EARBA STORAGE

A GILKES ENERGY COMPANY

Earba Pumped Storage Hydro Scheme

CAR Licence Application Report

Appendix G: Loch Leamhain drawdown and buffer storage assessment

December 2024

Loch Earba PSH

Loch Leamhain drawdown and buffer storage assessment

Project:	Loch Earba PSH		
Our reference:	100112953/03/B	**Your reference:**	<Insert Text>
Prepared by:	[redacted]	**Date:**	15 Oct 2024
Approved by:	[redacted]	**Checked by:**	[redacted]
Subject:	Loch Leamhain drawdown and buffer storage assessment		

1 Introduction

Following the previous work carried out for the Loch Earba PSH scheme[1], this technical note assesses the time required to draw down water in Loch Leamhain prior to the Leamhain Dam construction works. Additionally, this note assesses the use of a potential buffer storage which may be required to protect construction activities against periods of high runoff within the catchment.

The construction of the dam will increase the natural catchment area of the Loch and therefore different catchment outfalls, areas and flow series have been used for the loch drawdown and loch buffer storage assessments (Figure 1.1; Table 1.1).

[1] [redacted] (2024). Hydrology study: Loch Earba PSH (Rev D)

Figure 1.1: Map of existing natural Loch Leamhain catchment and proposed dammed catchment

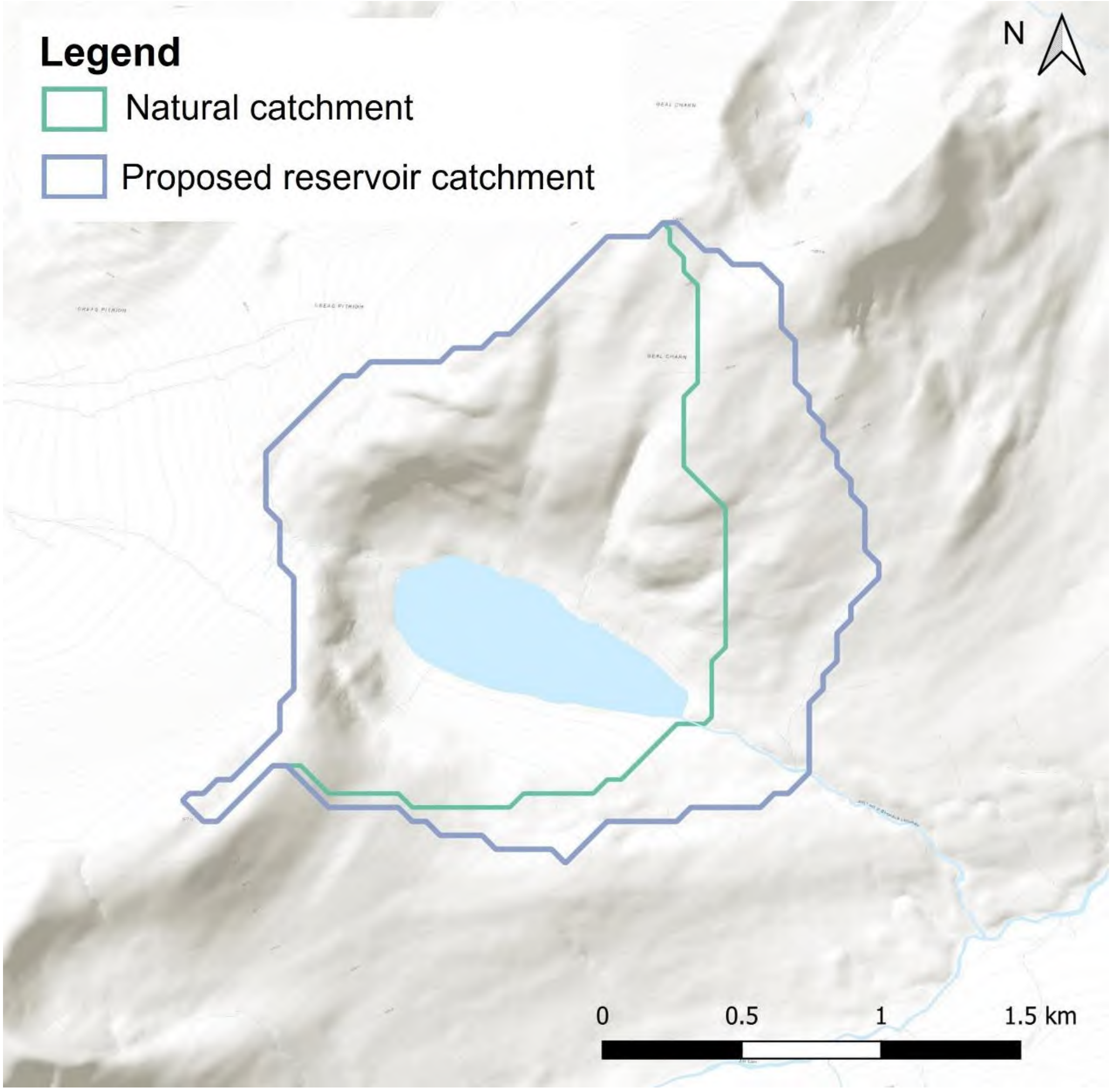


Table 1.1: Existing natural and proposed dammed Loch Leamhain FEH catchment outfalls

Catchment code	Description	Easting	Northing	FEH area (km^2)
BH-BHE	Outfall of natural Loch Leamhain catchment	250550	779400	2.57
BH-BHE update	Outfall of proposed dammed Loch Leamhain catchment after dam construction	250900	779200	3.61

2 Drawdown assessment

This section assesses the drawdown period of the existing natural Loch Leamhain, detailing the data used, model development, and discussing simulation results.

2.1 Data

- GR6J daily simulated catchment inflows to the existing Loch Leamhain from 1981-2021.
- FEH catchment and descriptors defined at point 250550 779400.
- ReFH2 1 in 2-year winter storm (2-hour 54-minute duration) hydrographs for the natural Loch Leamhain
- Depth-storage curve for the existing natural catchment of Loch Leamhain covering the range 605-635mAOD provided by Gilkes[2].

2.2 Model development

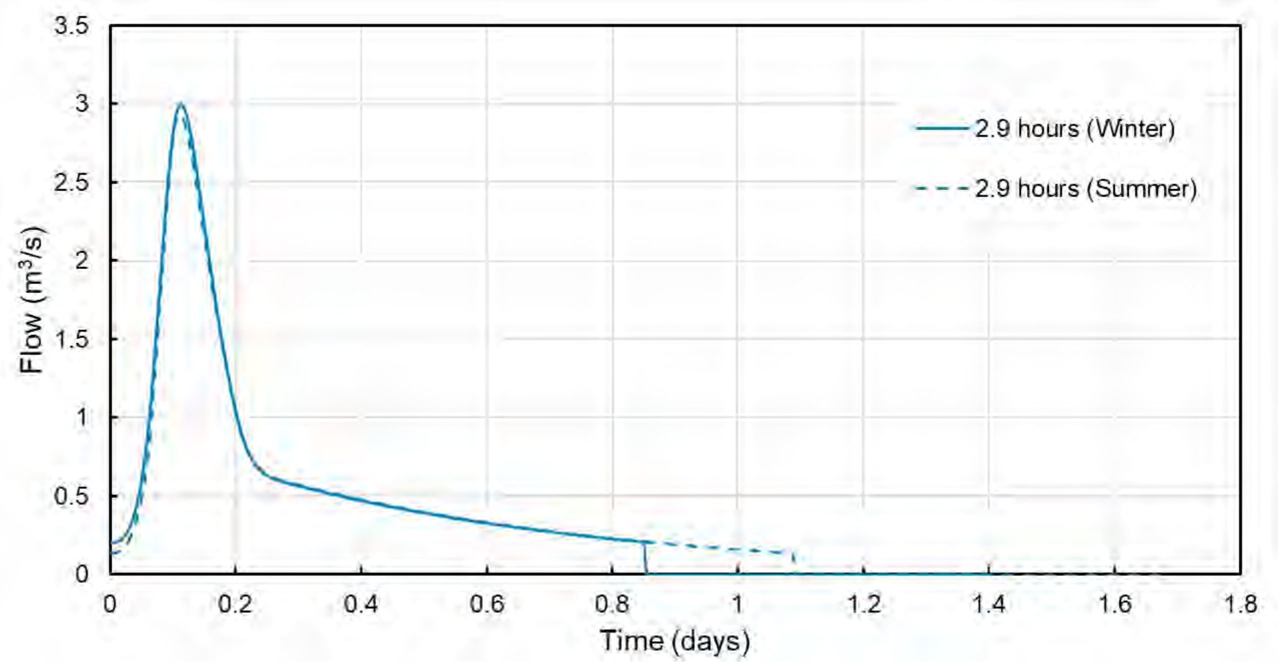
A spreadsheet-based daily water balance model was developed to investigate the time required to draw down Loch Leamhain prior to construction activities. The model represents Loch Leamhain as a single bucket using the depth-storage curve of the existing natural loch. Loch storage at the end of each day was then calculated as follows:

End of day storage = start of day storage + catchment inflow – release

Daily catchment inflows to Loch Leamhain are the only input to the model and were simulated as part of the previous Earba hydrology assessment[3] using GR6J.

A constant release from the Loch (towards Allt Cam) equivalent to the catchment's 2-year return period storm event peak flow is assumed. The catchment's 2-year return period storm event was estimated in ReFH2 using the FEH catchment descriptors highlighted in section 2.1. Summer and winter storm hydrographs are quite similar, each having a recommended design storm duration of 2 hours 54 minutes for a 2-year return period event, with peak flows of 2.93m^3/s and 2.99m^3/s, respectively (Figure 2.1).

Figure 2.1: 2-year return period summer and winter storm hydrograph – natural loch catchment



[2] Leamhain Existing Volume 240911.xlsx received via email, 11/09/2024

[3] [redacted], (2024). Hydrology study: Loch Earba PSH (Rev D)

The developed model was then used to determine the number of days required to completely draw down the loch.

2.2.1 Model initial conditions and parameters

Initial loch water level was set to the natural loch's maximum water level (635mAOD) according to its depth-storage curve, so that the drawdown duration estimates correspond to the storage capacity of the loch.

Following discussions with Gilkes Energy (11/09/2024), it was established that four $0.5m^3/s$ capacity pumps ($2.0m^3/s$ total capacity) would likely be used to draw down the loch. Therefore, the model was tested with a constant $2.0m^3/s$ release rate as well as the $3.0m^3/s$ determined via ReFH2. Modelling with a release rate of $3.0m^3/s$ also reflects the drawdown duration should 6 pumps be used.

Preliminary catchment flow gauging recordings over a nine-month period from September 2024 potentially indicate higher flows than those simulated via GR6J. The observed record time-period is not captured within the simulated hydrology and therefore differences in flow could be due to natural inter-annual variability. Nonetheless simulations considered a sensitivity test on the underlying hydrology by scaling the catchment inflows up by 20%.

An overview of the tested model initial conditions and parameterisations is outlined in Table 2.1.

Table 2.1: Natural Loch Leamhain drawdown assessment scenarios

Scenario	Starting level (mAOD)	Release rate (m^3/s)	Flow Factor
Scenario 1	635.00	2.0	1.0
Scenario 2	635.00	3.0	1.0
Scenario 3	635.00	2.0	1.2

2.3 Results

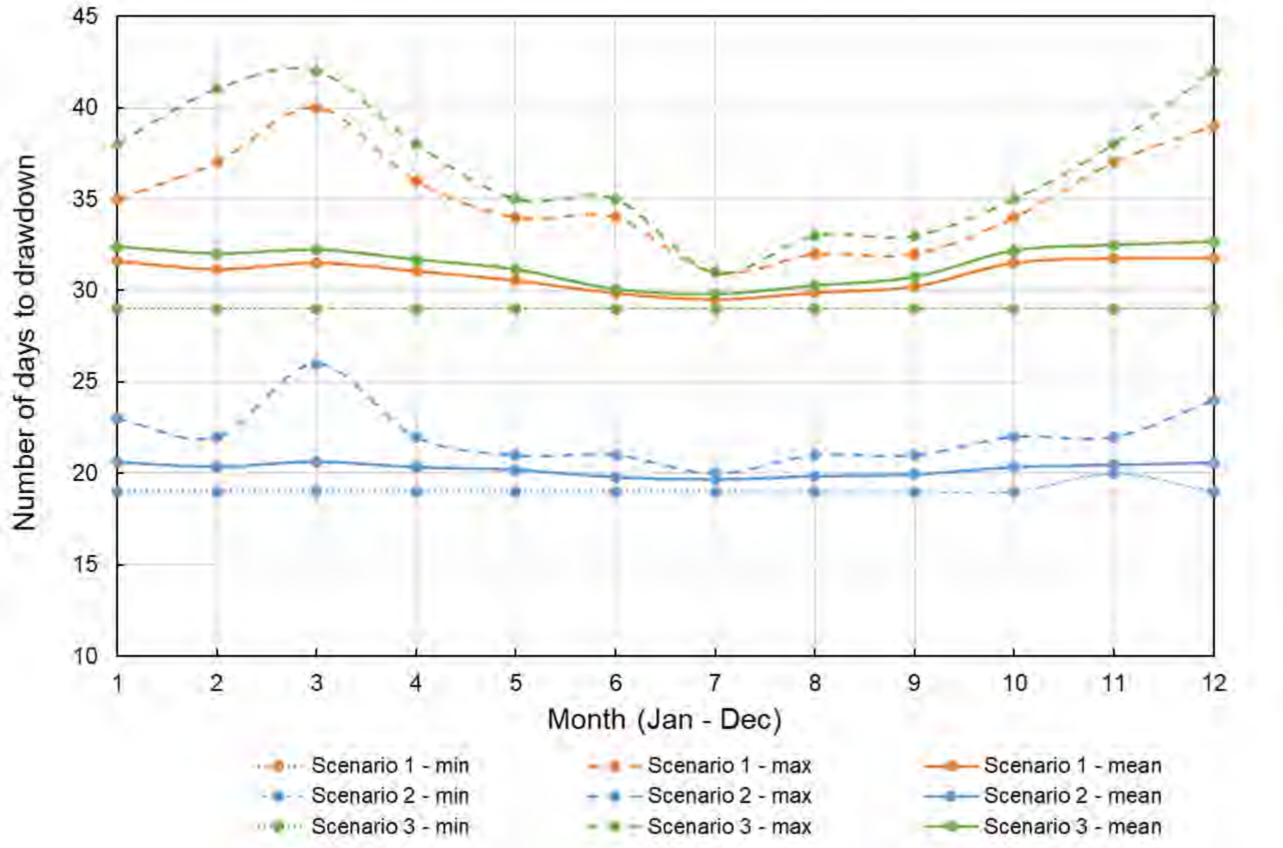
Simulations were initiated on the first day of each month in the forty-one-year period between January 1981 and November 2021 to produce 491 results for each modelling scenario/parameter set (Table 2.1) to provide a distribution of estimated drawdown durations for each month in the calendar year (Figure 2.2). The model was not run for December 2021 due to insufficient data (drawdown period goes beyond the temporal extent of the hydrological inputs).

Increasing the loch release rates from $2m^3/s$ to $3m^3/s$ can substantially reduce the time required to draw down the loch (Figure 2.2). On average the time required to draw down the loch is 20 days with $3m^3/s$ release (Scenario 2) in comparison to 31 days with a $2m^3/s$ release (Scenario 1). Maximum drawdown duration estimates vary between 31 and 40 days with a $2m^3/s$ release and between 20 and 26 days with $3m^3/s$ release.

Uncertainty in the model's hydrological inputs has less impact on drawdown duration estimates than the tested release rates. The impact of uncertainty in the simulated (GR6J) flows for the natural Loch Leamhain catchment to estimates of loch drawdown, is investigated by comparing results from scenario 3 to scenario 1. On average the time required to draw down the loch is 32 days with the underlying hydrology scaled up by 20% (Scenario 3) in comparison to 31 days without this scaling (Scenario 1). Additionally, findings show that scaling up the underlying hydrology by 20% increases the monthly maximum drawdown duration estimates by between 0 (July) to 4 days (February) reflecting increased loch inflows under scenario 3 in comparison to scenario 1.

The findings are tabulated in Table 2.2, Table 2.3 and Table 2.4.

Figure 2.2: Comparison of estimated drawdown duration (days)



Source Minimum values for Scenarios 1 and 3 are the same.

Table 2.2: Estimated drawdown duration (days) statistics – Scenario 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	29	29	29	29	29	29	29	29	29	29	29	29
Max	35	37	40	36	34	34	31	32	32	34	37	39
Mean	32	31	32	31	31	30	30	30	30	32	32	32
Range	6	8	11	7	5	5	2	3	3	5	8	10

Table 2.3: Estimated drawdown duration (days) – Scenario 2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	19	19	19	19	19	19	19	19	19	19	20	19
Max	23	22	26	22	21	21	20	21	21	22	22	24
Mean	21	20	21	20	20	20	20	20	20	20	20	21
Range	4	3	7	3	2	2	1	2	2	3	2	5

Table 2.4: Estimated drawdown duration (days) – Scenario 3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	29	29	29	29	29	29	29	29	29	29	29	29
Max	38	41	42	38	35	35	31	33	33	35	38	42
Mean	32	32	32	32	31	30	30	30	31	32	32	33
Range	9	12	13	9	6	6	2	4	4	6	9	13

3 Buffer storage assessment

This section assesses the buffer storage which may be required during the development phase of Loch Leamhain to protect construction activities against periods of high runoff within the catchment.

3.1 Data

- ReFH2 72-hour storm winter hydrographs across a range return periods for the proposed dammed Loch Leamhain reservoir
- Depth-storage curve for the natural Loch Leamhain reservoir covering the range 605-635mAOD provided by Gilkes[4]

3.2 Model development

The buffer storage assessment again used a spreadsheet-based water balance model to investigate whether the proposed buffer storage within the natural catchment is sufficient for potential peak flow periods. The model represents Loch Leamhain as a single bucket using the depth-storage curve of the reservoir. Reservoir storage at the end of each day was then calculated as follows:

End of day storage = start of day storage + storm inflow – release

Storm inflows were generated using ReFH2 to define 72-hour winter storm hydrographs for a range of different return periods. 72-hour winter storms are regarded as a conservative assumption with respect to the required buffer storage as they have larger total storm volumes than storms of short duration or summer storms. After the end of the storm event inflows, a constant loch inflow is assumed which is equivalent to the baseflow at the end of the 2-year return period 72-hour winter storm event. The temporal resolution of the model is 30 minutes, aligning with the temporal resolution of the generated storm hydrographs.

Releases from the catchment are expected to be facilitated via pumping. Notably, proposed cut-off ditches (designed to a capacity of 1.5m^3/s) in the catchment to mitigate against the transfer of Invasive Non-Native Species are assumed to not support catchment releases towards Allt Cam during storm events, as they are not designed for high return period storm events and could be impacted by sedimentation during these periods. It is expected that releases will only be permitted 24 hours after the end of the storm event, to allow for inflowing sediment to settle.

The buffer storage assessment uses the depth-storage curve of the natural loch but applies ReFH2 storm hydrographs generated for the larger dammed Loch Leamhain reservoir catchment (Table 1.1) to allow for a conservative assessment of water levels within Loch Leamhain during the construction phases of the dam.

3.2.1 Model initial conditions and parameters

For each model, the initial water level was set to 612mAOD aligning with the level at which the buffer storage begins, and to which the loch would have been drawn down. Dam construction activities are expected to take place at levels above 616mAOD (and probably above 620mAOD) although the loch outflow is at 635mAOD highlighting substantial storage capacity within the loch.

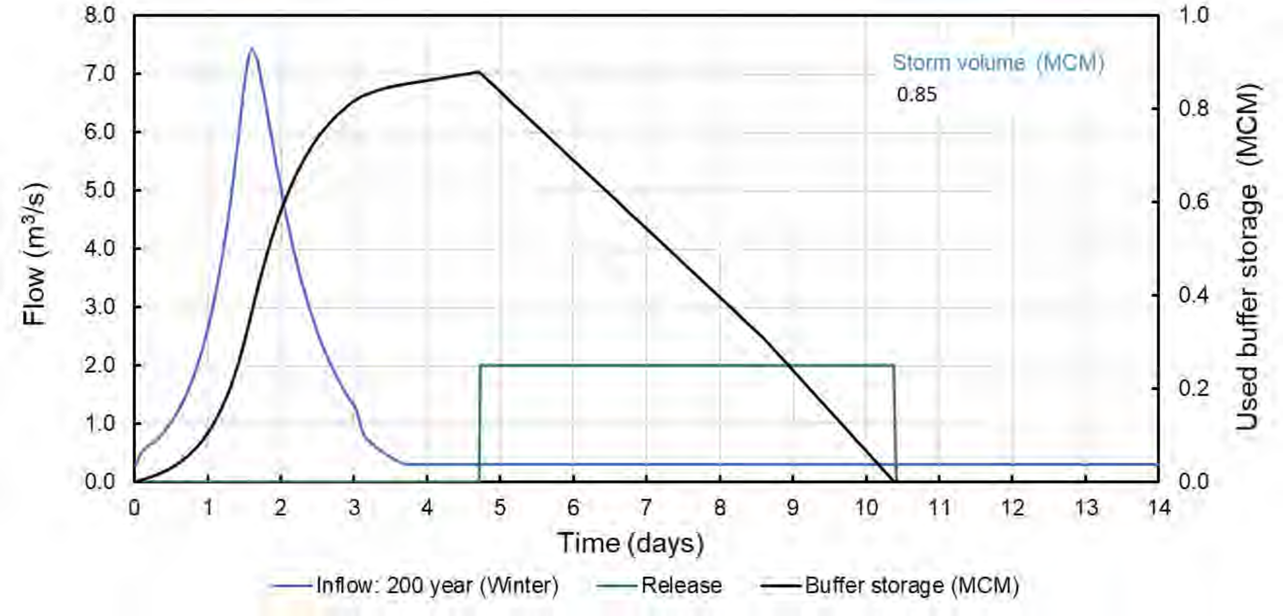
In line with discussions with Gilkes Energy, the impact of the pumping capacity on findings was tested by assuming capacities of either 1m^3/s or 2m^3/s.

[4] Leamhain existing volume 240911.xlsx received via email 11/09/2024

3.3 Results

Figure 3.1 shows an example of the simulation dynamics for the natural Loch Leamhain reservoir with a 2m³/s release during a 1 in 200-year return period 72-hour winter storm event, including storm inflows, reservoir releases / outflows and the volume of buffer storage used. Storm flows peak after approximately 1.6 days at 7.4m³/s and stop after 3.7 days, after which inflow represents baseflow. The volume of used buffer storage peaks at 0.88MCM at approximately 4.7 days, after which the buffer storage is drained at 2m³/s until empty (10.4 days after start of storm). The used buffer storage is slightly greater than the total storm event volume due to baseflow contributions after the storm event but before releases begin (24 hours after the storm event).

Figure 3.1: Natural Loch Leamhain storage and water level dynamics during a 200-year return period winter storm event of 72-hour duration



As releases only start 24 hours after the end of the storm flow event, the buffer storage is expected to hold the entire volume of the storm event and does not vary according to the assumed release capacity (Table 3.1). The assumed release capacity will therefore only adjust the time required to drawdown water levels to pre-event conditions. Simulations find that the used storage during winter storms increases from 0.40MCM for 1 in 2-year events up to 1.03MCM for 1 in 1,000-year events.

Assessing simulation results with regards to maximum estimated water levels instead of used storage shows that water levels during the 1 in 2-year winter storm event would exceed 616mAOD and encroach upon construction activities (Table 3.1**Error! Reference source not found.**). However, water levels are not expected to exceed 621mAOD (well within the natural storage capacity of the loch) up to the 1 in 1,000-year return period event. Estimated water levels are rounded up to the next metre as a conservative approach to account for any underestimation of inflow.

Table 3.1: Used buffer storage volumes (MCM) during 72-hour winter storm events

Return period	Buffer storage used (MCM)	Estimated maximum water level (mAOD)
2-year	0.40	617
5-year	0.48	617
10-year	0.55	618
30-year	0.67	619

Return period	Buffer storage used (MCM)	Estimated maximum water level (mAOD)
50-year	0.73	619
100-year	0.81	620
200-year	0.88	620
500-year	0.97	621
1,000-year	1.03	621

4 ReFH2 storm hydrographs

This section details the winter and summer storm hydrographs generated by ReFH2 using FEH webservice catchment descriptors for the existing natural Loch Leamhain catchment and the dammed catchment (Table 1.1). Parts of this analysis fed into the previous loch drawdown (Section 2) and buffer storage assessments (Section 3).

4.1 Existing Loch Leamhain natural catchment

Figure 4.1: 200-year return period storm hydrographs – Existing natural Loch Leamhain

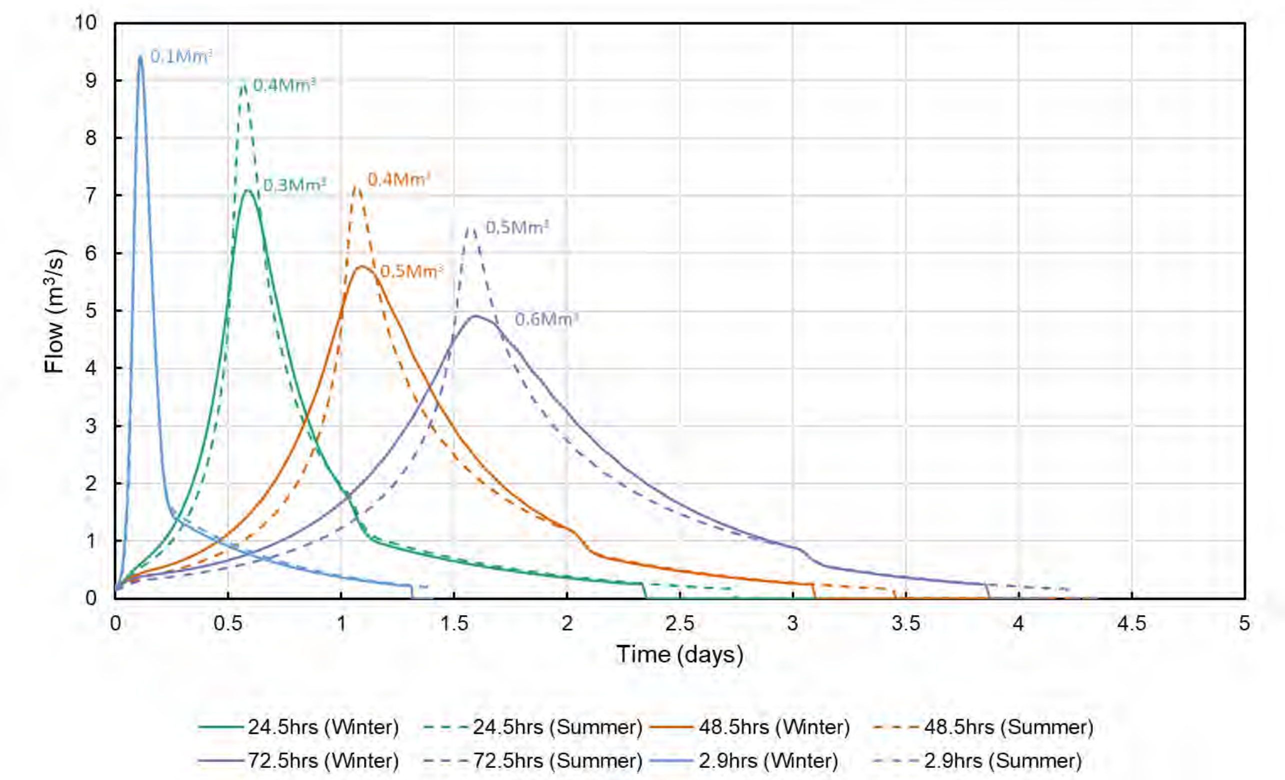


Table 4.1: Total Winter storm event volumes (MCM)

Return Period	2.9-hour (default)	24hour	48hour	72-hour
2-year	0.05	0.16	0.22	0.27
5-year	0.07	0.20	0.27	0.33
10-year	0.09	0.23	0.32	0.38
30-year	0.11	0.28	0.39	0.47
50-year	0.12	0.31	0.42	0.51
100-year	0.13	0.34	0.47	0.56
200-year	0.15	0.38	0.52	0.61
500-year	0.17	0.43	0.57	0.68
1,000-year	0.18	0.46	0.61	0.72
10,000-year	0.24	0.57	0.74	0.87

Table 4.2: Total Summer storm event volumes (MCM)

Return Period	2.9-hour (default)	24hour	48hour	72-hour
2-year	0.05	0.15	0.20	0.25
5-year	0.07	0.18	0.25	0.30
10-year	0.09	0.21	0.29	0.35
30-year	0.11	0.26	0.35	0.43
50-year	0.12	0.28	0.39	0.46
100-year	0.14	0.31	0.43	0.51
200-year	0.15	0.35	0.47	0.56
500-year	0.18	0.39	0.52	0.62
1,000-year	0.19	0.42	0.56	0.66
10,000-year	0.25	0.52	0.68	0.79

4.2 Dammed Loch Leamhain catchment

Figure 4.2: 200-year return period storm hydrographs – Dammed Loch Leamhain

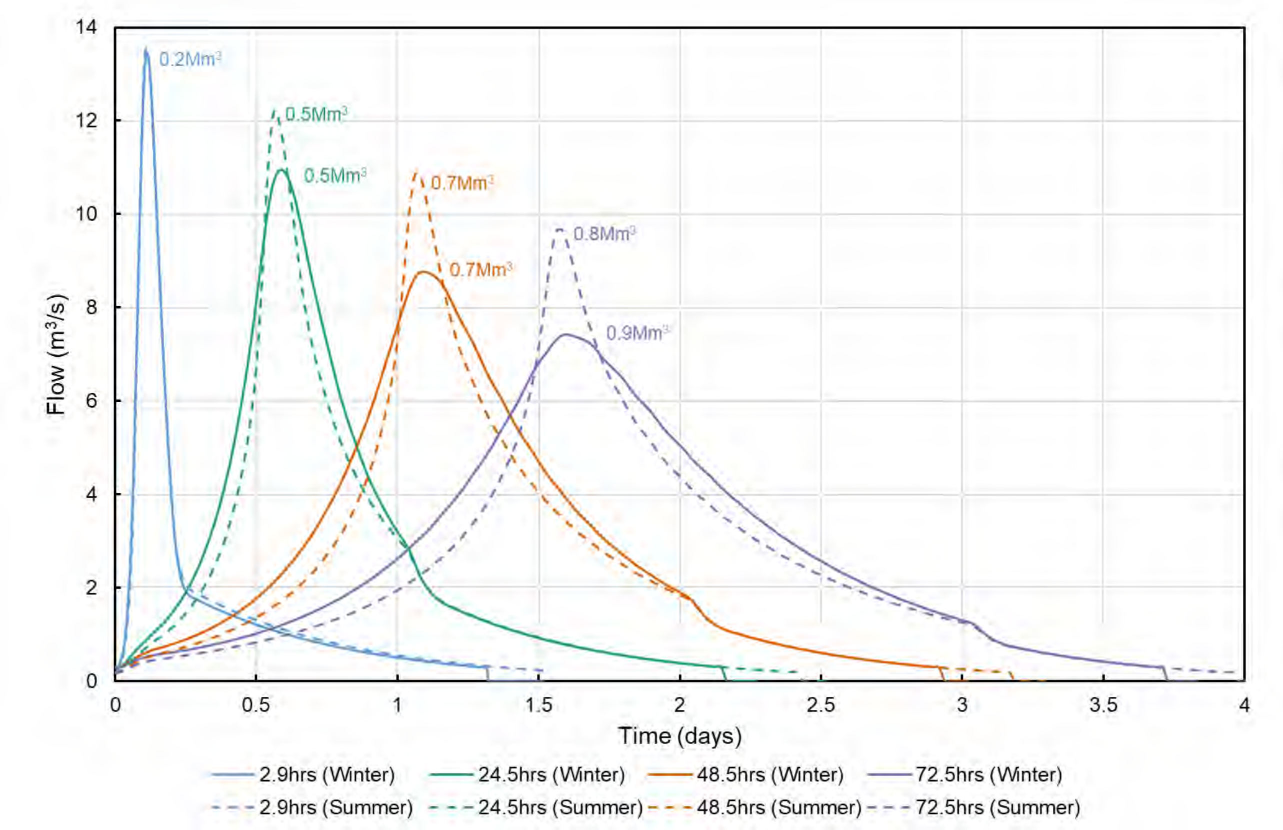


Table 4.3: Total Winter storm event volumes (MCM)

Return Period	2.9-hour (default)	24hour	48hour	72-hour
2-year	0.07	0.23	0.31	0.37
5-year	0.10	0.28	0.38	0.46
10-year	0.12	0.32	0.44	0.53
30-year	0.15	0.39	0.54	0.65
50-year	0.16	0.43	0.59	0.71
100-year	0.18	0.48	0.65	0.78
200-year	0.21	0.53	0.72	0.85
500-year	0.23	0.59	0.80	0.94
1,000-year	0.26	0.64	0.85	1.01
10,000-year	0.34	0.80	1.04	1.21

Table 4.4: Total Summer storm event volumes (MCM)

Return Period	2.9-hour (default)	24hour	48hour	72-hour
2-year	0.07	0.21	0.28	0.34
5-year	0.10	0.26	0.35	0.42

Return Period	2.9-hour (default)	24hour	48hour	72-hour
10-year	0.12	0.30	0.40	0.48
30-year	0.16	0.36	0.49	0.59
50-year	0.17	0.39	0.54	0.65
100-year	0.19	0.44	0.60	0.72
200-year	0.22	0.48	0.66	0.78
500-year	0.25	0.54	0.73	0.86
1,000-year	0.29	0.59	0.78	0.92
10,000-year	0.35	0.73	0.95	1.11

5 Conclusions

The estimated time to draw down the natural Loch Leamhain is on average 31 days when assuming four pumps (total capacity $2m^3/s$) are used to dewater the loch. This can be reduced to 20 days on average if it is assumed that six pumps ($3m^3/s$) are available for dewatering. Scaling up the hydrological inputs by 20% to account for potential hydrological modelling uncertainty only increased the average drawdown period from 31 days to 32 days (dewatering at $2m^3/s$).

Finally, simulations show that water levels in Loch Leamhain could exceed 616mAOD during a 1 in 2-year winter storm event and impact dam construction activities if they occur down to that level. However, it is considered likely that such activities will not be required below about 620mAOD. Maximum estimated water levels are not expected to exceed 621mAOD for the 1 in 1,000-year winter storm event, which is well within the storage capacity of the loch which has an outflow at 635mAOD. Modelling reflects that storm flow releases can only occur 24 hours after the end of the storm event to allow inflowing sediment to settle within the loch. Therefore, the loch is required to store the entire storm volume.