Report No: P WMA
19/G10/00/2413/5

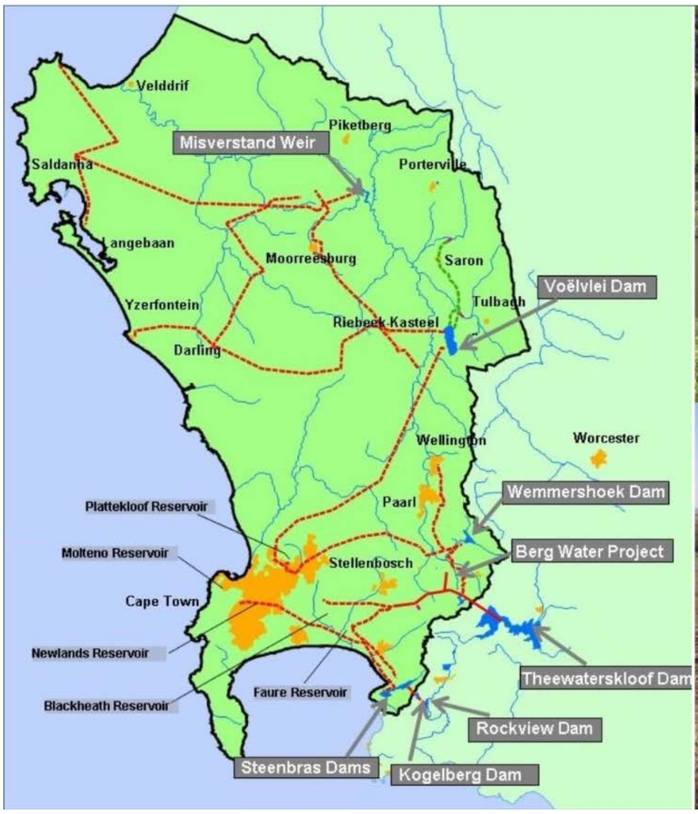
Department of Water Affairs
Directorate: Options Analysis

PRE-FEASIBILITY AND FEASIBILITY STUDIES FOR AUGMENTATION OF THE WESTERN CAPE WATER SUPPLY SYSTEM BY MEANS OF FURTHER SURFACE WATER DEVELOPMENTS

REPORT No.3 – VOLUME 1
Berg River-Voëlvlei Augmentation Scheme

APPENDIX No.1

Updating of the Western Cape Water Supply System Analysis for the Berg River Voelvlëi Augmentation Scheme



December 2012

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1	**ECOLOGICAL WATER REQUIREMENT ASSESSMENTS**	Vol 1	PWMA19 G10/00/2413/1	**Riverine Environmental Water Requirements**
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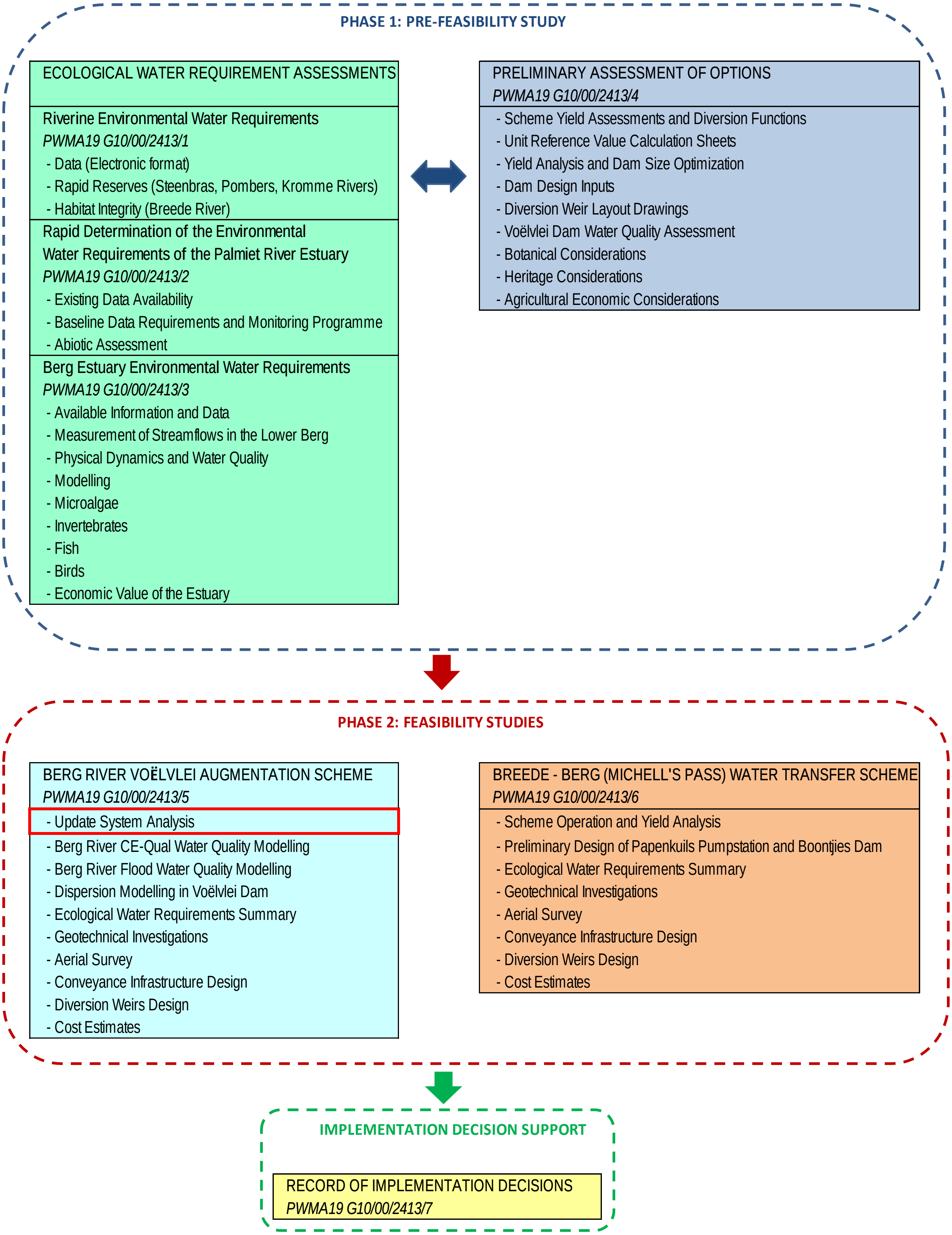
STUDY REPORT MATRIX DIAGRAM



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RECORD OF IMPLEMENTATION DECISIONS
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1 Review of Theewaterskloof Dam Naturalised Inflow Sequence

The evaporation and rainfall input data for Theewaterskloof Dam was reviewed, in recognition of the dam's large surface area of approximately 50 km^2 and the following adjustments were made:

- Evaporation – The evaporation for Theewaterskloof was selected from the average of the three driest consecutive years recorded at Theewaterskloof, namely 1981 to 1983, as this will more accurately represent the behaviour of the dam during the dry critical drawdown period.

- Mean Annual Rainfall – The WAAS study erroneously used the average mean annual rainfall of the Theewaterskloof Basin, rather than the rainfall at the Dam itself, which is significantly less. During the current study the rainfall value represents the rainfall at the Dam itself.

During the WAAS study a careful assessment was made of the streamflows entering Theewaterskloof Dam to obtain a representative sequence. The sequence selected nevertheless results in higher stochastic than historical yields as is explained below.

During the WAAS study a careful assessment was made of the various streamflow records related to the Theewaterskloof Dam site. The historical observed streamflow record at Theewaterskloof Dam comes from a number of different sources of varying degrees of reliability. Initially a gauge, H6H003, was constructed upstream of the (then) proposed dam and this was used for about 6 years (Oct 1967-May 1974) until it was submerged during the construction of Theewaterskloof Dam. The latter period happened to be one of the driest on record. The WAAS interpretation was that this gauge had under-recorded the high streamflows, leading to depressed simulated inflows and yields during the WCSA and the later Berg River Dam Feasibility Study. The naturalised inflow sequence finally derived during WAAS results in markedly higher stochastic than historical firm yields. In this study, this work was reviewed in detail and the WAAS findings were fully confirmed.

After submergence of H6H003, a new gauge, H6H012, was constructed downstream of Theewaterskloof Dam to measure releases and spills from the Dam. The bulk transfers to Cape Town, the Berg River Irrigation Board and the Wemmershoek WTW through the Riviersondend Tunnel, the abstractions by the Vyeboom Irrigation Board from the Dam and the evaporation and rainfall on the Dam surface need to be taken into account to determine the inflow into the dam.

After construction of the Dam the inflow to the Dam was determined by a "reverse mass balance" calculation. Over any time period, say one month, the inflow into dam is determined from:

- Change in storage in the dam (H6R001) plus
- Abstractions from the Dam (G1H053 + G1H054 + G1H055 + H6H020) plus
- Spills/Releases from the Dam (H6H012) plus
- Net evaporation from the Dam (H6E001-P01 for precipitation and H6E001-E01 for evaporation).

The locations of the different gauges are shown schematically in **Figure 1** while **Figure 2** shows the streamflow measuring periods for each different approach.

The accuracy of this derived inflow sequence for the Dam is highly dependent on the accuracy of the individual components of the reverse mass balance. The major component for Theewaterskloof is the transfer into the Riviersonderend Tunnel and comprises about 45% of the total. Unfortunately, while this measurement may be reasonably accurate, it is very difficult to check. **Figure 3** compares the reported transfer/ from the Tunnel with the outflows from the Tunnel. In isolated hydrological years (1987, 1991, 2002, 2003 and 2004) the correspondence is good, but in others it is poor, likely as a result of errors in the other measurements besides G1H053.

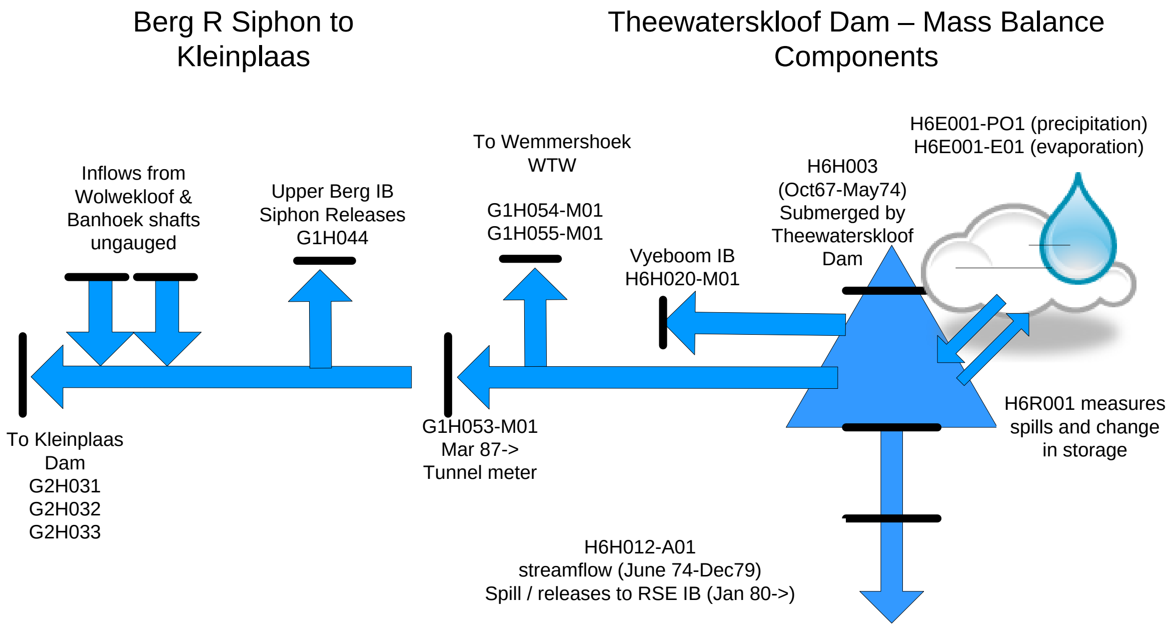


Figure 1: Mass balance components for the Theewaterskloof Dam

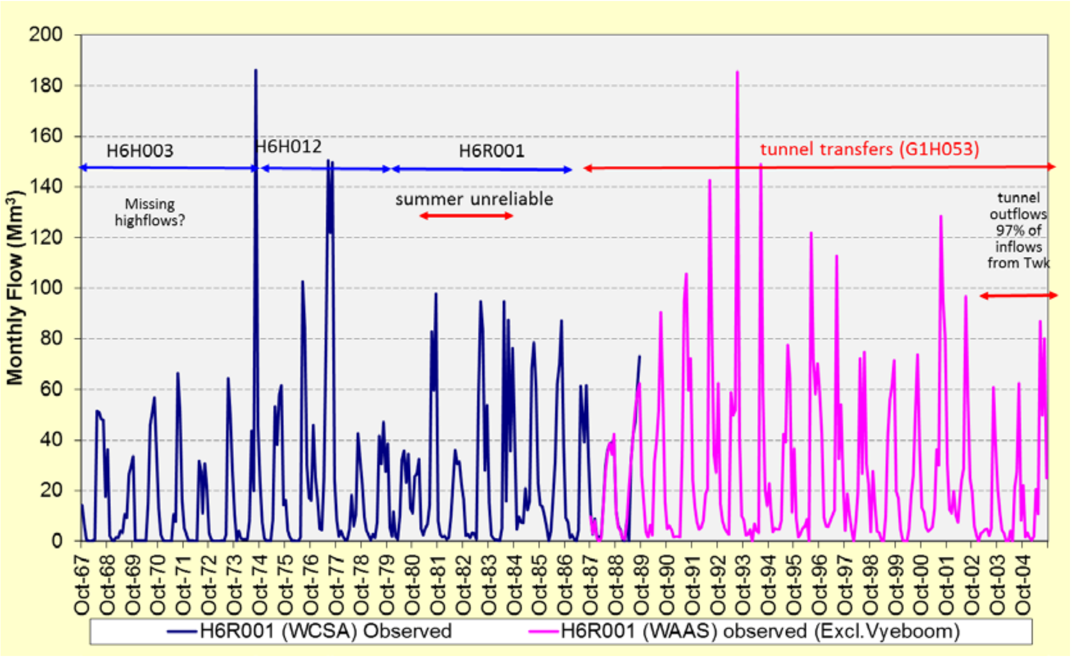
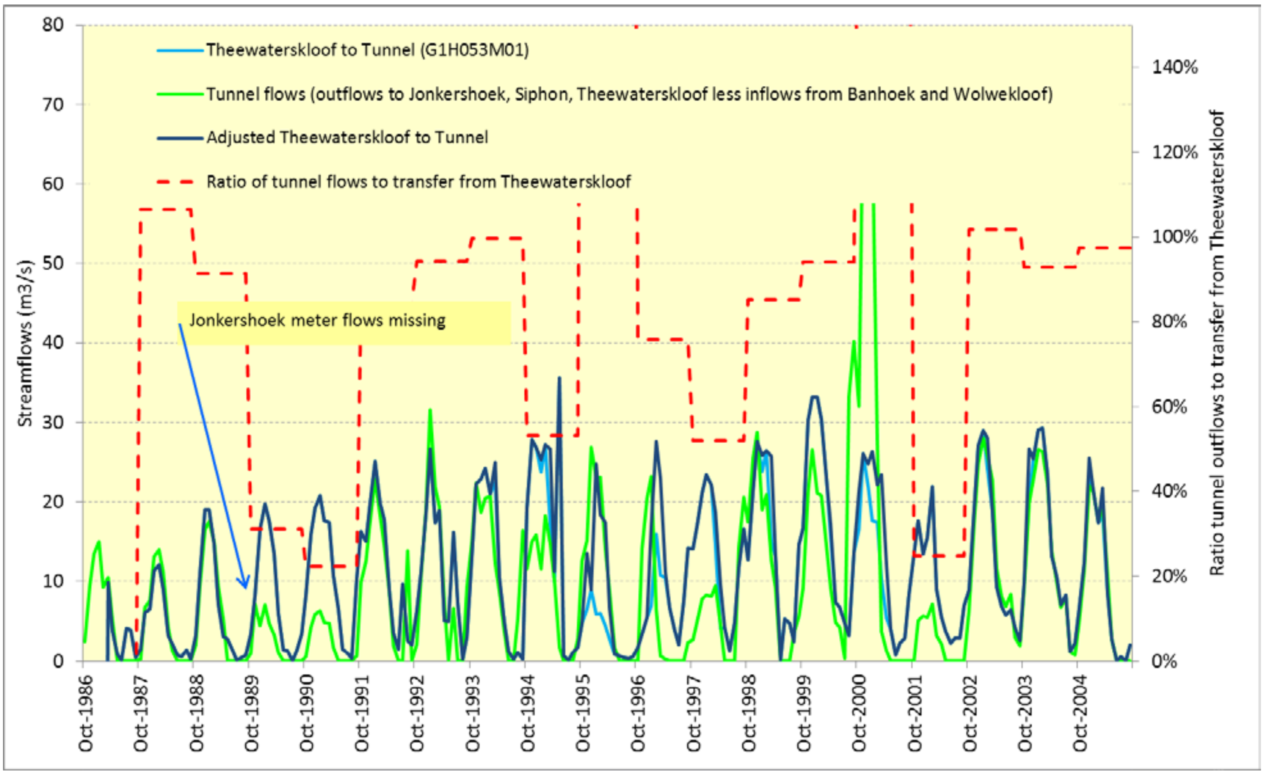


Figure 2 Different Periods that make up of the streamflow record at Theewaterskloof Dam



I:\Hydro\402812\PHASE 2\meeting\2Nov2011\Check Flows@H6r001\H6r001 dam balance calcs v3.xls" sheet “TheewaterskloofToTunnel”

Figure 3: Verification of transfers from Theewaterskloof into the Riviersonderend Tunnel

A calibrated rainfall-runoff model can provide an independent check of the streamflow measurements, in that a rainfall sequence is used to estimate the runoff from a catchment and this can be compared with the observed streamflows. Obviously rainfall records can also be faulty, but when the streamflow simulated from rainfall and the observed streamflow for any selected period agree it helps to confirm the accuracy of the streamflow gauge for that period, or vice versa.

The observed streamflows and the simulated streamflows developed during the WCSA and the WAAS study are compared for the different periods in **Table 1**. During the period 1967 to 1974, the simulated streamflows from both the WCSA (196 million m^3/a) and WAAS (237 million m^3/a) studies are larger than the observed streamflows at H6H003 (179 million m^3/a), indicating that gauge H6H003 under-recorded high streamflows.

Table 1 Simulated versus Observed Streamflows at Theewaterskloof Dam

Period			Observed			Simulated			Ratio simulated to observed		
		a	b	c	c*0.79	e	f	g=f-e	h=e/b	i=f/b or f/c	
Dates	Description	no wet seasons	WCSA observed	WAAS observed	97% WAAS	WCSA simulated	WAAS simulated	Diff in simulated MARs	WCSA	WAAS	
Oct 67 - May 74	H6H003 (before submergence)	6	179			196	237	41	109%	132%	
Jun74 - Dec 79	H6H012 ds dam	5	371			371	419	48	100%	113%	
Jan80 - Sep 89	Theewaterskloof Dam	9	319			280	331	50	88%	104%	95%
Oct89 - Sep 02		12		380			331			87%	
Oct02 - Sep 05		3		206	200		203			99%	
Oct28 - Sep 89	Long term simulated record	61				274	312	38			

In the later periods, which may arguably have better streamflow records if the Tunnel meter G1H053 is sufficiently accurate, the simulated sequences for both WCSA and WAAS are less than the observed streamflows. For instance, in the WCSA study the simulated streamflows over the period January 1980 to September 1989 are 88% of the observed streamflows. Had the WCSA ignored the period prior to 1979 and calibrated the model on the period from January 1980 to September 1989, then the streamflows generated would have been about markedly higher. Similarly, in the WAAS study, the simulated streamflows averaged over the period from January 1980 to September 2005 are 95% of the observed streamflows.

The composite record of streamflows at the Theewaterskloof Dam site was also compared with two upstream gauges to identify trends. **Figure 4** depicts the ratio of recorded annual streamflow at Theewaterskloof to the combined annual streamflows from H6H007 and H6H008 located upstream. During the period prior to 1974 the ratio is less than afterwards, suggesting that the streamflows at Theewaterskloof are under-recorded during that period.

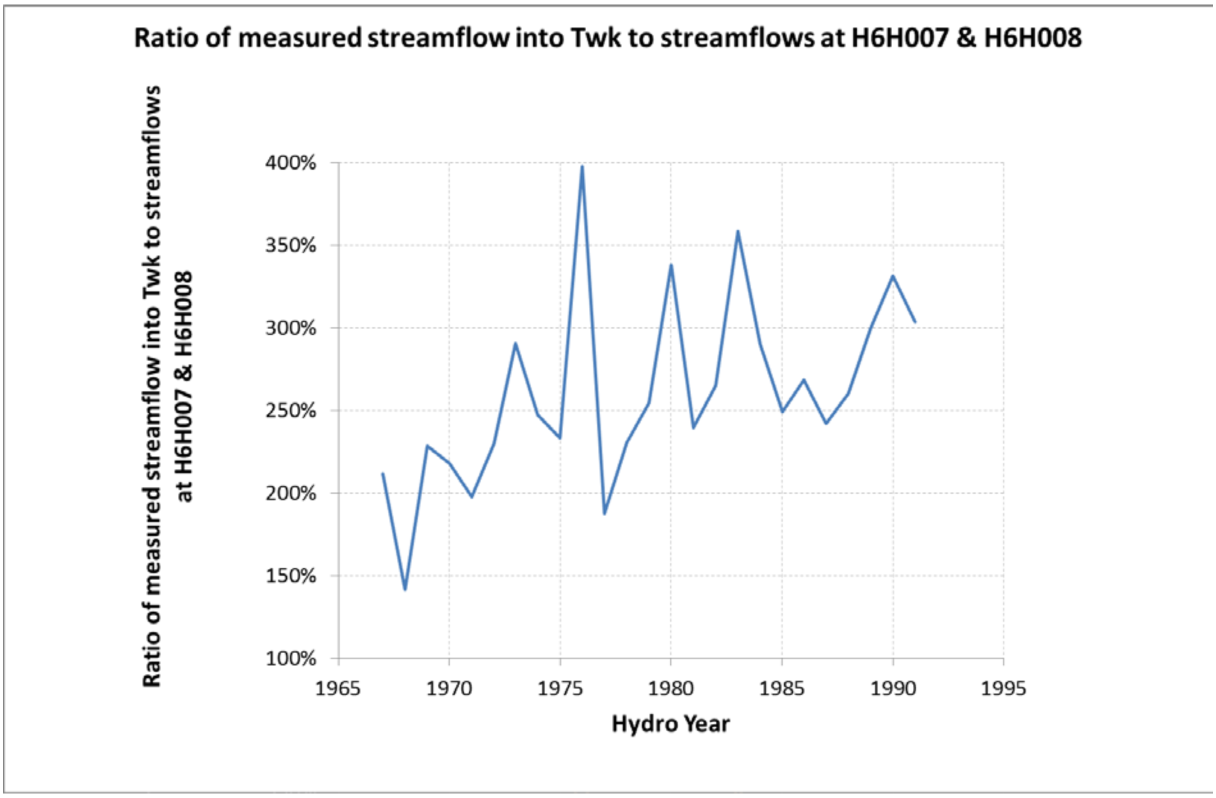


Figure 4: Ratio of measured annual inflow to the combined streamflows from H6H007 and H6H008 located upstream

The area upstream of H6H007 and H6H008 is mountainous with a higher MAP than the area between those gauges and the Theewaterskloof Dam site. The period prior to 1974 was a drought period and during such periods it is possible that the lower rainfall areas such as that around the Dam may experience a larger decrease in runoff than the higher mountainous areas upstream of gauges H6H007 and H6H006. To check the effect of MAP on the ratio of the streamflows at Theewaterskloof to the streamflows at gauges H6H007 and H6H008, the ratio was plotted as a function of annual rainfall rather than hydrological year in **Figure 5**. This diagram confirms that the ratio is sensitive to the annual rainfall and increases as the annual rainfall increases. However, if a line is fitted to the points from 1968 to 1974 and another line is fitted to the points from 1975 to 1991, then the line for the earlier period lies well below that from the latter period. The difference is about 12%, which equates to about 40 million m^3/a for a Theewaterskloof MAR of about 300 million m^3/a (see **Table 1**).

This analysis also confirms that streamflows at the Dam site were under-recorded for the period from 1968 to 1974.

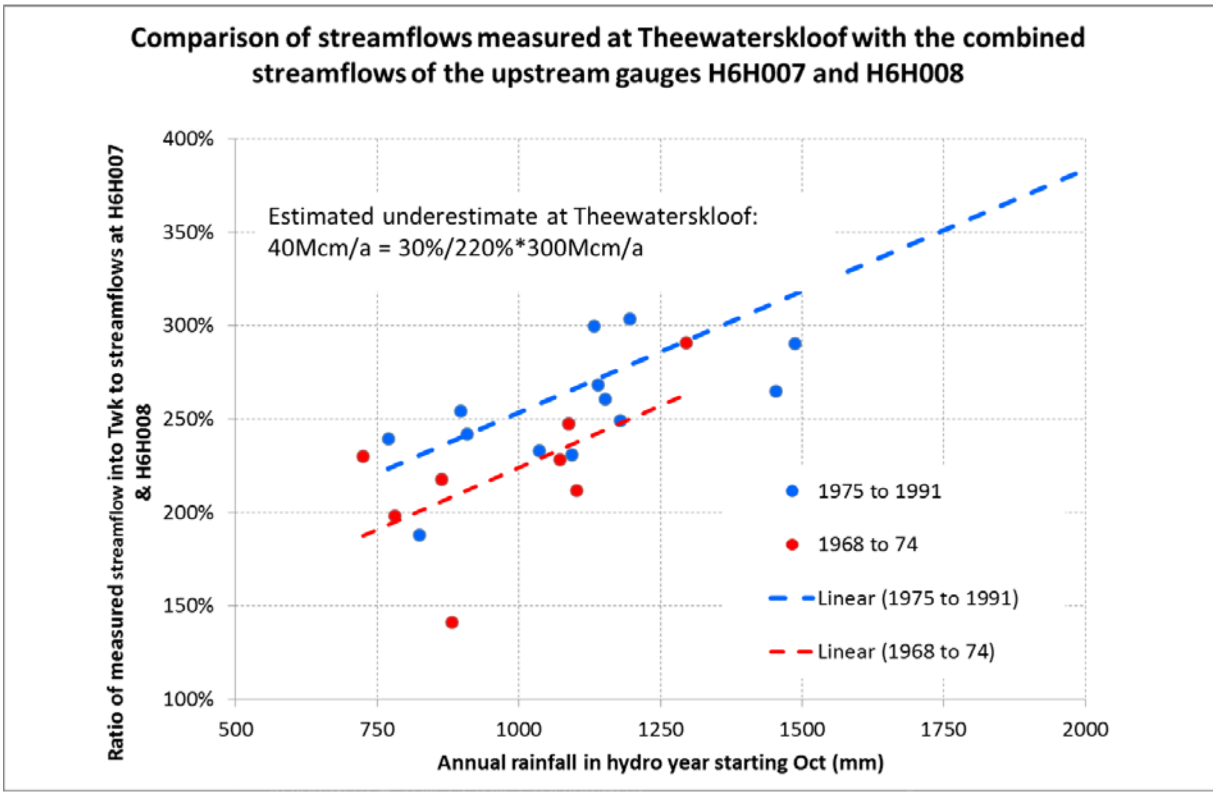


Figure 5: Comparison of annual streamflows measured at Theewaterskloof with the combined streamflows of the upstream gauges H6H007 and H6H008

The Theewaterskloof streamflow sequence used in WAAS was obtained by splicing together the simulated natural sequence for the period prior to 1967 with the observed record post-1967, which had first been naturalised. The critical period in this sequence occurs during 1968 to 1974, which also corresponds with the period when the streamflows were probably under-recorded.

The GENTEST program outputs allow a further perspective on this matter: **Figure 6** indicates that the stochastic yields for the incremental sub-catchment downstream of gauges H6H007 and H6H008 and Elandskloof Dam are larger than the corresponding historical firm yield over a wide range of dam capacities. For example, for a hypothetical dam capacity of 100% MAR, the historical firm yield (blue line) is given as 60% of the MAR while the median stochastic yield (green line) is 70% of the MAR. This offers further support for the view that the embedded drought sequence was quite likely under-recorded.

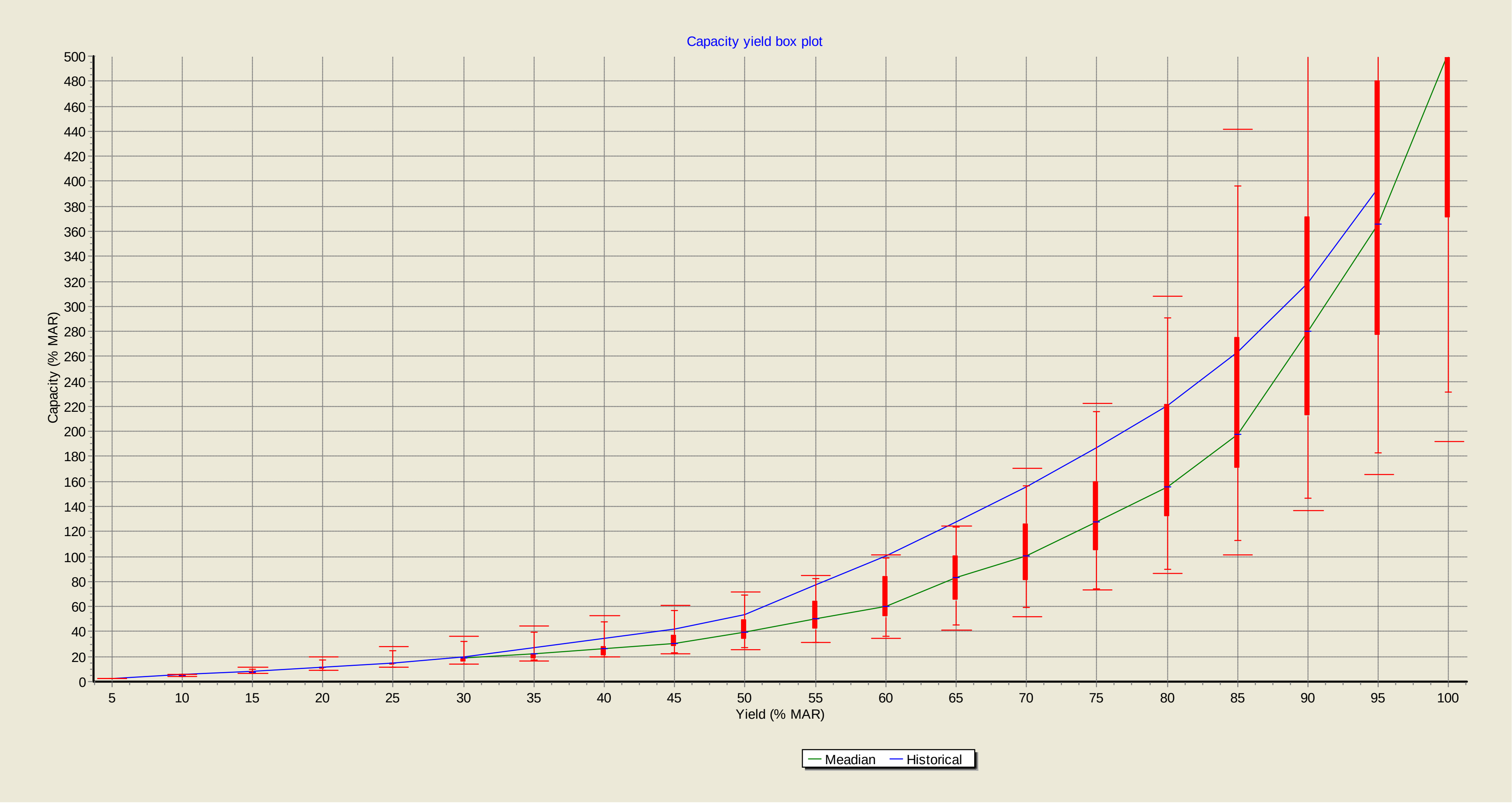


Figure 6: **Capacity/yield comparison of the historical and stochastic time series for the Theewaterskloof Dam incremental catchment (based on 41 sets of stochastic streamflow sequences).**

2 Unpacking the difference between the HFY and the 1:50 stochastic yield for the Updated WCWSS Model

In the Main Report on the BRVAS Feasibility Study it is reported that the historical firm yield (HFY) of the fully updated and refined WCWSS model, incorporating the WAAS naturalised streamflow sequences, is 529 million m^3/a. The 1:50 year stochastic yield of the fully updated, refined and integrated WCWSS model , incorporating the WAAS naturalised streamflow sequences, is 579 million m^3/a. In order to evaluate the veracity of this yield difference the incremental yields of the incremental sub-systems of the WCWSS were inspected in great detail, as follows:

GENTEST-generated box-whisker plots and curves comparing the stochastic and historical firm yields were prepared for each of the incremental sub-system in the WCWSS (using 41 sets of stochastic streamflow sequences). The results are presented in **Table 2**.

Column "d" in **Table 2** gives the ratio of storage to MAR used when the sub-systems operate separately and column "n" gives the ratio of storage to MAR for the system if the sub-systems are operated in an approximately integrated manner. A scaling factor was determined so that the historical firm yields from applying the ratios from the Yield/MAR curves match the historical firm yields from the WRYM modelling for the separate and integrated cases (columns "j" and "t"). The same scaling factor was applied to the stochastic yields for each of the cases in column "l" and "t".

Table 2 shows that the accumulated sub-system median stochastic yields for the entire system would be about 26 million m^3/a more than the historical firm yields if the sub-systems operated separately, while that difference increases to 30 million m^3/a, if the system operated in an approximately integrated manner. This difference, based on the stochastic medians, is substantial and verifies that the difference in the 1:50 year stochastic yield and the HFY for fully updated, refined and integrated WCWSS model is to be expected.

Table 2: Evaluation of the difference between the historical and stochastic yields for the Updated WCWSS Model (based on 41 sets of stochastic streamflow sequences)

Incremental Sub-Systems	MARs			Separate sub-systems									Approximate Integrated system							
				Ratios from GENTEST Yield/MAR curves		Estimated historical and stochastic yields from GENTEST curves		Actual simulated HFYs taking environmental releases and diversion efficiencies into account	Fraction	Scale yields to match HFYs			Storage/ MAR	Ratios from GENTEST Yield/MAR curves		Estimated historical and stochastic yields from GENTEST curves		Actual simulated HFYs taking environmental releases and diversion efficiencies into account	Scale yields to match HFYs	
	Storage	MAR	Storage/MAR	HFY/ MAR	Median Stochastic Yield / MAR	HFY	Median Stochastic yield			HFY	Median Stochastic yield	Median Stochastic - HFY		HFY/ MAR	Median Stochastic Yield / MAR	HFY	Median Stochastic yield		Scale factor	Median Stochastic - HFY (scaled)
column a	b	c	d	e	f	g=c*e	h=c*f	i	j=i/g	k=g*j	l=h*j	m	n	o	p	q=e*o	r=e*p	s	t=s/q	t=(r-q)*s
Theewaterskloof	**431**												98%							
h6r02gw		22.0	136%	75%	78%	17	17							70%	74%	15	16			1
H6INCGW		191.9		67%	78%	129	150							60%	70%	115	134			17
H6SONGW		64.3		89%	91%	57	59							83%	86%	53	55			2
H6DUTGW		38.7		81%	82%	31	32							72%	72%	28	28			0
sub-total		316.9				234	257	216	92%	216	238	22				211	233			
Wemmershoek	**58.5**		79%																	
g1r02-d		74.1		71%	74%	53	55							75%	78%	55	57			2
sub-total		74.1				53	55	51	97%	51	53	2				55	57			
BRD	**122.2**		85%																	
g1h04a-s		84.8		74%	77%	63	65							76%	78%	64	66			1
g1h04b-s		27.4		75%	77%	21	21							76%	78%	21	21			0
g1h38-s		24.6		75%	77%	18	19							76%	78%	19	19			0
g1skf-d		6.2		57%	59%	4	4							60%	61%	4	4			0
sub-total		143.1				105	109	87	83%	87	90	3				108	110			
Voelvlei	**150.7**		64%																	
g1h08-d		29.3		55%	55%	16	16							62%	62%	18	18			0
g1h08-s		54.9		67%	70%	37	38							73%	76%	40	42			1
g1h28-s		125.5		75%	72%	94	90							79%	83%	99	104			4
g1h29-s		21.5		71%	73%	15	16							81%	81%	17	17			0
g1r01-d		2.5		61%	59%	2	1							67%	65%	2	2			0
sub-total		233.8				164	161	99	61%	99	98	-1				176	183			
Steenbras Upper	**30.0**		89%																	
Steenbras Lower	**33.9**																			
g4r01-s		47.2		82%	85%	38	40							82%	86%	39	41			2
Palmiet (g4h05-s) - scaled to average transfer		24.5		86%	84%	41	40							87%	85%	21	21			0
sub-total		71.7				79	80	62	78%	62	63	1				60	61			
Total	826.2	839.5	98%			634	662	515				26				611	646	529	87%	30

3 Review of Inefficiencies of the Operation of Kleinplaas Dam on the Jonkershoek River

The spillage at Kleinplaas was investigated in more detail, comparing the actual spillage with the theoretical for the period 1999 to 2010 – illustrated in **Figure 7** and **Figure 8.** In theory, Kleinplaas should have very little spillage given the large abstraction capacity of the pipelines supplying the 400 Ml/d Blackheath and 500 Ml/d Faure WTWs. In practice, the abstraction capacity is affected by:

- the closure of the WTWS for maintenance
- the reduced water requirement during winter
- the need to increase the abstraction from other dams which might be at risk of spillage during winter.

The behaviour of the Water Resources Yield Model (WRYM) at Faure was adjusted to reflect the historical spillage at the dam, rather than the theoretically possible abstraction by using the diversion function in **Table 3** to model the spills. This exercise indicates that the system yield will increase by up to 9 million m^3/a if the Jonkershoek inflows were intercepted rather than allowed to spill.

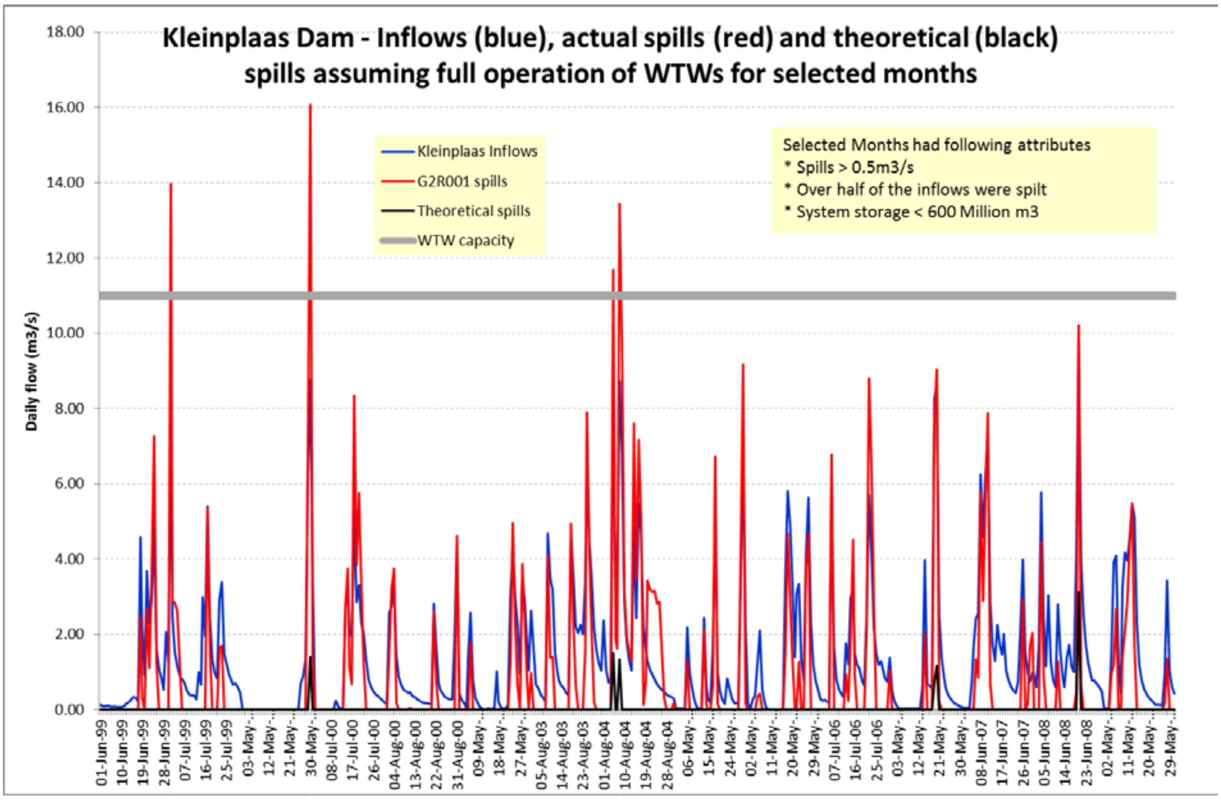


Figure 7: Inflows(blue), Measured Spills (red) and Modelled / Theoretical Spills (black) at Kleinplaas Dam

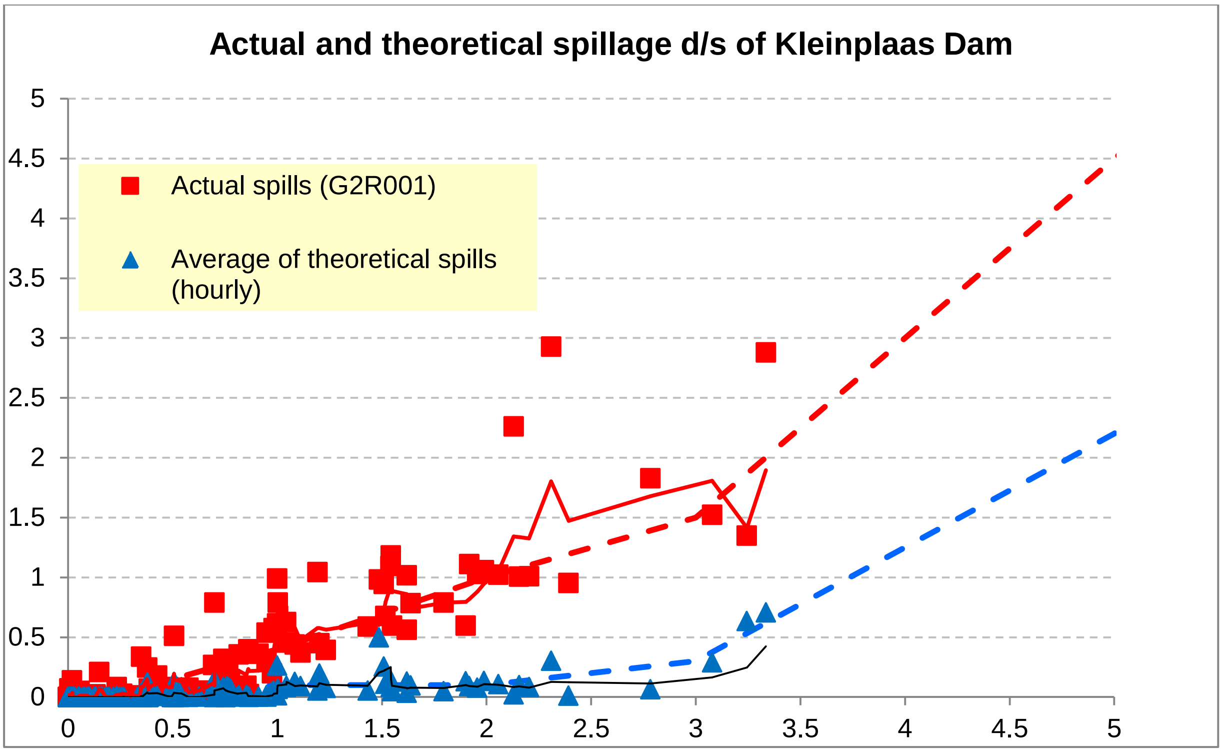


Figure 8: **Relationship of average monthly Inflows (blue) (m^3/s) to average monthly Measured Spills (red) (m^3/s) and Modelled / Theoretical Spills (black) (m^3/s) at Kleinplaas Dam**

Table 3: Relationship of Monthly Inflow (m^3/s) to Monthly Spillage (m^3/s) at Kleinplaas Dam

Inflow (m^3/s)	0	0.4	1	2	3	5	99
Fitted spill (actual)	0	0.1	0.4	1	1.5	3.5	99
Theoretical reduced spill (hourly model)	0	0.1	0.1	0.1	0.3	2.2	96

4 Finer Discretization of Natural streamflows, Irrigation Demands, Lumped Farm Dams and Transmission Losses in the Berg River

As part of this study additional 24 EWR nodes were introduced into the Water Resources Yield Model (WRYM) to enable streamflows to be simulated at these sites and compared, if necessary, with the EWRs. The introduction of the EWR nodes required that the various components in the current model had to be split into portions upstream and downstream of the node site, including:

- Natural streamflows
- Irrigation Demands
- Lumped Farm Dams
- Losses

4.1 Natural streamflows

The natural runoff was apportioned by examining the natural runoffs determined as part of the WAAS study and establishing a relationship between the mean annual precipitation (MAP) and the unit mean annual runoff (MAR) from each catchment, namely:

$$\text{Unit MAR} = 6344.(\text{MAP})^{(-385/\text{MAP})}$$

This relationship was used to determine the unit MAR from each of the sub-catchments introduced in this study. Scaling the unit MAR by the sub-catchments' areas gave the relative MAR from each of the sub-catchments and these relative MARs could be used to apportion the MAR from each WAAS sub-catchment to its constituent EWR sub-catchments.

The scaling factors applied to discretize the WAAS streamflows in order to obtain the streamflows at the EWR nodes are given in **Table 4.** The WAAS streamflows were already discretized to provide separate streamflow sequences upstream and downstream of the farm dams and separate factors were provided to discretize each of these sets of streamflows.

Table 4: Allocating WAAS catchments upstream of farm dams to subcatchments upstream of EWR nodes, which are defined at a finer resolution

		EWR nodes																							Total
		Bi1	Biii2	Biii3	Biii4	Biii5	Biv1	Biv3	Biv4	Biv5	Bvii10	Bvii11	Bvii12	Bvii2	Bvii3	Bvii4	Bvii5	Bvii6	Bvii7	Bvii8	Bvii9	Bviii2	Bviii3	Bviii4	Bviii8	
WAAS sub-catchments	g1h028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1h029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1h03	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1h08	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h19	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h20	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	1.0
	g1h35x30%(1)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h36t	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0.1	0.1	0.4	0	0	0	0	0	0	0	0	1.0
	g1h38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1hhr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1hsup	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1rlli	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1ro2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1rskf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	g1whc	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	glrlltd	0	0	0	0	0	0.2	0.1	0.6	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	1.0

Allocating WAAS catchments downstream of farm dams to finer subcatchments upstream of the EWR nodes

		EWR nodes																							Total
		Bi1	Biii2	Biii3	Biii4	Biii5	Biv1	Biv3	Biv4	Biv5	Bvii10	Bvii11	Bvii12	Bvii2	Bvii3	Bvii4	Bvii5	Bvii6	Bvii7	Bvii8	Bvii9	Bviii2	Bviii3	Bviii4	Bviii8	
WAAS sub-catchments	g1h028	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h029	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h03	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.0
	g1h08	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h19	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h20	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	1.0
	g1h35x70%(1)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1h36t	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.3	0.3	0	0	0	0	0	0	0.1	0	1.0
	g1h38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.0
	g1hhr	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	1.0
	g1hsup	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1rlli	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1ro2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0
	g1rskf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.0
	g1whc	0	0.4	0	0	0	0	0	0	0.3	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	1.0
	glrlltd	0	0	0	0	0	0.2	0.3	0.2	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0	0	1.0

[1] The WAAS streamflow for G1H035 was not split into a portion upstream and downstream of the farm dams and for the purposes of this analysis it was estimated that 30% of the G1H35 streamflow was upstream of farm dams

4.2 Irrigation demands

In the original WAAS study the irrigation demands were disaggregated according to the sub-catchment in which they were located (the sub-catchments were basically determined using DWA's streamflow gauges and the proposed schemes to determine the boundaries) and whether the demands were supplied from farm dams or pumped from the river.

The current study required greater discretization of the demands and the following information was used to apportion the demands with respect to the EWR sites:

- Location of the EWR sites (see **Figure 9**).
- Map showing the location and type of irrigation in the Berg River (see **Figure 10**). In the WAAS study irrigation areas downstream of Misverstand Dam were not digitised. These were estimated approximately for the current study using Google Earth images. The results of the current water use verification exercise by DWA can in future be used to update the land-use downstream of Voëlvlei Dam.
- Location of large pump schemes associated with large abstractions and the variation in application rates down the Berg River, which means that the same planted area located in the drier Northern reaches of the Berg requires more water that the equivalent area in the Southern reaches (see **Figure 11).**
- Extent of the sub-catchments associated with the original WAAS study and those associated with the EWR sites (see **Figure 12**).
- MAP Surface developed as part of the WAAS study and used to disaggregate the natural streamflows (see previous Section). These natural streamflows were used to estimate the summer streamflows from each sub-catchment which also reduced the volume of water that abstracted from the river.
- Farm Dam capacities based on data collected in the WAAS study, which determine the proportion of the demands that can be supplied from farm dams rather than from run-of-river abstractions.
- Actual releases to the Upper Berg Irrigation Board (i.e. excluding supply from farm dams, natural streamflow and other transfers). The annual consumption during a drought of 65 million m^3/a was taken to represent the potential current usage, which is slightly less than the actual allocation of 76.7 million m^3/a. From examining the location of the irrigation it was estimated that the undeveloped portion lay in the high application rate area. If the scheduled land allocated to the large irrigation boards (such as Riebeek Kasteel and Riebeek West) are assumed to be fully used, then about 45% of the remaining scheduled land is currently not in use. The assumed consumption of 65 million m^3/a was taken to represent the current situation during droughts and should be taken into account when determining the water available for other users. During wetter periods, irrigators might be able to irrigate less and also use water from their farm dams so the average releases to the Upper Berg River Irrigators, if the wetter periods are also considered, might be less than 65 million m^3/a.
- The scheduled release from Voelvlei Dam to the Lower Berg River irrigators is 18.1 million m^3/a, including an allowance for losses. The total irrigation requirement based on the approximate Google Earth-based digitised irrigation areas was increased to 18.1 million m^3/a by adding conveyance losses.

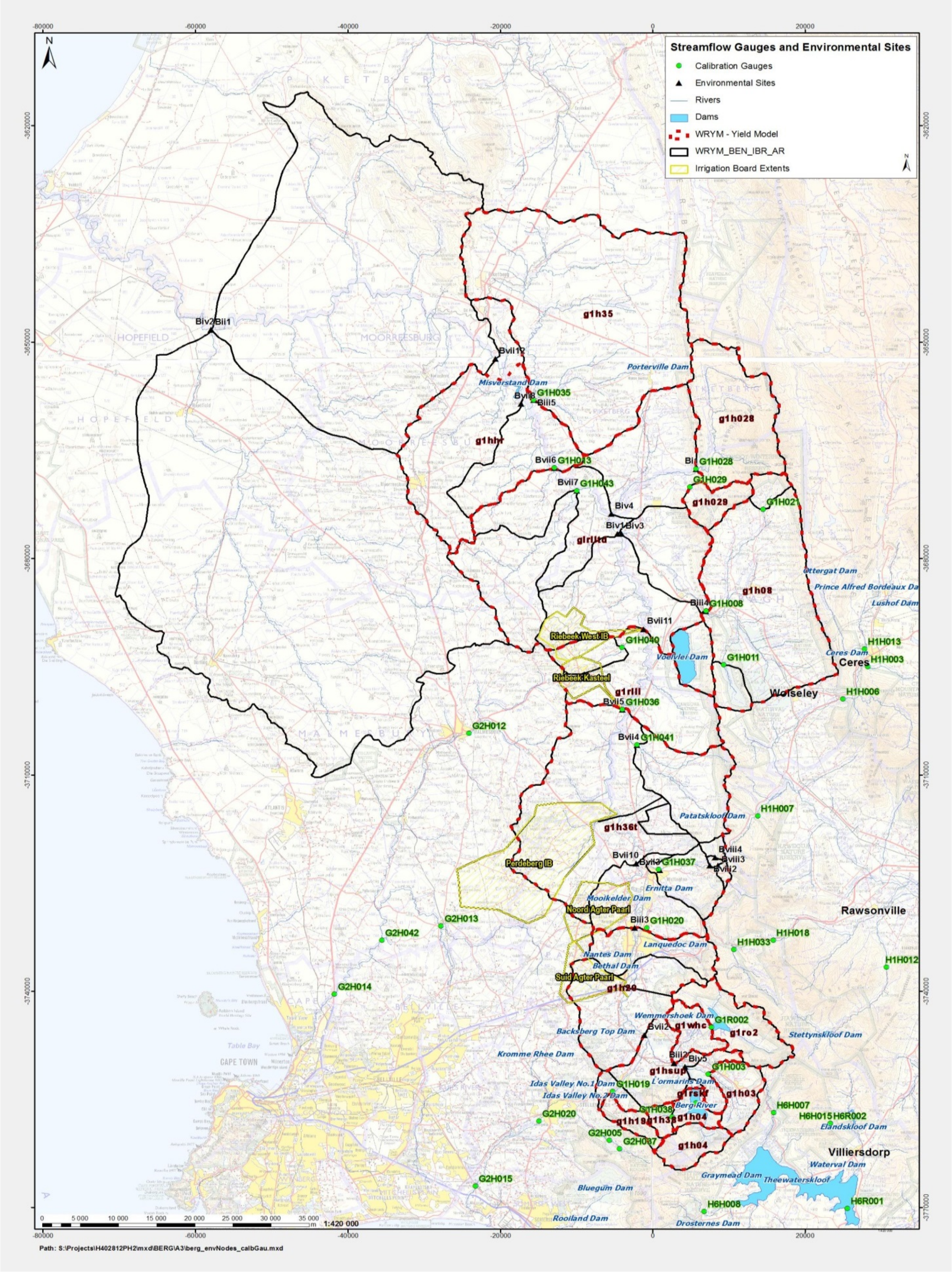
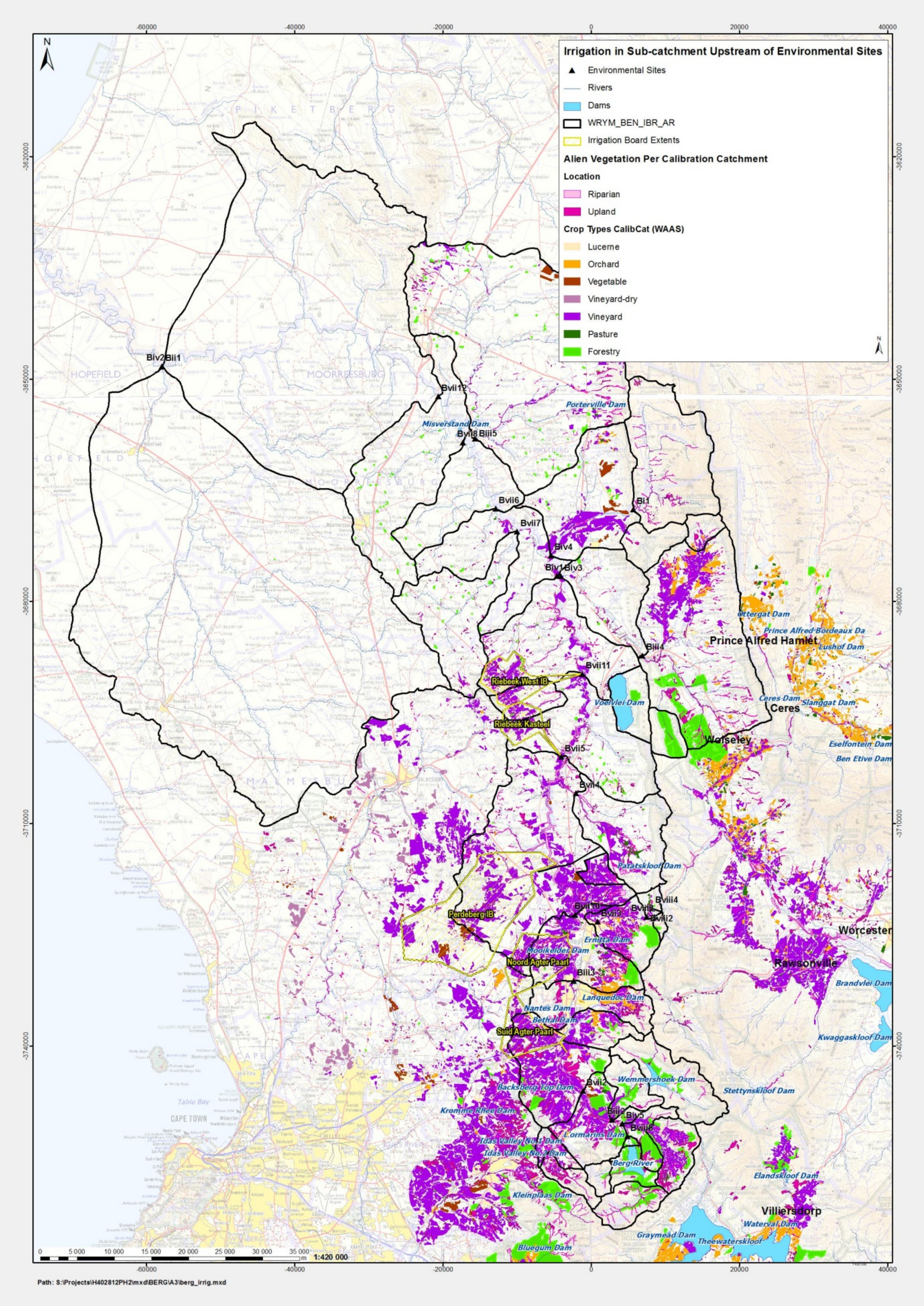


Figure 9: **Streamflow gauges and EWR sites**



Path: S:\Projects\H402812PH2\mxd\BERG\A3\berg_irrig.mxd

Figure 10: Irrigation in Sub-Catchments upstream of EWR Sites

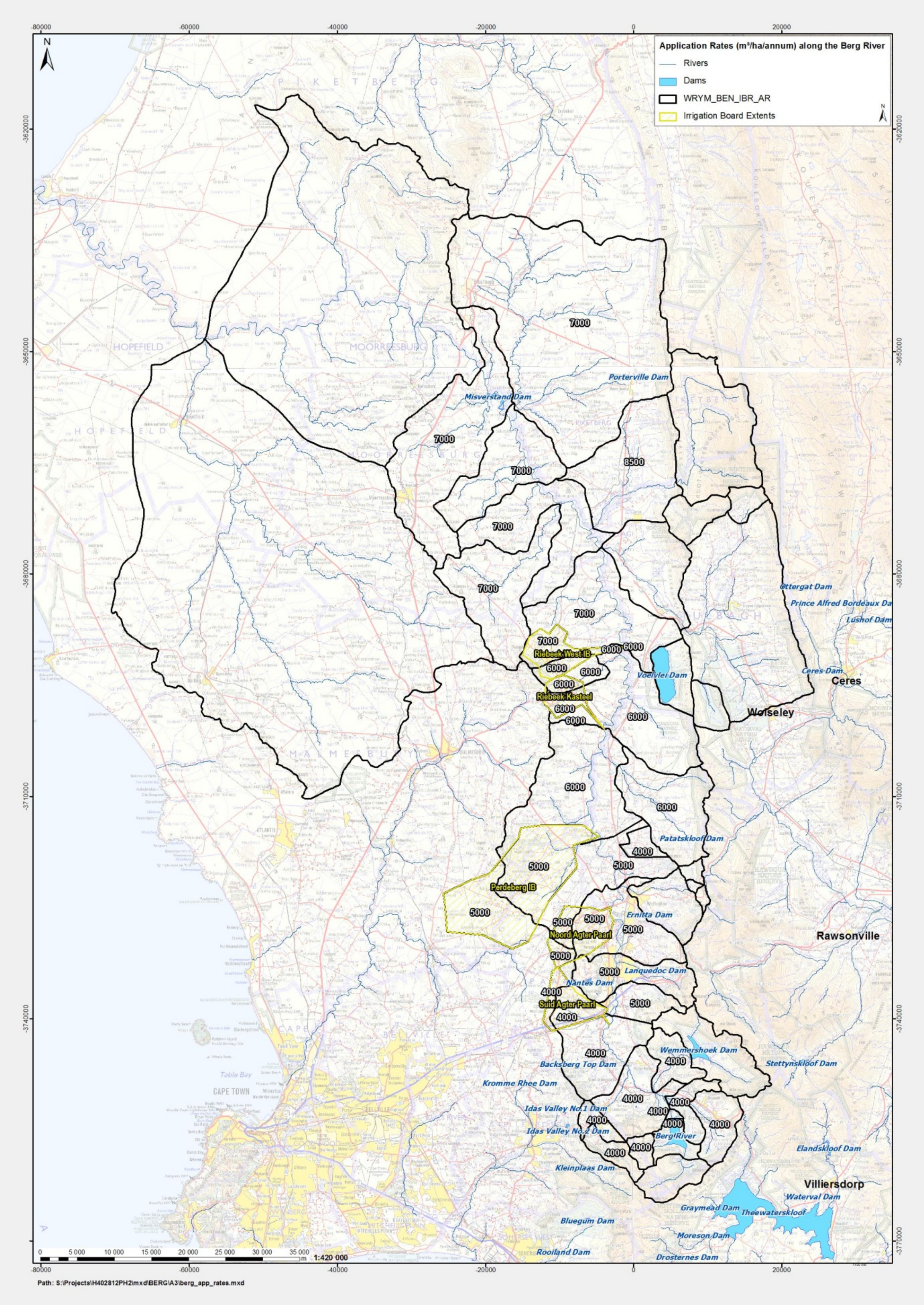


Figure 11: Major Irrigation Schemes and application rates (m^3/ha/annum) along the Berg River

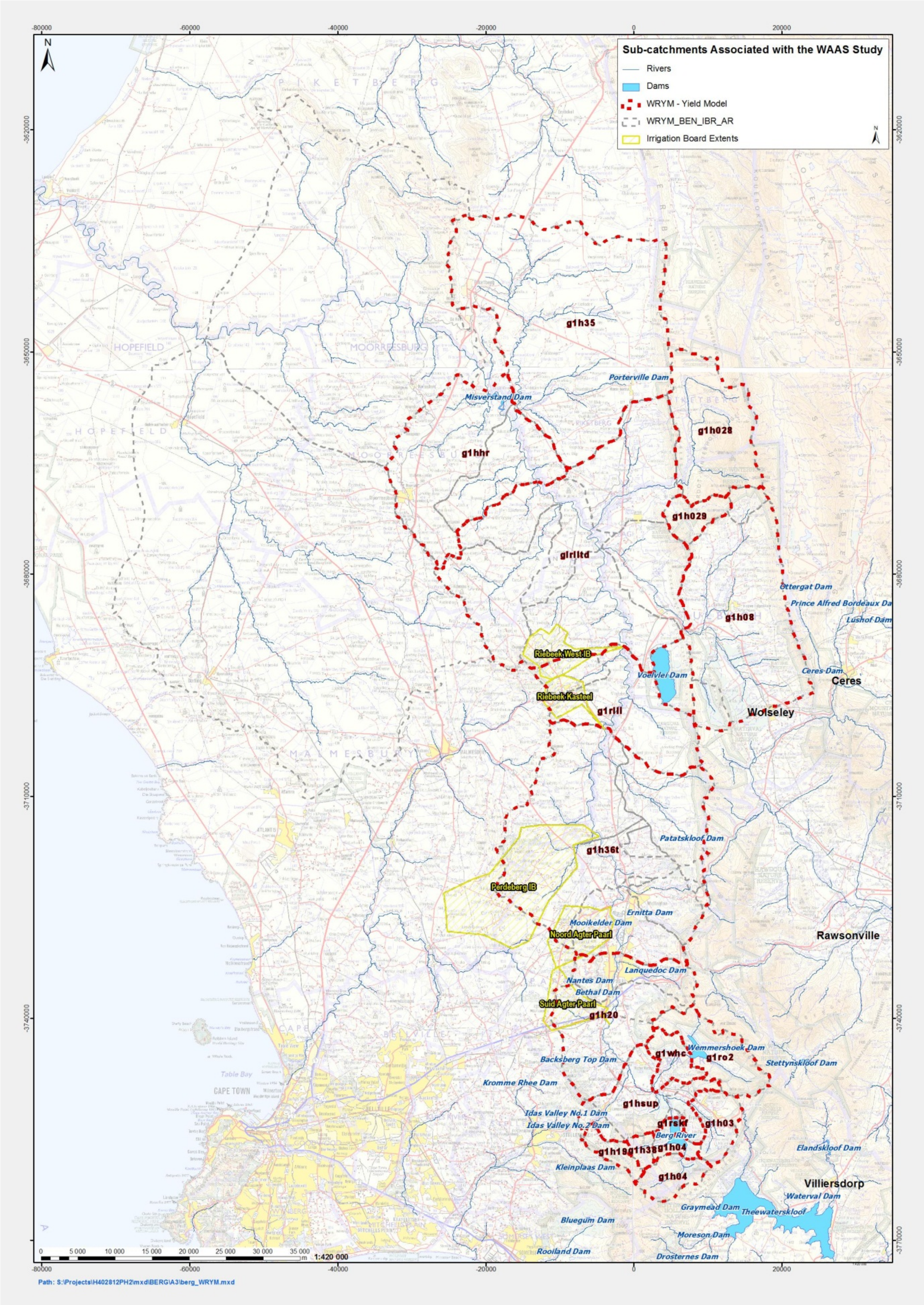


Figure 12: Sub-catchments used in the WAAS Study

4.3 Comparison of Irrigation Water Requirements - current study versus WAAS

Table 5 shows that the modelled irrigation in the Berg River in the current study is about 10% larger than that used in the WAAS study, primarily because the current demands are based on the water requirements during drought years rather than during average years.

Table 5: Irrigation demands by major reaches - current study versus WAAS (million m^3/a)

Irrigation demands by major reaches - current study versus WAAS (million m^3/a)		
	WAAS	Current Study
G1H020	59.8	76.2
G1H008	24.8	23.2
G1H035	5.5	7.4
u/s G1H013	6.1	8.3
24 R	24.5	24.5
G1H003	6.0	5.3
G1H036	74.3	83.9
G1RLLI	14.5	10.4
d/s G1H013 including 6 million m^3/a losses	16.0	16.0
Total	231.4	255.2

For reference purposes extracts from the spreadsheet used to estimate the irrigation demands are presented below:

- **Table 6: Estimating breakdown of irrigation areas into areas supplied from farm dams, catchment streamflows, Upper Berg IB allocation and Lower Berg IB allocation”.** In this table, within each EWR subcatchment, the farm dam capacities and runoff in the summer period, were used to estimate the irrigation area that could be supported from local resources without the need for releases from the major dams. Where water was imported from outside the catchment (Wit River and White Bridge transfers) this supply was also deducted from the water required from the major dams.
- **Table 7: Refining Upper Berg IB areas according to the scheduled areas and estimates of proportion of the scheduled areas used in different reaches. Estimating Irrigation Volumes supplied from different sources.** If irrigation boards (such as Riebeek Kasteel and Riebeek West) are assumed to use their full allocation then it was estimated that about 45% of the scheduled areas with application rates of 6000m^3/ha may not be used while all the remaining allocations of the Upper Berg IB are fully utilized. This estimate was used to adjust the irrigation areas in the spreadsheet so the utilized scheduled areas.
- **Table 8: Aggregating irrigation volumes into channels for the WRYM. Determine scaling factors to apply to WAAS irrigation demands”.** Where practical, irrigation demands were aggregated to simplify the modelling and the scaling factors were determined to scale the WAAS irrigation demands for use in the more detailed model.

Table 6: Estimating breakdown of irrigation areas into areas supplied from farm dams, catchment streamflows, Upper Berg IB allocation and Lower Berg IB allocation

Catchment Description					Estimate which proportion of the irrigated area can be supplied from farm dams and from summer streamflows so that the residual that must be supplied from releases from Theewaterskloof / Berg River Dam (Upper Berg IB) and from Voelvlei (Lower Berg IB) can be determined																	Breakdown of irrigated areas into the Upper Berg IB, Lower Berg IB and other (farm dams, streamflows imports). The Grand Total matches the digitized total and some of the other demands were reduced to correspond.						
Subcatchments from current study			WAAS subcatchments		Supply from farm dam storage								Summer streamflow							Considerations								
Environmental Node at outlet of subcatchment	Irrigation Board	Note	WAAS WRYM INC	WAAS WRYM INC for Farm Dams	4000	5000	6000	Other	Total farm dam capacity	Factor to account for insufficient inflow	Scaled FOS (for evaporation)	Grand Total farm dam supply (Mm3)	Summer flow	Summer flows intercepted by major dams	Major dam intercepting flows	Utilization factor	Scaled Utilization factor	Available summer flows	Transfers into catchment during summer (Mm3)	Assumed application rate (mm)	Potential area supplied from farm dams, imports & summer streamflows (km2)	4000	5000	6000	Total Upper Berg Irrig Board + Groenberg	Lower Berg Scheme	Other (farm dams, streamflows, imports)	Grand Total (Irrigation Area) km2
Bi1	Main Berg		g1h028	g1h028					0	1.0	1	0.0	20.6	-21	Vlv	1.0	0.8	0		850	0.0				0.0		0.2	0.2
Bii1	Main Berg		Sout R	Sout R					0	1.0	1	0.0				1.0	0.8	0		700	0.0				0.0		0.1	0.1
Biii2	Main Berg		g1r02/ g1hwhc	g1r02/ g1hwhc					0	1.0	1	0.0	15.4	-11	Whk	0.5	0.4	1.76		400	4.4	0.0			0.0		2.7	2.7
Biii3	Main Berg		g1h20	g1h20		3.0			3.0	1.0	1	2.4	3.09			1.0	0.8	2.47		600	8.1		*4.3*		4.3		8.1	12.4
Biii4	Main Berg		g1h08	g1h08				14.5	14.5	1.0	1	11.6	14.4			1.0	0.8	11.5		498	46.5				0.0		46.5	46.5
Biii5	Main Berg		g1h35	g1h35				5.5	5.5	1.0	1	4.4	3.69			1.0	0.8	2.95		620	11.9				0.0		11.9	11.9
Biv1	Main Berg		g1rlltd	g1rlltd				1.0	1.0	1.0	1	0.8	2.23			0.0	0.0	0		700	1.2				0.0	6.4		6.4
Biv3	Main Berg		g1rlltd	g1rlltd				0.9	0.9	1.0	1	0.7	2.49			1.0	0.8	1.99		700	3.9				0.0		0.2	0.2
Biv4				g1h029					0.0	1.0	1	0.0				1.0	0.8	0										0.0
Biv4	Main Berg		g1rlltd	g1rlltd				9.2	9.2	1.0	1	7.4	6.74	-3	Vlv	1.0	0.8	2.98	12.6	850	27.0				0.0		28.6	28.6
Biv5	Main Berg		g1h03	g1h03				1.0	1.0	1.0	1	0.8	5.64			1.0	0.8	4.51		375	14.1				0.0		14.1	14.1
Biv5	Main Berg		g1whc	g1whc				0.3	0.3	1.0	1	0.2				1.0	0.8	0		400	0.6						4.2	4.2
									0.0	1.0	1	0.0				1.0	0.8	0										0.0
Bvii10	Main Berg		g1h36t	g1h36t		5.9			5.9	1.0	1	4.7	2.25			0.5	0.4	0.9		500	11.2		14.6		14.6		11.2	25.8
Bvii11	Main Berg		g1rll	g1rll			1.8		1.8	1.0	1	1.4	2.89			0.0	0.0	0		600	2.4			4.5	4.5		2.4	6.9
Bvii2	Main Berg		g1h19/ g1hsup	g1h19/ g1hsup	4.4			x	4.4	1.0	1	3.5	4.11			0.5	0.4	1.64		400	12.9	*###*			10.8		12.9	23.7
Bvii3	Main Berg		g1h36t	g1h36t		*2.4*		0.0	2.4	1.0	1	1.9	2.54			1.0	0.8	2.03	4.9	600	14.7		*0.0*		0.0		18.4	18.4
Bvii4	Main Berg		g1h36t	g1h36t			*0.0*	3.9	3.9	1.0	1	3.1	3.67			0.5	0.4	1.47		600	7.6			*0.0*	0.0		11.6	11.6
Bvii5	Main Berg		g1h36t	g1h36t	1.6	2.3	2.3		6.2	1.0	1	4.9	3.96			0.5	0.4	1.58		600	10.9	8.1	26.4	*###*	50.3		10.9	61.1
Bvii6	Main Berg		g1rlltd	g1rlltd				0.6	0.6	1.0	1	0.5	1.29			1.0	0.8	1.03		700	2.2				0.0	2.0	2.2	4.2
Bvii7	Main Berg		g1rlltd	g1rlltd				1.3	1.3	1.0	1	1.0	1.57			1.0	0.8	1.26		700	3.3				0.0		1.0	1.0
Bvii8	Main Berg		Misv	g1rlltd					0.0	1.0	1	0.0	0.89			0.0	0.0	0		700	0.0							0.0
Bvii9	Main Berg	On Berg R, u/s Paarl	g1h20	g1h20	5.3	3.6			8.9	1.0	1	7.1	4.25			0.5	0.4	1.7		400	22.1	22.9	7.6		30.6		22.1	52.6
Bviii2	Main Berg		g1h36t	g1h36t					0.0	1.0	1	0.0	0.12			1.0	0.8	0.1		400	0.2				0.0		0.5	0.5
Bviii3	Main Berg		g1h36t	g1h36t		0.0			0.0	1.0	1	0.0	0.3			1.0	0.8	0.24		400	0.6						0.0	0.0
Bviii4	Main Berg		g1h36t	g1h36t					**0.0**	**1.0**	1	0.0	0.5			1.0	0.8	0.4		400	1.0		*0.0*		0.0		0.5	0.5
Bviii8	Main Berg	see Noord Agter P	g1h04	g1h04	0.0				0.0	1.0	1	0.0	19.2	-19	BRD	1.0	0.8	-0		400	0.0	0.2			0.2		0.0	0.2
na-export	Noord Agter Paarl		-	-		0.0			0.0	1.0	1	0.0				1.0	0.8	0		500	0.0		2.2		2.2		0.0	2.3
Bvii10	Noord Agter Paarl	On Berg R, d/s Krom	g1h36t	g1h36t		3.7			3.7	1.0	1	3.0	0.79			1.0	0.8	0.63		500	7.2		6.9		6.9		7.2	14.0
Bvii5	Noord Agter Paarl		g1h36t	g1h36t		0.7			0.7	1.0	1	0.5	0.27			1.0	0.8	0.22		500	1.5		4.5		4.5		1.5	6.0
na-export	Perdeberg IB		-	-		0.8			0.8	1.0	1	0.6				1.0	0.8	0		500	1.2		11.8		11.8		1.2	13.0
Bvii5	Perdeberg IB		g1h36t	g1h36t		5.8			5.8	1.0	1	4.6	1.78			1.0	0.8	1.42		500	12.1		12.8		12.8		12.1	24.9
Bvii11	Riebeek Kasteel		g1rll	g1rll			2.2		2.2	1.0	1	1.8	0.39			1.0	0.8	0.31		600	3.5			5.6	5.6		3.5	9.1
Biv1	Riebeek West IB		g1rlltd	g1rlltd			1.7		1.7	1.0	1	1.3	0.61			1.0	0.8	0.49		600	3.0			5.1	5.1		3.0	8.2
Bvii11	Riebeek West IB		g1rll	g1rll			0.7		0.7	1.0	1	0.6	0.39			1.0	0.8	0.31		600	1.4			7.7	7.7		1.4	9.1
na-export	Suid Agter Paarl		-	-	0.1				0.1	1.0	1	0.1				1.0	0.8	0		400	0.1	3.0			3.0		0.1	3.2
Bvii9	Suid Agter Paarl		g1h20	g1h20	2.0				2.0	1.0	1	1.6	0.51			1.0	0.8	0.41		400	5.1	10.3			10.3		5.1	15.3
Bvii8										**1.0**	1	**0.0**				1.0	0.8			**700**	0.0					**4.8**		**4.8**
Bvii12				dummy					**0.0**	**1.0**	1	**0.0**				1.0	0.8											**0.0**
Biv2									**12.5**	**1.0**	1	**10.0**				1.0	0.8			**700**	14.3					**3.6**	**8.5**	**12.0**
Biv2																												
	Losses															1.0	0.8											**0.0**
Total	-		-	-	**13.4**	**28.1**	**8.6**	**38.3**	**100.9**			**70.8**	127	-54		1.0	0.8	44.3	**17.5**	**476**	278.5	**55.3**	**91.2**	**38.7**	**185.1**	**8.5**	**245.4**	**439.0**

Table 7: Refining Upper Berg IB areas according to the scheduled areas and estimates of proportion of the scheduled areas used in different reaches. Estimating Irrigation Volumes supplied from different sources.

Catchment Description					Adjustment of irrigation areas in the Upper Berg to match the scheduled areas, except in the 6000 m^3/ha application zone where it appears that about 55% of the scheduled area (after deducting the major schemes such as Riebeek Kasteel and Riebeek West) is utilized															Irrigation volume (Mill m^3/a) for the irrigation areas associated with each demand grouping					
Subcatchments from current study			**WAAS subcatchments**		**Irrigation areas (GIS) NOT supplied from farm dams & imports (km^2)**							**UPPER BERG IRRIGATION BOARD: SCHEDULED AREAS (ha)**				**UPPER BERG IRRIGATION BOARD: UTILIZED AREA ESTIMATE**									
Environmental Node at outlet of subcatchment	**Irrigation Board**	**Note**	**WAAS WRYM INC**	**WAAS WRYM INC for Farm Dams**	**4000**	**5000**	**6000**	**Total Berg Main Board + groenberg**	**Lower Berg Scheme**	**Other (farm dams, streamflows, imports)**	**Grand Total (Irrigation Area) km2**	**Application rate: 4000 (including Banhoek,Simonsberg,Simondium)**	**Application rate: 5000 (including Groenberg)**	**Application rate: 6000**	**Total Upper Berg (ha)**	**Application rate: 4000 (including Banhoek,Simonsberg,Simondium)**	**Application rate: 5000 (including Groenberg)**	**Application rate: 6000**	**Total Upper Berg (ha)**	**Estimated Volume for Upper Berg utilized area (Mm3/a)**	**Lower Berg IB Demands**	**Farm dams**	**Other irrigation if no farm dam**	**Imports**	**Total**
Bi1	Main Berg		g1h028	g1h028	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0	0	0	0	**0**	**0**	0	0	0.0		0.0	0.2	0.0	0.2
Bii1	Main Berg		Sout R	Sout R	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0	0	0	0	**0**	**0**	0	0	0.0		0.0	0.1	0.0	0.1
Biii2	Main Berg		g1r02/ g1hwhc	g1r02/ g1hwhc	0.0	0.0	0.0	0.0	0.0	2.7	2.7	0	0	0	0	**0**	**0**	0	0	0.0		0.0	1.1	0.0	1.1
Biii3	Main Berg		g1h20	g1h20	0.0	4.3	0.0	4.3	0.0	8.1	12.4	0	380	0	380	**0**	**380**	0	380	1.9		2.4	2.5	0.0	6.8
Biii4	Main Berg		g1h08	g1h08	0.0	0.0	0.0	0.0	0.0	46.5	46.5	0	0	0	0	**0**	**0**	0	0	0.0		11.6	11.5	0.0	23.2
Biii5	Main Berg		g1h35	g1h35	0.0	0.0	0.0	0.0	0.0	11.9	11.9	0	0	0	0	**0**	**0**	0	0	0.0		4.4	3.0	0.0	7.4
Biv1	Main Berg		g1rlltd	g1rlltd	0.0	0.0	0.0	0.0	6.4	0.0	6.4	0	0	0	0	**0**	**0**	0	0	0.0	4.5	0.0	0.0	0.0	4.5
Biv3	Main Berg		g1rlltd	g1rlltd	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0	0	0	0	**0**	**0**	0	0	0.0		0.2	0.0	0.0	0.2
Biv4				g1h029	0.0	0.0	0.0	0.0	0.0	0.0	0.0							0					0.0		0.0
Biv4	Main Berg		g1rlltd	g1rlltd	0.0	0.0	0.0	0.0	0.0	28.6	28.6	0	0	0	0	**0**	**0**	0	0	0.0		7.4	4.3	12.6	24.3
Biv5	Main Berg		g1h03	g1h03	0.0	0.0	0.0	0.0	0.0	14.1	14.1	0	0	0	0	**0**	**0**	0	0	0.0		0.8	4.5	0.0	5.3
Biv5	Main Berg		g1whc	g1whc	0.0	0.0	0.0	0.0	0.0	4.2	4.2	0	0	0	0	**0**	**0**	0	0	0.0			1.7		1.7
					0.0	0.0	0.0	0.0	0.0	0.0	0.0							0					0.0		0.0
Bvii10	Main Berg		g1h36t	g1h36t	0.0	14.6	0.0	14.6	0.0	11.2	25.8	0	1295	0	1295	**0**	**1295**	0	1295	6.5		4.7	0.9	0.0	12.1
Bvii11	Main Berg		g1rll	g1rll	0.0	0.0	4.5	4.5	0.0	2.4	6.9	0	0	695	695	**0**	**0**	379	379	2.3		1.4	0.0	0.0	3.7
Bvii2	Main Berg		g1h19/ g1hsup	g1h19/ g1hsup	10.8	0.0	0.0	10.8	0.0	12.9	23.7	1024	0	0	1024	**1024**	**0**	0	1024	4.1		3.5	1.6	0.0	9.3
Bvii3	Main Berg		g1h36t	g1h36t	0.0	0.0	0.0	0.0	0.0	18.4	18.4	0	0	0	0	**0**	**0**	0	0	0.0		1.9	4.2	4.9	11.1
Bvii4	Main Berg		g1h36t	g1h36t	0.0	0.0	0.0	0.0	0.0	11.6	11.6	0	0	0	0	**0**	**0**	0	0	0.0		3.1	3.9	0.0	7.0
Bvii5	Main Berg		g1h36t	g1h36t	8.1	26.4	15.7	50.3	0.0	10.9	61.1	768	2343	2412	5522	**768**	**2343**	1316	4427	22.7		4.9	1.6	0.0	29.2
Bvii6	Main Berg		g1rlltd	g1rlltd	0.0	0.0	0.0	0.0	2.0	2.2	4.2	0	0	0	0	**0**	**0**	0	0	0.0	1.4	0.5	1.0	0.0	3.0
Bvii7	Main Berg		g1rlltd	g1rlltd	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0	0	0	0	**0**	**0**	0	0	0.0		0.7	0.0	0.0	0.7
Bvii8	Main Berg		Misv	g1rlltd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	**0**	**0**	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Bvii9	Main Berg	On Berg R, u/s Paarl	g1h20	g1h20	22.9	7.6	0.0	30.6	0.0	22.1	52.6	2175	678	0	2853	**2175**	**678**	0	2853	12.1		7.1	1.7	0.0	20.9
Bviii2	Main Berg		g1h36t	g1h36t	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0	0	0	0	**0**	**0**	0	0	0.0		0.0	0.2	0.0	0.2
Bviii3	Main Berg		g1h36t	g1h36t	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	**0**	**0**	0	0	0.0		0.0	0.0	0.0	0.0
Bviii4	Main Berg		g1h36t	g1h36t	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0	0	0	0	**0**	**0**	0	0	0.0		0.0	0.2	0.0	0.2
Bviii8	Main Berg	see Noord Agter P	g1h04	g1h04	0.2	0.0	0.0	0.2	0.0	0.0	0.2	15	0	0	15	**15**	**0**	0	15	0.1		0.00	0.00	0.00	0.1
na-export	Noord Agter Paarl		-	-	0.0	2.2	0.0	2.2	0.0	0.0	2.3		180		180	**0**	**180**	0	180	0.9		0.0	0.0	0.0	0.9
Bvii10	Noord Agter Paarl	On Berg R, d/s Krom	g1h36t	g1h36t	0.0	6.9	0.0	6.9	0.0	7.2	14.0		549		549	**0**	**549**	0	549	2.7		3.0	0.6	0.0	6.3
Bvii5	Noord Agter Paarl		g1h36t	g1h36t	0.0	4.5	0.0	4.5	0.0	1.5	6.0		358		358	**0**	**358**	0	358	1.8		0.5	0.2	0.0	2.5
na-export	Perdeberg IB		-	-	0.0	11.8	0.0	11.8	0.0	1.2	13.0		741		741	**0**	**741**	0	741	3.7		0.6	0.0	0.0	4.3
Bvii5	Perdeberg IB		g1h36t	g1h36t	0.0	12.8	0.0	12.8	0.0	12.1	24.9		805		805	**0**	**805**	0	805	4.0		4.6	1.4	0.0	10.1
Bvii11	Riebeek Kasteel		g1rll	g1rll	0.0	0.0	5.6	5.6	0.0	3.5	9.1			177	177	**0**	**0**	177	177	1.1		1.8	0.3	0.0	3.1
Biv1	Riebeek West IB		g1rlltd	g1rlltd	0.0	0.0	5.1	5.1	0.0	3.0	8.2			62	62	**0**	**0**	62	62	0.4		1.3	0.5	0.0	2.2
Bvii11	Riebeek West IB		g1rll	g1rll	0.0	0.0	7.7	7.7	0.0	1.4	9.1			93	93	**0**	**0**	93	93	0.6		0.6	0.3	0.0	1.4
na-export	Suid Agter Paarl		-	-	3.0	0.0	0.0	3.0	0.0	0.1	3.2	200			200	**200**	**0**	0	200	0.8		0.1	0.0	0.0	0.9
Bvii9	Suid Agter Paarl		g1h20	g1h20	10.3	0.0	0.0	10.3	0.0	5.1	15.3	676			676	**676**	**0**	0	676	2.7		1.6	0.4	0.0	4.7
Bvii8									**4.8**												3.4				3.4
Bvii12				dummy																					0.0
Biv2									**3.6**												2.5	5.9			8.4
Biv2																									
	Losses																				6.3				6.3
Total	-		-	-	**55.3**	**91.2**	**38.7**	**185.1**	**8.5**	**245.4**	**439.0**	**4857**	**7329**	**3438**	**15624**	**4857**	**7329**	**2027**	**14213**	**68.2**	**18.1**	**74.7**	**47.9**	**17.5**	**226.4**

Table 8: Aggregating irrigation volumes into channels for the WRYM. Determine scaling factors to apply to WAAS irrigation demands

Catchment Description					Irrigation volume (Mill m3/a) for the irrigation areas associated with each demand grouping						Aggregate demands into appropriate reaches (demands from rows having the same colour may have been aggregated)										Aggregate demands for reaches, as per previous section, but group the "other" demands together. If, on any line, the channel of a demand is preceded by "to" then that lines demand has been aggregated with the demand of that channel number.						Scaling factors used to scale existing irrigation demand files from the WAAS study to obtain demands at a finer spatial resolution			
Subcatchments from current study			Associated WAAS subcatchments								Demands					Channel Nos of demands					Demand (Mill m^3/a)			channels						
Environmental Node at outlet of subcatchment	Irrigation Board	Note	WAAS WRYM INC	WAAS WRYM INC for Farm Dams	Estimated Volume for Upper Berg utilized area (Mm3/a)	Lower Berg IB Demands	Farm dams	Other irrigation if no farm dam	Imports	Total	Estimated Volume for Upper Berg utilized area (Mm3/a)	Lower Berg IB Demands	Farm dams	Other irrigation if no farm dam	Imports/Schemes	Estimated Volume for Upper Berg utilized area (Mm3/a)	Lower Berg IB Demands	Farm dams	Other irrigation if no farm dam	Imports	Estimated Volume for Upper Berg utilized area (Mm3/a)	Lower Berg IB Demands	Other Demands (farm dams, summer flows, imports)	Upper Berg	Lower Berg	Other	File to scale (dem suffix)	Demand	Scale	Demand file name (dem suffix) (new?)
Bi1	Main Berg		g1h028	g1h028	0.0		0.0	0.2	0.0	0.2											0.00	0								
Bii1	Main Berg		Sout R	Sout R	0.0		0.0	0.1	0.0	0.1											0.00	0								
Biii2	Main Berg		g1r02/ g1hwhc	g1r02/ g1hwhc	0.0		0.0	1.1	0.0	1.1				1.1					316		0.00	0	1.1			316	g1hwhc-d	2.3	0.47	g1whc-db
Biii3	Main Berg		g1h20	g1h20	1.9		2.4	2.5	0.0	6.8	1.9		4.9			514		218			1.90	0	4.9	514		218				
Biii4	Main Berg		g1h08	g1h08	0.0		11.6	11.5	0.0	23.2			23.2					77			0.00	0	23.2			77	g1h08-d	23.0	0.99	g1h08-d
Biii5	Main Berg		g1h35	g1h35	0.0		4.4	3.0	0.0	7.4			7.4					536			0.00	0	7.4			536	g1rlltdd	18.8	0.39	g1h35
Biv1	Main Berg		g1rlltd	g1rlltd	0.0	4.5	0.0	0.0	0.0	4.5		4.7					531				0.00	4.676			531	529				
Biv3	Main Berg		g1rlltd	g1rlltd	0.0		0.2	0.0	0.0	0.2											0.00	0				to 267				
Biv4				g1h029				0.0		0.0											0.00	0								
Biv4	Main Berg		g1rlltd	g1rlltd	0.0		7.4	4.3	12.6	24.3			24.5					527			0.00	0	24.5			527	g1rlltdd	18.8	1.30	24River
Biv5	Main Berg		g1h03	g1h03	0.0		0.8	4.5	0.0	5.3				5.3					314		0.00	0	5.3			314	g1h03-d+ g1h03-s	5.9	0.89	g1h03
Biv5	Main Berg		g1whc	g1whc	0.0			1.7		1.7				1.7					524		0.00	0	1.7			524	g1hws-s	6.8	0.24	g1hws-sb
								0.0		0.0											0.00	0								
Bvii10	Main Berg		g1h36t	g1h36t	6.5		4.7	0.9	0.0	12.1	11.9		10.0			515		258			11.91	0	10.0	515		258				
Bvii11	Main Berg		g1rll	g1rll	2.3		1.4	0.0	0.0	3.7	4.3	0.0	5.1	1.1	0.0						4.26	0	6.2	517		261				
Bvii2	Main Berg		g1h19/ g1hsup	g1h19/ g1hsup	4.1		3.5	1.6	0.0	9.3	4.2		5.2			513		224			4.16	0	5.2	513		224				
Bvii3	Main Berg		g1h36t	g1h36t	0.0		1.9	4.2	4.9	11.1			11.5					501			0.00	0	11.5			501	UBergDam	61.3	0.19	Krom
Bvii4	Main Berg		g1h36t	g1h36t	0.0		3.1	3.9	0.0	7.0			7.0					504			0.00	0	7.0			504	UBergDam	61.3	0.11	Komp
Bvii5	Main Berg		g1h36t	g1h36t	22.7		4.9	1.6	0.0	29.2	30.4		13.2			516		507			30.41	0	13.2	516		507				
Bvii6	Main Berg		g1rlltd	g1rlltd	0.0	1.4	0.5	1.0	0.0	3.0		1.4	1.5				533	267			0.00	1.411	1.5		533	267	g1rlltdd	18.8	0.08	G1h13d
Bvii7	Main Berg		g1rlltd	g1rlltd	0.0		0.7	0.0	0.0	0.7			0.7					535			0.00	0	0.7			535	g1rlltdd	18.8	0.04	G1h43
Bvii8	Main Berg		Misv	g1rlltd	0.0	0.0	0.0	0.0	0.0	0.0											0.00	0			540					
Bvii9	Main Berg	On Berg R, u/s Paarl	g1h20	g1h20	12.1		7.1	1.7	0.0	20.9	15.6		10.9			522		506			15.59	0	10.9	522		506				
Bviii2	Main Berg		g1h36t	g1h36t	0.0		0.0	0.2	0.0	0.2											0.00	0				to 501				
Bviii3	Main Berg		g1h36t	g1h36t	0.0		0.0	0.0	0.0	0.0											0.00	0				to 501				
Bviii4	Main Berg		g1h36t	g1h36t	0.0		0.0	0.2	0.0	0.2											0.00	0				**to 501**				
Bviii8	Main Berg	see Noord Agter P	g1h04	g1h04	0.1		0.00	0.00	0.00	0.1											0.00	0								
na-export	Noord Agter Paarl		-	-	0.9		0.0	0.0	0.0	0.9											0.00	0								
Bvii10	Noord Agter Paarl	On Berg R, d/s Krom	g1h36t	g1h36t	2.7		3.0	0.6	0.0	6.3											0.00	0				**to 258**				
Bvii5	Noord Agter Paarl		g1h36t	g1h36t	1.8		0.5	0.2	0.0	2.5											0.00	0				**to 507**				
na-export	Perdeberg IB		-	-	3.7		0.6	0.0	0.0	4.3											0.00	0								
Bvii5	Perdeberg IB		g1h36t	g1h36t	4.0		4.6	1.4	0.0	10.1											0.00	0				to 507				
Bvii11	Riebeek Kasteel		g1rll	g1rll	1.1		1.8	0.3	0.0	3.1											0.00	0				**to 261**				
Biv1	Riebeek West IB		g1rlltd	g1rlltd	0.4		1.3	0.5	0.0	2.2											0.00	0				**to 261**				
Bvii11	Riebeek West IB		g1rll	g1rll	0.6		0.6	0.3	0.0	1.4											0.00	0				to 261				
na-export	Suid Agter Paarl		-	-	0.8		0.1	0.0	0.0	0.9											0.00	0								
Bvii9	Suid Agter Paarl		g1h20	g1h20	2.7		1.6	0.4	0.0	4.7											0.00	0				to 506				
Bvii8						3.4				3.4		3.4					**540**				0.00	3.36			540?					
Bvii12				dummy						0.0											0.00	0								
Biv2						2.5	5.9			8.4		2.5	**3.9**				**544**	**563**			0.00	2.499	3.9		544	563	g1rlltdd	18.8	0.20	Brood
Biv2													**2.1**					**565**			0.00	0	2.1			565	g1rlltdd	18.8	0.11	PlatKf
	Losses					6.3				6.3		6.3					**543**				0.00	6.325			530/532/539/543					
Total	-		-	-	**68.2**	**18.1**	**74.7**	**47.9**	**17.5**	**226.4**	**68.2**	**18.3**	**130.8**	**9.2**	**0.0**						68.2	18.27	139.9							

4.4 Farm dam capacities

In WAAS, the farm dam capacities in the catchments were estimated from records for individual dams from the DWA dam safety database and, for the smaller dams, by using a relationship between the surface area of the dam and the dam volume.

The farm dam volumes downstream of Misverstand were not estimated. As part of this study the farm dam capacities downstream of Misverstand were estimated using the dam safety database, some dam volumes were adjusted, and the individual farm dams were aggregated using the finer spatial resolution required by the EWR sub-catchments. If both the WAAS and the current study are assumed to use the same total storage downstream of Misverstand, then the reworked farm dam storages in the Berg River from the current study are 100.9 million m^3 as opposed to the 97.2 million m^3 estimated previously.

Details of the farm dam capacity estimates are included in **Table 9**.

4.5 Losses

Transmission losses were determined for the drier lower reaches of the Berg River downstream of Misverstand Dam by estimating the area of the river channel and of the riparian vegetation and applying an evaporation loss based on pan evaporation data. In the case of the river itself, the river width was assumed to be 20 metres in summer and the mean annual evaporation at station G1E002S01 (see **Table 10**) was factored by 0.8 to allow for the reduction in evaporation that takes place over large water bodies. In the case of the riparian vegetation, it was assumed that this would extend 20 metres on each bank and a crop factor of 0.65 was applied to the evaporation to take into account the evapotranspiration from riparian vegetation (see **Table 11**). The monthly losses determined for each of the reaches are summarised in **Table 12.**

Table 9: Farm Dam Capacities in the EWR sub-catchments and scaling factors applied to adjust the volumes and surface areas of the lumped farm dams from WAAS

					Farm dam volumes (million m^3)							
Catchment Description					Farm dam capacities disaggregated into finer resolution							
Subcatchments from current study			**WAAS subcatchments**		Farm dam capacities		WAAS dam characteristics to scale (maintain the same elevation and full supply levels but scale the associated surface area and capacity)			Comparable dam volumes from the WAAS study		
Environmental Node at outlet of subcatchment	**Irrigation Board**	**Note**	**WAAS WRYM INC**	**WAAS WRYM INC for Farm Dams**	**node**	**volume**	**node**	**cap**	**factor**	**Storages (WAAS)**	**Storage for region in Lower Berg not covered in WAAS**	**Storage for same region as covered in the Feasibility Study**
Bi1	Main Berg		g1h028	g1h028								
Bii1	Main Berg		Sout R	Sout R								
Biii2	Main Berg		g1r02/ g1hwhc	g1r02/ g1hwhc	210	0	210	0.2	0	0.2		
Biii3	Main Berg		g1h20	g1h20	216	3	216	15	20%			
Biii4	Main Berg		g1h08	g1h08	102	15	102	15	97%	15.0		
Biii5	Main Berg		g1h35	g1h35	374	6	147	14	40%			
Biv1	Main Berg		g1rlltd	g1rlltd	370	1.9	147	14	14%			
Biv3	Main Berg		g1rlltd	g1rlltd								
Biv4				g1h029	373	9	147	14	68%	13.7		
Biv4	Main Berg		g1rlltd	g1rlltd								
Biv5	Main Berg		g1h03	g1h03	208	1	208	1	100%	1.0		
Biv5	Main Berg		g1whc	g1whc	350	0	208	1	30%			
Bvii10	Main Berg		g1h36t	g1h36t	218	10	218	29	36%			
Bvii11	Main Berg		g1rll	g1rll	220	6.3	220	5.5	116%	5.5		
Bvii2	Main Berg		g1h19/ g1hsup	g1h19/ g1hsup	213	4	213	4.1	107%	4.1		
Bvii3	Main Berg		g1h36t	g1h36t	355	2	218	29	8%			
Bvii4	Main Berg		g1h36t	g1h36t	358	4	218	29	13%			
Bvii5	Main Berg		g1h36t	g1h36t	362	13	218	29	44%	28.8		
Bvii6	Main Berg		g1rlltd	g1rlltd	147	1						
Bvii7	Main Berg		g1rlltd	g1rlltd	379	1.3	147	14	9%			
Bvii8	Main Berg		Misv	g1rlltd	na	0						
Bvii9	Main Berg	On Berg R, u/s Paarl	g1h20	g1h20	353	11	216	15	72%	15.3		
Bviii2	Main Berg		g1h36t	g1h36t								
Bviii3	Main Berg		g1h36t	g1h36t								
Bviii4	Main Berg		g1h36t	g1h36t								
Bviii8	Main Berg	see Noord Agter P	g1h04	g1h04	**na**	0						
na-export	Noord Agter Paarl		-	-								
Bvii10	Noord Agter Paarl	On Berg R, d/s Krom	g1h36t	g1h36t								
Bvii5	Noord Agter Paarl		g1h36t	g1h36t								
na-export	Perdeberg IB		-	-								
Bvii5	Perdeberg IB		g1h36t	g1h36t								
Bvii11	Riebeek Kasteel		g1rll	g1rll								
Biv1	Riebeek West IB		g1rlltd	g1rlltd								
Bvii11	Riebeek West IB		g1rll	g1rll								
na-export	Suid Agter Paarl		-	-								
Bvii9	Suid Agter Paarl		g1h20	g1h20								
Bvii8												
Bvii12				dummy								
Biv2					366&365	12.43	147	14	use known area Say A=c*V^0.66		13.66	
Biv2												
	Losses											
Total	**-**		-	-		**100.9**				**83.6**	**13.7**	**97.2**

Table 10: Average Monthly Evaporation (mm) at G1E002:S01

Gauge	Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
G1E002S01	1972-2007	191	248	297	316	271	235	148	85	58	59	78	111	2102

Table 11: Reach characteristics used to determine the transmission losses downstream of Misverstand Dam

Reach characteristics for determining transmission losses							
Upstream point	Downstream point	Reach (m)	River width (m)	Factor to convert evaporation to free-water evaporation	Riparian Vegetation zone width (m)	Factor to convert evaporation to evapotranspiration of riparian vegetation	Proposed Channel number
Misverstand	Steenboksfontein	47000	20	0.8	40	0.65	578
g1h013	Misverstand	18000	20	0.8	40	0.65	539
g1h036	G1H079	13910	20	0.8	40	0.65	512
G1H079	Biv1	18895	20	0.8	40	0.65	530
Biv1	G1H013	16195	20	0.8	40	0.65	532

Table 12: Reach Losses downstream of Misverstand Dam

Upstream point	Downstream point	Units	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Proposed Channel number
Misverstand	Steenboksfontein	m^3/s	0.14	0.19	0.22	0.23	0.22	0.17	0.11	0.06	0.04	0.04	0.06	0.08		578
g1h013	Misverstand	m^3/s	0.05	0.07	0.08	0.09	0.08	0.07	0.04	0.02	0.02	0.02	0.02	0.03		539
g1h036	G1H079	m^3/s	0.04	0.06	0.06	0.07	0.06	0.05	0.03	0.02	0.01	0.01	0.02	0.02		512
G1H079	Biv1	m^3/s	0.06	0.08	0.09	0.09	0.09	0.07	0.05	0.03	0.02	0.02	0.02	0.03		530
Biv1	G1H013	m^3/s	0.05	0.06	0.08	0.08	0.08	0.06	0.04	0.02	0.02	0.01	0.02	0.03		532
Total		m^3/s	0.34	0.46	0.53	0.56	0.53	0.42	0.27	0.15	0.11	0.10	0.14	0.20		
		Mill m^3	0.91	1.19	1.42	1.51	1.30	1.13	0.71	0.41	0.28	0.28	0.37	0.53	10.0	

5 Effect of the Proposed Preliminary Reserve on the Yield of the Berg River Dam and Supplement Scheme

5.1 Synopsis

The relative effects on total system yield of alternative approaches to the simulated operation of the proposed Preliminary Reserve for the Berg River Dam Supplement Scheme were analysed as part of this study. Depending on the approach, the historical firm yield of the total system differs over a range of -4 to +6 million m^3/a relative to the historical firm yield obtained in the original Berg River Dam Feasibility Study. In this study the more conservative approach of adjusting the Reserve release volumes on a monthly basis was adopted. The relationship between upstream streamflow and abstraction to Berg River Dam that was developed is presented in **Table 13**.

Table 13: "Diversion" function for EWR Operating Rule at Supplement Scheme

Component	Average monthly pump rate (m^3/s) for a given average streamflow (m^3/s)							
Average monthly streamflow (m^3/s)	0.00	0.90	1.60	4.00	6.50	7.50	10.00	999.00
Average monthly pumping rate (m^3/s)	0.00	0.55	0.75	1.30	3.10	3.30	3.40	3.40

5.2 Introduction

In the original Feasibility Study for the Berg River Dam and the Supplement Scheme the EWRs were not specified using flow duration curves, but as a set of average releases for each month of the year (see **Table 14**). The river channel immediately downstream of the Berg River Dam was considered to be in a much better state (Ecological Class “C”) than the remaining reaches at and downstream of the Supplement Site, which had little indigenous vegetation and was primarily used as a conduit to distribute irrigation water. The required streamflows downstream of the Berg River Dam were allowed to decrease during drought conditions (about 8 times in 61 years). However, the environmental streamflow conditions at the Supplement Scheme were assumed to be close to “drought” conditions already and no additional allowance was made to reduce these requirements during drought periods.

Table 14: EWR at Supplement Site from the Berg River Dam Feasibility Study

Month	Berg River Dam baseflow (m^3/s)	Supplement baseflow (m^3/s)	Incremental baseflow (m^3/s)
Jan	0.300	0.460	0.160
Feb	0.300	0.460	0.160
Mar	0.300	0.460	0.160
Apr	0.500	1.000	0.500
May	1.000	2.000	1.000
Jun	1.600	2.860	1.260
Jul	1.600	2.860	1.260
Aug	1.600	2.860	1.260
Sep	1.200	2.860	1.660
Oct	0.800	1.540	0.740
Nov	0.500	0.610	0.110
Dec	0.400	0.460	0.060

Some time after the completion of the Feasibility Study, the EWRs specified in the Preliminary Reserve were defined using monthly flow-duration curves. To determine the ecological requirements the relative exceedence of the natural streamflows for a particular month needs to be known (usually determined using streamflows measured at relatively natural indicator sites within the catchment) and this is used to “look up” the environmental streamflow with the same exceedence. Practically, these requirements are difficult to implement, as the natural flow is the average value for the entire month, which is not known until the month is complete. In practice, the environmental requirements can be implemented using a shorter time period, where the average “natural” streamflows for the preceding hour, day or maybe week are used to determine the environmental streamflow requirement for the next period.

To assess the effect of the operating rule on the yield of the system, the volume of water that could be pumped into the Berg River Dam over the historical critical drawdown period (from 1 November 1968 to 31 May 1974) was analysed for different scenarios. The proposed Supplement Scheme will normally operate in the winter months, from May to October, unless there are exceptionally heavy summer rains resulting in significantly elevated streamflows; therefore, for this analysis the summer periods were ignored.

The winter EWRs corresponding to

- the Feasibility Study
- the Preliminary Reserve (using a monthly interval)
- the Preliminary Reserve (using an hourly interval)

are presented as solid green, red and blue lines, respectively, in **Figure 13.** The actual simulated downstream flows for each of these scenarios are presented using the corresponding dashed line.

The EWRs downstream of the Supplement Scheme are provided partly from the environmental releases from Berg River Dam and partly from unregulated accruals from tributaries located downstream of Berg River Dam and Wemmershoek Dam. Because unregulated streamflows contribute a large portion of the EWRs, the streamflows occurring downstream of the Supplement Site can differ significantly from the environmental requirements. The streamflows can be less than the requirement even if no pumping takes place at the Supplement Scheme, because the water simply is not available at the site - as in the case of the Feasibility Study EWR which exceeded the available streamflow about 30% of the time. The streamflows can also exceed the requirements at the site, as happens at least 45% of the time in the various scenarios, because the streamflows exceed the abstraction capacity of the Supplement Scheme. These exceedences occur throughout the winter, not just when the Berg River Dam spills; therefore, the Supplement Site gets the benefit of reliable baseflows from the Berg River Dam plus variability introduced from accruals downstream of the major dams.

It should be noted that the water requirement of the Preliminary Reserve (determined on a monthly basis) is larger than the water requirement of the original Feasibility Study requirement about 60% of the time and could be expected to decrease the system yield. However, if the Preliminary Reserve is modelled on an hourly basis, the total modelled EWR is reduced. The hourly natural streamflows are more variable than the monthly streamflows, some being higher than the monthly average and some lower. The EWRs of the lower streamflows are significantly less than the average flows and this is not sufficiently offset by an increased EWR for the higher natural streamflows. Consequently, **Figure 13** shows that the water flowing downstream of the Supplement Scheme for the Preliminary EWR when evaluated *hourly* (blue dashed line) is closer to that of the original Feasibility Requirement (green dashed line) than the water flowing downstream for the Preliminary EWR when evaluated *monthly*.

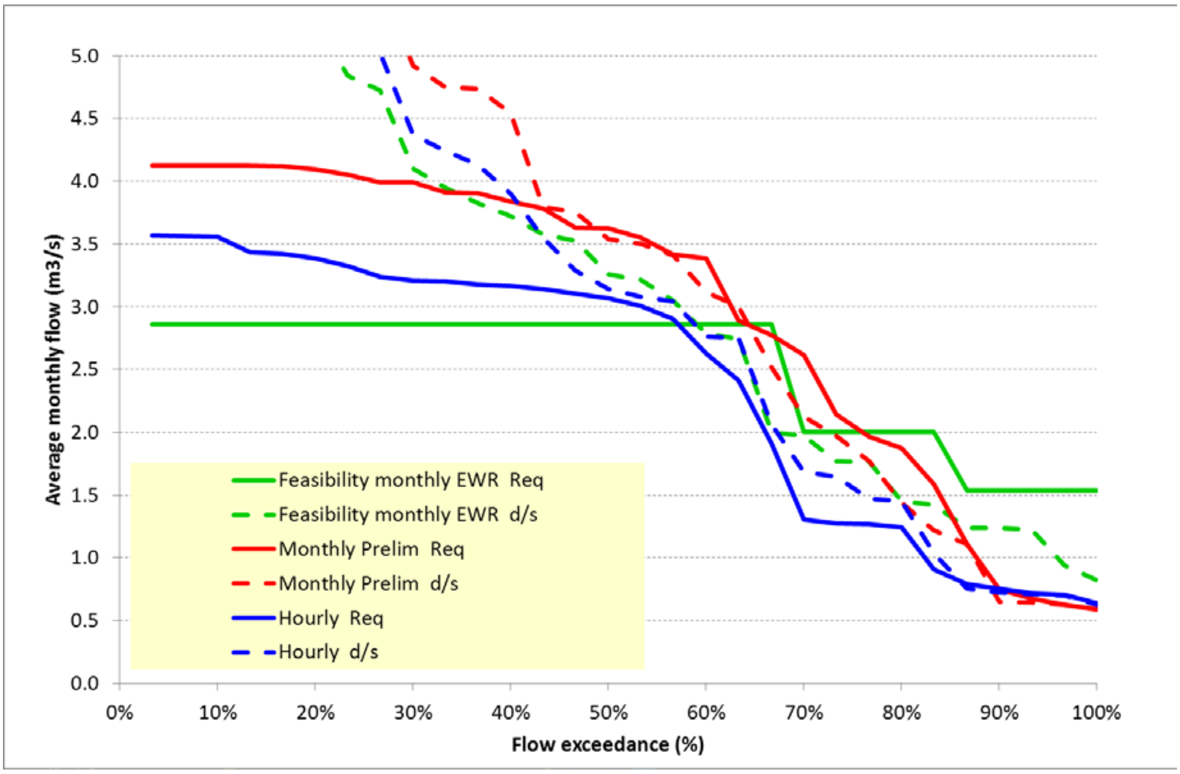


Figure 13: Comparison of EWRs and simulated average monthly streamflows from May to October downstream of the Supplement Site

5.3 Comparison of streamflows downstream of the Supplement Scheme and effects of different operating rules on yield

A spreadsheet was used to model the operation of the Supplement Scheme on an hourly basis over the historical critical drawdown period of the system - from 1 November 1968 to 31 May 1974. The "HFY" from the Supplement Scheme was taken as the volume of water that could be pumped into the Berg River Dam over the historical critical drawdown period for each of the different scenarios. This approach relies on water being pumped from Berg River Dam into Theewaterskloof Dam (with its larger relative storage and greater ratio of storage to mean annual runoff) to minimise spillage from Berg River Dam.

The results are summarized in row "n" of **Table 16.** Using the EWR from the Feasibility Study, the Berg River Dam and Supplement increase the "HFY" of the system by 92 million m^3/a. If the EWR is changed to the Preliminary Reserve and this is implemented on a monthly basis then the "HFY" of the system reduces to 88 million m^3/a. Applying the Preliminary Reserve on an hourly basis would actually increase the Feasibility Study-related "HFY" to about 94 million m^3/a.

Another means of implementing the Reserve was also investigated, similar to the "stepped – pumping" method envisaged for the BRVAS. This approach is based on switching on pumps of, say, 1.5 m^3/s whenever the streamflow reaches, say, 2.4 m^3/s until all the available pumps are operational. This ensures a minimum baseflow thresh hold of 0.7 m^3/s and the streamflow varies from 0.7 to 2.4 m^3/s until all the pumps are all operational (see **Figure 14**). For the purposes of this analysis the threshold was increased during the wetter winter months (see **Table 15**) and an abstraction step of

1.5 m^3/s was adopted. This approach increased the yield by a further 4 million m^3/a to 98 million m^3/a, as it permits pumping to start a little earlier than if the full baseflow was left before pumping started.

Table 15: Adopted variable baseflow threshold

Month	May	Jun	Jul	Aug	Sep	Oct
Threshold	0.5	1.0	1.5	1.5	1.0	0.5

Because a large portion of the streamflows is unregulated, the freshets exceeding the abstraction capacity of the Supplement Pumpstation occur throughout the season so that the cumulative streamflows downstream of the pumpstation are fairly similar for the various pumping rules (see **Figure 15). Figure 15** shows the cumulative streamflows for each of the five winters in the critical drawdown period. The solid red line is the baseflow EWR (evaluated on a monthly basis) while the red dashed line is the baseflow EWR evaluated on a daily basis. The streamflows downstream of the Supplement Pumpstation exceed the Preliminary Reserve Flow (determined daily) in all years. When compared with the Preliminary Reserve Flow (determined monthly) the streamflows downstream of the Supplement exceed the Preliminary Reserve in most years. In 1969 the streamflows from the variable threshold scenario are about 8 million m^3 less than the Preliminary Reserve (determined monthly) while in the other years the streamflows are greater than the Reserve.

A similar analysis was performed using the WRYM for the longer period from 1928 to 1988 which shows that the annual streamflows downstream of the Supplement Site will normally exceed the baseflow requirements except for the 1:20 year drought - corresponding to a 5% exceedance (see **Table 16**).

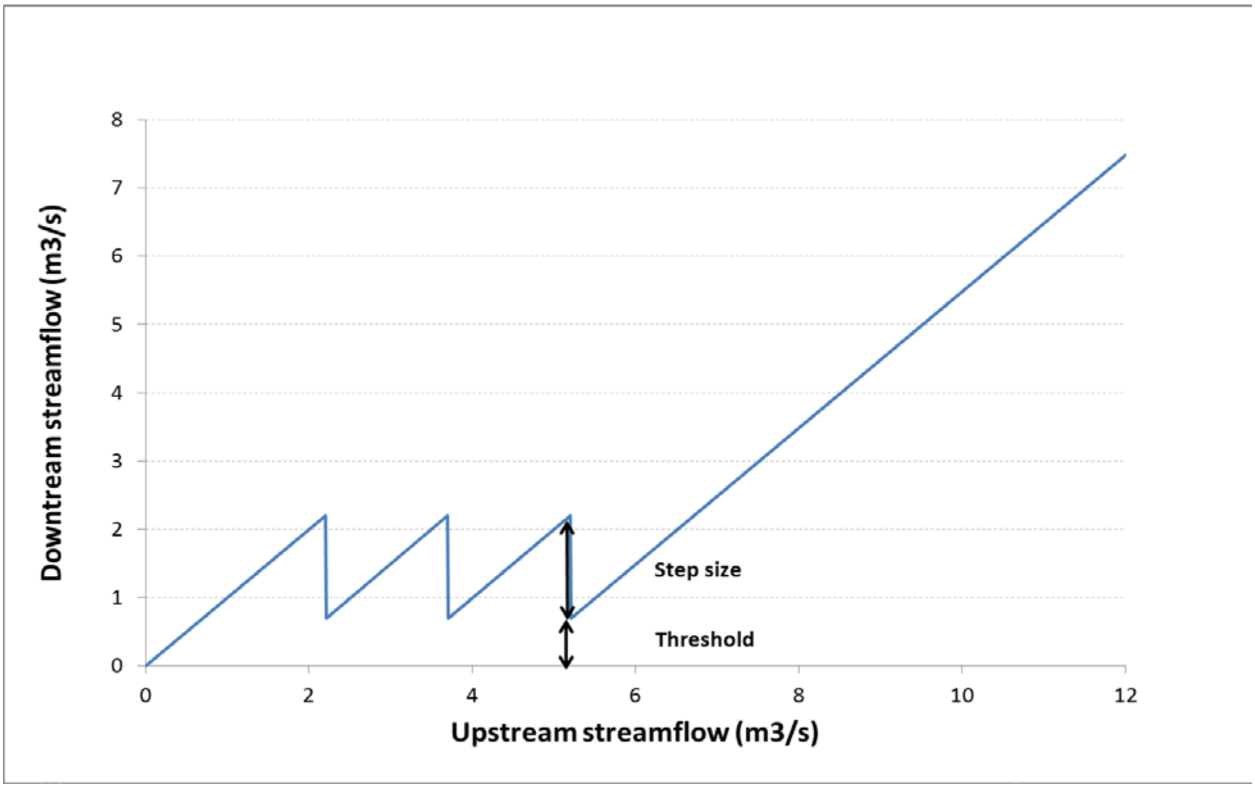


Figure 14: Relationship of upstream streamflow to downstream streamflow assuming a threshold of 0.7 m³/s and three pumping steps of 1.5 m³/s

Table 16: Mass balance for the critical period from 1 November 1968 to 31 May 1974 to determine the effect of operating rules on yield at the Berg River Dam

Source		Row a	Feasibility EWR	Preliminary reserve (applied monthly)	Preliminary reserve (applied weekly)	Preliminary reserve (applied hourly)	Stepped (threshold of 0.5,1,1.5,1.5,1,0.5 threshold from May-Oct with 1.5 step)
Initial live storage	(1)Mm³	a	127	127	127	127	127
Natural Inflow at G1H004	(1)Mm³	b	572	572	572	572	572
Wolwekloof Diversion to Theewaterskloof	(1)Mm³	c	-77	-77	-77	-77	-77
High flow (Flood/Freshettes) Environmental Releases	(1)Mm³	e	-59	-59	-59	-59	-59
High flow summer release	(1)Mm³	f	0	0	0	0	0
Summer Release included with Theewaterskloof Dam yield	(1)Mm³	g	-50	-50	-50	-50	-50
Low Flow Winter Releases	(1)Mm³	h	-104	-104	-109	-78	-80
Nett evaporation	(1)Mm³	i	-4	-4	-4	-4	-4
Flows pumped from Supplement	(1)Mm³	j	102	82	92	86	111
Spill	(1)Mm³	k	-2	-2	-2	-2	-2
BRD yield	Mm³/a	l=sum(rows b to i)/5.5	74	74	73	78	78
Supplement yield	Mm³/a	m=sum(rows I to j)/5.5	18	15	16	15	20
(2) Total BRD + Supplement Yield (after deducting yield included with Theewaterskloof - assuming uniform demand	Mm³/a	n=l+m	92	88	89	94	98
Flow downstream of Supplement (ignoring irrigation releases)	(1)Mm³	o	304	325	319	294	270
Flow downstream of Supplement (ignoring irrigation releases)	(1)Mm³/a	p	55	59	58	53	49

(1) Flow over critical period from 1 November 1968 to 31 May 1974
(2) Demand could be up to two milllion m³/a less if the seasonality of urban and agricultural demands on the combined Theewaterskloof Dam / Berg River Dam is taken into account

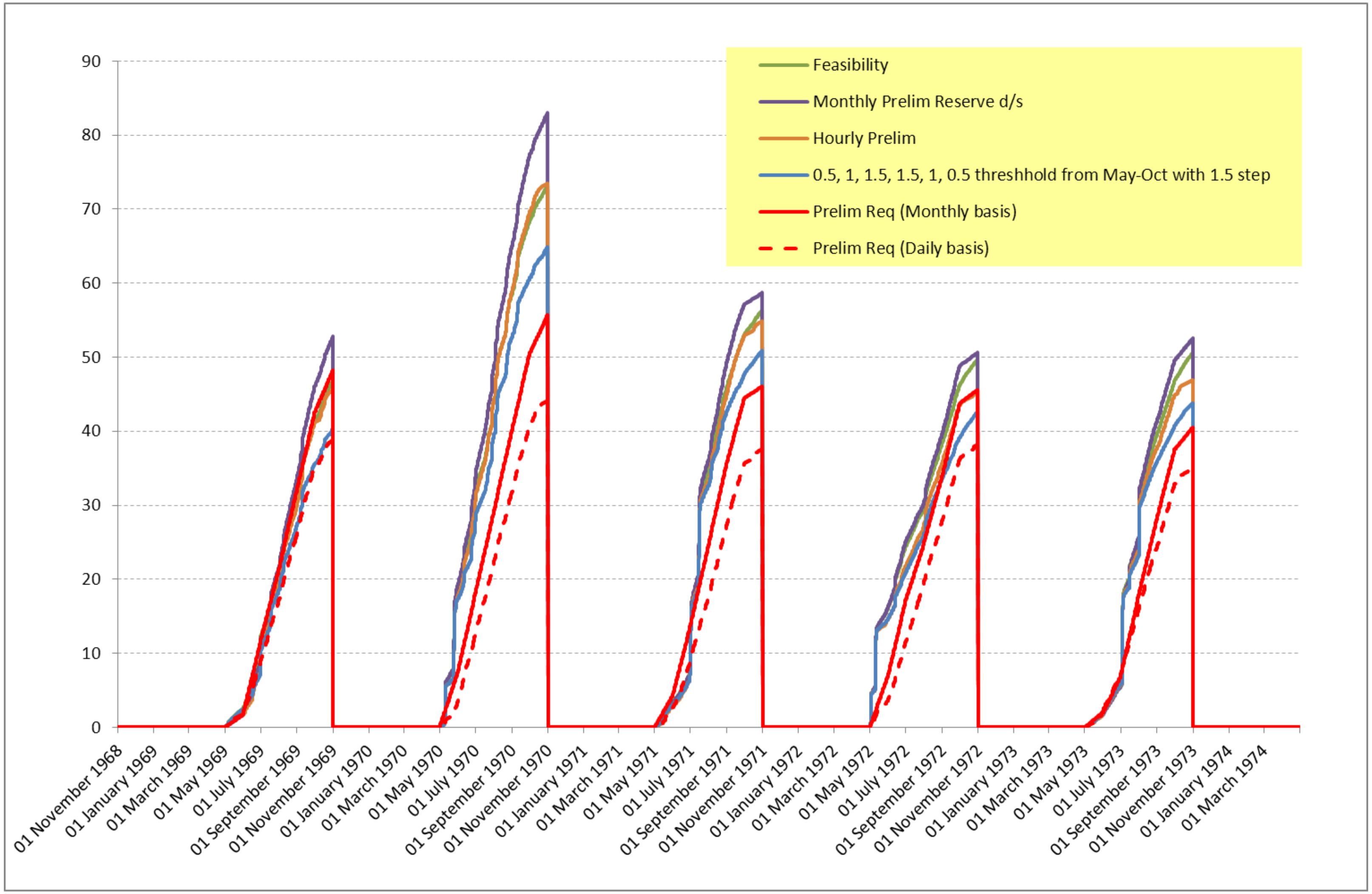


Figure 15: **Required baseflows and actual streamflows downstream of the Supplement Scheme for different implementations of the EWR**

Table 17: Comparison of required and modelled streamflows (m^3/s) for the period 1928-1988 using different methods of operating the Supplement Abstraction

	Baseflow requirement						Feasibility supply						Variable threshold						Variable / requirement	Variable / Feasibility
	May	Jun	Jul	Aug	Sep	Oct	May	Jun	Jul	Aug	Sep	Oct	May	Jun	Jul	Aug	Sep	Oct	%	%
0%	1.3	4.3	14.1	24.7	35.0	40.8	1.4	6.8	12.0	20.1	29.8	33.1	1.7	7.4	12.5	20.6	28.1	31.9	78%	96%
5%	1.8	10.6	20.7	30.6	40.4	43.4	1.7	9.0	17.1	24.8	38.3	44.6	2.1	10.0	16.1	23.5	33.3	38.6	85%	84%
10%	2.6	12.0	22.0	32.0	41.7	45.1	2.3	9.5	20.8	38.0	49.0	54.3	3.0	10.7	20.3	36.5	46.9	50.9	118%	93%
20%	4.5	13.8	24.3	34.5	43.7	47.7	3.3	14.7	37.3	49.9	60.0	64.4	4.0	15.4	35.4	46.3	54.1	58.4	126%	91%
50%	7.1	17.3	27.3	37.7	47.5	51.9	5.4	24.0	54.1	74.3	88.1	92.5	5.3	20.6	50.5	71.3	84.7	89.1	179%	97%
75%	7.4	18.0	29.0	40.0	49.4	54.3	9.9	37.3	99.1	152.9	171.6	174.9	7.4	36.3	97.2	150.2	169.1	172.9	337%	99%
95%	7.5	18.2	29.3	40.3	50.6	56.3	21.9	71.8	179.6	243.3	258.5	261.2	20.8	71.4	178.4	241.3	256.6	260.2	471%	100%
100%	7.5	18.2	29.3	40.4	50.7	56.4	34.3	135.1	250.8	363.7	390.0	398.9	33.2	132.8	248.5	361.4	387.7	394.0	698%	99%