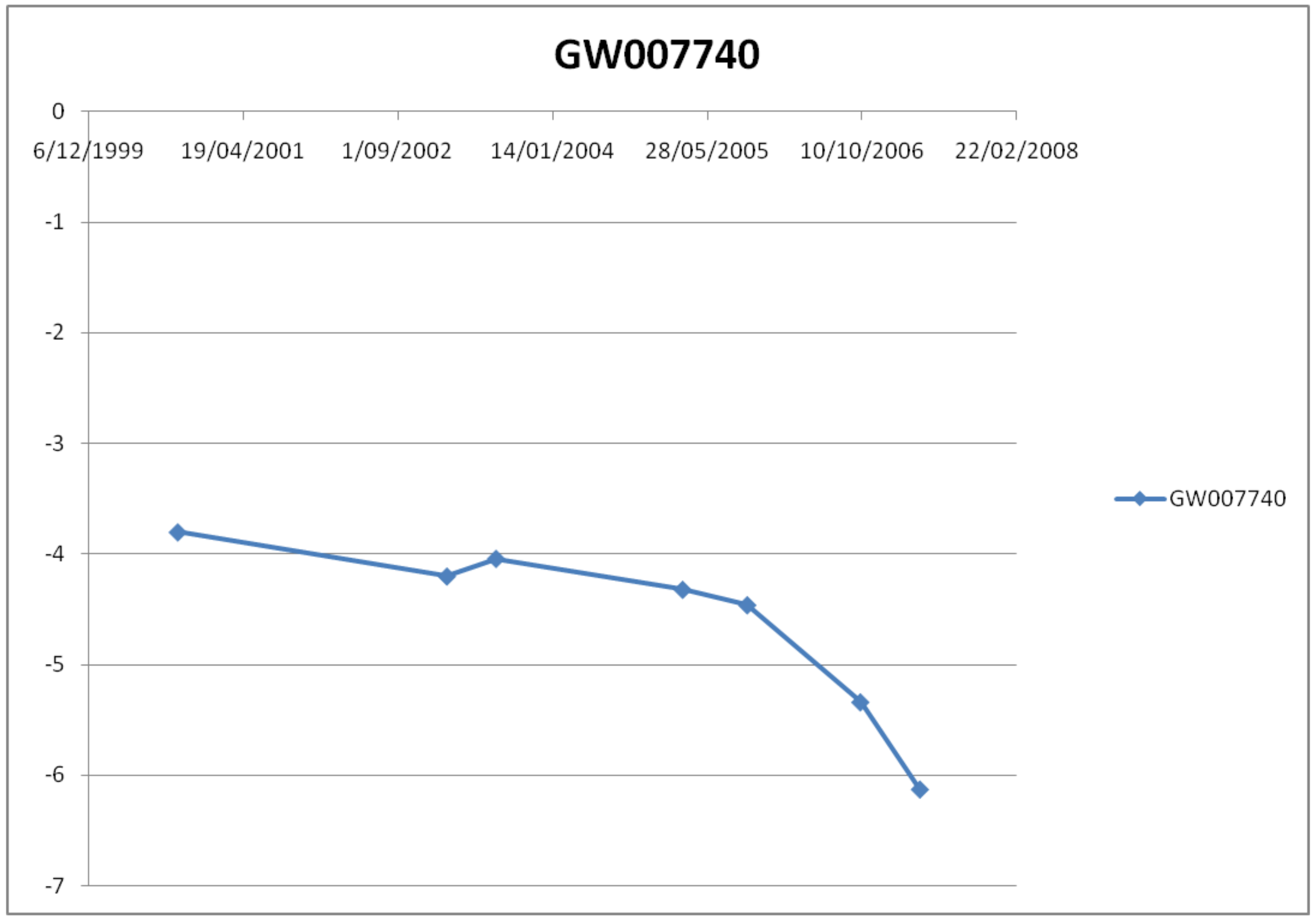
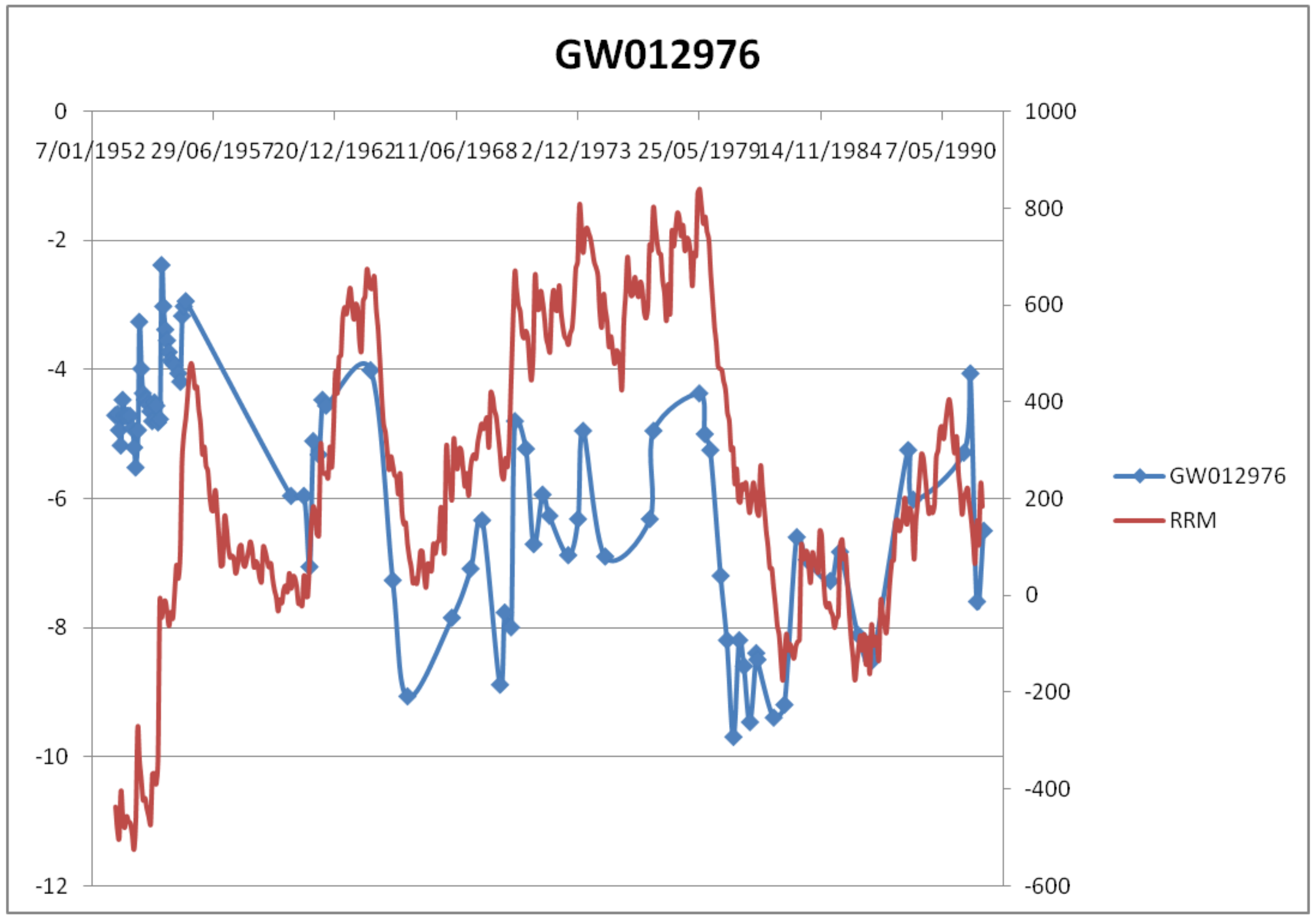
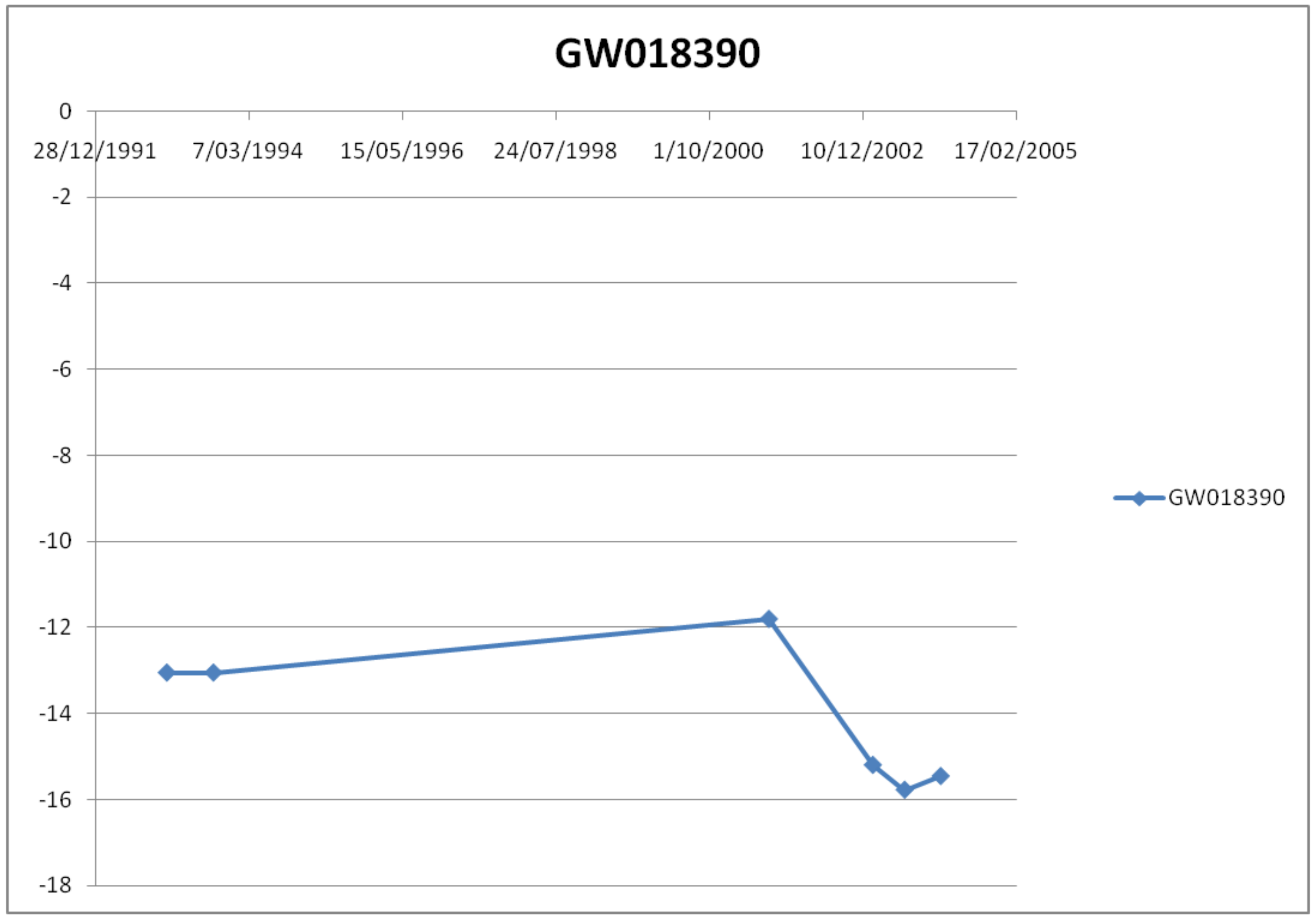
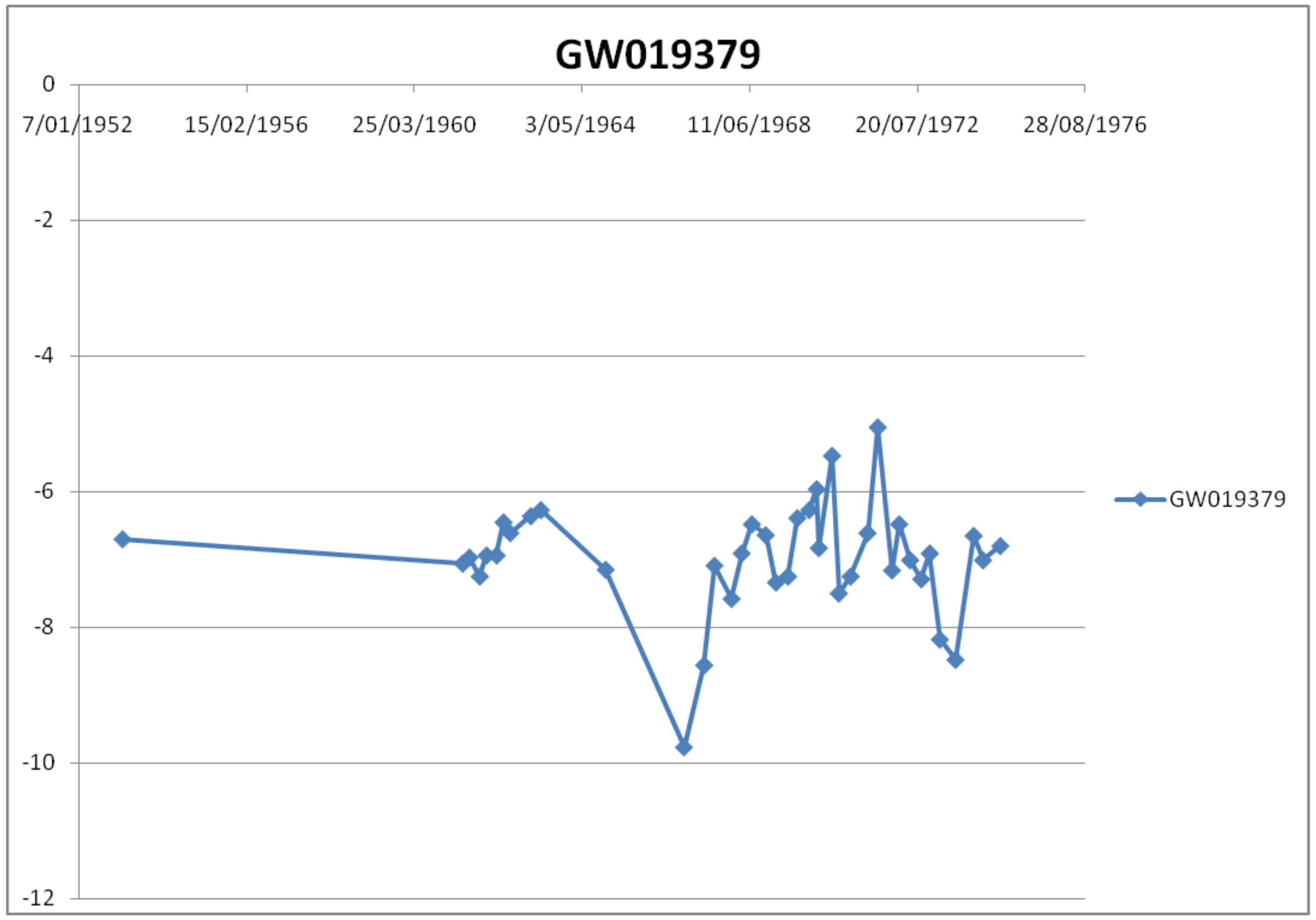
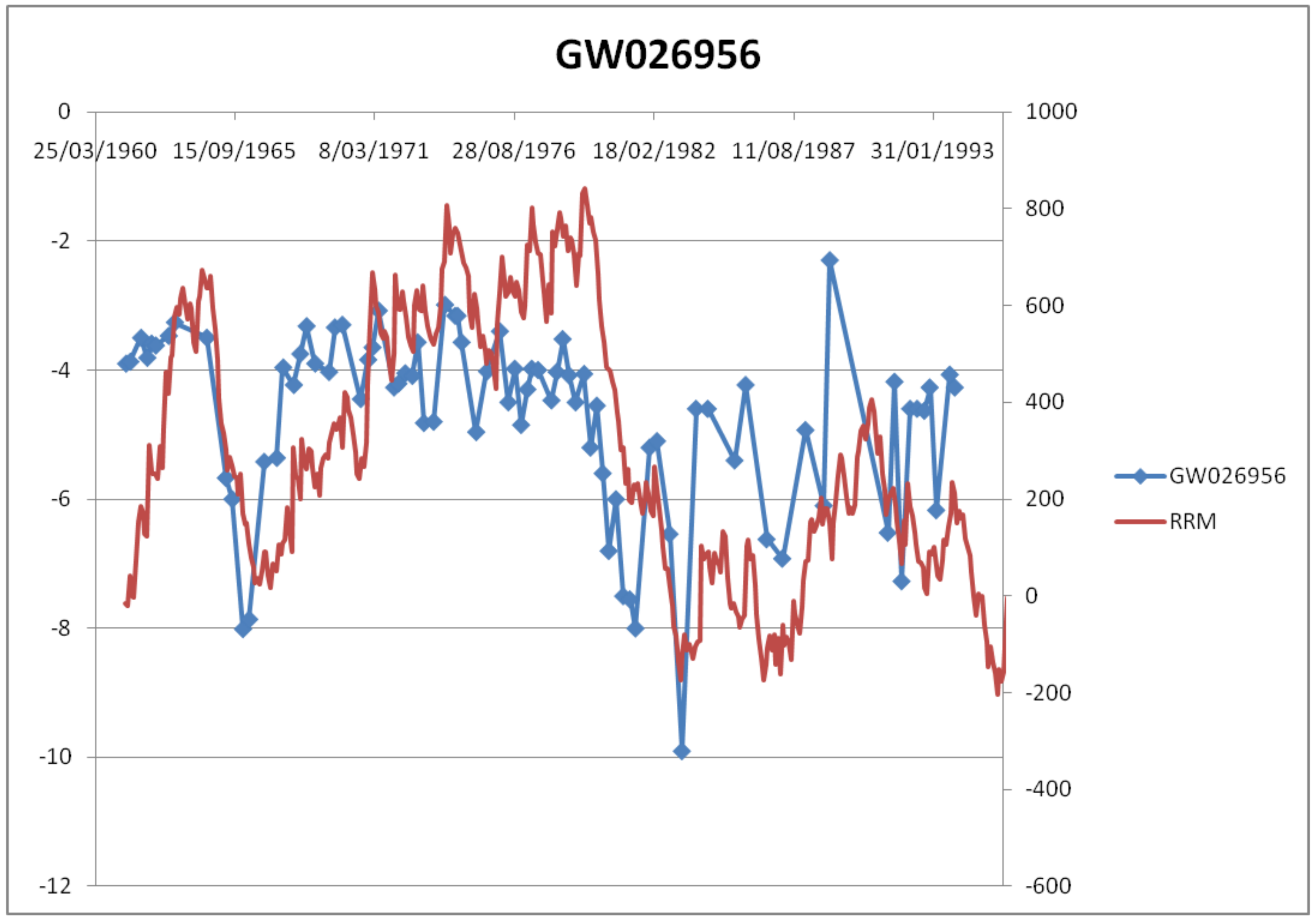

GW000919
-51
-51.5
-52
-52.5
-53
-53.5
-54
-54.5
-55
28/12/1991
7/03/1994
15/05/1996
24/07/1998
1/10/2000
10/12/2002
GW000919

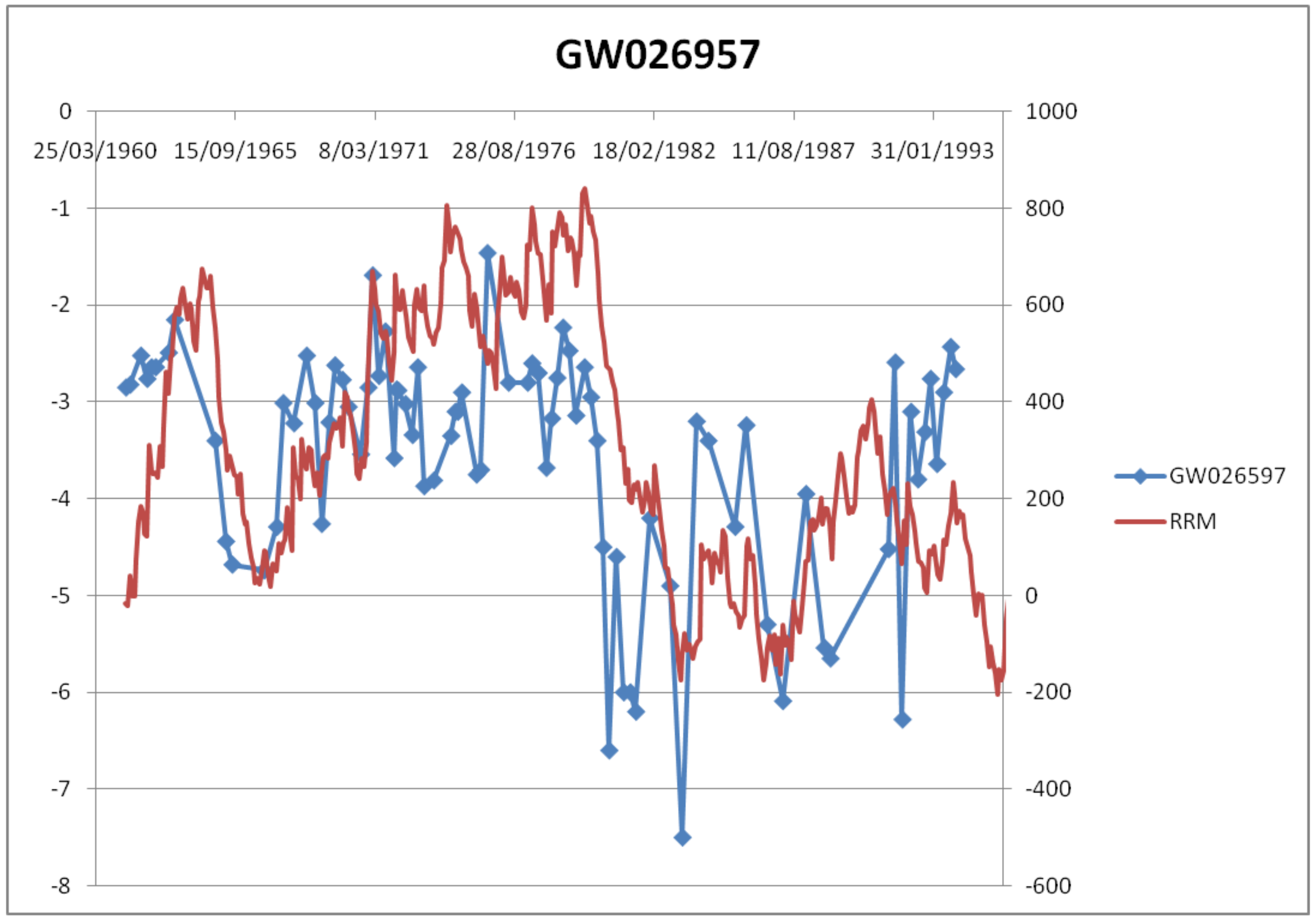

GW007740
0
-1
-2
-3
-4
-5
-6
-7
6/12/1999
19/04/2001
1/09/2002
14/01/2004
28/05/2005
10/10/2006
22/02/2008
GW007740

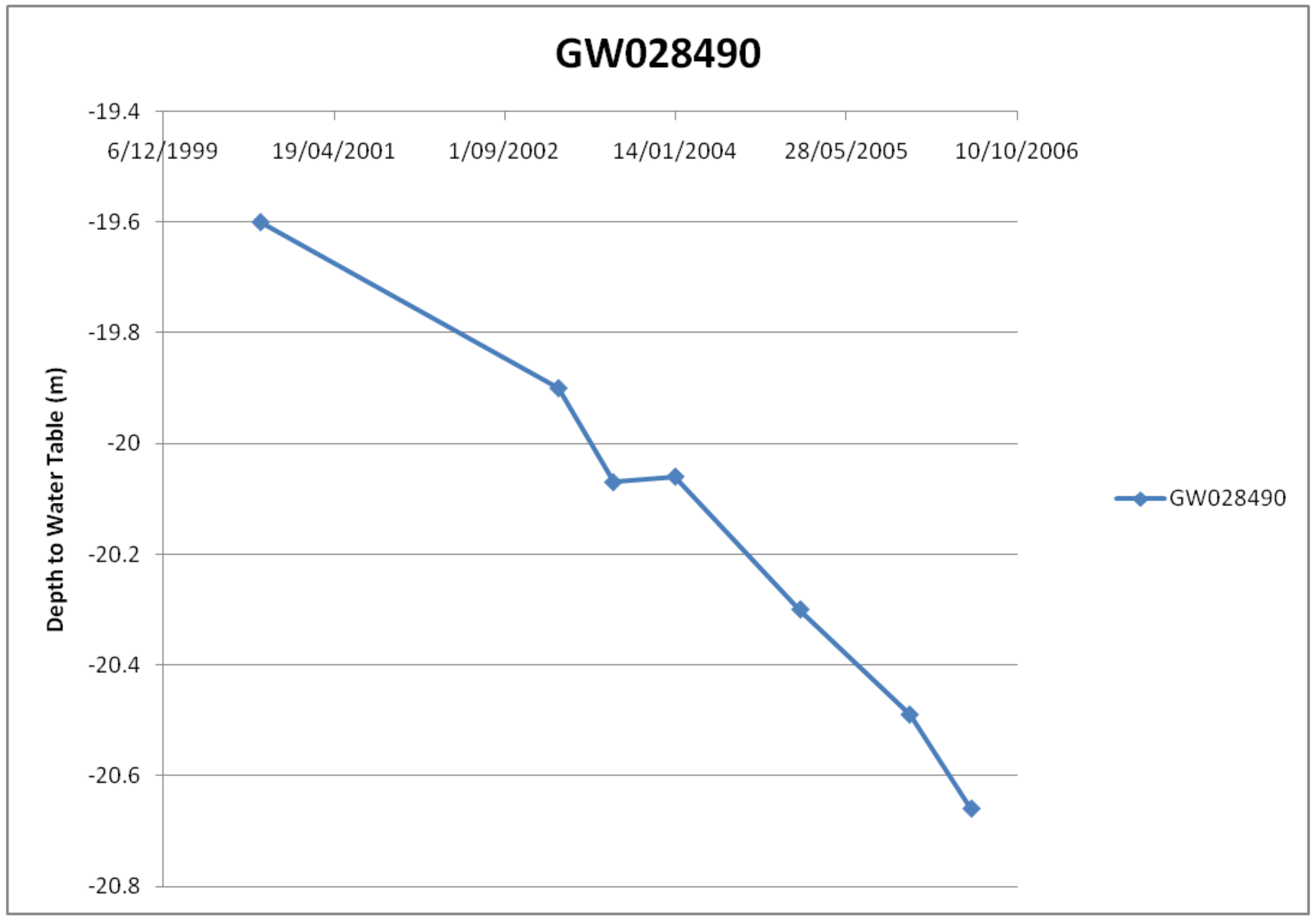

GW012976
0
-2
-4
-6
-8
-10
-12
1000
800
600
400
200
0
-200
-400
-600
7/01/1952
29/06/1957
20/12/1962
11/06/1968
2/12/1973
25/05/1979
14/11/1984
7/05/1990
GW012976
RRM


GW018390
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
28/12/1991
7/03/1994
15/05/1996
24/07/1998
1/10/2000
10/12/2002
17/02/2005
GW018390









FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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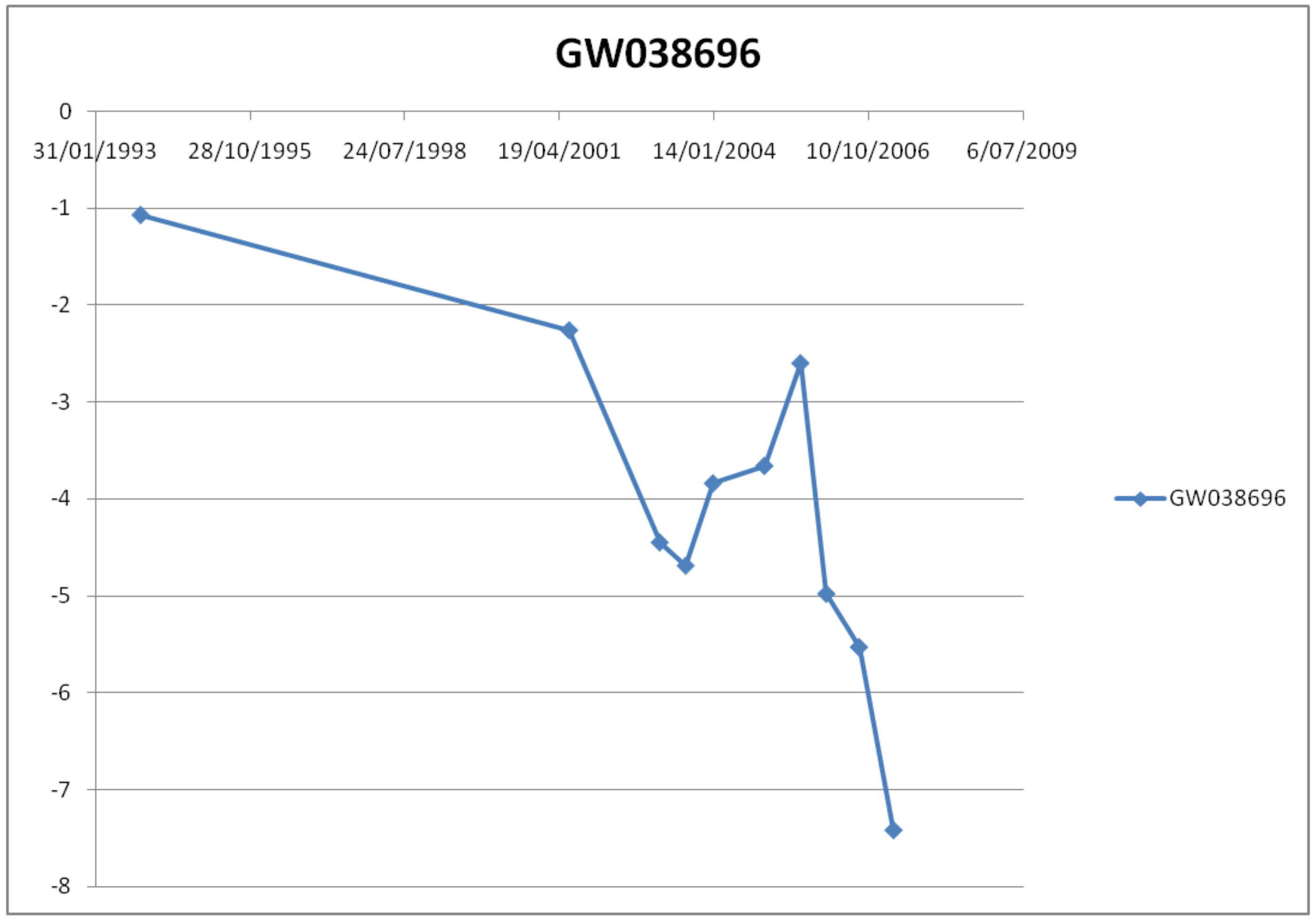

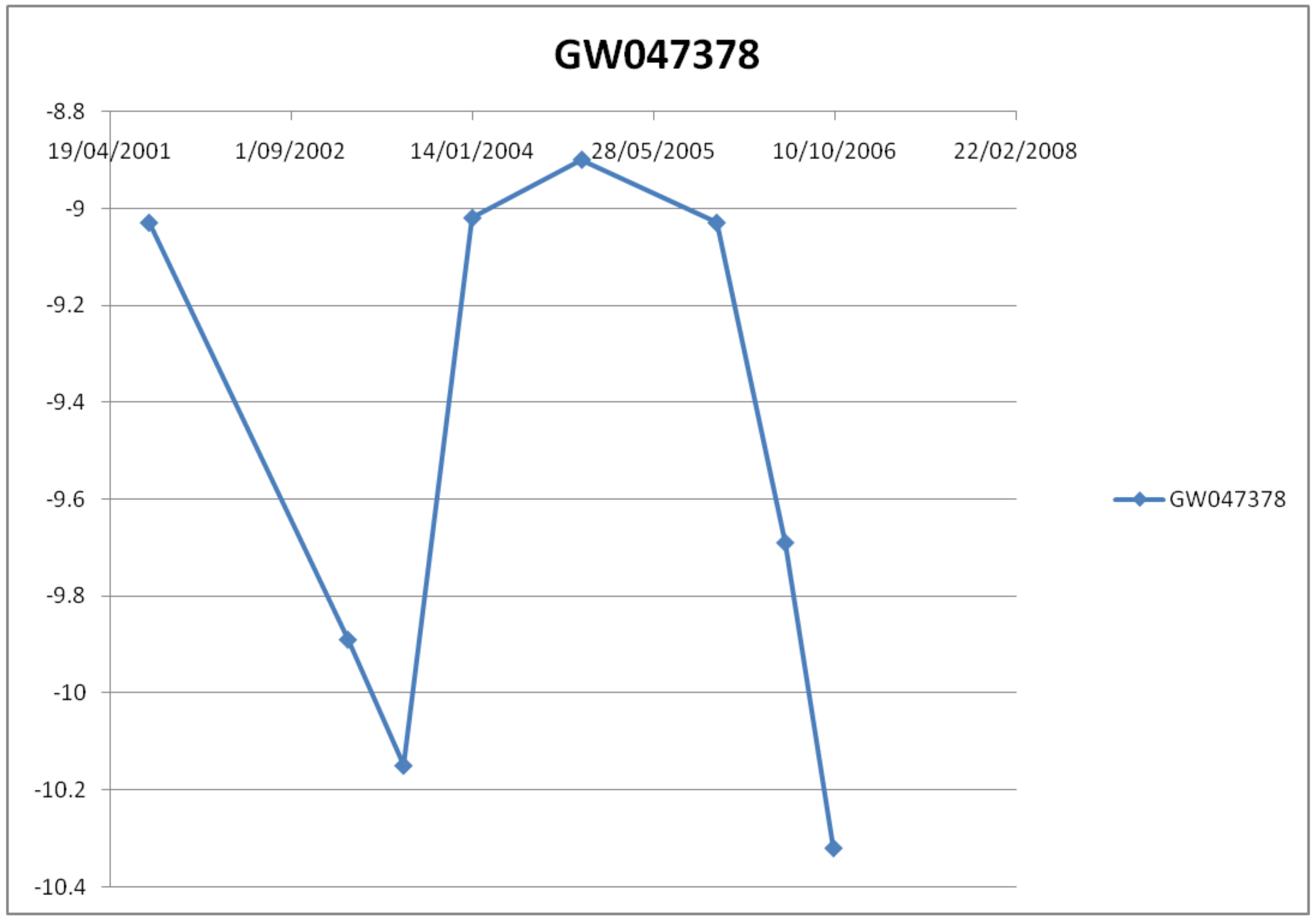

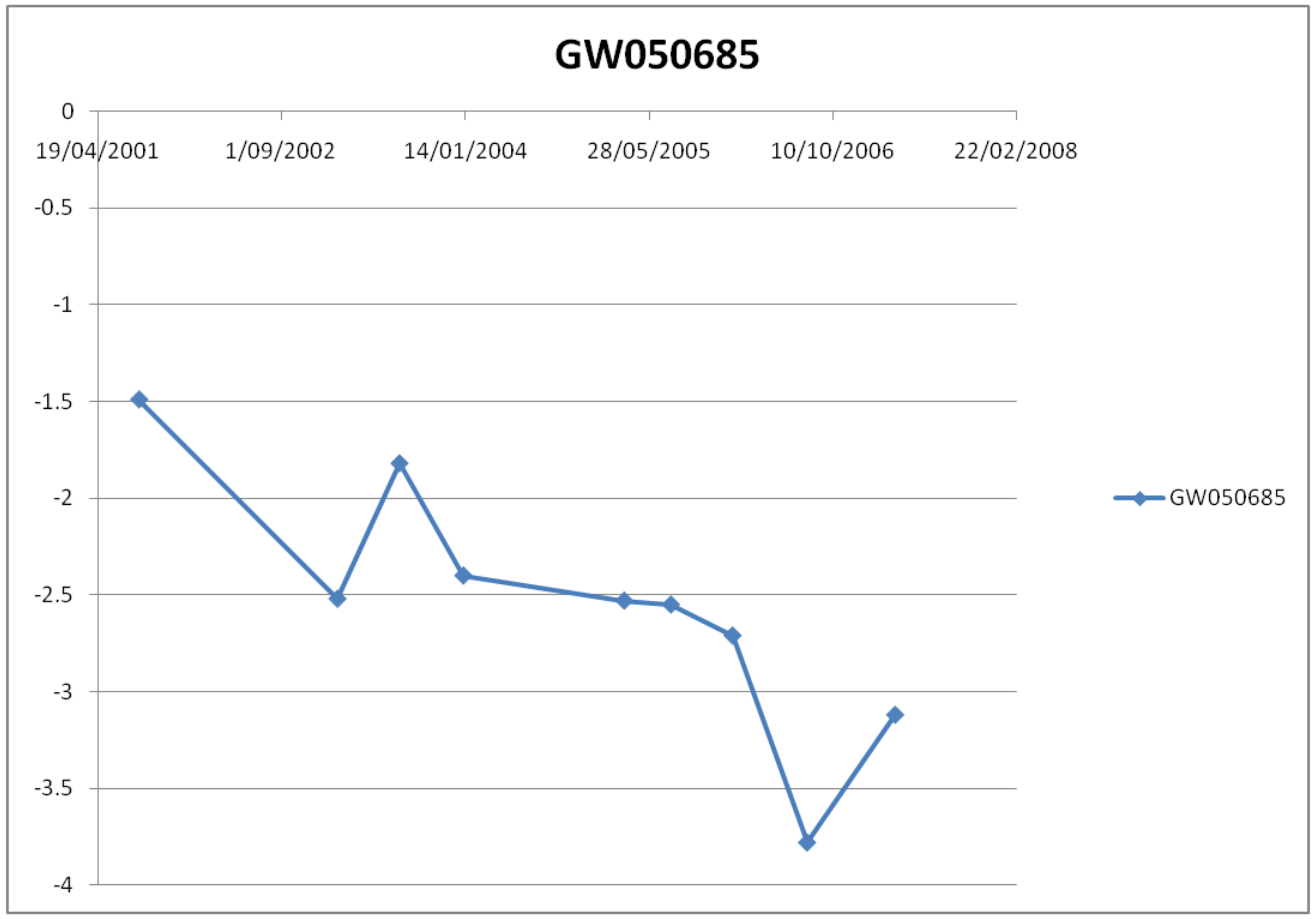

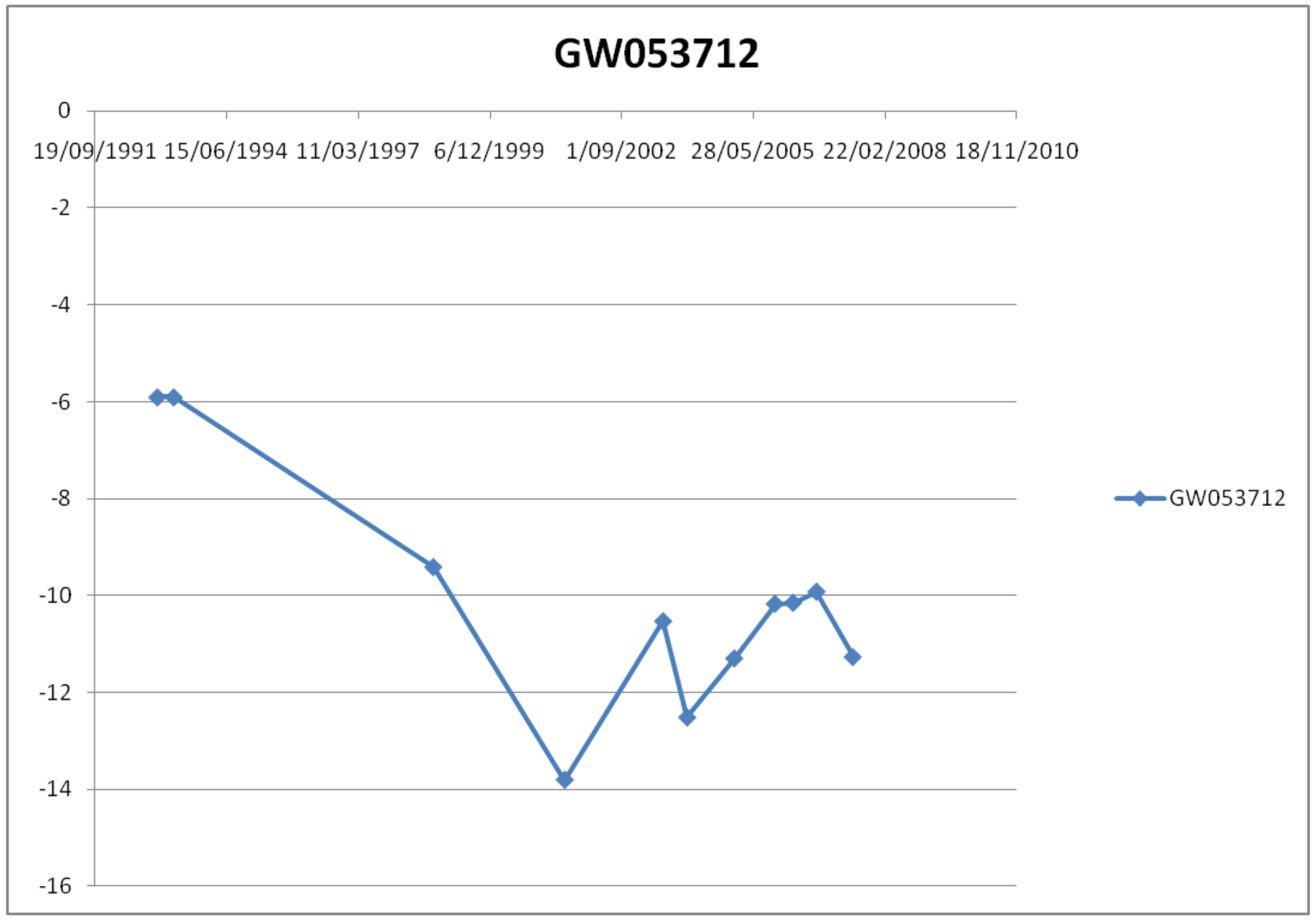

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PO Box 250
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Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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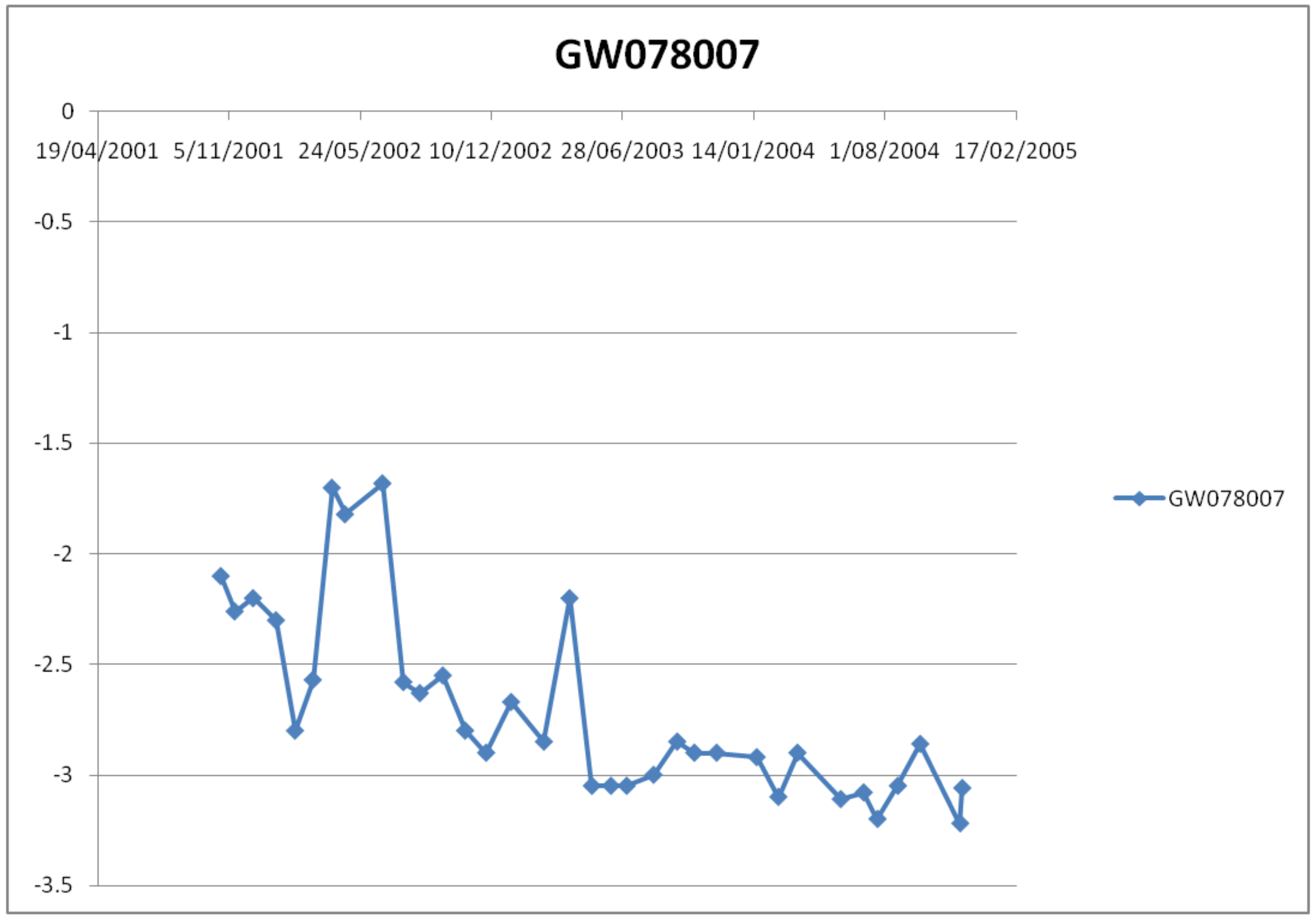

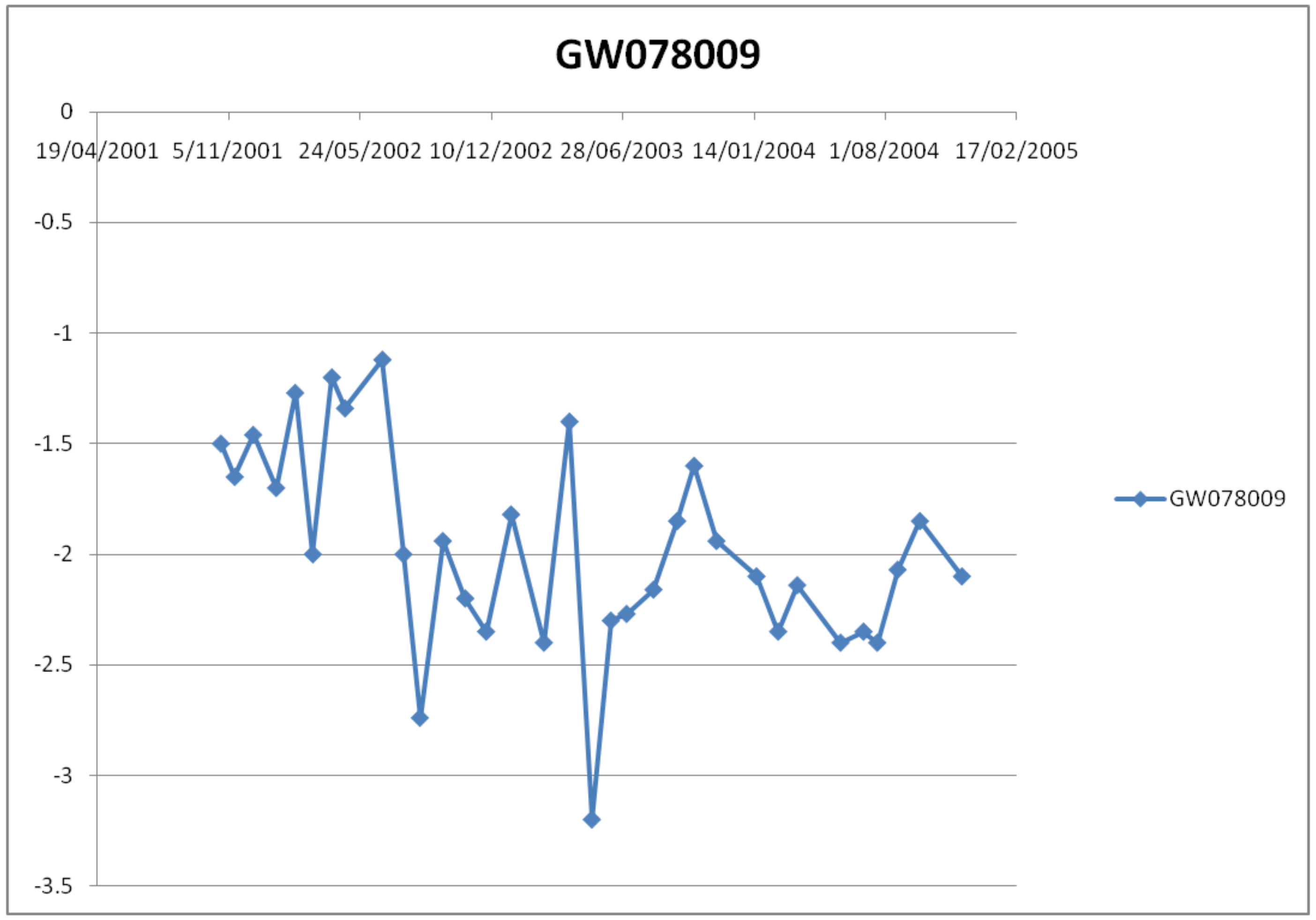

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Element	Median Value (mg/L)	Estimated Total Precipitation (tons)[1]
Total Dissolved Solids[2]	1309	1.3-2.6 million
Sulphate[2]	23	23-46
Iron[2]	0.04	400-800
Aluminium[2]	0.05	50-100
Boron[2]	0.255	255-510
Copper[2]	0.03	30-60
Cadmium[2]	0.000275	0.28-0.56
Lead[2]	0.00443	4.4-8.8
Nickel[2]	0.0154	15-30
Chromium[2]	0.00563	5.6-11.2
Arsenic[2]	0.0025	2.5-5

Table 1: Median water chemistry of selected analytes in the Upper Hunter

A major concern of CSG mining is the high volume of co-produced water. Long term average water production from CSG in Australia is estimated to be about 200-400 ML/PJ (http://www.dme.qld.gov.au/zone_files/None_Zoned_Files/csg_water_m_s_final_7.pdf). Exploration for CSG in the Gunnedah Basin is relatively recent so the total reserves of natural gas are not yet fully established, but current estimates are ~336 PJ (https://www.ga.gov.au/image_cache/GA17412.pdf). However, the geologically similar, Bowen Basin has over 5000 PJ of natural gas (https://www.ga.gov.au/image_cache/GA17412.pdf).

If the Bowen Basin model holds true for the Gunnedah Basin, then from 1000-2000 GL of water could be co-produced the Gunnedah Basin. Assuming a 20 year lifespan of a CSG field, this equates to ~50-100 GL/yr of co-produced water. As a comparison, the volume allocated for "local water utilities licenses" (28 licenses) in the NSW Great Artesian Basin is 5.8 GL/yr (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_nsw_gab_background.pdf.aspx).

Extracting this volume of water will result in depressurisation of the coal seams and other aquifers in hydrodynamic contact with the coal seams. As a consequence groundwater levels (and connected surface water flows) will also decrease.

Another consequence of the high volume of water being extracted from the coal seams is the large amount of salt and heavy metals that are naturally present in the groundwater. Values for the salinity of co-produced water from coal seams in the Upper Hunter have not been examined in detail yet, but Aquaterra (2009) quotes an average salinity of 1309 mg/L TDS. If the volume of co-produced water mentioned above is realised, then as Table 1 shows, over 1 million tones of salt will be brought to the surface. In comparison the total annual salt load in the Namoi River is estimated to be ~135,000 tons/yr (www.water.nsw.gov.au/.../34/quality_iqqm_mbd_**namoi**.pdf.aspx), while the total annual salt load in the Macquarie River at Narromine is estimated to be 224,100 tons/yr (*www.water.nsw.gov.au/.../34/quality_iqqm_mbd_**macquarie**.pdf.aspx*).

In addition to salt, tons of heavy metals naturally present in the co-produced water will also be brought to the surface including arsenic, lead, nickel and chromium.

Because of the high volume of water and salt, CSG water should not be stored on site in evaporation ponds where it could contaminate the area and add to the salt load of the rivers. Preference should instead be for re-injection of the brine back into the originating coal seam, this practice will both dispose of the salt and act to maintain groundwater levels in connected aquifers.

1 Assuming volume of co-produced water 1000-2000 GL.
2 Aquaterra (2009)

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Highly Stressed System

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
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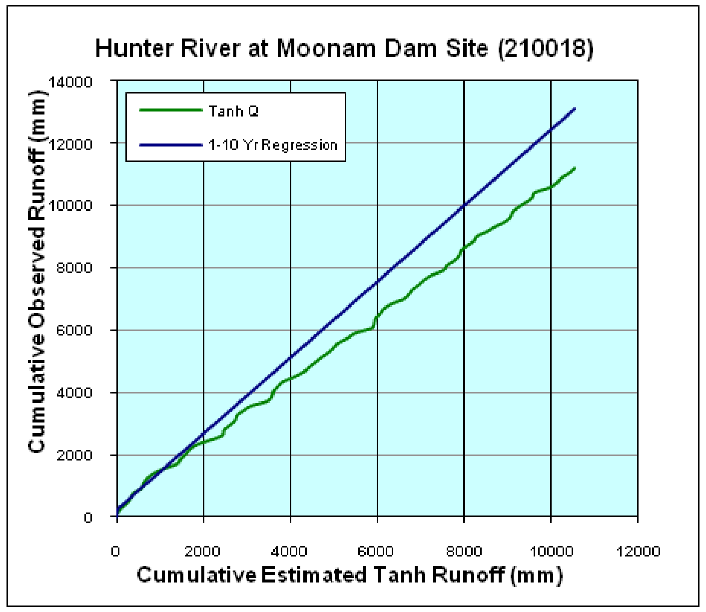
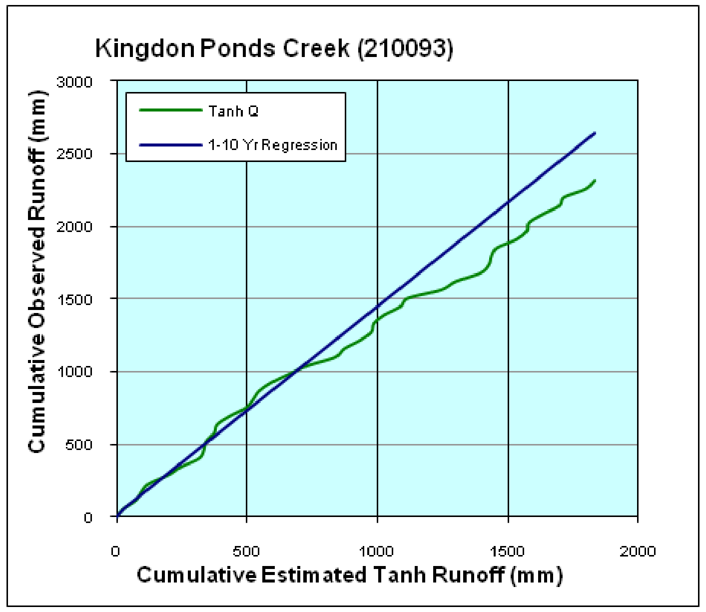
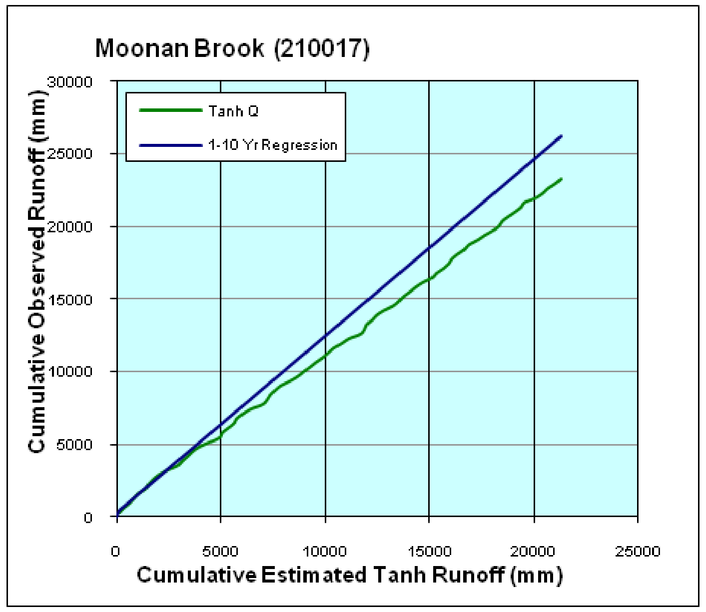
Due to consumptive use, the volume of water in the gauged rivers in the Upper Hunter is a ~113 GL/yr lower than under "natural" conditions. Losses for each river and the accompanying tanh graph are shown **below**. See **pages 68-69** for a full explanation of the tanh curve.



Total volume of water less than modelled: 1461.8 GL
Average decrease in streamflow per year: 24 GL
Average decrease in streamflow per day: 65.7 ML

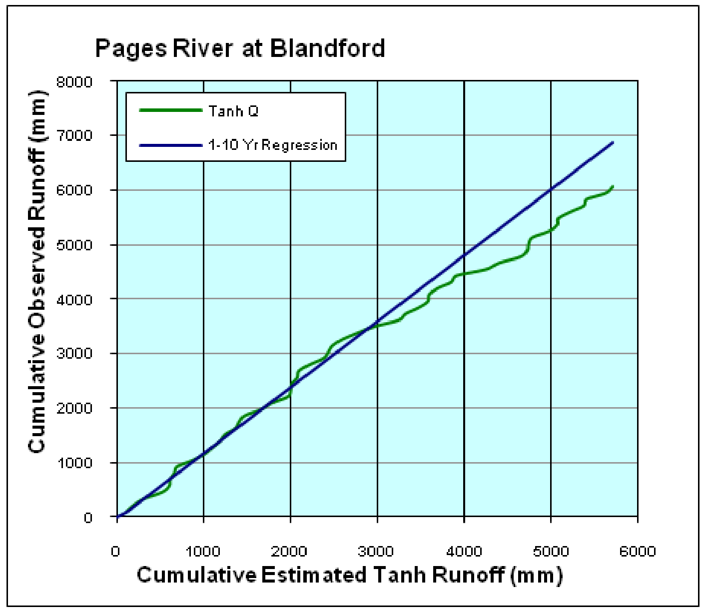
Total volume of water less than modelled: 57.6 GL
Average decrease in streamflow per year: 2 GL
Average decrease in streamflow per day: 5.4 ML

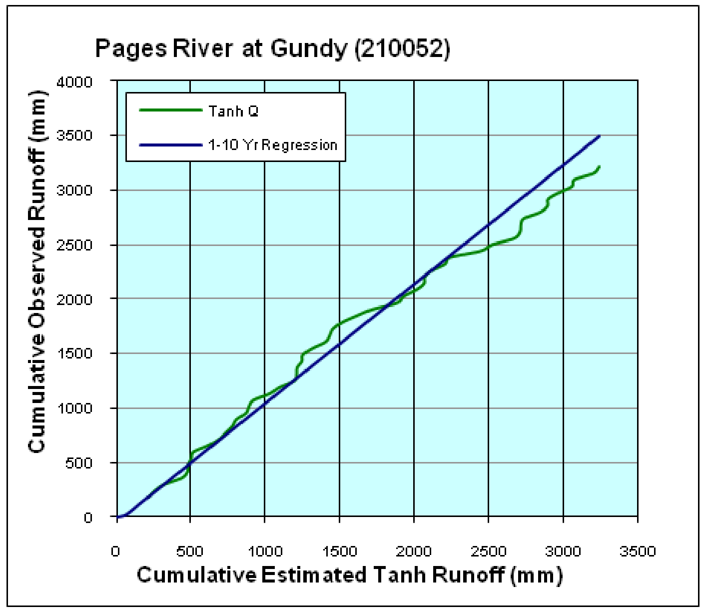




Total volume of water less than modelled: 296.3 GL
Average decrease in streamflow per year: 4.9 GL
Average decrease in streamflow per day: 13.3 ML

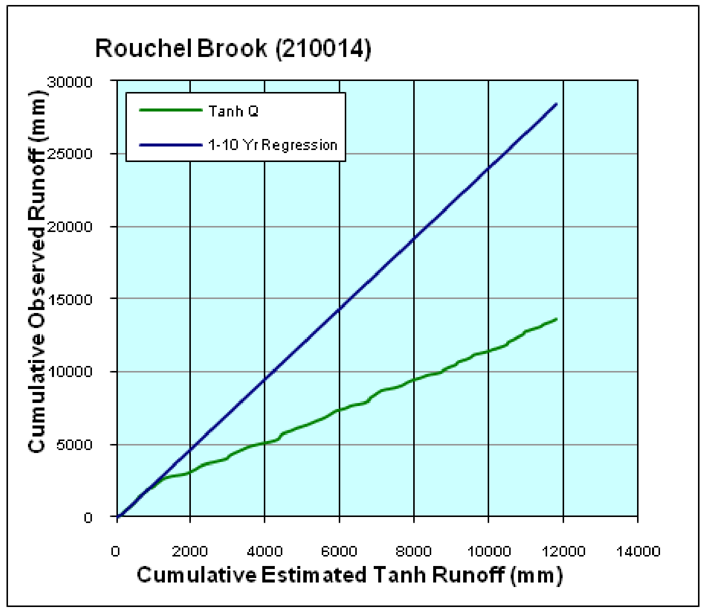
Total volume of water less than modelled: 243.7 GL
Average decrease in streamflow per year: 5.9 GL
Average decrease in streamflow per day: 16.3 ML





Total volume of water less than modelled: 302.5 GL
Average decrease in streamflow per year: 7 GL
Average decrease in streamflow per day: 19.3 ML

Total volume of water less than modelled: 4667 GL
Average decrease in streamflow per year: 69.8 GL
Average decrease in streamflow per day: 191.3 ML



FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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According to the "report cards" associated with the NSW Water Sharing Plans (http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-commenced/Water-source/Hunter-Unregulated-and-Alluvial/default.aspx) all but one river, for which there is a report, suffers from a high level of hydrologic stress. The exception being Stewarts Brook, which is under Medium stress.

Because of the high volume of co-produced this stress will likely increase due to CSG mining.

Background information

Water source attributes	Rating	Justification for initial classification
Relative instream value (within catchment)	Medium	• 1 threatened amphibian species. • Moderate fish community integrity. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	Medium	Medium economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Medium	Instream values are at medium risk of being impacted by extractions within the water source.

Hydrological Stress of the Isis River according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_isis_river.pdf.aspx)

Background information

Water source attributes	Rating	Justification for initial classification
Relative instream value (within catchment)	Medium	• 1 threatened amphibian species. • Moderate fish community integrity. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	High	High economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Medium	Instream values are at low risk of being impacted by extractions within the water source.

Hydrological Stress of Dart Brook and Kingdon Ponds Creek according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_dart_brook.pdf.aspx)

Background information

Water source attributes	Rating	Justification for initial classification
Relative instream value (within catchment)	Medium	• No known threatened frog, bird or flora species. • Moderate fish community integrity. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	Medium	Medium economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Low	Instream values are at low risk of being impacted by extractions within the water source.

Hydrological Stress of the Krui River according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_krui_river.pdf.aspx)

Background information

Water source attributes	Rating	Justification for initial classification
Relative instream value (within catchment)	High	• No known threatened frog, bird or flora species. • High species diversity. • Moderate fish community integrity. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	Medium	Medium economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Medium	Instream values are at low risk of being impacted by extractions within the water source.

Hydrological Stress of the Merriwa River according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_merriwa_river.pdf.aspx)

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA
T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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Background information		
Water source attributes	**Rating**	**Justification for initial classification**
Relative instream value (within catchment)	Medium	• 1 threatened amphibian species. • 1 threatened bird species. • Camerons Gorge Nature Reserve. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	High	High economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Medium	Instream values are at low risk of being impacted by extractions within the water source.

Hydrological Stress of Pages River according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_pages_river.pdf.aspx)

Background information		
Water source attributes	**Rating**	**Justification for initial classification**
Relative instream value (within catchment)	High	• 1 threatened Orchid species. • 6 threatened amphibian species. • 1 threatened Herbs and Forbs species. • 4 threatened bird species. • Platypus have been identified in this water source. • High species diversity. • Drought refuge for water plants and animals. • The ecology value of the rivers for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	Medium	Medium economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	High	Instream values are at medium risk of being impacted by extractions within the water source.

Hydrological Stress of Rouchel Brook according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_rouchel_brook.pdf.aspx)

Background information		
Water source attributes	**Rating**	**Justification for initial classification**
Relative instream value (within catchment)	High	• 5 threatened amphibian species. • 1 threatened bird species. • High species diversity. • High recreation value. • High wet flora values. • Moderate fish community integrity. • The ecology value for invertebrates is deemed to be moderate.
Hydrological stress	Medium	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	Medium	Medium economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Medium	Instream values are at medium risk of being impacted by extractions within the water source.

Hydrological Stress of Stewarts Brook according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_upper_hunter.pdf.aspx)

Background information		
Water source attributes	**Rating**	**Justification for initial classification**
Relative instream value (within catchment)	Low	• 1 threatened bird species. • 1 threatened amphibian species. • The ecology value of the river for invertebrates is deemed to be moderate.
Hydrological stress	High	Peak extraction demand exceeds available flows in December.
Relative economic significance of irrigation (within catchment)	High	High economic dependence of the local community on water extracted for irrigation.
Risk to instream value (from extraction)	Low	Instream values are at low risk of being impacted by extractions within the water source.

Hydrological Stress of Wybong Creek (part of Lower Goulburn River assessment(according the NSW Office of Water (http://www.water.nsw.gov.au/ArticleDocuments/34/wsp_hunter_report_card_lower_goulburn_river.pdf.aspx)

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
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Groundwater Modelling

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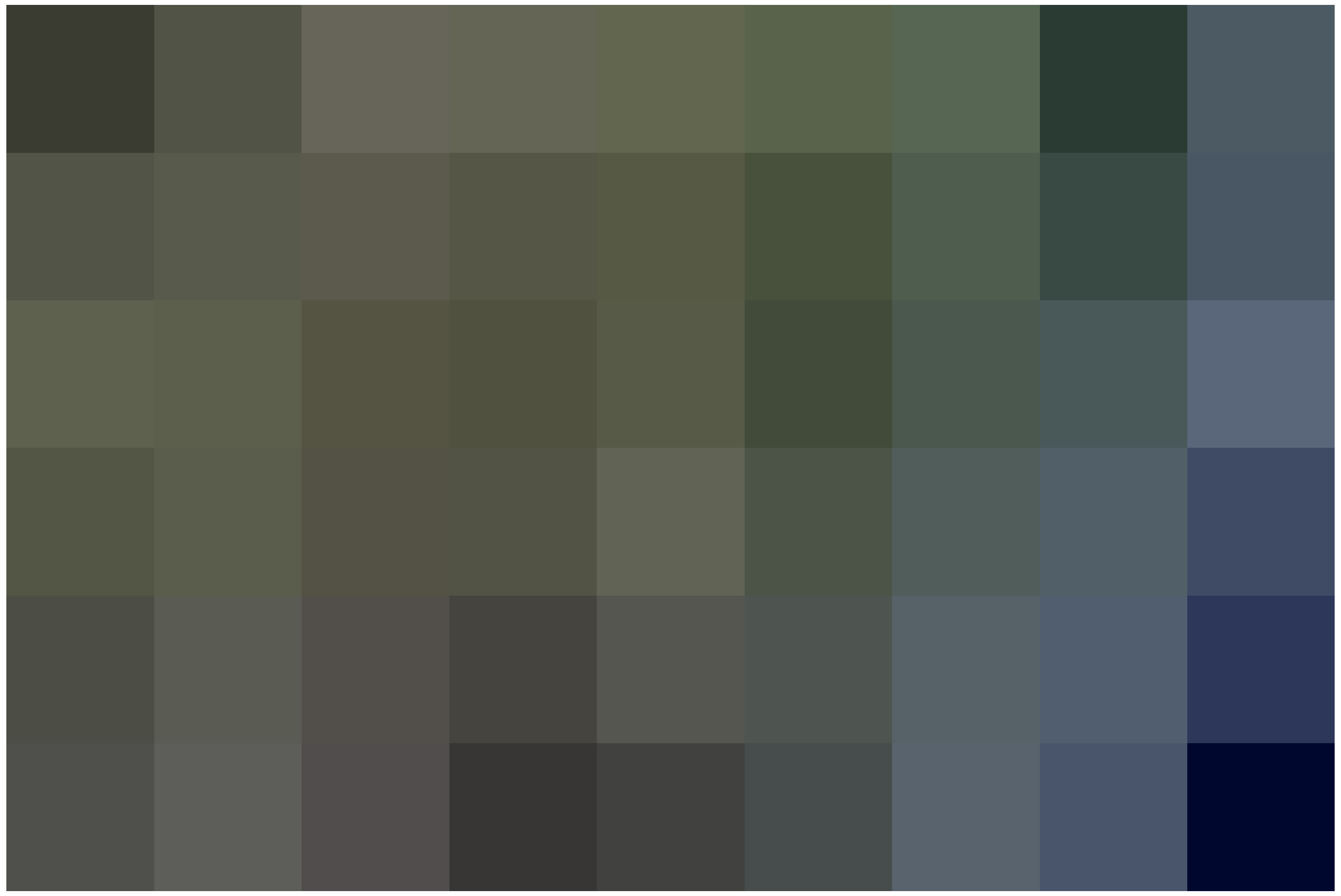
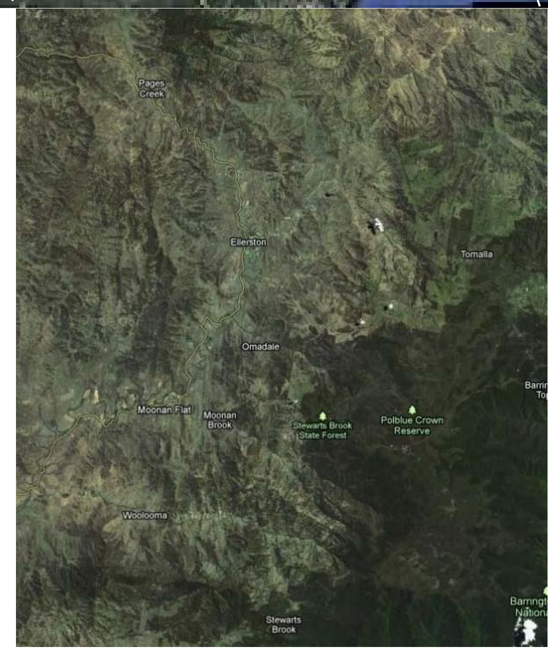


Above left:
Low resolution image of the same area as the high resolution image to the **right**, but at a resolution equivalent to the data density available in the Upper Hunter for groundwater modelling (Image from Google Maps).



Above right:
High resolution image needed for managing resources at a local scale. Despite zooming in, there is still plenty of detail (Image from Google Maps).

Groundwater models are a vital tool for understanding the groundwater impacts of both individual CSG wells, as well as the cumulative impacts all CSG wells in the Upper Hunter.

In order to give confidence to landowners and the community in the Upper Hunter, a groundwater model needs to have sufficient resolution to model groundwater impacts both across the region and between neighbouring properties.

A groundwater model, like a digital image, is built out of "cells", although unlike a digital image, groundwater models are 3-dimensional Within a cell, hydrological characteristics such as hydraulic conductivity, porosity, water level etc. are assumed to be the same.

For the information in the cells to be valid, the hydrological values need to be based on "real" data, such as from wells, seismic or geophysical data. Therefore the maximum resolution of a groundwater model is limited to the density of calibration datasets.

George Box, a modeller, is quoted as saying "All models are wrong, some models are useful." While a groundwater model can be made with little or even no "real" data, its effectiveness in predicting the behaviour of real world water problems is doubtful.

The Upper Hunter LGA is approximately 170 kilometres from east to west and 90 kilometres from north to south and it contains a total of 17 petroleum/CSG wells and 9 partial seismic lines (**page 61**).

Without a dramatic increase in the amount of calibration data available to build a groundwater model, no model will be able to resolve even the most basic questions on the impacts of CSG mining in the Upper Hunter. Before CSG production proceeds, a dedicated program, not associated with CSG exploration, to obtain calibration needs to be undertaken.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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Geology

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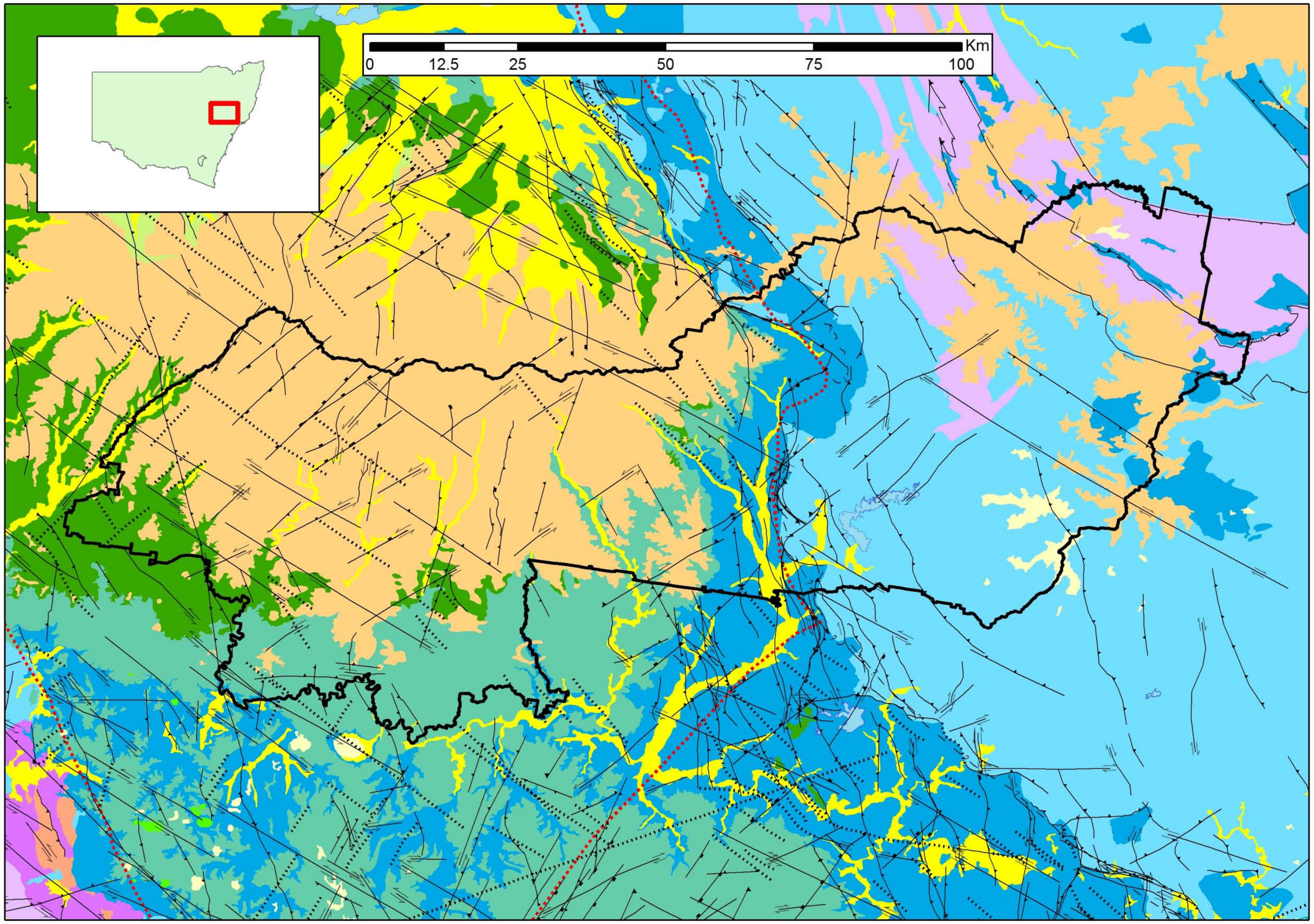
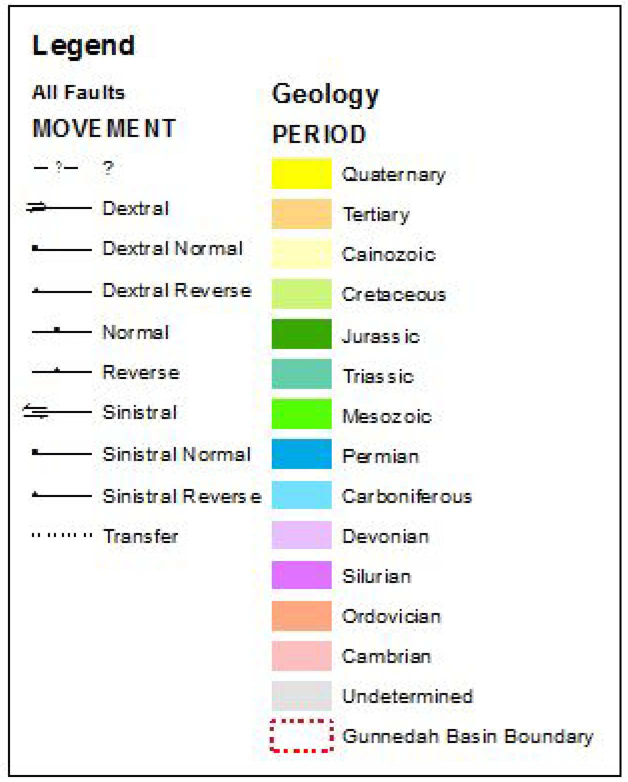


Geology from Geoscience Australia 1:1,000,000 Geology of Australia



The Upper Hunter LGA spans two geological provinces.

The New England Fold Belt is dominated by Middle Devonian to Early Carboniferous mafic volcanics, lithic-felsic volcaniclastics and felsic volcanogenic rocks (www.dpi.nsw.gov.au/__data/assets/.../**Sydney Basin** Reservoir **Study**.pdf*)*. It is unlikely to be a major target for CSG exploration.

The Gunnedah Basin contains up to 5500m of mostly Permian to Triassic age sediments that thin to the west across a basement-controlled depositional hinge, and around the margins of the basin as a result of uplift (www.dpi.nsw.gov.au/__data/assets/.../Sydney_Basin_Reservoir_Study.pdf). The coal seams within the Gunnedah Basin are the primary target of CSG exploration.

Also of note, are the series of faults throughout the region. Depending on type and location, faults can act either as a barrier or a conduit for groundwater flow.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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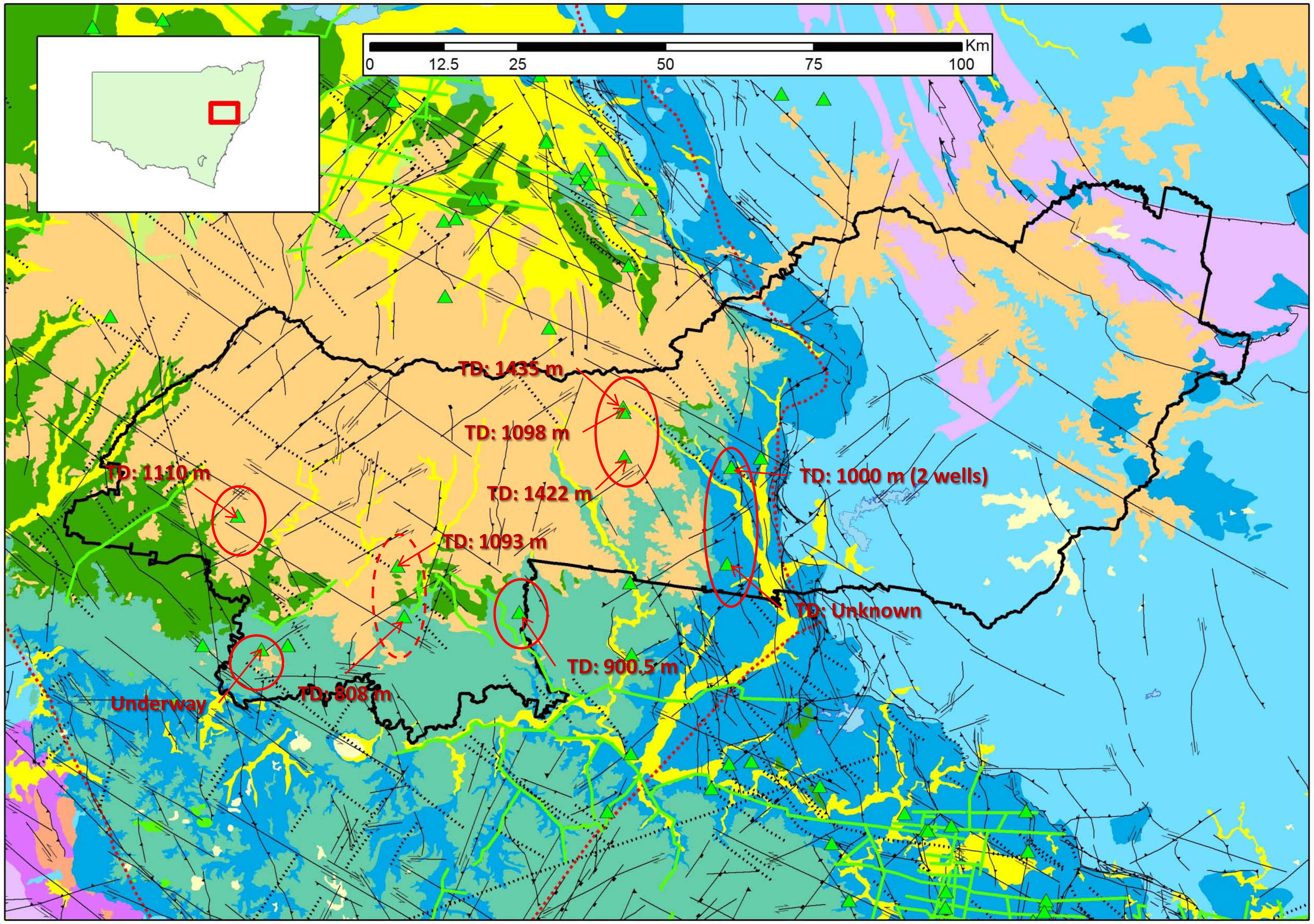

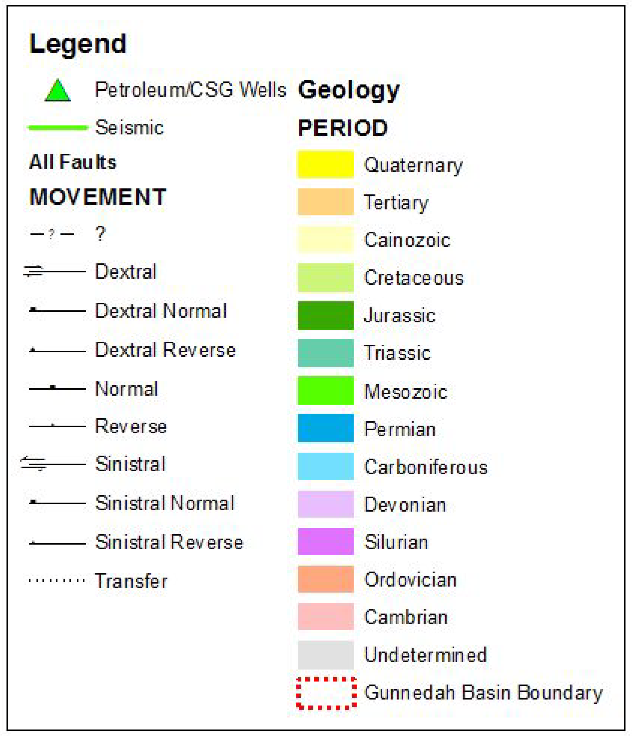

Recent (since 1995) CSG exploration wells are shown on the map to the **right** as **green** triangles circled in **red**. Wells drilled since 2009 are shown encircled with solid **red** lines, while the older CSG exploration wells are shown as encircled with **dashed** lines. While much of the information remains confidential, total depth of the well are shown where known. One CSG exploration well (Meads Crossing 1) is currently being drilled by Planet Gas and CBM P/L.

There are also four petroleum wells (not circled) in the Upper Hunter LGA dating from the 1960s.

In addition, the Upper Hunter LGA contains 9 whole or partial seismic refraction lines from the 1960s (source GPinfo August 2011).

Geology from Geoscience Australia 1:1,000,000 Geology of Australia

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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Stratigraphy of Open File CSG Wells

East Dunlop 1

0-98.8 m Tertiary Volcanics (Liverpool Plains)

98.9-519.6 Undifferentiated Digby Formation (Triassic)

519.6-664.3 Digby Formation Conglomerate (Triassic)

664.3-782.3 Upper Black Jack Formation Coal (Permian)

782.3-1093.8 Lower Black Jack Formation Coal (Permian)

Doolans Creek 1

0-226.7 Undifferentiated Digby Formation (Triassic)

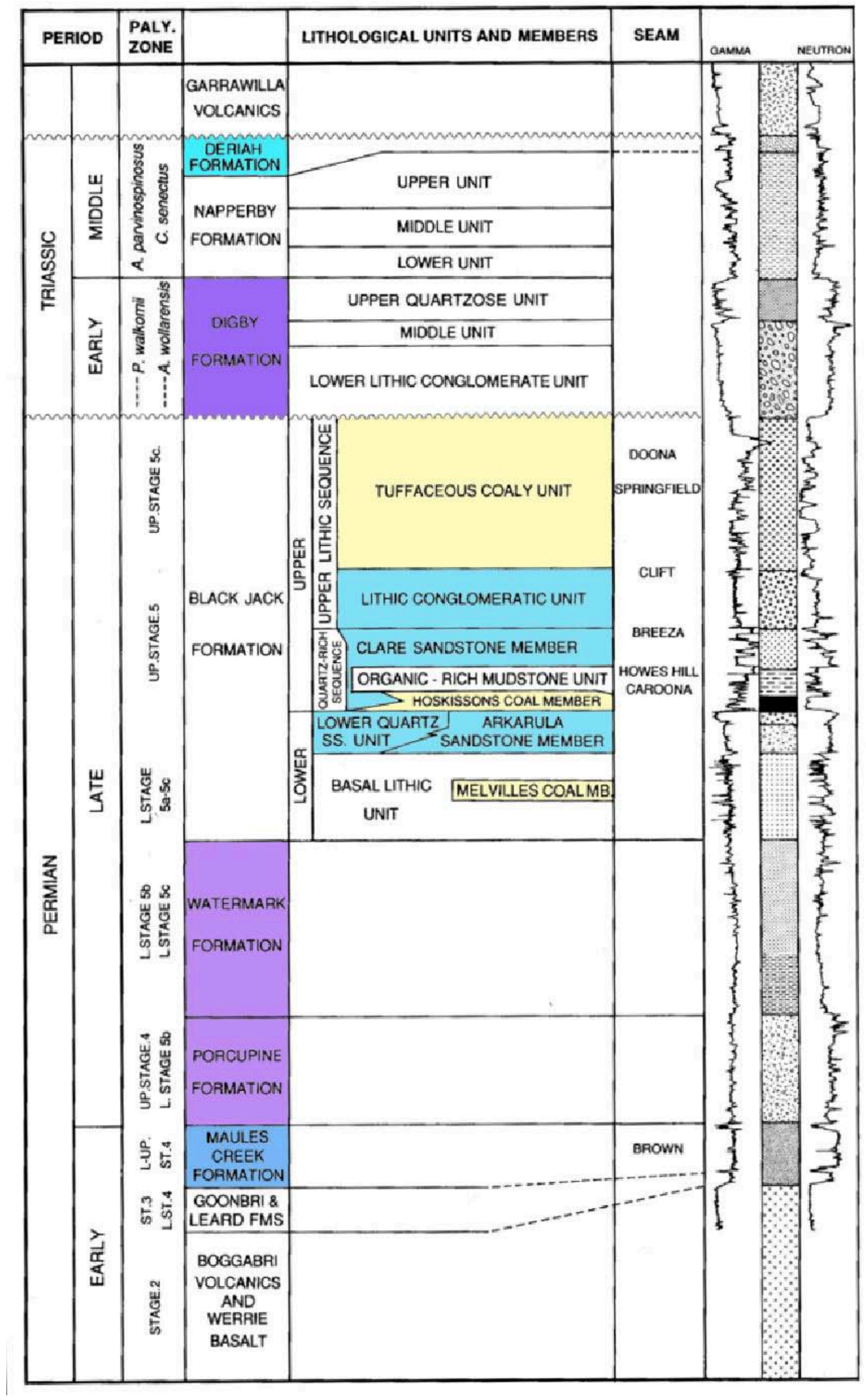
226.7-329 Digby Formation Conglomerate (Triassic)

329-449 Upper Black Jack Formation Coal (Permian)

449-859.4 Lower Black Jack Formation Coal (Permian)

859.4-946.6 Undifferentiated Watermark/Porcupine Formations (Permian)

Although the CSG targets within the Black Jack Formation are hundreds of metres below the surface (329-664), the intervening formation is the Digby Formation which is a valuable aquifer itself (see Groundwater section).



Above: Generalised Gunnedah Basin stratigraphic column, Potential CSG targets are shown in yellow, while potential aquifers are shown in shades of blue. Modified from Othman 2003.

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Landuse

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

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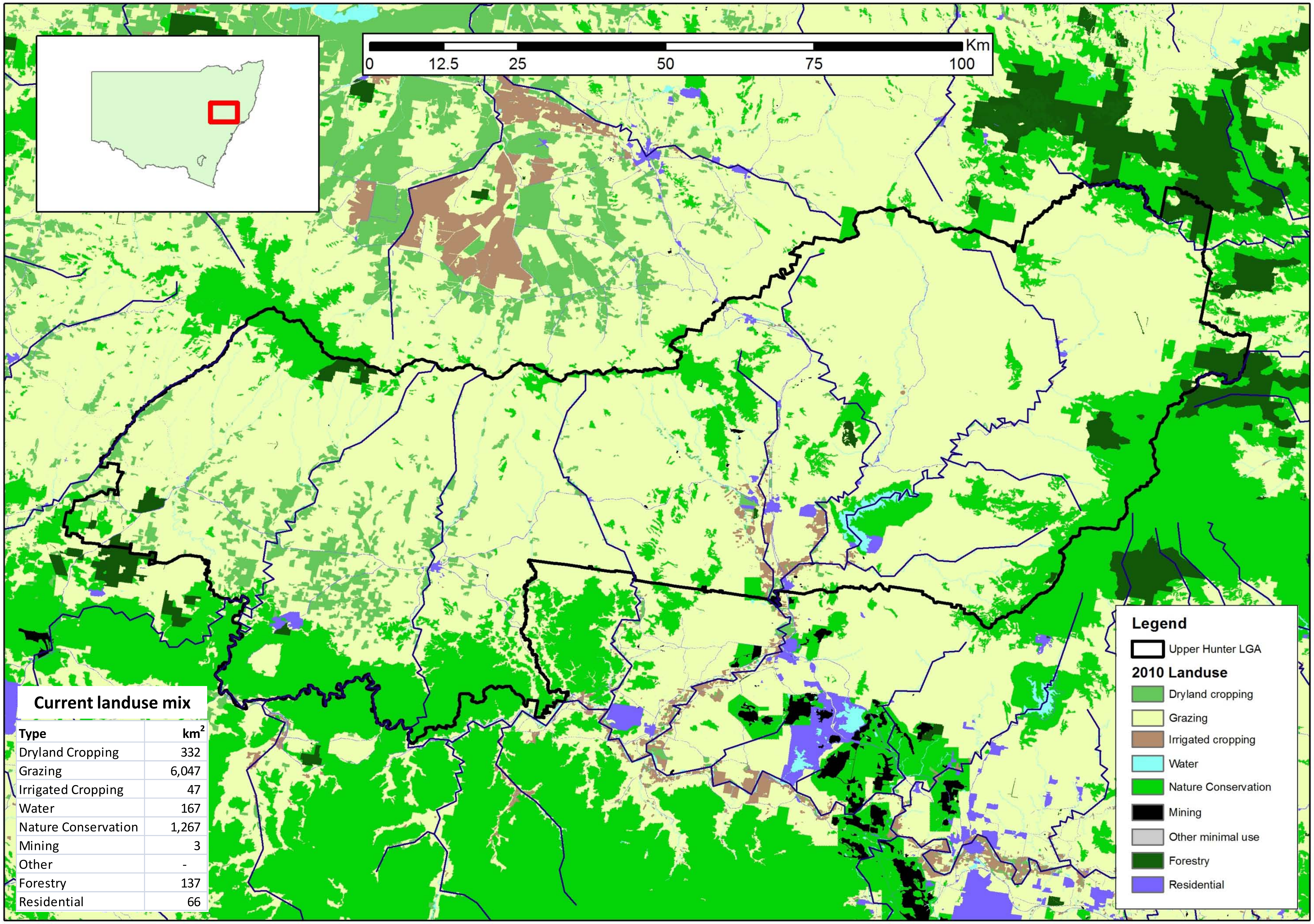
Landuse type in the Upper Hunter



Current landuse mix

Type	km^2
Dryland Cropping	332
Grazing	6,047
Irrigated Cropping	47
Water	167
Nature Conservation	1,267
Mining	3
Other	-
Forestry	137
Residential	66

(Landuse data as of March 2010 from ABARES http://adl.brs.gov.au/data/warehouse/luausr9abll076/luausr9abll07612b00egialb132.zip)

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CANBERRA, AUSTRALIA

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Other Risks to Water Resources

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
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Table 2: Water and Landuse Modelling (based on AWR2005)

Current	Rain (ML)	ET (ML)	Runoff (ML)	Deep drainage (ML)	Area (km^2)
Forestry & plantations	1,307,629	1,122,691	163,851	21,087	1,404
Irrigated areas	41,137	35,753	4,757	626	47
Pasture	5,266,656	4,523,245	665,066	78,345	6,047
Dryland Farming	223,710	206,409	8,016	9,295	332
Intensive use / urban	78,969	58,947	18,810	1,212	66
Bare ground	2,364	1,891	438	36	3
Water	171,788	135,584	33,683	2,521	167
Total	7,092,253	6,084,520	894,621	113,123	8,065

Table 3a: 10% Change from Pasture to Forestry (based on AWR2005)

10% Change to Forests	Rain (ML)	ET (ML)	Runoff (ML)	Deep drainage (ML)	Area (km^2)
Forestry & plantations	1,307,834	1,122,867	163,877	21,090	1,404
New Forests	526,945	457,985	60,937	8,024	605
Irrigated areas	41,137	35,753	4,757	626	47
Pasture	4,739,894	4,070,838	598,547	70,509	5,442
Dryland Farming	223,710	206,409	8,016	9,295	332
Intensive use / urban	78,969	58,947	18,810	1,212	66
Bare ground	2,364	1,891	438	36	3
Water	171,788	135,584	33,683	2,521	167
Total	7,092,640	6,090,273	889,064	113,314	8,065

Table 3b: 20% Change from Pasture to Forestry (based on AWR2005)

20% Change to Forests	Rain (ML)	ET (ML)	Runoff (ML)	Deep drainage (ML)	Area (km^2)
Forestry & plantations	1,307,834	1,122,867	163,877	21,090	1,404
New Forests	1,053,331	915,483	121,808	16,040	1,209
Irrigated areas	41,137	35,753	4,757	626	47
Pasture	4,213,325	3,618,596	532,053	62,676	4,837
Dryland Farming	223,710	206,409	8,016	9,295	332
Intensive use / urban	78,969	58,947	18,810	1,212	66
Bare ground	2,364	1,891	438	36	3
Water	171,788	135,584	33,683	2,521	167
Total	7,092,458	6,095,530	883,442	113,497	8,065

Table 3c: 30% Change from Pasture to Forestry (based on AWR2005)

30% Change to Forests	Rain (ML)	ET (ML)	Runoff (ML)	Deep drainage (ML)	Area (km^2)
Forestry & plantations	1,307,834	1,122,867	163,877	21,090	1,404
New Forests	1,579,997	1,373,225	182,713	24,060	1,814
Irrigated areas	41,137	35,753	4,757	626	47
Pasture	3,686,659	3,166,272	465,546	54,841	4,233
Dryland Farming	223,710	206,409	8,016	9,295	332
Intensive use / urban	78,969	58,947	18,810	1,212	66
Bare ground	2,364	1,891	438	36	3
Water	171,788	135,584	33,683	2,521	167
Total	7,092,458	6,100,947	877,839	113,682	8,065

Page 64, shows current landuse in the Upper Hunter LGA as of March 2010 (http://adl.brs.gov.au/data/warehouse/luausr9abll076/luausr9abll07612b00egialb132.zip). As can be seen, most (75%) of the LGA is currently used for grazing/pastures. All landuses have a unique relationship between rainfall and runoff based on soil, slope and landuse (**Table 2 left** see http://www.water.gov.au/).

One consequence of a price on carbon, is that some land currently used for grazing could be converted to forestry, which will in turn change the runoff characteristics of the Upper Hunter. Tables 3a-3c look at the effects of a 10%, 20% and 30% (respectively) change from grazing to forests.

The results, show that each 10% change in landuse from grazing to forestry could result in a 0.6% decrease in runoff.

Coupled with the modelled 10% decrease in runoff due to climate change (CSIRO 2007) and the already stressed nature of surface water in the Upper Hunter, the additional impact of landuse change, means that the region may struggle to meet the needs of both the environment and currently licensed consumptive users.

The addition impact on surface water due to CSG production could push the system beyond its capacity.

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Appendix

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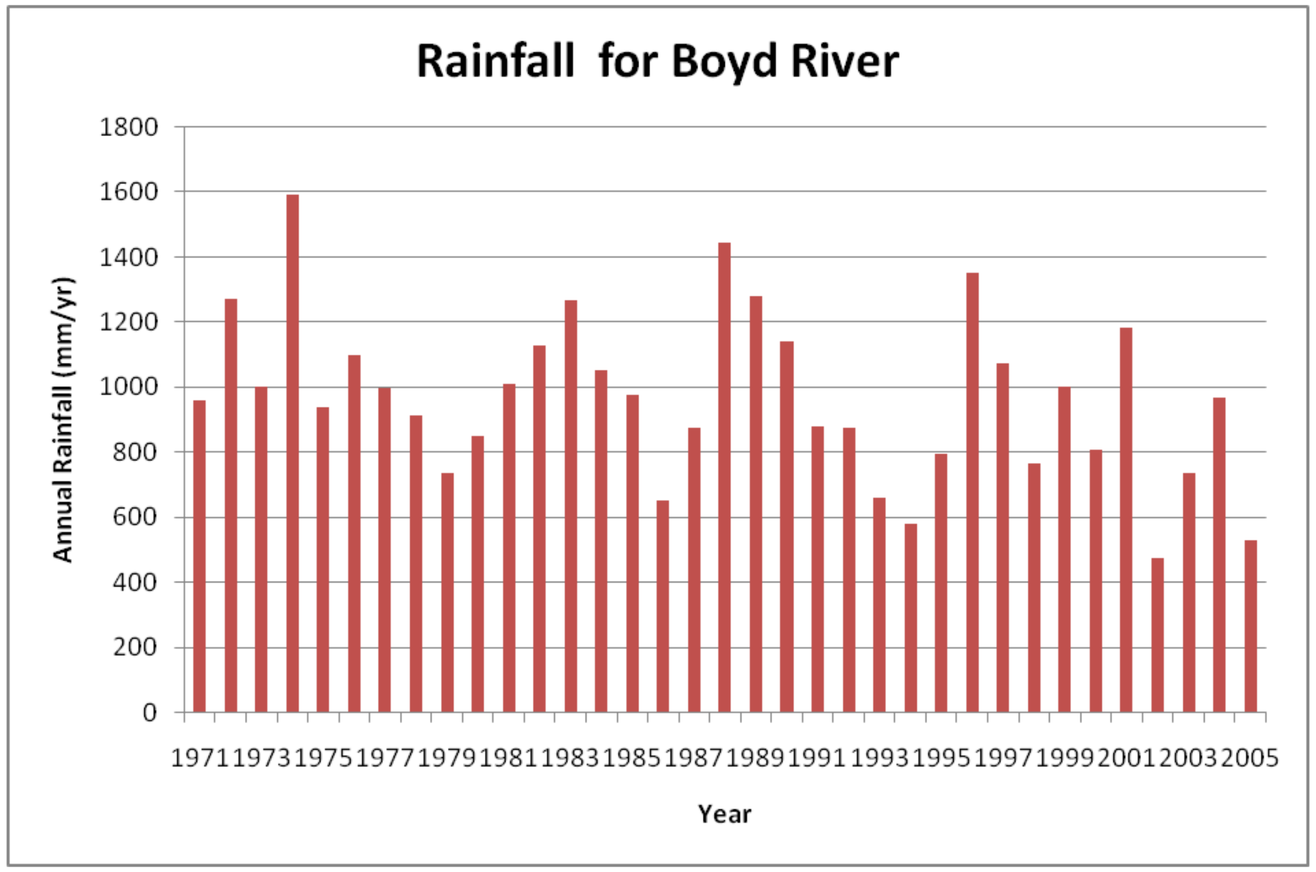
Double Mass Analysis (DMA) is a commonly used hydrologic tool to assess the relationship between rainfall and runoff. (Searcy and Hardison 1960, Wigbout 1973, Kalra and Kuma 1989, Zaho et al. 2004, and Alansi et al. 2009). It works by plotting the cumulative values of one variable against the cumulative values of another quantity during the same time period (Searcy and Hardison 1960). The theory being that by plotting the accumulation of two quantities the data will plot as a straight line, regardless of the individual values in any one year. In the example of rainfall and runoff, the slope of the double mass curve represents a relationship that is characteristic of the catchment. A break in slope of the double mass curve indicates a change in conditions between the two values (Searcy and Hardison 1960). This change in conditions could be due to landuse changes, changes in consumptive water use or changes in the method of observation or data processing (Wigbout 1973).

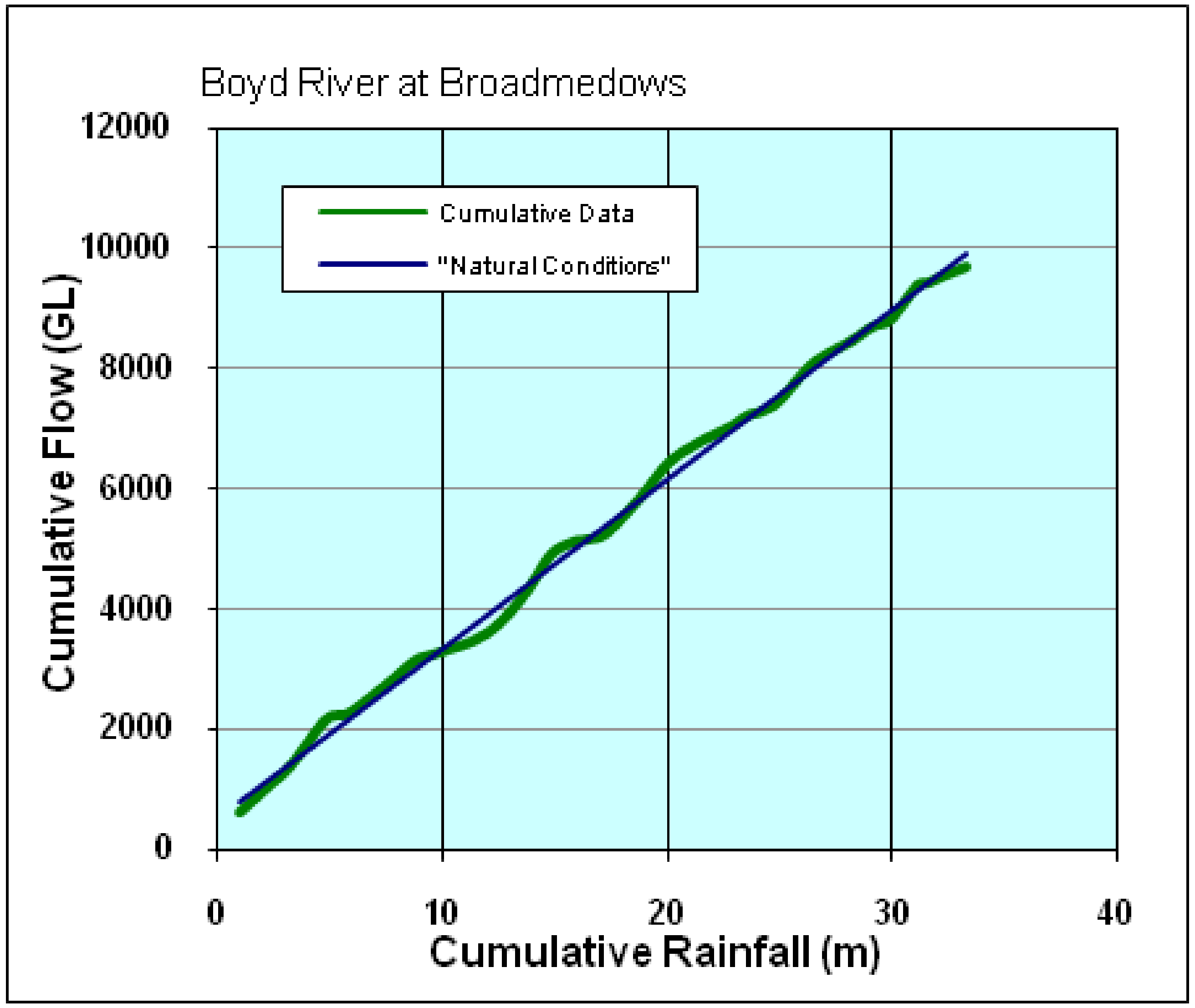
The “Natural Conditions” line is a regression line carried forward from the first 10 years of flow data. It is meant as a means of comparison only, so that it is easy to see whether there has been any change in catchment conditions from when the monitoring gauge was installed. Note that it is unlikely that the this line truly represents “Natural Conditions,” that is, the condition existing in a completely undisturbed catchment. However, as this information is generally absent in most catchment, the earliest flow data in any catchment is a useful means of comparison.

The Boyd River at Broadmeadows example to the **right** shows that despite a range of rainfall (475-1591 mm/yr) the relationship between rainfall and runoff has been steady.

- Average rainfall “base” period: 1035 mm/yr
- Average rainfall rest of period: 940 mm/yr

Note that some Australian workers have preferred to using a Tanh curve to examine the relationship between rainfall and runoff (Grayson et al. 1996). This curve is constructed by using accumulated values of rainfall excess (streamflow estimated using the Tanh function) and observed streamflow (Grayson et al. 1996).





Right: Example of a double mass analysis (1971-2004) for the Boyd River at Broadmeadows, NSW, which is located about 65 kilometres southeast of Glen Innes. The catchment is located in the uplands of northern NSW and is heavily forested. As such, it is expected that there should be little change in the streamflow-rainfall relationship over time, despite a high variability in rainfall.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
E: info@frogtech.com.au
ABN: 29 129 411 981

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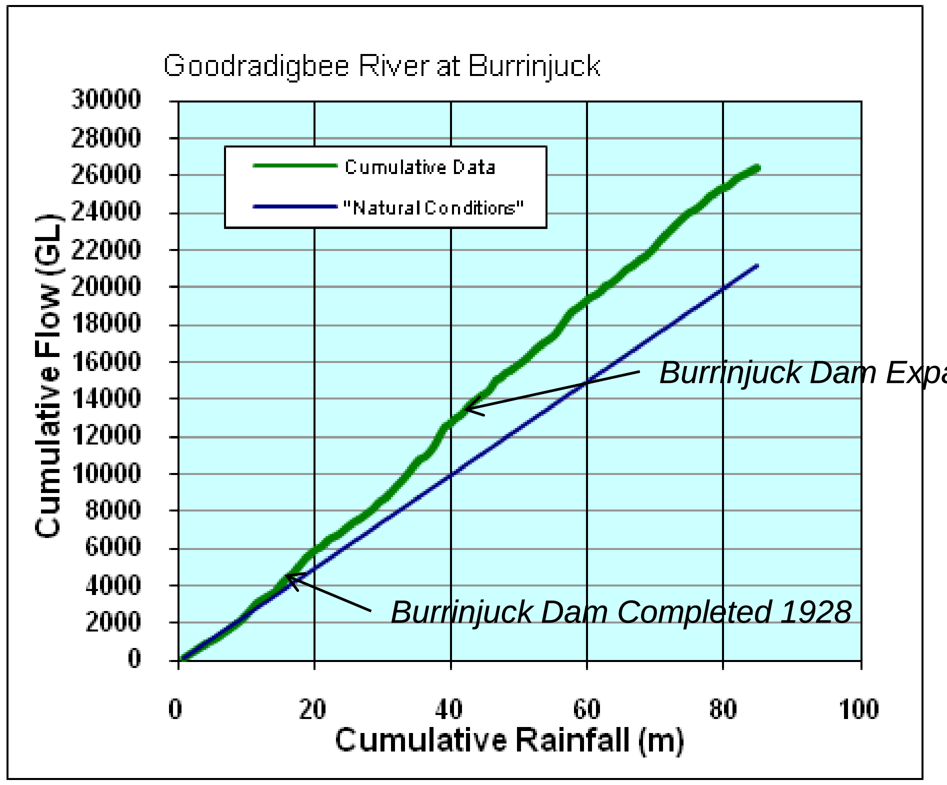
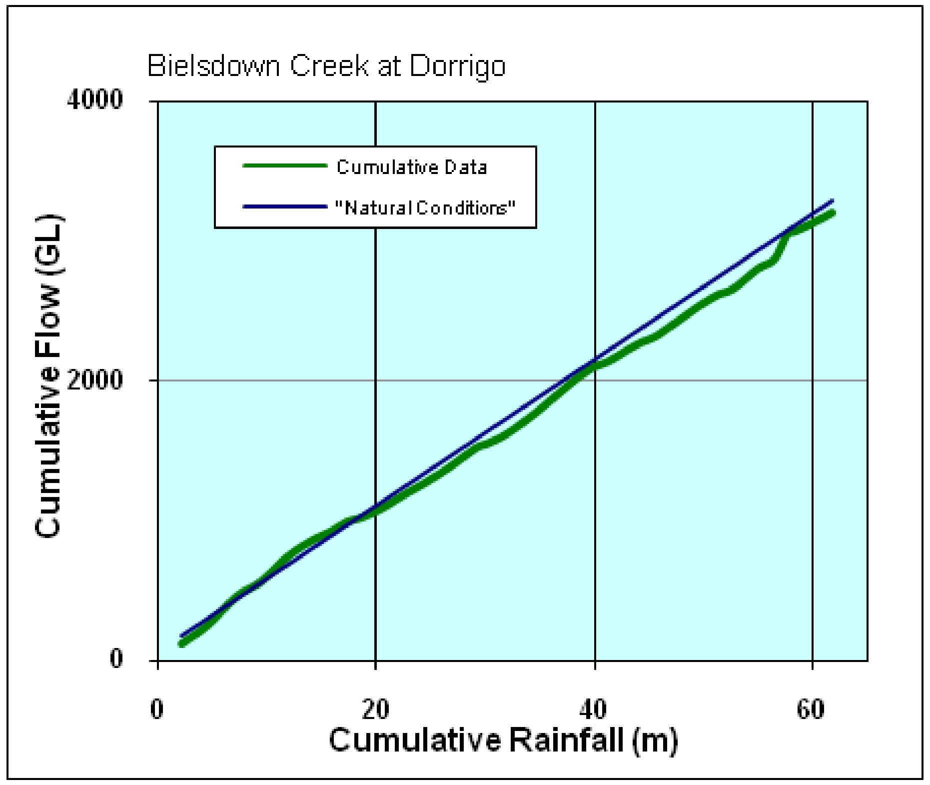
Double Mass Analysis cont.

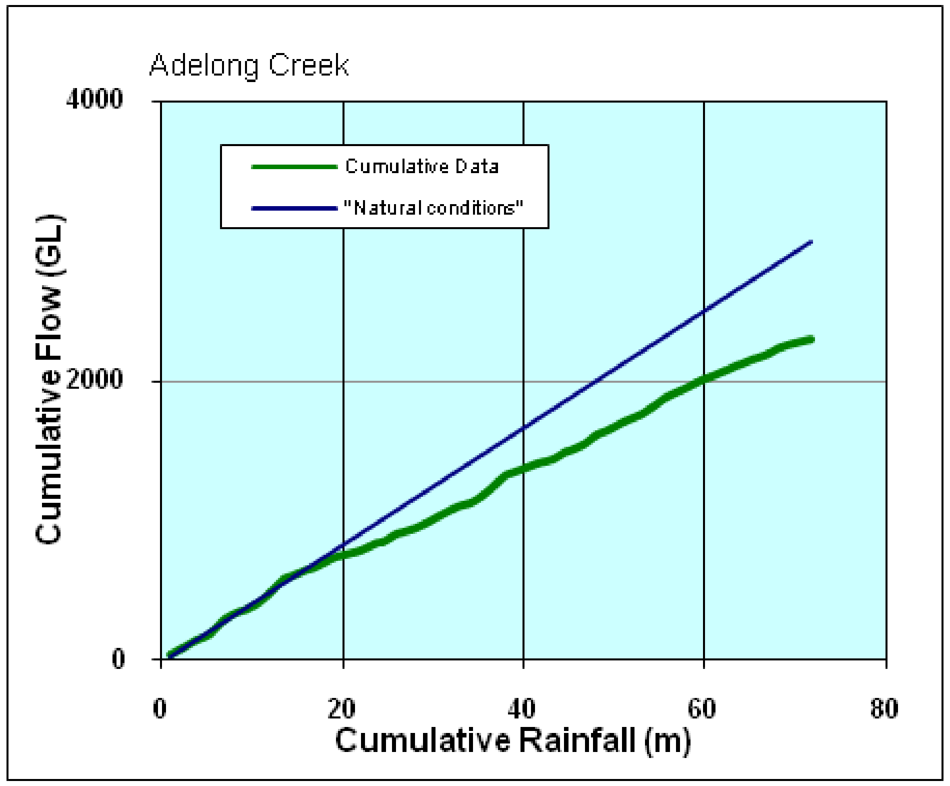
There many several possible changes in the relationship between streamflow and rainfall. Streamflow can increase relative to rainfall **(A)**; there can be little or no change **(B)**; or streamflow can decrease relative to rainfall **(C)**. In addition, there can be intermediate catchments in which the relative increase or decrease in streamflow relative to rainfall is not constant through time (not shown).



A. Double Mass Analysis for Goodradigbee River at Burrinjuck (from 1915-2004) showing an increase in the streamflow-rainfall relationship over time. This could be due to land clearing (forests use more water than grassland) or changes in farming practices. The increase may also be due to the presence of Burrinjuck Dam as the inflection points (shown) tend to occur during major phases of construction. Average increase in flow over the last 80 years is ~66.4 GL/yr.



B. Double Mass Analysis for Bielsdown Creek at Dorrigo (from 1972-2004) showing little change in flow conditions through time. This would suggest that there has been no significant change to the catchment.



C. Double Mass Analysis for Adelong Creek at Batlow Road (from 1948-2004) showing a relative decrease in streamflow-rainfall relationship over time. This change is probably due to a combination of direct consumptive use from the river and shallow groundwater, the increase in farm dams and/or the increase in commercial forestry in the Adelong Creek catchment. The average decrease in streamflow over the last 47 years is ~5.8 GL/yr.

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Lack of baseline hydrological datasets
The Upper Hunter has a lack of longterm surface water and groundwater monitoring. Without adequate baseline datasets, the effects of CSG mining cannot be adequately measured or modelled.

Recommendation 1

Therefore, before CSG exploration or production starts, there needs to be established:

- a network of surface water gauges in affected catchments with a baseline establishment period of at least 10 years;
- a network of continuously monitored, telemetered, nested piezometers throughout the Upper Hunter to provide calibration and baseline data on groundwater at various depths. Such a network will also help to understand the relationship between potable aquifers and the targeted coal seams; and
- a program of groundwater quality sampling in the Upper Hunter to establish both baseline data, but also to allow for early warning on potential contamination from CSG mining. Samples to be taken from both groundwater bores under use and from the piezometer network described above. Water samples should be analysed for major and minor chemistry, as well as BTEX chemicals and other volatile compounds.

Highly stressed system
While rainfall in the Upper Hunter has remained near normal, streamflow and groundwater levels have decreased.

Co-produced water and salt
CSG mining produces a high volume of co-produced water, which also contains high levels of salt and heavy metals.

Recommendation 2
The preferred method of disposal of co-produced water should be re-injection of the water back into the original coal seam as soon as possible.

Such a policy will not only dispose of the salt and water safely, but it will act to re-pressurise the coal seam, limiting potential negative effects on groundwater and surface water levels.

Groundwater modelling
Groundwater models are a key tool for understanding the effects of CSG mining on other users.

Recommendation 3
In order to measure the effects of not just a single CSG scheme, but the cumulative effects throughout the region/state, a master groundwater model of the Upper Hunter (and indeed NSW) should be built and maintained by an independent group.

Data resolution can be enhanced through incorporation of data from the groundwater and surface water baseline datasets, and through extensive, longterm (1-3 months) pump tests in strategic locations, so that the groundwater model is based on the best available information.

As part of maintaining the groundwater model, the independent group will be able to advise the NSW Government, CSG companies and landholders if there is enough data in an area to give certainty about the effects of CSG mining.

Other stresses
CSG mining is just one potential pressure point for the Upper Hunter.

Recommendation 4
In order to understand and manage these risks, it is recommended that the NSW Government in partnership with the local government, industries and people from the Upper Hunter, develop a comprehensive, whole of region plan. Such a plan should include an assessment of known and unknown information, potential risks and strategies to limit/manage risks.

FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
Deakin West, ACT 2600
CANBERRA, AUSTRALIA

T: +61 2 6283 4800
F: +61 2 6283 4801
W: www.frogtech.com.au
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FrOG Tech Pty Ltd
PO Box 250
Suite 17F, Level 1, 2 King St
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