THE LESOTHO HIGHLANDS DEVELOPMENT AUTHORITY (LHDA)

NOVEMBER 2006 FLOOD DOWNSTREAM OF THE KATSE DAM STRUCTURE

Effects of the November 2006 Flood

THE DAMAGE CAUSED BY THE FLOOD AS IT PROPAGATES DOWNSTREAM

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HYDROLOGY

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Executive Summary

The massive and disastrous flood that has the estimated recurrence period of one in fifty (1:50) years occurred within the Katse catchment area for four (4) consecutive days from the 2^{nd} to the 5^{th} November 2006.

The peak magnitude of this flood has been calculated to be 1345.29 m^3/s and its corresponding specific force has been computed as 3.2×10^7 Newtons. This is a huge amount of force that uprooted trees and destroyed the newly constructed hydrometric station at IFR site 2.

The survey results analysis in this report, however, interprets that the whole country was in flood phenomena and therefore all the impacts that were observed and experienced could not be attributed to the operations of the Katse Dam Low Level Outlet gates.

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1. INTRODUCTION

The highlands of the Mountain Kingdom of Lesotho received exceptionally high flows during November 2006. The Katse dam catchment area became flooded and severe impacts on the environment were encountered. Various damages to properties of downstream communities were also reported. Because of its importance to the Basotho nation, the Katse Dam then came to the front page on the news.

Massive and disastrous floods occurred within the Katse catchment area for four (4) consecutive days, from the 2^{nd} to the 5^{th} November 2006. Announcements informing the nation of expected high flows in river courses and the potential danger entailed in high river flow situations were released countrywide, through the national broadcaster, from the Disaster Management Authority (DMA) Offices, and in association with the Lesotho Meteorological Services (LMS). People were also advised to practice caution when approaching or near those river courses.

Reported damages caused by this flood to properties of communities living downstream of the Katse dam include livestock killing and damages on their boats, and those communities that suffered loss, including some government officials, attributed the cause of the disaster to the Katse dam releases.

The thinking behind this attribution was that the Low Level Outlet gates (LLOs) at the Katse dam were fully opened to release floodwater as a normal practice that is effected during summer months, where a certain magnitude of a flood for IFR requirements is released in accordance with the forecasted Hydrological Year Class.

The biggest floods that could be released as specified in the IFR Policy and Procedures range between 71 and 142 m^3/s for a Plus 2 Hydrological Year Class. The capacity of the LLOs is however much bigger, close to 420 m^3/s for each LLO gate. Therefore when both gates are fully opened the flood magnitude of 840 m^3/s could be released downstream.

The downstream communities believed that the flood was released without proper notification. They were not aware that this situation was, however, natural and beyond human control because heavy rains led the Katse dam to overflow.

Survey results and computed flow rates on Malibamatšo River at Kao and IFR site 2 also confirm that the November 2006 flood was evenly distributed over the Katse catchment area. In fact the entire Country was in flood phenomena with quite heavy rainfall that caused rivers to over flow and dams to spill.

The Hydrology Team comprising Mr. Thabang Marumo, Mr. Sephiwe Rafutho and B. Makakole took a field trip to IFR site 2 downstream of the Katse dam, IFR site 4 in Senqu River at Sehong – hong and Malibamatšo River at Kao from the 18th to the 22nd December 2006 to survey the flood marks, the flood magnitude and to assess visible damages this flood phenomenon had caused. The magnitude of the flood had to be computed and presented to the Project Authorities and to the entire Basotho nation so that everyone knows that the November 2006 flood was naturally driven and the claimed losses are not the responsibility of the Katse dam.

The Hydrology Team had to calculate, precisely, the magnitude of this flood propagation as it progressed passed Malibamatšo River at Kao, Katse dam site as dam releases and spill flow, and at IFR site 2 downstream of the Katse dam.

Thus three (3) sites were identified for cross – sectional survey, two (2) sites along the Malibamatšo River, namely; Malibamatšo River at Kao and Malibamatšo River at IFR site 2. The third one was identified along the Senqu River, namely Senqu River at Sehong – hong. All sites were surveyed and this report provides the obtained results and flood magnitude computations.

1.1 OBJECTIVES

The main objective of surveying the November 2006 flood is to derive its magnitude and route the flood from Malibamatšo River at Kao all the way through the Katse reservoir to IFR site 2 downstream of the Katse dam wall. It is also to compare the obtained survey results for the Malibamatšo River catchment with survey results obtained from other catchments such as the Senqu River catchment at Sehong – hong (IFR site 4) to establish that the November 2006 flood was actually a natural event. Specific objectives of the exercise are to:

- Establish and survey the flood marks due to the November 2006 flood and present the surveyed cross – sections.
- Derive the Hydraulic river flow characteristics from the survey results.
- Compute the channel conveyance from the obtained results.
- Compute the magnitude, in cubic metres per second, of the November 2006 flood.
- Check the return period of the obtained flood magnitude.
- Compute the specific force that the November 2006 flood had attained.

- Highlight on the severity of the impacts caused as the flood propagated downstream.

- Establish circumstances relating to demolition of the IFR Site 2 Hydrometric Station.

2. Surveying Methodology

The Hydrology Team selected three important and representative sites to be surveyed to extract the parameters that are required for the computations of the November 2006 flood magnitude along the Malibamatšo River and Senqu River catchments.

The instruments that were used are the Tripod for holding the Survey Level Machine, the Survey Level Machine, the Staff Gauge and the Water Level to ensure that the Staff Gauge is vertically placed and correctly read for the surveyed points across the cross – section.

The Tripod was properly set during the survey exercise to ensure that the Survey Level Machine is horizontal such that the markings that are read from the Staff Gauge are perpendicular to the center of the Survey Level Machine.

The initial point where the Staff Gauge was placed is called the Back site, see first column of the Tables 1, 2 and 3. Normally the very first point that is measured is the established Bench Mark and it can be named as shown in the fourth column of the Tables, which is named Remarks on Survey.

The last point that is measured during the survey exercise is called the Fore site. See third column of Tables 1, 2 and 3. The points that are surveyed between the Back Site and the Fore Site are called Intermediate Sites and these are shown in the second column of Tables 1, 2 and 3. Intermediate Sites are the points that show how the cross – section behaves and can be plotted against their intervals.

If the Staff Gauge cannot be clearly read on the next point the surveyor has to move the Tripod and the Survey Level Machine to another place where the next point will be clearly read but the Staff Gauge is not moved. It is read twice to make both the Back Site and the Fore Site. This is called Change Point and both the Back Site and the Fore Site are in the same row. See the Remarks on Survey in the fourth column.

3. SURVEY RESULTS

3.1 Senqu River at Sehong - Hong (IFR site 4)

The Hydrology Team began its surveying exercise from Senqu River at Sehong – Hong on the 19th December 2007. The Senqu River catchment at Sehong – Hong is downstream of the confluence of both the Senqu and Malibamatšo River systems. Its surveying was basically to extract information on the coverage and the distribution of the flood in the country to ascertain that the November 2006 flood did not only occur over the Katse catchment alone but it was distributed all over the country.

The flood marks of the November 2006 flood along the Senqu River at Sehong – hong were established. See Survey Results in Table 1 on page 7. However, the selected cross – section was not completely surveyed due to very high flow in the mighty Senqu River system. It was difficult to cross through to the other side of the river.

Hydraulic parameters that include the flow depth, flow width, wetted perimeter and the cross – sectional area could therefore not be derived for this river cross – section, hence the accuracy of the results and the purpose of surveying this site could not be achieved.

Much damage was also observed where trees were uprooted and valleys eroded along side the main Senqu River channel and on both flood plains and the river – banks. The farm fields that are close and/or on flood plains were also deeply scoured and eroded.

Figure 1 below indicates the severity of the impacts caused by the November 2006 flood.

Figure1

Table 1

IFR site 4 Survey Results

Back Site	Intermediate Site	Fore Site	Remarks on Survey	Distance in metres	Height of Instrument	Reduced Level
0.421			Surveyed PC2*		100.421	100
	3.541		Flood Mark	7.9m		96.880
0.130		2.369	Change Point 1		98.182	98.052
1.029		3.448	Change Point 2		95.633	94.604
	1.830		Left Edge of Water			93.803
	1.532		Right Edge of Water			94.101
2.149		0.410	Change Point 3		97.372	95.223
3.199		2.149	Change Point 4		98.422	95.223
1.515		0.425	Change Point 5		99.512	97.997
	0.151					99.361
	3.195					96.317
3.768		2.801	Change Point 6		100.479	96.711
	0.512		Surveyed PC2			99.967
0.841		3.768	Change Point 7		97.552	96.711
	1.834					95.718
1.355		1.559	Change Point 8		97.348	95.993
		2.950	Left Edge of Water			94.398

*PC2 is the Surveyed bench mark.

The results presented in Table 1 provide few intermediate points surveyed between the left and the right water edges. There are many ‘change points’ that were done and quite a few points that indicate the required information and the behavior of the river system during the flood event.

3.2 Malibamatšo River at Kao

Malibamatšo River System at Kao was visited and surveyed on the 20th December 2006. The Malibamatšo River at Kao is located upstream of the Katse reservoir and supplies the main inflow into the Katse reservoir.

The requirement for surveying the cross – section upstream of the Katse dam, the Malibamatšo River at Kao, had been to derive the general conditions of flood coverage as proof that the November 2006 flood event was not only dominating the Katse Dam site but it was also being experienced upstream of the reservoir. It was a natural phenomenon that was not influenced by the Katse Reservoir operations. Table 2 on page 8 shows the surveyed points along the Malibamatšo River cross – section at Kao.

The effects of erosion and deposition were visually discovered to be minimal at this cross – section. The Malibamatšo River at Kao cross – section is situated on a bedrock with very steep riverbanks that are formed on firm solid rocks.

Table 2

Malibamatšo River at Kao Survey

Survey at Malibamatšo River at Kao Upstream of the Katse Dam on the 20 December 2006						
Back Site	**Intermediate Site**	**Fore Site**	**Chanage in Metres**	**Remarks on Survey**	**Height of Instrument**	**Reduced Level**
3.235				TB M1*	103.235	100
	1.055			Flood Mark		102.180
0.798		3.577	4.0		100.456	99.658
	1.661		4.0			98.795
	2.290		4.0			98.166
	2.886		4.0			97.570
	3.001		4.0			97.455
	2.751		4.0			97.705
	2.975		4.0			97.481
	3.089		1.5	Right Edge of Water		97.367
	3.395		4.0			97.061
	3.451		4.0			97.005
	3.539		4.0			96.917

Survey at Malibamatšo River at Kao Upstream of the Katse Dam on the 20 December 2006						
Back Site	**Intermediate Site**	**Fore Site**	**Chanage in Metres**	**Remarks on Survey**	**Height of Instrument**	**Reduced Level**
1.678		3.296	4.0	Change Point 2	98.838	97.160
	1.731		4.0			97.107
	1.809		4.0			97.029
	1.929		4.0			96.909
	2.060		4.0			96.778
	1.911		4.0			96.927
	1.652		4.0			97.186
	1.452		1.8	Left Edge of Water		97.386
	0.729		4.0			98.109
2.190		0.460	4.0		100.568	98.378
	1.951		4.0			98.617
	1.693		4.0			98.875
	1.166		4.0			99.402
1.675		0.549	4.0	Change Point 3	101.694	100.019
2.013		0.788	4.0	Change Point 4	102.919	100.906
	0.985		2.9	Flood Mark		101.934
			4.0	Flood Mark		102.180
		2.899		TB M1		100.020
	Longitudinal					
0.609					100.629	
	2.563					98.066
	2.244		9.0			98.385
	2.005		16.0			98.624
	2.200		18.0			98.429
		0.609				100.020

*TBM1 is the Bench Mark

Survey results, as seen in Table 2, indicate successful completion of the survey exercise on the selected cross – section along the Malibamatšo River system at Kao. The flood marks on the riverbanks were located and surveyed so that the discharge carrying capacity and the associated specific force of flow could be computed for the November 2006 flood event.

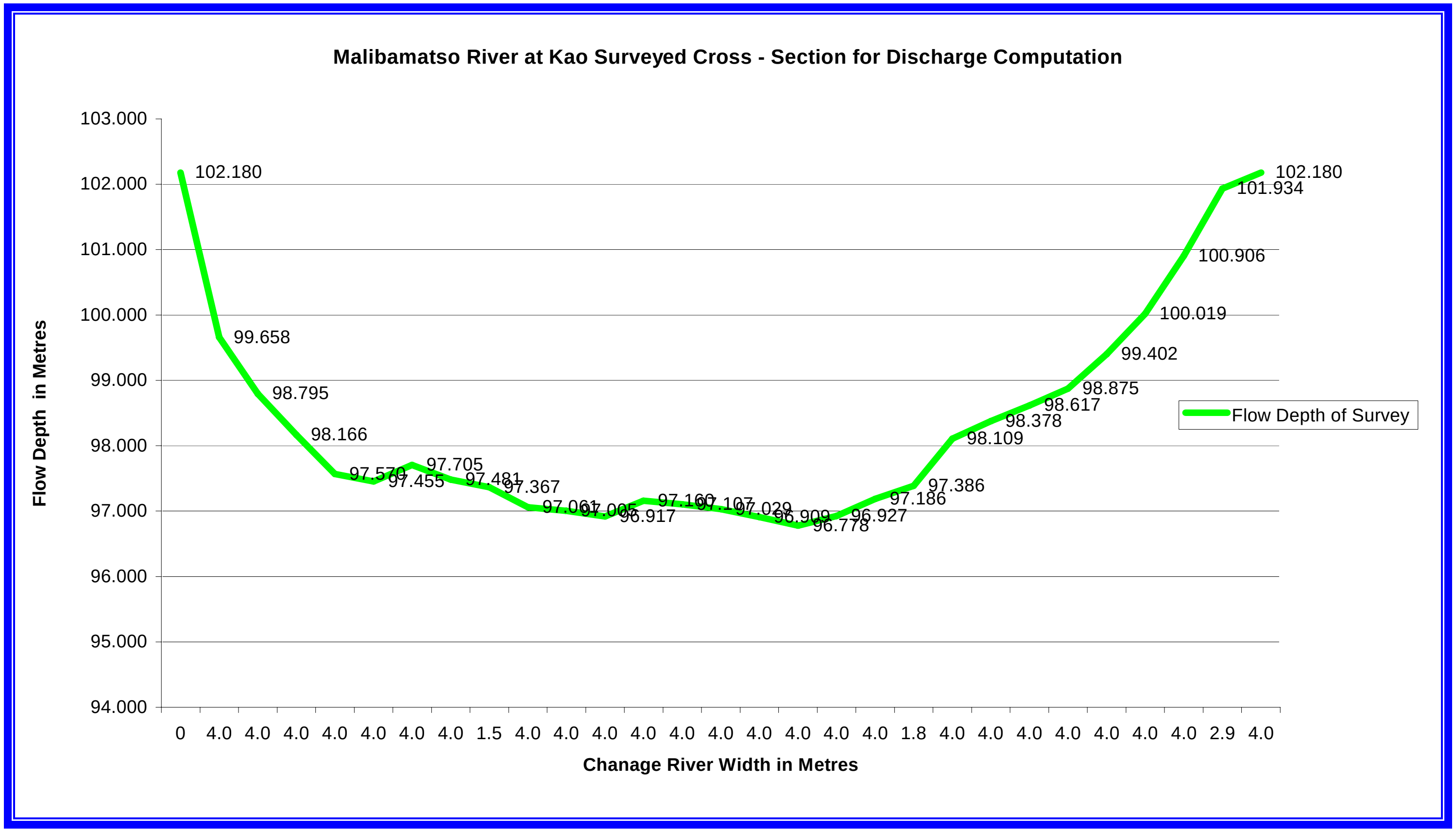
The survey results along the length of the river channel, the longitudinal points, are also presented towards the bottom of Table 2. It is from these survey results that the required Hydraulic river flow characteristics for the calculation of the channel conveyance and its associated discharge are obtained.

The Hydrology Team could only locate one suitable cross – section through which it could safely cross the river system. More than one cross – sections were required to ensure accuracy of the results obtained for the intended purpose, however the river flow conditions at the time of surveying could not allow, thus this could have negative impacts on the precision and accuracy of the obtained results.

Chart 1 on page 11 presents the actual surveyed cross – section for the Malibamatšo River System at Kao. The corresponding Hydraulic river flow parameters are also derived and provided on page 12.

Chart 1

Cross – Section on Malibamatšo River at Kao



This cross – section shows that the river – banks are very steep and the flood plains are not visible. The river – banks are supported with a solid rock, very big rock boulders and some finer rock particles. Intensive vegetation of grasses, shrubs and medicinal plants have grown on this banks; adding some value to the manning roughness coefficient and some resistance to soil erosion by the exertion of frictional forces against the strength of flow. Thus no damage was seen or evident at and around this cross – section.

The flow within the Malibamatšo River at Kao was too high during the surveying exercise but the Team was able to cross, however with difficulty, to the other side to complete and obtain all the required points along the selected cross - section.

The required channel characteristics for the computations of the channel conveyance, its associated flow rate and the specific force of flow for Malibamatšo River at Kao could then be derived from the survey results and these are presented as follows:

- The flow width at the cross – section during the flood event is found to be **112** metres wide.
- The average flow depth is found to be **4.273** metres deep, with the deepest flow depth at **4.475** metres.
- The Wetted Perimeter is calculated as **113.48** metres and
- The bed slope for Malibamatšo River is found to be **0.0091**

3.3 Malibamatšo River at (IFR Site 2)

The Malibamatšo River at IFR site 2 was visited and surveyed on the 21st December 2006. The Malibamatšo River at IFR site 2 is located 3.06 km downstream of the Katse reservoir. Flows at this site include all the Katse dam releases, hence it is used to monitor releases for Instream Flow Requirements downstream of the Katse Dam and the response of the catchment between the dam and IFR site 2.

The survey exercise at this cross – section was undertaken to establish the magnitude of the flood that went downstream of the Katse dam and caused the reported disasters that include washing away of the newly constructed Hydrometric Station at IFR site 2. The effect of other contributing catchments needs to also be considered so that the appropriate magnitude and return period for the November 2006 flood could be precisely established. Table 3 shows the surveyed points along the Malibamatšo River cross – section at IFR site 2.

It is worth mentioning that this flood magnitude was not anticipated immediately downstream of the Katse dam structure and at IFR site 2 due to the presence of the Katse dam wall and the fact that the site is too close to the dam structure. The expectations were that flooding might occur at some distal reaches after more tributaries and catchment contributions are factored into the system.

Table 3

IFR site 2 Survey

Survey at IFR site 2 Downstream of the Katse Dam on the 21 December 2006						
Back Site	**Intermediate Site**	**Fore Site**	**Chanage in Metres**	**Remarks on Survey**	**Height of Instrument**	**Reduced Level**
2.461				B2*	102.461	100.000
2.432		0.149		First Cross - section: Flood Mark	104.744	102.312
	0.128		4.0			104.616
	1.219		4.0			103.525
	0.971		4.0			103.773
0.355		2.381	4.0		102.718	102.363
	1.082		4.0			101.636
	1.505		4.0			101.213
	1.646		4.0			101.072
0.207		2.671	4.0		100.254	100.047
	1.909		4.0	Right Edge of Water		98.345
	2.479		4.0			97.775
	2.659		4.0			97.595
	2.398		4.0			97.856
	2.272		4.0			97.982
	2.085		4.0			98.169
	1.979		4.0			98.275
	1.899		1.8	Left Edge of Water		98.355
	1.780		4.0			98.474
	1.595		4.0			98.659

Survey at IFR site 2 Downstream of the Katse Dam on the 21 December 2006						
Back Site	**Intermediate Site**	**Fore Site**	**Chanage in Metres**	**Remarks on Survey**	**Height of Instrument**	**Reduced Level**
	1.765		4.0			98.489
	1.842		4.0			98.412
	1.802		4.0			98.452
	1.234		4.0			99.020
2.325		0.305	4.0		102.274	99.949
	1.341		3.8			100.933
	2.259			B2		100.015
0.364		2.350		Second Cross - Section	100.288	99.924
	1.895		3.5	Right Edge of Water		98.393
	2.267		4.0			98.021
	2.458		4.0			97.830
	2.575		4.0			97.713
	2.534		4.0			97.754
	2.390		4.0			97.898
	2.010		4.0			98.278
	1.900		4.0	Left Edge of Water		98.388
2.098		0.312			102.074	99.976
		2.045		B2		100.029

*B2 is the Bench Mark

The survey results for the Malibamatšo River at IFR site 2 are presented in Table 3. The flood marks on the riverbanks were located and surveyed so that the discharge carrying capacity and the associated specific force of flow could be computed for the November 2006 flood event.

River flow at this cross – section was smooth and enough to allow the Hydrology Team to cross anywhere it could. Hence two sections were identified and surveyed to ensure accuracy of the obtained results.

Chart 2

Cross – Section on Malibamatšo River at IFR Site 2

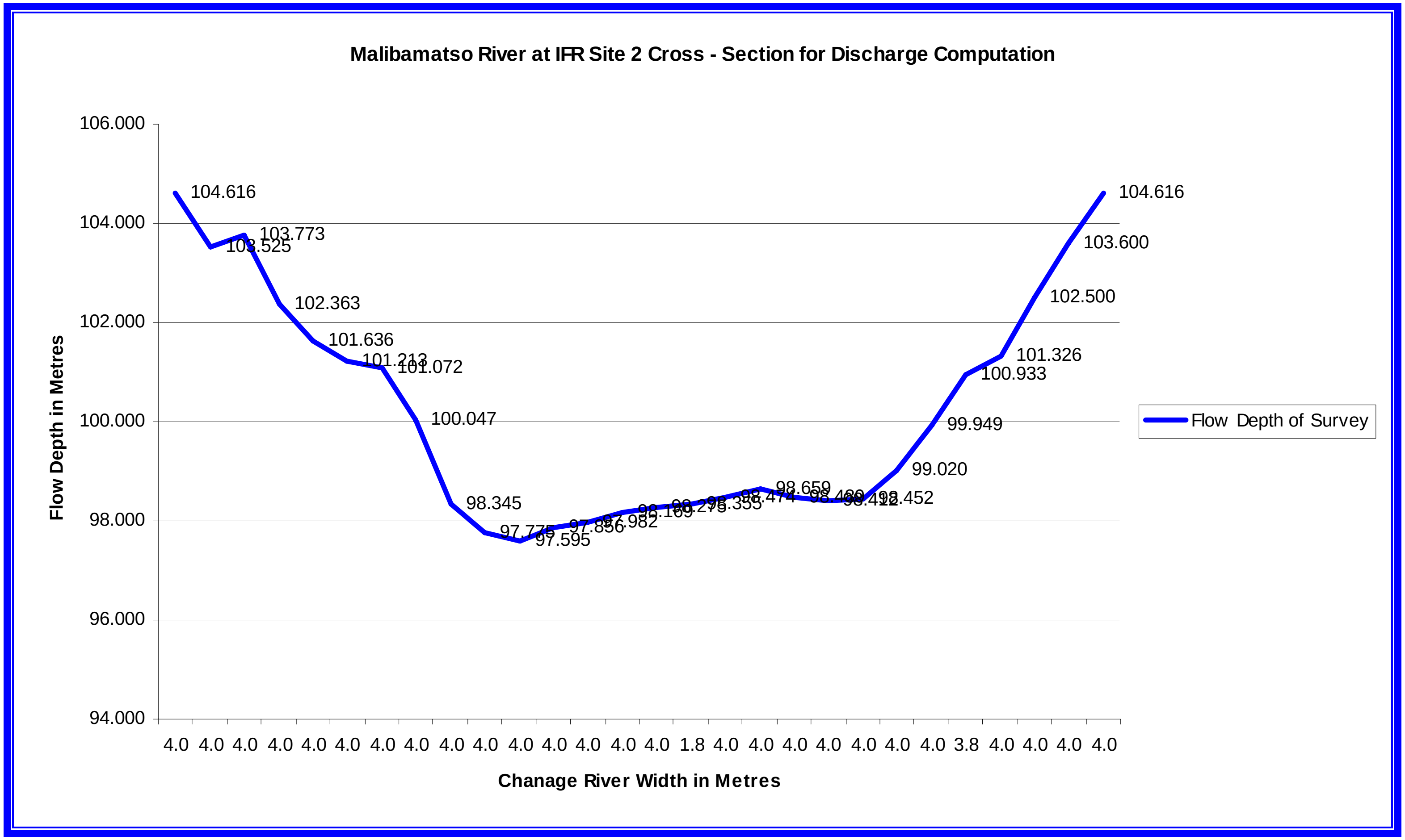


Chart 2 on page 15 presents the actual surveyed cross – section for the Malibamatšo River System at IFR site 2. It is from this graphical presentation where the required hydraulic river flow parameters are easily obtained.

This cross – section shows that the river – banks have high gradients with smaller and sloppy flood plains. Intensive vegetation of grasses, shrubs, medicinal plants and some trees have grown along side the river – banks and on some of the Islands within the main channel.

Much damage was seen to have occurred on uprooted trees and eroded fields on flood plains, see figure 2. The culvert on Khohlontšo stream was destroyed and washed away, some valleys forming channels were established along side the main river channel and the newly constructed Hydrometric station at IFR site 2 was destroyed and washed off, see figures 3 and 4.

Figure 2

The required channel characteristics for the computations of the channel conveyance, its associated flow rate and the specific force of flow for Malibamatšo River at IFR site 2 could then be derived from the survey results and these are presented as follows:

- The flow width at the cross – section during the flood event is found to be **108** metres wide.

- The average flow depth is found to be **5.9335** metres deep, with the deepest flow depth at **6.271** metres.

- The Wetted Perimeter is calculated as **109.7624** metres and
- The bed slope for Malibamatšo River is found to be **0.0091**

4. FLOOD MAGNITUDE COMPUTATIONS

4.1 Senqu River at Sehong – Hong

The Hydraulic parameters could not be established for the mighty Senqu River system at Sehong – Hong. The survey exercise could not be completed at this site due to very high river flow.

The observed flood marks on river – banks and the intensity of scouring on flood plains and fields that are ploughed in flood plains indicate that flow was extremely high and energetic within the mighty Senqu River system and had attained a very high specific force of flow.

4.2 Malibamatšo River at Kao

The Hydraulic parameters derived from survey results provide the required information for the computation of the channel carrying capacity. These survey results enabled cross – sectional area calculations, wetted perimeter calculations and the hydraulic radius calculations, which are the basic requirements in the discharge carrying capacity computation. See Table 4 below.

The cross – section was divided into three potions for ease of computations, these being the main channel and two flood plains. Manning roughness coefficient for the main channel was calculated as 0.088 from available waded discharge measurements and the Manning roughness coefficient for flood plains was calculated as 0.065 estimated from observed channel characteristics during the survey exercise.

Table 4

Discharge and Channel Conveyance

Section	Area in m^2	Wetted Perimeter in m	Hydraulic Radius in m	Channel Conveyance m^3/s	Discharge in m^3/s
1	53.70	24.92	2.15	1, 378.30	131.48
2	239.29	56.23	4.26	7, 140.69	681.18
3	65.14	32.33	2.01	1, 598.52	152.49
	358.13	**113.48**		**10117.51**	**965.15**

Rows 1 and 3 in Table 4 represent computations on the flood plains and row 2 represents the main channel. Column 5 presents the channel carrying capacity on both the flood plains and the main channel. The total channel carrying capacity for Malibamatšo River at Kao is therefore calculated as 10117.51 m^3/s for the November 2006 flood.

The corresponding discharge is computed as 965.15 m^3/s, which is the maximum amount of flow rate that was realized during the November flood.

This flow rate generated the Specific Force of Flow of $1.79X10^7$ Newtons, which is a very big force.

4.3 Malibamatšo River at IFR site 2

The Katse dam started spilling from the 1st November 2006. The peak spill flow was realized on the 2nd November 2006 and it was recorded as 1010.48 m^3/s. The peak flow rate downstream of the Katse dam including normal compensation flow was 1011.54 m^3/s.

The Low Level Outlet gates were not opened on the 2nd November 2006 and all the downstream flow was due to the occurrence of spill and normal compensation flow from the Katse dam.

Katse dam is located 3.06 km upstream of IFR site 2 and all the dam releases went passed IFR site 2. The Hydrometric Station that is located between IFR site 2 and the Katse dam wall recorded the peak flow rate of 1352.59 m^3/s, which is slightly more than the flow rate of 1345.29 m^3/s calculated from the survey results at IFR site 2.

The peak flow rate that went passed IFR site 2 as shown in Table 5 is 1345.29 m^3/s. The Hydrology team went to survey a while later, after the flood occurrence and the flood marks were not clearly and readily identified and this could be the source of the observed shortfall in these flow rates.

The difference between the downstream flow of 1011.54 m^3/s and the flow of 1345.29 m^3/s calculated at IFR site 2 gives the Khohlontšo and incremental catchment contribution of 333.75 m^3/s. The Khohlontšo stream is the main tributary to the Malibamatšo River upstream of IFR site 2.

Table 5

Discharge and Channel Conveyance

Section	Area in m^2	Wetted Perimeter in m	Hydraulic Radius in m	Channel Conveyance	Discharge in m^3/s
1	100.34	32.96	3.04	1, 621.16	154.65
2	308.54	52.11	5.92	11, 474.85	1, 094.63
3	67.15	56.23	2.72	1, 006.49	96.01
	476.03	**141.3**		**14,102.50**	**1,345.29**

The channel carrying capacity for Malibamatšo River at IFR site 2 is shown as 14, 102.50 m^3/s for the November 2006 flood in Table 5. The Manning's roughness coefficient used for the main channel is 0.088 and it is estimated as 0.13 for the flood plains.

The flow rate computed at IFR site 2 generated the corresponding Specific Force of Flow of $3.20X10^7$ Newtons.

Figure 3 below shows the impact caused by this huge amount of specific force.

Figure 3

5. HYDROMETRIC STATION CONSTRUCTION at IFR SITE 2

5.1 Station Design and site selection

The Department of Water Affairs – Lesotho designed the Hydrometric Tower plan in 2000. This plan is a standard plan that meets the Hydrometric Tower requirements for flow measurements.

This Tower plan was constructed on Malibamatšo River at Kao, which is upstream of the Katse dam. The Tower is still standing and functional. The requirement for appropriate tower construction is the accurate computation of the specific force of flow, which was done for the Kao Hydrometric Tower. So the strength of the Tower is such that it can absorb the specific forces generated by the flow rate of approximately 2, 000.00 m^3/s.

The IFR policy and procedures stipulate the flood flows for Instream Flow Requirements. The stipulated flood flows were then used as the basis for the computations of the specific forces to be overcome at IFR site 2. The highest flood required is for the Plus 2 Hydrological Year class and it only amounts to 142 m^3/s. This amount of flood flow can generate quite insignificant specific force of flow.

Figure 4

The location where the Tower is constructed was selected on the basis that this amount of flow would not reach it and that the flow amounting to 420 m^3/s, which is the capacity of one Low Level Outlet gate, will only reach the bottom part of the Tower.

It was therefore not anticipated that there would be any floods of magnitudes greater than or even equal to 420 m^3/s immediately downstream of the Katse dam due to the presence of the dam structure as a major control device for downstream flows. Hence reinforcing the station at IFR site 2 was only optional and enough to absorb smaller specific forces.

6. Discussions

There is no long – term data record available for Hydrometric stations along the Malibamatšo River. The Hydrometric station at Kao was constructed in 2000. It has seven years of data record, from 2000 to 2007. This station has not yet been rated to convert the observed gauge height readings into its corresponding flow rate and there is neither historic data nor the flood event within this data set to compare with the November 2006 flood.

The Hydrometric station that is situated at the Katse Bridge downstream of the Katse dam was commissioned on the 1st October 1990. The station was closed on the 15th April 1997, seven (7) years later.

There was a need to monitor releases from the Katse dam and this station was reopened on the 6th August 2002. Therefore the Katse Bridge hydrometric station has seventeen (17) years of data record that has considerable amount of missing data. There has not been an event within the seventeen years of data that resemble or correspond to the November 2006 flood event.

Recent studies on flood hydrology has, however, adopted twenty (20) years return period for a flood of 1, 190.00 m^3/s and a fifty (50) years return period for a flood of 1, 660.00 m^3/s. The calculated November 2006 flood magnitude is 1, 345.29 m^3/s, which is quite close to the fifty years flood magnitude.

The flow rates as derived in this report are presented in Table 6. It can be seen that there is a short fall of flow of approximately 7.3 m^3/s between the measured flow at the Katse Bridge hydrometric station and the surveyed flood at IFR site 2.

Table 6

Flow rates along Malibamatšo River system

	Malibamatšo at Kao m^3/s	**Katse Total Inflow m^3/s**	**Katse Dam Spill m^3/s**	**Malibamatšo at Katse Bridge** m^3/s	**Malibamatšo at IFR site 2** m^3/s
Flow Rate	965.29	1, 011.57	1, 011.54	1, 352.59	1, 345.29

The flood obtained at IFR site 2 must be greater than the flood magnitude at the Katse Bridge hydrometric station due to the supply from the Khohlontšo stream. The method used to calculate this flood is seen to be accurate; however the flood marks during surveying were not clear due to the delay to execute the surveying exercise. The survey was done two months after the flood event and the debris that were found on site were used as the basis for flood marks. This thus shows that if the correct flood marks were identified the flood computations could have been very close to the fifty years flood magnitude.

There is a clear flood routing relationship between the flow rates shown in Table 6. The catchments between Kao station and the Katse dam, including the local catchments between Kao Station and Katse dam wall contributed flow rate up to 46.28 m^3/s, from 965.29 m^3/s computed at Kao station to 1011.57 m^3/s computed as the peak inflow into the Katse dam.

The Katse dam was almost full on the 2^{nd} November 2006 and all the inflow was released as spill and compensation flows amounting to the peak flow of 1011.54 m^3/s. Only 0.03 m^3/s was held back in the Katse reservoir.

It is further noted that the catchment between the Katse dam and the station at the Katse Bridge contributed flow rate up to 341.02 m^3/s, from 1011.54 m^3/s computed as the peak downstream flow to the peak flow of 1352.59 m^3/s recorded at the Katse Bridge Hydrometric station.

If it is thus assumed that the catchment between Katse Bridge hydrometric station and IFR site 2 contributed the same amount of flow, 341.02 m^3/s, then the peak flow rate at IFR site 2 could have been computed as 1693.61 m^3/s, which is very close and above the adopted average flood flow for the 50 years return period. The November 2006 flood was therefore successfully routed from Kao Hydrometric Station, through the Katse dam to IFR site 2.

7. CONCLUSIONS

The November 2006 flood is seen to be a natural event that has affected the whole country as the flood routing results in Table 6 shows. It is a one in fifty (1:50) years flood event with the flood magnitude of 1345.29 m^3/s. The corresponding specific force of flow is found to be $3.20X10^7$ Newtons.

The discussions section, however show that the flood peak at IFR site 2, as adopted in the flood studies for LHWP dams is higher and ranges around 1693.61 m^3/s.

It can also be concluded that floods of this magnitude are disastrous and can cause a lot of damage to properties.

Though the effects of erosion and deposition were seen to be minimal at the Kao cross – section, there were severe erosion impacts that include scouring of farm fields, uprooted trees and formed valleys along side Senqu River at Sehong – hong and Malibamatšo River at IFR site 2. The culvert on Khohlontšo stream is also washed away.

8. RECOMMENDATIONS

It is recommended that:

- The reconstruction of the hydrometric station at IFR site 2 must be fast tracked and the structure be reinforced and designed to overcome floods of this magnitude. The specific force of flow to be designed for is $3.20X10^7$ Newtons.

- The surface area of the upstream side of the station must be reduced so that there is minimal resistance to flow. The triangular structure on the upstream side is recommended.

It is, however noted that this flood magnitude will take another fifty years to be realized again. The available data will enable modeling and accurate flood predictions for appropriate decisions to be made in the future.