Lough Ree Power, Cooling Water Outfall Modification Options, Risk Summary and Cost Estimates

ESBI Civil and Environmental Engineering

and

ESBI Process and Performance Engineering

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1 Executive Summary

The following report is on potential modification options and Indicative Pricing solicited to undertake work on Lough Ree Power (LRP), entailing design modifications to the Cooling Water (CW) Systems.

- As part of the ongoing licence compliance investigation ESB Generation and Wholesale Markets (GWM), LRP requested an assessment of potential options for the CW systems and the applicability of these options. A thermal plume model for the cooling water dispersion was developed to assist in the evaluation of the following scenarios:
  - An abstraction of 8m^3/s at the cooling water intake and a discharge of 8m^3/s at the cooling water discharge point.
  - An abstraction of 4m^3/s at the cooling water intake and a discharge of 8m^3/s at the cooling water discharge point.
  - An abstraction of 4m^3/s at the cooling water intake and a discharge of 4m^3/s at the cooling water discharge point.
- A scope document was submitted to vendors to get Indicative Proposals for potential changes to the CW cycles and the applicability of these options. The “Indicative Scope” document was also used by to assist in the costing exercise.
- The current configuration of LRP’s CW systems have been reviewed and assessed.
- A total of twelve options to alter thermal load characteristics to the River Shannon at Lanesborough were evaluated

Contents

2 Introduction

ESBI were requested by ESB Generation and Wholesale Markets to review and cost options for reduction of the thermal load input to the River Shannon arising from the thermal cooling water discharges at Lough Ree Power (LRP).

This report sets out the options considered to reduce thermal load and/or its potential impact to the receiving water in terms of their feasibility, technical applicability and estimated capital investment cost to the plant.

2.1 Lough Ree Power

Lough Ree Power Generating Station is located adjacent to the River Shannon at Lanesborough County Longford as illustrated in Figure 2-1 below. The station is a peat fired base load station i.e. continuous operation, subject to availability. The installed gross capacity is 100MWe and the station was commissioned in 2004. The CFB peat-fired boiler generates steam which is used to drive turbines which produce electricity. The steam is then cooled to hot water and recirculated to the boiler. The steam is cooled by water abstracted from and returned to the River Shannon.

The principal aqueous discharge from the power station is cooling water discharge. The station discharges approximately 135MWth to the River Shannon when operating on full load. This consists of a flow through the condenser of 4m^3/s with a temperature rise of approximately 8℃.

There has been continuous production of electricity on an adjacent site at Lanesborough since 1958 when a 20MW unit was commissioned. The station was extended in 1966 and again in 1983. The installed capacity in 1983 was 85MW and this plant discharged a thermal load to the River Shannon of approximately 185MWth. This load consisted of a flow through the condenser of 5.5m^3/s with an approximate 8℃ temperature rise when all units were on full load. Lanesborough Generating Station was decommissioned in 2003 and its associated Integrated Pollution Control Licence (P0629) was surrendered in 2010.

Lough Ree Power has been designed as a once through cooling system which is fully in line with the applicable BAT.

With respect to the Large Combustion Plant BAT Reference Document (LCP Bref) 2017, LRP operates in accordance with the BAT associated energy efficiency levels (BAT-AEELs) set out in Table 8 of the BAT Conclusions for the combustion of solid biomass and/or peat. The units need to operate net electrical efficiency of between 28-38%. LRP operates to a net electrical efficiencies of between 36-37%.

Figure 2-1: General Location of Lough Ree Power at Lanesborough

3 Approach and Methodology

3.1 General Approach

Twelve options were identified as being potentially feasible, based on:

- ESBI's engineering experience associated with the plant and
- a desktop review of potential options
- site visits to the plant to identify physical space constraints and conflicts,

Direct engagement with suppliers took place to establish plant sizing requirements and cost estimates for well-established cooling option technologies

In addition a thermal plume model for Lough Ree Power was developed using Telemac-3D by an independent modelling specialist (Dr. Adrian Buckley). Telemac-3D is a three dimensional hydrodynamic modelling software. The report on the outputs for the model is provided in Appendix 1.

The following four model scenarios were run with no wind, for the 95 percentile Shannon flows at Lanesborough. Based on historical data The 95 percentile flow at Lanesborough is 11.2m^3/s and this is the upstream boundary condition for all model runs.

1) Model 1- Baseline see Appendix 1

An abstraction of 4m^3/s at the cooling water intake and a discharge of 4m^3/s at the cooling water discharge point. The cooling water discharge has a temperature rise of 9.5°C. The flow in the main channel of the river Shannon is 7.2m^3/s. This is representative of current conditions.

2) Model 2

An increased abstraction of 8m^3/s at the cooling water intake and a discharge of 8m^3/s at the cooling water discharge point. The additional 4m^3/s reduces the temperature rise from 9.5°C to 4.75°C. In this case there is a reduction in the flow in the main river channel from 7.2m^3/s to 3.2m^3/s.

3) Model 3

An abstraction of 4m^3/s at the cooling water intake and an increased discharge of 8m^3/s at the cooling water discharge point. The additional discharge of 4m^3/s is a consequence of an additional abstraction downstream of the station. This scenario reduces the temperature rise from 9.5°C to 4.75°C. In this case there is no reduction in the flow in the main river channel. The additional 4m^3/s increase the flow locally in the river Shannon at Lanesborough from 11.2m^3/s to 15.2m^3/s.

4) Model 4

An abstraction of 4m^3/s at the cooling water intake and a discharge of 4m^3/s at the cooling water discharge point. The cooling water discharge has a temperature rise of 9.5°C. However for this scenario a channel has been cut through the Reed Bed upstream of the outfall to allow additional river water to flow into the outflow channel. The flow in the river is 11.2m^3/s.

3.2 12 Options Considered

3.2.1 Option 1: Extract 4m^3/s additional cooling water

The option of extracting an additional 4m^3/s of cooling water from the Shannon adjacent to the cooling water intake, mixing it with the cooling water from the plant and discharging it to the cooling water outfall location was examined. This concept involves additional extraction to dilute the CW outfall water in order to cool the outfall water to the desired temperatures. It would involve additional pumping using an already existing spare CW inlet pump which would need to be connected to the outlet pipe before it reached the river (see **Figure 3-1** below).

During the 95%ile flow conditions when the river flow is at 11m^3/s (low river summer conditions and high temperatures) the extraction of an additional 4m^3/s of river water to mix with the existing cooling water abstract action and discharge of 4m^3/s would result in a residual flow of approximately 3m^3/s in the river.

Modelling (Model 2) of the potential impact of this scenario was undertaken (see Figure 3-2**,** Figure 3-4 and Figure 3-4) and indicated that the thermal plume footprint would be altered. It would quickly impact across the entire river section due to the increased hydraulic load from the increased discharge. The temperature level of the cooling water outfall would decrease but would not be below 1.5˚C above ambient and significantly more than 25% of the cross sectional area of the entire river section would be impacted.

There would be no benefit derived from implementing this option and the option was deemed unfeasible.

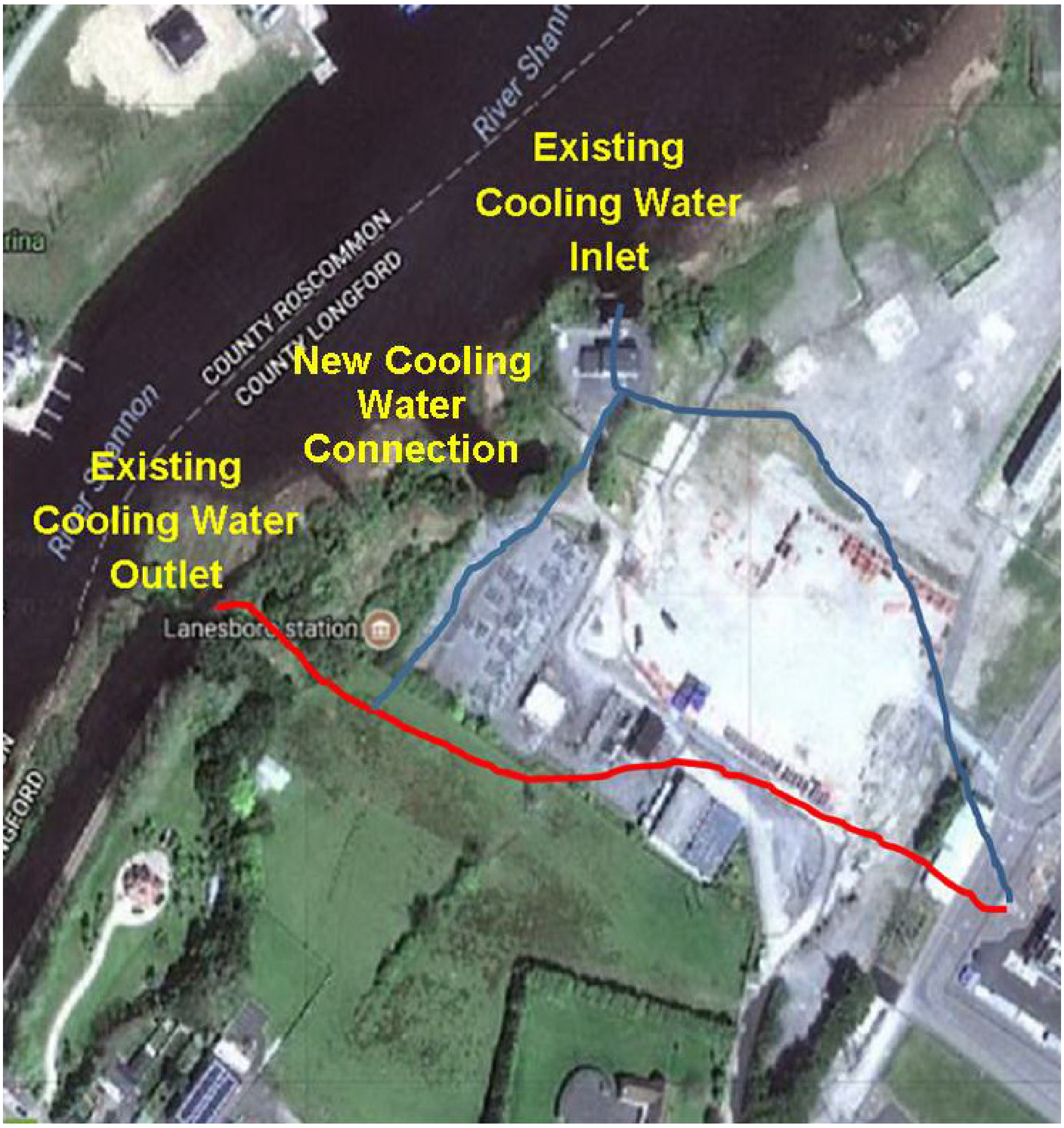


Figure 3-1: CW Connections to the Shannon River with Pump and Mixing Pipe

Approximately 200m of new Piping, Trenching and a new Pump House or annex

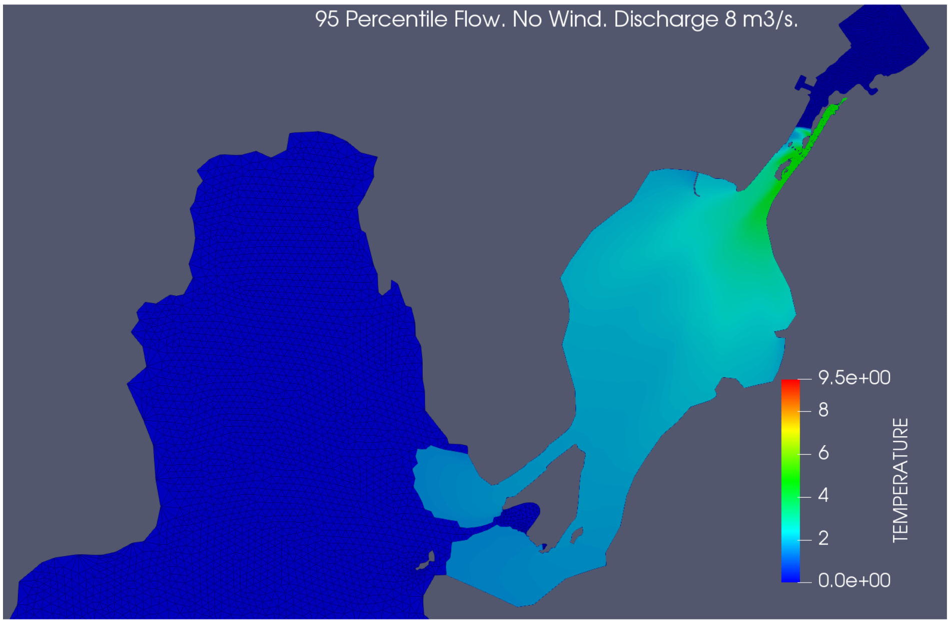


Figure 3-2:Plan of Thermal Plume at Surface

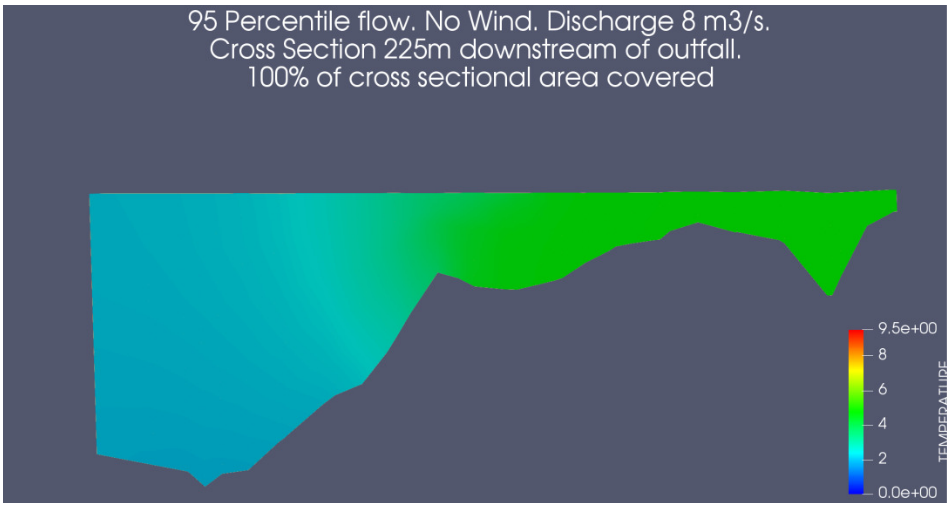


Figure 3-3: Cross Section at 225m downstream of Outfall

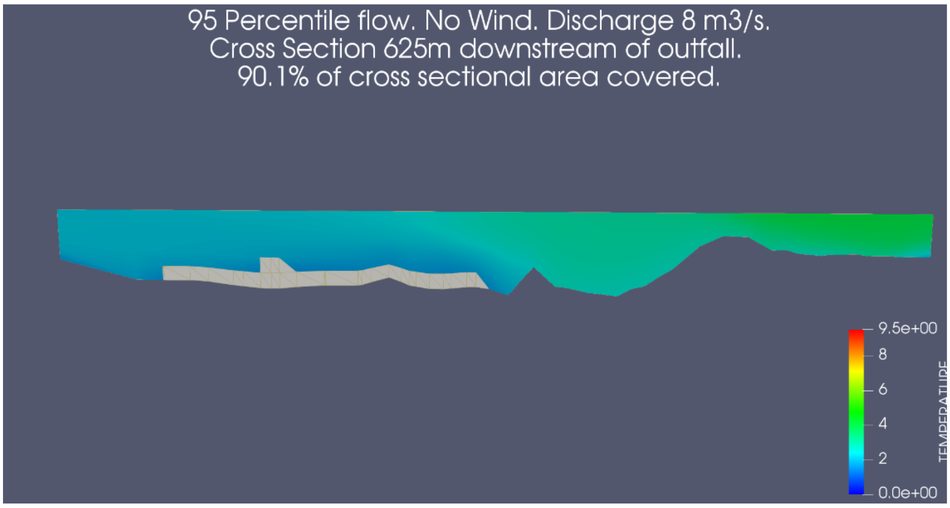


Figure 3-4: Cross Section at 625m downstream of Outfall

3.2.2 Option 2: Attemperate the Cooling Water outfall at LRP by additional cooling water abstraction from Lough Ree

This option to extract an additional 4m^3/s of lake water from Lough Ree and discharge it to the cooling water outfall location to reduce thermal load input was also examined (see Figure 3-5 below).

The option would require the installation of a 3km length abstraction pipe of approximate diameter 1.2m and diffuser intake system in the lake with associated pumping facilities at the station.

During the 95%ile flow conditions when the river flow is at 11m^3/s (low river summer conditions and high temperatures) the extraction of an additional 4m^3/s of lake water to mix with the existing cooling water extraction and discharge of 4m^3/s would result in a combined discharge of 8m^3/s into the residual flow of 7m^3/s locally in the river.

Modelling (Model 3) of the potential impact of this scenario was undertaken (see Figure 3-6, Figure 3-7 and Figure 3-8) and indicated that the thermal plume footprint would again be altered. It would impact across the entire river section due to the increased hydraulic load forcing it to the main channel side. The temperature level of the cooling water outfall would again decrease but would not be below 1.5°C above ambient. More importantly more than 25% of the cross sectional area of the entire river section would still be impacted.

With this option the impact on the Lough Ree ecology is unknown and would take significant time to evaluate. At LRP a new pump house and the installation of piping underwater in the Shannon and in Lough Ree would be required. There would also be very significant engineering costs required to make this option operational.

There would be no benefit derived from implementing this option and the option was deemed unfeasible.

Figure 3-5: CW Connections to Lough Ree with Pump and Mixing Pipe

Approximately 3000m of new underwater Piping, and a new Pump House or annex

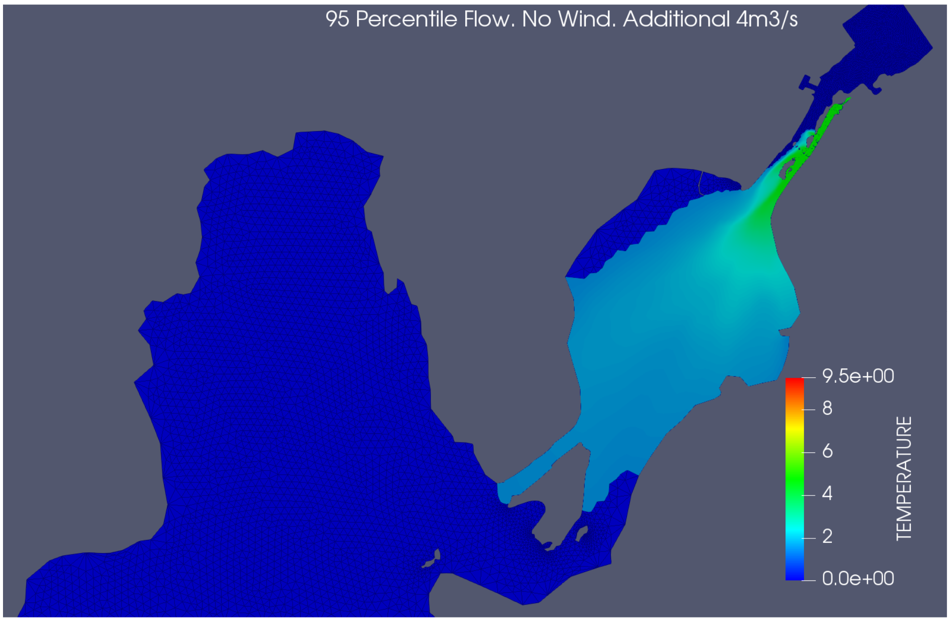


Figure 3-6: Plan of Thermal Plume at Surface

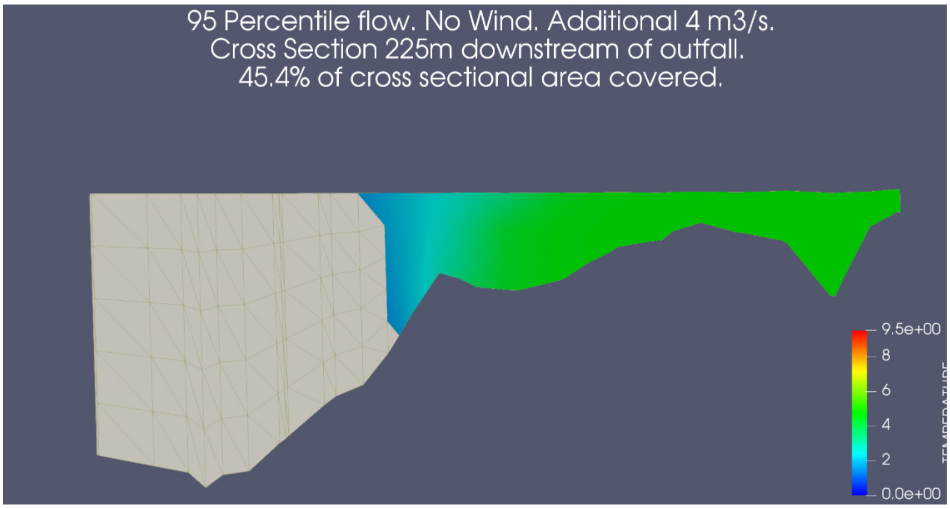


Figure 3-7: Cross Section at 225m downstream of Outfall

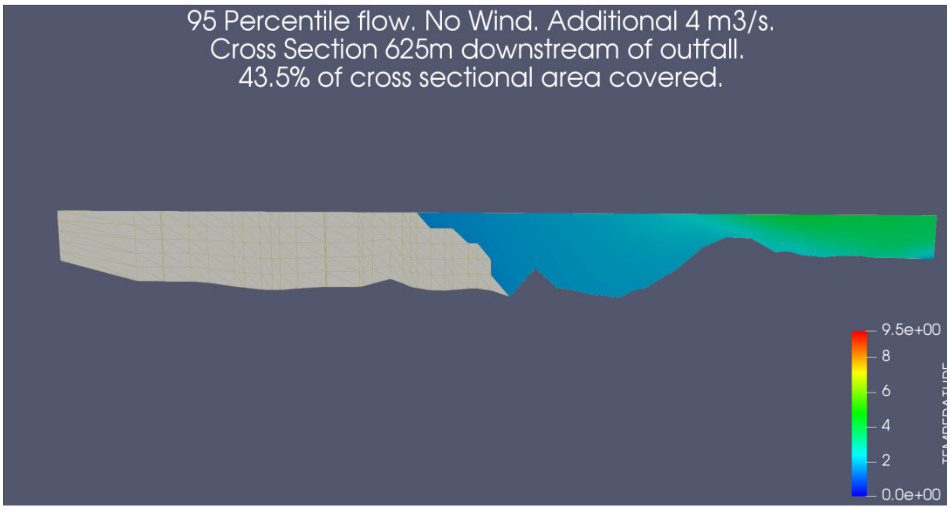


Figure 3-8: Cross Section at 625m downstream of Outfall

3.2.3 Option 3: Increase natural flow into the cooling water discharge channel

The option to increase natural river flow to the cooling water channel was considered and would involve the removal of part of the headland located just above the cooling water discharge point. This would allow additional river water to flow through the channel reducing the thermal discharge temperature though mixing. There would be no change to the 95%ile overall river flow of 11m^3/s but more river water would flow through the discharge channel on the left bank.

Modelling (Model 4) of the potential impact of this scenario was undertaken (see Figure 3-9, Figure 3-10 and Figure 3-11. It should be noted that creating a channel in the reed bed upstream of the outfall also results in a portion of the simulated thermal plume flowing northwards and under certain wind conditions could result in discharged cooling water reaching the cooling water intake. Under 95 percentile flow conditions the thermal plume would continue to occupy all of the cross section of the river (approximately 225m downstream of the outfall) at a temperature more than 1.5˚C above ambient. A slight reduction in the cross sectional area of the simulated thermal plume is predicted at 625m downstream of the outfall.

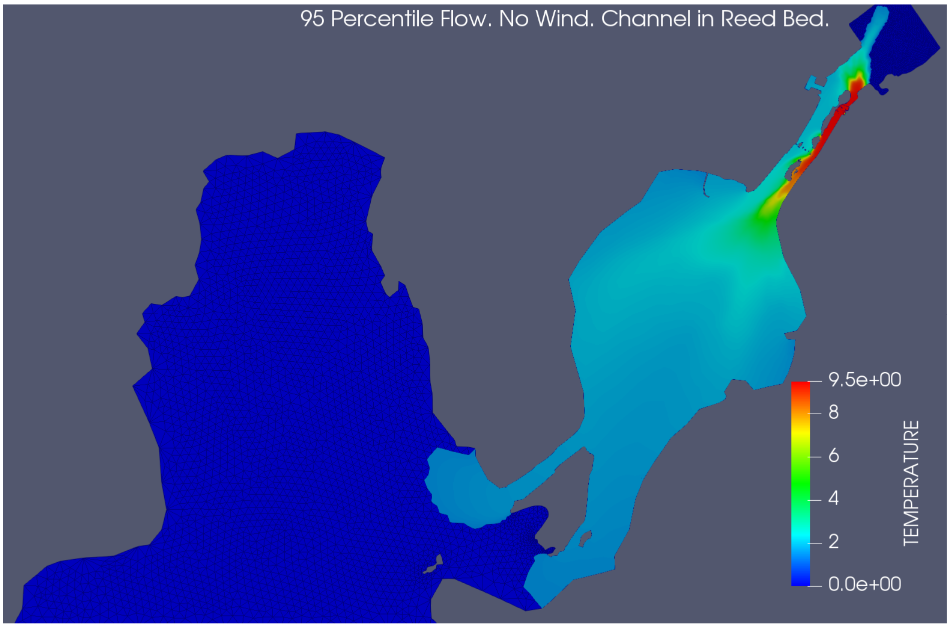


Figure 3-9: Plan of Thermal Plume at Surface

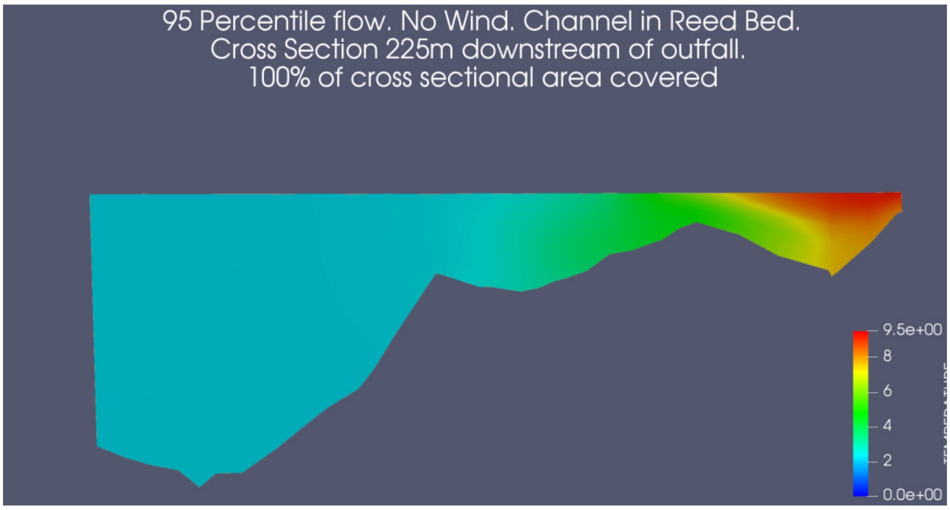


Figure 3-10: Cross Section at 225m downstream of Outfall

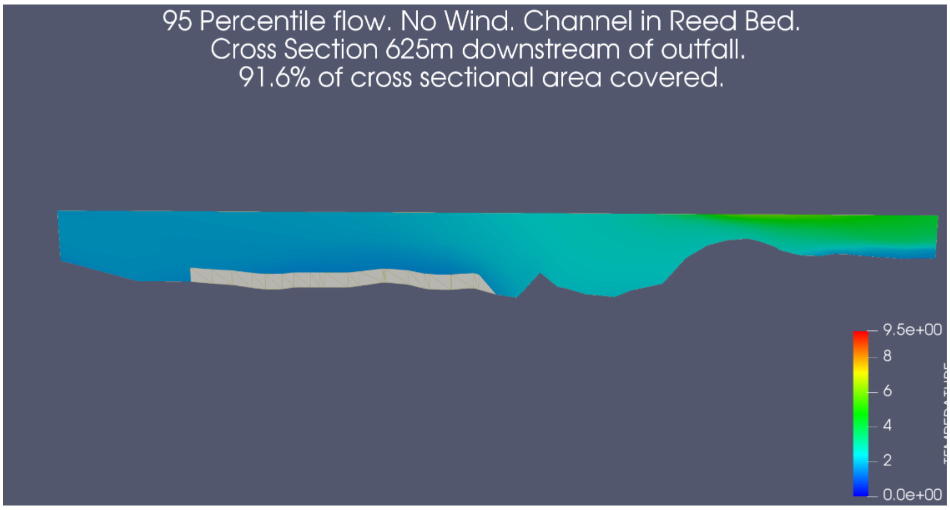


Figure 3-11: Cross Section at 625m downstream of Outfall

3.2.4 Option 4: Extend the cooling water into Lough Ree

The option to extend the cooling water outfall down to Lough Ree itself and disperse the cooling water through a diffuser system in the lake was considered. This would require the installation of approximately 3km of cooling water discharge pipe, additional pumping requirement and a diffuser embedded in the lake bed. The configuration of the piping would be similar to the piping layout in 3.2.2 (see Figure 3-5 above).

Although this option might be technically feasible it would require significant study and design to identify the optimum location for thermal load discharge and dispersion and would require long term environmental surveys to determine the potential impact on the ecology of Lough Ree. Therefore there are significant unknown potential impact factors which could render the option non viable.

This option would also entail significant capital investment requirement.

Given the high degree of uncertainty that this option would be acceptable environmentally or from a planning aspect and that it would entail very high cost, it was deemed unfeasible.

3.2.5 Option 5: Air Cooled Heat Rejection (ACHR) units, dry systems.

This option reviewed the potential use of air cooled heat exchangers to dissipate the cooling water temperature to the atmosphere. It is a typical type of industrial heat exchanger (see Figure 3-12, Figure 3-13 and Figure 3-14 below). The Air Cooled Heat Rejection (ACHRs) units are water circulation heat exchangers which has forced air flowing across it to allow the dissipation of heat.

These units are very similar in design to Air Cooled Condensers (ACCs) which condense steam inside of them while assisting a power plant in its power generation cycle.

The ACHR units would require a large footprint area within or adjacent to the plant with engineering tie in requirements to the plants cooling system and with realignment of existing services and electrical infrastructure.

3.2.5.1 Inherent Risk in ACHR units

Feedback from ACHR equipment vendors with respect to the application of this technology to LRP concluded that during summer conditions, at the time when abatement is required, the air cooled heat exchangers are unlikely to work due to “Approach to Dew Point”.

Note: Dew point is the temperature to which air must be cooled to become saturated with water vapour. The Approach to Dew Point issue for the ACHR heat exchangers is caused by humidity in air preventing heat exchange at air temperatures close to the 27° temperature of the water and the 20° temperature that the CW water needs to be when it leaves the CW outfall in order to meet the EPA requirements. Primarily this is when the air temperature is higher than 20° and humidity is also high.

As a result of the problems caused by “Approach to Dew Point” the ACHR design will not achieve the required temperature reduction in the event that abatement of the thermal plume load is required in the Shannon River.

ACHR units, are large closed dry systems

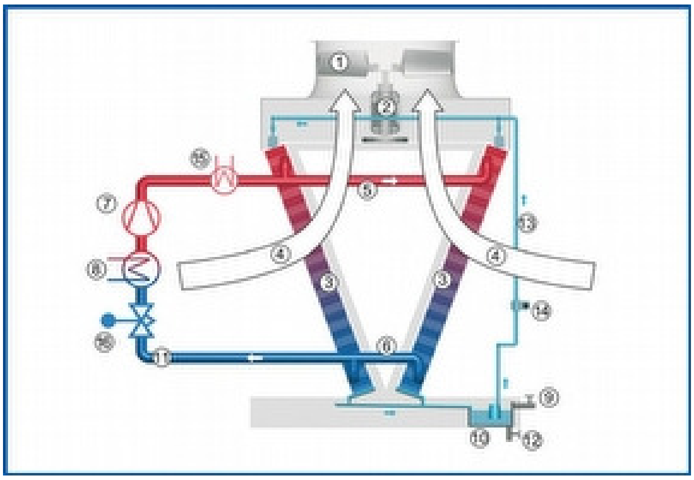


Figure 3-12: Schematic of an ACHR a Dry Cooling Unit

Figure 3-13: Example Dry Cooling Unit

Figure 3-14: Multiple Assembly of Dry Cooling Units

3.2.6 Option 6: Forced Draft Cooling Towers (air to water, wet systems).

The option to use a Forced Draft Cooling Tower to reduce the thermal load was also examined. This is a traditional power plant cooling system design (see Figure 3-15 below). This option is found in many older industrial cooling systems and power plants as a direct method of reducing temperatures in heated water. This method uses evaporation to cool water.

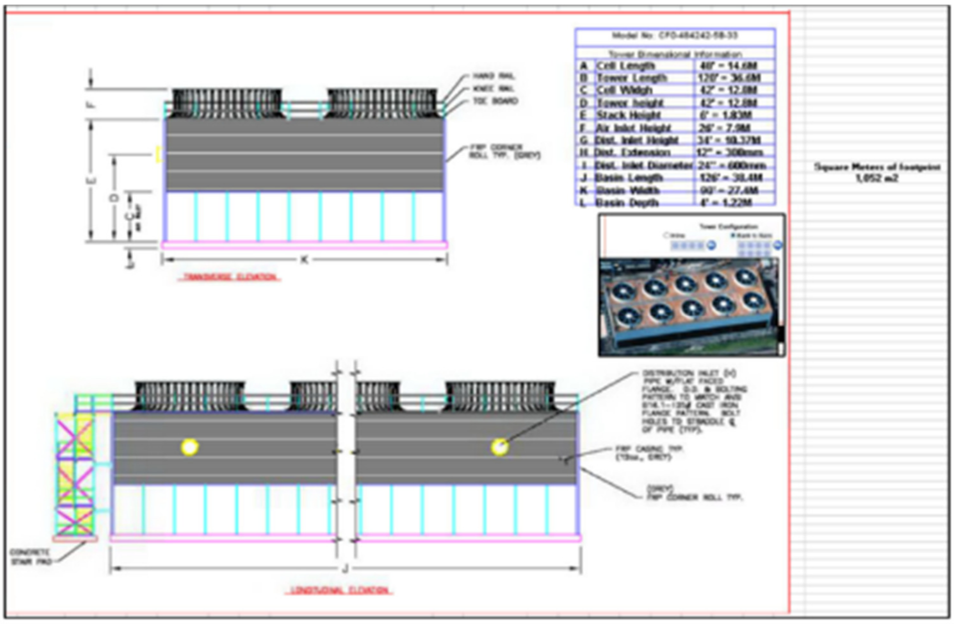
3.2.6.1 Inherent Risk in Forced Draft units

This option has a significant environmental risk as it directly employs Shannon River water inside of the cooling towers thereby requiring an additional extraction. The use of river water in a direct interface with air can also promote Legionaries' disease. In order to eliminate the disease potential, the water has to be inoculated and this chemical additive inoculation would have a significant impact on the river water. The addition of these chemicals may impact negatively of the ecology of the river system.

The forced draft cooling system assessed has 250kW fans in individual cells that produce the forced draft. There is one fan per cell and the current number of cells predicted for LRP by using sizing and pricing software indicates that there will be six cells and six fans. Thus the parasitic loading of the fans is approximately 1.5MWs for LRP and hence would impact on the overall efficiency of the plant.

The Forced Draft Cooling system will achieve the required thermal load reduction and it has a similar footprint as the ACHRs (see Figure 3-18 below). But, it will require significant engineering works and site alterations. It would require the moving of power lines. It would lose a significant amount of the cooling water to vapour even with an extra vapour capture condensing equipment. The additional vapour capture condenser may use a significant amount of power. Forced draft cooling would require harsh chemical treatment of the cooling water with potentially significant potential impact on the receiving water quality.

This option would also entail significant capital investment requirement



	Model No: CFD-484242-58-33	
	Tower Dimensional Information	
A	Cell Length	48' = 14.6M
B	Tower Length	120' = 36.6M
C	Cell Widgh	42' = 12.8M
D	Tower height	42' = 12.8M
E	Stack Height	6' = 1.83M
F	Air Inlet Height	26' = 7.9M
G	Dist. Inlet Height	34' = 10.37M
H	Dist. Extension	12" = 300mm
I	Dist. Inlet Diameter	24" = 600mm
J	Basin Length	126' = 38.4M
K	Basin Width	90' = 27.4M
L	Basin Depth	4' = 1.22M

Figure 3-15: Forced Draft Cooling at a 7 Degree Temperature Drop

3.2.7 Option 7: Replace Existing Condenser and CW Systems with New Air Cooled Condensers (ACC)s.

An ACC is a typical modern type of power plant heat exchanger (see Figure 3-16 below). ACCs, are steam condensing heat exchangers which uses forced air as a cooling medium.

These units are very close in design to the ACHR cooling device (see above). The two designs look similar and work in similar fashion, thus they have a lot of the same equipment and footprint sizes and costs can be assumed to be about the same.

3.2.7.1 Inherent Risk in ACC units

Replacing existing Condensers with ACCs poses significant risks, as it requires demolition of the existing plant condenser system which will have various unknown risks, plant impacts and costs.

ACC systems have the same "Approach to Dew Point" problems as the ACHR equipment have (see 3.2.5 above) can reduce overall plant efficiency.

Changing the condenser system is likely to have a significant impact on the overall plant efficiency.

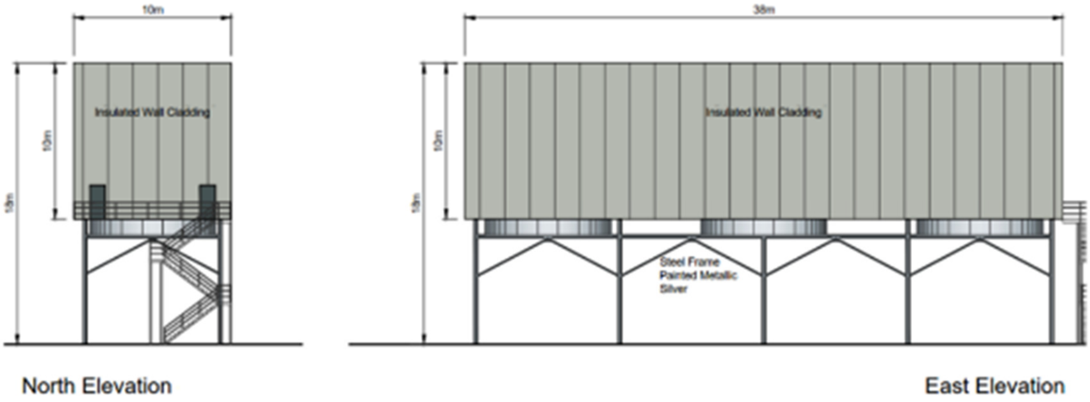


Figure 3-16: Typical ACC for LRP X 2

3.2.8 Footprint requirements and locations for mechanical cooling

The current configuration of LRP’s CW inlet and outfall piping is as per Figure 3-17 below. The CW piping would need to be connected to an additional cooling cycle to enable the temperature drop during times when the Shannon River is in low flow conditions or the river water temperature is higher than normal.

A representative equipment footprint is shown in Figure 3-18 below. The estimated footprint size requirement for an ACC, Forced Draft or ACHR air cooled heat rejection units is approximately 2000m^2 inclusive of unit footprints, separation distances and utility requirements.

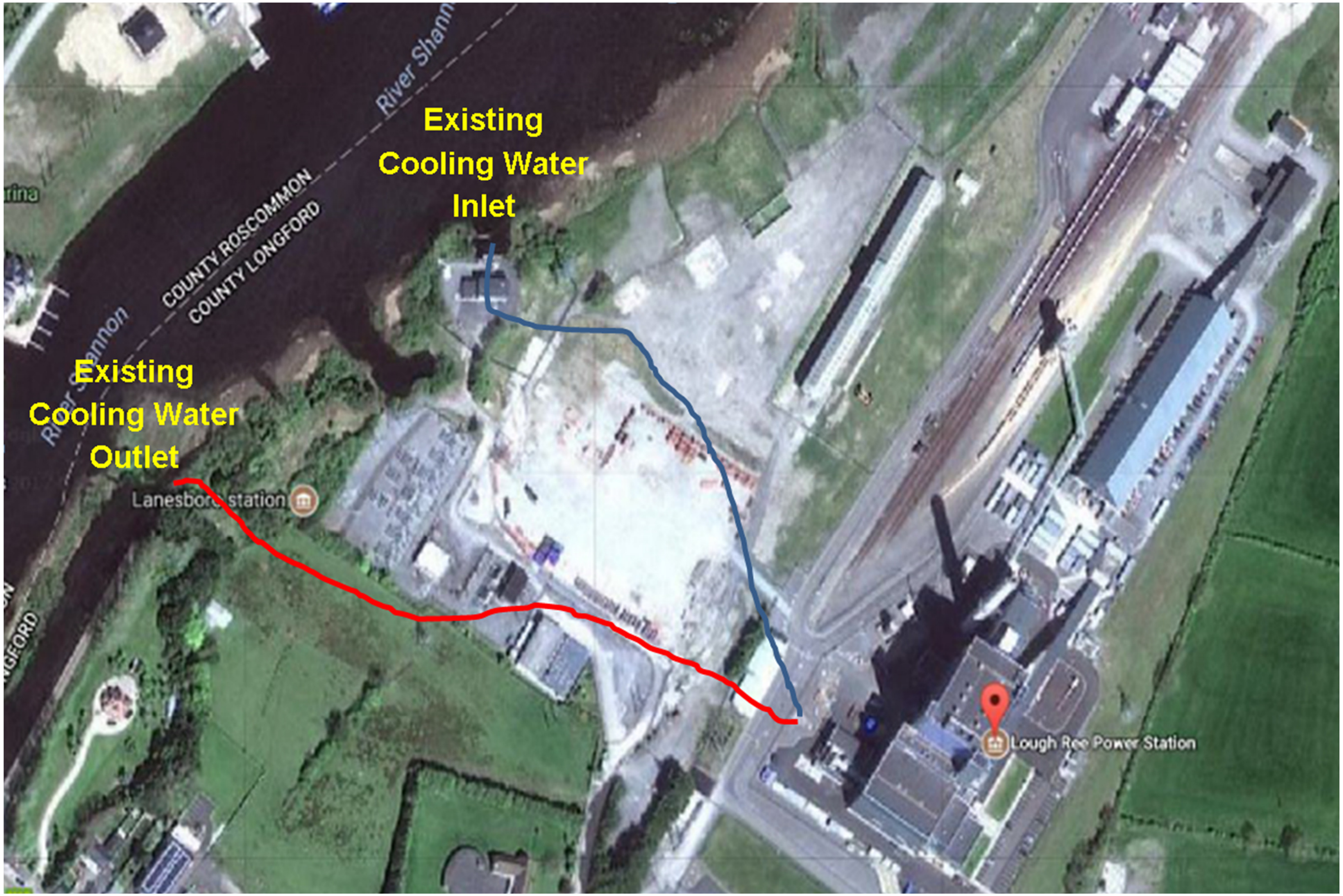


Figure 3-17: CW System Connections to the Shannon River

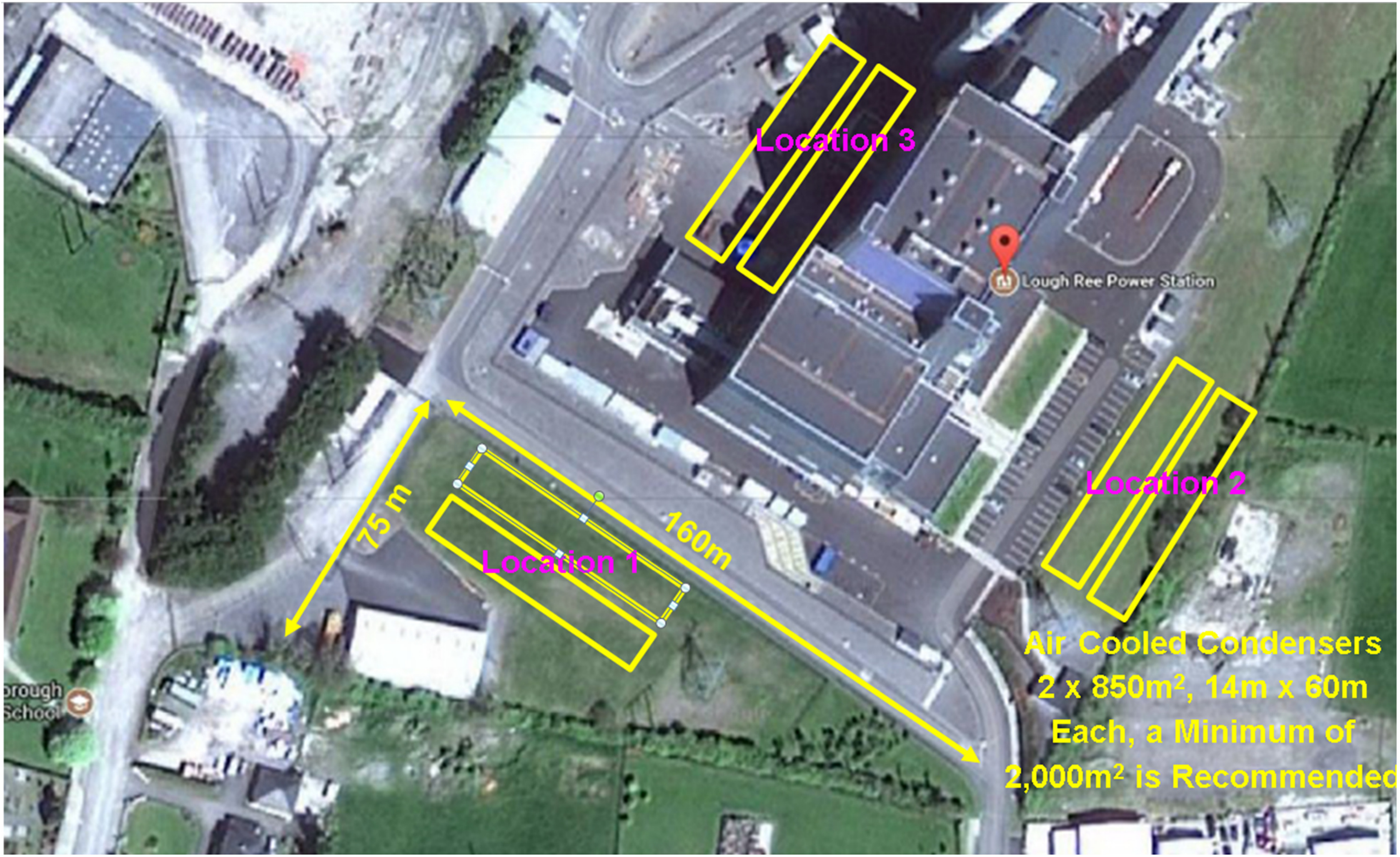


Figure 3-18: Possible Locations of ACCs or Cooling Towers for LRP

3.2.9 Option 8: Construct cooling ponds for outflow water.

In this option the cooling water discharge would be directed to cooling ponds before re-entering the Shannon River. Cooling ponds are a very simple way of bringing CW outfall water temperatures back to ambient temperatures. The water comes from an external source such as a river, in the LRP scenario, it runs through a plant, rests for a time in a large shallow pond to allow some degree of cooling before being discharged back to the river.

3.2.9.1 Inherent Risk in Cooling Ponds

A Cooling Pond system will require diversion of the cooling water directly to the cooling ponds. This cooling system evaporates water directly to the air in order to cool the water – resulting in a water loss to vapour.

An example of a cooling pond system in use in the US associated with a 2,000MWe generating plant is shown in Figure 3-19 below, the ponds are approximately half a kilometre across.

Figure 3-19: Example Cooling Ponds Taking up Large Areas of Land

Such a solution considering the LRP cooling load would require approximately 40 Hectares of land for ponds which is more land than is currently available to ESB. Obtaining 40 Hectares, rights of way and land leases in order to lay the pipe, getting planning and the cost of these agreements are unknown and are significant risk items. Vaporization of most of the cooling water is also a high potential risk as it will ultimately reduce the return flow to the Shannon River.

This option would also likely result in the creation of heavily modified water body downstream of the cooling water abstraction point with implications under the EU Water Framework Directive.

3.2.10 Option 9: Cooling pond with spray system.

A variation of the cooling pond solution whereby a smaller footprint of land for water ponds is required, is to spray water into the air within the cooling ponds. The water spray method consists of a pumped fountain of cooling water spraying into the air to force water cooling by using up energy through creating a fine spray of water. This process is called atomization as it creates water droplets as small as individual atoms. Thus the water will exchange heat with air very efficiently through these small droplets.

3.2.10.1 Inherent Risk in Cooling Ponds including Spraying

Again this option may require more land than ESB currently owns. ESB owns 6.4 Hectares at LRP that may be available to be used for ponds, although subject to further study it is anticipated that this area may not be sufficient to create the vapour spray ponds. In scenarios of high wind the water spray may be blown away from the ponds resulting in water loss and ultimately a reduction in volume returned to the river. Significant water loss to the atmosphere may occur reducing the return flow to the Shannon River.

ESB have assessed the spray process and concluded that this option has an environmental risk as it directly employs Shannon River water as the spray, requiring additional extraction. The use of river water in a direct interface with air, may again promote Legionaries’ disease. In order to eliminate the disease potential, the water has to be inoculated and this inoculation is a harsh chemical additive to the river water. The addition of these chemicals may impact negatively of the ecology of the river system.

This option has a large potential environmental risk as it can vaporize and eliminate the cooling water in large amounts and at the right conditions it has an even higher risk of vaporizing most, if not all, of the river water. Such concerns compound the problems associated with the normal cooling pond design.

This option consumes significant power used to pump the water in the ponds and to create the vapour spray increasing the house load on the plant.

Furthermore this option would require planning and environmental consent. It would also likely result in the creation of heavily modified water body downstream of the cooling water abstraction point with implications under the EU Water Framework Directive.

3.2.11 Option 10: Construction of a second loop in the CW/Condensing system.

The possibility of installing a second pass cooling loop in the CW system was examined. This would require the abstraction of an additional quantity of cooling water from the Shannon River which would be circulated inside of a new installation of additional heat exchange surface area (a second loop), which amounts to more tubes to extract more heat from the depleted steam inside of the existing condenser. The consequences of this would be similar to those discussed in 3.2.7 above.

3.2.11.1 Inherent Risk in Installation of a Second Loop in the CW system

It may not be possible to retrofit this kind of installation within the existing design of condenser. This would entail significant design calculations to balance the condenser sizing and layouts. From the assessment carried out by ESB this process would not provide any significant improvement in thermal abatement.

The solution wouldn’t provide any improvement in the total thermal outflow

This option would require a major rebuild and redesign of the existing condenser system, the risks imposed by the rebuild would be very high.

Note: Options 3.2.12 and 3.2.13 were formerly considered by ESB and were not deemed viable for environmental and practical reasons.

3.2.12 Option 11: District heating

The concept to use the thermal load from the power station for a District Heating scheme was investigated. This option would require a water tap off from the CW outfall piping that can then be rerouted to communal service pipes that provide low level heat for homes and businesses - thus, using that extra low level heat for productive purposes.

Due to the size of the adjacent community, minimal industry in the vicinity community and lack of an existing installed district heating network it was determined that any such scheme would not be feasible. The thermal load reduction would also be unlikely to be achieved as the level of utilisation would not be sufficient to reduce the thermal load in the cooling water discharge.

3.2.13 Option 12: Alternative heat uses

Historically, two alternative heat usage projects were developed. One in the form of heated greenhouses for horticultural purposes and one for peat drying.

These two projects used the CW Outfall water as a low level heat source through heat exchange from the water to the air in green houses and in the peat storage silos.

Usage of the excess heat for both horticultural purposes and peat drying was very small and both projects were discontinued. This option was therefore deemed to be unfeasible.

4 Cost Estimates for technological solutions

Cost estimates for technological solutions were obtained from commercial vendors for mechanical cooling equipment. Civil, mechanical and electrical engineering costs were developed by ESBI.

The following table is a summary of the costs for each of the mechanical solutions which have been totalled in Appendix 3 below. This total includes the extra costs such as moving required utilities and ancillary items required to change the CW systems of LRP. The combined cost tables including contingencies of these totals are also supplied in Appendix 3 below.

Modification cost estimates for the CW system changes listed in 3.2.5 through 3.2.10 above were solicited from the three following vendors

- Lodge Cottrell
- HAMON D'HONDT S.A.
- ICS Cool Energy (Withdrew from submission)

All were provided with an Indicative Scope Document which outlined the modification requirements (see Appendix 2).

Proposed Design Modifications (see the line item pricing in Appendix 3 below):	**Costs**
Note 1: All heat exchanger installation costs at LRP include Power Line relocation (see Table 5 below)* Note 2: It has been assumed that the cost of Option 3.2.6 is the same as the cost of Option 3.2.5. Note 3: it has been assumed that the cost of Option 3.2.10 is, at a minimum, the same as Option 3.2.9 and it may be a lot more.	
3.2.1 Extract 4m^3/s additional cooling water	
• Installation of Piping and Pumping to move river water from Shannon River into the CW Outfall (This option will not work for several reasons, see Section 6 below and Section 3.2.3 above):	€1,810,050
3.2.2 Attemperate the Cooling Water outfall at LRP by taking cooling water from Lough Ree:	
• Installation of Piping and Pumping to move Lough Ree water from Lough Ree into the CW Outfall:	€14,780,250
3.2.4 Extend the cooling water outflow into Lough Ree	
• Installation of pipes and pumping from the Plant CW outlet into Lough Ree:	€14,780,250
3.2.5 ACHR, heat exchangers (If they work)	
• Equipment, piping and power lines installed*:	€12,527,816
3.2.6 Forced Draft Cooling, heat exchange (If it doesn't contaminate the river)	
• Equipment, piping and power lines installed:*	€12,527,816
3.2.7 ACCs (Requires demolition of existing condensers, an extra unknown cost)	
• Equipment, piping and power lines installed*:	€21,745,862
3.2.9 Cooling Ponds (LRP haven't enough land, an extra unknown cost)	
• Ponds and piping installed:	€7,277,571
3.2.10 Cooling Ponds with Evaporative Cooling Spray Systems (LRP may not have enough land, an extra unknown cost)	
• Ponds and piping installed:	€6,369,472
3.2.11 Install Second Pass Cooling Loop in the CW System (Requires demolition of existing condensers, an extra unknown cost)	
• Equipment, piping and power lines installed*:	€21,745,862

Table 1: LRP Price Summary by Equipment

5 Summary of technological solutions

The review identified potential options for mechanical cooling of the thermal load from the stations or alterations to cooling water discharge to the Shannon River. These options were not deemed to be feasible for the following reasons:

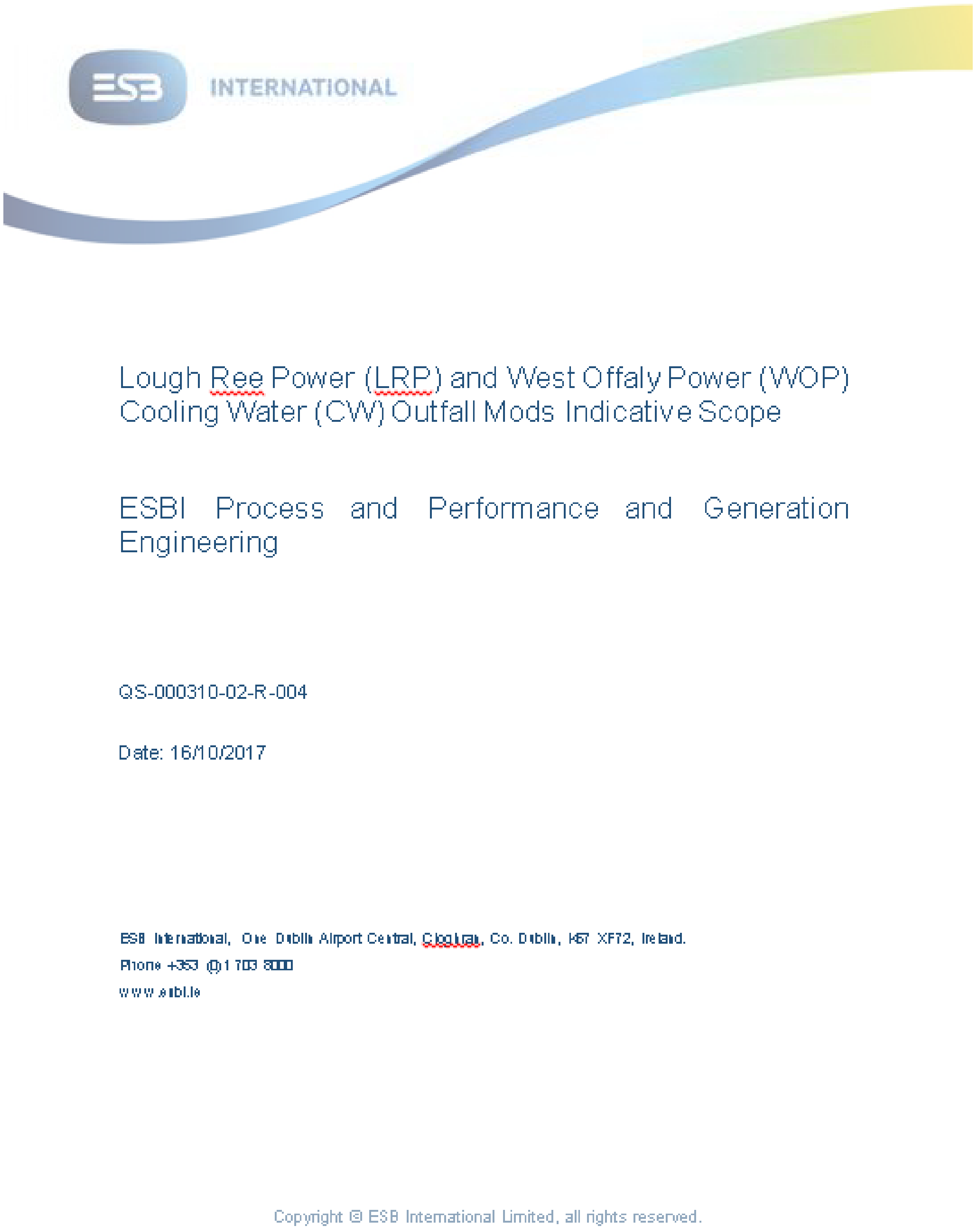
1. Option 1: Extraction of additional cooling water at the current extraction point will not achieve the requirement of the existing Condition 5.5 of the IE Licence.
2. Option 2: Attemperation, the extraction of an additional 4m^3/s of lake water from Lough Ree and discharge it to the cooling water outfall to reduce thermal load input will not achieve the requirement of existing Condition 5.5 of the IE licence
3. Option 3: Increasing natural flow into the cooling water discharge channel by removing the headland above the discharge point will not achieve the requirement of the existing Condition 5.5 of the IE Licence
4. Option 4: Extend the cooling water outfall by pipe to Lough Ree and discharge it to the lake to reduce thermal load into the Shannon River. This option would require significant study and long term environmental surveys to determine the potential impact on the ecology of Lough Ree. Given that the current planning permission expires in 2020, no solution would be in place before that date.
5. Option 5: The option to install an Air Cooled Heat Rejection Unit will not technically deliver the reduction in temperature in the cooling water required.
6. Option 6: Forced draft cooling towers are feasible but carry the risk of Legionnaire's disease requiring harsh chemical treatment of the cooling water with likely significant impact on the river ecology.
7. Option 7: Replacing the existing plant condenser system with Air Cooled Condensers would require a complete rebuild of the power generation plant
8. Option 8: Use of cooling ponds require very large areas of land not available to ESB and would lead to evaporative losses with reduced return flow to the river. This would have implication sunder the Water Framework Directive.
9. Option 9: Additional cooling by air dispersal to reduce the size of cooling ponds would also lead to evaporative losses and still require additional lands not available to ESB.
10. Option 10: Installation of a second pass cooling loop would not achieve the requirement of the existing Condition 5.5 of the IE Licence.
11. Option 11: District Heating – there is insufficient capacity in the local environment to make district heating feasible.
12. Option 12: Alternative Solutions – there are no or insufficient alternate heat uses available in the vicinity of the plants to utilise the thermal cooling water load effectively.

All of the above scenarios would require consent from the planning and environmental authorities. At a minimum planning would likely require a 14 month duration followed by a procurement phase and subsequent construction. Given that the current planning permission expires in 2020 it is unlikely that a feasible solution would be in place before that date.

The identified costs for the potential cooling water load reduction solutions are also high and given the fact that scientific studies have demonstrated that no significant negative impact is occurring on the ecology of the Shannon River or on fish migratory species the costs would be disproportionate to any environmental benefits achieved.

Appendix 1: Thermal Plume Model Report

Appendix 2: Indicative Scope Document and Request for Proposal



Lough Ree Power (LRP) and West Offaly Power (WOP) Cooling Water (CW) Outfall Mods Indicative Scope

ESBI Process and Performance and Generation Engineering

QS-000310-02-R-004

Date: 16/10/2017

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Appendix 3: Cost Estimates

1. Items and Costs for CW System changes

Requirements for CW system changes include:

a. Moving Power Lines at LRP,
b. Additional Civil Works,
c. Installation and trenching of new piping,
d. The installation and commissioning of new Cooling Equipment,
e. The installation and construction of Cooling Ponds (Options 3.2.11 & 3.2.12)
f. The installation of the Enabling Works including a Contractors village and utilities

A contingency of 15% was added to select pricing.

1.1. Option 1: Extract 4m^3/s additional cooling water

ESB have looked at the installation of pipes from the plant CW inlet into the CW outflow channel, the use of the spare CW inlet pump to Shannon River water into the CW outlet and to allow the water to mix with the CW outlet water (see **Figure 3-1** above). The costs of a new pump house has also been evaluated. Table 2 below is a cost estimate for the changes.

Option 3.2.1 Installation of Piping and Pumping to move river water from Shannon River into the CW Outfall	**Lough Ree Power (LRP)**	
Construction of new CW Pump House	**Reference: ESBI Civil. 26/01/18**	**€250,000**
Connection and Refurbishment of Existing Spare CW Pump		**€100,000**
Glass Reinforced Pipe approximately = €345/m	**200m and 1.4m OD**	**€69,000**
Underground Piping: 2m wide x 3m deep excavation and Cl.804 backfill (exclude pipe)	**200m and 1.4m OD**	**€68,000**
Sub Total		**€487,000**
+ 15% contingency	**x 15%**	**€73,050**
Enabling Works	**Contractors Village and Utilities**	**€250,000**
Pumping Equipment and Demolition Contingency		**€1,000,000**
Total		**€1,810,050**

Table 2: Piping and Pumping Installed to Move Water into the CW Outfall

1.2. Option 2: Attemperate the Cooling Water outfall at LRP by additional cooling water abstraction from Lough Ree

ESB have looked at the Installation of Piping and Pumping to move Lough Ree water from Lough Ree into the CW Outfall, the use of the spare CW inlet pump to pump Lough Ree water Into the CW inlet and to allow the water to mix with the CW outlet water. The costs of a new pump house has also been evaluated. Table 3 below is a cost estimate for the changes.

Option 3.2.2 Installation of Piping and Pumping to move Lough Ree water from Lough Ree into the CW Outfall	Lough Ree Power (LRP)	
Construction of new CW Pump House	Reference: ESBI Civil. 26/01/18	€250,000
Connection and Refurbishment of Existing Spare CW Pump		€100,000
Glass Reinforced Pipe approximately = €345/m	ESBI Civil 26/01/18: 3000m and 1.4m OD	€1,035,000
Underwater Piping: 2m wide x 3m deep excavation and backfill (exclude pipe)	ESBI Civil 26/01/18: 3000m and 1.4m OD	€11,250,000
Sub Total		€12,635,000
+ 15% contingency	x 15%	€1,895,250
Enabling Works	Contractors Village and Utilities	€250,000
Total		€14,780,250

Table 3: Piping and Pumping Installed to Move Water from Lough Ree into the CW Outfall

1.3. Option 3: Option to extend the cooling water into Lough Ree

ESB have looked at the installation of Pipes from the Plant CW outlet into Lough Ree, the spare CW inlet pump will be connected to the CW outflow water and that water will be pumped into to Lough Ree. The costs of a new pump house has also been evaluated. Table 4 below is a cost estimate for the changes.

Option 3.2.4 Installation of Piping and Pumping to move cold water from Lough Ree into the CW Outfall	**Lough Ree Power (LRP)**	
Construction of new CW Pump House		**€250,000**
Connection and Refurbishment of Existing Spare CW Pump		**€100,000**
Glass Reinforced Pipe approximately = €345/m	**3000m and 1.4m OD**	**€1,035,000**
Underwater Piping: 2m wide x 3m deep excavation and backfill (exclude pipe)	**3000m and 1.4m OD**	**€11,250,000**
Sub Total		**€12,635,000**
+ 15% contingency	**x 15%**	**€1,895,250**
Enabling Works	**Contractors Village and Utilities**	**€250,000**
Total		**€14,780,250**

Table 4: Piping and Pumping Installed to Move Water from the CW Outfall into Lough Ree

1.4. Moving Power Lines to Accommodate new Cooling

ESBI's Networks Department determined a cost estimate for moving LRP Power Lines underground.

Power Line Relocation or Interference	**Lough Ree Power (LRP)**	
Demolition of existing cables	**Reference: ESBI PWR Line Dept. 02/11/2017**	**€500,000**
Installation Underground Cable Costs	**Reference: SC Power Proposal to Pilkington**	**€500,000**
Excavation and installation of underground cables	**Reference: ESBI PWR Line Dept. 02/11/2017**	**Included**
Total		**€1,000,000**

Table 5: Power Line Relocation Costs by Equipment

1.5. Options 4 & 5: ACHR and Forced Draft Civil Requirements

ESBI’s Civil Department has calculated a cost estimate for footings, excavation and Civil construction of Forced Draft Cooling Equipment and has used the same estimate for ACHR units. Pipe material costs were also estimated.

ESBI’s Civil Department requested a 15% contingency be included in this pricing.

Option 3.2. 5 and Option 3.2.6 Include equivalent Civil Works	**Lough Ree Power (LRP)**	
Foundation and Excavation of land for Units	**Reference: ESBI Civil. Department 25/10/17 + 15% contingency**	**€975,000** **x 1.15 .** **€1,121,250**
Underground Piping: 2m wide x 3m deep excavation and Cl.804 backfill (exclude pipe)	**2 No x 50m and 1.4m OD + 15% contingency**	**€34,000** **x 1.15 .** **€39,100**
Glass Reinforced Pipe approximately = €345/m	**2 No x 50m and 1.4m OD**	**€34,500**
Total		**€1,194,850**

Table 6: Additional Civil Requirements for ACHR and Forced Draft installation

1.6. Option 4: ACHR Cooling Equipment

Vendors were presented an Indicative Scope Document by ESBI (see Appendix 2). Those Vendors have estimated an Indicative cost estimate for the Mechanical, Electrical and Process equipment including installation.

Vendor preliminary equipment price estimates Option 3.2.5 Air Cooled Heat Rejection Units	**Lough Ree Power (LRP)**	
Vendor Equipment Prices with daily exchange rate of 1.18€/$	**Lodge Cottrell at 15° Ambient Design Temp December 4th 2017**	**$11,897,900/ 1.18€/$ = €10,082,966**

Table 7: Pricing of ACHR Unit Costs from Vendors

1.7. Cost Totals for Option 4: ACHR

The costs from the Vendors added to the Civil Installation costs and the costs of moving power lines results in the total costs for the ACHR units (Table 8 below is the sum of Table 5, Table 6 and Table 7 above and the enabling works).

Totals Option 3.2.5 Air Cooled Heat Rejection Units	Lough Ree Power (LRP)	
Vendor Equipment Prices	Lodge Cottrell at 15˚ Ambient Design Temp December 4th 2017	€10,082,966
Pricing for Moving Power Lines		€1,000,000
Pricing for extra Civil Works with 15% Contingency		€1,194,850
Enabling Works	Contractors Village and Utilities	€250,000
Total		€12,527,816

Table 8: Sum of Individual Cost Items for ACHR Installations

1.8. Option 5: Forced Draft Cooling Equipment

Vendors were presented an Indicative Scope Document by ESBI (see Appendix 2). The Vendor who was working on Forced Draft design (see Table 9 below) quit the process without having estimated an Indicative cost for the Mechanical, Electrical and Process equipment and installation.

It was assumed that pricing would be of the same order as ACHR due to the similar size, footprint and construction of the ACHRs and the Forced Draft Heat Exchangers.

Assumed to be as per ACHRs		
Option 3.2.6 Forced Draft Cooling Units	**Lough Ree Power (LRP)**	
Total	**Assumed to be same as Vendor costs from Option 3.2.5 ACHRs**	**€10,082,966**

Table 9: Forced Draft Unit Costs from Vendors

1.9. Cost Totals for Option 5: Forced Draft

Vendors were presented an Indicative Scope Document by ESBI. Vendors provided Indicative cost, for extra work required, for Forced Draft Cooling, but not equipment. As stated above in 5.4 it was assumed that the costs for Forced Draft Cooling (see Table 7 below) are equivalent to ACHRs due to equipment configurations.

Totals Option 3.2.6 Forced Draft Units	**Lough Ree Power (LRP)**	
Vendor Equipment Prices	**Assumed to be same as Cost Totals from Option 5 ACHRs**	**€10,082,966**
Pricing for Moving Power Lines		**€1,000,000**
Pricing for extra Civil Works with 15% Contingency		**€1,194,850**
Enabling Works	**Contractors Village and utilities**	**€250,000**
Total		**€12,527,816**

Table 10: Sum of Individual Cost Items for Forced Draft Installation

1.10.Option 6: Replace with Air Cooled Condensers

On consideration of a current ESB Project (Pilkington EfW Project) (see Table 11 and Table 12 below) ESBI has broken out ACC costs for the 29MW plant (No demolition of existing condensers is included in this costing exercise).

Condensate Cooling Costs in £ for 29MW		
£4,410,000		
to € at 1.143 =	**€6,306,300**	
Condensate Cooling Costs in £ for 100MW		
£15,206,897		
to € at 1.143 =	**€21,745,862**	
Condensate Cooling Costs in £ for 150MW		
£22,810,345		
to € at 1.143 =	**€32,618,793**	

Table 11: ACC Costs Derived from Pilkington Data

Option 3.2.7 Installation of ACC Units	**Lough Ree Power (LRP)**	
Temperature drop from Saturated Steam Conditions to Outflow temperatures	**Reference 29MWe Pilkington Project**	**€21,745,862**

Table 12: ACC Costs for LRP

1.11.Option 7: Construction of Cooling Ponds

ESBI's Civil Department has calculated a cost estimate for construction of cooling ponds. This cost estimate was combined with piping costs and a 15% contingency (see Table 13 below).

Option 3.2.9 Cooling Ponds	**Lough Ree Power (LRP)**	
Pond Construction	**Reference: ESBI Civil. Department 25/10/17**	**€5,778,750**
Underground Piping: 2 m wide x 3 m deep excavation and CI.804 backfill (exclude pipe)	**2 No. x 500m long**	**€249,573**
Sub Total		**€6,028,323**
15% Contingency		**€904,248**
Pumping Equipment and Land Contingency		**€4,500,000**
Glass Reinforced Pipe approximately €345/m	**2 No x 500m and 1.4 m OD**	**€345,000**
Total + Contingency		**€7,277,571**

Table 13: Cooling Pond Construction Costs

At present ESB owns 6.4 Hectares of available land at LRP but needs 40 Hectares for ponds.

ESBI's Civil Department requested a 15% contingency be added to the pricing.

1.12.Option 8: Cooling Ponds with Spray

ESBI's Civil Department has calculated a cost estimate for construction of cooling ponds. This option has an addition of spray nozzles and pumping to induce atomization spraying to induce additional cooling.

Using a nominal ratio of the sizes of the existing land currently owned at both plants and applied to the costs of construction already estimated by ESBI Civil Engineering for Option 8 the following ratio was applied to the cost estimate of Option 7: 6.4Ha/40Ha. This ratio has provided a cost of construction for Option 8 but this calculation does not provide pricing for the spray systems or the unknown quantity of land that may be required. This cost estimate was combined with piping costs and a 15% contingency (see Table 14 below).

Option 3.2.10 Cooling Ponds with Spray	**Lough Ree Power (LRP)**	
Pond Construction	**Reference: ESBI Civil. Department 25/10/17**	**€924,600**
Underground Piping: 2 m wide x 3 m deep excavation and Cl.804 backfill (exclude pipe)	**2 No. x 500m long**	**€249,573**
Sub Total		**€1,174,173**
15% Contingency		**€176,126**
Pumping Equipment and Land Contingency		**€3,500,000**
Glass Reinforced Pipe approximately €345/m	**2 No x 500m and 1.4m OD**	**€345,000**
Total + Contingency		**€6,369,472**

Table 14: Estimated costs of Small Cooling Ponds Assisted by Spray Atomization of River Water

1.13. Option 9: Install Second Pass Cooling Loop in the CW System

ESB have looked at this process and have determined that it would not provide financial savings (see Table 15 below) with respect to other options given as the design would be a combination of the ACHRs and the ACCs plus extra demolition and the thermal abatement would be the same as it is at present.

Option 3.2.11 Installation of a Second Pass to the CW System	**Lough Ree Power (LRP)**	
Vendor Equipment Prices	**Reference 29MWe Pilkington Project**	**€ 21,745,862**

Table 15: Installation of a Second Pass in the CW System

This cost is in the tens of millions and wouldn’t provide any improvement in the thermal outflow temperatures. Additionally this would require a major rebuild and redesign of the existing condenser system the risks and costs imposed by the demolition and rebuild of the condensers would be very high.

Appendix 4: Evaluation of Proposed CW System Changes

1. Evaluation of Proposed CW System Changes

1.1. Review and Evaluation

Option 1: Extract 4m^3/s Additional Cooling Water

- Extracting an additional 4m^3/s of cooling water from the Shannon adjacent to the cooling water intake and discharging it to the cooling water outfall location was examined. During the 95%ile flow conditions when the river flow is at 11m^3/s (low river summer conditions and high temperatures) the extraction of an additional 4m^3/s of river water to mix with the existing cooling water extraction and discharge of 4m^3/s would result in a residual flow of 3m^3/s in the river.
- Modelling indicated that the thermal plume footprint would be altered. It would no longer be confined to the left bank of the river in the discharge channel but would quickly impact across the entire river section due to the increased hydraulic load forcing it to the now low flow (3m^3/s) side. The temperature level of the cooling water outfall would decrease but would not be below 1.5℃ above ambient and significantly more than 25% of the cross sectional area of the entire river section would be impacted.
- The changes associated with the river main channel at Lanesborough and the navigation right of ways have to be approved by the competent local authority through the appropriate planning process.
- There would be no benefit derived from implementing this option this approach would have operational problems river flow impact and would disrupt the 25% cross sectional area called for in EPA Clause 5.5 thus the option was deemed unfeasible.

Option 2: Attemperate the Cooling Water outfall at LRP by additional cooling water abstraction from Lough Ree

- Extract an additional 4m^3/s of lake water from Lough Ree and discharge it to the cooling water outfall to reduce the outfall thermal load. Modelling of the potential impact of this scenario indicated that the thermal plume footprint would again be altered. It would no longer be confined to the left bank of the river in the discharge channel but would impact across the entire river section due to the increased hydraulic load forcing it to the main channel side. The temperature level of the cooling water outfall would again decrease but would not be below 1.5℃ above ambient and more than 25% of the cross sectional area of the entire river section would still be impacted.
- There would also be significant engineering costs required to make this option operational.

Option 3: Option to increase natural flow into the cooling water discharge channel

- There would be no change to the 95%ile overall river flow of 11m^3/s but more river water would flow through the discharge channel on the left bank.
- Modelling of the potential impact was undertaken, creating a channel in the reed bed upstream of the outfall results in a portion of the thermal plume flowing northwards and under certain wind conditions resulting in warmer discharged cooling water reaching the cooling water intake. Under 95 percentile flow conditions the thermal plume would continue to occupy all of the cross section of the river at Lanesborough at a temperature more than 1.5℃ above ambient.

Option 4: Option to extend the cooling water into Lough Ree

- To extend cooling water outfall down to Lough Ree would require dispersing cooling water through a diffuser system in the lake cooling water discharge pipe, additional pumping requirement and a diffuser embedded in the lake bed.
- This option would require significant study and design to identify the optimum location for thermal load discharge and dispersion and would require long term environmental surveys to determine the potential impact on the ecology of Lough Ree. There are significant unknown potential impact factors which could render the option non viable.
- The proposal would require the consent of the relevant competent planning and environmental authorities.
- This option would also entail significant capital investment requirement.
- Given the high degree of uncertainty that this option would be acceptable environmentally or from a planning aspect and that it would entail very high cost it was deemed unfeasible.

Option 5: Air Cooled Heat Rejection (ACHR) units, heat exchangers which are closed dry systems.

- The cost of this is in the tens of millions of Euros. This design has a sizeable design flaw as it won’t work under the very conditions that it would be required to work, due to the “Approach to Dew Point” issues.
- There are many other risks associated with this installation.

Option 6: Forced Draft Cooling Towers

- This option directly employs Shannon River water and can produce Legionnaire's disease, thus the water flowing through has to be inoculated to prevent the disease. Vendors haven’t confirmed that this can be done safely.
- The cost of this is in the tens of millions of Euros.
- There are many other risks associated with this installation.

Option 7: Replace existing Condensers with Air Cooled Condensers (ACC)

- In order to undertake this option the condensers will have to be replaced.
- This solution is in the tens of millions, more than each of the other available options and it requires demolition of the existing condenser system which poses many risks.
- There are many other risks associated with this installation.

Option 8: Cooling Ponds

- In order to undertake this option the method requires more land than is currently available to ESB.
- ESB needs to secure more land, if this land can be acquired reasonably.
- The concept of a cooling pond has a major drawback due to evaporation. The cooling ponds could theoretically vaporize the full flow of the CW system.
- There are many other risks associated with this installation.

Option 9: Spray outflow water into the air while flowing the water through cooling ponds

- In order to undertake this option the method requires more land than is currently available.
- The concept of a cooling pond has a major drawback due to evaporation. The cooling ponds could theoretically vaporize the full flow of the CW system. The spray cooling ponds will lose more water than a standard cooling pond.
- ESB may need to secure more land, if this land can be acquired reasonably.
- There are many other risks associated with this installation.

Option 10: Install second pass cooling loop in the CW system

- The concept of a second pass cooling loop wouldn't provide financial savings with respect to other options given nor any better thermal abatement.
- During summer conditions it's likely there wouldn't be enough water flowing in the Shannon River to keep a second loop operational when needed.
- There are many other risks associated with this installation.

Option 11: District Heating

- This option would require a water tap off from the CW to communal pipes that provide low level heat for homes and businesses. Due to the size of the community, minimal industry in the community and lack of installed district heating network it was determined that any such scheme would not be feasible.
- The thermal load reduction would also be unlikely to be achieved as the level of utilisation would not be sufficient to reduce the thermal load in the cooling water discharge.

Option 12: Alternative Heat Uses

- Two projects, one in the form of heated greenhouses for horticultural purposes and one for peat drying used the CW Outfall water. Usage of the excess heat for both horticultural purposes and peat drying was very small and both projects were discontinued. This option was therefore deemed to be unfeasible.