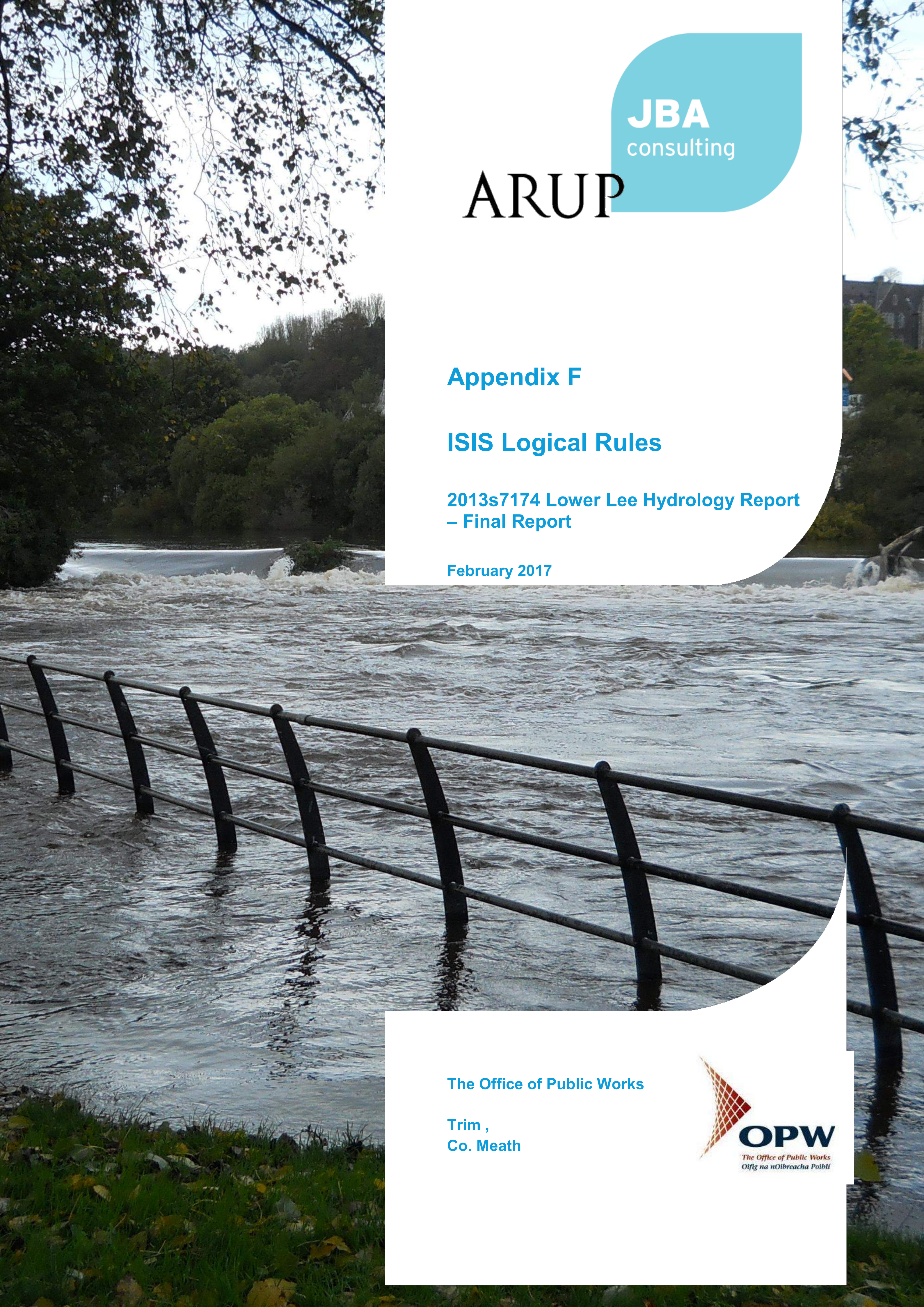


Appendix F

ISIS Logical Rules

2013s7174 Lower Lee Hydrology Report – Final Report

February 2017

The Office of Public Works

Trim ,
Co. Meath

Graphical representation of logical rules controlling reservoir operation in the Lee ISIS model

Inniscarra Rules [InnisSluice]							
Rule Number	Reservoir Level v Overtopping	Reservoir Level	Rising / Falling	Outflow v Inflow	Outflow v Regulations	Level now compared to 1hr ago at Inniscarra	Action
1a	> Cill + Gate Height + Opening						Position=0.05+Reservoir Level-Cill-Gate Height
1c	≤ Cill + Gate Height + Opening	<MiNOL					-0.1
1b		>= MiNOL and <49.5					Pre-Rel
5a		49.5 ≤ level ≤ 50.85	Rising OR FloodPrdctd >0.019	<Inflow	< InnisTable2		+0.1
6a					≥ InnisTable2		-0.1
7a				≥ Inflow	≥ InnisTable2		-0.1
8					< InnisTable2		-0.1
5b			NOT Rising OR FloodPrdctd >0.019			>0.02	-0.02
7b						≤0.02, ≥0.01	0
6b						<0.01	+0.02
2		>50.85	Rising	< Inflow			+0.1
12				≥ Inflow			-0.1
13			Falling				0

FloodPrdctd – looks at the forecasts (FcastShrt and FrcastLng) to see if a threshold has been crossed (set at 90m3/s at Dromcarra). Is 0.01 if long threshold crossed, 0.02 if short threshold crossed.
FcastShrt and FrcastLng are the Dromcarra flow series with an offset (currently 24 and 48 hours)
TrgtRelseA – Target to release once FcastShrt is triggered (FloodPrdctd = 0.01)
TrgtRelseB – Target to release once FrcastLong is triggered (FloodPrdctd = 0.02)
InnisTable2 calculated below

Pre-release positioning of gate [PreRelease]					
Rule number	Flood Predicted?	Inniscarra level	Inniscarra discharge	Free flow?	Move
1a	N		<Carrig pre-release	N	0.05
1b				Y	0
1c			≥Carrig pre-release + 5		-0.1
1d			≥ Carrig pre-release <Carrig pre-release + 5		0
8	@V long hrs	<InnisTrgtOL			-0.1
9		>=InnisTrgtOL	<Target release C	N	0.05
10				Y	0
11			≥ Target release C + 5		-0.1
12			≥ Target release C < Target release C + 5		0
2a	@long hrs		<Target release Ba	N	0.05
2b				Y	0
3			≥ Target release Ba + 5		-0.1
4			≥ Target release Ba < Target release Ba + 5		0
5a	@short hrs		<Target release Bb	N	0.05
5b				Y	0
6			≥ Target release Bb + 5		-0.1
7			≥ Target release Bb < Target release Bb + 5		0

For Carrig pre-release see table below
Target Release C – release rate for early release (96 hrs) AND release to make when Carrig starts to spill
Target release Ba – release rate for long lead time threshold crossing (early)
Target release Bb – release rate for long lead time threshold crossing (late)
InnisTrgtOL – the target operating level for Inniscarra prior to a big event

Carrig pre-release [CarrigOT]			
Rule number	CarrigSluice	Carrig Pre-rel	ABS
1	0		0
2	>100		TargetRelC
3	>0 ≤100	>0	TargetRelC
4		≤0	0

TargetRelC – release rate to be made from Inniscarra when there is spill from Carrigadrohid

All Clear [AllClear]		
MaxFlow at InnisRes	Flow now at InnisRes	ABS
<340		0.01
>=340	>=80	0.01
	<80	0

InnisTable2 [InnisTable2]			
Rule number	Flood predicted	Regulated flow (InnisTable)	Regulation Flow
1	≥0.02	<TargetRlseB	TargetRlseB
2		≥ TargetRlseB	Flow from InnisTable
3	<0.02		Flow from InnisTable

InnisTable [InnisTable]		
Rule number	Inniscarra level	Regulation Flow
1	<49.5	0
2	≥49.5 <50.5	224.3*(LEVEL(InnisRes)-49.5)+108
3	≥50.5 <50.8	510*(LEVEL(InnisRes)-50.5)+333)
4	≥50.8	1280*(LEVEL(InnisRes)-50.8)+486

Rising Flood [RISINGFLD]				
Rule number	Flow into Inniscarra	Maximum flow [MaxTestQ]	Maximum level [MaxTestL]	
1	>200	< Innis Inflow OR < Innis level		0.001
2		NOT (< Innis Inflow OR < Innis level)		0
3	≤ 200	> 200	≤ Innis level	0.001
4			> Innis level	0
5		≤ 200		0

Flood predicted [FloodPrdctd]							
Rule number	All clear	Flood predicted?	FcastShort	FrcastLong	FcastVLong	Flood predicted	Flood predicted
1a	N	0 or 0.03	N	N	N	0	0
1b						0.03	0.03
1c					Y		0.03
2			Y	N			0.02
3			Y	Y			0.02
4			N	Y			0.01
5		0.01	N				0.01
6			Y				0.02
7		0.02					0.02
8	Y						0

Result of 0.01 means a flood is predicted at the long time window, 0.02 means it is predicted at the short window. 0.03 means predicted at very long window. Zero means no flood predicted.

Inniscarra Turbine [InnisTurbine]						
Reservoir level	Forecast	Reservoir level	Inflow	TrgtRelseBb	ABS	Rule no.
<=MiNOL					0	0
>MiNOL	NOT FloodPredicted OR RisingFlood	<= InnisPreOL	>80		InnisTurbQ	1
			<=80		Inflow	2
		> InnisPreOL			InnisTurbQ	3
	FloodPredicted OR RisingFlood			> InnisTurbQ	InnisTurbQ	4
				< InnisTurbQ	TrgtRelseBb	5

Where InnisPreOL is an abstraction unit that choses either the Target or maximum normal operating level, depending on whether a flood is predicted
InnisTurbQ is a QTBDY that gives the flow out of the turbine during flood periods

Rules for operating Carrigadrohid Sluices in the 'deep sluice' scenario [InnisSluice]					
Forecast	Reservoir level	Change in water level (shortened to 1hr)	Discharge (inc. Turbine and spill)	Gate movement	Rule no.
FloodPredicted	>= 63m and <65.17m	<0.6m/24hrs	<CarrigTable	+0.1	1
			>=CarrigTable	-0.1	2
		>=0.6m/24hrs		-0.1	3
	>MiNOL and <63m	<1.0m/24hrs	<CarrigTable	+0.1	4
			>=CarrigTable	-0.1	5
		>=1.0m/24hrs		-0.1	6
	>=65.17m			+0.1	7
	<=MiNOL			-0.1	7b
NOT FloodPredicted or Early PreRelease	>=CarrigPreOLm	<0.6m/24hrs	<CarrigTable	+0.1	8
			>= CarrigTable	-0.1	9
		>=0.6m/24hrs		-0.1	10
	<CarrigPreOLm			-0.1	11

Where CarrigPreOL is an abstraction unit that choses either the Target or maximum normal operating level, depending on whether a flood is predicted

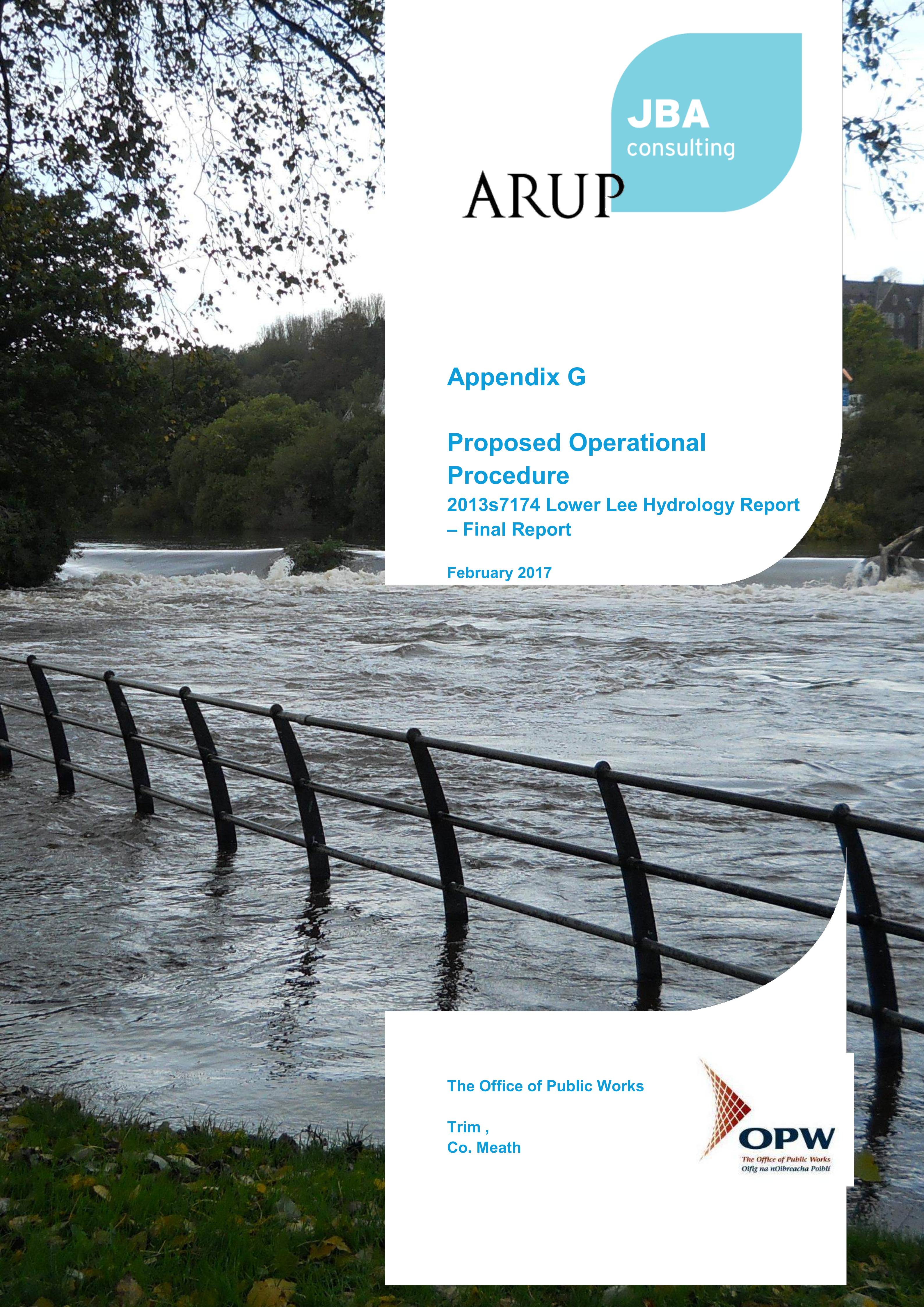
Carrigadrohid Turbine [CarrTurbine]						
Reservoir level	Forecast	Reservoir level	Change in water level (shortened to 1hr)	Inflow	ABS	Rule no.
<=MiNOL					0	0
>MiNOL	FloodPredicted OR RisingFlood	>= 63m	<0.6m/24hrs		CarrigTurbQ	5
			>=0.6m/24hrs		0.8 * ABS	4
		<63m	<1.0m/24hrs		CarrigTurbQ	7
			>=1.0m/24hrs		0.8* CarrigTurbQ	6
	NOT FloodPredicted OR RisingFlood	<= CarrigPreOL		> CarrigTurbQ	CarrigTurbQ	1
				<= CarrigTurbQ	Inflow	2
		> CarrigPreOL			CarrigTurbQ	3

Where CarrigPreOL is an abstraction unit that choses either the Target or maximum normal operating level, depending on whether a flood is predicted
And CarrigTurbQ is

CarrigTable (release table) [CarrigTable]			
Rule number	FloodPrdctd	Carrig level	Outcome
1	<>0.02	<Table level for TrgtReleseA	TrgtReleseA
		>=Table level for TrgtReleseA	Table flow for Carrig level
	0.02	<Table level for TrgtReleseD	TrgtReleseD
2		>=Table level for TrgtReleseD	Table flow for Carrig level

TrgtReleseD Max release rate for Carrig from 24 hours (300m³/s)

TargtRelseA		
Rule number	Level in Inniscarra	Outcome
1	<49	0.3
2	>=49.5	0.15
3	>=49 and <49.5	0.3-0.15*((LEVEL(InnisRes)-49)/0.5)



Appendix G

Proposed Operational Procedure

2013s7174 Lower Lee Hydrology Report – Final Report

February 2017

The Office of Public Works

Trim ,
Co. Meath

G.1 Overview

Peak inflows to Carrigadrohid that exceed 400m3/s require operational flood control procedures. This threshold was obtained from the continuous simulation modelling by identifying the event (among the 870 simulated) having the smallest inflow to Carrigadrohid that still exceeded the design flow in Cork (approximately 550m3/s).

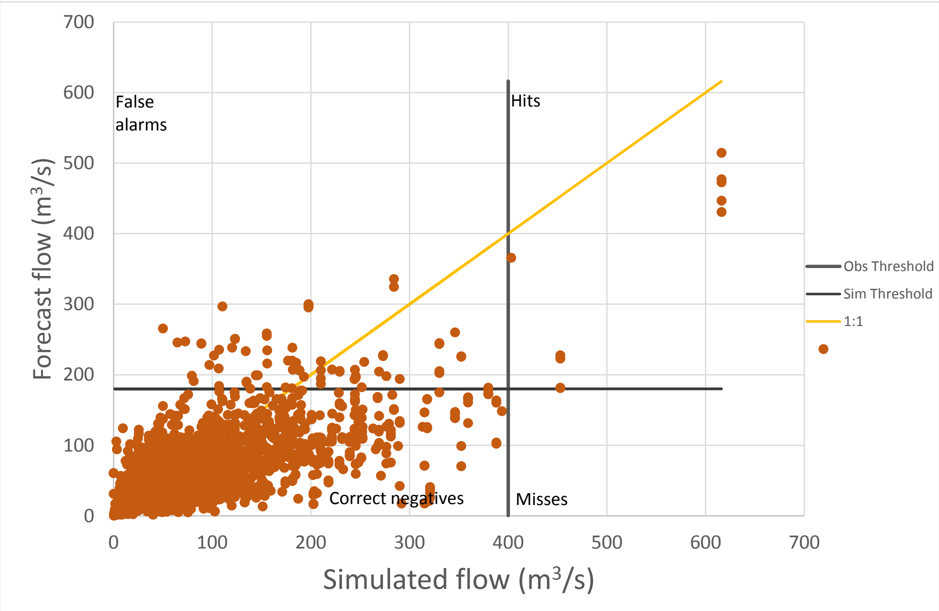
Flow into Carrigadrohid is predicted by FEWS from a hierarchy of rainfall sources. Every forecast uses:

- Observed data where it is available (from the start of the simulation up to time now);
- Met Eireann's Harmonie data for the first 4 hours into the future; and
- The European Centre for Medium Range Forecasts' (ECMWF) deterministic forecast from 4 to 120 hours beyond that. Rainfall ensembles from ECMWF are also run for information.

The merged rainfall series is fed to four PDM rainfall runoff models which together predict flow into the reservoir. Ensemble forecasts will also be available to inform the decision making process. The Flood Authority maintains and operates the forecasting system.

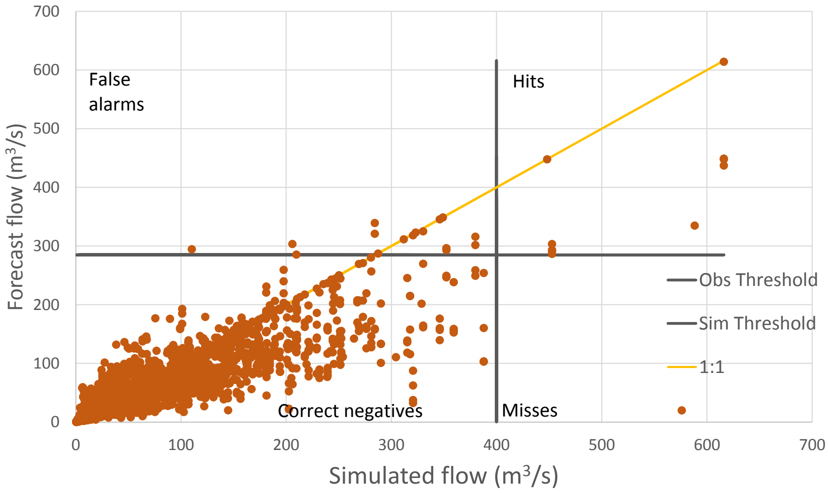
Under predictive bias in the rainfall forecast, together with general modelling uncertainty mean that, in order to identify all 400m3/s threshold crossings, the threshold for the forecast must be 180m3/s at 96 to 48 hours lead time and 285m3/s at leads times of 48 hours or less. These thresholds were set after running every rainfall forecast, between January 2007 and December 2014, through the FEWS system. Predicted maxima, using forecast rainfall, were compared to simulations using observed rainfall (and a second version that used observed flow where available). A threshold was set which identified all of the 400m3/s simulations in the 'observed[19]' series at the required lead times. In fact, there are only two events which meet this criteria (November 2009 and October 2013 – and October 2013 doesn't quite make the criteria in the 'updated' simulation), although there are multiple forecasts for each. Plots correlating peak simulated flow, using forecast and observed rainfall inputs, are shown below for the 96-48 hour and 48-24 hour forecasts (see Figures 1 and 2 respectively). A listing of the events where the thresholds are crossed is provided at the end of this document for both simulations.

Figure 1 – Peak flow, simulated without error correction[20] using observed (X) and forecast (Y) rainfall for 96 to 48 hours lead time



[19] In fact, the observed series is the flow simulated by the models when fed with observed rainfall. This was necessary because of the lack of a continuous flow series at the river gauges feeding Carrigadrohid reservoir.
[20] Error correction is the process where flows simulated by the rainfall runoff model are aligned with the observed before time now. This correction also persists for a time after time now.

Figure 2 – Peak flow, simulated without error correction using observed (X) and forecast (Y) rainfall for 48 to 0 hours lead time



Crossing either threshold (in their respective time slots) signals that 'flood conditions' are in force. Reservoir drawdown is triggered initially if the 180m3/s threshold is predicted to cross within the next 4 days (96 hours). New forecasts are available from ECMWF every 12 hours. New forecasts are made in FEWS every time these become available. Met Eireann forecasts are newly available every 6 hours, but only affect the first 4 hours of the rainfall hierarchy and only become truly relevant when the event is very close to happening.

An alarm is raised by FEWS if the forecast inflow to Carrigadrohid exceeds either threshold at the respective time. The timing of the threshold crossing is noted by the Flood Authority, who initiates a discussion with the reservoir operator. That discussion will take into account the predictions from FEWS, the current status of the reservoirs and the outlook for the coming days and hours. A drawdown regime for the coming 12 hour period (most commonly that suggested by the FEWS system) will be agreed in a telephone conference and the Flood Authority will record this decision in an email to the Reservoir Operator. The plan is enacted by the Reservoir Operator.

Flood control procedures fall into four main time categories, called Flood States, all related to when the threshold is forecast to be crossed. Each has been allocated a letter (Flood State D to A, which an additional State – F - to cover false alarms). Imminent floods always take priority, so Flood State A is the first step in the flow chart in Figure 7.

- Flood State D: between 96 and 48 hours before inflows to Carrigadrohid exceed 400m3/s;
- Flood State C: Between 48 and 24 hours before the threshold is crossed;
- Flood State B: Between 24 and 3 hours before the threshold is crossed; and
- Flood State A: When the threshold is crossed (or forecast at a short lead time of 3 hours).
- Flood State F occurs if the peak is less than 400m3/s at a lead time of 3 hours or less.

Mobilisation of ESB staff to respond to an upcoming flood event requires up to 4 hours. A mobilisation delay is only expected on the first instance of a forecast crossing. The station will be manned once the first releases begin. A delay is allowed for by looking at forecasts 96+4 hours into the future, as indicated in the flowchart.

G.2 96 to 48 hours to threshold crossing [Flood State D]

G.2.1 General

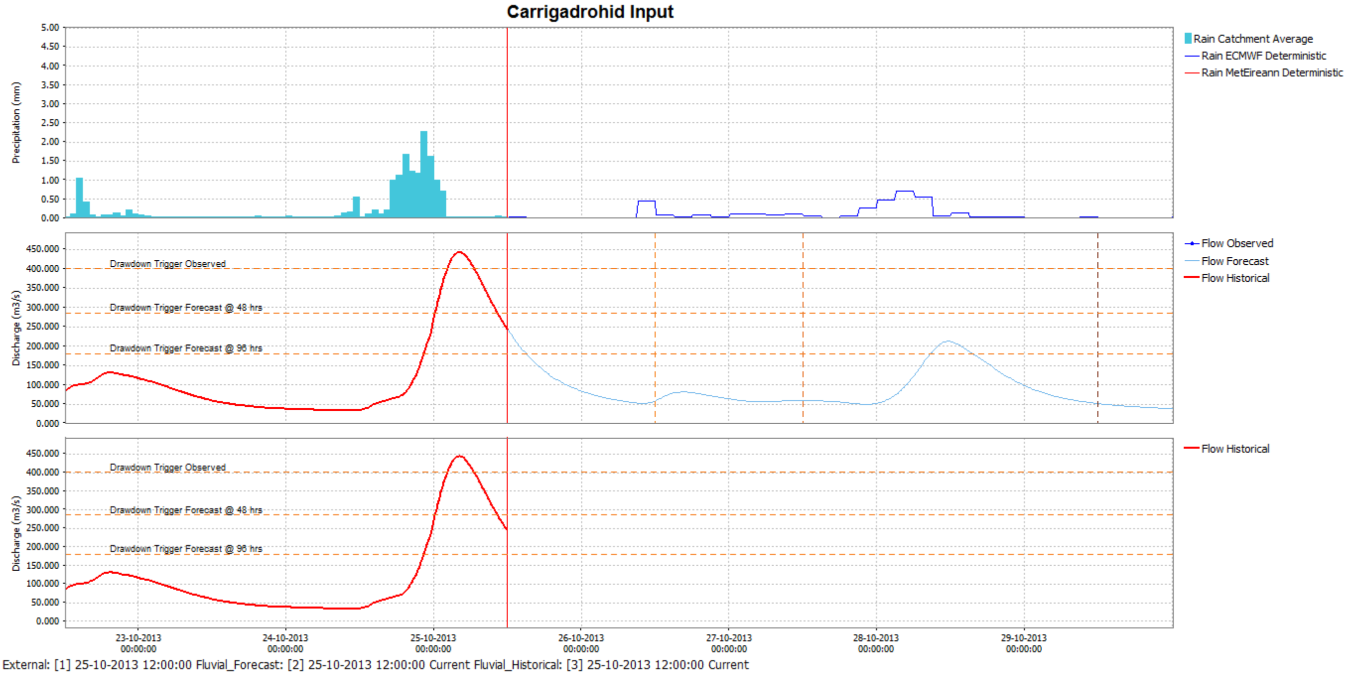
Carrigadrohid and Inniscarra reservoirs are drawn down to 'Flood Risk Level' (FRL) in Flood State D. The trigger is inflow to Carrigadrohid exceeding 180m3/s. FRL is almost 1.5m lower than Maximum Normal Operating Level (MNOL). FRL is proposed to be 63.1m for Carrigadrohid and 48.0m in Inniscarra.

Using observed reservoir levels and simulated inflows, FEWS calculates the average release rate required to achieve FRL 48 hours before the predicted crossing (iii). For information only, the system also shows the release needed to achieve FRL in the next 48 hours. The Flood Authority will communicate the computed release rate to the Reservoir Operator, who will make releases at the required rate (hydraulic head allowing).

Once drawdown begins, the Flood Authority will check the release rate every 12 hours and communicate any change to the Reservoir Operator (i). Only changes in release rate greater than 25m3/s are likely to be actioned.

If a forecast predicts the threshold late (i.e. at a lead time shorter than 96 hours), procedures begin at whatever time the threshold crossing is predicted. In some cases it might not be possible to achieve FRL at 48 hours within the constraints outlined below (i.e. maximum draw down and maximum allowable release), either because inflows are elevated or because the process has started late.

Figure 3 – FEWS display showing total inflow to Carrigadrohid



Note: The plot does not show the observed inflows to Carrigadrohid because, for this event, the data were not available.

10.1.1 Constraints

Releases from Carrigadrohid are constrained by a maximum drawdown rate of 0.6m/24 hours when the reservoir is above 63m and 1.0m/24 hrs when it is below. There is no physical constraint on the maximum flow release (other than the capacity of the gates), but releases should not exceed 150m3/s when Inniscarra is at or above MNOL (49.5m). These are also constraints on the minimum water level in both reservoirs: 61m in Carrigadrohid and 45.7m in Inniscarra.

Inniscarra releases are constrained. They should not normally exceed 150m3/s in this period. If the Flood Authority calculates that the required release rate from Inniscarra is greater than 150m3/s, it is acceptable to discharge up to 200m3/s from that reservoir. Outflows from Carrigadrohid should be restricted to 150m3/s in that circumstance. Such a decision will be made by the Flood Authority in consultation with the Reservoir Operator and will take into account the current reservoir state, the prevailing flow conditions and the FEWS forecast. The agreed regime will be implemented by the Reservoir Operator.

Drawdown stops if the forecast inflow drops >10%[21] below the threshold and normal management resumes. This lower threshold for aborting drawdown provides some flexibility where the forecast 'flicks' between drawdown and non-drawdown criteria on consecutive forecasts.

[21] 10% is an arbitrary reasonable value for this tolerance

G.3 48 to 24 hours to threshold crossing [Flood State C]

G.3.2 General

Between 48 and 24 hours, the threshold to initiate drawdown is 285m3/s. The higher value reflects the lower uncertainty in the rainfall forecast at this shorter lead time. In Flood State C, Carrigadrohid is drawn down at the maximum permissible rate (subject to constraints on Inniscarra level outlined in 10.1.1). Inniscarra should discharge 200m3/s when hydraulic head allows (part of which may be accounted for by turbine releases). The Flood Authority will instruct the reservoir operator that the mode of operation has changed to one of 'target release'. The Reservoir Operator will implement the required release pattern.

If the Flood Authority forecasts a rise in Inniscarra levels in this period with a maximum discharge of 200m3/s (for example due to an intervening flood event), a higher rate (up to 300m3/s) can be set to mitigate this. Such a decision would again be taken with the Reservoir Operator and would take into account all relevant information. The ultimate limit is to maintain a discharge less than 540m3/s in Cork. Such a scenario is expected to be RARE.

Drawdown stops if the forecast drops >10% below the threshold and normal management resumes.

G.3.3 Constraints

- Maximum release rate from Inniscarra is 200m3/s. 300m3/s is allowable in exceptional circumstances;
- Other constraints remain in force

G.4 24 hours to threshold crossing [Flood State B]

G.4.4 General

Between 24 and 3 hours, the threshold to initiate drawdown remains 285m3/s. Carrigadrohid continues to be drawn down at the maximum permissible rate (in terms of level) in Flood State B, but a maximum release flow of 300m3/s is now imposed, regardless of Inniscarra levels. This stays in force for the duration of the event to limit inflows to Inniscarra and utilise storage in Carrigadrohid. The Flood Authority will inform the Reservoir Operator that the release rates have changed.

The maximum discharge rate for Inniscarra is increased to 300m3/s. This should rapidly draw the reservoir down. Hydraulic head will diminish quickly, soon preventing a discharge as large as 300m3/s. The reservoir will be allowed to drain as quickly as the head allows (by opening all gates).

G.4.5 Constraints

- Maximum discharge from Inniscarra is 300m3/s;
- Other constraints remain in force.

G.5 3 hours to threshold crossing or peak inflow to Carrigadrohid [Flood State A or F]

G.5.6 General

Forecast flow into Carrigadrohid is influenced by rainfall forecasts just 2 to 3 hours beyond time now. An accurate inflow (based on observed rainfall) will only be available for the forthcoming 2 to 3 hours. When the forecast at a 3 hour lead time (xi) indicates:

- a flow of 400m3/s or more, operations enter Flood State A – managing the flood through Cork; or
- a peak flow of less than 400m3/s, operations enter Flood State F – managing the event as a false alarm in order to recover water discharged to create storage

Variable discharge from Inniscarra, giving 540m3/s in Cork, is the default operation for a flood event and will always be simulated by FEWS. i.e. It is calculated as 540 minus the sum of forecast flow at Healy's Bridge and Ovens, forecast 2 hours ahead[22]. Results of these simulations will be shown in FEWS at Carrigadrohid (level), Inniscarra (level) and Waterworks Weir (flow). The relevant display is shown in Figure 5.

[22] The 2 hour ahead forecast is to allow for the travel time between Inniscarra and the confluence of the Shournagh and Bride

Alternative reservoir operation is considered if the event is forecast to be:

- Larger than 400m3/s but significantly smaller than the design event (smaller releases to save water); or
- An exceedance event (larger releases to minimise damage).

Both possibilities are discussed below.

G.5.7 Alternative operation to refill reservoirs

If the peak of the event is predicted to be less than 400m3/s at a 3 hour lead time then this is a false alarm and full regulation will not be necessary (Flood State F). Even if it is more than this amount (Flood State A), the release pattern may not need to be as severe as for the design case. Releasing less water at this point from Inniscarra and Carrigadrohid will allow the reservoirs to refill and result in a smaller flow in Cork.

The same displays and tools in FEWS are available to help the user choose an alternative release pattern:

- The Release Adapter, which predicts what average release would be required to achieve FRL in 48 hours, based on current reservoir levels and predicted inflows. The Release Adapter runs automatically;
- An ISIS model simulation, run automatically, that takes the fixed release pattern suggested by the Release Adapter as its target. Note however that it may not be possible to achieve the releases calculated because of other constraints – the ISIS model (which does observe constraints) will highlight this. When the event is a False Alarm (i.e. the peak is less than 400m3/s), the release adapter flows are the default for all ISIS simulations. When the event is NOT a false alarm, both the default and the release adapter target releases are simulated. Operators will look at the two sets of results and decide which is the most appropriate release pattern; and
- Operators also have the ability to run bespoke 'what if' scenarios through the ISIS model in FEWS. The system can simulate a range of release scenarios and many parameters can be varied. This type of run will be initiated by the operator and, unlike those mentioned already, is not automated.

The Flood Authority will evaluate alternative release patterns using the displays and tools provided. A fixed release pattern that brings the reservoirs back to FRL will be selected by the FA and implemented by the Reservoir Operator following discussion between the two organisations. Simulations should be repeated every 2 hours to check that they are correct. This frequency can be relaxed if the event is small and the amount of storage created is large. Changes to release rates, suggested by different FEWS simulations, will only be implemented where the rate changes by more than 25m3/s. This is the minimum 'step change' considered reasonable by the ESB.

Figure 4 shows an example of the output from the automated scenarios for an event in October 2013 at Carrigadrohid and Inniscarra. As the predicted peak is less than 400m3/s, FEWS is only simulating a fixed release, with values for Carrigadrohid and Inniscarra set using the Release Adapter (both at around 150m3/s). It aims to return the reservoirs to FRL in 48 hours. Only a few hours after the peak, the Flood State clears (indicated by FloodPredicted returning to zero in the second plot). The model then abandons the fixed release and works to return levels to MNOL by cutting outflows.

Note that if another exceedence event is predicted immediately following this one, then the 'drawdown' rules might be in place while the current event is being managed. Priority will always be given to maintaining a flow less than the design in Cork for the current event.

Finally, when the flood has passed, control reverts to the reservoir operator. Criteria for the flood having passed are that inflows have peaked and are falling, water levels are stable or falling in Cork and reservoir levels are at or below FRL.

Figure 4: Reservoir releases for a False Alarm in October 2013

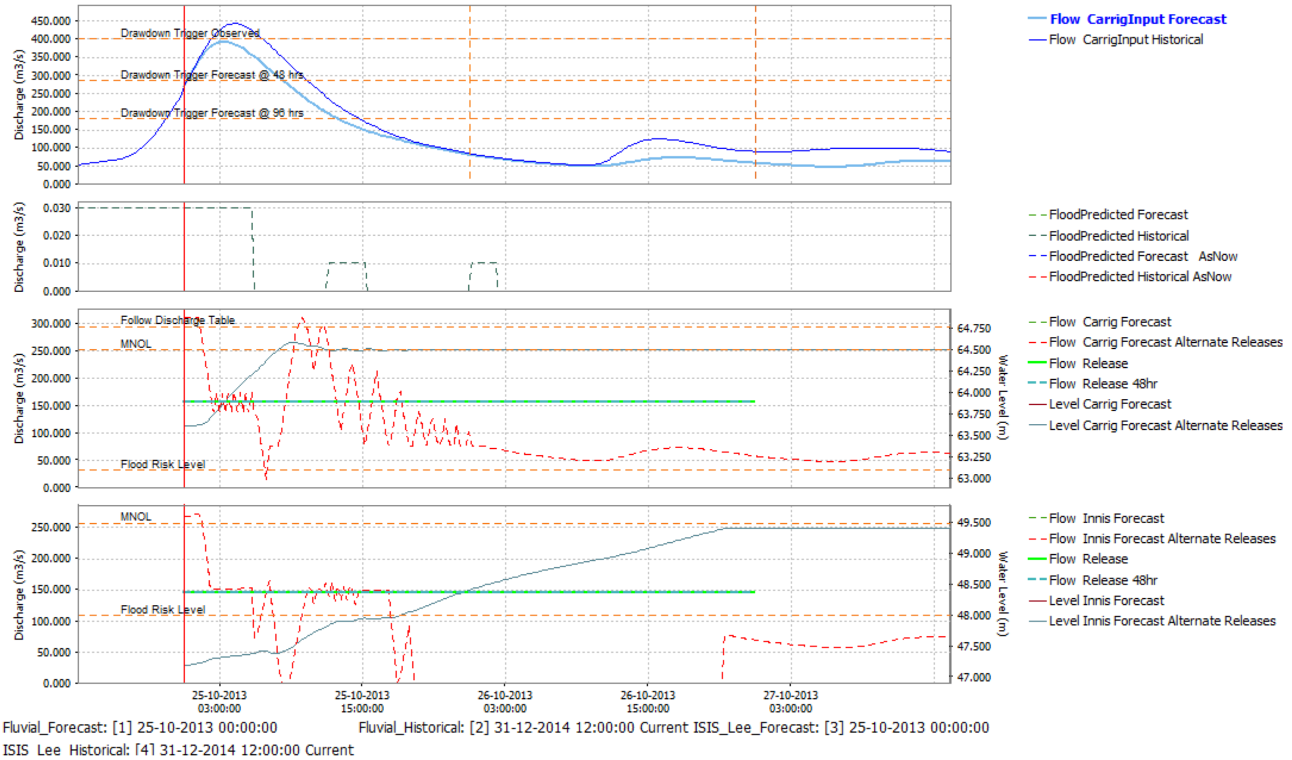


Figure 5: Cork default and alternative simulations for November 2009

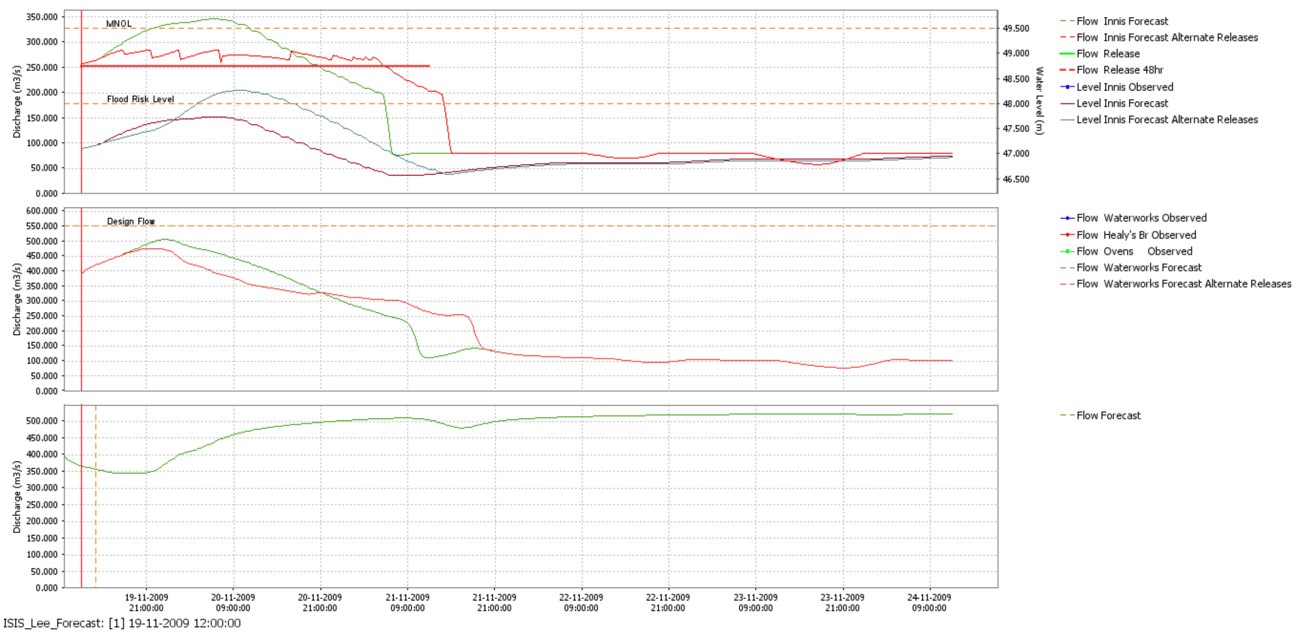


Figure 5 shows the Cork display from FEWS for a forecast in November 2009. The first plot is of Inniscarra reservoir outflow (left axis) and level (right axis). Outflow simulated by the ISIS model and release adapter are both shown. The second plot shows simulated and observed flow at Waterworks Weir, Healy's Bridge and Ovens. The final plot shows the release pattern required from Inniscarra to maintain a flow of 540m3/s in Cork. Results are shown for two model runs: using the release adapter to set discharge limits from Carrigadrohid and Inniscarra and using the default settings. The 'default' is only run when the flow is forecast to exceed 400m3/s at a 3 hour lead time.

G.5.8 Exceedence event

If the event is larger than the design, it should be possible to minimise overtopping of the defences by adjusting the operation of the Dam.

Regulating at a higher flow than 540m3/s in Cork might be less damaging than regulating at 540m3/s, as a result of the available freeboard in the defence level. Figure 6 shows an exceedance event. The last vertical dashed line indicates when the final magnitude of the event would be known. At this point, there is still time to simulate other release patterns to minimise damages (e.g. regulating to a higher flow than 540m3/s in Cork).

Figure 6 Example double peaked (exceedance) event from continuous simulation to illustrate the steps in the Flood Operations

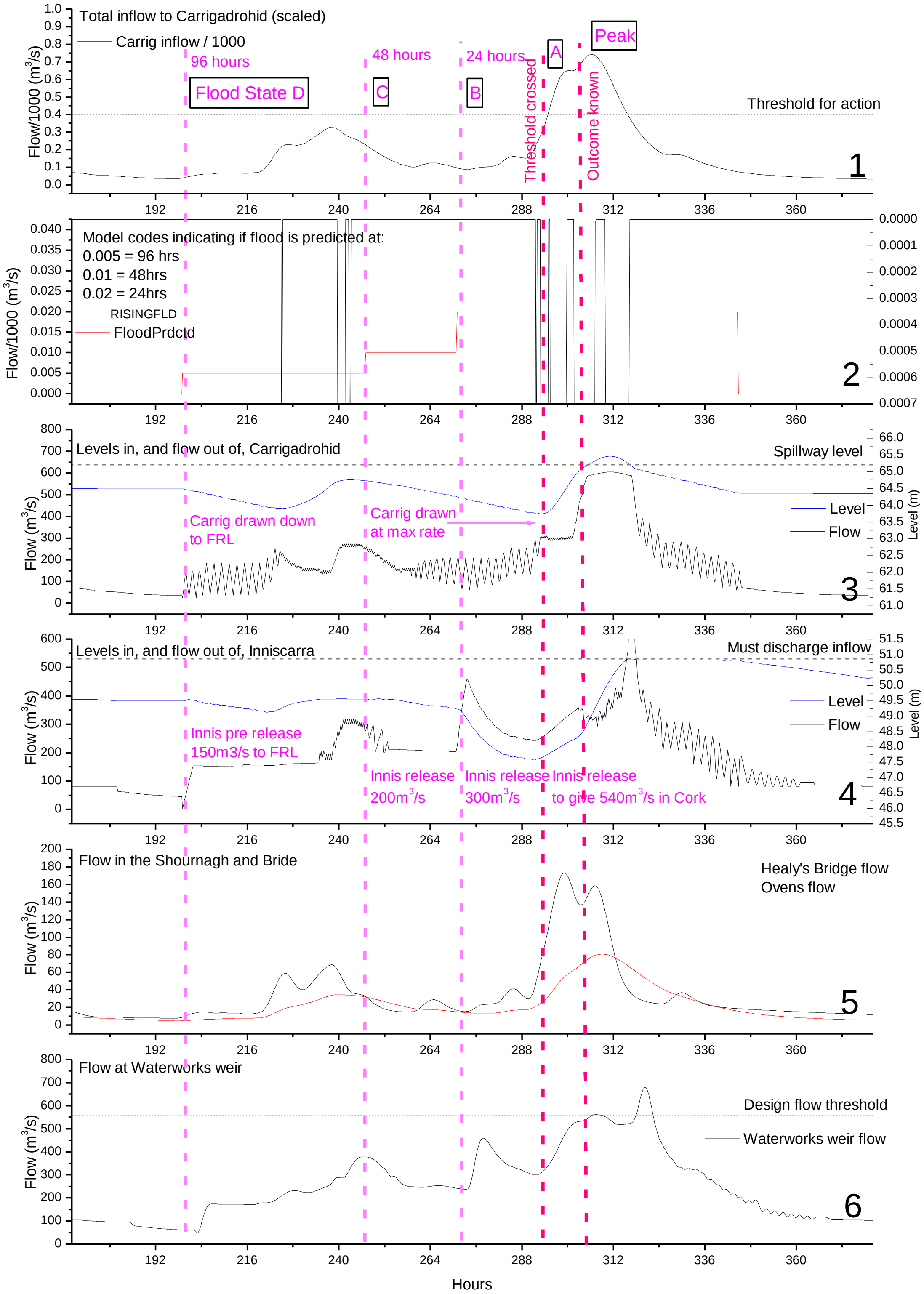


Table 1 : List of threshold crossings between 1 January 2007 and 31 December 2014 for the 'error corrected' scenario

Peak flow 0 to 24 hrs (m3/s)		Peak flow 24 – 48hrs (m3/s)		Peak flow 48 – 96hrs (m3/s)		
Historical	Forecast	Historical	Forecast	Historical	Forecast	Date
334.1	334.1					06/03/2007 01:00
				123.1	250.9	24/12/2007 13:00
				123.1	250.7	25/12/2007 01:00
				352.3	225.5	07/01/2008 13:00
				352.3	226.8	08/01/2008 01:00
				269.0	232.9	08/01/2008 13:00
				143.3	199.3	09/01/2008 01:00
352.3	285.3					09/01/2008 13:00
352.3	293.5					10/01/2008 01:00
				101.7	225.8	15/01/2008 01:00
				123.0	181.8	01/02/2008 13:00
				49.9	265.1	11/03/2008 01:00
320.7	324.0					01/08/2008 01:00
				181.6	205.8	12/01/2009 13:00
				151.3	199.0	13/01/2009 01:00
				181.0	218.8	15/01/2009 13:00
				158.0	189.1	16/01/2009 01:00
		131.0	286.1			29/01/2009 13:00
197.7	309.3					30/01/2009 01:00
				110.3	297.2	21/08/2009 13:00
		110.3	294.3	70.5	197.8	22/08/2009 01:00
				269.1	204.4	28/10/2009 13:00
				245.5	196.9	29/10/2009 13:00
				245.5	198.6	30/10/2009 01:00

				174.6	207.6	12/11/2009 01:00
				284.2	335.6	13/11/2009 13:00
				284.2	326.7	14/11/2009 01:00
				179.4	196.4	15/11/2009 01:00
284.2	337.1			564.8	377.6	15/11/2009 13:00
284.2	316.0			616.1	515.1	16/11/2009 01:00
				616.1	471.9	16/11/2009 13:00
				616.1	477.4	17/11/2009 01:00
		564.8	307.8	616.1	446.7	17/11/2009 13:00
		616.1	449.3	426.4	389.9	18/11/2009 01:00
564.8	375.7	616.1	436.7	273.0	226.5	18/11/2009 13:00
616.1	444.2	426.4	309.4	273.0	228.5	19/11/2009 01:00
616.1	637.5					19/11/2009 13:00
426.4	426.4					20/11/2009 01:00
				155.6	232.1	21/11/2009 13:00
				155.6	216.4	22/11/2009 01:00
				337.7	188.5	12/01/2010 01:00
346.1	346.8					16/01/2010 01:00
				81.2	186.1	27/10/2010 01:00
				251.5	181.3	14/11/2010 01:00
				330.2	244.2	12/01/2011 13:00
				330.2	245.3	13/01/2011 01:00
				330.2	202.8	13/01/2011 13:00
				330.2	204.7	14/01/2011 01:00
330.2	329.0					16/01/2011 01:00
				140.7	218.1	05/05/2011 01:00
				197.6	295.5	05/05/2011 13:00
				197.6	298.0	06/05/2011 01:00
				197.6	299.5	06/05/2011 13:00

				197.6	298.2	07/05/2011 01:00
				183.0	218.9	07/05/2011 13:00
				180.8	180.7	21/10/2011 13:00
				179.2	181.7	22/10/2011 01:00
				221.4	207.5	30/10/2011 01:00
				296.7	208.1	27/11/2011 13:00
296.7	296.7					29/11/2011 13:00
				154.0	236.4	05/06/2012 13:00
				124.8	234.4	06/06/2012 01:00
				160.2	205.5	19/11/2012 13:00
				160.2	207.0	20/11/2012 01:00
				75.8	199.2	21/11/2012 13:00
				133.4	180.2	22/11/2012 01:00
				133.4	255.6	22/11/2012 13:00
				133.4	258.7	23/11/2012 01:00
				80.1	189.8	28/01/2013 13:00
				80.1	244.6	29/01/2013 01:00
				69.3	246.1	29/01/2013 13:00
				59.3	243.8	30/01/2013 01:00
				117.7	185.8	29/07/2013 13:00
				117.7	184.5	30/07/2013 01:00
				380.2	180.5	21/10/2013 13:00
				380.2	181.5	22/10/2013 01:00
				380.2	225.2	22/10/2013 13:00
				380.2	224.9	23/10/2013 01:00
				169.6	181.1	23/10/2013 13:00
		380.2	292.3			24/10/2013 01:00
380.2	286.6			107.0	237.9	24/10/2013 13:00
380.2	328.7			97.0	233.6	25/10/2013 01:00

				96.9	209.0	25/10/2013 13:00
				85.8	213.8	26/10/2013 01:00
222.3	287.0					14/12/2013 13:00
				195.1	204.3	19/12/2013 13:00
				195.1	205.7	20/12/2013 01:00
				315.3	181.8	28/12/2013 01:00
315.3	313.0					29/12/2013 13:00
315.3	309.9					30/12/2013 01:00
				154.4	219.8	28/01/2014 01:00
				154.4	193.6	28/01/2014 13:00
				154.4	200.2	29/01/2014 01:00
				154.4	184.2	29/01/2014 13:00

Table 2 : List of threshold crossings between 1 January 2007 and 31 December 2014 for the 'simulated' scenario

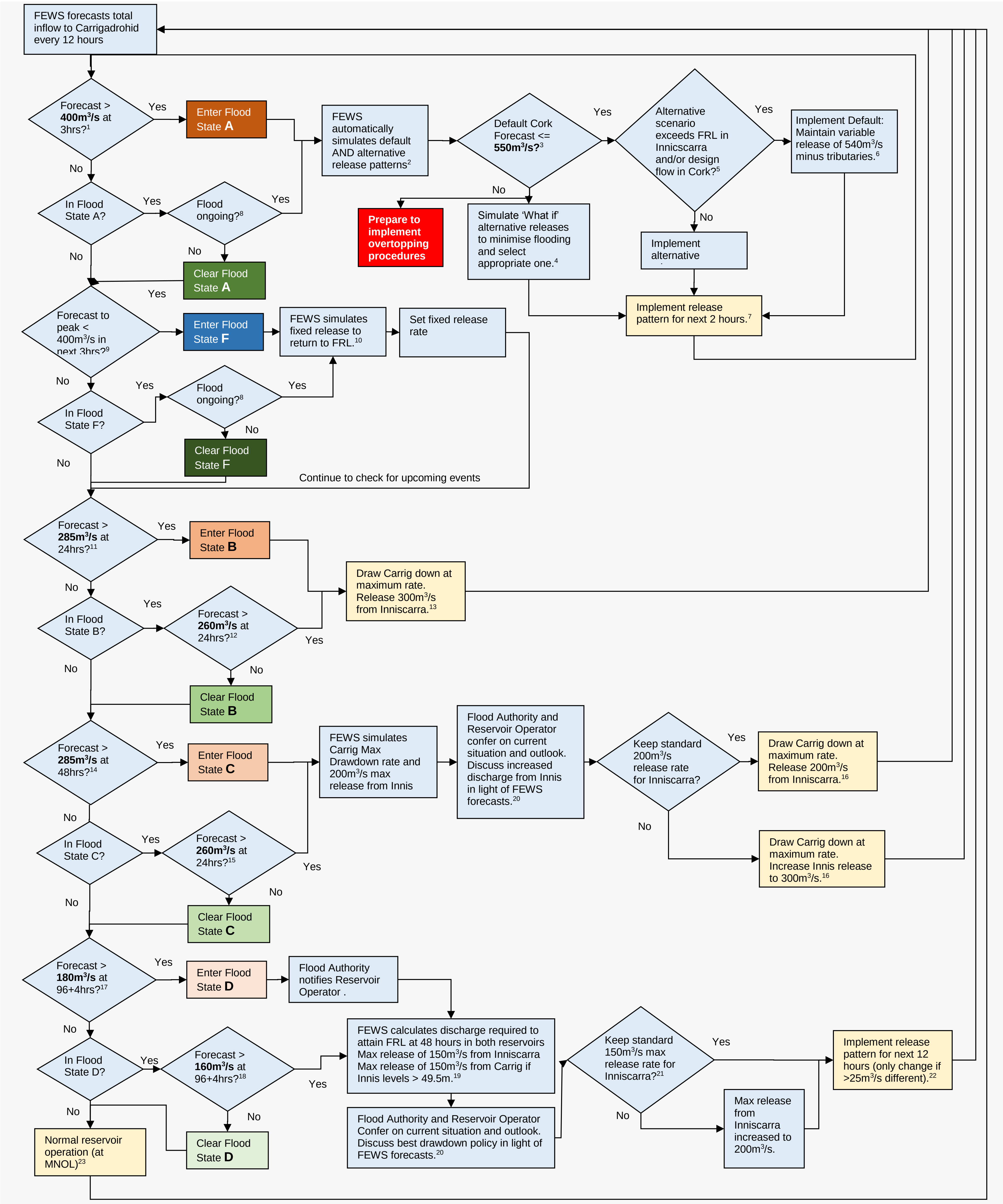
Peak flow 0 to 24 hrs (m3/s)		Peak flow 24 – 48hrs (m3/s)		Peak flow 48 – 96hrs (m3/s)		Date
Historical	**Forecast**	**Historical**	**Forecast**	**Historical**	**Historical**	
334.1	334.1					06/03/2007 01:00
				129.6	250.8	24/12/2007 13:00
				129.6	250.7	25/12/2007 01:00
				351.9	226.3	07/01/2008 13:00
				351.9	228.3	08/01/2008 01:00
				291.8	234.2	08/01/2008 13:00
				149.3	201.1	09/01/2008 01:00
351.9	303.9					10/01/2008 01:00
291.8	291.8					10/01/2008 13:00
				118.1	218.2	15/01/2008 01:00
				126.6	181.9	01/02/2008 13:00
				61.7	265.1	11/03/2008 01:00
344.8	344.8					01/08/2008 01:00
				181.6	205.8	12/01/2009 13:00
				151.3	199.0	13/01/2009 01:00
				181.0	218.8	15/01/2009 13:00
				158.0	189.1	16/01/2009 01:00
		131.0	286.1			29/01/2009 13:00
197.7	309.3					30/01/2009 01:00
				111.4	286.9	21/08/2009 13:00
				64.3	187.1	22/08/2009 01:00
				278.1	204.2	28/10/2009 13:00
				263.0	196.2	29/10/2009 13:00
				263.0	197.5	30/10/2009 01:00
				179.1	207.6	12/11/2009 01:00

				295.1	335.4	13/11/2009 13:00
				295.1	326.6	14/11/2009 01:00
				177.9	196.4	15/11/2009 01:00
295.1	335.1			502.5	377.6	15/11/2009 13:00
295.1	319.0			560.1	513.8	16/11/2009 01:00
				560.1	476.5	16/11/2009 13:00
				560.1	475.7	17/11/2009 01:00
		502.5	304.7	560.1	444.1	17/11/2009 13:00
		560.1	447.9	376.9	388.6	18/11/2009 01:00
502.5	373.7	560.1	436.0	226.6	226.4	18/11/2009 13:00
560.1	435.6	376.9	302.0	226.6	225.6	19/11/2009 01:00
560.1	578.7					19/11/2009 13:00
376.9	376.9					20/11/2009 01:00
				157.8	191.5	21/11/2009 13:00
				157.8	191.0	22/11/2009 01:00
				323.3	188.6	12/01/2010 01:00
329.1	329.1					16/01/2010 01:00
				83.5	187.0	27/10/2010 01:00
				239.9	181.3	14/11/2010 01:00
				256.2	244.7	12/01/2011 13:00
				256.2	245.2	13/01/2011 01:00
				256.2	201.2	13/01/2011 13:00
				256.2	201.3	14/01/2011 01:00
				140.7	218.1	05/05/2011 01:00
				197.6	295.5	05/05/2011 13:00
				197.6	298.0	06/05/2011 01:00
				197.6	299.5	06/05/2011 13:00
				197.6	298.2	07/05/2011 01:00
				183.0	218.9	07/05/2011 13:00

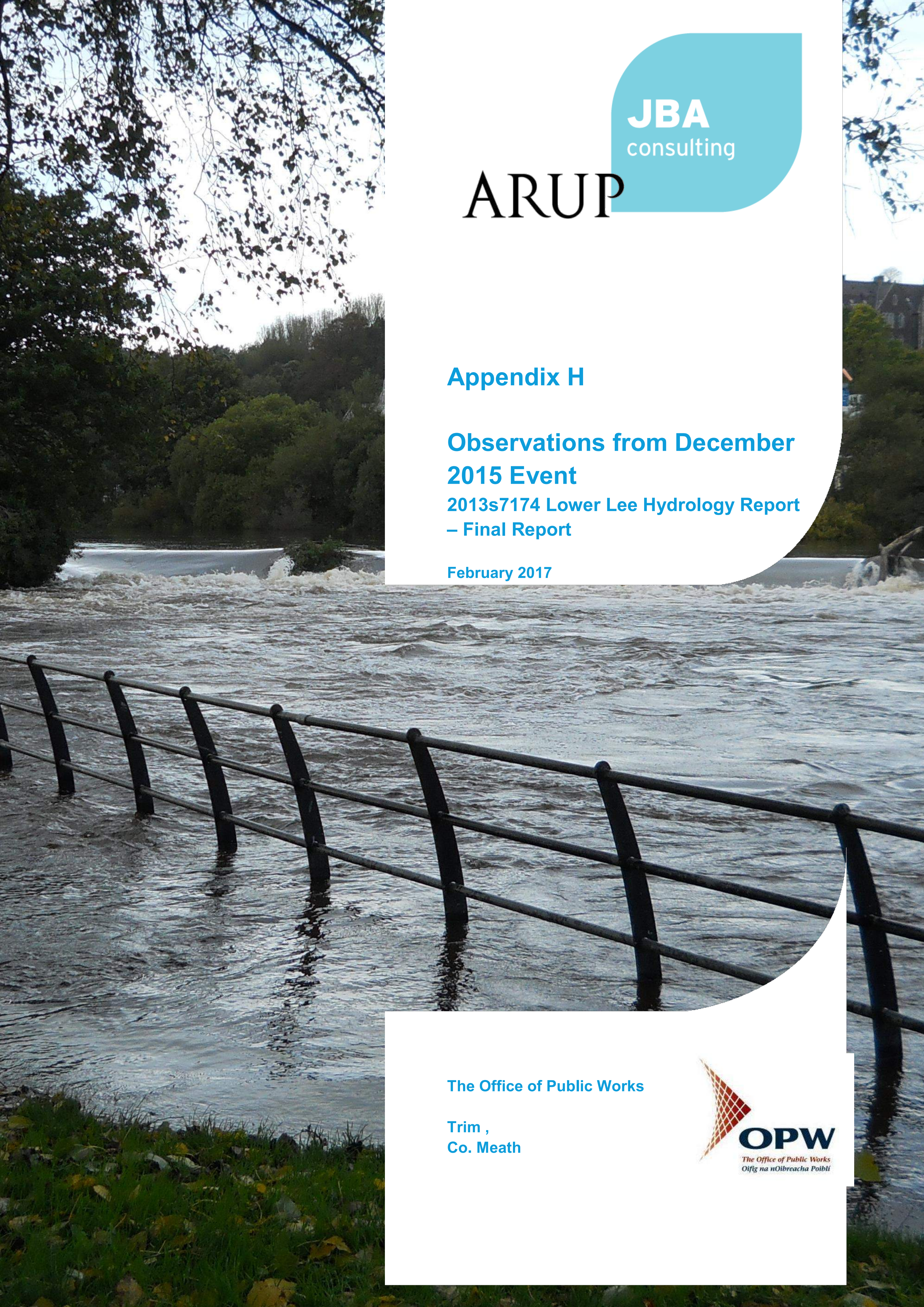
				180.8	180.7	21/10/2011 13:00
				179.2	181.7	22/10/2011 01:00
				221.4	207.5	30/10/2011 01:00
				296.7	208.1	27/11/2011 13:00
296.7	296.7					29/11/2011 13:00
				198.7	235.5	05/06/2012 13:00
				158.0	232.2	06/06/2012 01:00
357.9	294.7					19/11/2012 01:00
				206.7	204.4	19/11/2012 13:00
				206.7	203.2	20/11/2012 01:00
				56.7	186.9	21/11/2012 13:00
				118.8	183.8	22/11/2012 01:00
				118.8	256.9	22/11/2012 13:00
				118.8	258.6	23/11/2012 01:00
				76.5	189.8	28/01/2013 13:00
				76.5	244.7	29/01/2013 01:00
				66.8	246.1	29/01/2013 13:00
				45.1	243.8	30/01/2013 01:00
				208.5	185.8	29/07/2013 13:00
				208.5	184.5	30/07/2013 01:00
				447.3	180.7	21/10/2013 13:00
				447.3	181.7	22/10/2013 01:00
				447.3	225.2	22/10/2013 13:00
				447.3	225.2	23/10/2013 01:00
		447.3	285.1	216.9	181.2	23/10/2013 13:00
		447.3	288.1			24/10/2013 01:00
447.3	284.6			123.2	237.7	24/10/2013 13:00
447.3	428.0			98.9	237.3	25/10/2013 01:00
				96.9	210.5	25/10/2013 13:00

				91.6	211.4	26/10/2013 01:00
286.8	304.8					14/12/2013 13:00
				233.9	204.6	19/12/2013 13:00
				233.9	205.7	20/12/2013 01:00
				392.0	181.2	28/12/2013 01:00
392.0	300.6					29/12/2013 13:00
392.0	380.3					30/12/2013 01:00
274.2	299.3					12/01/2014 13:00
				201.6	219.8	28/01/2014 01:00
				201.6	194.4	28/01/2014 13:00
				201.6	196.2	29/01/2014 01:00

Figure 7 - Flow chart illustrating the decision making process for flood control procedures on the River Lee. FA actions are blue, RO actions yellow



Notes:
Reservoir operations to maintain a design flow in Cork are summarised in the flow chart. Actions appear in order of priority, not chronological order. For example, managing a flood through the city (Flood State A) always takes priority over preparing for another future event (Flood States B to D). There are four distinct phases of operation (Flood States D to A in their likely chronological order), outlined and labelled in the chart.
Flood State D – 96 to 48 hours. Draw reservoirs down to flood risk level, constrained by maximum discharge of 150m3/s.
Flood State C – 48 to 24 hours. Aim to release 200m3/s.
Flood State B – 24 to 3 hours. Aim to release 300m3/s.
Flood State A – During event. Manage flow at 540m3/s or less through Cork.
Flood State F – This is a FALSE ALARM. Event managed as a calculated fixed release to refill reservoirs to FRL.
Decisions to deviate from 'normal' operation of the reservoirs are taken on the basis of forecast inflow into Carrigadrohid. This is based on the ECMWF rainfall forecast at lead times > 4 hours, Harmonie from T0 to 4 hours and observed rainfall up to T0 (Time now). Figure 3 shows the flow forecast graph as it appears in FEWS. This prediction is evaluated every 12 hours against threshold values of 180m3/s and 285m3/s (depending on lead time). The frequency of checks increases close to the predicted threshold crossing and when the system is in State A.
1 Flow forecasts into Carrigadrohid at a short lead time (3 hours or less) are based on observed, not forecast, rainfall. Error correction will also constrain uncertainty at this point. The 'true' threshold of 400m3/s can therefore only be evaluated at that lead time. Note that the maxima (or exceedance) in Cork will occur much more than 3 hours after this point. For reference, in November 2009, in the Baseline scenario, 11 hours elapse between 400m3/s being exceeded on the inflows to Cork and 550m3/s being exceeded in the City. With 3 additional hours lead time and better use of storage, that figure is likely to be 15-18 hours.
2 At 3 hours lead time, uncertainty in forecast inflows is close to a minima, allowing possible impacts in Cork to be considered with more confidence. If the event is smaller than the design, 'default' operation (where releases are designed to maintain 540m3/s in the city) may not be needed. Likewise, if it is larger than the design, an alternative strategy may reduce damages. The first of these scenarios will be much more common. FEWS automatically calculates and presents both the default scenario and the release rate needed to reach FRL in 48 hours' time (calculated by the Release Adapter).
3 The FEWS operator will first check that the event is likely to be manageable at 550m3/s in Cork (a flow rate chosen to give some tolerance on the 540m3/s target for regulation in the city). If the FEWS system predicts an exceedance, or the simulated Cork flow is close to being exceeded, the operator should consider alternative release strategies (4). If the result is in doubt, a 'What If' scenario, with the forecast rainfall scaled by a factor, should be checked to understand the impact of rainfall forecast errors on the outcome. Other scaled scenarios could be tried to give confidence that the event can be managed. These 'what if' scenarios are not currently automatic and are run by the forecaster.
4 Alternative strategies might include: increasing the regulation flow in Inniscarra and/or Carrigadrohid.
5 In most instances, it will not be necessary to regulate the Lee at 540m3/s in Cork. A smaller fixed release will reduce flows in the city and retain water in the reservoirs. FEWS will automatically calculate the release rate required from Carrigadrohid and Inniscarra to achieve FRL in 48 hours. This rate will be targeted by the ISIS model. The results will inform a decision on whether to adopt the fixed release rate, or to regulate according to the default mode of operation. If a fixed release is preferable, it is implemented. Otherwise, default operation is required.
6 Default operation aims to maintain a flow of 540m3/s in Cork. Releases are calculated on the basis of flows forecast for the Shournagh and Bride in 2 hours' time. The FEWS display in Figure 5 calculates the required release rate. The rate is set every 2 hours and communicated to the Reservoir Operator who implements it.
7 At this stage of the event, all operations and forecasts are reviewed every two hours. Fixed release patterns are only adjusted if there is a need for a change > 25m3/s
8 The Flood State State A ends when:
Inflows to the reservoirs have peaked (for the main event) and are falling
Water levels are at or below FRL
Water levels are falling in Cork (and are forecast to continue falling)
No further threshold crossing is forecast in the next 96 hours
Once invoked, other Flood States are only cleared when the forecast maxima drops 10% below the relevant threshold.
9 If the event peak is forecast at less than 400m3/s in the 3 hour time window then it will almost certainly not require full regulation. It is a FALSE ALARM and the system enters Flood State F to manage it.
10 In Flood State F, the aim is to manage the reservoirs back to FRL, using water from the event if possible. FEWS will simulate the release rate needed to achieve this (calculated by the Release Adapter). The Flood Authority will pass the information to the Reservoir Operator and the release pattern will be implemented and reviewed every 2 hours (or as necessary).
11 Flood State B is invoked if the Carrigadrohid inflows are forecast to exceed 285m3/s within the next 24 hours
12 Flood State B is only cleared if the forecast flow drops below 260m3/s. This is to avoid operations flicking between states for different forecasts.
13 In Flood State B, the aim is to release 300m3/s from Inniscarra (although this will only be achieved for a short period due to hydraulic head limitations). The maximum drawdown rate for Carrigadrohid is always 0.6m/24hrs above 63m and 1.0m/24hrs below 63m. There is no restriction on the rate of drawdown for Inniscarra. In the last 24 hours before an event, the discharge restriction on Carrigadrohid is 300m3/s regardless of Inniscarra levels.
14 Flood State C is invoked if the Carrigadrohid inflows are forecast to exceed 285m3/s between 24 and 48 hours beyond time now
15 Flood State C is only cleared if the forecast flow drops 10% below 285m3/s. This is to avoid operations flicking between states for different forecasts.
16 Between 48 hours and 24 hours, releases of 200m3/s (including any turbine releases) are prescribed for Inniscarra where hydraulic head allows. In extreme circumstances, it is permissible to release 300m3/s in this period. A decision to do this is taken jointly by the Flood Authority and Reservoir Operator, informed by FEWS forecasts. Such action is only likely when two large events are occurring together but the first one is not large enough to be regulated in its own right). Releases from Carrigadrohid are restricted to 300m3/s if Inniscarra levels are below 49.0 and to 150m3/s above 49.0 (and an interpolated rate in between). The usual draw down rate restriction applies at Carrigadrohid.
17 Flood State D is invoked if the Carrigadrohid inflows are forecast to exceed 180m3/s between 48 and 100 hours (96 plus 4 for response) beyond time now
18 Flood State D is only cleared if the forecast flow drops 10% below 180m3/s. This is to avoid operations flicking between states for different forecasts.
19 Flood State D is the first response to a flood at the longest lead time. Uncertainty is therefore considerable. Reservoir operation aims to lower water levels to FRL by the time the 48 lead time point is reached. This is an aim, not a requirement. Carrigadrohid releases are constrained by the drawdown rate limits13 and by levels in Inniscarra16. Releases from Inniscarra should not exceed 150m3/s in this period. This constraint can be relaxed to 200m3/s in certain circumstances16. FEWS will calculate the release rate to achieve FRL 48 hours before the threshold is crossed. This may exceed the allowable rate, particularly if the crossing is detected late (i.e. not at 96 + 4 hours).
20 The Flood Authority and Reservoir Operator will have an informed discussion about the likely nature of the predicted event, current dam levels, the proposed discharge regime suggested by the FEWS system etc. In most cases, the outcome will be to agree to do as the FEWs system says. In some instances, however it may be agreed to modify the discharge regime if there are good reasons and both parties are satisfied that the basis of the decision can be justified and recorded. In both these cases, the Flood Authority will confirm the agreed instruction to the Reservoir Operator in writing (email). If there is disagreement between the parties on the proposed course of action and a consensus can't be reached, the Flood Authority will be responsible for issuing an instruction to do what the FEWS suggests. The Reservoir Operator will carry out the instruction.
21 In rare circumstances, for example when a large event is preceded by a second event (but not large enough to be managed in its own right), the maximum release from Inniscarra in Flood State D may be increased to 200m3/s.
22 In Flood State B, release patterns are implemented on a 12 hour cycle with each new rainfall forecast. They will only be adjusted if the prescribed flow rate changes by more than 25m3/s.
23 Normal reservoir operation resumes when the criteria in 8 are met.



Appendix H

Observations from December 2015 Event

2013s7174 Lower Lee Hydrology Report – Final Report

February 2017

The Office of Public Works

Trim ,
Co. Meath

H Observations from December 2015 event

H.1 Introduction

Changed operation of Carrigadrohid and Inniscarra reservoirs is an intrinsic part of the Cork flood alleviation scheme (FAS). A set of procedures has been written to limit flows in Cork to 550m3/s by pre-emptively drawing the reservoirs down before a large flood. Design flows have been calculated for the system (with and without the procedures) using a continuous simulation (CS) approach. A forecasting system has also been developed that simulates the procedures and shows the probable resulting levels and flows in the reservoirs and Cork.

Two significant high flow events occurred in the Lee catchment in December 2015. They rank higher than any event previously simulated except November 2009 and provide new information to:

- Further prove the forecasting models;
- Re-test the proposed operational procedures and their trigger thresholds; and

Each of these points are addressed in this note.

H.2 Prove forecasting models

This work updates the 'model evaluation sheets' to include the latest events. Model runs use revised rain gauge weights to account for the new operational gauges and those now abandoned. Significant new data are available at:

- Macroom – where recent observations include a new highest recorded level where the model performs well;
- Kill –new event is ranked 3 and the model matches the observed closely;
- Dripsey – the model is generally reasonable, but under predicts December 2015/January 2016 by 15-21% (ranked 3 and 4).
- Total inflow to Carrigadrohid (a series calculated on the basis of changing levels by ESB) – December 2015 is reportedly the largest peak flow (exceeding November 2009) – the model matches the hydrograph shape well but predicts a flow 18% less than the derived series (560m3/s versus 680m3/s). Reasons for this are not obvious but is likely to be related to either rainfall recorded or errors in the derivation of the inflow series from reservoir levels and outflows; and
- Ovens – December 2015 is a new maxima and the model predicts the peak within 1%. However the observed hydrograph looks suspicious: the river rises very late and steeply.

Notable omissions are:

- Healy's Bridge; and
- Dromcarra.

Where no data were available for the new large events Rain gauge weights were updated to reflect the current network as part of this work.

Conclusion: We see no reason to revise the PDM model parameters on the basis of these results.

H.3 Testing operational procedures

H.3.1 Thresholds

JBA technical note "Revised description of proposed Flood Operation Procedures" (See Appendix G) describes how Carrigadrohid and Inniscarra Reservoirs will be drawn down before, and managed during, a flood event. Triggers for implementing the operational procedures were set out in the note. When operational procedures are not in force, ESB will operate the reservoirs 'as normal'.

Operational procedures are triggered on the basis of maximum forecast Carrigadrohid inflow at up to 100 hours ahead using the ECMWF deterministic rainfall forecast. Flood State D is triggered at 180m3/s 50 to 100 hours ahead. Exceeding 285m3/s at <50 hrs triggers Flood States C and B. Triggers are based on an analysis of flows simulated using ECMWF rainfall forecasts. At the time they were derived, only one event (November 2009) needed operational procedures (i.e. inflows to Carrigadrohid exceeded 400m3/s). Two more events now meet that criteria (early and late December 2015) making a re-analysis worthwhile.

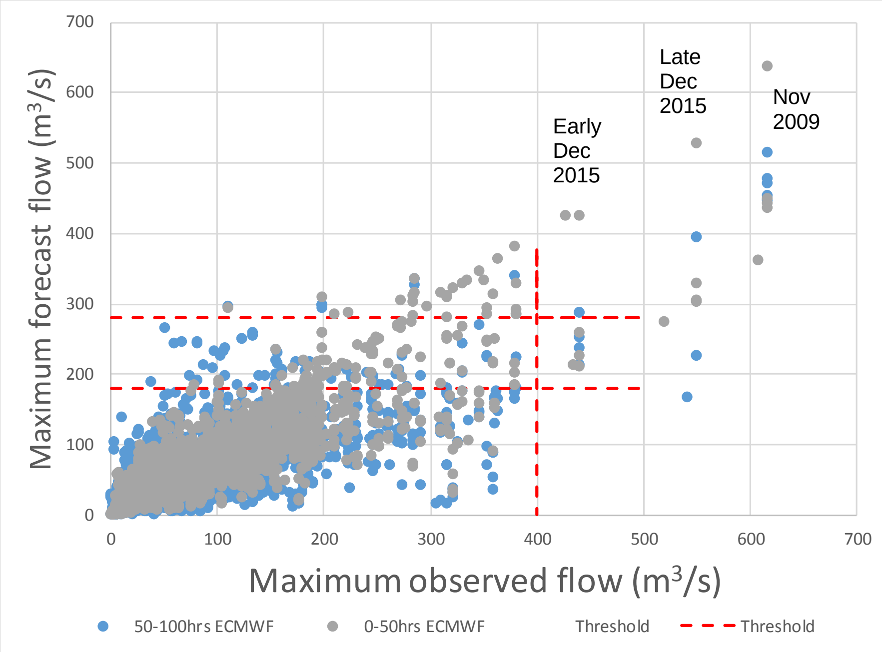
Combined results for the full period simulated are plotted in Figure 1. It shows the maximum simulated and 'observed' Carrigadrohid inflow within an individual forecast. Blue points are the long lead time forecasts (50 to 100 hours), grey points the shorter lead time forecasts (0 to 50 hours). The red dashed lines represent the thresholds applied at different lead times (180m3/s and 280m3/s).

An under predictive bias is evident in the results. This was noted previously and resulted in a lower threshold being applied than the flow to be identified.

Three events now exceed the 400m3/s threshold for 'observed' data and there are multiple forecasts for each. Some forecasts miss the threshold at the required lead time. However, the misses are marginal and the eventual events were still managed successfully.

We conclude that there is no need to adjust the thresholds on the basis of the new information.

Figure 1 – Maximum forecast and observed inflow to Carrigadrohid, plotted for each ECMWF forecast (12 hourly intervals) for a run using error correction



H.4 Reservoir simulation

The new forecasting system (Lower Lee FEWS) simulates the reservoirs using the proposed operational procedures. It allows us to see 'what would have happened' to reservoir levels and outflows for the period January 2015 to February 2016. The system is programmed with the parameters outlined in Table 7-5 of the Lower Lee Hydrology Report (JBA, January 2017).

FEWS was run from 1 January 2015 to 6 February 2016 – the period for which rainfall forecasts were supplied. ECMWF deterministic and Met Eireann deterministic forecasts were both available and were applied in a rainfall hierarchy, with observed data preferred, then Harmonie applied to 12 hours' lead time and finally ECMWF for the remainder. Error correction was applied to PDMs wherever data were available (note the omissions in Section XX). Reservoirs were not state updated because the observed data represents a different operational regime to that simulated.

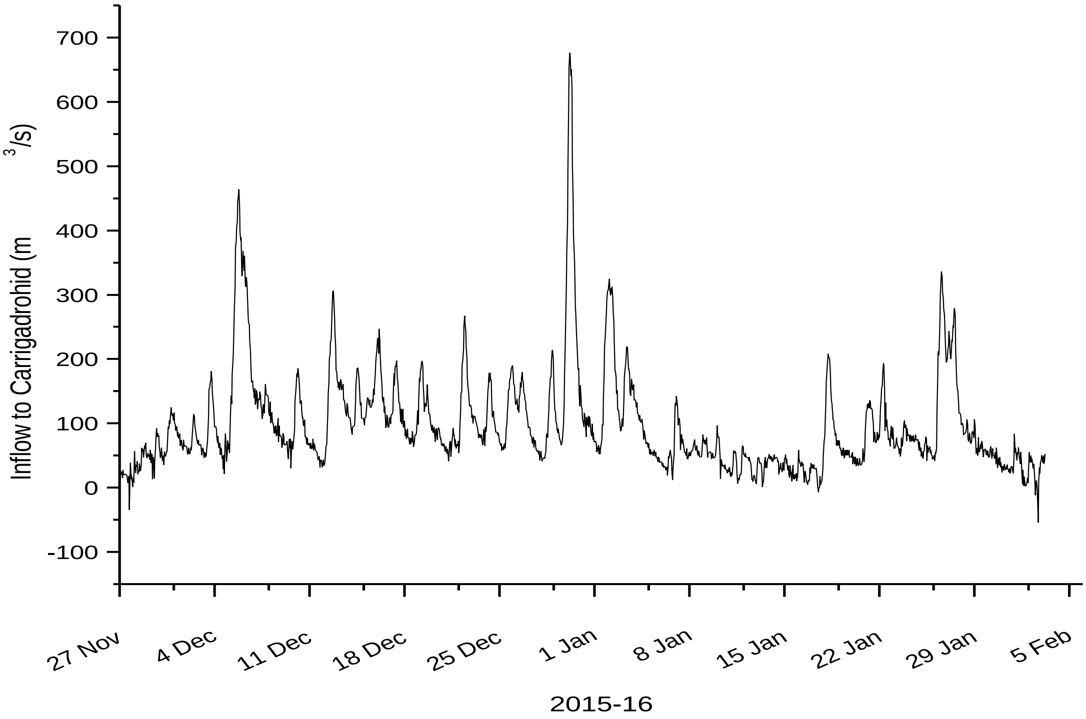
Operational procedures would have been triggered on seven occasions:

Start Date	End Date	Flood State reached
14 Jan 2015 22:00	15 Jan 2016 13:00	B
11 Sep 22:00	12 Sep 13:00	B
13 Sep 10:00	15 Sep 01:00	B
1 Dec 2015 11:15	7 Dec 2015 01:00	B (almost A)
12 Dec 2015 11:00	13 Dec 2015 13:00	B
26 Dec 2016 03:30	31 Dec 2015 03:00	A
23 Jan 2016 01:30	28 Jan 2016 01:30	B

Two inflows to Carrigadrohid exceed 400m3/s and would have required regulation. They occurred during a wet winter period lasting from mid November 2015 to February 2016 (see derived

Carrigadrohid inflow series below). Both are reviewed below with reference to the 'Lee Releases' display configured into FEWS.

Figure 2 - Derived inflow series to Carrigadrohid for Winter 2015-16



H.4.2 4 December 2015

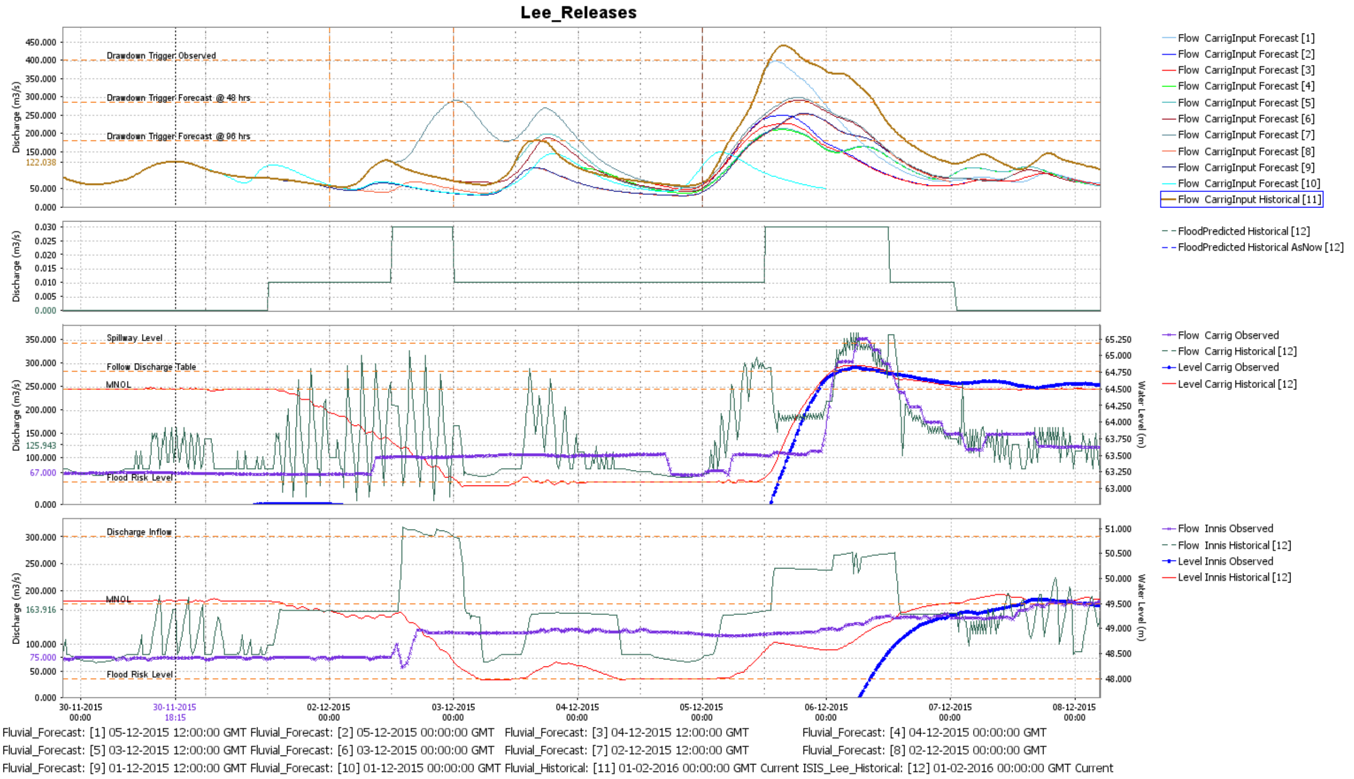
The Lee Releases Display (described in detail in the FEWS User Guide) has four plots (see Figure 3):

The uppermost shows the total inflow to Carrigadrohid, on which operational triggers are based. The bold line is the historical simulation - closest to an 'observed' series. It makes most use of observed data by error correcting at Dromcarra, Macroom and Kill (the remainder of the catchment is simulated by a PDM model) when data are available. In this event there were no observed data for Dromcarra, so this, too, is simulated by the PDM. The multiple lines represent the different forecasts made (every 12 hours) with each new ECMWF rainfall forecast. They extend from their origin to 120 hours.

The second plot shows the 'Flood State', as described by the proposed operational procedures for the Lee Reservoirs. 0 means no Flood State in force, 0.01 means Flood State D (draw down to FRL), 0.02 is Flood State C (draw down as far as possible with outflow constraints), 0.03 is Flood State B (draw down with increased flow rates allowed) and (finally) Flood State A where the forecast predicts that a flow of > 400m3/s will happen and regulation may be necessary. Flood States are all triggered on the basis of the forecast inflow to Carrigadrohid. Flood State D is triggered when inflows exceed 180m3/s at a lead time of between 50 and 100 hours. Flood States C and B are triggered at 280m3/s at lead times of 48 and 24 hours respectively.

The third and fourth plots show the simulated level in, and flow out of, Carrigadrohid and Inniscarra alongside that recorded by ESB. NOTE that the simulated is a poor match to the observed because ESB currently follow different procedures. Also, that oscillations in the releases from Carrigadrohid are intentional and are a result of flows increasing, then being checked, to maintain the maximum allowable drawdown rate in that reservoir.

Figure 3 – Lee Releases display for 30 November 2015 to 8 December 2015



This period had three inflow maxima, the last of which was the main event (4 December). The first event triggered Flood State D, beginning the drawdown process. Flood State B was briefly triggered, before D was reinstated when that peak passed. Flood State D persisted because a further event followed as the other cleared. Flood State B was again triggered close to the larger third event. Flood State A is not shown as having been reached because forecasts are 12 hourly. An intermediate forecast (not shown) did result in Flood State A being triggered and the event being managed through Cork as an 'alternative release' (i.e. full regulation at 500m3/s was not necessary). The peak flow at Waterworks Weir would have been roughly 380m3/s (compared to scheme capacity of 550m3/s).

Levels in both reservoirs were predicted to be able to recover to MNOL within hours after the event if ESB needed to.

H.4.3 31 December 2015

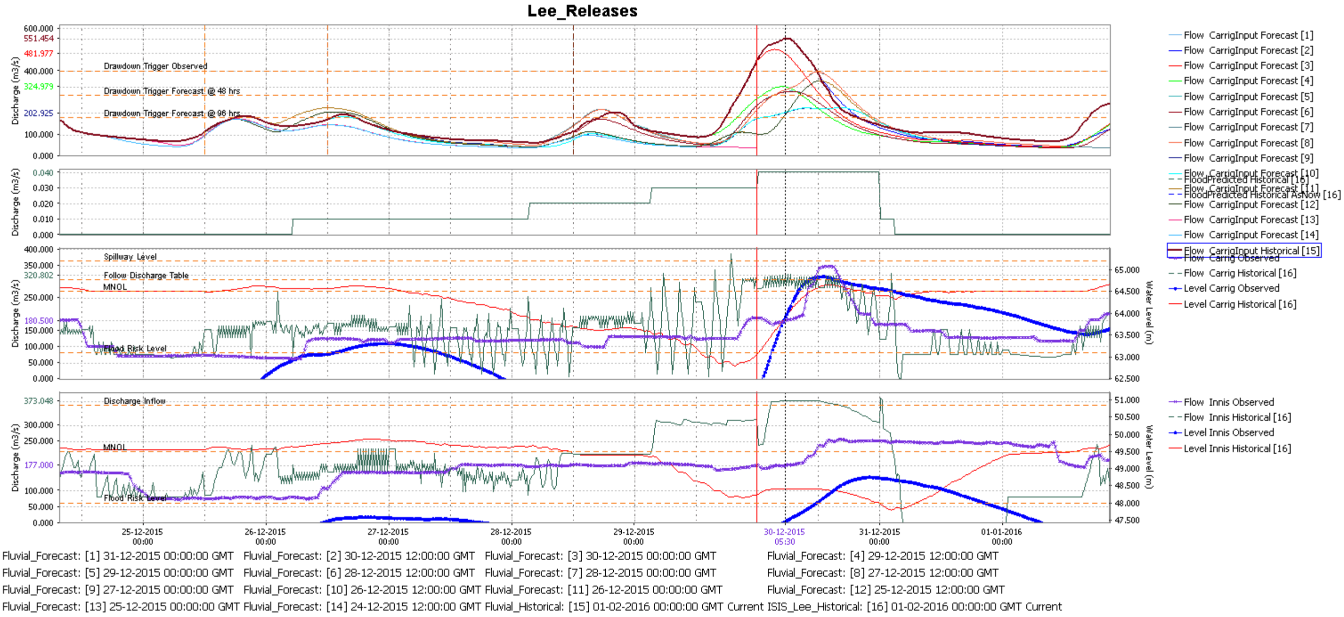
A sequence of three minor events, followed by the largest of the winter, occurred in late December (Figure 4). The large event was consistently identified by the thresholds set on Carrigadrohid inflows and appropriate Flood states triggered. Flood State progressed from D to A, initiating the full drawdown sequence. The smaller preceding event was not large enough to interrupt the process.

The simulated maximum Carrigadrohid inflow (using error correction at Macroom and Kill, the only places with data available) was 560m3/s but the ESB derived inflow series gives a maxima of 680m3/s. Without Dromcarra flows, the source of the discrepancy cannot be known. It could be due to any (or all) of: rainfall averaging error; PDM error; errors in the calculation of the derived inflow series.

From a starting level of MNOL in both reservoirs, which is the worse case design assumption, FEWS predicts that Carrigadrohid would have reached a minima of 62.8m and Inniscarra of 48.15m immediately prior to the event. It would therefore have passed through Inniscarra with 1m to spare (maximum of 48.5m) before the level for prescribed discharges. Even with the discrepancy in Carrigadrohid inflows, the procedures would have been capable of limiting flows to 500m3/s in Cork. Following the 'alternative release' strategy (returning levels to MNOL in Inniscarra) would have resulted in a flow of 405m3/s in Cork.

Both reservoirs were again returned to MNOL, as per the assumptions made in the design scenario, within hours of the event passing.

Figure 4 – Lee Releases display for 24 December 2015 to 2 January 2016



H.5 Conclusions

Both events were dealt with effectively by the operational procedures, as implemented by the forecasting system. These dictate that reservoirs are maintained at MNOL when there is no Flood State in force. Operational procedures, and the forecasting system worked, in the expected way. Even if the true inflow to Carrigadrohid was larger than that simulated, this conclusion is still reasonable.

Operational procedures were triggered on another 5 occasions. Each time, the reservoirs were managed back up to MNOL within hours or days of the drawdown being triggered (i.e. there was minimal loss of water).

Registered Office

24 Grove Island
Corbally
Limerick
Ireland

t: +353 (0) 61 345463
e:info@jbaconsulting.com

JBA Consulting Engineers
and Scientists Limited

Registration number 444752