

## 09 - MASS BALANCE ASSIMILATIVE CAPACITY MODEL OF INNISCARRA RESERVOIR

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### Abstract

Wastewater arising from the Coachford agglomeration is treated at the existing Coachford Waste Water Treatment Plant (WWTP). This wastewater treatment facility has a primary treatment only with a design capacity of 450 population equivalent (PE) and it discharges the effluent into the Inniscarra Reservoir. The discharge from Coachford WWTP has been identified by the Lower Lee - Owenboy Water Management Unit Action Plan (WMUAP) as a point source pressure on the waters of the Lower Lee - Owenboy catchment and also as a cause of the strongly eutrophic status of Inniscarra Reservoir water quality by the EPA in 2009. Therefore, new emission limit values (ELVs) for the main water quality parameters in the effluent from Coachford WWTP have been proposed by the EPA to ensure compliance with the relevant water quality standards downstream of effluent discharging point. For lakes, the most important water parameters are phosphorus and nitrogen and the relevant environmental quality standards define permissible concentrations for total phosphorus and total ammonia as 0.025 mg/l and 0.14 mg/l respectively.

The new ELVs will be implemented by the end of 2018 after the construction of a new WWTP in Coachford. The impact of the new ELVs on water quality of receiving water has been examined by a previous assimilative capacity model developed by NUI Galway. This model used effluent discharge loading reflecting the current number of population in Coachford. However, an increase in the PE of the agglomeration is expected in the future and there is a need to predict the impact of the increased effluent loading from Coachford WWTP on the receiving water. An analogous assimilative capacity model to the NUI Galway (NUIG) model has been developed in this study based on simple mass balance computation. The newly developed model was used to predict concentrations of main water quality parameters downstream of effluent discharging point due to: (1) increased effluent discharge loadings representing the projected increase in number of population in Coachford agglomeration while maintaining the proposed ELVs; (2) a range of ELVs to test the effect of increasing the emission limit values on the water quality of the downstream reach of the lake.

The calibrated MBAC model was then used to estimate the concentration ( $C_{out}$ ) of TP and TAmmonia at the complete mixing zone downstream of the discharge point of Coachford under: (i) a range of  $Q_{eff}$  scenarios representing the projected increase in number of population in Coachford agglomeration; and (ii) a range of ELVs to test the effect of increasing the emission limit values on the water quality of the downstream reach of the lake.

The MBAC model predictions indicate that the concentrations of TP in the downstream complete mixing zone are unlikely to exceed the standard value of 0.025 mg/l under the

proposed ELV of 1.2 mg/l and also under a higher value of 2.0 mg/l for TP. However, if the ELV is increased to 5 or 10 mg/l the concentrations of TP in the downstream complete mixing zone is likely to exceed the standard value of 0.025 mg/l under low flow conditions. The MBAC model predictions for TAmmonia indicate that under the tested ELVs (5, 6.5, 10, and 15 mg/l), the concentrations of TAmmonia in the downstream complete mixing zone is unlikely to exceed the standard value of 0.14 mg/l.

## 1. INTRODUCTION

Wastewater arising from the Coachford agglomeration is treated at the existing Coachford Waste Water Treatment Plant (WWTP) (see Figure 1). This wastewater treatment facility has a primary treatment only with a design capacity of 450 population equivalent (PE) and it discharges the effluent into the Inniscarra Reservoir. The discharge from Coachford WWTP has been identified by the Lower Lee - Owenboy Water Management Unit Action Plan (WMUAP) as a point source pressure on the waters of the Lower Lee - Owenboy catchment (WFD Ireland, 2017) and also as a cause of the strongly eutrophic status of Inniscarra Reservoir water quality by the EPA in 2009. Therefore, a new emission limit values (ELVs) for the main water quality parameters in the effluent from Coachford WWTP have been proposed by the EPA to ensure compliance with the relevant water quality standards downstream of effluent discharging point. The European Communities Environmental Objectives (Surface Water) Regulations, 2009 set environmental quality objectives for lakes for ammonia but not for phosphorus or Biochemical Oxygen Demand (BOD). BOD is not a physicochemical parameter used to measure lake quality. Total phosphorus is an important measure of lake trophic status and is included as part of the Agency's lakes monitoring programme. In the absence of statutory standards for total phosphorus, interim environmental quality standards of 0.010 mg/l and 0.025 mg/l for high/good and good/moderate boundaries have been adopted by Office of Environmental Assessment (OEA). For lakes the most important water parameters are phosphorus and nitrogen and the relevant standards define permissible concentrations for total phosphorus and total ammonia as 0.025 mg/l and 0.14 mg/l respectively (EPA, 2015).

The new ELVs will be implemented by the end of 2018 after the construction of a new WWTP at Coachford. The impact of the new ELVs on water quality of receiving water has been examined by assimilative capacity model developed by NUI Galway. This model used effluent discharge loading reflecting the current number of population in Coachford. However, an increase in the population is expected in the future and there is a need to predict the impact of the increased effluent loading from Coachford WWTP on the receiving water. An analogous assimilative capacity model to the NUI Galway (NUIG) model has been developed in this study based on simple mass balance computation. The newly developed model was used to predict concentrations of main water quality parameters downstream of effluent discharging point due to: (1) increased effluent discharge loadings with the proposed ELVs; (2) a range of ELVs. Before presenting the results of the model, characterisation of flow regimes and water quality status in Inniscarra Reservoir are discussed.



**Figure 1:** Coachford WWTP, ESB hydrometric stations (Carrigadrohid and Inniscarra Dams) and Cork Coco WQ sampling points (LS190022800800010, LS190022800800020, LS190022800800030, LS190022800800040)

## 2. CHARACTERISATION OF FLOW REGIMES AND WATER QUALITY IN INNISCARRA RESERVOIR

Flow data was provided by the ESB for two locations in the Inniscarra Lake (Figure 1). The first location is at Carrigadrohid dam while the second location is at Inniscarra dam. On the other hand water quality data are obtained from Cork County Council (Cork Coco) for 16 water quality parameters at Carrigadrohid dam and at other four points along the Inniscarra Reservoir (Figure 1).

### 2.1 Flow data - Carrigadrohid and Inniscarra Dams

Hourly time series of estimated flow at Carrigadrohid and Inniscarra dams were provided by the ESB for a 10 year period (01/01/2007 – 01/01/2017). These flow estimates are based on water level staff gauges which form part of the ESB hydrometric network. An assessment of the data indicated that 63% of the recorded flow data at Carrigadrohid dam fell below  $10 \text{ m}^3/\text{s}$ . Similarly, the flow data at Inniscarra dam had 60% of its data falling below  $10 \text{ m}^3/\text{s}$ . Therefore, a frequency distribution re-analysis was carried out this time with excluding flow records below  $10 \text{ m}^3/\text{s}$  in order to characterise other flow regimes. The frequency distribution of flow at Carrigadrohid and Inniscarra dams are shown below in Figures 2 and 3 respectively. The most frequent flow ranges at Carrigadrohid are  $70\text{-}80 \text{ m}^3/\text{s}$  at 52% and  $60\text{-}70 \text{ m}^3/\text{s}$  at 19.5%. At Inniscarra Dam the most frequent flow ranges are  $80\text{-}90 \text{ m}^3/\text{s}$  at 32% and  $70\text{-}80 \text{ m}^3/\text{s}$  at 20%.

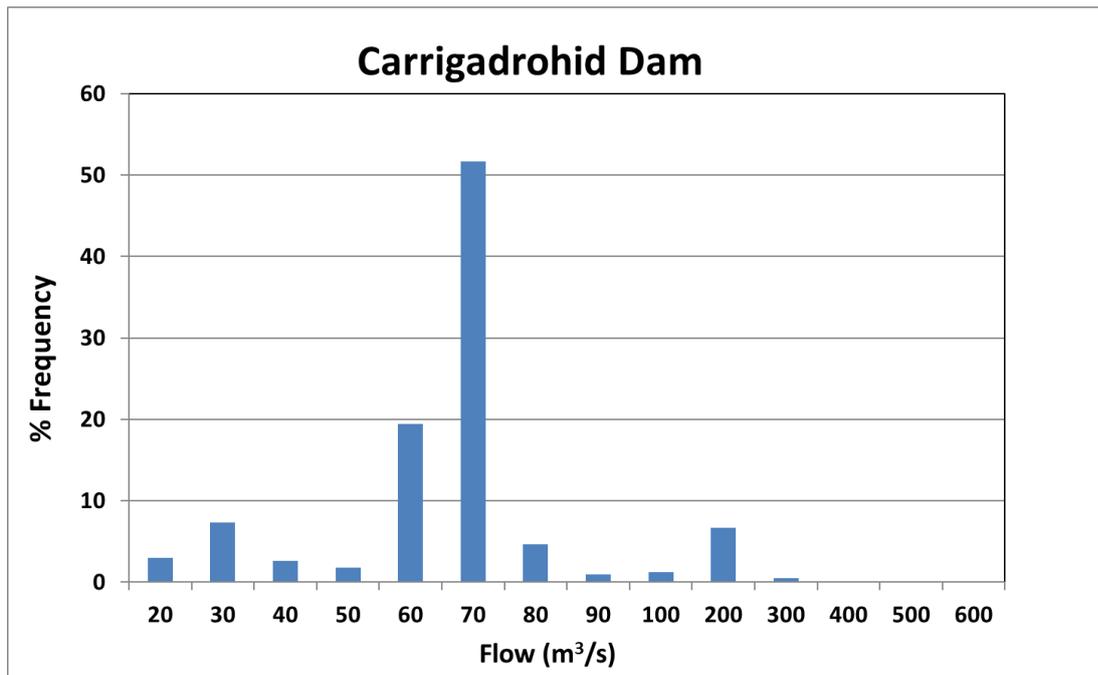


Figure 2.: Frequency distribution of flow data at Carrigadrohid Dam

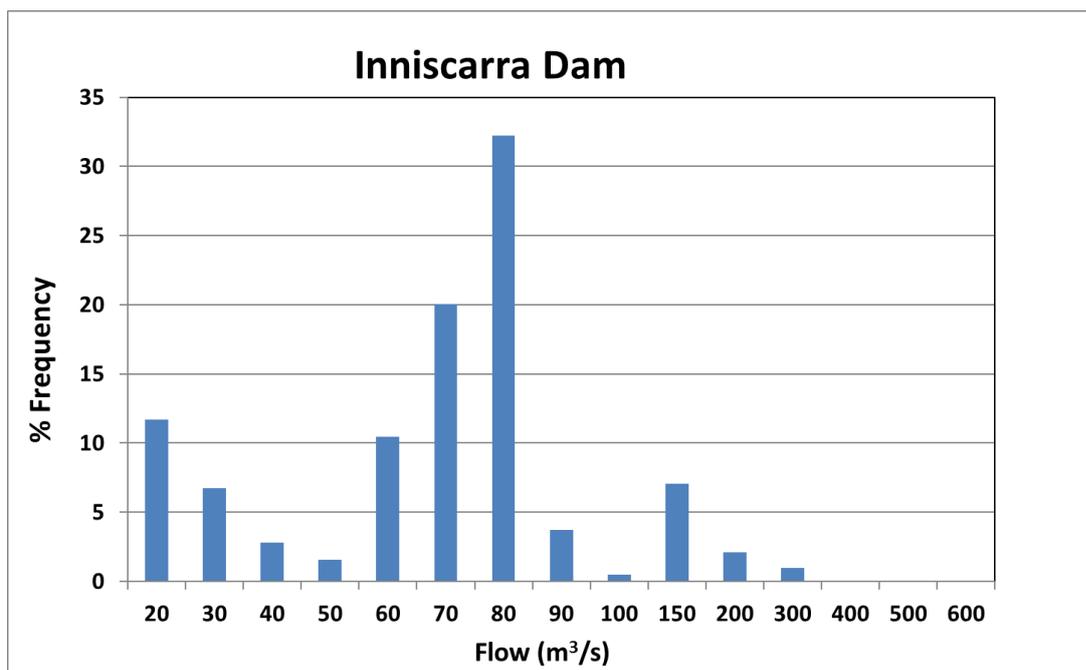


Figure 3.: Frequency distribution of flow data at Inniscarra Dam

### 2.2 Water quality data - Carrigadrohid and Inniscarra Reservoir

Total phosphorus (TP) and Total Ammonia (TAmmonia) data at Carrigadrohid dam constituted of 16 samples taken on 4 days in 2015 (21<sup>st</sup> April, 23<sup>rd</sup> July, 25<sup>th</sup> August, and 20<sup>th</sup> October). Average concentrations of four samples of the two water quality parameters in each day are shown in Table 1. It is obvious that at Carrigadrohid dam, which is located upstream of the

Coachford WWTP discharging point, the TP and the TAMmonia concentrations are below the permissible concentrations for the two parameters indicating full compliance with the standards.

Table1. TP and TAMmonia at Carrigadrohid

Date	TP	TAMmonia
21-Apr-2015	0.018	0.012
23-July-2015	0.023	0.009
25-Aug-2015	0.022	0.035
20-Oct-2015	0.017	0.033

At each of the four points along Inniscarra lake water quality data is available for 36 days between 24<sup>th</sup> Jan 2013 and 15<sup>th</sup> Dec 2015. The TP and TAMmonia concentrations are plotted in Figures 4 and 5 respectively. The graphs show clearly there are a number of samples where the permissible concentrations for both parameters were exceeded indicating to failure in meeting the standards. 45 samples (30%) have exceeded the TP standard concentration of 0.025 mg/l while only two samples exceeded the 0.14 mg/l limit for TAMmonia.

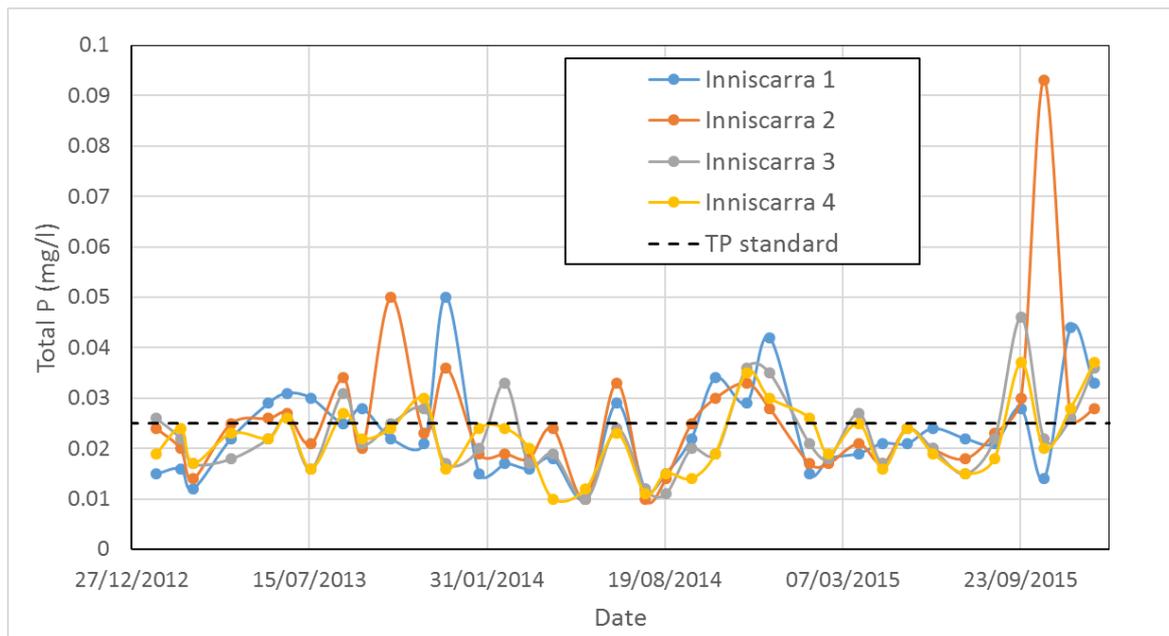
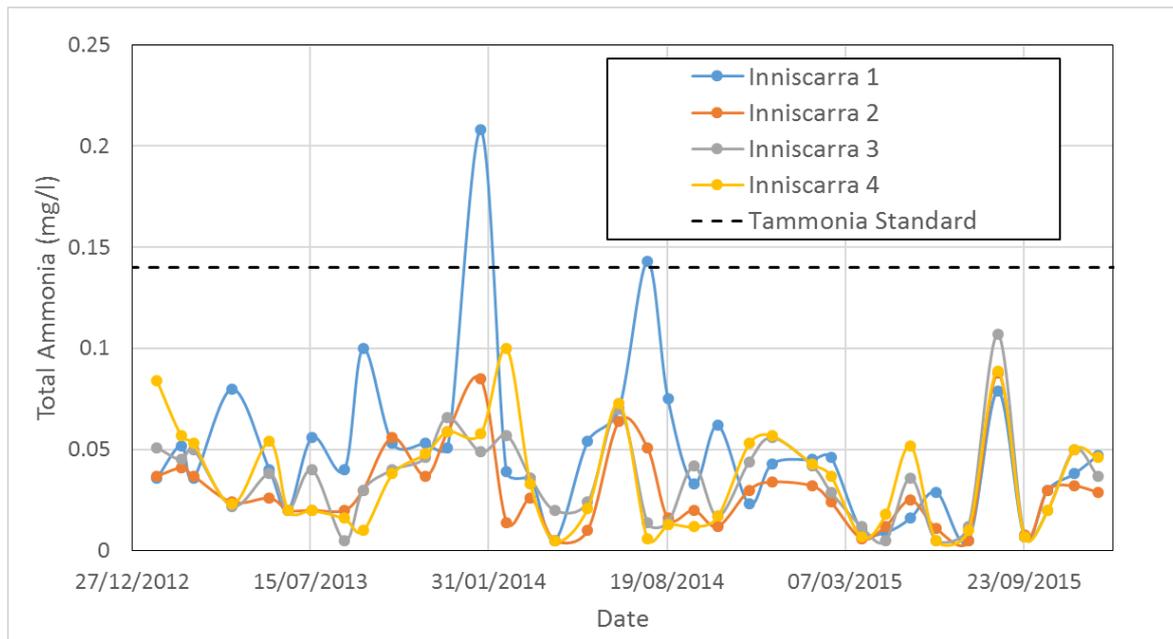


Figure 4: Total Phosphorus at Inniscarra lake



**Figure 5:** Total Ammonia at Inniscarra lake

### 3. ASSILITATIVE CAPACITY – SIMPLE MASS BALANCE MODEL

The assimilative capacity of the lake was computed using the simple form of the Continuously Stirred Tank Reactor (CSTR) mass balance model. The main assumptions behind developing this model are:

- (i) Well-mixed conditions in the lake and hence density variations (e.g. due to thermal discharges) are ignored;
- (ii) Steady flow conditions dominate;
- (iii) The water quality parameters are conservative and hence processes such as decay, adsorption, and resuspension are ignored.

Structure of the CSTR mass-balance model is illustrated in Figure 6 below and its main equations are as follows:

$$Q_{out} * C_{out} = Q_{in} * C_{in} + Q_{eff} * C_{eff}$$

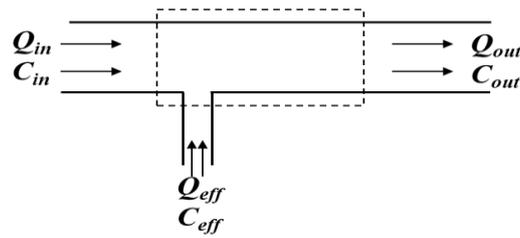
$$Q_{out} = Q_{in} + Q_{eff}$$

Where:

$Q_{out}$  ( $m^3/s$ ) and  $C_{out}$  (mg/l) are the discharge and the concentration of pollutant in the complete mixing zone downstream of effluent discharge location;

$Q_{in}$  ( $m^3/s$ ) and  $C_{in}$  (mg/l) are the discharge and the background concentration of pollutant upstream of the discharge location (initial pollutant levels);

$Q_{eff}$  ( $m^3/s$ ) and  $C_{eff}$  (mg/l) are the effluent discharge and the concentration.



**Figure 6:** Continuously Stirred Tank Reactor (CSTR) mass balance model

## 4. MODEL APPLICATION

### 4.1 Model Calibration

As previously mentioned the aim of developing the mass balance assimilative capacity (MBAC) model in this study is to produce a model which is capable of producing results similar to those obtained from the previous Inniscarra reservoir model (NUIG model). There are four input variables in the MBAC model which are  $Q_{in}$ ,  $C_{in}$ ,  $Q_{eff}$ , and  $C_{eff}$ . The model uses these input variables to calculate two output variables;  $Q_{out}$  and  $C_{out}$ . Values defined for  $Q_{in}$ ,  $Q_{eff}$ , and  $C_{eff}$  in the NUIG model, and given in Table 2 below, were also used as inputs to the MBAC model. The value of  $C_{in}$  has been calibrated to produce results for  $C_{out}$  similar to the ones produced by the NUIG model (see Table 2 below).

**Table 2:** Inputs & outputs of the previous NUIG model and current MBAC model results

Model variable	Value	Source
$Q_{in}$	35 m <sup>3</sup> /s	Inspectors report on a waste water discharge licence application (Application for a Waste Water Discharge Licence from Irish Water, for the agglomeration named Coachford)
$Q_{eff}$	176 m <sup>3</sup> /day	Current effluent discharge from Coachford – Inspectors report on a waste water discharge licence application (Application for a Waste Water Discharge Licence from Irish Water, for the agglomeration named Coachford)
$C_{eff}$	1.2 mg/l TP 6.5 mg/l TAmmonia	ELVs for TP and TAmmonia Inspectors report on a waste water discharge licence application (Application for a Waste Water Discharge Licence from Irish Water, for the agglomeration named Coachford)
$C_{out}$	0.022 TP 0.12 TAmmonia	NUIG model
$C_{in}$	0.0219 TP 0.1196 TAmmonia	MBAC model

### 4.2 Model Prediction

The calibrated MBAC model was then used to estimate the concentration ( $C_{out}$ ) of TP and TAmmonia at the complete mixing zone downstream of the discharge point of Coachford under: (i) a range of  $Q_{eff}$  scenarios representing the projected increase in number of population

in Coachford agglomeration (See Table 3 below); and (ii) a range of ELVs to test the effect of increasing the emission limit values on the water quality of the downstream reach of the lake. Table 3 below shows the current and projected population growth over the next 10 and 30 years in the catchment area served by Coachford WWTP. The corresponding wastewater flow is estimated based on a per capita consumption of 225 l/day (as reported by Irish Waters).

**Table 3: Current and predicted effluent discharges from the Coachford agglomeration**

Scenario	Flow (m <sup>3</sup> /day)	Source
Current population	178	Inspectors report on a waste water discharge licence application (Application for a Waste Water Discharge Licence from Irish Water, for the agglomeration named Coachford)
10 year design horizon	315	Nicholas O'Dwyer – 1400 PE
30 year design horizon	360	Nicholas O'Dwyer – 1600 PE
Maximum discharge	538	Inspectors report on a waste water discharge licence application (Application for a Waste Water Discharge Licence from Irish Water, for the agglomeration named Coachford)

The background concentrations of TP and TAmmonia were obtained from the calibrated MBAC model (0.0219 and 0.12 mg/l respectively). For the purpose of the scenario testing, a range of inflow values ( $Q_{in}$ ) were considered due to their direct effect on the assimilative capacity of the lake. Representative values of the various flow regimes at Carrigrohid Dam (see Figure 3) were selected. These values are 5, 25, 35, 65, and 75 m<sup>3</sup>/sec.

The results of MBAC model predictions of TP and TAmmonia are displayed in Figures 7 and 8 respectively. The figures also show the maximum allowed downstream concentrations for TP and TAmmonia (0.025 and 0.14 mg/l respectively) as set out by the Office of Environmental Assessment for TP and the European Communities Environmental Objectives (Surface Waters) Regulations 2009 for TAmmonia.

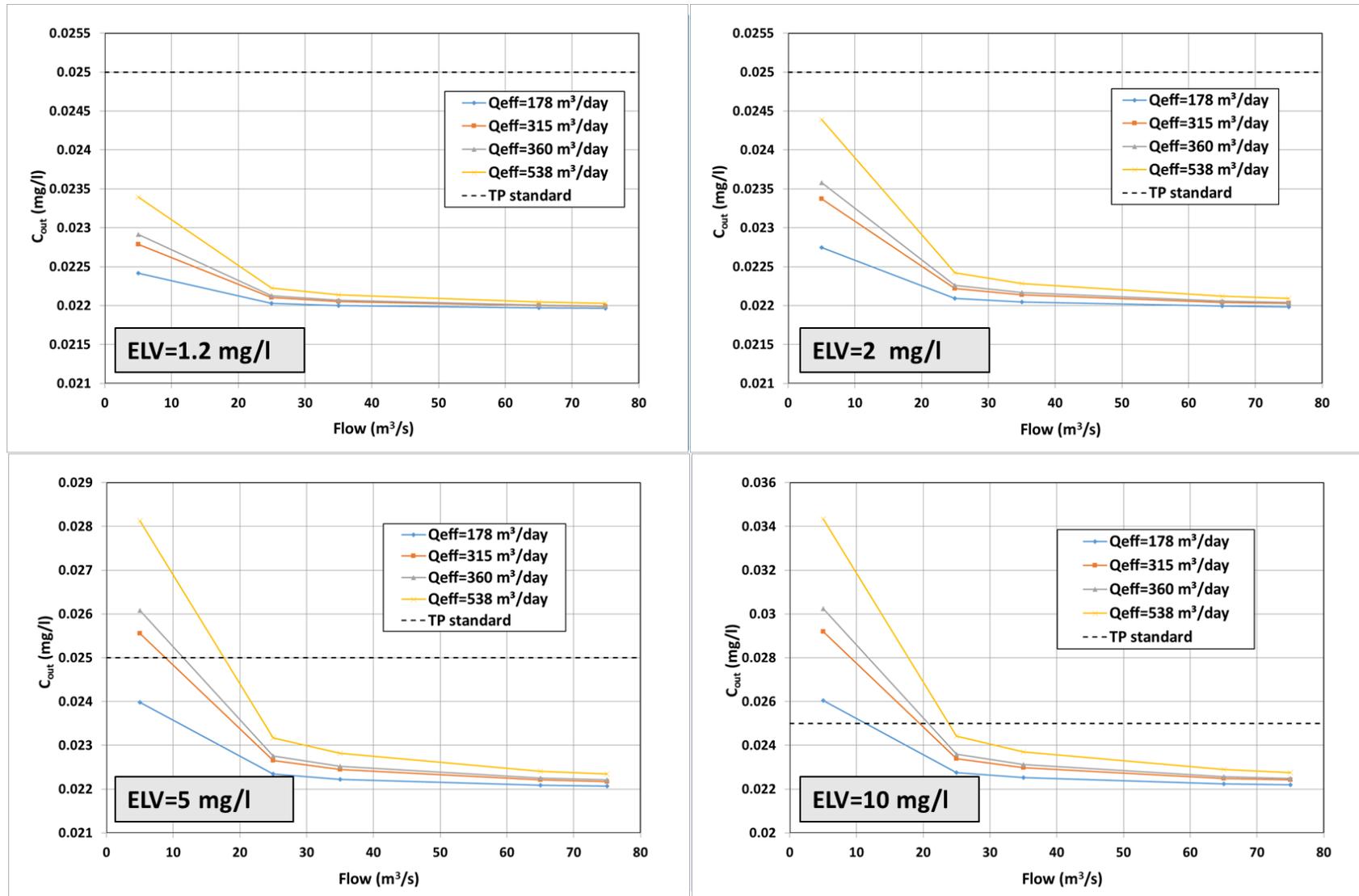


Figure 7: Downstream TP concentrations ( $C_{out}$ ) under various Effluent discharge conditions ( $Q_{eff}$  and ELV)

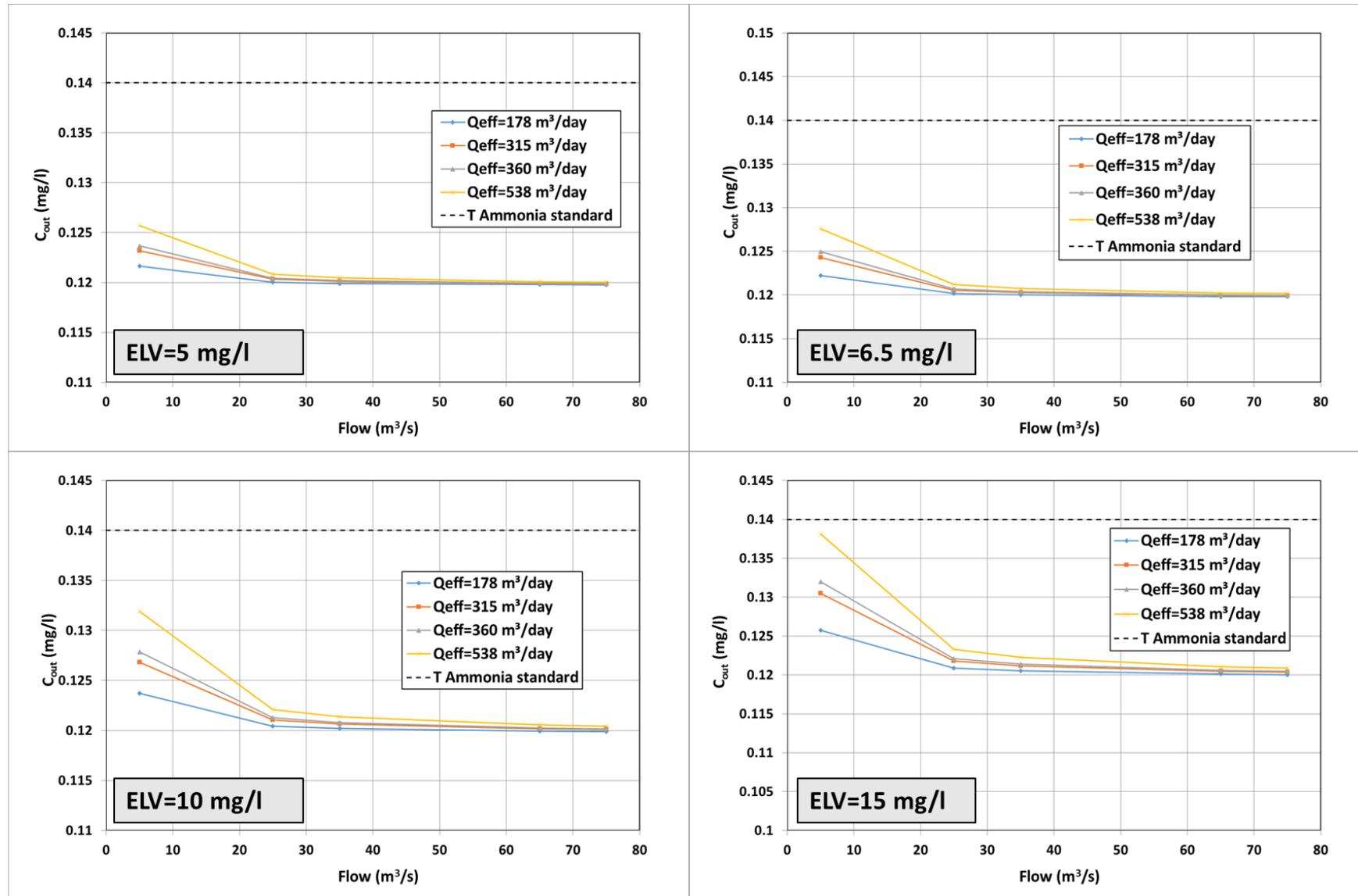


Figure 8: Downstream TAmmonia concentrations ( $C_{out}$ ) under various Effluent discharge conditions ( $Q_{eff}$  and ELV)

## 5. RESULTS AND DISCUSSION

The results in Figures 7 and 8 show that for a constant effluent loading, the concentration in the complete mixing zone decreases with the increase of inflow ( $Q_{in}$ ). Also, the figures clearly demonstrate that increasing the effluent discharge ( $Q_{eff}$ ) yields a consistent increase in the TP and TAmmonia concentrations downstream of the discharging point.

The MBAC model predictions (Figure 7) indicate that under the proposed ELV of 1.2 mg/l for TP, the concentrations of TP in the downstream complete mixing zone is unlikely to exceed the standard value of 0.025 mg/l. This may also be the case if the ELV is increased to 2 mg/l. On the other hand, the model predictions show that the adoption of higher ELVs of 5 and 10 mg/l might not significantly increase the downstream concentrations of TP under high flow conditions (when compared to ELVs of 1.2 and 2 mg/l) but would likely to result in the exceedance of TP standards under low flow conditions in the lake ( $< 20 \text{ m}^3/\text{sec}$ ).

The MBAC model predictions for TAmmonia (Figure 8) indicate that under the tested ELVs (5, 6.5, 10, and 15 mg/l), the concentrations of TAmmonia in the downstream complete mixing zone is unlikely to exceed the standard value of 0.14 mg/l.

## 6. CONCLUSION

The purpose of this study is to develop a mass balance assimilative capacity (MBAC) model to predict concentrations of main water quality parameters downstream of effluent discharging point due to: (1) increased effluent discharge loadings with the proposed ELVs; (2) a range of ELVs.

The MBAC model predictions indicate that the concentrations of TP in the downstream complete mixing zone are unlikely to exceed the standard value of 0.025 mg/l under the proposed ELV of 1.2 mg/l and also under a higher value of 2.0 mg/l for TP. However, if the ELV is increased to 5 or 10 mg/l the concentrations of TP in the downstream complete mixing zone is likely to exceed the standard value of 0.025 mg/l under low flow conditions.

The MBAC model predictions for TAmmonia indicate that under the tested ELVs (5, 6.5, 10, and 15 mg/l), the concentrations of TAmmonia in the downstream complete mixing zone is unlikely to exceed the standard value of 0.14 mg/l.

## ACKNOWLEDGEMENT

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