Assessment of Future Water Quality Conditions in the Grand and Speed Rivers

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January 2012

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The Assimilative Capacity Working Group for the Grand River Water Management Plan recently completed an analysis of future river water quality conditions using a 20 year planning horizon (2031). A number of water management scenarios were developed which incorporated wastewater treatment plant upgrades in current municipal wastewater master plans, wastewater treatment plant optimized performance targets and rural / agricultural and urban non-point source load reductions. This is a key deliverable set out in the Steering Committee's Project Charter for the Grand River Water Management Plan.

The Grand River Simulation Model, a dynamic nutrient and dissolved oxygen model developed for the Grand River by the Ministry of the Environment, maintained and upgraded by Grand River Conservation Authority, and most recently used for the Kitchener Wastewater Treatment Plant Assimilative Capacity Study was used to evaluate four wastewater management scenarios. The working group noted, in particular, the importance of the Grand River Simulation Model and the availability of continuous water quality monitoring data to their ability to evaluate and project the cumulative effects of point and non-point source management approaches for the Grand and Speed Rivers for the purposes of strategic planning.

The model study area extends from Shand Dam on the Grand River and Guelph Dam on the Speed River downstream to the Six Nations intake. The model includes discharges from 10 of the 30 wastewater treatment plants in the watershed. The 10 modeled wastewater discharges serve approximately 92% of the watershed's serviced population. Most of the twenty smaller wastewater treatment plants discharge into tributaries such as the Conestogo, Canagagigue and Nith Rivers and are included implicitly in the Grand River Simulation Model as part of model boundary inputs. However, population projections or optimization at these smaller plants were not incorporated into model inputs for this planning exercise.

The Working Group investigated the following scenarios during spring-high flow, summer-low flow, and winter-low flow conditions:

- Current Conditions – 2010 existing effluent concentration and flows
- Future (2031) population growth and anticipated wastewater treatment plant upgrades as outlined in wastewater master plans;
- Future population growth, anticipated wastewater treatment plant upgrades and optimized performance to achieve phosphorus operational targets; and
- Reductions to model boundary conditions which reflect a reduction in both Urban and Rural non-point sources.

Additional scenarios were run on the sensitivity of the model to changes in river flows and river temperatures.

Key findings from the model scenarios are as follows:

- Within the 2031 planning horizon, planned wastewater treatment plant upgrades will significantly improve river water quality especially during the low flow summer period relative to current conditions, specifically:

  - dissolved oxygen levels in the summer are predicted to improve in heavily impacted reaches of the Grand and Speed Rivers. The improvements will be reflected in reduced severity and frequency of low dissolved oxygen events. The greatest improvement will occur in the Grand River at Blair;

  - total phosphorus levels in the summer are predicted to decrease, on average, by 8% with some reaches realizing a reduction of up to 25% (0.026 mg/L lower than current conditions) however, levels of total phosphorus will still be above the interim Provincial Water Quality Objective of 0.03 mg/L due to the nature of the Grand River Watershed;

  - un-ionized ammonia levels in the summer are predicted to decrease by 97% in the most impacted river reach. Reaches on the Grand and Speed Rivers that currently experience high un-ionized ammonia concentrations are expected to meet the Provincial Water Quality Objective in future.

- Implementation of process optimization of wastewater treatment plants to achieve lower total phosphorus operating targets is predicted to achieve additional significant improvements in total phosphorus levels in the Grand River of up to 19%.

- Model predictions suggest that reducing total phosphorus delivery from rural / agricultural watersheds (e.g. Conestogo, Canagagigue and Nith) by 25% results in a reduction of phosphorus levels in the Grand River during the spring by an average of 20% and as much as 23%. It is important to note that approaches to achieve a 25% reduction in rural runoff are outside the scope of this study. Considerations should be made to determine which best management practices will yield the greatest results and draw upon the Grand River Simulation Model to predict which land management scenarios will best improve water quality. These questions will be investigated by the Water Quality Working Group as part of the current work plan.

- During cold, low-flow winter conditions, background nitrate levels in the Grand River between the Shand Dam and Bridgeport, above the Region of Waterloo, increase considerably (i.e. by an estimated 3.4 mg/L). The source of these elevated nitrate levels is not known but it is hypothesized that one source may be shallow groundwater.

- Nitrate levels in the Grand River will also increase as a result of planned wastewater treatment plant upgrades, e.g. nitrification at the Waterloo and Kitchener Wastewater Treatment Plants; however, the magnitude of increase resulting from wastewater treatment plant upgrades is small (approximately 1.1 mg/L increase) relative to background levels from cumulative upstream sources. Nitrate levels in the Grand River are expected to remain elevated downstream toward Brantford, especially during the winter.

- Urban non-point source impacts on the Grand and Speed Rivers are not well quantified or characterized and their influence on the physiochemical/biological processes in the large rivers is poorly understood. The in-river mechanisms and processes associated with urban non-point sources (e.g. sediment delivery and deposition during high flows) are different than those associated with point source discharges (e.g. constant nutrient discharges during low flows). The impact of urban stormwater on the river likely requires a different monitoring/modelling approach than applying a dynamic dissolved oxygen model specific for low flow periods. While further work to characterize urban non-point source delivery has not been included in this study, it will be investigated further by the Storm Water Management Working Group as part of the current work plan.

Key points for water management planning include:

1. Significant improvements to water quality will result from the implementation of planned (or assumed as per model scenarios) wastewater treatment upgrades, in particular:
    - The Elora Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration
    - The Waterloo Wastewater Treatment Plant upgrade to include nitrification
    - The Kitchener Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration
    - The Hespeler Wastewater Treatment Plant upgrade to include nitrification
    - The Paris Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration. (note: it has been assumed that Paris will require nitrification and tertiary filtration upgrades but this has not been determined through a formal Environmental Assessment or Waste Assimilation Assessment process)
2. The adoption of wastewater treatment process optimization as a best practice by watershed municipalities is a win-win for river water quality and for municipalities, given its proven cost-effectiveness (e.g. Guelph, Haldimand experience). Wastewater treatment plant optimized operating targets for total phosphorus could be established as follows:
    - The Fergus and Galt Wastewater Treatment Plants are currently equipped with tertiary filtration and should aim for a monthly average total phosphorus concentration of 0.3 mg/L
    - The Elora, Kitchener, Hespeler and Paris Wastewater Treatment Plants will be upgraded to include tertiary filtration and should aim for a monthly average total phosphorus concentration of 0.3 mg/L once these upgrades have been completed. An interim target of 0.4 mg/L total phosphorus should be adopted by these wastewater treatment plants until tertiary filtration is implemented
    - The Guelph Wastewater Treatment Plant has established an optimized treatment objective of 0.15 mg/L total phosphorus
    - Secondary wastewater treatment plants such as Waterloo, Preston and Brantford should aim for a monthly average total phosphorus concentration of 0.4 mg/L
3. Continued work with rural and agricultural landowners to reduce concentrations of nutrients in rural runoff is important to maintain or improve water quality beyond what can be achieved with wastewater treatment upgrades and optimization and to build resilience in the Grand River system.

4. Of concern are the projected in-river nitrate concentrations during the winter and the implications to downstream drinking water intakes. Water quality monitoring during the winter will help to fully characterize this issue and studies will help to investigate the sources of nitrate to the central Grand River. Appropriate and cost effective source controls or mitigation can be applied once the sources are identified.
5. While population growth projections and changes in effluent quality due to upgrades or optimization at the 20 smaller wastewater treatment plants have not been incorporated into the model, each plant may have water quality impacts that need to be assessed within a local subwatershed context.
6. The Grand River Simulation Model is an effective decision support tool that enables watershed municipalities and partners to evaluate the cumulative effects of point and non-point source management approaches for the Grand and Speed Rivers for the purposes of strategic wastewater management planning.
7. Continuous monitoring data underpins the ability to measure progress over time and to calibrate/validate the Grand River Simulation Model to predict future conditions of water quality for wastewater management planning in the Grand River watershed.

To achieve the Water Management Plan goal to “improve water quality to maintain river health and to reduce the rivers’ impacts on the aquatic ecosystems in the eastern basin of Lake Erie” multiple approaches are needed over the next 20 years by all watershed partners to fully address current water quality issues in the Grand and Speed Rivers.

1. INTRODUCTION

The Grand River watershed covers approximately 6800 square kilometers and is home to a growing population of close to one million people. There are five major urban areas - Kitchener, Waterloo, Cambridge, Guelph and Brantford – as well as many towns and villages such as Grand Valley, Drayton, Arthur, Elora, Fergus, Elmira, Paris, St George, Caledonia, Cayuga and Dunnville. The watershed is also home to some of the most intensively farmed lands in the province.

The Grand River system is highly valued by watershed residents for its fishery, recreational, natural heritage, cultural amenities and agricultural uses. The people of the Grand River watershed depend on the river to serve several essential functions, including:

- the Grand and several of its tributaries receive treated effluent from 30 municipal wastewater treatment plants;
- the river system receives drainage and runoff from agricultural, rural and urban lands;
- it is a raw water source for drinking water supplies for municipal water systems serving about 600,000 people; and
- the watershed supports a diverse aquatic and riparian ecosystem.

Since the continued growth, prosperity and sustainability of the communities within the Grand River watershed depend on a healthy river system, a primary goal of the Grand River Water Management Plan is to improve water quality to maintain river health. The Assimilative Capacity Working Group was formed to support this goal. This group was given the task of assessing future water quality in the Grand and Speed Rivers taking into consideration planned upgrades to wastewater treatment included in existing master plans and environmental assessments. Key questions that will be addressed by the Assimilative Capacity Working Group include:

- Will the planned upgrades to wastewater treatment result in improved river water quality in future?
- What additional actions may be required to improve water quality, e.g. optimization of wastewater treatment processes, reducing nutrient inputs to the river from agricultural or urban non-point sources?

Water quality issues in the Grand River are influenced by both wastewater treatment plant discharges and rural/agricultural non-point sources. The relative importance of these drivers changes from season to season. For example, water quality issues in the central Grand River and lower Speed River are largely attributed to wastewater discharges during the low flow summer months, whereas high levels of total phosphorus are delivered to the river from agricultural fields during spring runoff conditions. Water quality issues in the Grand and Speed Rivers need to be addressed using multiple approaches including planned upgrades and optimization of wastewater treatment plants, as well as strategic implementation of agricultural best management practices.

The Grand River Simulation Model (GRSM) has been used to evaluate a number of scenarios to determine how water quality in the Grand and Speed Rivers may change in future in response to wastewater treatment plant upgrades and optimization of wastewater treatment plant processes.

Scenarios were also developed to assess the model sensitivity and response to changes in non-point source delivery of nutrients to the river from urban and rural/agricultural areas.

1.1. Background

Wastewater assimilation is a significant use of the Grand River and its tributaries. There are 30 municipal wastewater treatment plants of varying size and treatment level (Figure 1) that discharge treated effluent into the Grand River or one of its tributaries. Figure 1 also shows the area currently covered by the GRSM in dark blue and highlights the wastewater treatment plants (in light blue) that are explicitly included in the model.

The current modeling domain includes 10 of the 30 wastewater treatment plants in the watershed. These plants treat wastewater generated by approximately 92% of the serviced population in the watershed. Most of the remaining 20 wastewater treatment plants are located upstream of the current model domain and are incorporated implicitly in the model as their influences are included in the monitoring data that has been used to develop the model boundary conditions. While population growth projections and changes in effluent quality due to upgrades or optimization at the 20 smaller wastewater treatment plants have not been incorporated into the model, each plant may have water quality impacts that need to be assessed within a local context.

The assessment presented in this report focused water quality parameters that are typically of concern for waste assimilation related to wastewater discharges and rural non-point source pollution, i.e. dissolved oxygen, total phosphorus, nitrate and ammonia. This work did not consider other anthropogenic water quality impacts such as chloride, heavy metals, trace contaminants such as pharmaceuticals and personal care products, etc.

The GRSM is a one-dimensional, dynamic nutrient and dissolved oxygen water quality model. The model was developed primarily to predict impacts on dissolved oxygen as the main parameter of concern and indicator of impairment. Since dissolved oxygen concentrations can change very rapidly over time, particularly during ice-free conditions when aquatic plant growth is active, GRSM has been designed as a dynamic model using a 2 hour timestep to capture diurnal changes in dissolved oxygen.

Maintaining an adequate level of dissolved oxygen is a critical requirement for healthy aquatic ecosystems. In order to accurately estimate dissolved oxygen, it is necessary to model several other parameters of concern that can affect dissolved oxygen directly or indirectly.

The model simulates in-stream concentrations of dissolved oxygen, biochemical oxygen demand, nitrogenous oxygen demand, nitrate, un-ionized ammonia, total phosphorus and suspended solids. The model also calculates changes in aquatic plant biomass, as well as the resulting changes in dissolved oxygen and nutrient concentrations. GRSM considers the following nutrient and oxygen transformation processes:

- consumption of dissolved oxygen by biochemical oxygen demand, nitrogenous oxygen demand and sediments;

- photosynthetic production of oxygen by aquatic plants (function of light intensity, temperature, biomass);
- consumption of oxygen due to aquatic plant respiration (function of temperature, dissolved oxygen concentration and biomass);
- reaeration at the water surface;
- phosphorus, ammonia and nitrate uptake by aquatic plants;
- biochemical conversion of ammonia to nitrate;
- ammonia loss to the atmosphere through volatilization; and
- nitrate loss by denitrification.

The model incorporates pollutant concentrations and flows from a number of sources including point sources (e.g. wastewater treatment plant discharges, highlighted in light blue on Figure 1), non-point sources (i.e. runoff from urban and rural/agricultural areas) and model boundaries (e.g. rivers and major tributaries upstream of the simulation area).

GRSM has been and continues to be an important tool to assess impacts of wastewater treatment plant effluent and non-point sources on water quality in the Grand River watershed for strategic planning purposes. It can be used to estimate changes in nutrient and dissolved oxygen concentrations associated with pollutant discharges from a single point source (e.g. expansion, upgrades, etc.) or cumulative impacts from many sources simultaneously (e.g. to address watershed population growth). GRSM can be used for waste assimilation studies to estimate impacts of point source reductions on downstream nutrient concentrations and dissolved oxygen. In the current study, GRSM has been applied to assess water quality and waste assimilation from a broad, watershed-scale perspective.

The GRSM was most recently used for the Middle Grand River Assimilative Capacity Study and the model set up from that study will be used as a starting point or baseline for comparison with future scenarios. The GRSM has been calibrated using data from the summer of 2007, which represents one of the lowest precipitation summer periods on record. Future scenarios will be run using the same climate, water temperature and river flow inputs with changes to the wastewater effluent characteristics to simulate anticipated future changes in waste assimilation under low flow summer conditions. The sensitivity of the model to changes in water temperature and river flows will be assessed separately.

The GRSM is currently set up to simulate the Grand River from the Shand Dam to Chiefswood Road near Ohsweken and the Speed River from the Guelph Dam to the Grand River. This area is divided into 60 reaches for modeling purposes as shown in Figure 2. This portion of the watershed receives treated effluent from 10 wastewater treatment plants (WWTPs): Fergus, Elora, Waterloo, Kitchener, Guelph, Hespeler, Preston, Galt, Paris and Brantford. The following sections describe current and expected future effluent flow and quality from these WWTPs. Figure 2 also shows the location of major tributary inflows that form the model boundary conditions. Historical data (daily average flow and periodic water quality measurements) have been compiled and used to create inputs to GRSM describing these boundary inflows.

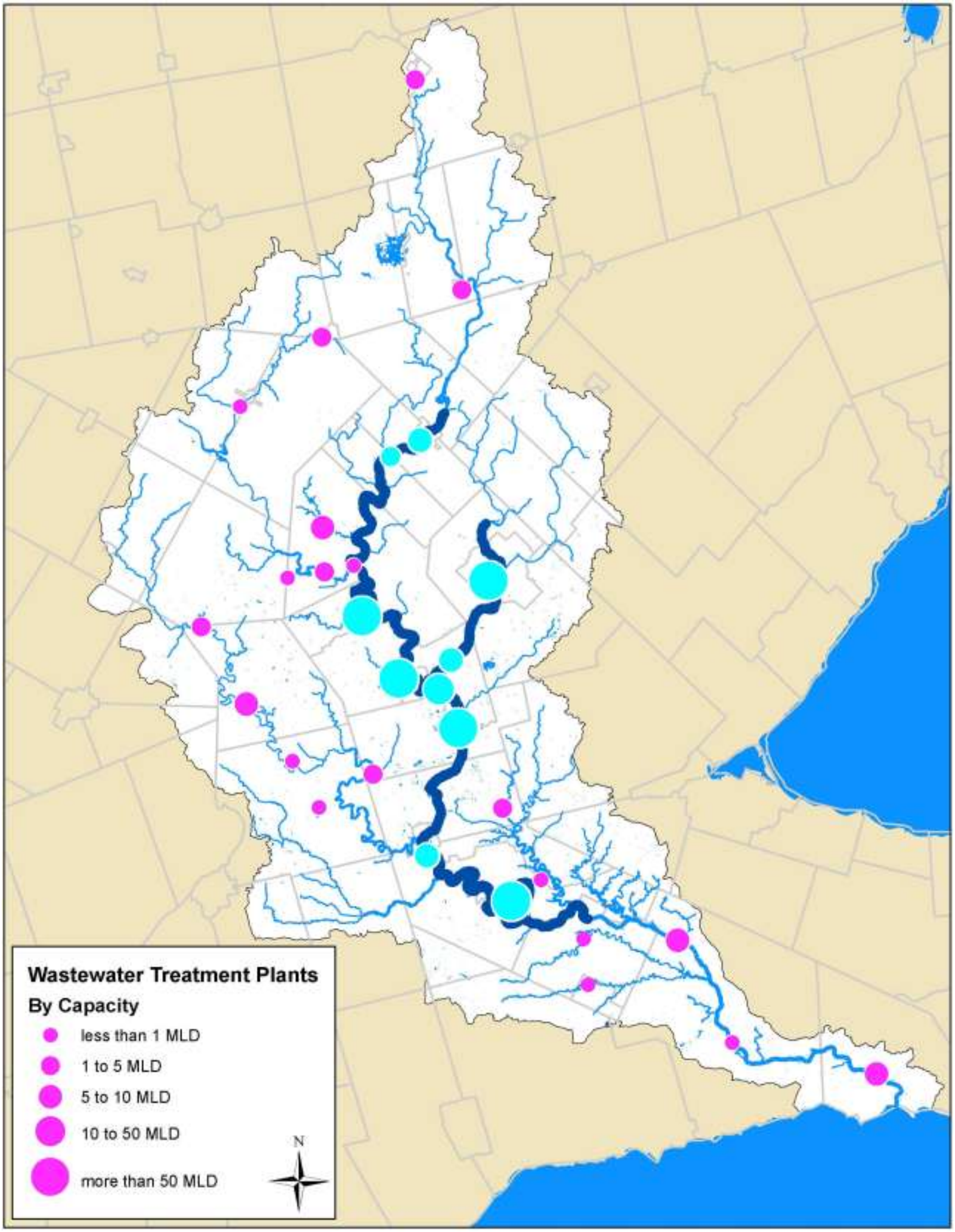


Figure 1. The location of municipal wastewater treatment plants in the Grand River watershed

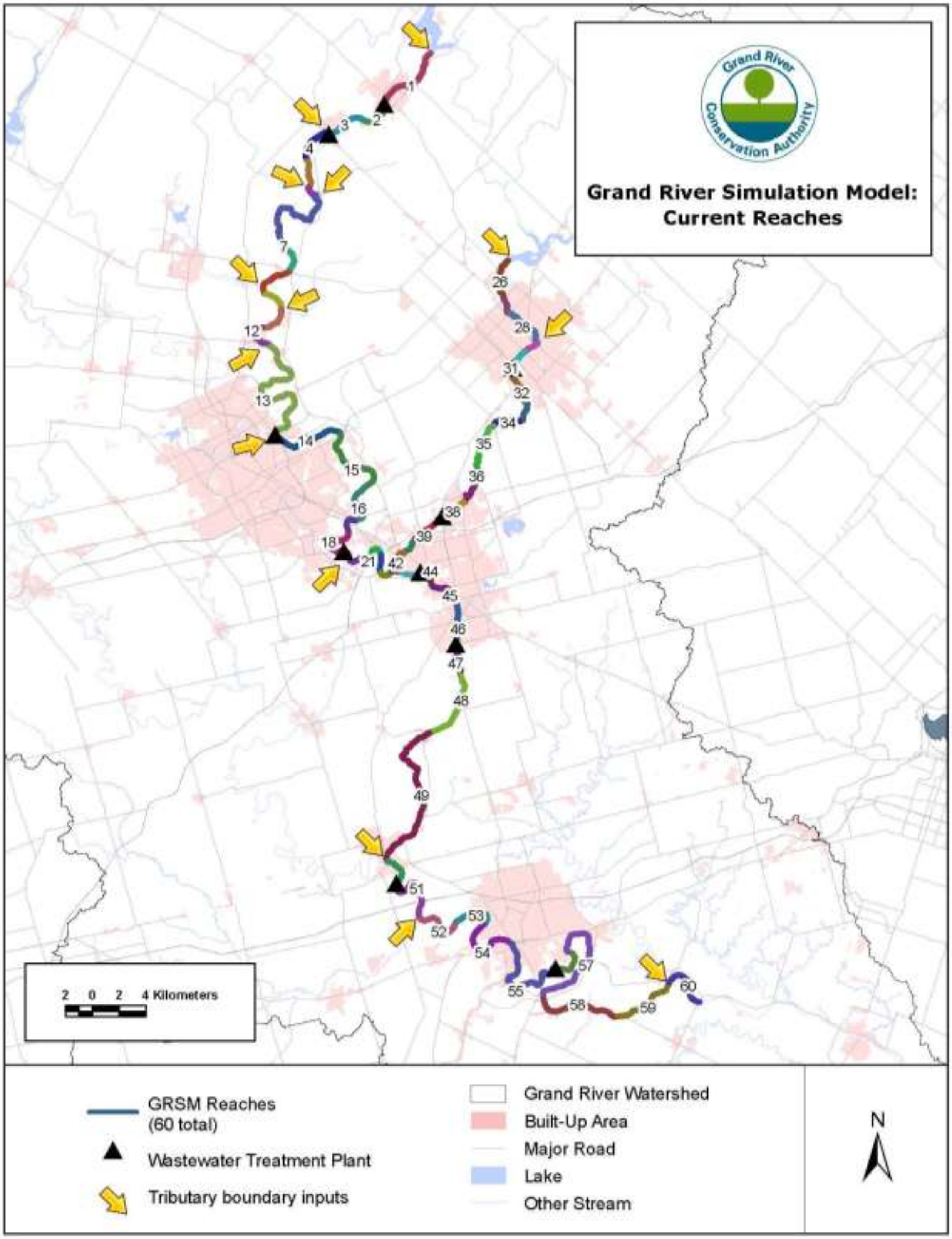


Figure 2: GRSM Reaches in the Grand and Speed Rivers

2. Development of Model Scenarios

2.1. Current Wastewater Effluent Characteristics

Information on current wastewater effluent flow and quality has been compiled and summarized in the following tables. Data on current effluent flow and quality was used as the basis of the baseline simulation against which future scenarios will be compared. Table 1 contains a summary of current annual average effluent flows discharged to the Grand or Speed River.

Table 1: Current Effluent Flows based on reported data for 2010

WWTP	Current Flow (m3/d)	Source
Fergus	3,804	2010 Annual Performance Report (Center Wellington, March 14, 2011)
Elora	1,539	2010 Annual Performance Report (Center Wellington, March 14, 2011)
Waterloo	45,994	2011 Water and Wastewater Monitoring Report (RoW, April 2011)
Kitchener	64,329	2011 Water and Wastewater Monitoring Report (RoW, April 2011)
Guelph	46,214	2010 Annual Report (Guelph, March 31, 2011)
Hespeler	8,297	2011 Water and Wastewater Monitoring Report (RoW, April 2011)
Preston	9,841	2011 Water and Wastewater Monitoring Report (RoW, April 2011)
Galt	35,635	2011 Water and Wastewater Monitoring Report (RoW, April 2011)
Paris	3,310	2010 Annual Performance Report (OCWA, March 30, 2011)
Brantford	36,957	2010 Annual Performance Report (OCWA, March 30, 2011)

Table 2 contains a summary of effluent quality data that is considered to be characteristic of each WWTP during the summer months (i.e June to September). In some cases, monthly average data was compiled to create the GRSM inputs, whereas others had more detailed data (e.g. data from the Region of Waterloo Wastewater Treatment Master Plan). It should be noted that Table 2 is only a summary of the more detailed data that was used to create probability distribution functions for input into GRSM.

2.2. Future Wastewater Effluent Characteristics

Effluent flow and quality is expected to change over time as population growth occurs and wastewater treatment plants are upgraded and expanded. Estimates of population growth to 2031 were gathered from several sources and are summarized in Table 3. Where data was available, employment figures have been included and are expressed as equivalent population.

Future effluent flow has been estimated based on the population projections provided in Table 3 for the Fergus, Elora and Brantford WWTPs. Future flows were estimated by multiplying the current flow by the ratio of future population to current population (note: employment equivalent population was included where available). The implicit assumption is that per capita flows based on 2010 effluent flow data will be unchanged in future. This approach is conservative and is likely to slightly overestimate the future wastewater flows. Recent experience suggests that per capita wastewater generation rates have declined as a result of conservation efforts and this trend is expected to continue.

Table 2: Current Effluent Quality

WWTP	cBOD (mg/L)			TP (mg/L)			CURRENT NH3 (mg/L as N)			NO3 (mg/L as N)			TSS (mg/L)		
	Min	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Fergus[1]	1.0	2.0	4.0	0.09	0.15	0.25	0.09	0.1	0.6	15.3	21.4	24.0	1.0	2.5	5.9
Elora[1]	2.5	4.1	12.8	0.10	0.25	0.55	1.93	6.15	14.8	3.1	4.9	6.1	4.3	6.6	11.2
Waterloo[2]	2.0	4.5	32.8	0.17	0.44	2.06	0.23	7.83	29.3	0.1	7.5	23.5	1.0	7.3	47.0
Kitchener[2]	2.0	6.0	20.0	0.23	0.55	1.68	12.8	21.7	38.7	0.1	1.2	2.4	1.0	6.0	18.4
Guelph[3]	2.0	2.0	4.0	0.04	0.16	0.63	0.01	0.2	4.8	14.4	20.6	31.1	1.0	1.0	10.0
Hespeler[2]	1.4	3.6	29.0	0.12	0.43	2.91	0.1	0.96	22.4	0.1	12.2	21.5	1.0	5.9	65.4
Preston[2]	1.0	2.0	16.8	0.07	0.27	1.97	0.1	0.12	16.2	0.1	8.1	22.9	1.0	3.1	52.3
Galt[2]	1.0	2.0	9.8	0.17	0.31	0.93	0.1	0.21	18.9	0.5	18.0	24.6	1.0	2.6	14.0
Paris[1]	1.0	3.0	27.0	0.30	0.60	0.94	0.1	0.25	13.3	0.1	6.5	19.1	2.0	5.0	15.4
Brantford[4]	2.0	7.5	31.0	0.26	0.43	0.72	0.1	2.57	11.68	0.1	4.2	13.2	5.7	9.6	17.3

1 based on monthly average data June to September, 2003 to 2010

2 from Region of Waterloo Wastewater Treatment Master Plan, all data June to September, 2003 to 2008

3 all data June to September, 2006 to 2008

4 based on monthly average data June to September, 2003 to 2008

Table 3: Current and Future Population and Employment

WWTP	Current (2011)		Future (2031)		
	Population	Employment	Population	Employment	Source
Fergus	15,260	n/a	22,760	n/a	Wellington County Official Plan (Amendment 61 of the Official Plan, June 2008)
Elora	5,530	n/a	10,950	n/a	current population from Elora WWTP Class EA Environmental Study Report (May 2010), future population from Wellington County (Amendment 61 of the Official Plan, June 2008)
Waterloo	128,400	72,400	165,629	n/a	based on 2011 Water and Wastewater Monitoring Report, Appendix D
Kitchener	226,800	104,000	311,502	n/a	based on 2011 Water and Wastewater Monitoring Report, Appendix D
Guelph	126,000	n/a	174,120	n/a	current population from 2010 Annual Performance Report includes Rockwood, future population from Table 4.1 of Guelph WWTMP (2009)
Hespeler	22,000	7,000	28,533	n/a	based on 2011 Water and Wastewater Monitoring Report, Appendix D
Preston	22,333	22,000	26,361	n/a	based on 2011 Water and Wastewater Monitoring Report, Appendix D
Galt	88,667	46,000	121,017	n/a	based on 2011 Water and Wastewater Monitoring Report, Appendix D
Paris	11,993	n/a	16,269	n/a	Draft Paris Water and Wastewater Servicing Strategy (2011)
Brantford	100,557	50,278	126,000	59,280	2009 Development Charges Background Study (2009)

Future effluent flows for the other WWTPs were taken directly from the Region of Waterloo Water and Wastewater Monitoring Report (2011) and the Guelph Wastewater Treatment Master Plan (2009). Table 4 provides a summary of future wastewater discharges.

Table 4: Estimated Future Effluent Flow in 2031

WWTP	Future (2031) Flow (m^3/d)	Rated Capacity (m^3/d)	Notes
Fergus	5,674	8,000	
Elora	3,064	3,066	A Class EA has recently been completed and it expected that the rated capacity of the Elora WWTP will be increased to 5000 m^3/d.
Waterloo	59,790	54,600/72,730	The Waterloo WWTP is currently being upgraded to be able to treat flows above 54,600 m^3/d
Kitchener	100,523	122,745	
Guelph[1]	81,957	64,000	The Guelph WWTP is currently carrying out a capacity demonstration to re-rate the WWTP
Hespeler	9,663	9,320	Future growth expected to exceed rated capacity
Preston	13,059	16,860	
Galt	51,620	56,800	
Paris[2]	15,093	7,056	Future growth expected to exceed rated capacity
Brantford	45,397	81,800	

1 projected flows interpolated from Guelph Wastewater Treatment Master Plan, Table 4.2 (Scenario 2 – higher growth)

2 L. Robinson (personal communication) from draft Paris Master Servicing Study

Future effluent quality is summarized in Table 5 based on information provided in the Elora WWTP Class EA Environmental Study Report, the Guelph Wastewater Treatment Master Plan, the Region of Waterloo Wastewater Treatment Master Plan, and the Middle Grand River Assimilative Capacity Study. For the purposes of developing GRSM inputs, it has been assumed that the effluent concentrations will not exceed the anticipated future compliance limits (e.g. maximum effluent concentration = compliance limit). The median concentration for this scenario has been set equal to the design objectives or operational targets for each WWTP. Nitrate levels in some cases are expected to increase as the effluent is nitrified (i.e. ammonia is converted to nitrate prior to discharge). In these cases it was assumed that the total nitrogen content of the effluent stays the same but nitrogen is discharged as nitrate rather than ammonia.

The Paris WWTP is expected to require an expansion prior to 2031 and this will likely result in revised compliance limits based on an assessment of waste assimilation of the Grand River at Paris. A formal environmental assessment or waste assimilation assessment has not been carried out at this point. For the purposes of this assessment and in the absence of a waste assimilation study or other environmental assessment, it has been assumed that final effluent compliance limits

Table 5: Future Effluent Quality

WWTP	FUTURE CBOD (mg/L)			TP (mg/L)			NH_3 (mg/L as N)			NO_3 (mg/L as N)			TSS (mg/L)		
	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
Fergus[1]	1.0	2.0	4.0	0.09	0.15	0.25	0.09	0.1	0.6	15.3	21.4	24.0	1.0	2.5	5.9
Elora[2]	2	8	15	0.1	0.2	0.3	0.1	0.6	2	16	17.4	17.9	2	8	15
Waterloo[3]	5	7	15	0.2	0.4	0.6	1	1.5	1.8	18	19.7	21.7	5	10	15
Kitchener[4]	5	7	15	0.1	0.2	0.4	1	2	3	16	18.5	23.4	5	10	15
Guelph[5]	1	1.5	2	0.1	0.1	0.1	0.1	0.3	0.5	3.5	20.2	31.3	1	1.5	2
Hespeler[3]	5	7	15	0.2	0.4	0.8	2	4	6	8.2	12.2	15.8	5	10	15
Preston[3]	5	7	15	0.2	0.4	0.8	2	4	6	5.3	5.8	6.9	5	10	15
Galt[3]	5	7	15	0.2	0.4	0.5	2	2	3.5	14	16.2	18.4	5	10	15
Paris[6]	5	7	15	0.1	0.2	0.4	1	2	3	12.1	18.5	31.1	5	10	15
Brantford[1]	2.0	7.5	31.0	0.26	0.43	0.72	0.1	2.57	11.68	0.1	4.2	13.2	5.7	9.6	17.3

1 Existing C of A provides sufficient capacity, no upgrades/expansions expected therefore effluent quality similar to current conditions

2 From Elora Class EA ESR, assume total nitrogen (NH3+NO3) is 18 mg/L based on 2005 data

3 Wastewater Master Plan Scenario 2

4 Middle Grand River Assimilative Capacity Study (Stantec, 2010)

5 Max values correspond to future compliance beyond 73.3 MLD per Wastewater Master Plan (CH2M Hill, 2009), NO_3 calculated based on total nitrogen in effluent (ranges from 4 to 31.4 mg/L based on historical data from 2004 to 2008).

6 Effluent compliance limits and operational targets are expected to be similar to Kitchener, except nitrate which includes an additional 12 mg/L nitrate from the proposed Bethel water treatment process.

will be similar to the ones that have recently been established for Kitchener (i.e. it is anticipated that Paris will require upgrades to include nitrification and tertiary filtration). One significant difference will be the concentration of nitrate in the effluent from the Paris WWTP. It is expected that high levels of nitrate will be discharged in future as a result of the proposed drinking water treatment system for the Bethel well field which will result in high levels of nitrate and chloride into the sanitary sewer system (Associated Engineering 2011). It is anticipated that this waste stream will contribute approximately 42 kg of nitrate per day to the Paris WWTP with an expected maximum daily load of up to 60 kg/d. This increased nitrate load would increase the effluent concentration of nitrate by approximately 12 mg/L based on current average flows.

An additional future effluent quality scenario was developed by assuming optimized wastewater treatment plant performance to reduce the concentration of total phosphorus and ammonia in final effluent from selected plants. For example, it is possible that total phosphorus concentrations may be reduced through optimal dosing of chemical precipitants, improved solids control, filter maintenance and operation, etc. It is expected that a fully optimized plant would be able to consistently meet a final effluent target of 1 mg/L for ammonia. A WWTP with tertiary filtration would be expected to be able to meet a target of 0.3 mg/L for total phosphorus, while secondary plants should be able to achieve 0.4 mg/L.

Arbitrary values were used to assess the models' sensitivity to non-point nutrient loads. Scenarios that are based on reductions in non-point nutrients sources from urban areas and rural runoff sources in both central and boundary areas in the watershed were modeled. The scenarios reflect the following values:

- A 40% reduction in total phosphorus, ammonia, nitrate and Total Suspended Solids from urban runoff;
- A 10% reduction in total phosphorus, ammonia and nitrate from rural/agricultural non-point sources, i.e. model boundary conditions that represent predominantly rural/agricultural tributaries such as Conestogo River, Nith River, etc.;
- A 25% reduction in total phosphorus, ammonia and nitrate from rural/agricultural non-point sources; and
- A 20% reduction in total phosphorus, ammonia, nitrate and Total Suspended Solids from urban runoff, i.e. urban drainage areas in Fergus, Guelph, Brantford, etc. and tributaries such as Laurel and Schneiders Creek.

It should be noted that an evaluation of the ways in which these reductions would be realized was outside the scope of this study. It is unknown which management practices would be most appropriate, where they should be applied to achieve the greatest benefit or how they might be implemented.

For ease of reference in the following sections, the scenarios will be referred to as:

- Scenario 1: Base Case – Current Effluent Flows and Concentrations

- Scenario 2: 2031 Future Effluent Flows and Concentrations, including increased effluent flows resulting from population growth and improved effluent quality associated with planned upgrades
- Scenario 3: 2031 Optimized Future Effluent Flows and Concentrations, including increased effluent flows resulting from population growth, improved effluent quality associated with planned upgrades and optimization to achieve lower total phosphorus and ammonia concentrations in final effluent
- Scenario 4a: 2031 Future Effluent Flows and Concentrations (i.e. based on Scenario 2) + Reduce Rural/Agricultural Non-point Source Concentrations by 10%
- Scenario 4b: 2031 Future Effluent Flows and Concentrations (i.e. based on Scenario 2) + Reduce Rural/Agricultural Non-point Source Concentrations by 25%
- Scenario 4c: 2031 Future Effluent Flows and Concentrations (i.e. based on Scenario 2) + Reduce Urban Non-point Source Concentrations by 20%
- Scenario 4d: 2031 Future Effluent Flows and Concentrations (i.e. based on Scenario 2) + Reduce Urban Non-point Source Concentrations by 40%

There are well known seasonal changes in river flow and water quality which can result in seasonal changes in water quality concerns or issues. During the summer period, water temperatures are high and river flows can be low which may result in concerns with low dissolved oxygen, elevated un-ionized ammonia, high total phosphorus concentrations and excessive aquatic plant growth. Spring is characterized by high run-off events due to snow melt and heavy rain which leads to soil erosion and sediment delivery to the river from agricultural and urban areas. Water quality concerns in the spring are primarily related to phosphorus delivered to the river system from non-point sources. Winter conditions are typified by cold water temperatures, ice cover on some sections of the river and less surface runoff. Under winter conditions, elevated nitrate levels have been observed especially in the Grand River between Shand Dam and Bridgeport.

These seasonal changes are also reflected in the relative importance of nutrient sources, e.g. wastewater treatment plants have a greater influence on waste assimilation and water quality during low flow summer conditions, whereas river water quality during spring runoff is largely dominated by non-point source pollution. All scenarios were run under low flow summer conditions to assess the potential changes in water quality during the most critical time of year from a waste assimilation perspective. Scenario 2, which takes into account future growth and wastewater treatment upgrades, was also run under winter conditions to assess potential concerns related to nitrate and the potential increased nitrate discharged from wastewater treatment plants in future. The non-point source reduction scenarios (Scenario 4) were run under spring high flow conditions to assess the model response during the period when these sources are believed to be most dominant.

3. MODEL CALIBRATION AND VALIDATION

The methodical application, testing and evaluation of a water quality model to predict observed field data is referred to as model calibration and validation. In general, the calibration process is an organized procedure to select model coefficients and improve unknown or poorly characterized model inputs such that model predictions are in the best possible agreement with measured data. Validation refers to running the model under different conditions and comparing the model output to an independent set of measurements. GRSM was calibrated against measured data for one year then validated using two additional years of data.

3.1. EXISTING DATA COMPILATION

The model variables of interest for the GRSM include dissolved oxygen, un-ionized ammonia, total phosphorus, and nitrate. All available measured data from 2005, 2007 and 2008 was compiled for these variables. Dissolved oxygen data from 2007 was used to calibrate GRSM. The model was validated for dissolved oxygen with 2005 and 2008 data. Nutrient variables were calibrated using grab sample data from 2008 because this was the only year with sufficient data to calibrate all seasons.

Continuous dissolved oxygen data from the GRCA's real-time water quality monitoring network were used to calibrate and validate the model for dissolved oxygen. Other model variables such as total phosphorus, un-ionized ammonia and nitrate were compared to grab sample data from the Provincial Water Quality Monitoring Network (PWQMN) supplemented with additional nutrient data collected by GRCA on behalf of the Region of Waterloo and City of Guelph.

Data for three years were selected against which GRSM would be calibrated and validated. Measured dissolved oxygen data for the summer of 2007 was used for the calibration of the GRSM. Grab sample data for nutrients is limited for 2005 and 2007, however there is a relatively good dataset in 2008 based on monitoring carried out by GRCA on behalf of the Region and City of Guelph.

Since 2005 was an average or typical summer in terms of climate, and 2008 was much wetter than normal, these years represented different environmental conditions versus the much drier than normal calibration year (i.e. 2007). The three years were selected because they represent a broad range of climate and hydrologic conditions that have been observed in recent years.

Hourly dissolved oxygen data from the GRCA's continuous water quality stations at Bridgeport, Blair, Glen Morris, Hanlon and Road 32 in 2005, 2007 and 2008 were visually inspected for data quality using professional judgment and experience. Poor data quality can result from improper oxygen probe calibration, probe failure, calibration drift over time, or pump failure leading to dissolved oxygen readings that are not representative of river conditions. Where possible, data corrections were applied to the data to compensate for calibration drift. Problems with poor data quality tend to occur more frequently in winter, spring and fall for a number of reasons including equipment problems (e.g. probes fail more frequently when there is high sediment load during spring runoff or cold conditions in winter) and staff resource challenges (e.g. reduced monitoring equipment maintenance schedule when summer students are not available). There is also a much greater emphasis on collecting high quality data during the summer months when dissolved oxygen levels are a greater concern. Clearly erroneous measurements or data with very poor data quality were not used in further analysis. In some cases, data quality may be questionable based on visual inspection but there was not sufficient justification to discard the data altogether. These cases occur when the calibration drifts slowly and/or the probe was not properly calibrated resulting in readings that are consistently too high or too low. Periods where the data quality is suspect are highlighted in subsequent graphs.

The data from the Blair continuous water quality station has challenges because it has been demonstrated that the sampling intake is not located in a representative location and the measurements reported for this station are significantly influenced by a small coldwater creek. Recent efforts have been made to extend the intake and collect more representative data, however site constraints have hampered this effort. Field data collected during the summer months of 2007 and 2008 showed that the monitoring station typically reports dissolved oxygen levels that are 1.6 to 2.2 mg/L too high compared to measurements collected near the centre of the river. The summer 2007 and 2008 continuous dissolved oxygen data from the Blair station was adjusted using the field data to produce a more realistic dataset for calibration. Adjustments were not applied to other years or seasons because there are no field data to support the development of an appropriate adjustment factor.

Nutrient data were also visually inspected for potential errors. No errors were observed.

Values for all input parameters have been largely defined through previous GRSM calibration efforts and/or published literature. The GRSM was recently used for the Middle Grand River Assimilative Capacity Study and the calibrated model from that project was used for the current study. Calibration of the model for the Speed River portion was not carried out during the Middle Grand River Assimilative Capacity Study. The Speed River reaches compared well with measured values and did not require extensive calibration effort prior to applying GRSM to the Water Management Plan scenarios.

As mentioned previously, there are limited data available to calibrate nutrient concentrations predicted by GRSM in 2007. For this reason, seasonal nutrient data from 2008 were used to calibrate the model. The available data for 2005 and 2007, which are sparse (e.g. often 2 or 3 data points at each monitoring site for each season), were taken into consideration as part of the calibration exercise. There were insufficient data to provide a comprehensive validation of the model.

Based on the model calibration with the 2007 dissolved oxygen dataset, GRSM was run for winter, spring, and summer periods for 2005 and 2008. Model output was compared to measured data collected by the GRCA continuous monitoring network to evaluate the robustness of the model calibration for dissolved oxygen. Model calibration and validation for dissolved oxygen was assessed using both graphical and quantitative approaches. Figure 3 shows the location of the continuous water quality monitoring stations relative to GRSM reaches used for calibration and validation. GRSM produces output for the downstream node of each reach therefore measured data are compared to the nearest upstream GRSM reach.

Measured data for other water quality variables are limited for all seasons in 2005 and winter, spring and fall in 2007. For un-ionized ammonia, TKN, nitrate and total phosphorus, GRSM was essentially calibrated with 2008 data and validated with summer 2007. Figure 4a and 4b shows the nutrient sampling locations relative to GRSM reaches on the Grand and Speed rivers. Graphical comparison of modeled and measured concentrations was used to assess model calibration and validation for nutrient variables. The limited size of the measured dataset and the probabilistic nature of the nutrient inputs in GRSM preclude rigorous, quantitative statistical analysis for these variables.

3.2. Calibration and Validation for Dissolved Oxygen

Model output from GRSM was compared to dissolved oxygen measurements from the GRCA's continuous water quality monitoring network. Modeled and measured concentrations for each season in each year were compared by plotting maximum and minimum dissolved oxygen for each day of the simulation period. The Root Mean Squared Error (RMSE) was used to quantitatively assess the differences between modeled and measured dissolved oxygen concentrations. The RMSE is a common statistic used in many modeling applications. RMSE provides an estimate of the absolute difference between paired datasets and is calculated according to the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(C_{observed,i} - C_{predicted,i}\right)^2}{n}}$$

where $C_{observed,i}$ is the observed or measured concentration, $C_{predicted,i}$ is the corresponding predicted or modeled concentration, and n is the number of pairs of measured and predicted concentrations. RMSE was calculated for both daily maximum and daily minimum dissolved oxygen for each day of each season for each calibration or validation year.

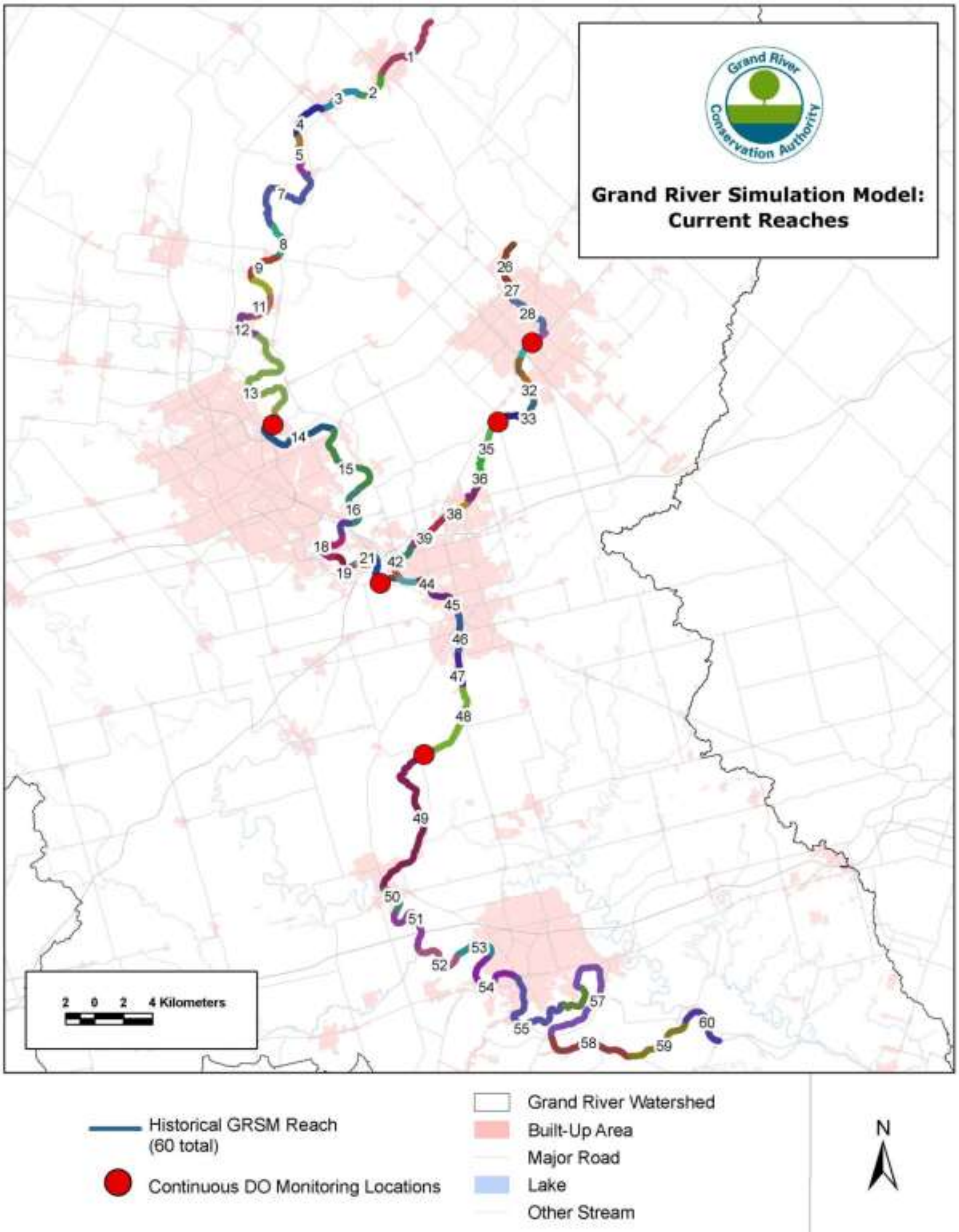


Figure 3: Continuous Monitoring Stations Used for GRSM Calibration

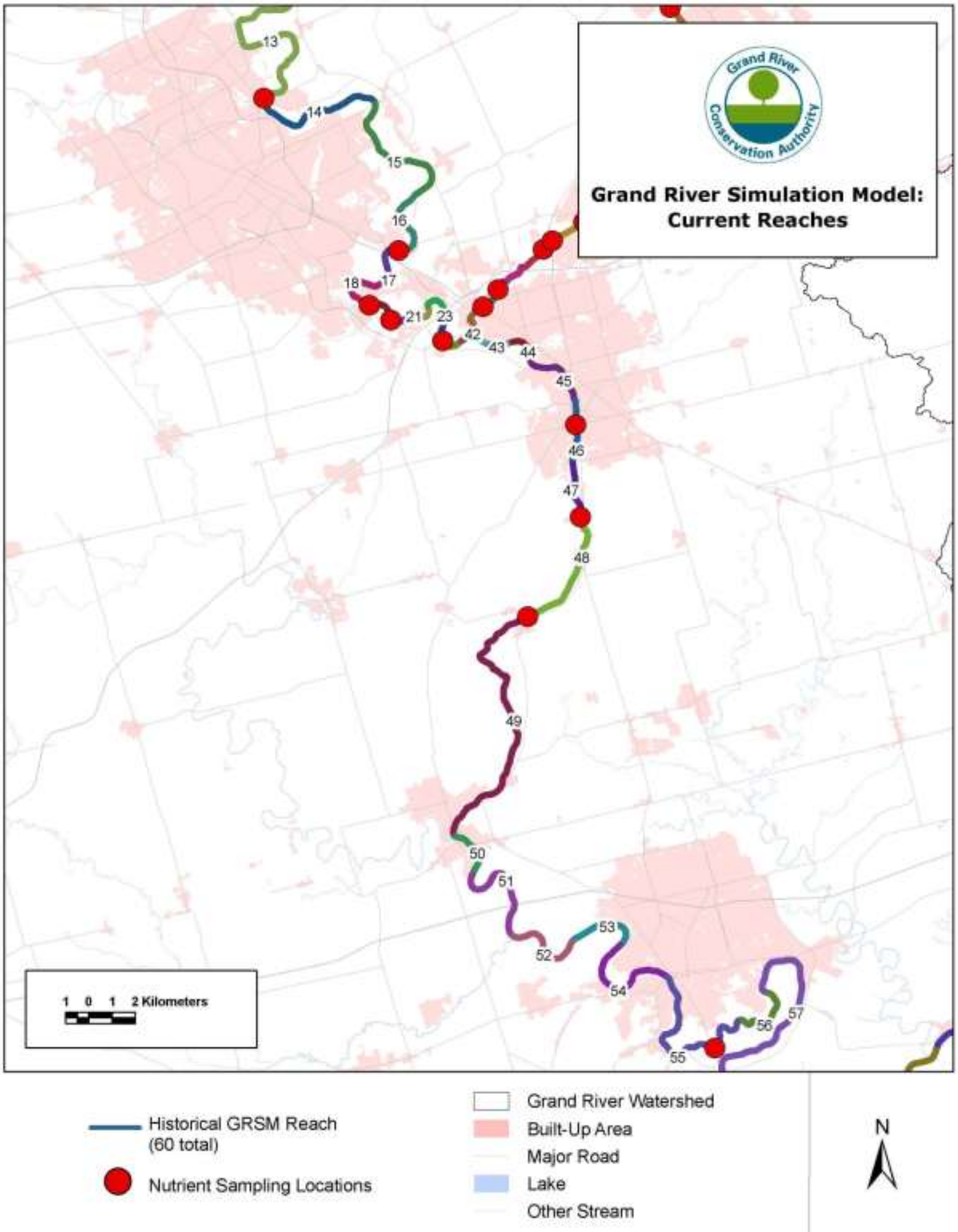


Figure 4 (a): Nutrient Sampling Locations Used for GRSM Calibration on the Grand River

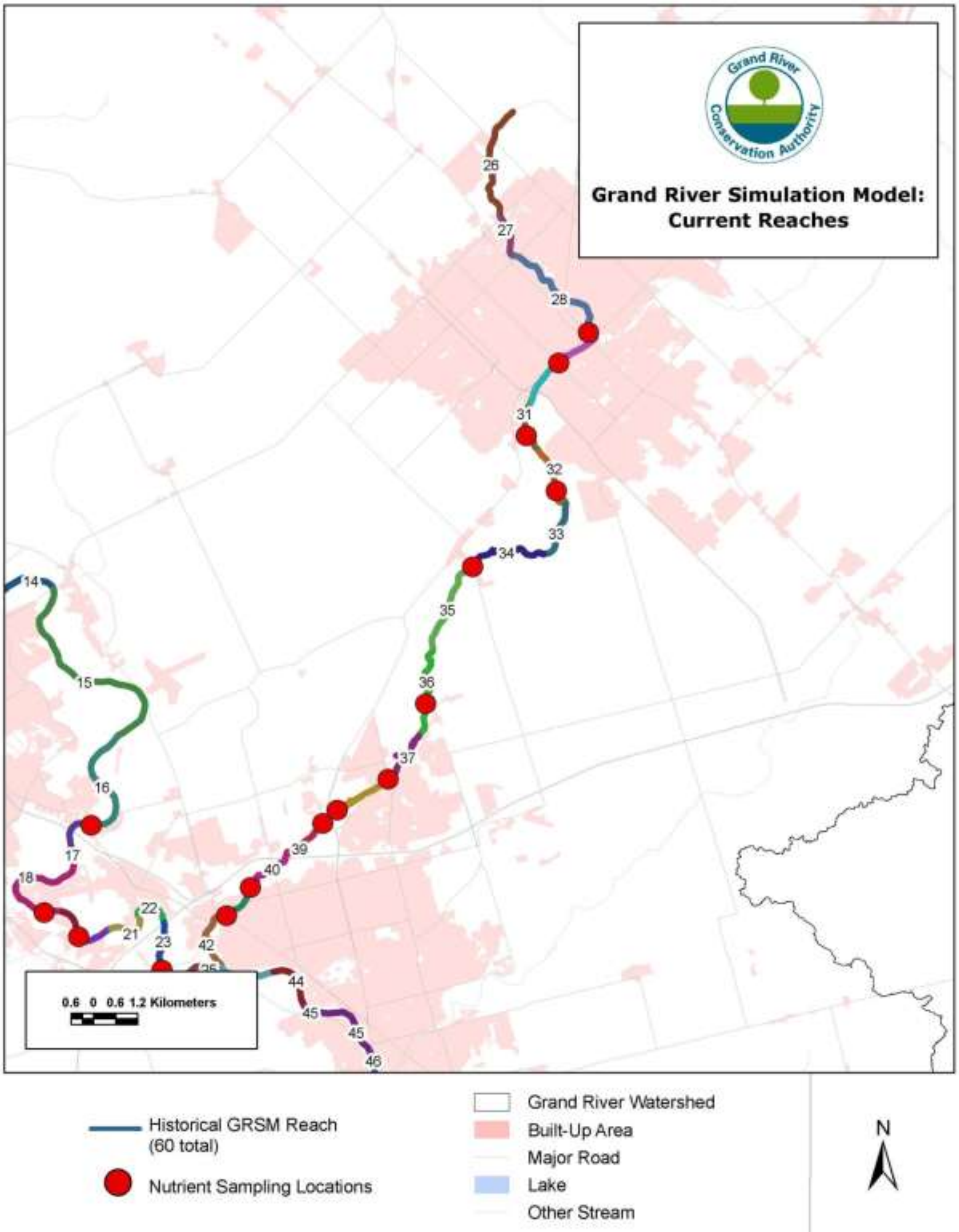


Figure 4 (b): Nutrient Sampling Locations Used for GRSM Calibration on the Speed River

Figure 5 shows an example of the measured daily maximum and minimum dissolved oxygen concentrations based on GRCA continuous water quality monitoring data in green and the corresponding daily maximum and minimum values predicted by GRSM in red. Appendix A contains all of the graphs for the 2007 calibration year, as well as the 2005 and 2008 validation years using all available data from the GRCA continuous water quality monitoring network. Table 6 provides a summary of the RMSE for the daily maximum and daily minimum dissolved oxygen for each season in each year.

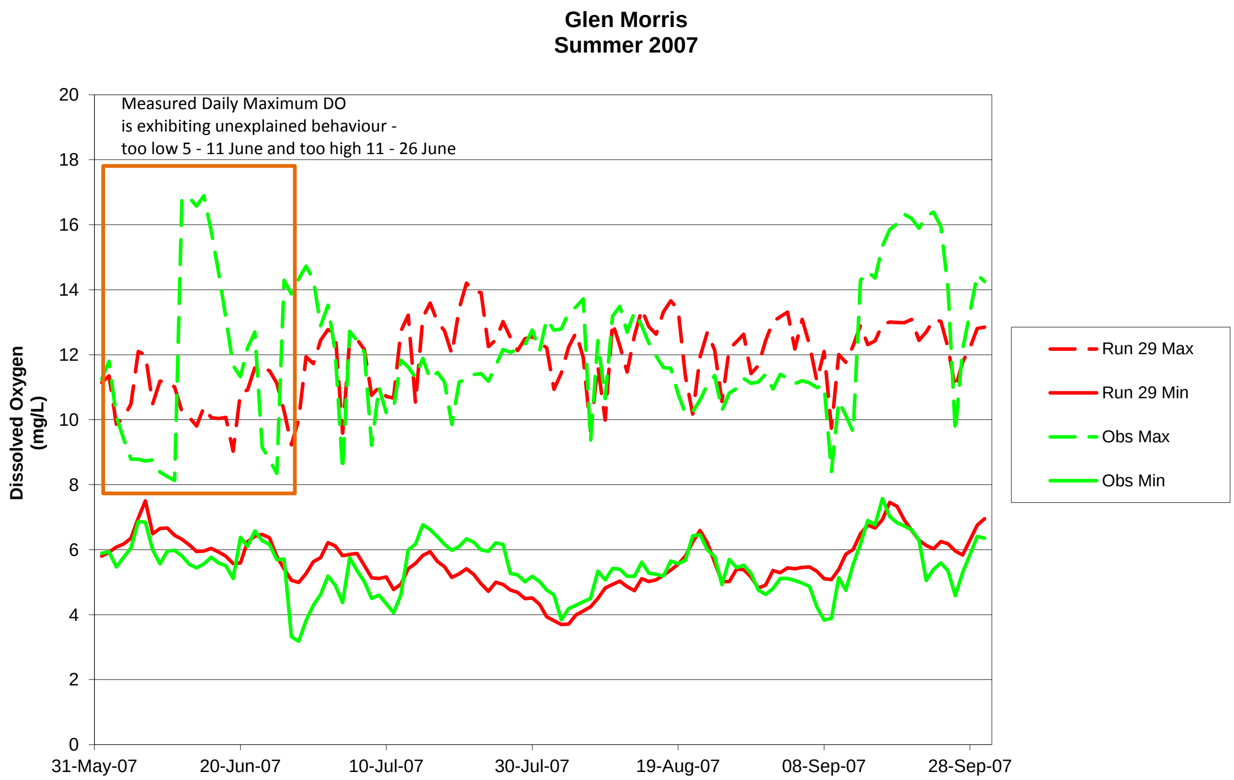


Figure 5: Comparison of GRSM output with measured dissolved oxygen at Glen Morris (summer 2007)

The model does not fit well for some periods when data quality is poor. For example, the Blair water quality station appears to have been reporting values that were approximately 2 mg/L too high from the 20th of February to the 19th of April, 2007 as a result of a calibration error. This can be clearly seen in Figures A-1 and A-2 for Blair where the measured data is much higher than the GRSM prediction. The poor data quality is also reflected in a higher RMSE for this period. A thorough analysis of the measured data reported by the Blair station indicates that reported dissolved oxygen levels were well above saturation for this entire period, which is not realistic based on previous experience and common sense, and therefore, these data are considered questionable.

Overall, GRSM reproduces the observed data over all seasons in 2007 as seen in Figures A-1 to A-3. Typically, GRSM does a much better job of matching the daily minimum dissolved oxygen levels and it frequently underpredicts the daily maxima during periods of active photosynthesis. This behavior has been noted in previous studies and is possibly related to a lack of sufficient detail in the model algorithms that describe the amount of oxygen generated during photosynthesis. Increasing the complexity of this algorithm could potentially produce a better model fit to the daily maximum concentrations but this is not seen as an important need given the model produces a good estimate of the daily minima and predictions follow the general trends across and within seasons. Achieving a reasonable prediction of the daily minimum dissolved oxygen is seen as much more important because the survival of aquatic organisms and quality of aquatic habitat can be impacted if dissolved oxygen drops too low.

Table 6 supports the observations made above. RMSE values for the daily minimum dissolved oxygen concentrations for the 2007 calibration are typically around 1 mg/L, which is considered acceptable. Some higher values are observed when data quality is poor, such as for Blair in spring 2007. As expected, RMSE values for the daily maxima are somewhat higher, around 1.5 to 3 mg/L.

Following calibration with 2007 data, the same model input parameters were used to validate the model with 2005 and 2008 data. The graphs demonstrating the model validation for dissolved oxygen are provided in Appendix A (Figures A-4 through A-9). RMSE values for the validation years range from 0.5 to 1.6 for daily minima and 0.8 to 4.4 for daily maxima. As expected, RMSE values for the validation years are slightly higher than those for the calibration year, but still within an acceptable range.

Table 6: RMSE for Daily Maximum and Daily Minimum Dissolved Oxygen

Winter

	2007 Calibration		**2005 Validation**		**2008 Validation**	
Water Quality Monitoring Station	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**
Blair	1.1	1.4	1.1	0.9	0.5	0.8
Bridgeport	1.1	1.0	1.6	1.3	1.4	0.8
Glen Morris	0.4	0.9	0.6	1.2	0.8	1.6
Hanlon[1]	-	-	-	-	-	-
Rd 32[1]	-	-	-	-	-	-

Spring

	2007 Calibration		**2005 Validation**		**2008 Validation**	
Water Quality Monitoring Station	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**
Blair	2.2	3.2	0.9	1.6	0.8	1.4
Bridgeport	0.8	1.2	1.0	1.4	1.0	2.0
Glen Morris	1.1	3.2	1.0	2.4	0.8	1.7
Hanlon[1]	-	-	-	-	-	-
Rd 32[1]	-	-	-	-	-	-

Summer

	2007 Calibration		**2005 Validation**		**2008 Validation**	
Water Quality Monitoring Station	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**	**Daily Minimum RMSE**	**Daily Maximum RMSE**
Blair	1.1	2.1	1.2	4.5	0.9	3.0
Bridgeport	0.9	2.3	1.2	2.3	0.7	2.2
Glen Morris	0.7	2.3	0.9	2.3	1.1	3.3
Hanlon	1.4	1.8	0.7	0.9	1.0	0.9
Rd 32	1.3	3.4	1.3	4.1	0.8	2.7

[1] Winter and spring dissolved oxygen data for Hanlon and Road 32 sites has not undergone any quality assurance screening and therefore RMSE statistics have not been calculated for these sites at this time

3.3. CALIBRATION OF GRSM FOR NUTRIENTS

Calibration of GRSM for nutrient variables was carried out using all available data to provide the best fit. Because the nutrient samples are collected at uneven, infrequent intervals and nutrient concentrations in GRSM are handled probabilistically, it is not possible to match measured nutrient concentrations with model predictions on a particular day, unlike the graphs provided above for dissolved oxygen.

Nutrient variables are compared to GRSM predictions for each season by considering the range of concentrations observed and predicted. Figures A-10 through A-13 presented in Appendix A show the range of values predicted by GRSM in red and measured concentrations in blue. The square symbols indicate the median concentration and the whiskers represent the interdecile range (i.e. the 90^{th} and 10^{th} percentiles) of the datasets. In some cases, there were only a few samples collected at a limited number of sites. Where there were less than 6 measurements per season, the interdecile range was not estimated and all measured values are plotted as individual points. Calibration of the model was assessed by visually comparing the ranges of measured and predicted concentrations over all seasons, with more weight given to sites with more than 3 samples. There was a significant sampling effort undertaken in the summer of 2007 and all seasons in 2008 resulting in a reasonable dataset for GRSM calibration.

Un-ionized ammonia and TKN levels were calibrated by adjusting NOD decay rates. Areas upstream of large wastewater discharges, e.g. upstream of Bridgeport were assigned low nitrification rates. Between the Waterloo and Kitchener WWTPs, there appears to be a moderate level of nitrification occurring in the Grand River. The first reach downstream of the Kitchener WWTP appears to have very limited or no nitrification occurring, possibly as a result of chlorine toxicity from the effluent. Substantial NOD decay occurs in the river between Schneiders Creek and Fountain Street. NOD decay rates appear to decline to more moderate levels between Fountain Street and Glen Morris.

Nitrate concentrations were calibrated by adjusting the denitrification rate constants for each reach. For spring, summer and fall, denitrification appears to be occurring in the upper part of the watershed upstream of Bridgeport, whereas denitrification rates appear to be somewhat lower between Bridgeport and Glen Morris. Additional efforts had to be undertaken to calibrate GRSM to winter nitrate levels based on data collected in 2008.

In the case of winter 2008, GRSM was predicting nitrate levels that were substantially lower (i.e. approximately 3 to 4 mg/L less) than observed at all monitoring locations. The model was unable to correctly estimate nitrate concentrations because the winter boundary conditions upstream of Bridgeport are poorly characterized. The boundary conditions are based on PWQMN sampling, which is typically focused on sampling during ice-free months. Analysis of GRSM output and PWQMN data indicate that the majority of the nitrate mass load to the upper part of the model domain in winter originates from the Conestogo River, Irvine Creek, Canagagigue Creek and the discharge from Shand Dam. The input files were adjusted to increase the nitrate concentrations associated with these boundaries until a reasonable calibration was achieved for nitrate. It is believed that shallow groundwater flow containing elevated nitrate may also have contributed to the high nitrate concentrations observed in 2008, however in the absence of data, the input files were not updated to reflect this input.

A review of the graphs below shows that the model is reasonably well calibrated for nutrients. Discrepancies between the model predictions and measured data can be attributed to the challenge of adequately characterizing all sources of nutrients to the river. For example, groundwater is thought to be a major source of nitrate to the Grand River, particularly in the winter when surface runoff is limited, but this influence is not well understood or represented in GRSM. Similarly, the concentration of nutrients in major tributary inflows is highly variable and may be dependent on flow but the correlation between concentration and flow is not currently considered in the model inputs. Differences between model output and observed nutrient concentrations may also be due to the fact that some processes are not included in GRSM such as deposition and resuspension of sediment-bound phosphorus.

3.4. CALIBRATION SUMMARY

GRSM was calibrated for dissolved oxygen for each season using measured data from 2007 and validated using measured data from 2008 and 2005 to represent a range of climate and hydrologic conditions. Model error was quantified by calculating RMSE for the daily minimum and daily maximum dissolved oxygen concentration. Daily minimum dissolved oxygen RMSE values for the 2007 calibration year were typically 1 mg/L or less indicating an acceptable calibration. Higher RMSE values were observed for one station in the spring of 2007 due to poor quality data from the Blair continuous monitoring station. The 2008 and 2005 validation years had slightly higher RMSE values, as expected but they were within acceptable limits. In addition to the quantitative assessment of RMSE, qualitative observation of time-series plots of daily minimum dissolved oxygen indicated a reasonable fit between GRSM and measured dissolved oxygen. Based on qualitative and quantitative measures, GRSM was considered to be calibrated for dissolved oxygen.

Calibration for nutrient variables, such as total phosphorus, nitrate and un-ionized ammonia, was assessed by qualitatively comparing model output and measured data. Quantitative assessment was not feasible due to the small number of nutrient grab samples available. Visual comparison of GRSM output and measured data for nutrient variables indicates that the model calibration is reasonable for these variables based on the available data.

4. RESULTS OF GRSM SCENARIOS

The calibrated GRSM has been used to predict concentrations of dissolved oxygen (DO), total phosphorus (TP), nitrate (NO_3) and un-ionized ammonia (NH_3) in the Grand and Speed Rivers for each scenario. For modeling purposes, the Grand and Speed Rivers have been divided into reaches as shown previously in Figure 2. All scenarios were run with the calibrated GRSM using river flows and water temperatures based on measured data from the summer of 2007, which was a very dry, low flow year.

Additional model runs were completed to assess potential seasonal importance of various water quality concerns. Spring runoff conditions were simulated in order to assess the response of the model to hypothetical reductions in non-point source concentrations of nitrogen and phosphorus from urban and rural/agricultural areas of the watershed (i.e. Scenarios 1, 2 and 4). Winter conditions were simulated to address concerns about the potential for elevated nitrate levels associated with future growth and wastewater treatment upgrades to include nitrification (i.e. Scenarios 1 and 2). The calibrated GRSM was run using river flows and water temperatures based on measured data from the spring and winter of 2008. Spring and winter 2008 were chosen as this is the only year for which there is sufficient data to calibrate GRSM for these months, particularly for nutrient parameters such as total phosphorus and nitrate.

The GRSM produces a significant amount of output data for each scenario. Output data has been summarized in graphical format in Appendix B for all scenarios for the key water quality parameters of interest for each scenario. For nutrient parameters such as total phosphorus, nitrate and un-ionized ammonia, the 75th percentile concentration for each reach has been plotted against downstream distance from the Shand Dam or the Guelph Lake Dam. For dissolved oxygen, the maximum and minimum concentration over the summer period for each reach is plotted. Water quality objectives or guidelines are shown on the graphs for comparison purposes. Table 7 provides a summary of the objectives used for each water quality parameter of concern. Each graph identifies a number of locations of interest, such as major tributaries or WWTPs, that are shown as green vertical dashed lines. In the case of Scenarios 2, 3 and 4, the graphs also include data from previous scenarios (e.g. Scenario 1 and 2 are plotted on the same figure) to allow the reader to compare scenarios. Figure 6 shows an annotated version of one of the output summary graphs for illustration purposes.

Table 7: Water quality objectives and guidelines

Parameter	Description	Value
Dissolved oxygen	PWQO[1] when water temperature exceeds 20°C	4 mg/L
Total phosphorus	Interim PWQO for rivers and streams	0.03 mg/L
Nitrate	Interim CEQG[2]	2.9 mg/L as N
Nitrate	ODWS[3]	10 mg/L as N
Un-ionized Ammonia	PWQO	0.0165 mg/L as N

1 Provincial Water Quality Objective

2 Canadian Environmental Quality Guideline for the protection of freshwater aquatic life, currently under review

3 Ontario Drinking Water Standard, this standard applies to treated drinking water but has been included for comparison purposes because the Grand River serves as a source of raw water for three local municipalities and nitrate is not removed using current treatment methods

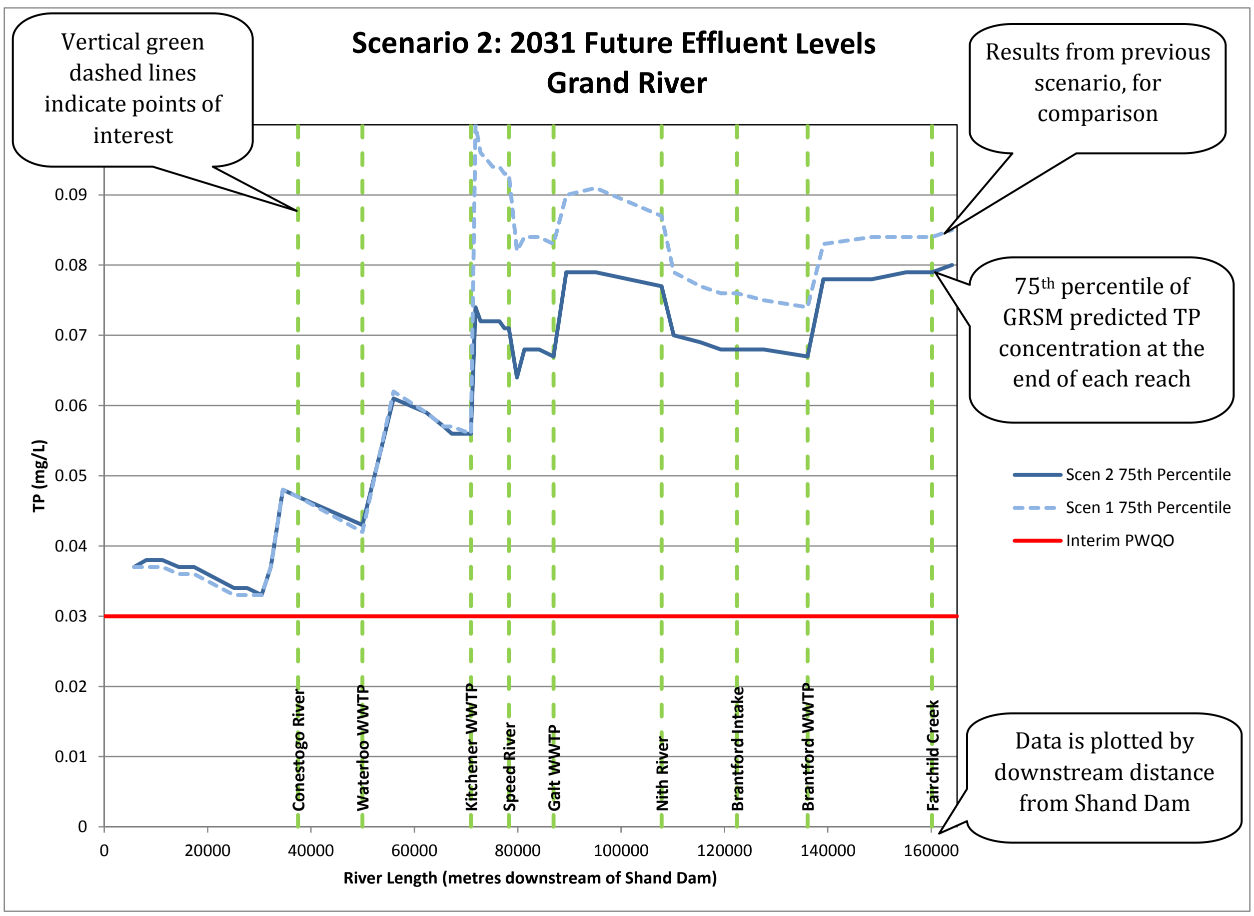


Figure 6: Annotated example of GRSM output summary graph

4.1. Summer Low Flow Conditions

Results for the base case Scenario 1 are shown in Figures B-1, B-2, B-3 and B-4. The results of Scenario 1 shown in Figures B-1 to B-4 are meant to illustrate water quality conditions in the central Grand and Speed Rivers under low flow summer conditions with current effluent flows and concentrations from municipal wastewater treatment plants. The results shown in these figures are consistent with the current understanding of water quality in the Grand River, i.e.:

- Dissolved oxygen levels are highly impacted between the Kitchener WWTP and the Speed River confluence. Dissolved oxygen falls below 4 mg/L very frequently (i.e. almost every day during the simulation period) and by a large amount (i.e. several events when dissolved oxygen is predicted to be at or near 0 mg/L);
- The 75th percentile of total phosphorus levels exceed the interim PWQO at most locations (except a portion of the Speed River between Guelph Lake and the Guelph WWTP) and they progressively increase at downstream reaches in response to cumulative discharges from the WWTPs ;
- Nitrate levels increase downstream of WWTPs but then there is some decline in concentration downstream of Cambridge due to dilution, biological uptake and denitrification; and
- Ammonia levels increase downstream of large WWTPs that do not currently nitrify but the levels decrease relatively quickly due to dilution, biological uptake, volatilization and nitrification in the river. The mass load of ammonia to the Grand and Speed Rivers represents a significant oxygen demand which exacerbates low dissolved oxygen conditions. Un-ionized ammonia levels exceed the PWQO and are a concern for aquatic toxicity.

Scenario 2 shows the expected impacts on river water quality under low flow summer conditions associated with future population growth and anticipated upgrades to wastewater treatment that will be implemented by 2031. GRSM results are summarized in Figures 7, 8, 9 and 10 for Scenario 2. Improvements and upgrades to wastewater treatment are reflected in the model output relative to current conditions (i.e. Scenario 1). The GRSM results show the following anticipated changes in water quality relative to Scenario 1:

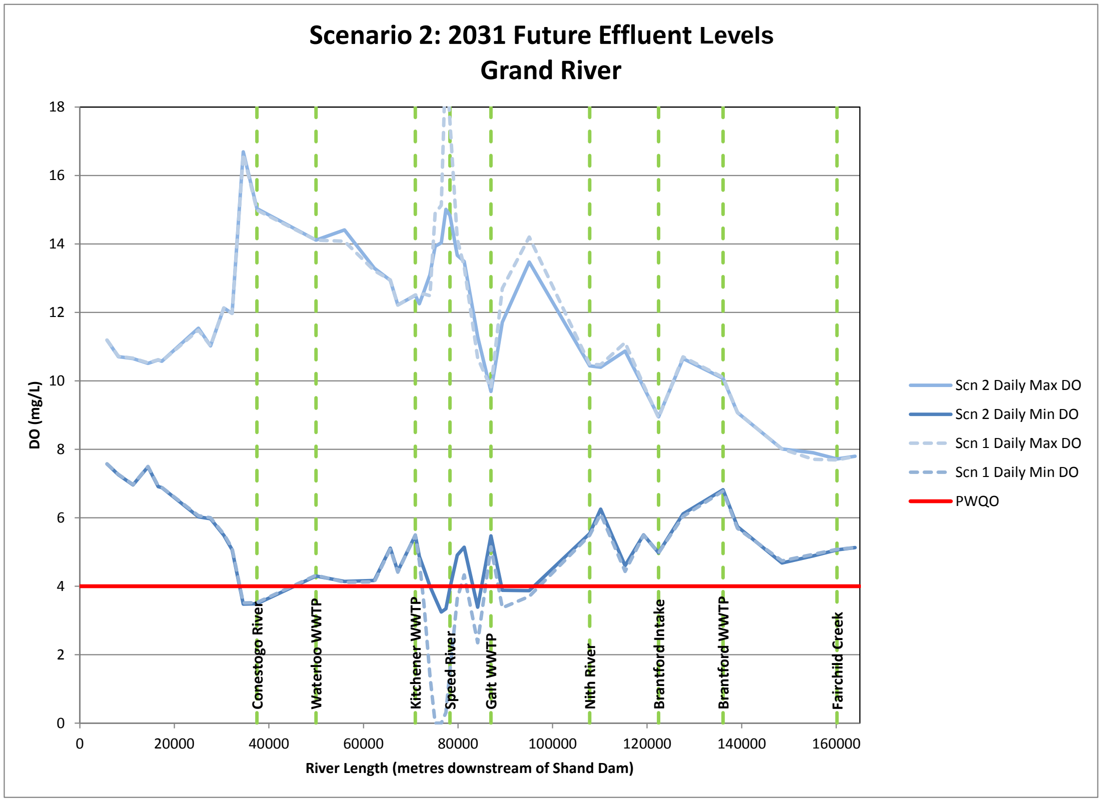
- Dissolved oxygen levels are expected to improve in the Blair reach of the Grand River downstream of the Kitchener WWTP due to upgrades that are currently being constructed and continue to be phased in over the next few years. Improvements will be reflected in a reduced frequency and severity of dissolved oxygen concentrations below 4 mg/L;
- The 75th percentile total phosphorus levels are expected to decrease from current conditions. Total phosphorus levels will decrease on average about 8% with some reaches realizing a reduction of up to 25% (i.e. 0.026 mg/L lower than Scenario 1). Although future levels are predicted to be lower than current conditions, total phosphorus concentrations will expected exceed the interim PWQO of 0.03 mg/L due to the nature of the hydrology, soils and land use in the Grand River Watershed.
- The 75th percentile un-ionized ammonia concentration is also predicted to decrease dramatically. Significant reductions in un-ionized ammonia concentrations downstream of

the Waterloo, Kitchener and Hespeler WWTPs are expected as these plants implement nitrification in future. Un-ionized ammonia levels in the summer are predicted to decrease by 97% in the most impacted reach. Reaches on the Grand and Speed Rivers that currently experience high un-ionized ammonia concentrations are expected to meet the PWQO in future.; and

- Nitrate levels are expected to increase as more WWTPs implement nitrification and therefore discharge higher levels of nitrate.

The daily maximum and minimum dissolved oxygen results shown in Figure 7 only provide part of the story by showing the lowest dissolved oxygen concentration that is predicted for any reach but it does not indicate how often this condition occurs. This is particularly relevant to heavily impacted areas such as the Blair reach downstream of the Kitchener WWTP which experiences very low dissolved oxygen levels almost every day during low flow summer conditions. Figure 11 shows a comparison of detailed GRSM output for the Blair reach (i.e. Reach 24 in GRSM) showing a continuous time series of dissolved oxygen levels under current and future conditions. Scenario 1, representing current conditions, shows dissolved oxygen levels that drop well below the Provincial Water Quality Objective on a frequent basis. Scenario 2 shows a dramatic improvement in oxygen conditions that are expected to result primarily from upgrades to the Kitchener WWTP. Under future conditions, dissolved oxygen levels are expected to be substantially higher with only a few days that are predicted to drop below the Provincial Water Quality Objective.

Figure 7: Scenario 2 Results, Low Flow Summer Conditions – Dissolved Oxygen



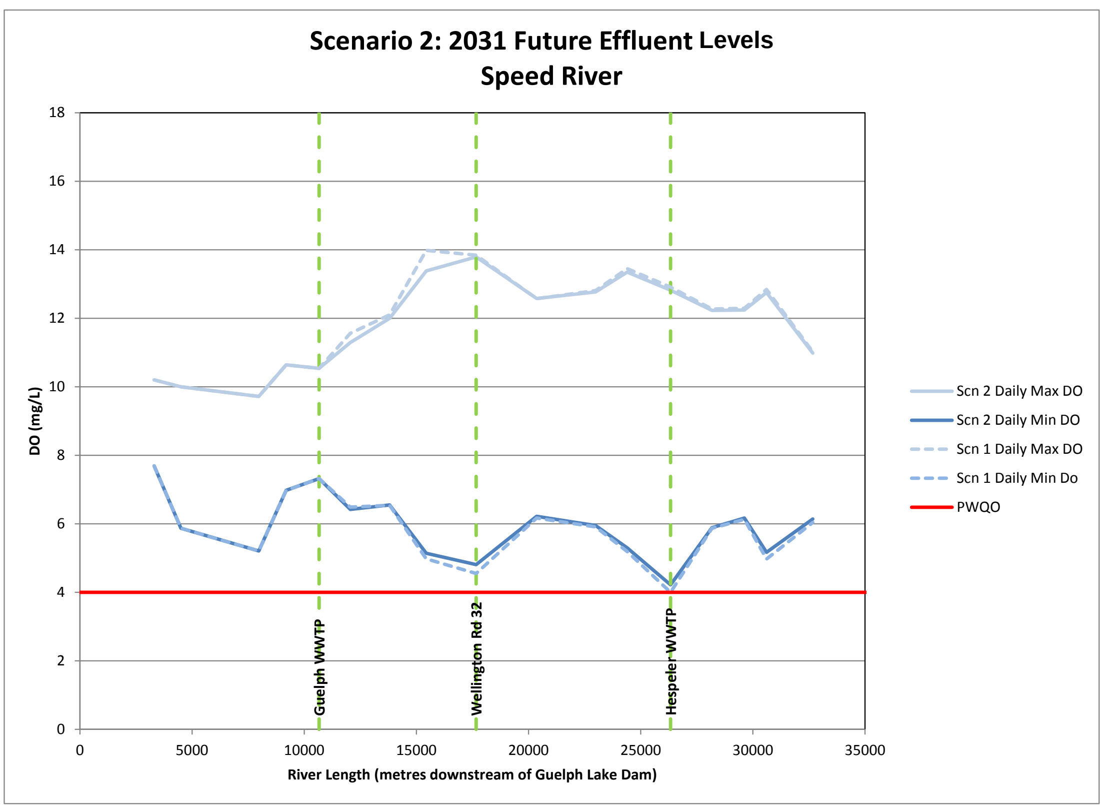
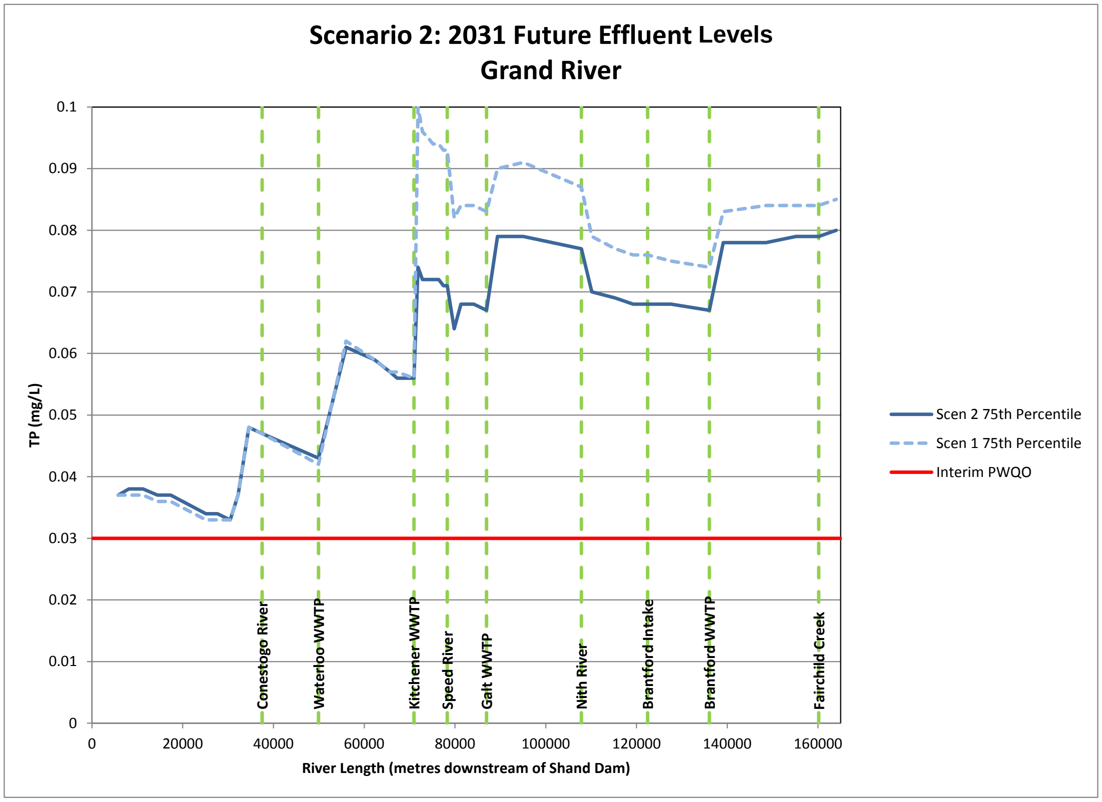


Figure 8: Scenario 2 Results, Low Flow Summer Conditions – Total Phosphorus



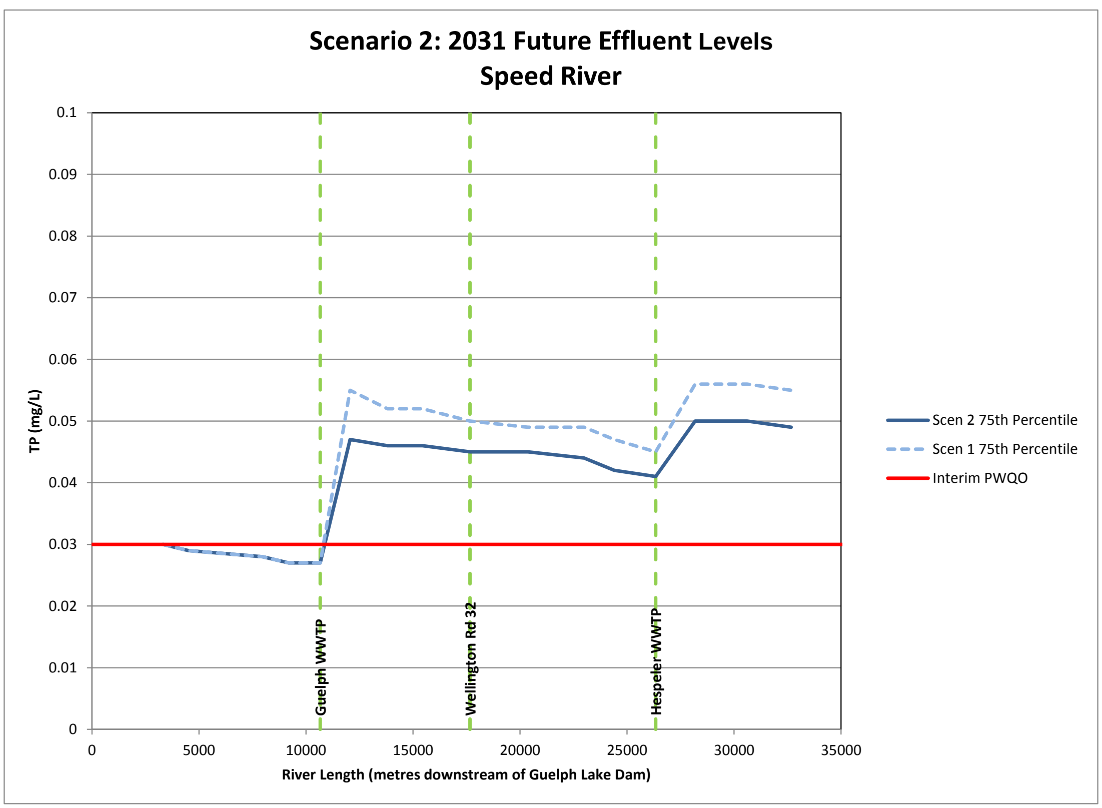
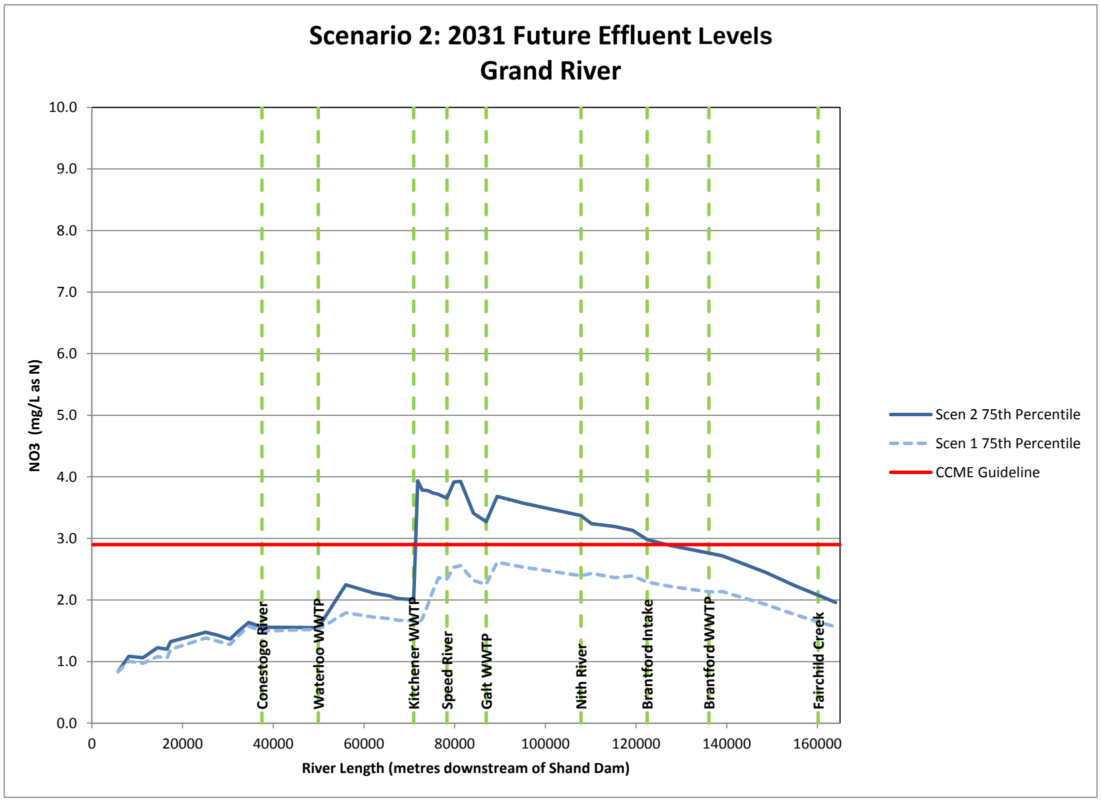


Figure 9: Scenario 2 Results, Low Flow Summer Conditions – Nitrate



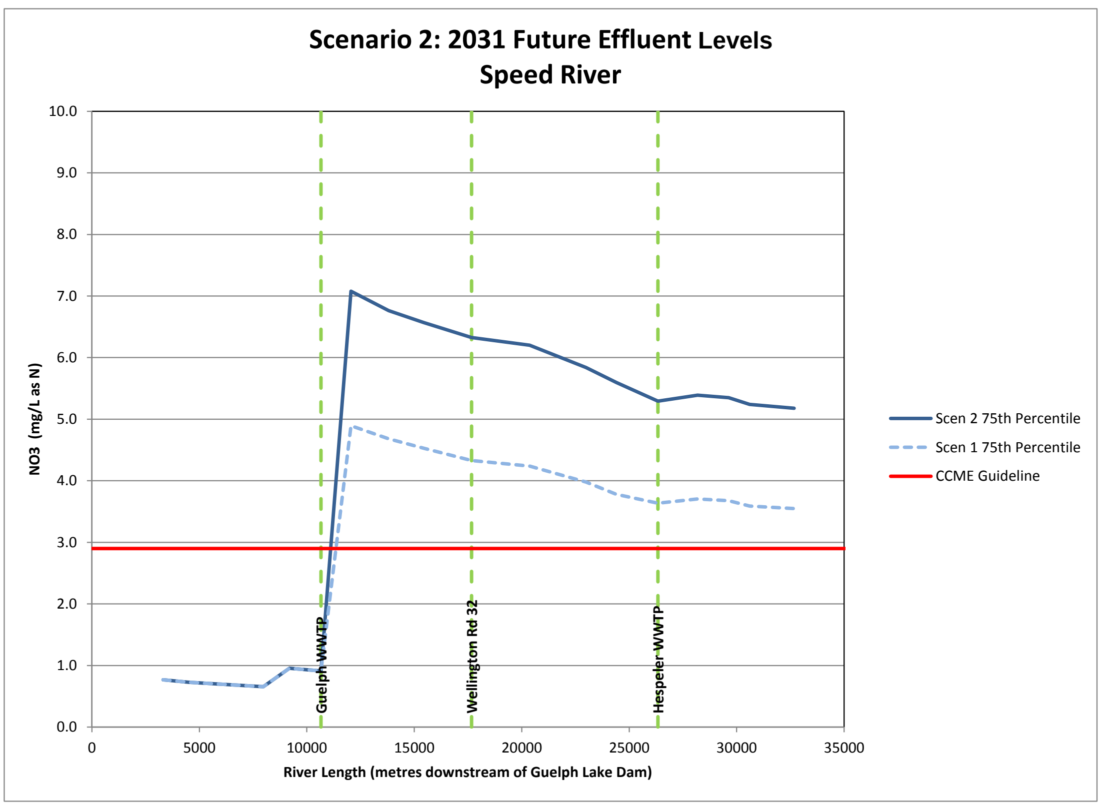
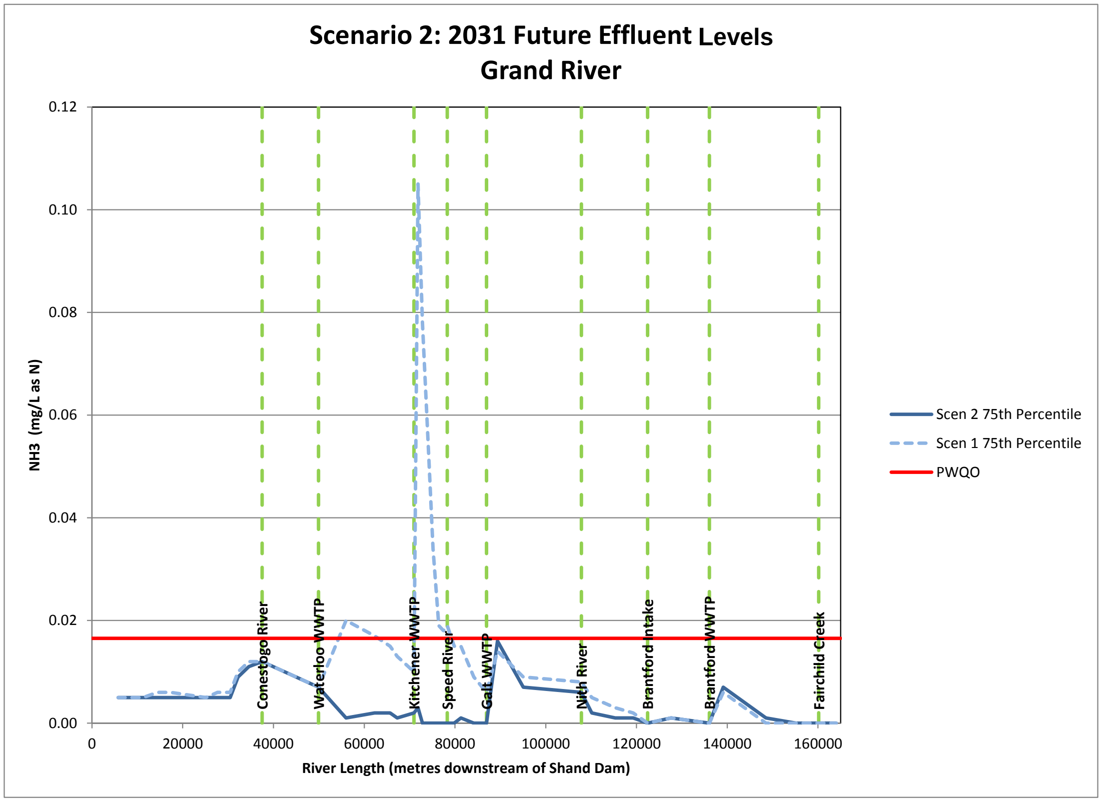


Figure 10: Scenario 2 Results, Low Flow Summer Conditions – Un-ionized Ammonia



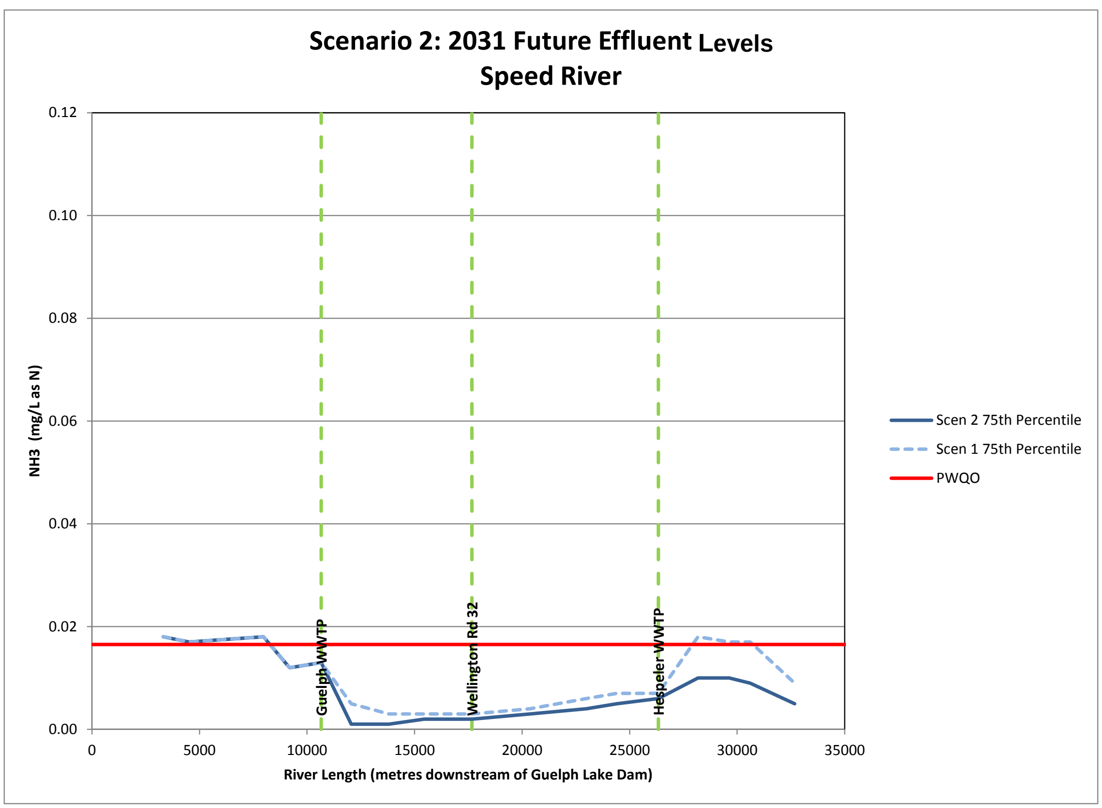
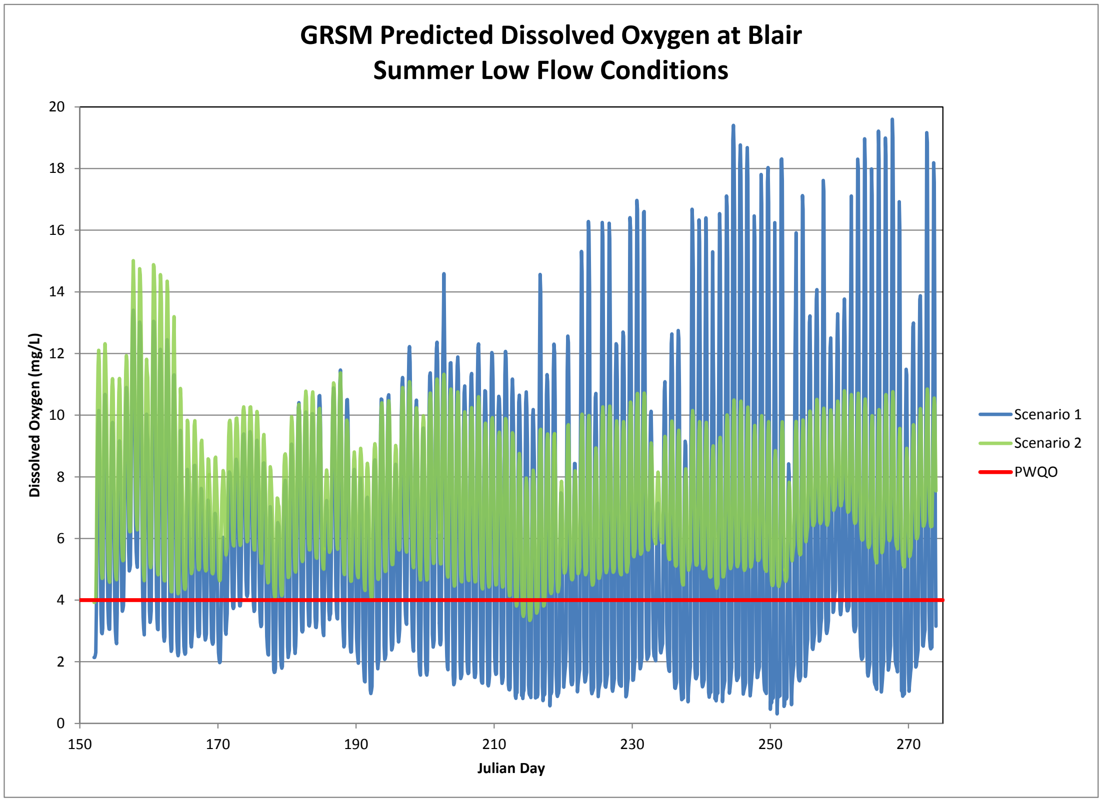


Figure 11: Comparison of Predicted Dissolved Oxygen Levels downstream of Kitchener WWTP under Low Flow Summer Conditions



Scenario 3 illustrates the benefits associated with optimization of WWTP operations to achieve consistent, high quality effluent through effective monitoring, process control and application of wastewater treatment concepts. This scenario is similar to Scenario 2 above with the additional assumptions that fully optimized WWTPs can produce final effluent with less than 1 mg/L total ammonia and less than 0.3 mg/L total phosphorus with tertiary filtration or less than 0.4 mg/L total phosphorus for WWTPs without tertiary filtration. The graphs shown in Figures B-9, B-10, B-11 and B-12 show the following changes in water quality associated with wastewater optimization relative to Scenario 2:

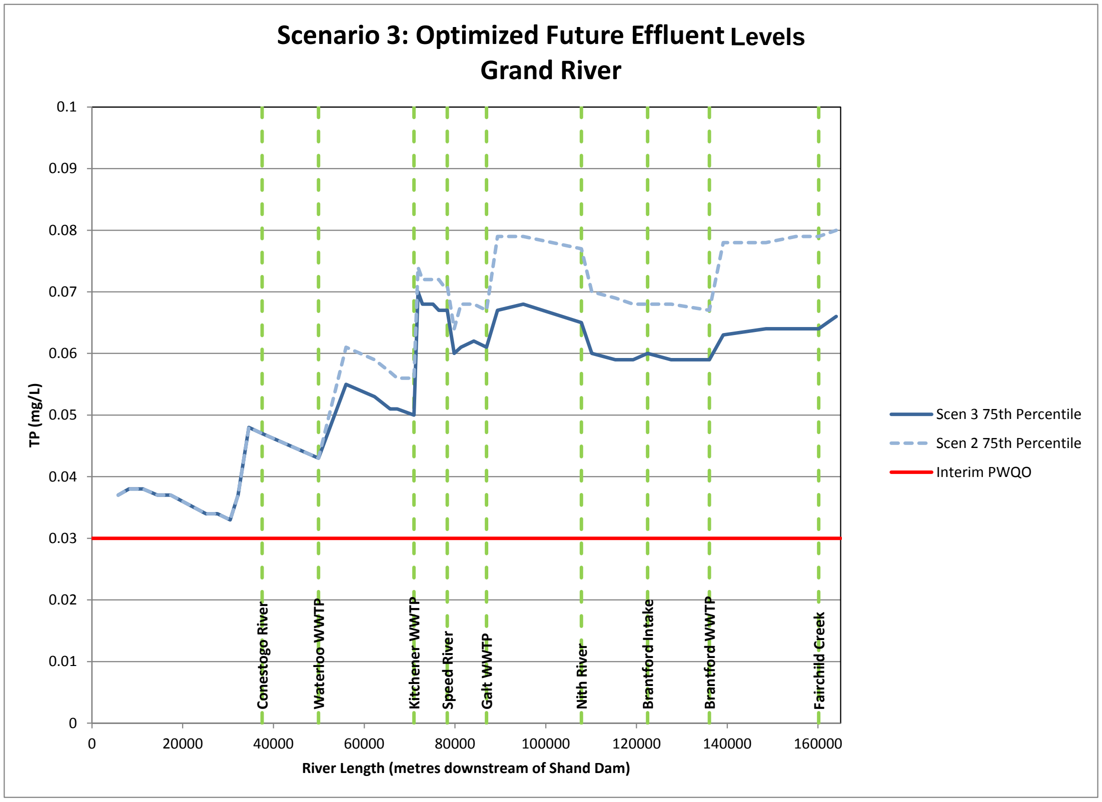
- Improved dissolved oxygen conditions in the Grand River due to reduced total phosphorus discharges from the optimized WWTPs;
- Total phosphorus and un-ionized ammonia concentrations are expected to decrease in the Grand River and the lower Speed River. Optimization of wastewater treatment plants to achieve lower total phosphorus operating targets is predicted to achieve additional significant improvements in total phosphorus levels in the Grand River of up to 19% (see Figure 12); and
- Slightly increased nitrate levels relative to Scenario 2 as a result of more efficient nitrification.

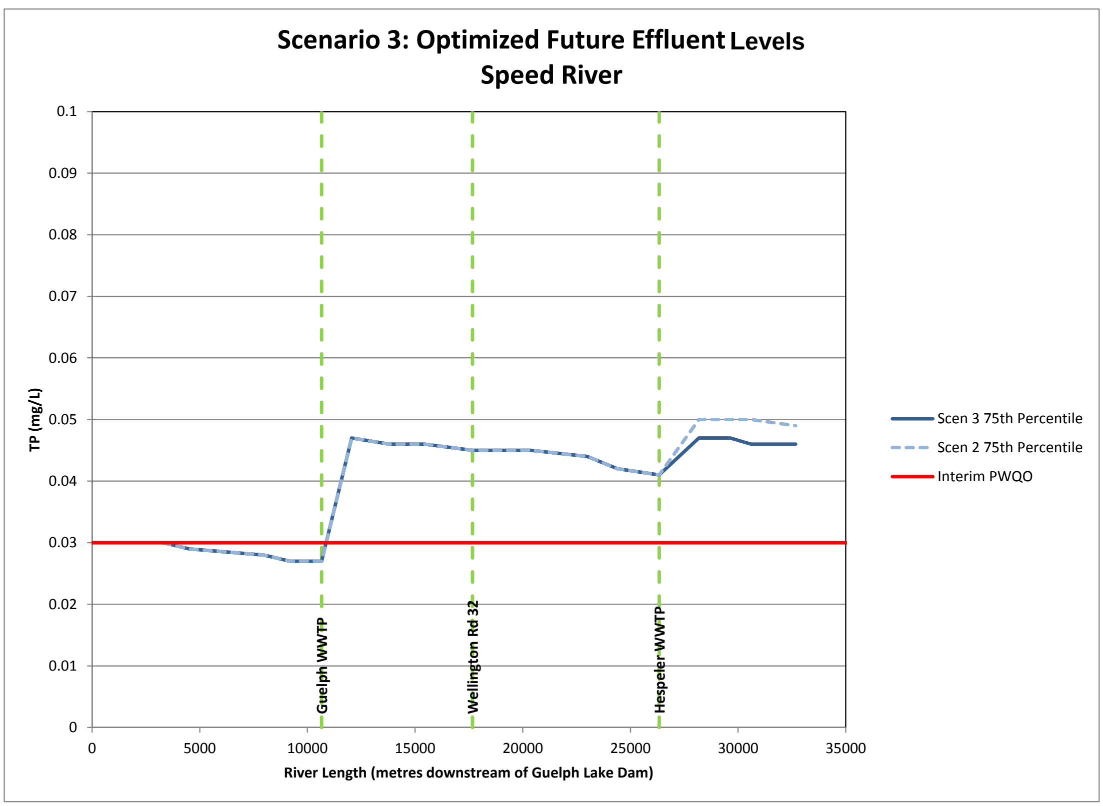
Results for Scenarios 4a (reduce rural/agricultural non-point sources by 10%) and 4b (reduce rural/agricultural non-point sources by 25%) are shown in Figures B-13, B-14, B-15 and B-16. Both scenarios have been summarized on a single graph for easy comparison. The results suggest the following:

- As expected, Scenario 4b shows improved water quality compared to Scenario 4a as mass loads of total phosphorus, nitrate and ammonia from rural/agricultural non-point sources are lower;
- Dissolved oxygen levels are improved in the upper Grand River between the Conestogo River confluence and the Waterloo WWTP relative to Scenario 2;
- Total phosphorus levels in the Grand River are predicted to be, on average, approximately 6 μg/L lower in Scenario 4a relative to Scenario 2. Slight reductions in total phosphorus in the Speed River are anticipated due to lower rural/agricultural non-point sources concentrations;
- Nitrate levels are very slightly influenced by agricultural non-point sources and decrease very little in Scenarios 4a and 4b compared to Scenario 2;
- Un-ionized ammonia concentrations are somewhat lower in Scenarios 4a and 4b compared to Scenario 2.

Figures B-17, B-18, B-19 and B-20 show the results for changes in non-point source nutrient concentrations in urban stormwater as illustrated in Scenario 4c (reduce urban non-point sources by 20%) and Scenario 4d (reduce urban non-point sources by 40%). Both scenarios have been summarized on a single graph for easy comparison. The results suggest that the GRSM is not sensitive to urban non-point sources concentrations of total phosphorus, nitrate and ammonia. Scenario 4c and 4d show little difference from one another and there is very little change from Scenario 2.

Figure 12: Scenario 3 Results, Low Flow Summer Conditions – Total Phosphorus





As mentioned previously, Scenario 4 is meant to illustrate the sensitivity of the model to reductions in non-point source concentrations from urban and rural/agricultural areas. The concentration reductions chosen for this scenario were arbitrary and there is insufficient information available to determined how these reductions would be realized or if they are achievable.

4.2. SPRING HIGH FLOW CONDITIONS

Results for the base case Scenario 1 under spring conditions are shown in Figures B-21, B-22, B-23 and B-24. These figures are meant to illustrate water quality conditions in the central Grand and Speed Rivers under spring runoff conditions with current effluent flows and concentrations from municipal wastewater treatment plants. The results shown in these figures are consistent with the current understanding of water quality in the Grand River, i.e.:

- Dissolved oxygen levels are consistently above 5 mg/L suggesting that dissolved oxygen is not a concern during this period.
- The 75th percentile of total phosphorus exceeds the PWQO at all locations and progressively increases at downstream reaches in response to cumulative mass loads from major tributaries such as the Conestogo and Nith Rivers;
- Nitrate levels in the Grand River are relatively consistent downstream of Irvine Creek with 75th percentiles between 3.5 and 4.5 mg/L. Nitrate concentrations in the Speed River are lower and increase somewhat in response to discharge from the Guelph WWTP; and
- Un-ionized ammonia levels are typically quite low due to cold water temperatures in the spring, although elevated levels are observed immediately downstream of the Kitchener WWTP.

Scenario 2 shows the expected impacts on river water quality under spring conditions associated with future population growth and anticipated upgrades to wastewater treatment that will be implemented by 2031. GRSM results are summarized in Figures B-25, B-26, B-27 and B-28 for Scenario 2. Improvements and upgrades to wastewater treatment are reflected in the model output relative to current conditions (i.e. Scenario 1). The GRSM results show the following anticipated changes in water quality relative to Scenario 1:

- Dissolved oxygen levels are expected to improve in the Grand River downstream of the Kitchener WWTP due to upgrades that are currently being constructed and continue to be phased in over the next few years;
- The 75th percentile total phosphorus and un-ionized ammonia levels are expected to decrease from current conditions. Total phosphorus levels in the spring are dominated by non-point source contributions and therefore reductions associated with WWTP upgrades will be modest during this period. Reductions in un-ionized ammonia concentrations downstream of the Waterloo, Kitchener and Hespeler WWTPs are expected as these plants implement nitrification in future; and
- Nitrate levels are expected to increase as more WWTPs implement nitrification and therefore discharge higher levels of nitrate.

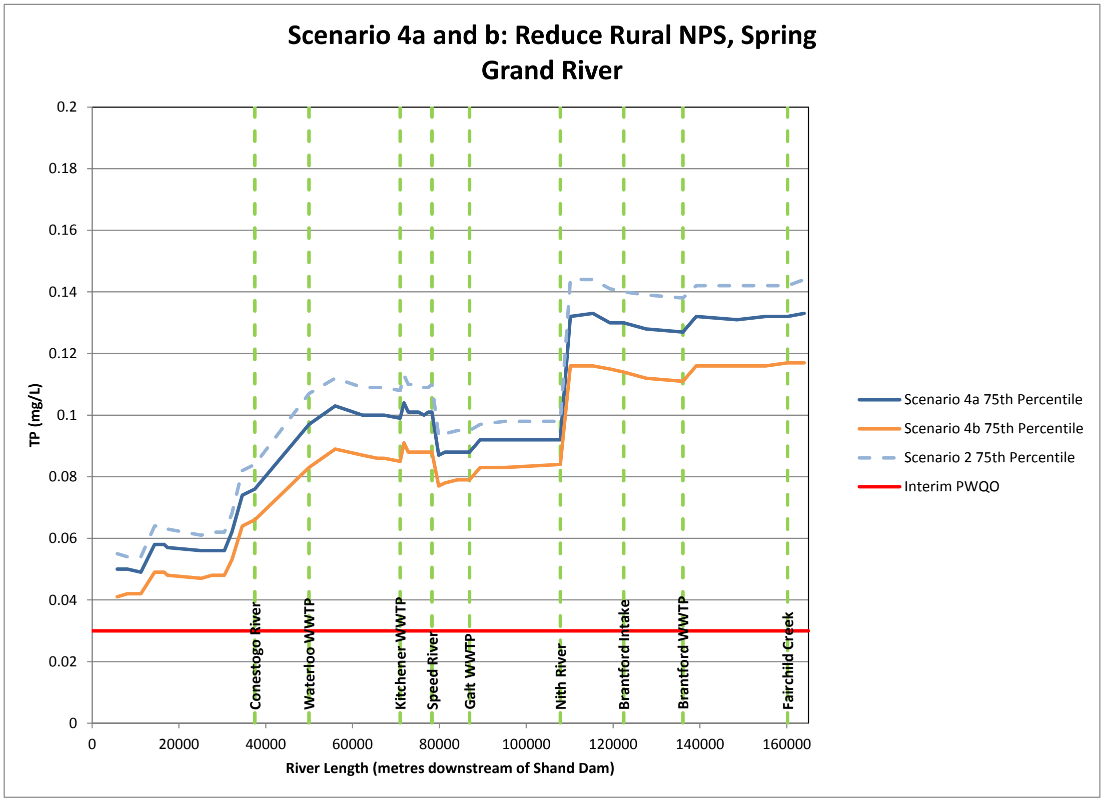
Figures B-29, B-30, B-31 and B-32 show the results for Scenarios 4a (reduce rural/agricultural non-point sources by 10%) and 4b (reduce rural/agricultural non-point sources by 25%), which consider changes in nutrient concentrations from major tributaries that are dominated by rural and agricultural lands. Both scenarios have been summarized on a single graph for easy comparison. The results suggest the following:

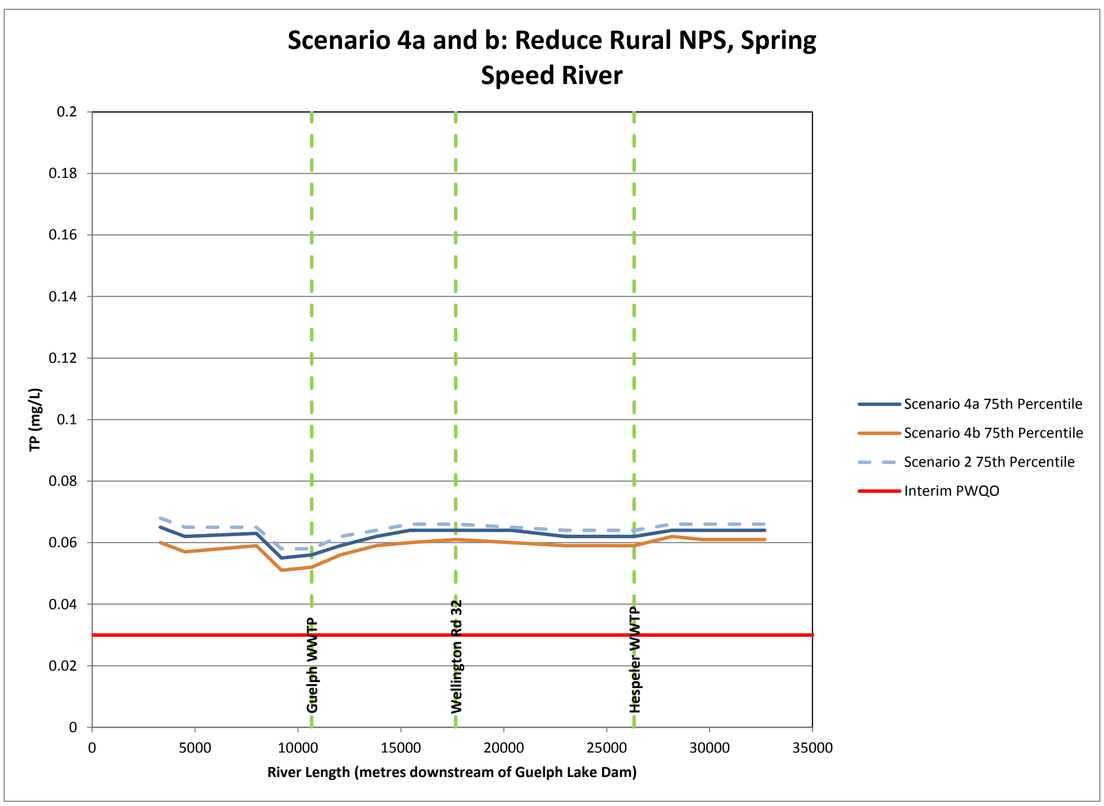
- As expected, Scenario 4b shows improved water quality compared to Scenario 4a as concentrations of total phosphorus, nitrate and ammonia from rural runoff are lower;
- Total phosphorus levels in the Grand River are predicted to be on average 20% or approximately 10 µg/L lower in Scenario 4a relative to Scenario 2, some areas may see a reduction up to 23% (see Figure 13). Scenario 4b shows a further reduction of total phosphorus of approximately 15 µg/L in the Grand River. Slight reductions in total phosphorus in the Speed River are anticipated due to lower rural/agricultural non-point source concentrations;
- Nitrate levels are only modestly influenced by rural/agricultural non-point sources and decrease slightly.

Figures B-33, B-34, B-35 and B-36 show the results for Scenarios 4c and 4d, which are meant to illustrate the sensitivity of the model to changes in NPS nutrient concentrations in urban stormwater. Both scenarios have been summarized on a single graph for easy comparison between Scenario 4c (reduce urban NPS by 20%) and Scenario 4d (reduce urban NPS by 40%). Scenario 4c and 4d show very little change from Scenario 2. These results suggest that the GRSM is not sensitive to urban NPS concentrations of total phosphorus, nitrate and ammonia. The lack of sensitivity of GRSM to changes in urban concentrations is likely due to several factors, described below.

A review of GRSM inputs for urban NPS was carried out and documented separately (Anderson 2011). That review found that the GAWSER model, which was used to generate urban runoff concentration and flow inputs for GRSM, appears to generate concentration estimates that are lower than expected. In addition, urban runoff tends to occur in very intense, short duration events during storms and snowmelt that tend to coincide with high river flows and high background nutrient concentrations. The impact of urban stormwater is likely to be localized and short in duration, these type of events are not well suited to analysis with a watershed-scale nutrient and dissolved oxygen model such as GRSM. The impacts associated with urban runoff are related to rapidly fluctuating flows, sediment load and delivery, and toxic contaminants such as heavy metals, petroleum hydrocarbons, etc. The impact of urban stormwater on the river's ability to assimilate nutrients is not well quantified or characterized and it is poorly understood. It is recommended that impact of urban runoff on the Grand and Speed Rivers be characterized and evaluated using more appropriate tools and approaches including monitoring and modeling. The influence of urban stormwater on water quality will be further investigated by the Stormwater Management Working Group as part of the current Water Management Plan work plan.

Figure 13: Scenario 4a and b Results, Spring – Total Phosphorus





4.3. WINTER LOW FLOW CONDITIONS

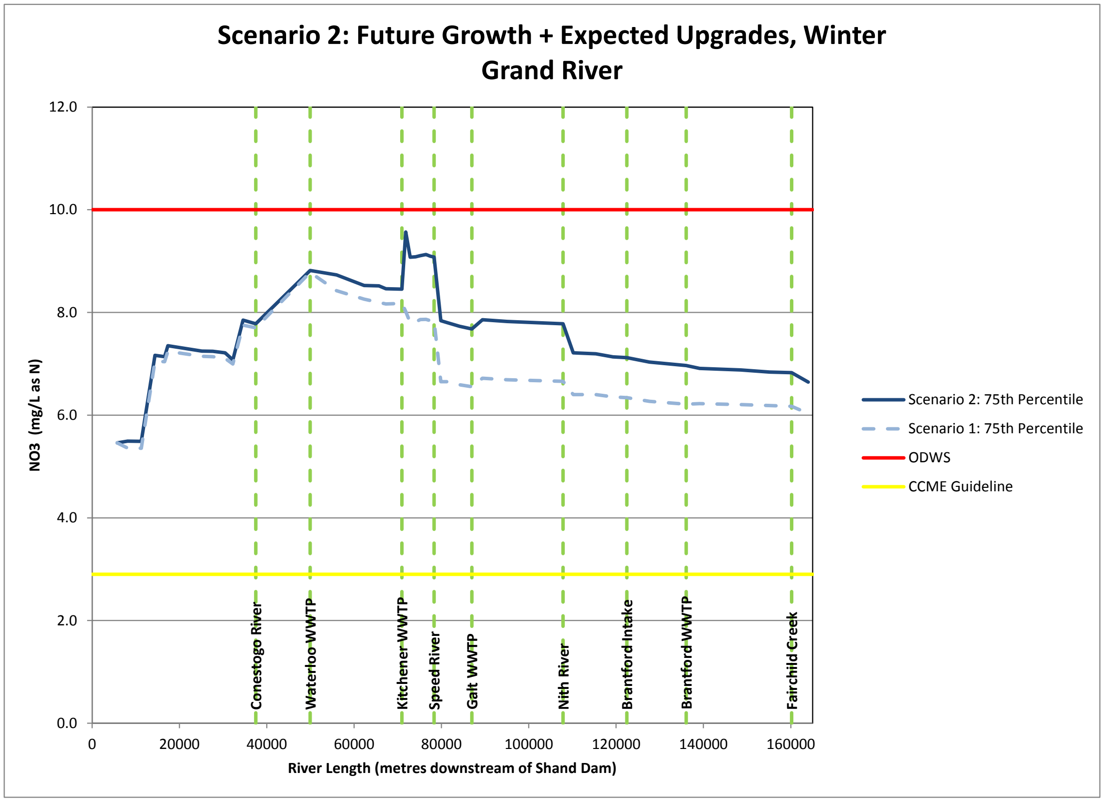
Results for the base case Scenario 1 under winter conditions are shown in Figures B-37, B-38, B-39 and B-40. These figures are meant to illustrate water quality conditions in the central Grand and Speed Rivers under winter conditions with current effluent flows and concentrations from municipal wastewater treatment plants. The results shown in these figures are consistent with the current understanding of water quality in the Grand River, i.e.:

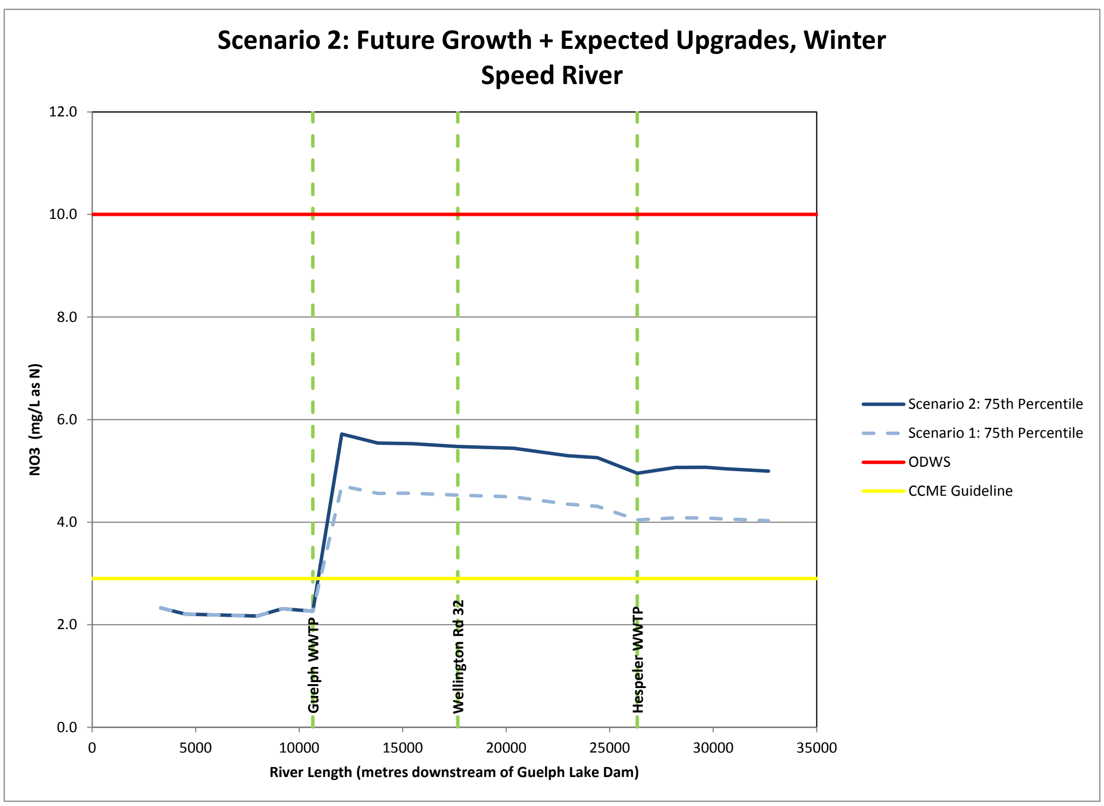
- Dissolved oxygen levels are consistently above 10 mg/L suggesting that dissolved oxygen is not a concern during the winter.
- The 75th percentile of total phosphorus exceeds the PWQO at all locations and progressively increases at downstream reaches in response to cumulative mass loads from WWTPs and major tributaries such as the Conestogo and Nith Rivers;
- Nitrate levels in the Grand River increase from the Shand Dam to the Waterloo WWTP and then decline slowly at points farther downstream. Nitrate concentrations in the Speed River are lower and increase somewhat in response to effluent discharge from the Guelph WWTP; and
- Un-ionized ammonia levels are typically quite low due to cold water temperatures and the model results suggest that un-ionized ammonia is not a concern during the winter period.

Scenario 2 shows the expected impacts on river water quality under winter conditions associated with future population growth and anticipated upgrades to wastewater treatment that will be implemented by 2031. GRSM results are summarized in Figures B-41, B-42, B-43 and B-44 for Scenario 2. Improvements and upgrades to wastewater treatment are reflected in the model output relative to current conditions (i.e. Scenario 1). The GRSM results show the following anticipated changes in water quality relative to Scenario 1:

- Dissolved oxygen levels are not expected to be substantially different in future under winter conditions;
- The 75th percentile total phosphorus and un-ionized ammonia levels are expected to decrease somewhat from current conditions. Total phosphorus levels in the winter are dominated by non-point source contributions during runoff events and therefore reductions associated with WWTP upgrades will be modest during this period. Reductions in un-ionized ammonia concentrations downstream of the Waterloo, Kitchener and Hespeler WWTPs are expected as these plants implement nitrification in future; and
- Nitrate levels are expected to increase as more WWTPs implement nitrification and therefore discharge higher levels of nitrate (see Figure 14). Although nitrate levels in future are expected to increase relative to current winter conditions, the 75th percentile is not anticipated to exceed 10 mg/L.

Figure 14: Scenario 2 Results, Winter – Nitrate





5. Summary and Conclusions

The results of the modeling scenarios presented in previous sections can be summarized as follows:

- Within the 2031 planning horizon, planned wastewater treatment plant upgrades will significantly improve river water quality, specifically:
    - dissolved oxygen levels in the summer are predicted to improve in heavily impacted reaches of the Grand and Speed rivers. The improvements will be reflected in reduced severity and frequency of low dissolved oxygen events. The greatest improvement will occur in the Blair reach;
    - total phosphorus levels in the summer are predicted to decrease, on average, by 8% with some reaches realizing a reduction of up to 25% (0.026 mg/L lower than current conditions). Although there will be a reduction in total phosphorus, it is expected that concentrations will continue to exceed the interim PWQO of 0.03 mg/L due to the nature of the watershed; and
    - un-ionized ammonia levels in the summer are predicted to decrease by 97% in the most impacted reach. Reaches on the Grand and Speed Rivers that currently experience high un-ionized ammonia concentrations are expected to meet the PWQO in future.

- Implementation of process optimization at wastewater treatment plants to achieve lower total phosphorus operating targets is predicted to achieve additional significant improvements in total phosphorus levels in the Grand River of up to 19%.

- During spring high flow conditions, significant increases in phosphorus levels in the Grand River result from rural runoff in areas such as the Conestogo, Canagagigue and Nith Rivers. Model predictions suggest that reducing total phosphorus delivery from rural runoff by 25% may result in a reduction of phosphorus levels in the Grand River by an average of 20% and as much as 23% (e.g. in the Grand River downstream of the Conestogo River). It should be noted that this study does not investigate the relative importance of areas where there are high concentrations of rural runoff or approaches to achieve the 25% reduction. Considerations should be made to combine GRSM and landscape scale non-point source modeling results to evaluate efforts to reduce source loads and compliment studies about implementation of best management practices. These questions will be investigated by the Water Quality Working Group as part of the Water Management Plan work plan.

- During low flow, cold winter conditions, background nitrate levels in the Grand River above the Region of Waterloo increase considerably (an estimated 3.4 mg/L) between the Shand Dam and Bridgeport. The source of these elevated nitrate levels is not known.

- Nitrate levels in the Grand River will also increase as a result of planned treatment upgrades, e.g. nitrification at the Waterloo and Kitchener Wastewater Treatment Plants; however, the magnitude of increase resulting from wastewater treatment plant upgrades is small (approximately 1.1 mg/L increase) compared to background levels from non-point sources. Nitrate levels in the Grand River are expected to remain elevated downstream toward

Brantford and may approach levels that can be of concern to drinking water intakes, especially during the winter.

- Urban non-point source impacts on the river's ability to assimilate nutrients (i.e. waste assimilation) are not well quantified or characterized and are poorly understood. The mechanisms or processes involved in urban non-point source delivery and the impact of urban stormwater on the river requires a different monitoring/modelling approach. While further work to characterize urban non-point source delivery has not been included in this study, it will be investigated further by the Stormwater Management Working Group as part of the current work plan.

The following conclusions have been made based on the findings presented above and are relevant to water management planning:

1. Implementation of planned wastewater treatment upgrades will result in significant improvements to water quality, in particular:
    a. The Elora Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration
    b. The Waterloo Wastewater Treatment Plant upgrade to include nitrification
    c. The Kitchener Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration
    d. The Hespeler Wastewater Treatment Plant upgrade to include nitrification
    e. The Paris Wastewater Treatment Plant upgrade to include nitrification and tertiary filtration (note: it has been assumed that Paris will require nitrification and tertiary filtration upgrades but this has not been determined through a formal Environmental Assessment or Waste assimilation Assessment process)
2. Adoption of wastewater treatment plant performance optimization as a best practice by watershed municipalities is an important next step for water quality improvement, given its proven cost-effectiveness. Optimized operating targets for total phosphorus could be established as follows:
    a. The Fergus and Galt Wastewater Treatment Plants are currently equipped with tertiary filtration and should aim for a monthly average total phosphorus concentration of 0.3 mg/L
    b. The Elora, Kitchener, Hespeler and Paris Wastewater Treatment Plants will be upgraded to include tertiary filtration and should aim for a monthly average total phosphorus concentration of 0.3 mg/L once these upgrades have been completed. An interim target of 0.4 mg/L total phosphorus should be adopted by these wastewater treatment plants until tertiary filtration is implemented
    c. The Guelph Wastewater Treatment Plant has established an optimized treatment objective of 0.15 mg/L total phosphorus
    d. Secondary wastewater treatment plants such as Waterloo, Preston and Brantford should aim for a monthly average total phosphorus concentration of 0.4 mg/L
3. Continued work with rural and agricultural landowners to reduce rural runoff is important to maintain and enhance water quality beyond what will be achieved through wastewater

treatment upgrades and optimization. This is essential to build watershed resilience in the Grand River system.

4. Nitrate concentrations in the Grand River during the winter are a concern for municipal raw water supplies and there is a likelihood that they will increase into the future. Investigation of the sources of elevated nitrate concentrations in the central Grand River is warranted. Appropriate and cost effective source controls or mitigation can be applied once the sources are identified.
5. While population growth projections and changes in effluent quality due to upgrades or optimization at the 20 smaller wastewater treatment plants have not been incorporated into the model, each plant may have water quality impacts that need to be assessed within a local context.
6. The GRSM is an effective decision support tool that enables watershed municipalities and partners to evaluate the cumulative effects of point and non-point source management approaches for the Grand and Speed Rivers for the purposes of strategic planning.
7. Continuous monitoring data underpins the ability to measure progress over time and to calibrate/validate the GRSM to predict future conditions of water quality for water management planning in the Grand River watershed.

6. REFERENCES

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APPENDIX A: GRSM CALIBRATION FIGURES

Figure A-1: Daily Maximum and Minimum Dissolved Oxygen Concentration – Winter 2007

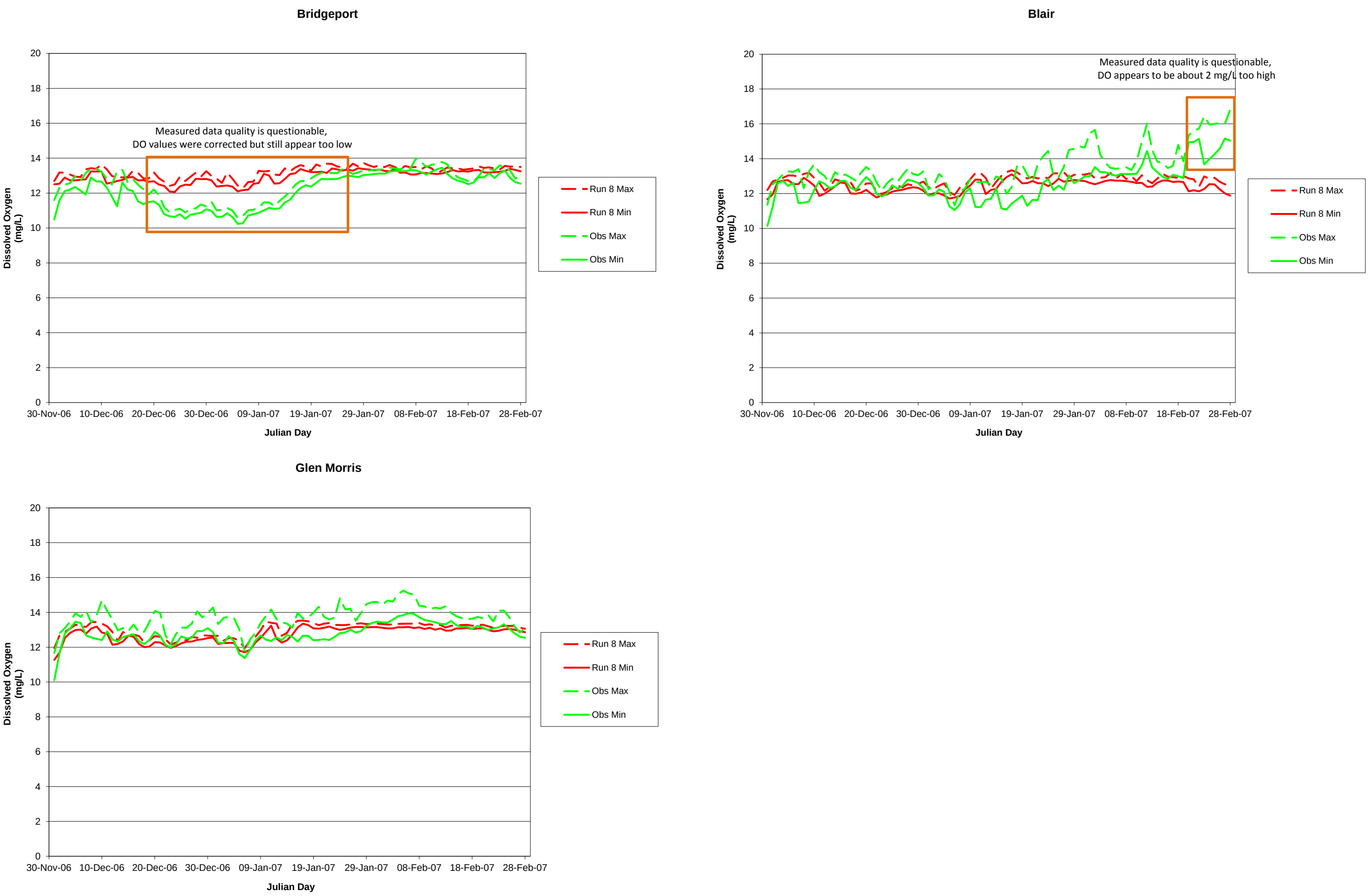
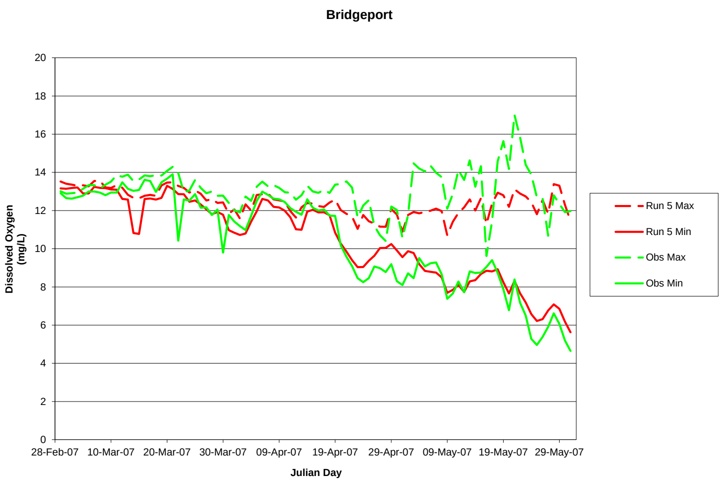
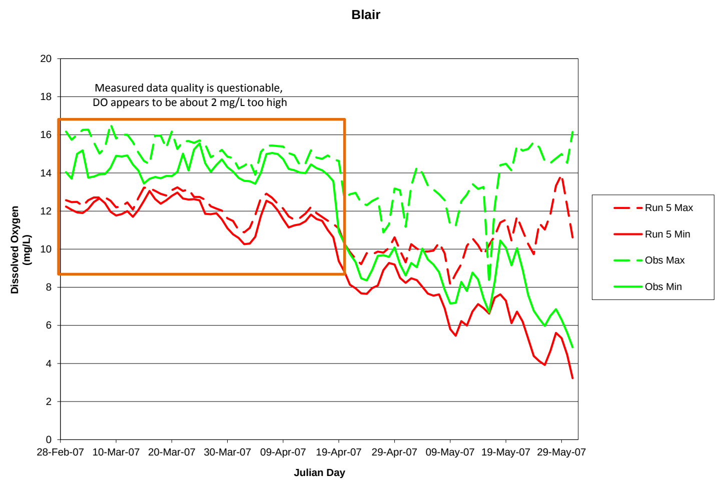


Figure A-2: Daily Maximum and Minimum Dissolved Oxygen Concentration – Spring 2007





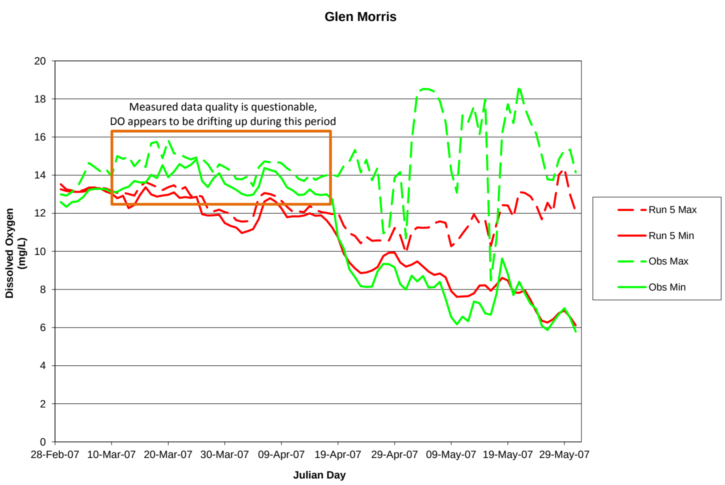
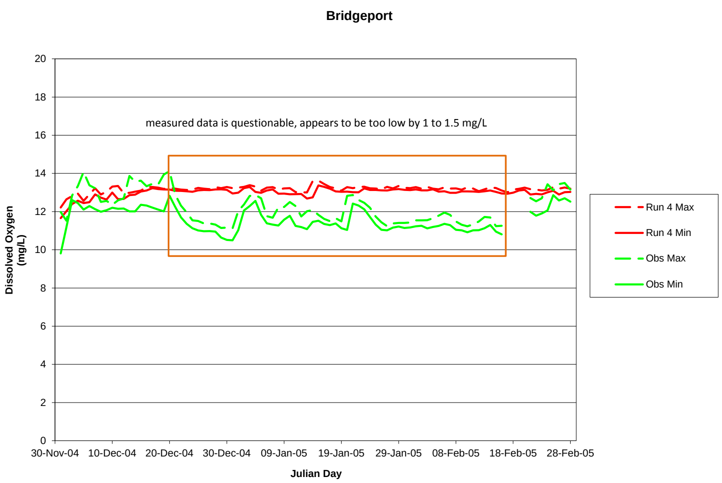
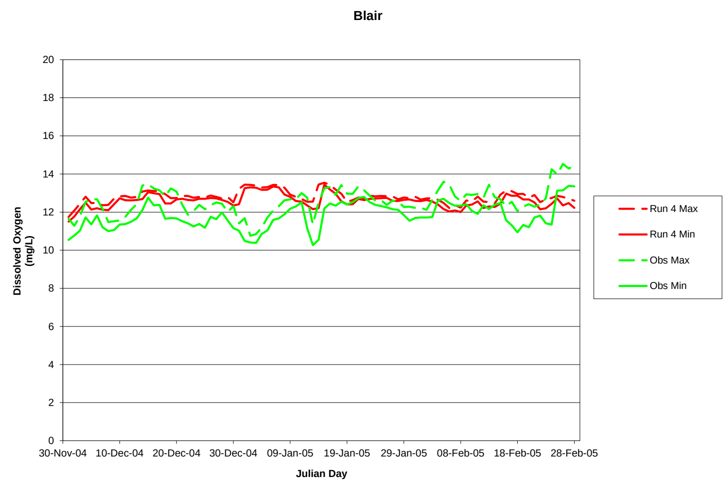


Figure A-3: Daily Maximum and Minimum Dissolved Oxygen Concentration – Summer 2007

Figure A-4: Daily Maximum and Minimum Dissolved Oxygen Concentration – Winter 2005





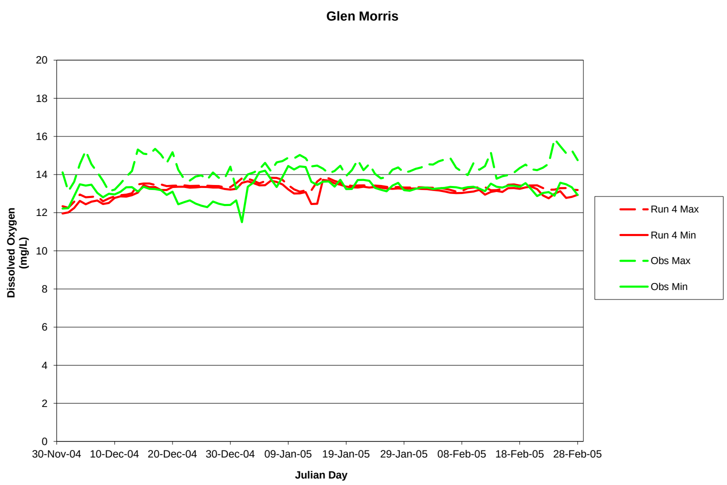
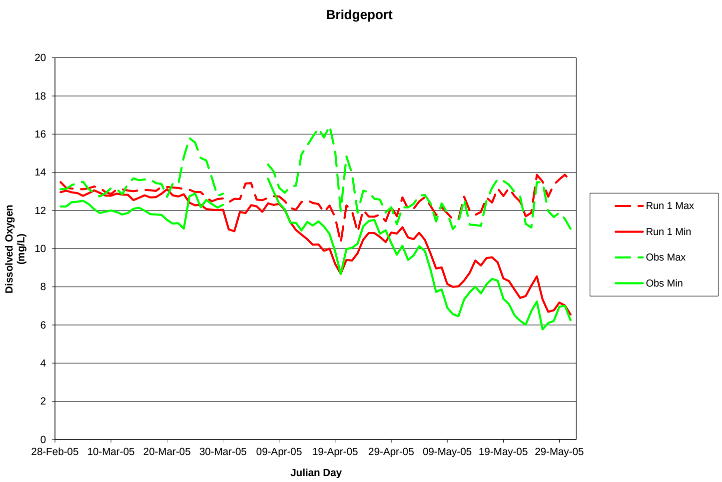


Figure A-5: Daily Maximum and Minimum Dissolved Oxygen Concentration – Spring 2005



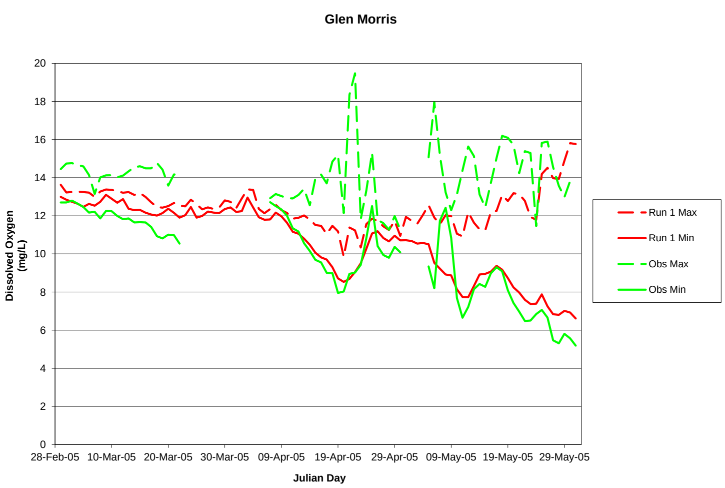
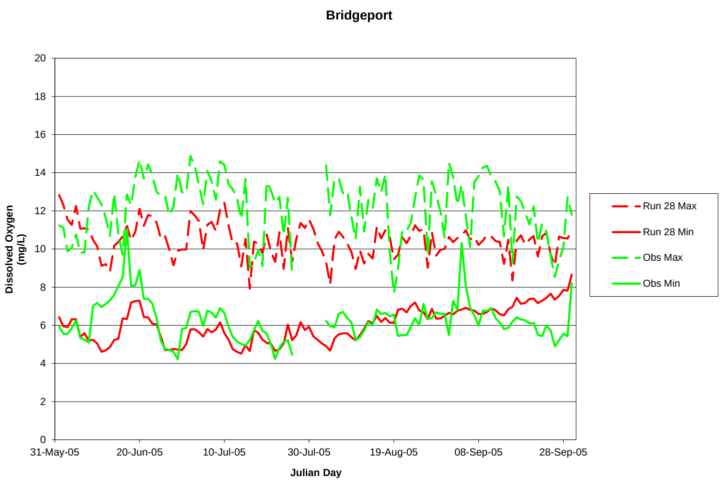
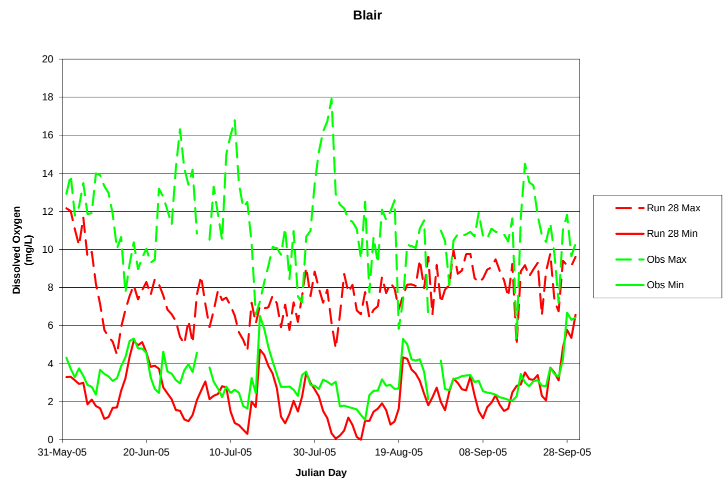
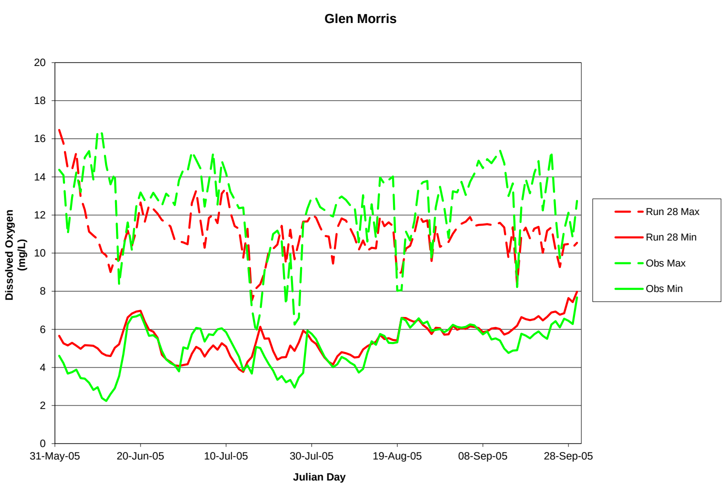
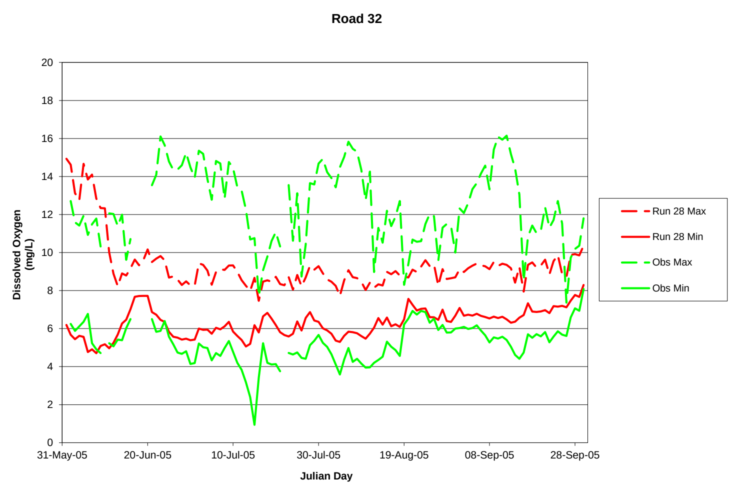


Figure A-6: Daily Maximum and Minimum Dissolved Oxygen Concentration – Summer 2005









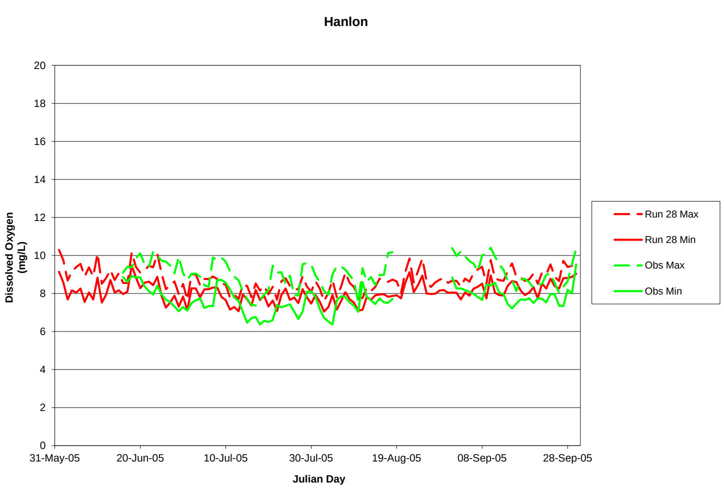
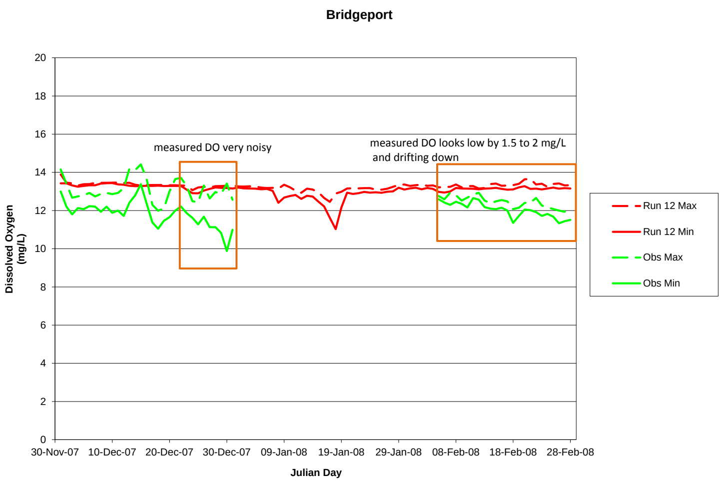
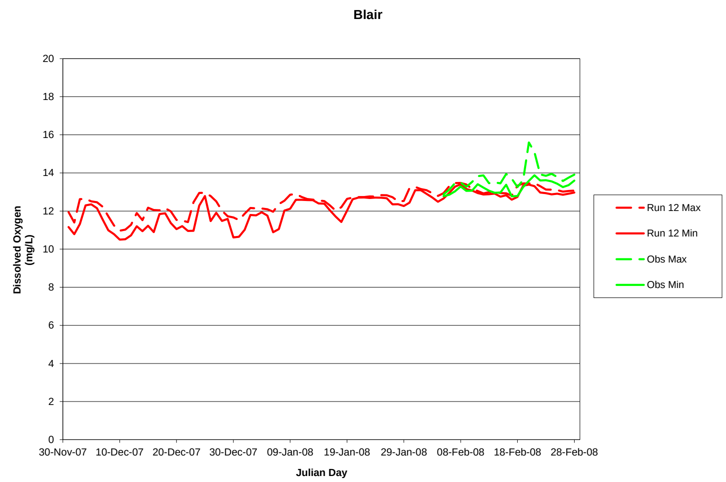


Figure A-7: Daily Maximum and Minimum Dissolved Oxygen Concentration – Winter 2008





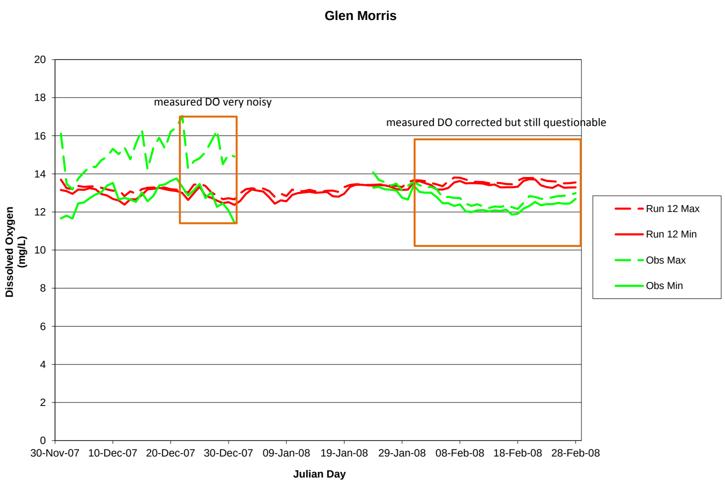
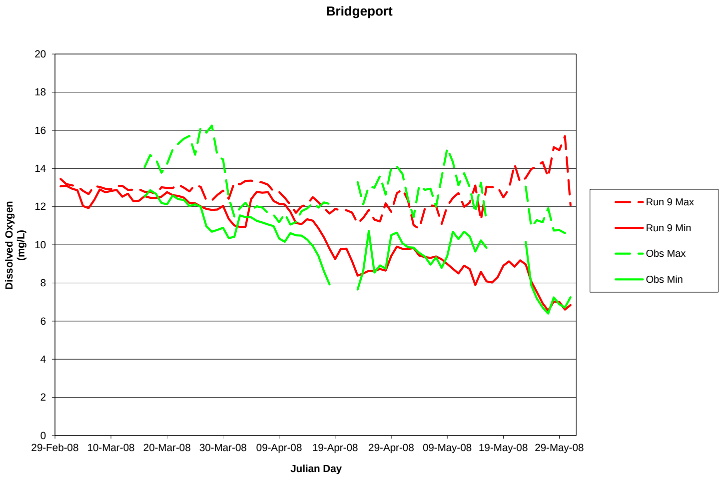


Figure A-8: Daily Maximum and Minimum Dissolved Oxygen Concentration – Spring 2008



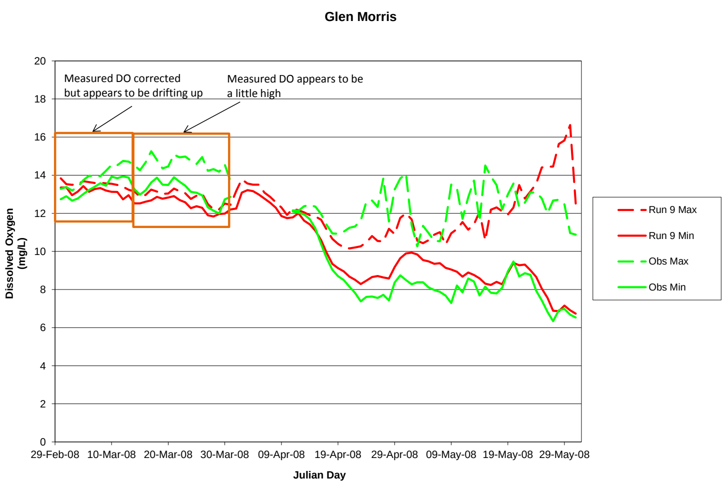
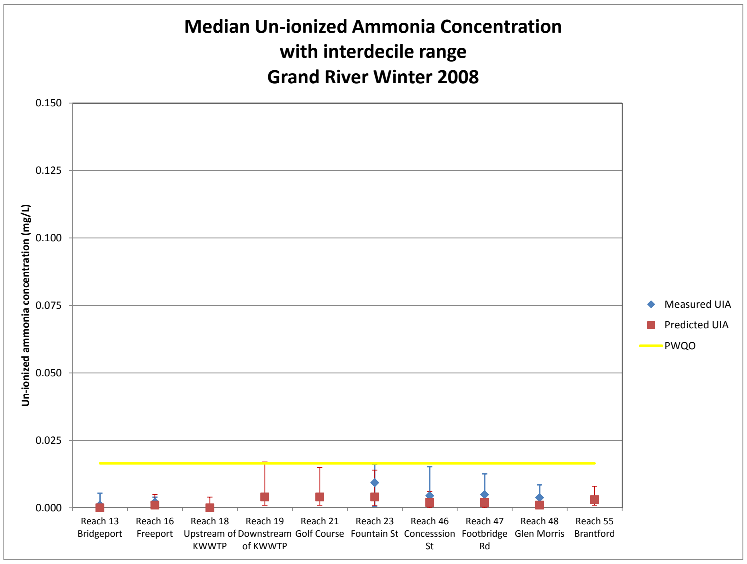
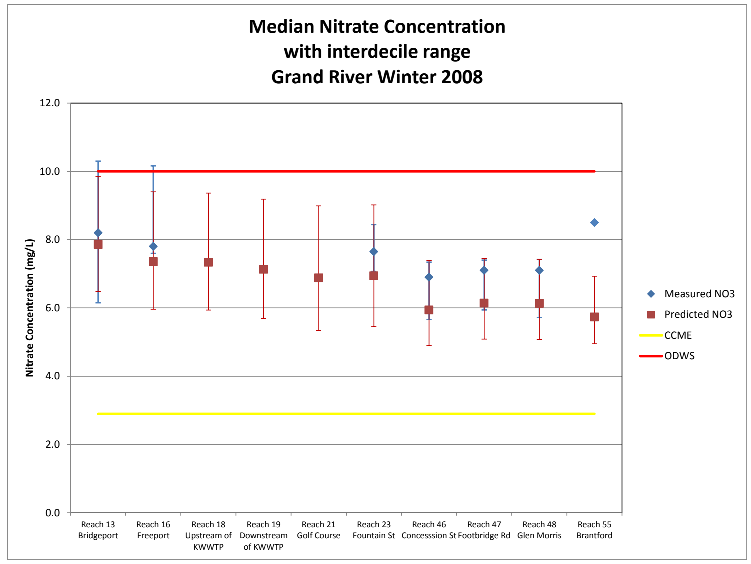
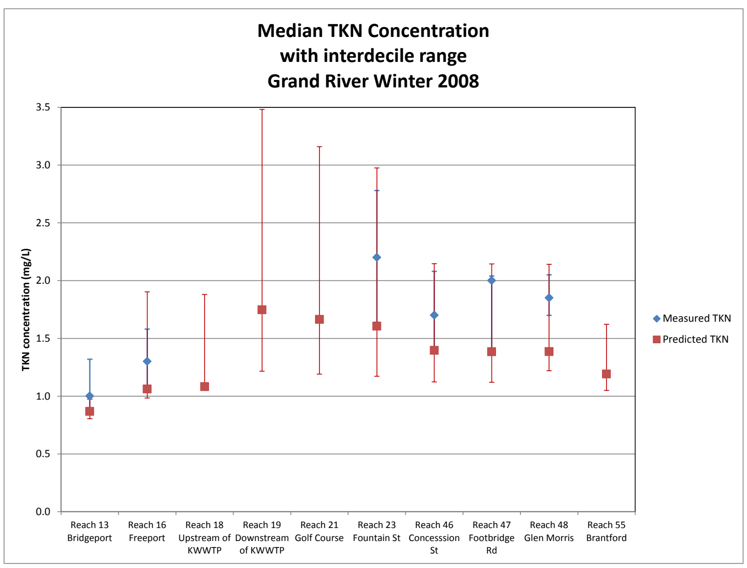


Figure A-9: Daily Maximum and Minimum Dissolved Oxygen Concentration – Summer 2008

Figure A-10(a): Measured and Predicted Nutrient Concentrations in the Grand River – Winter 2008







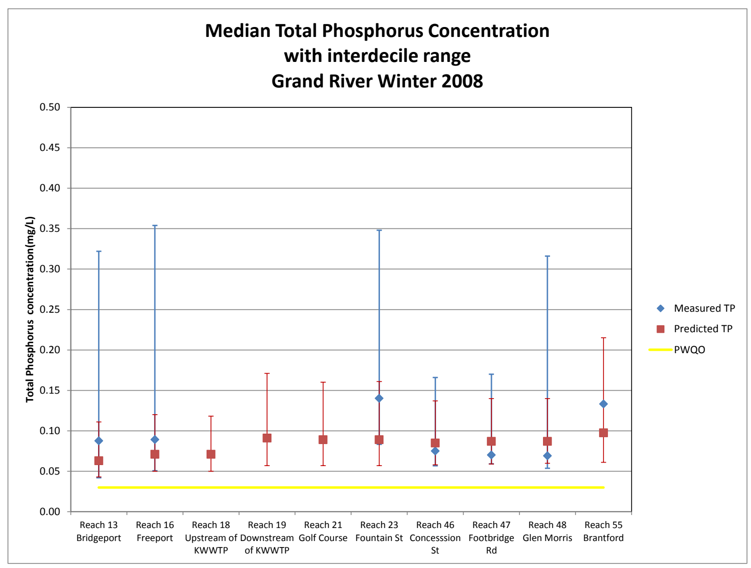


Figure A-10(b): Measured and Predicted Nutrient Concentrations in the Speed River – Winter 2008

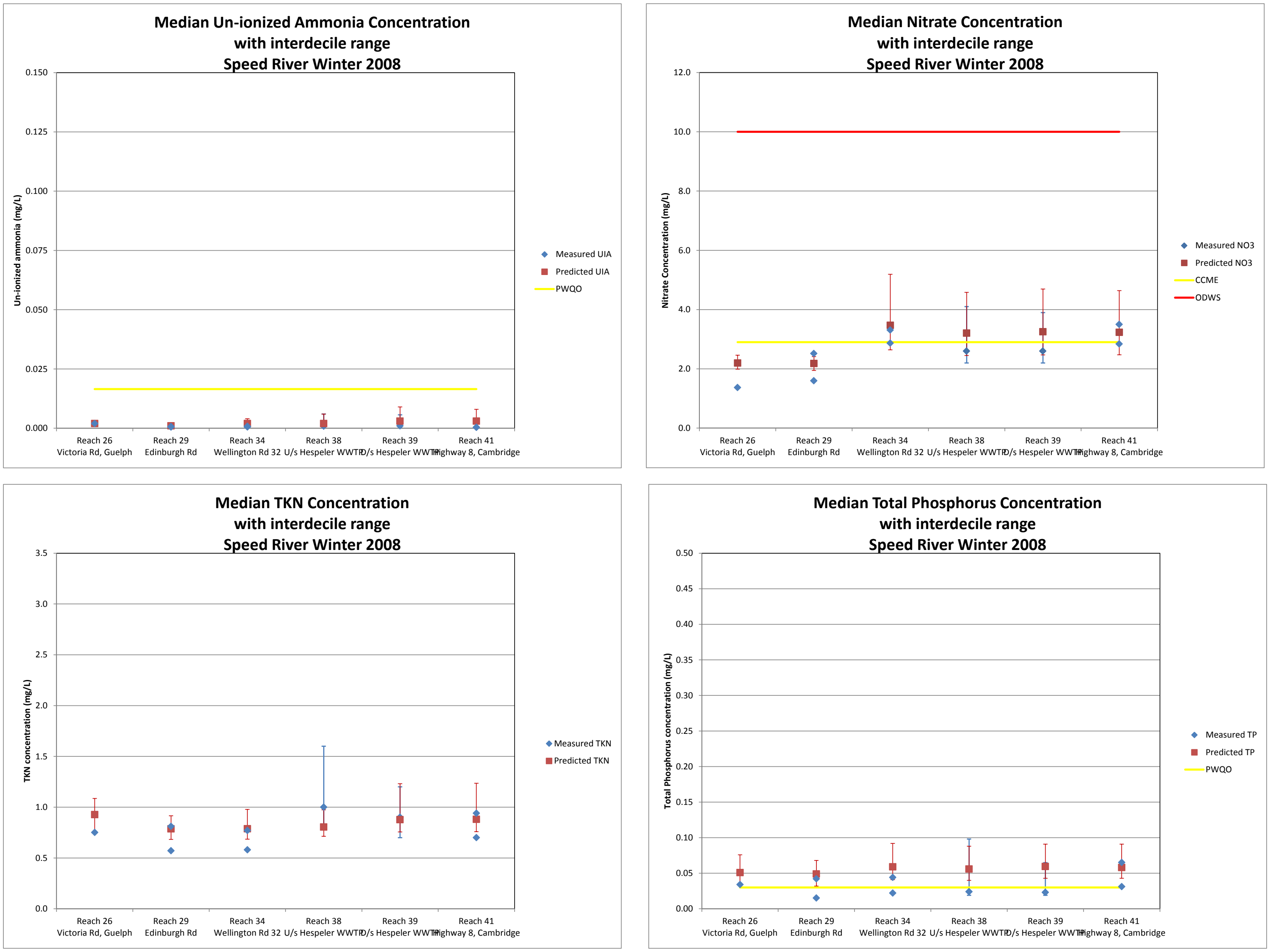
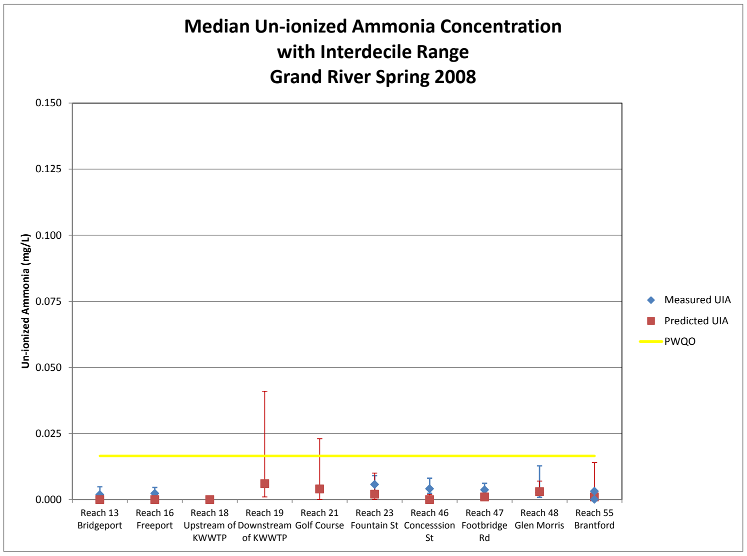
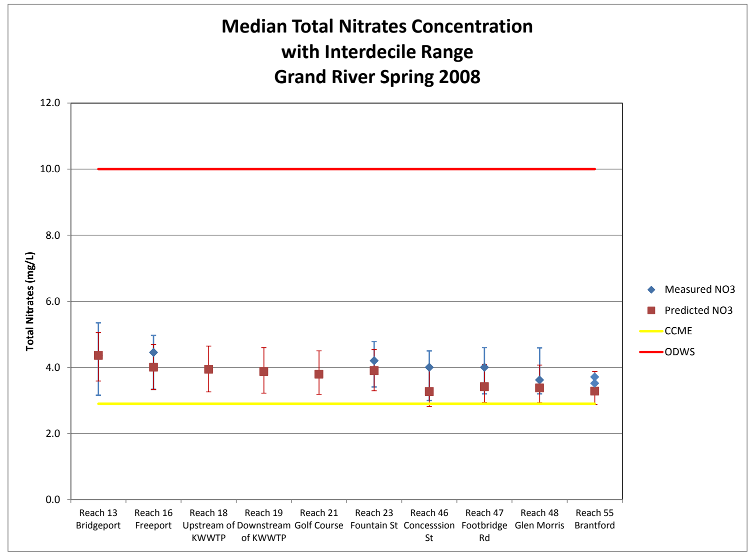
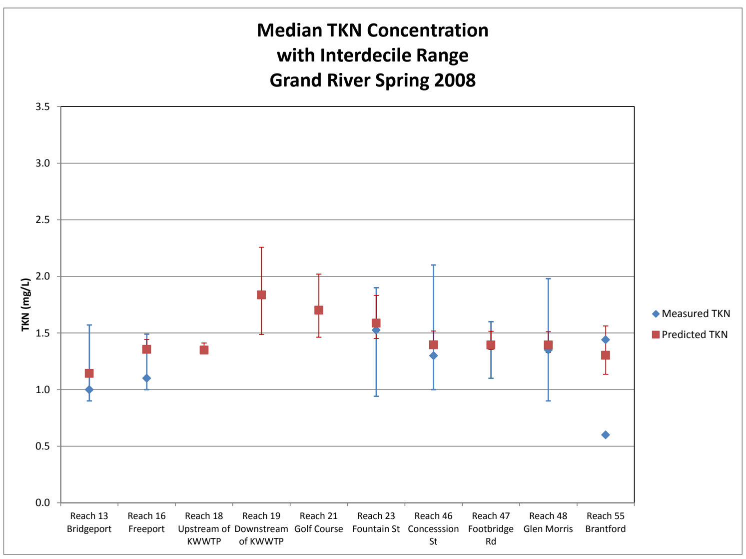


Figure A-11(a): Measured and Predicted Nutrient Concentrations in the Grand River – Spring 2008







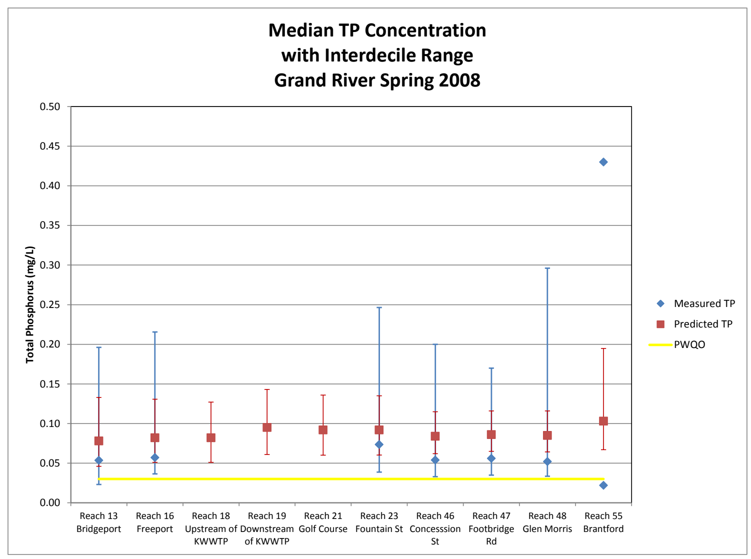
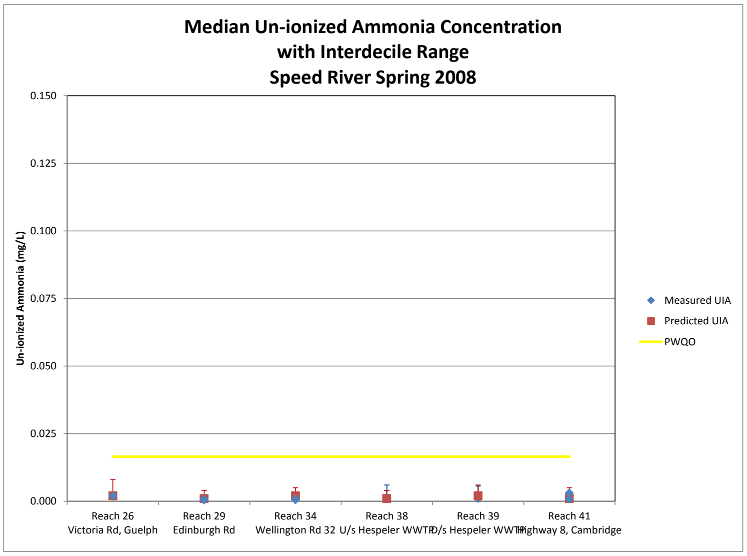
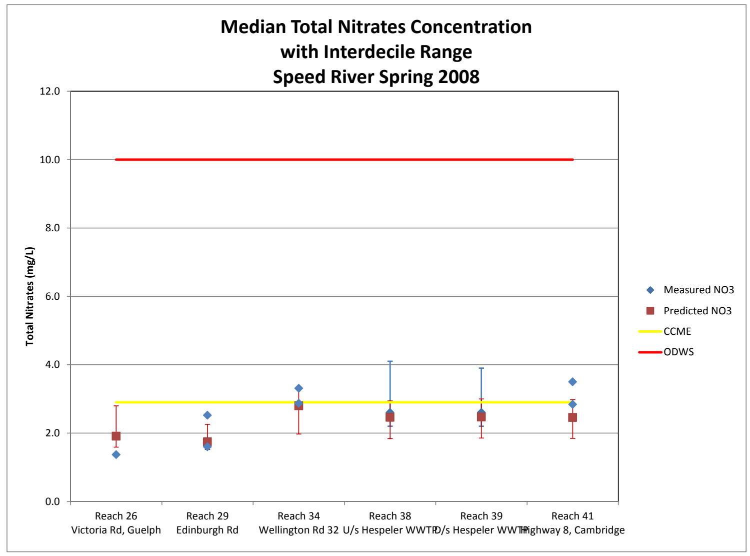
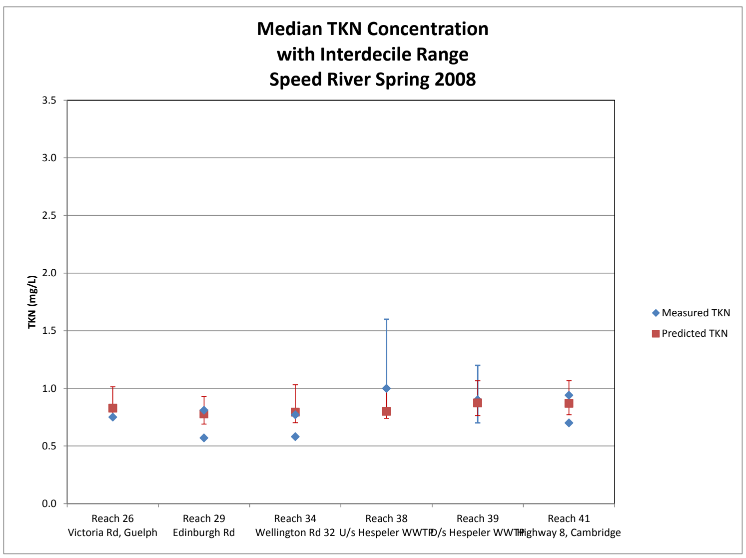


Figure A-11(b): Measured and Predicted Nutrient Concentrations in the Speed River – Spring 2008







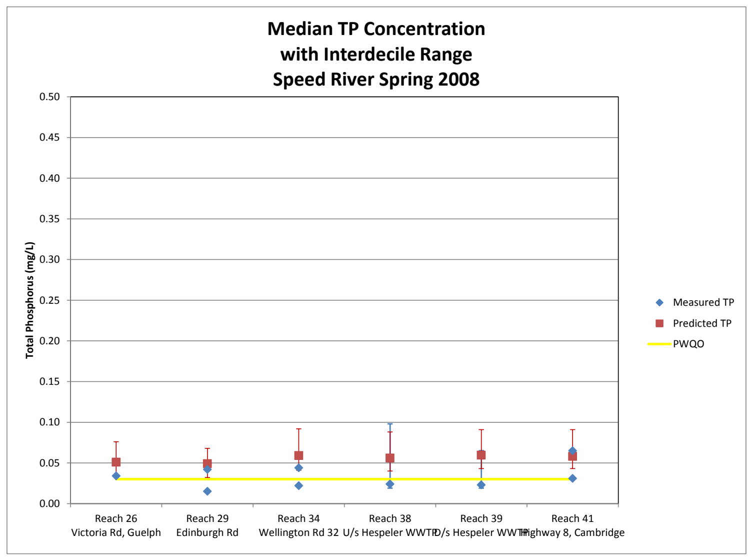
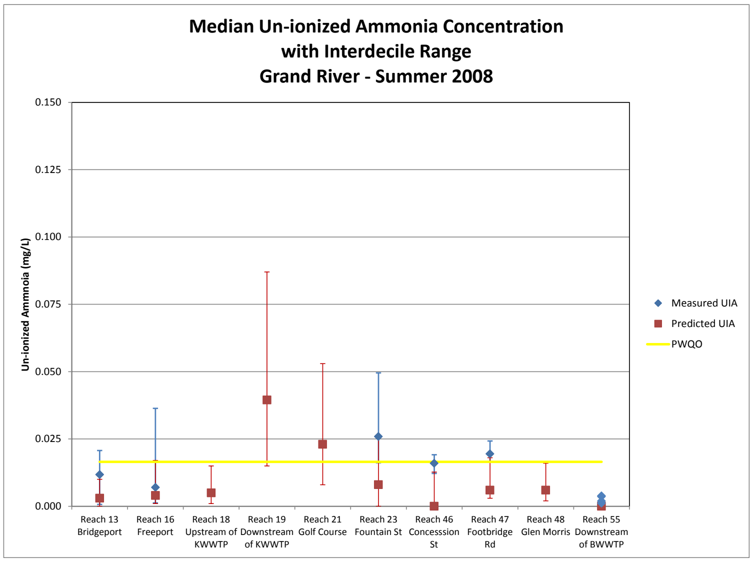
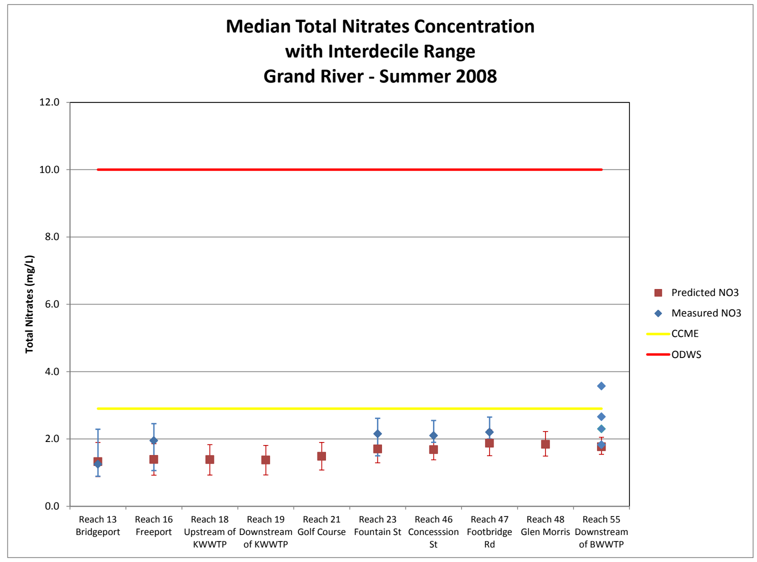
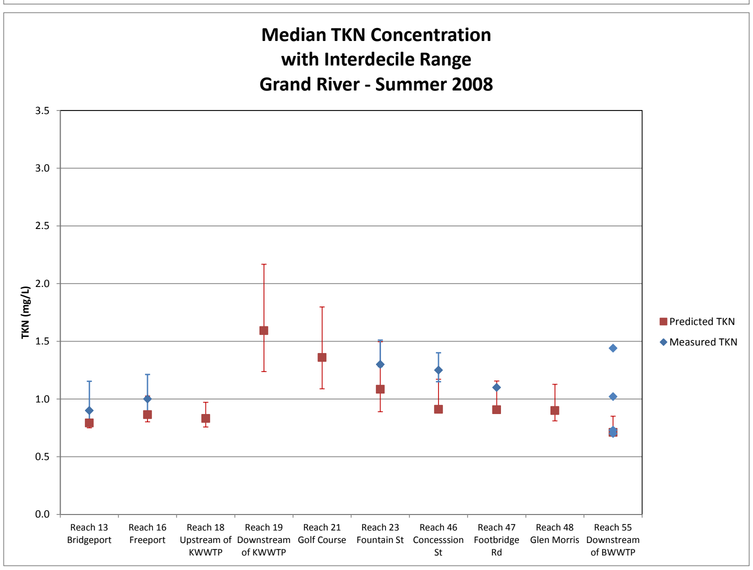


Figure A-12(a): Measured and Predicted Nutrient Concentrations in the Grand River – Summer 2008







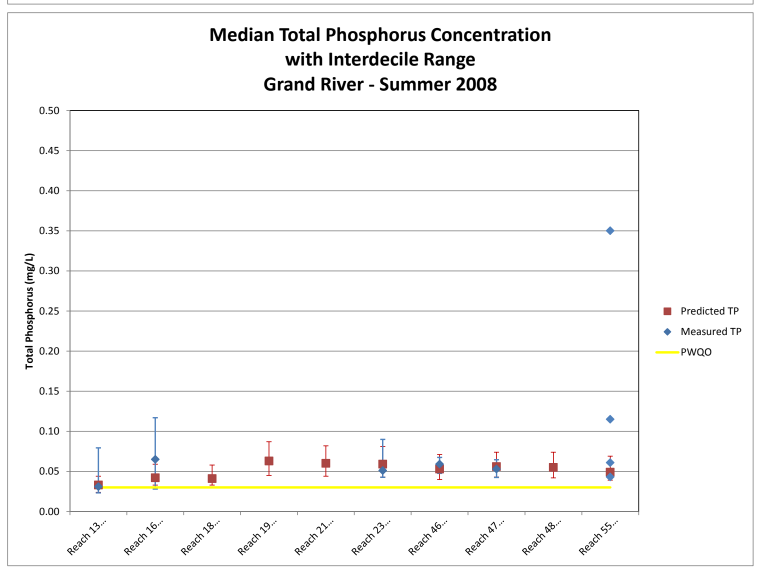
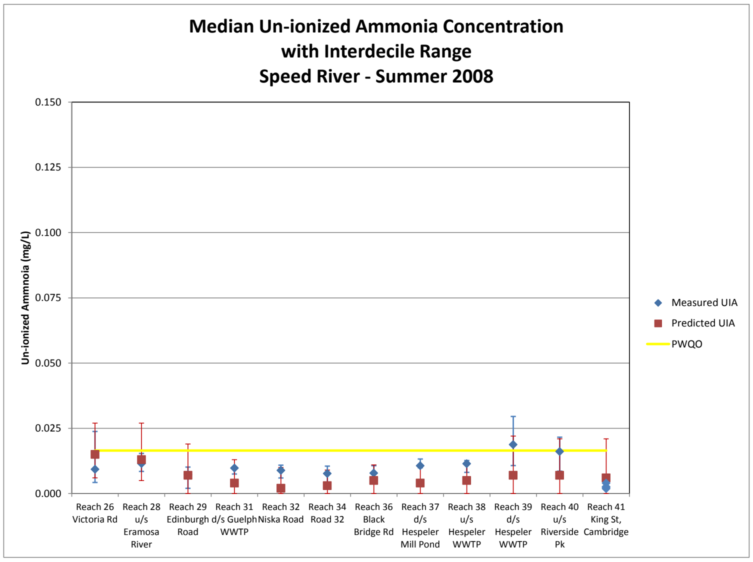
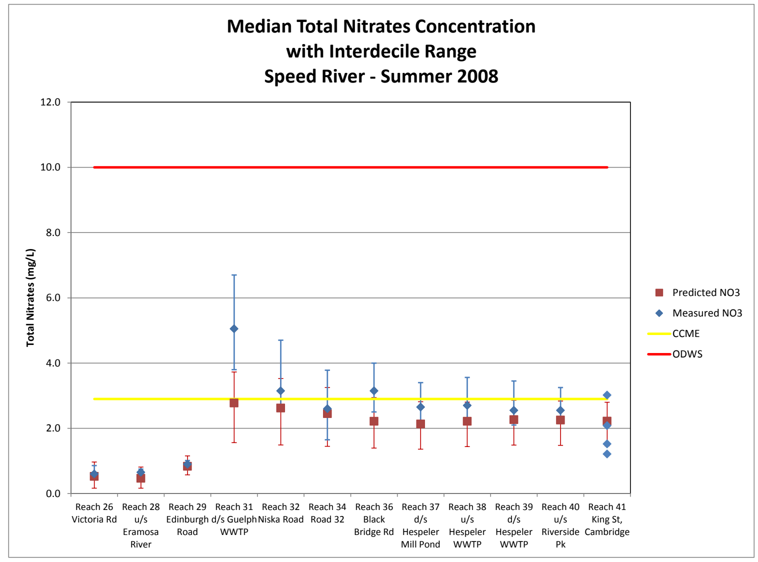
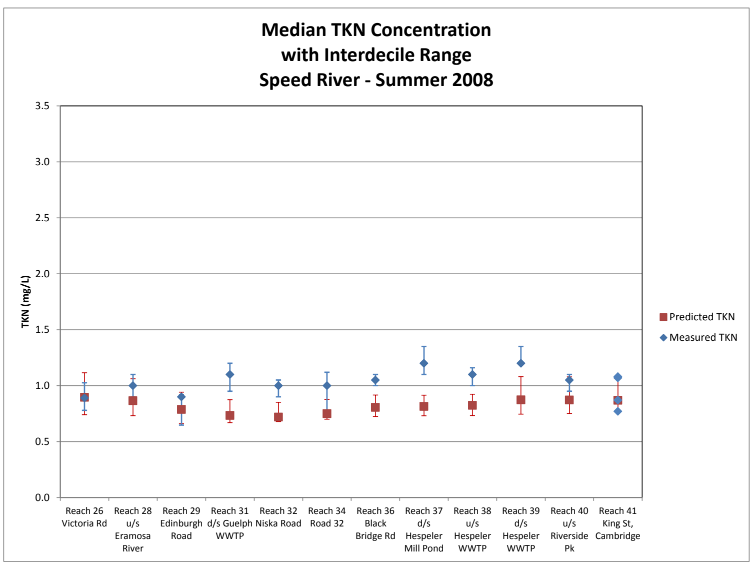


Figure A-12(b): Measured and Predicted Nutrient Concentrations in the Speed River – Summer 2008







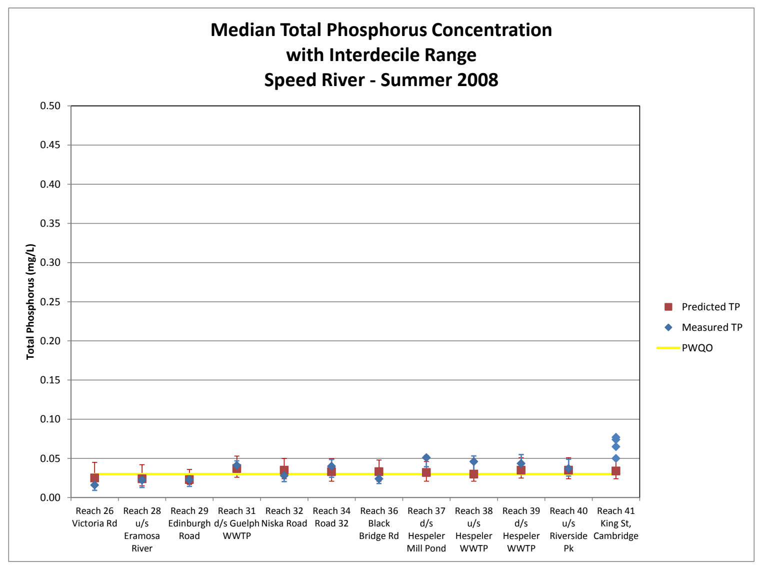


Figure A-13(a): Measured and Predicted Nutrient Concentrations in the Grand River – Summer 2007

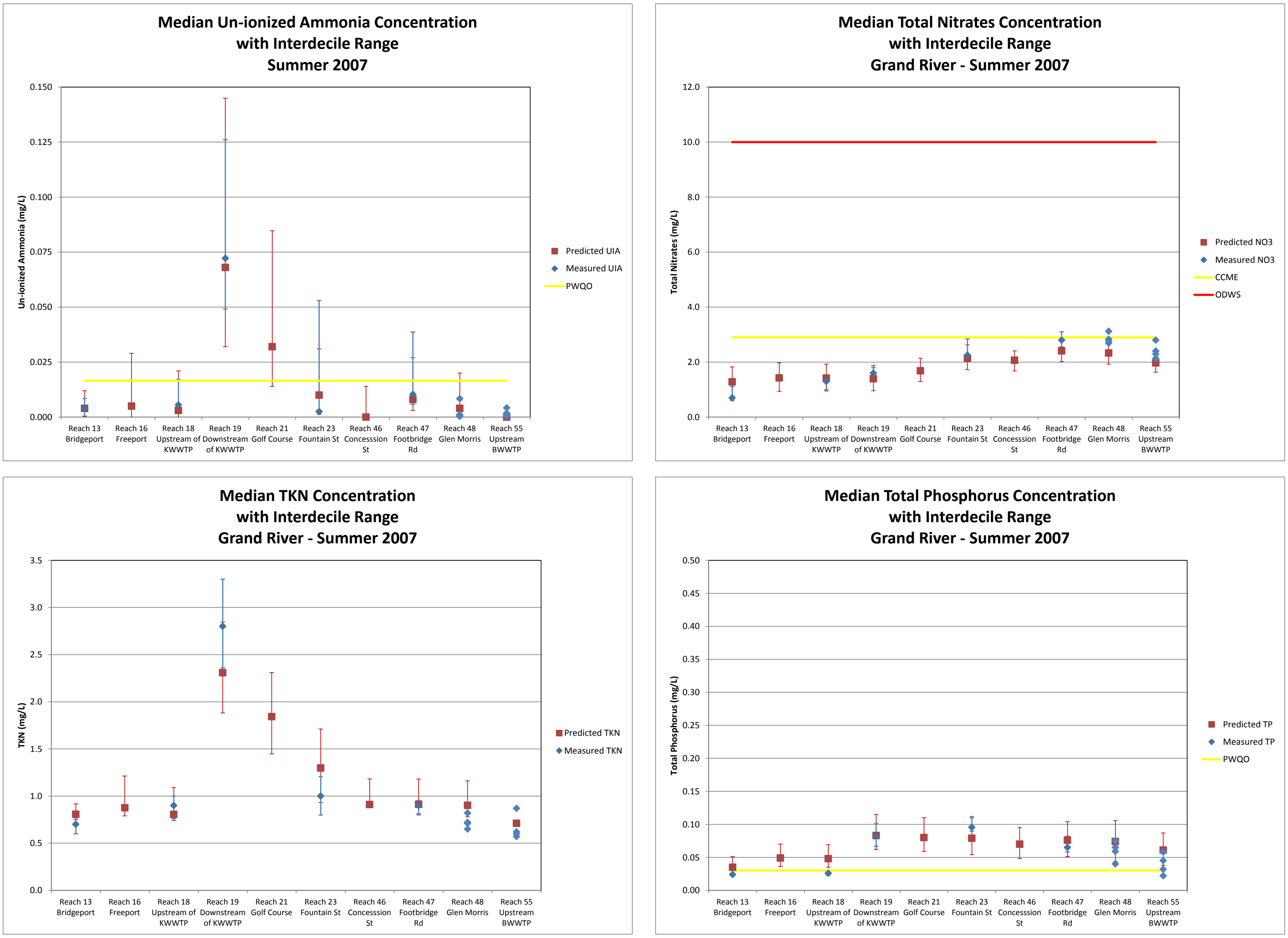
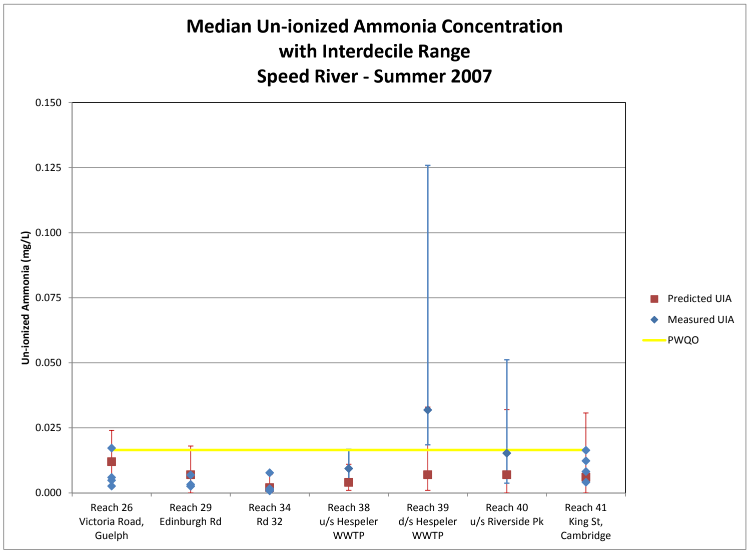
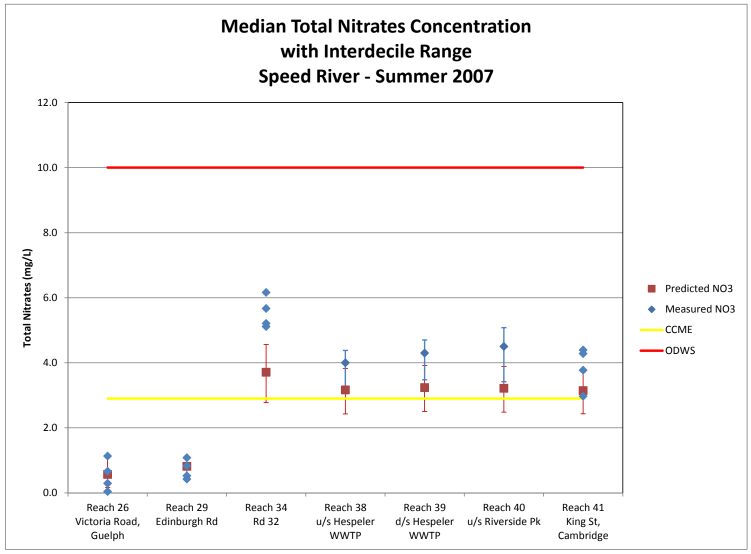
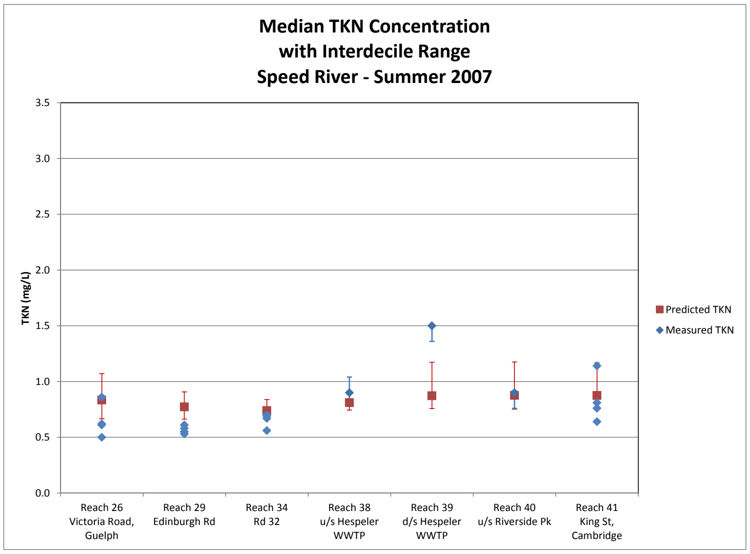
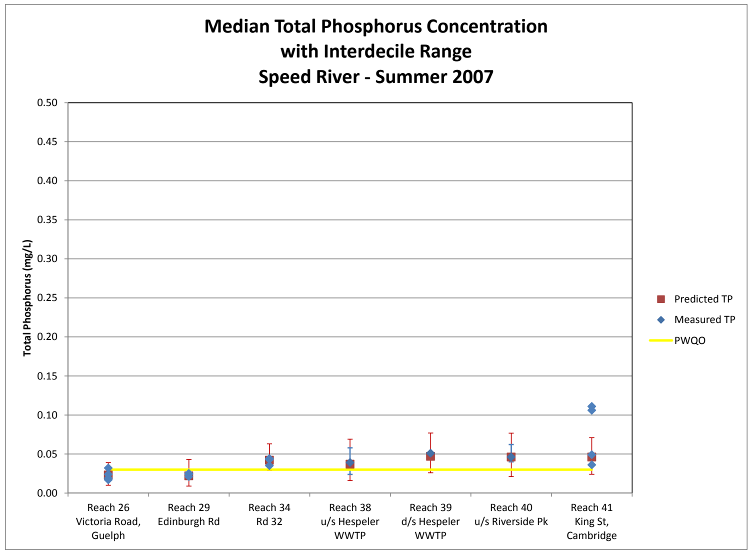


Figure A-13(b): Measured and Predicted Nutrient Concentrations in the Speed River – Summer 2007



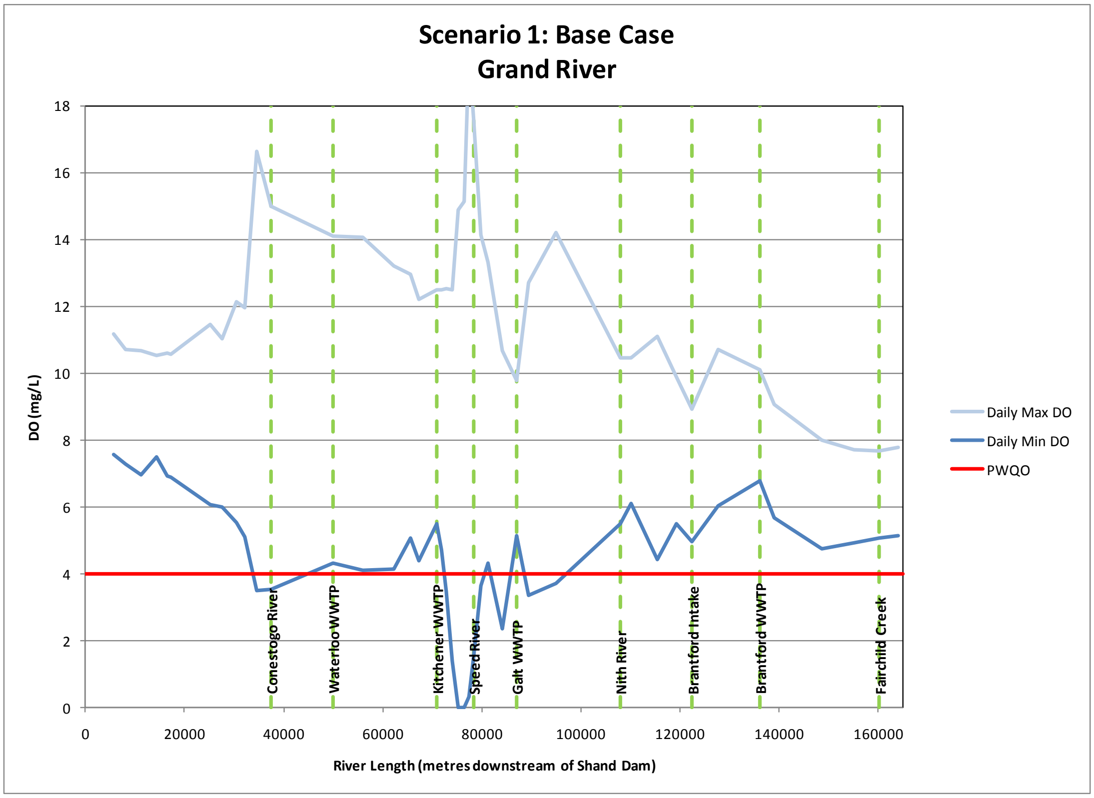






APPENDIX B: GRSM SCENARIO OUTPUT SUMMARY GRAPHS

Figure B-1: Scenario 1 Results, Low Flow Summer Conditions – Dissolved Oxygen



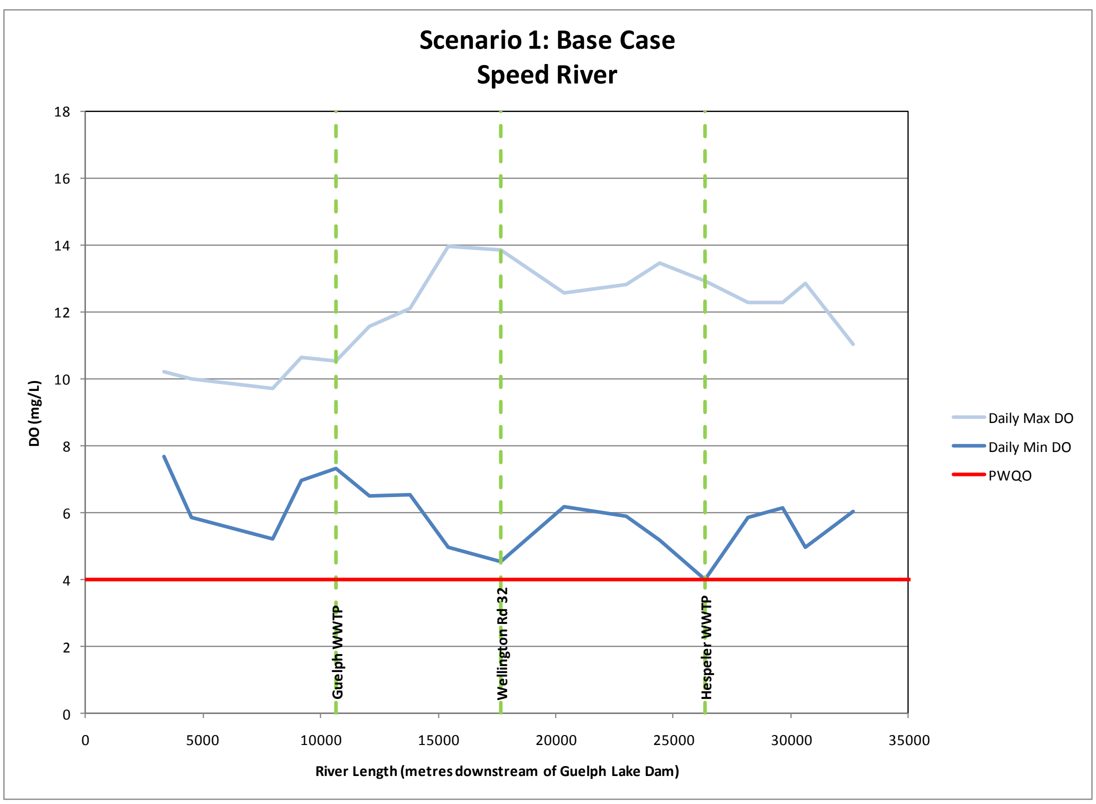
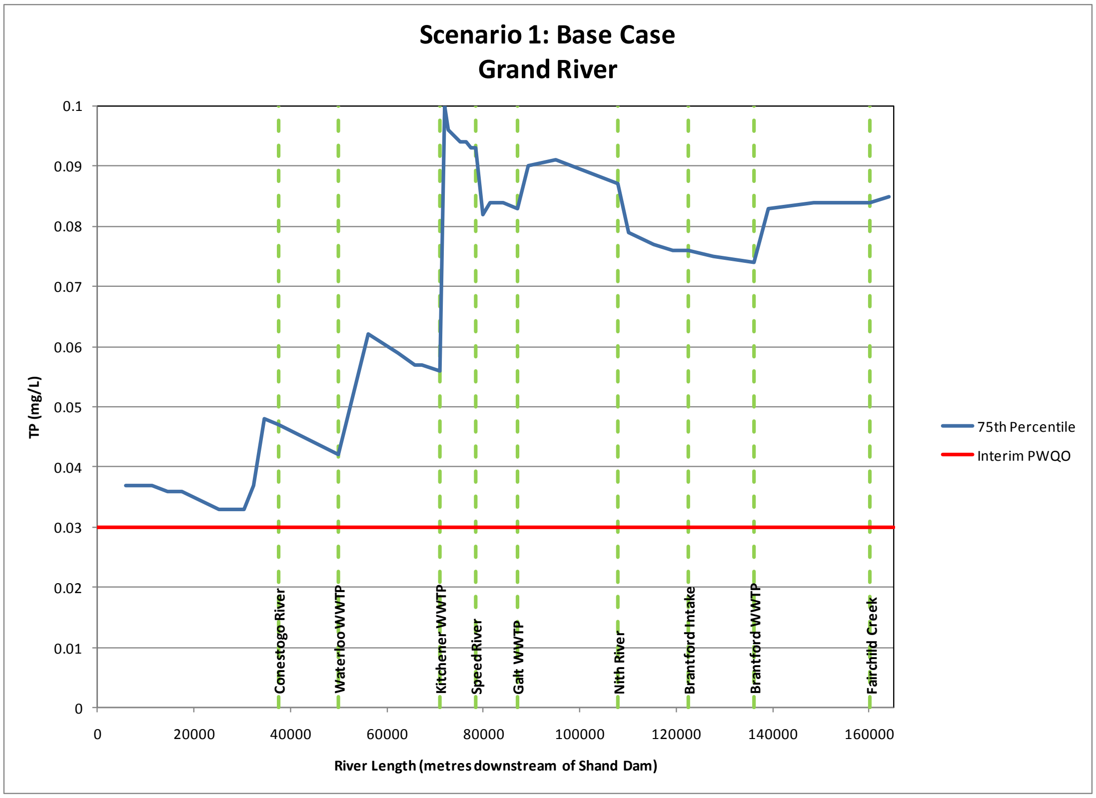


Figure B-2: Scenario 1 Results, Low Flow Summer Conditions – Total Phosphorus



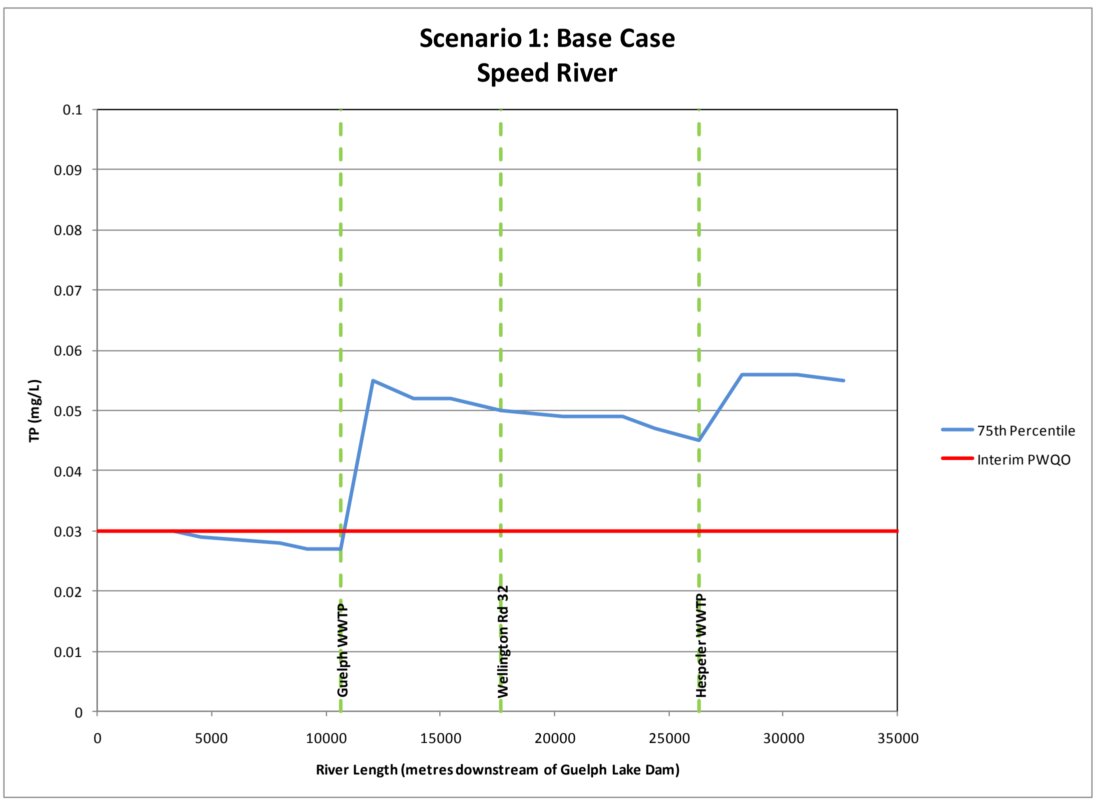
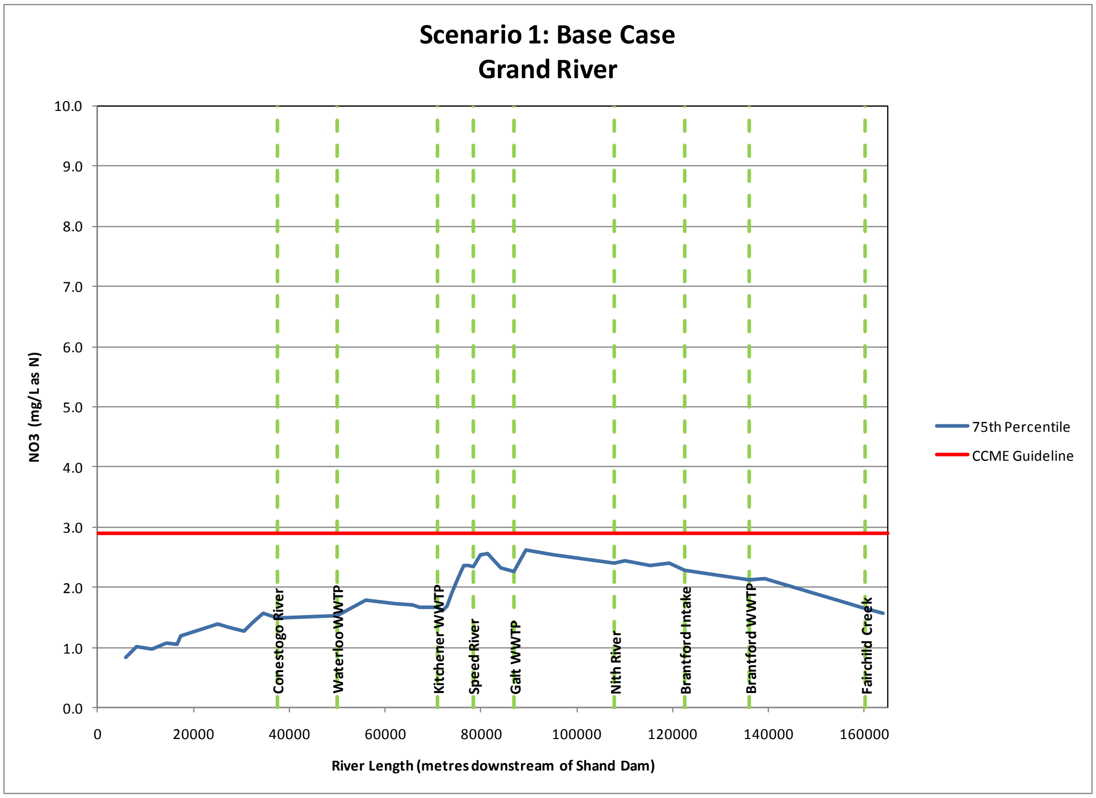


Figure B-3: Scenario 1 Results, Low Flow Summer Conditions – Nitrate



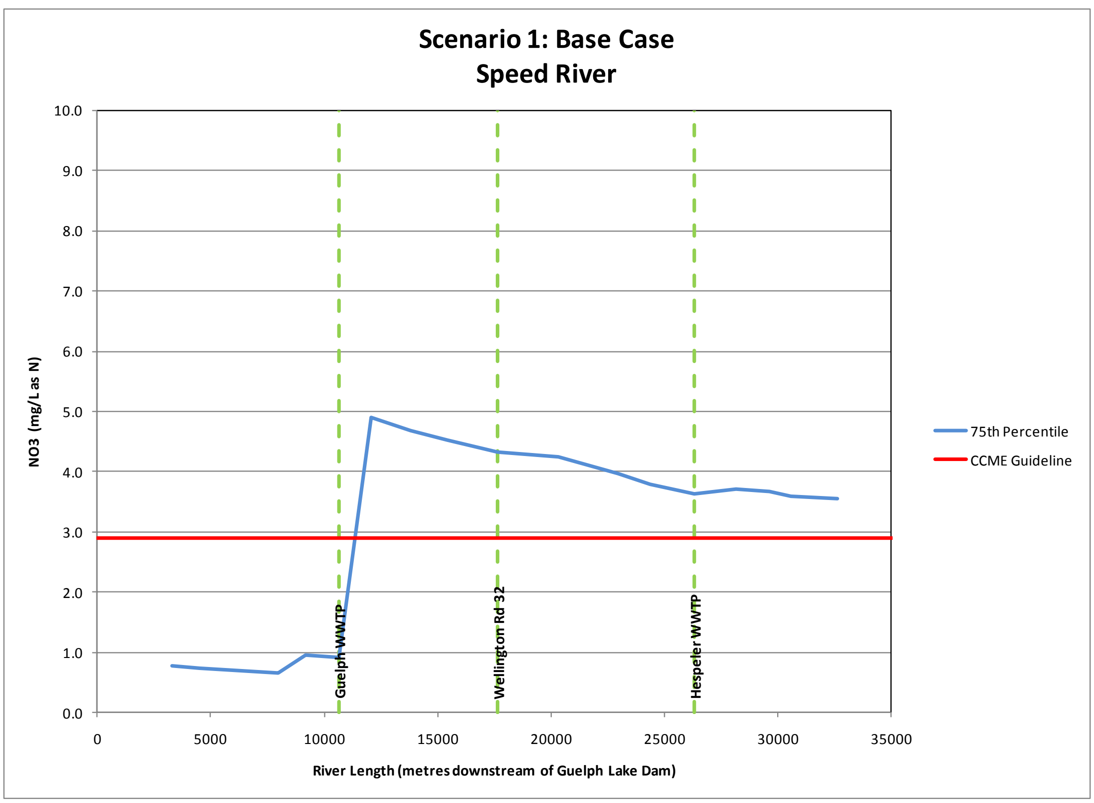
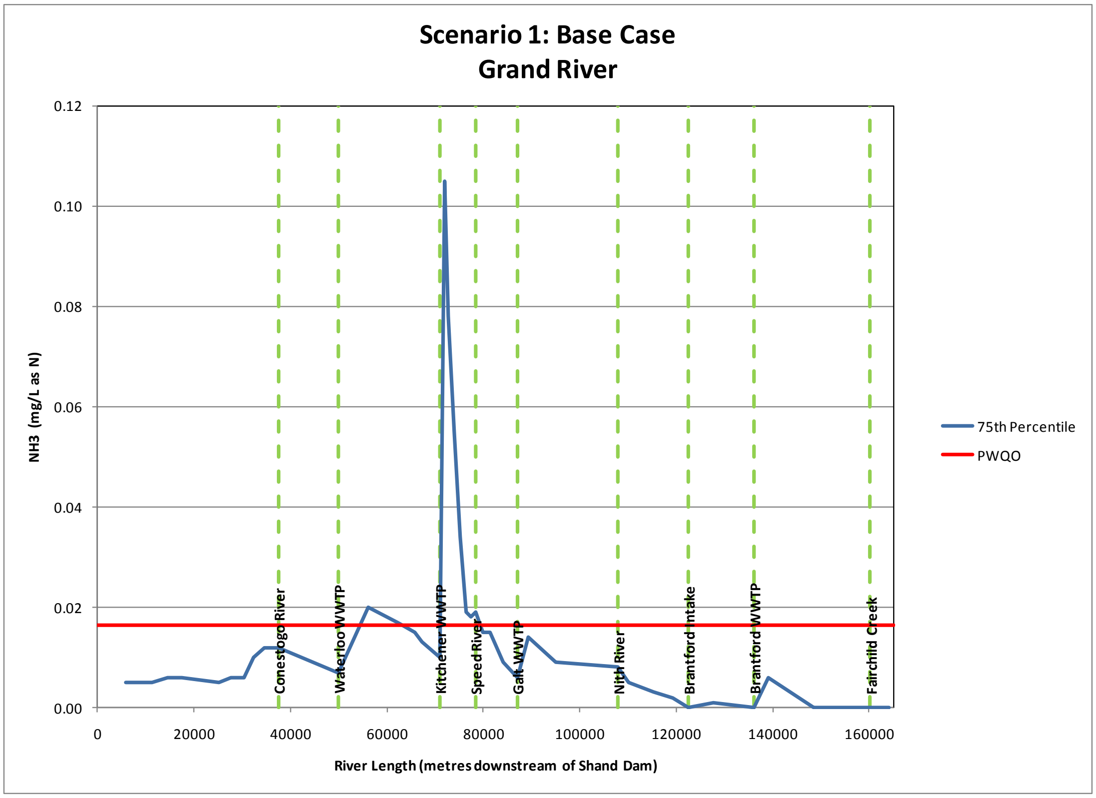


Figure B-4: Scenario 1 Results, Low Flow Summer Conditions – Un-ionized Ammonia



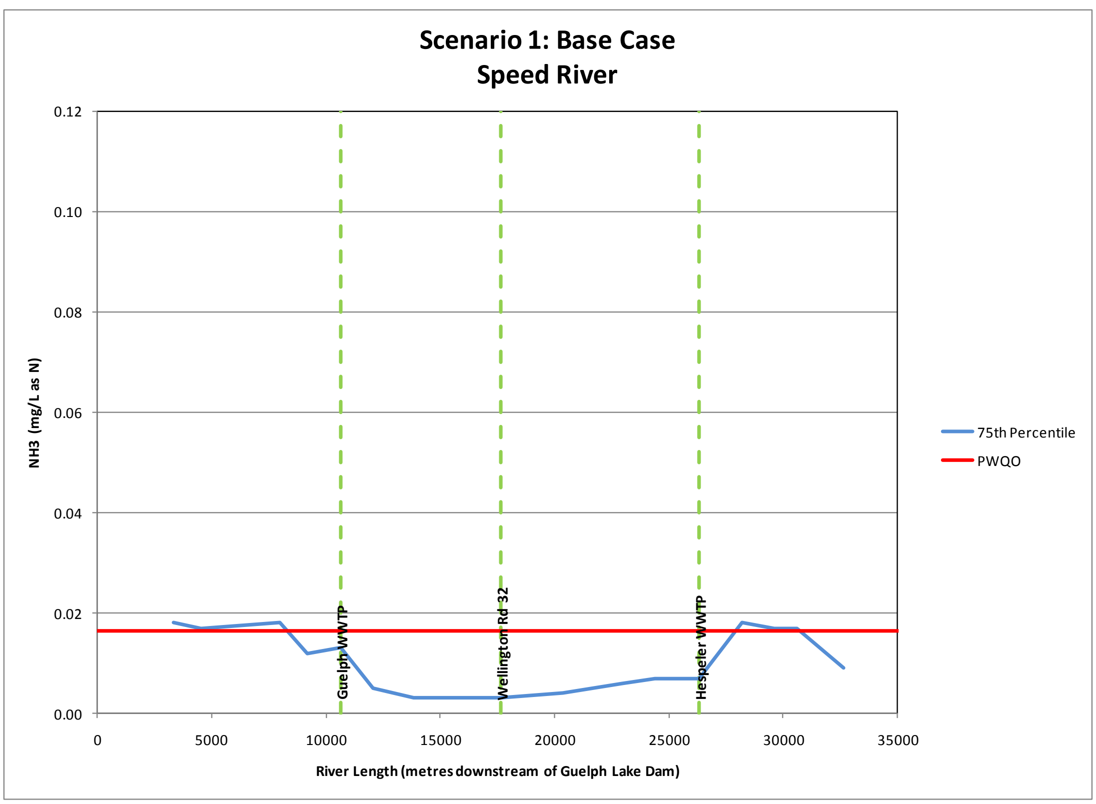
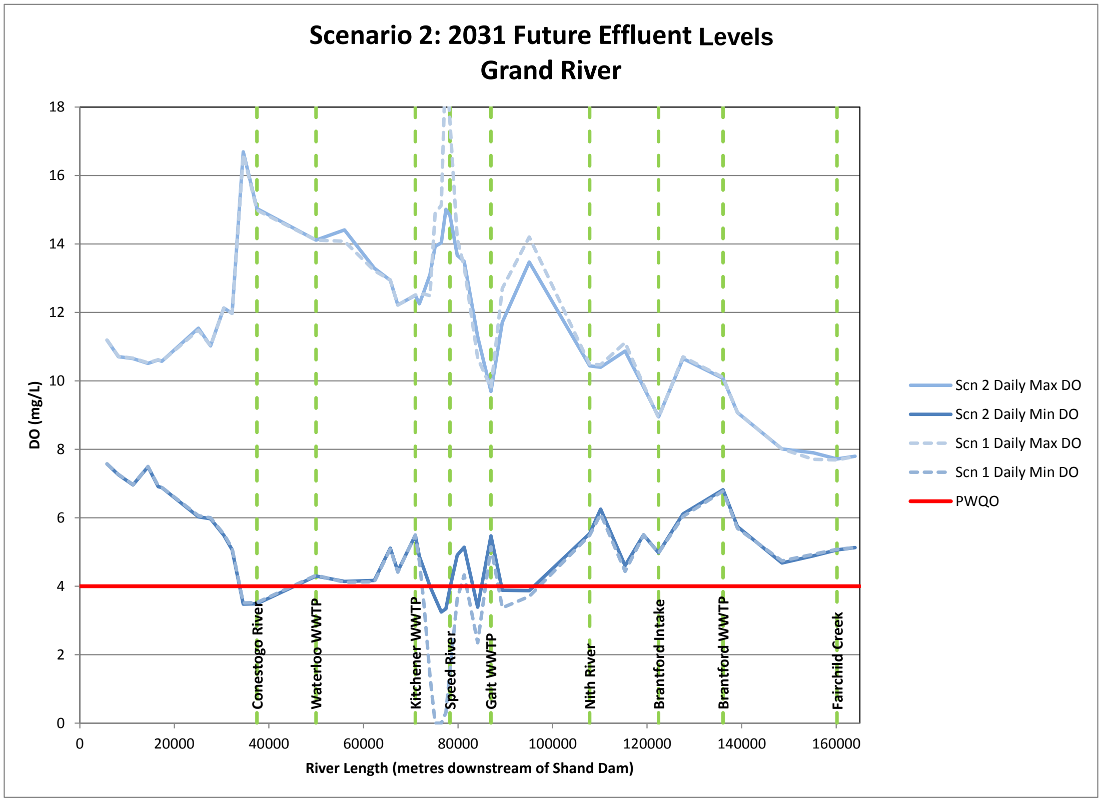


Figure B-5: Scenario 2 Results, Low Flow Summer Conditions – Dissolved Oxygen



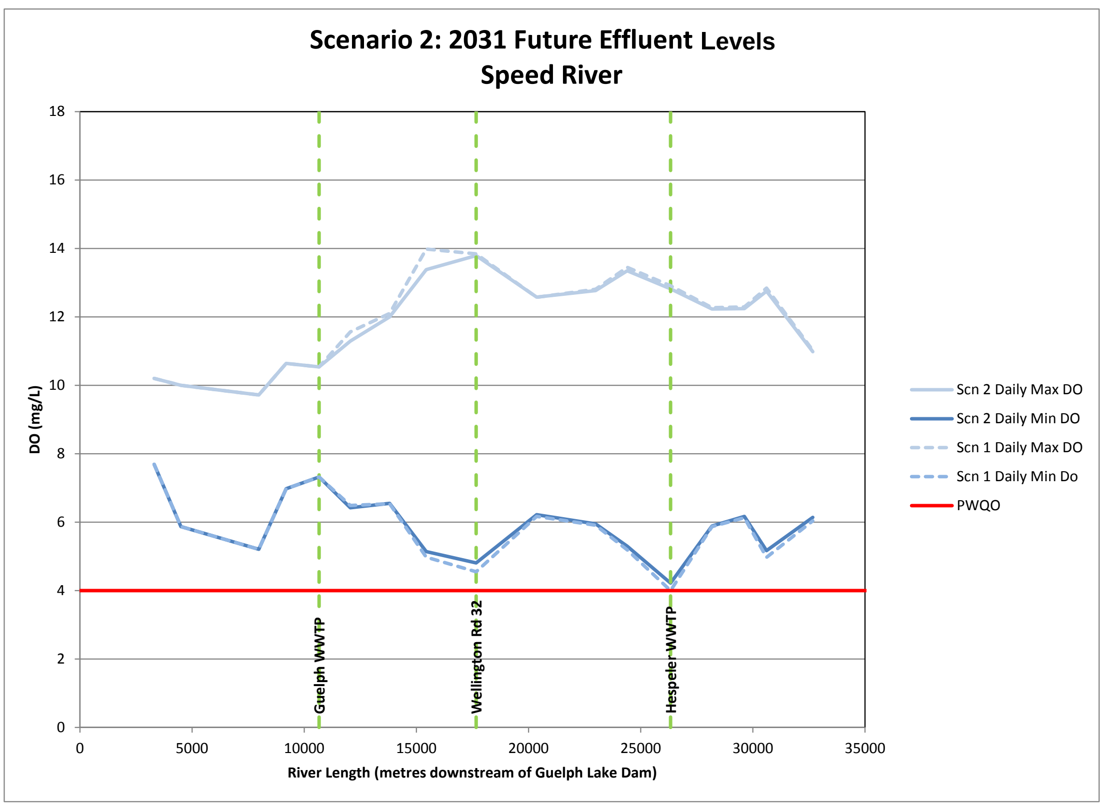
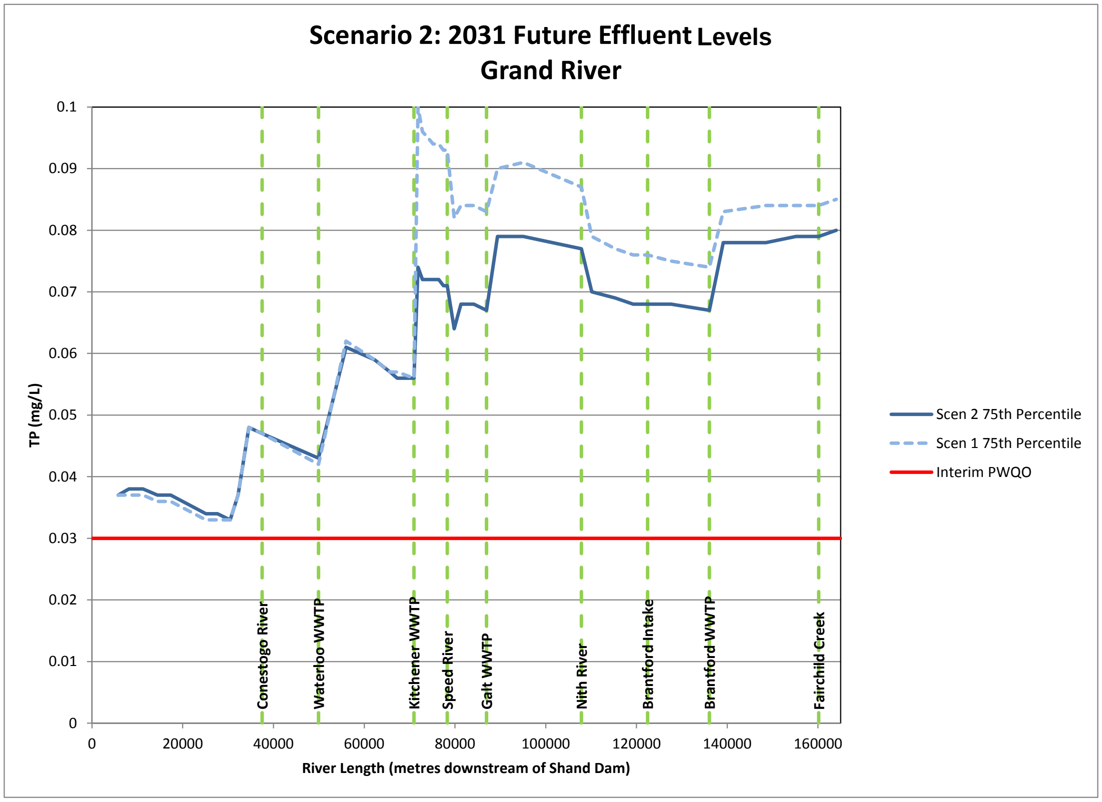


Figure B-6: Scenario 2 Results, Low Flow Summer Conditions – Total Phosphorus



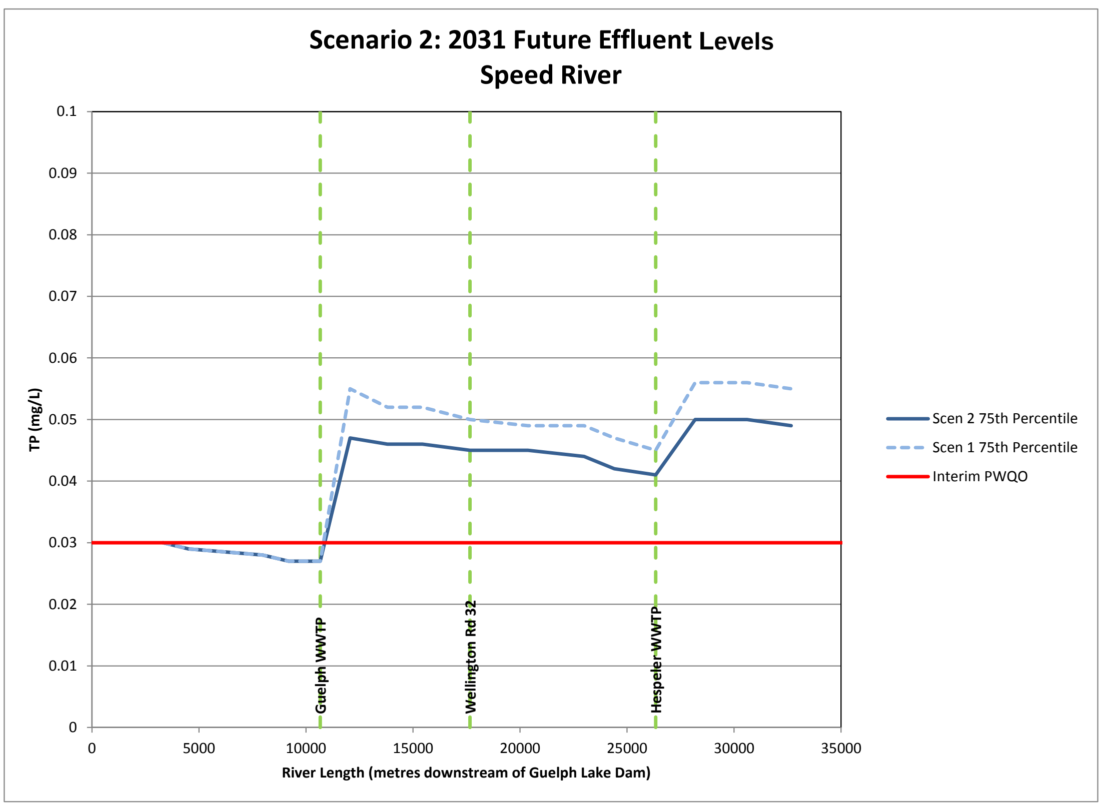
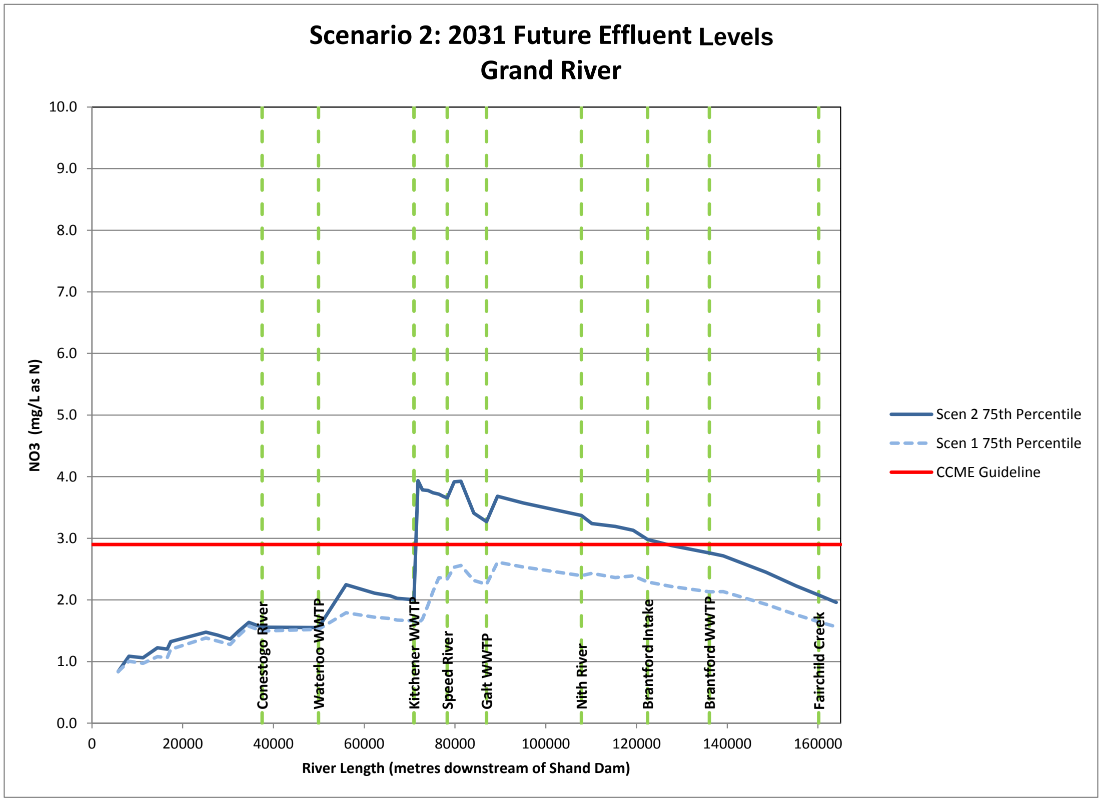


Figure B-7: Scenario 2 Results, Low Flow Summer Conditions – Nitrate



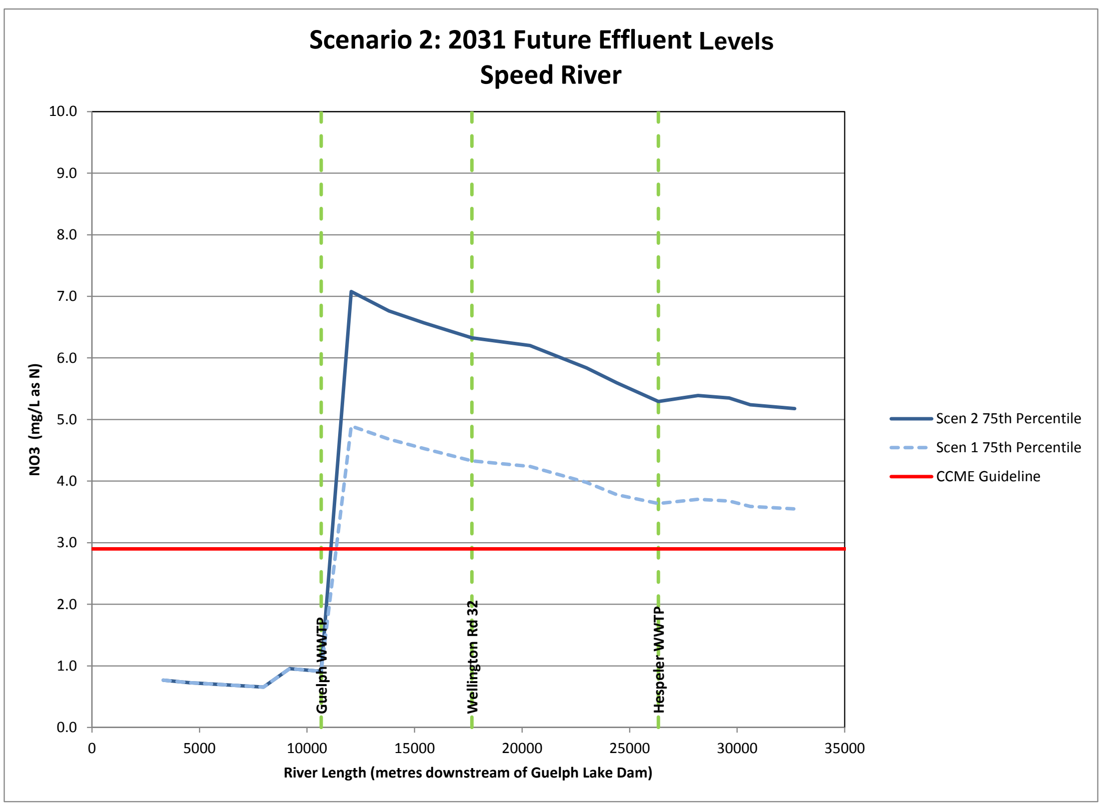
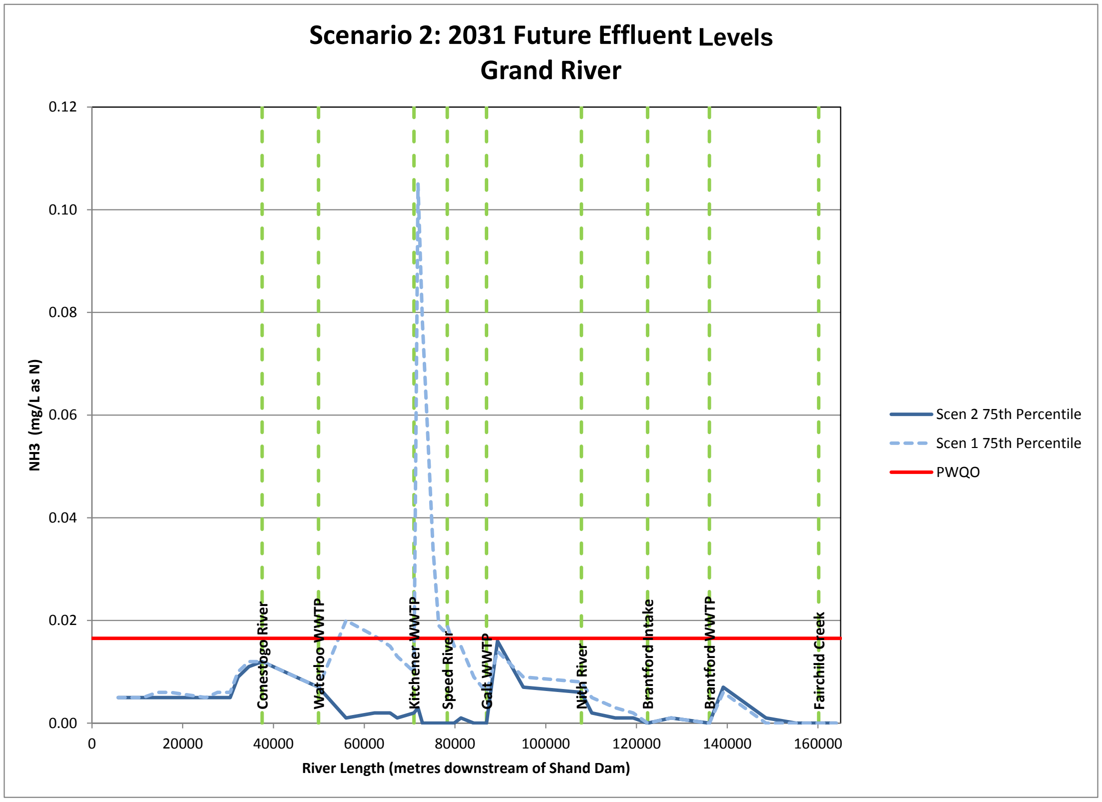


Figure B-8: Scenario 2 Results, Low Flow Summer Conditions – Un-ionized Ammonia



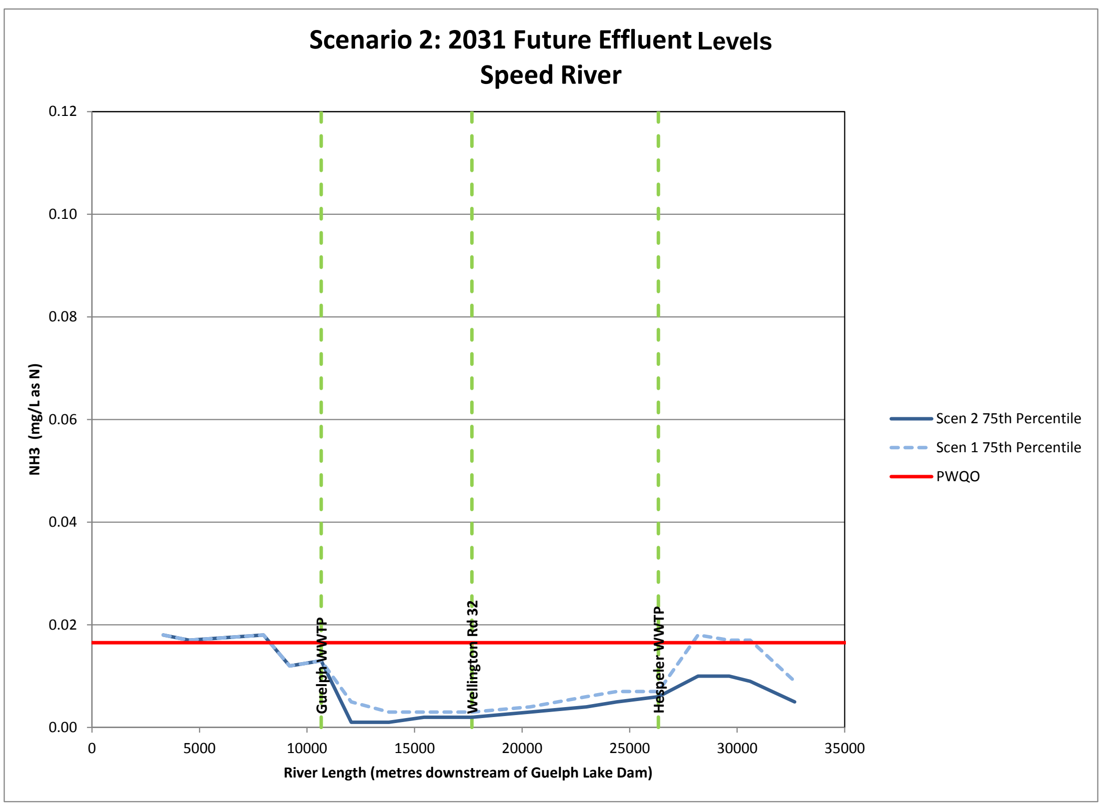
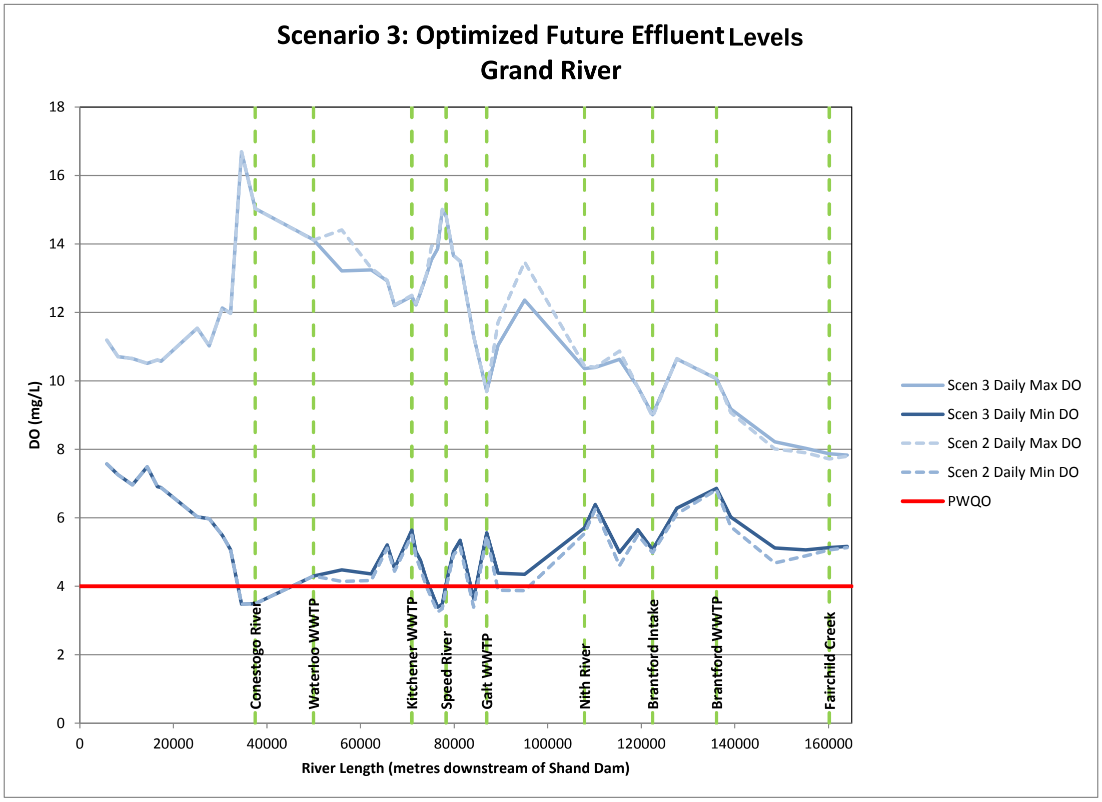


Figure B-9: Scenario 3 Results, Low Flow Summer Conditions – Dissolved Oxygen



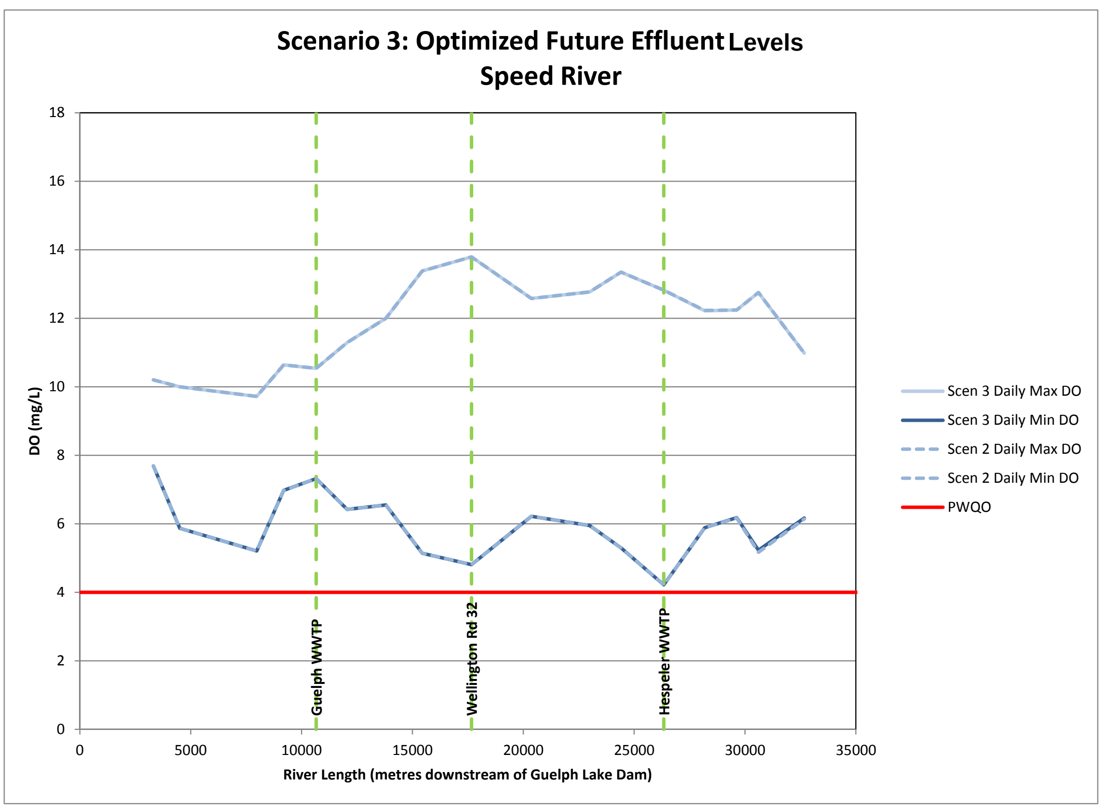
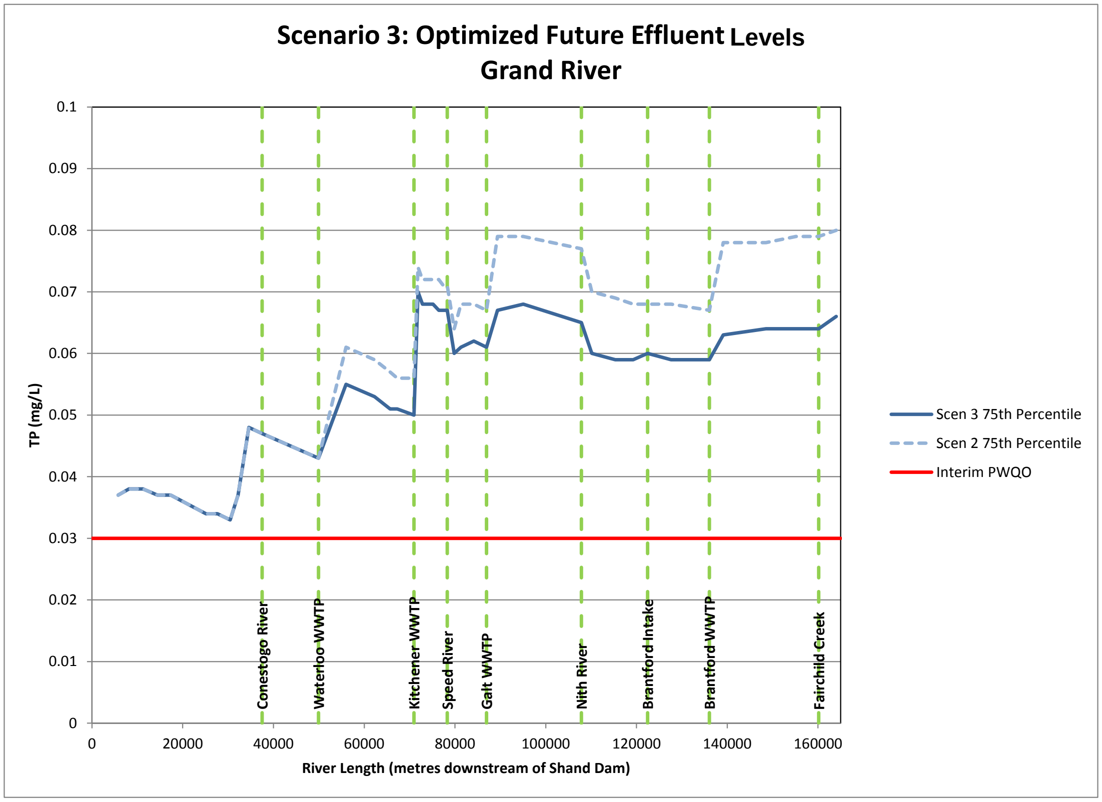


Figure B-10: Scenario 3 Results, Low Flow Summer Conditions – Total Phosphorus



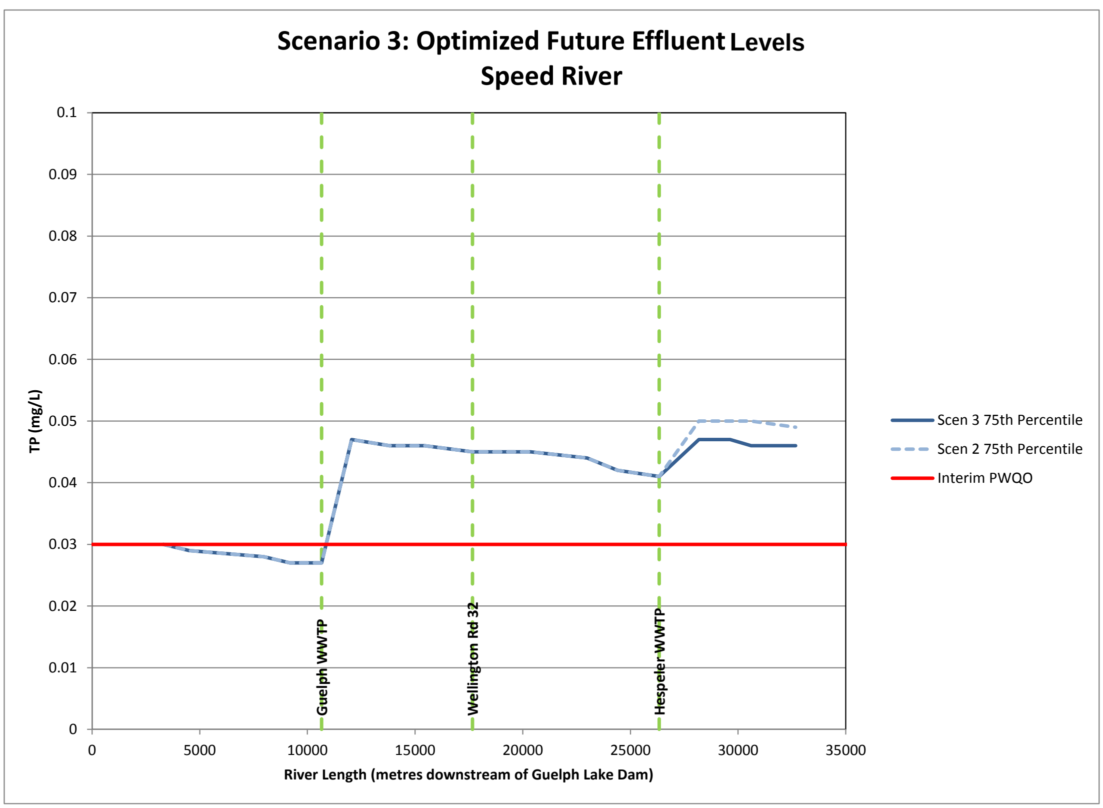
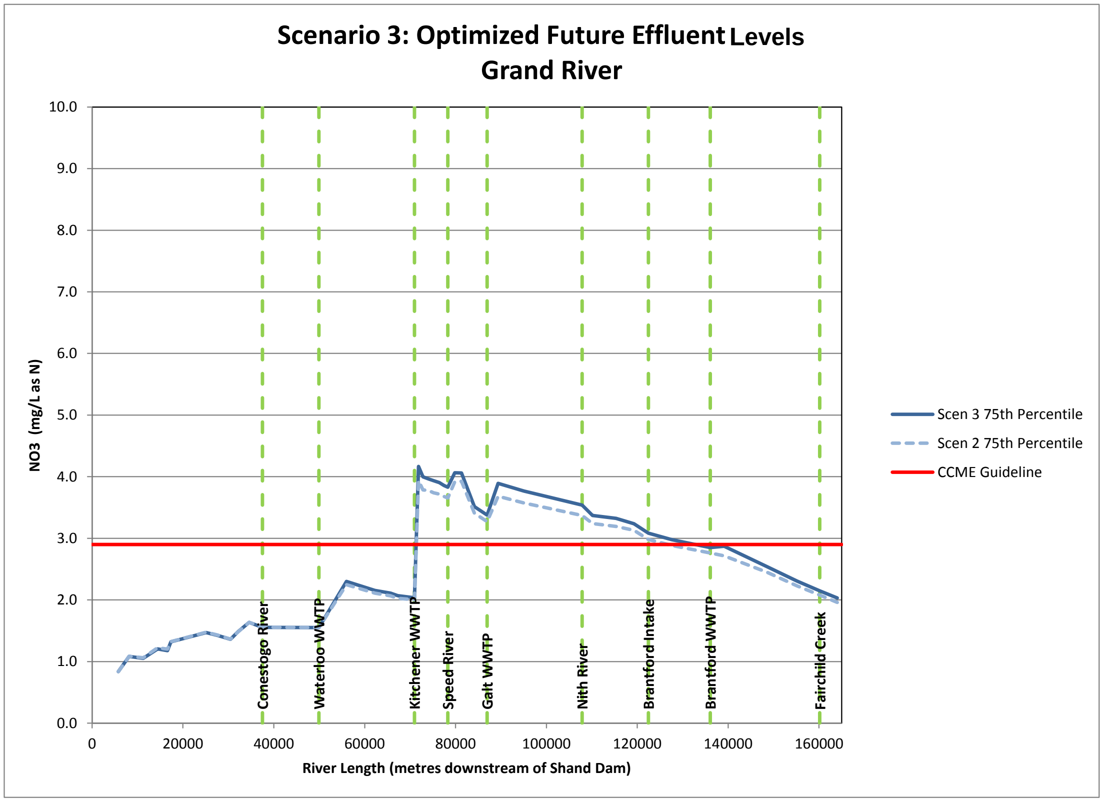


Figure B-11: Scenario 3 Results, Low Flow Summer Conditions – Nitrate



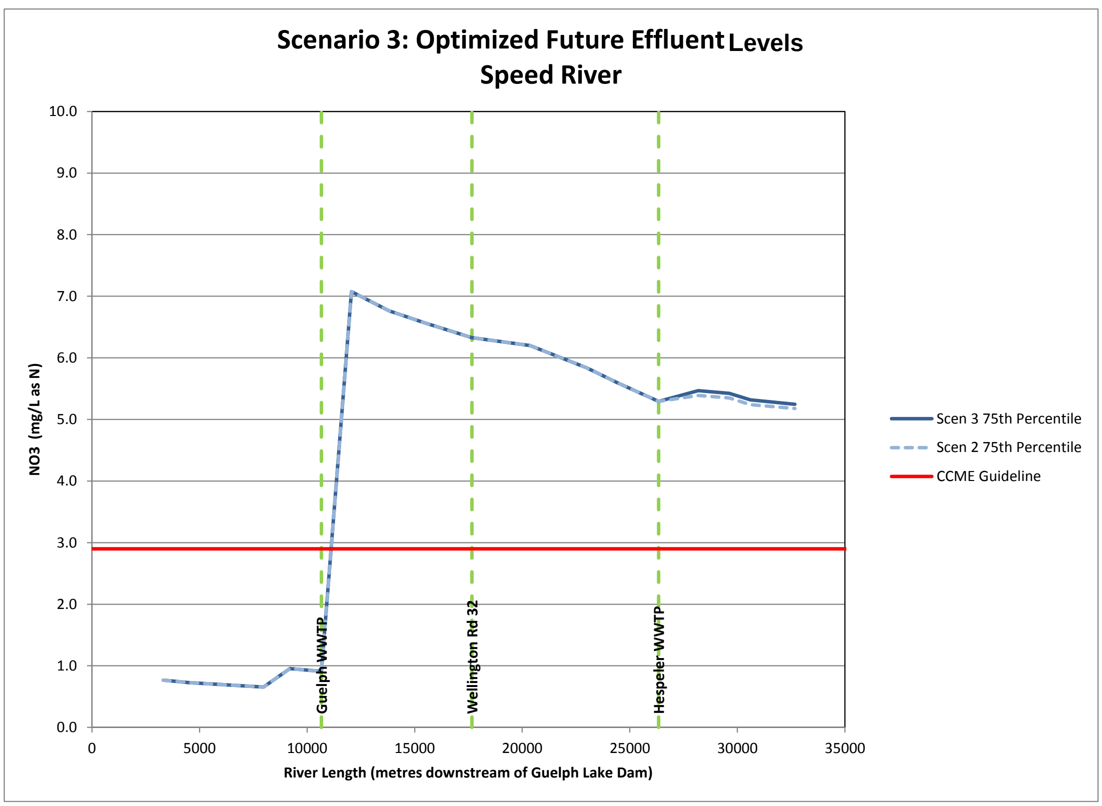
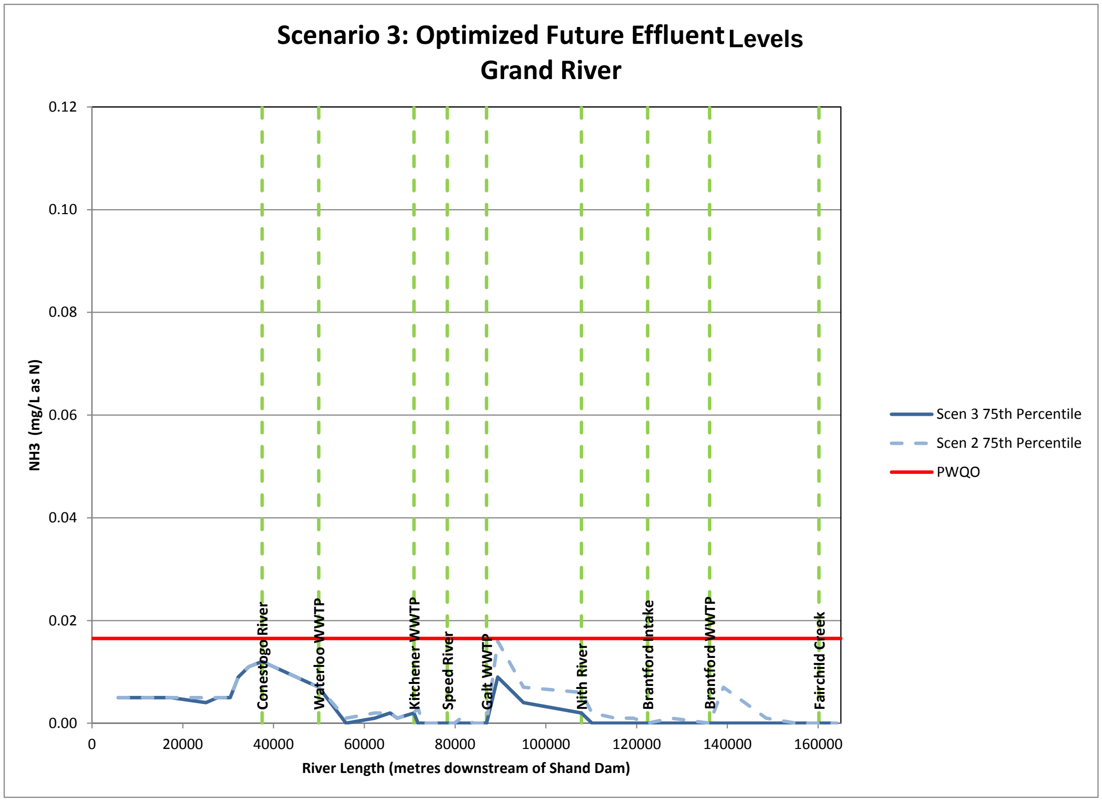


Figure B-12: Scenario 3 Results, Low Flow Summer Conditions – Un-ionized Ammonia



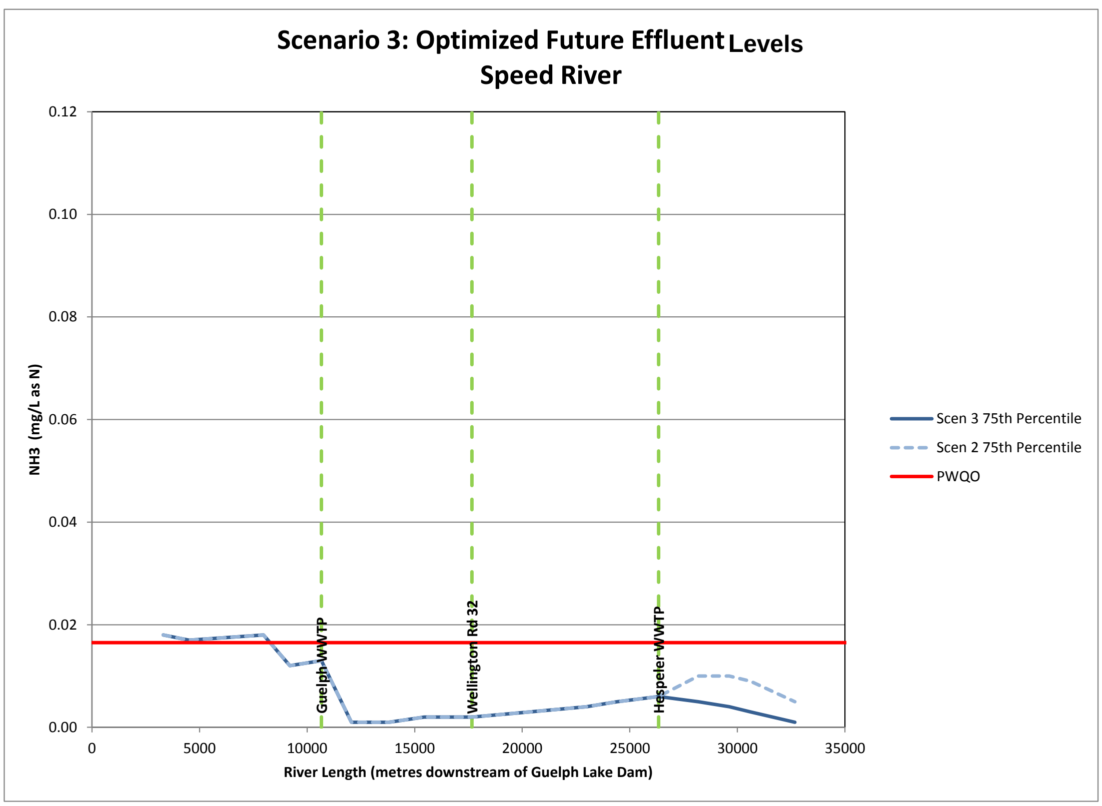
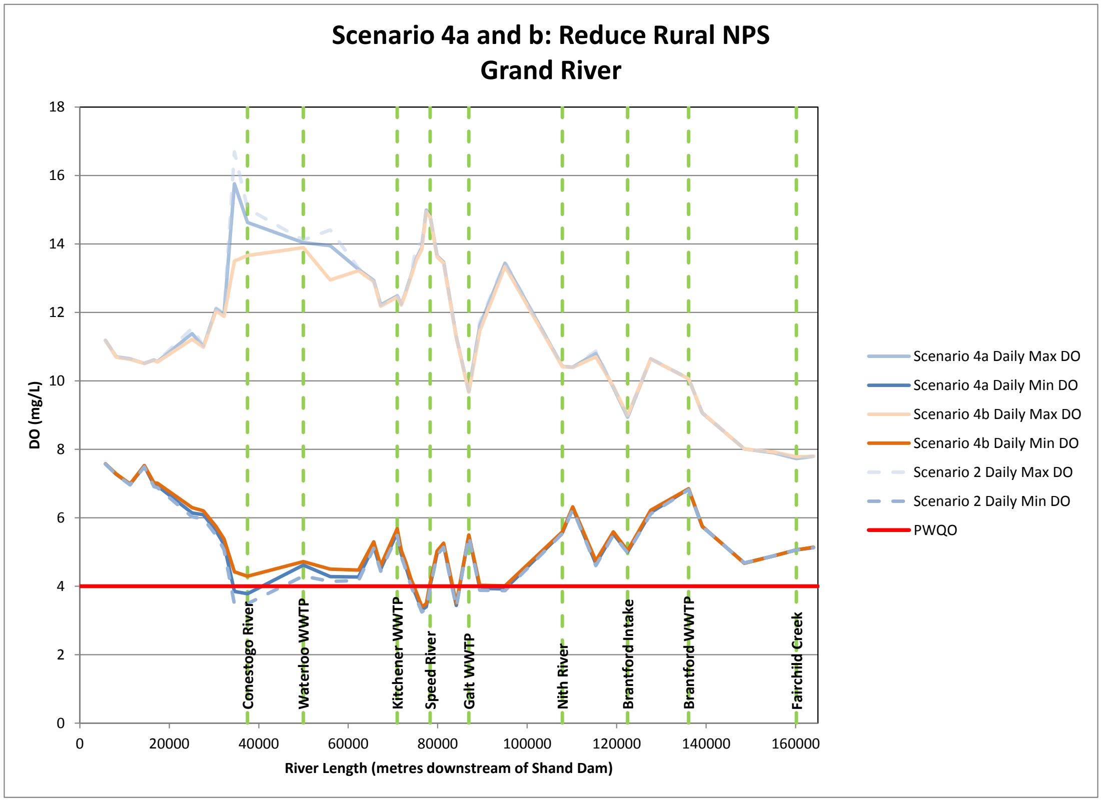


Figure B-13: Scenario 4a and b Results, Low Flow Summer Conditions – Dissolved Oxygen



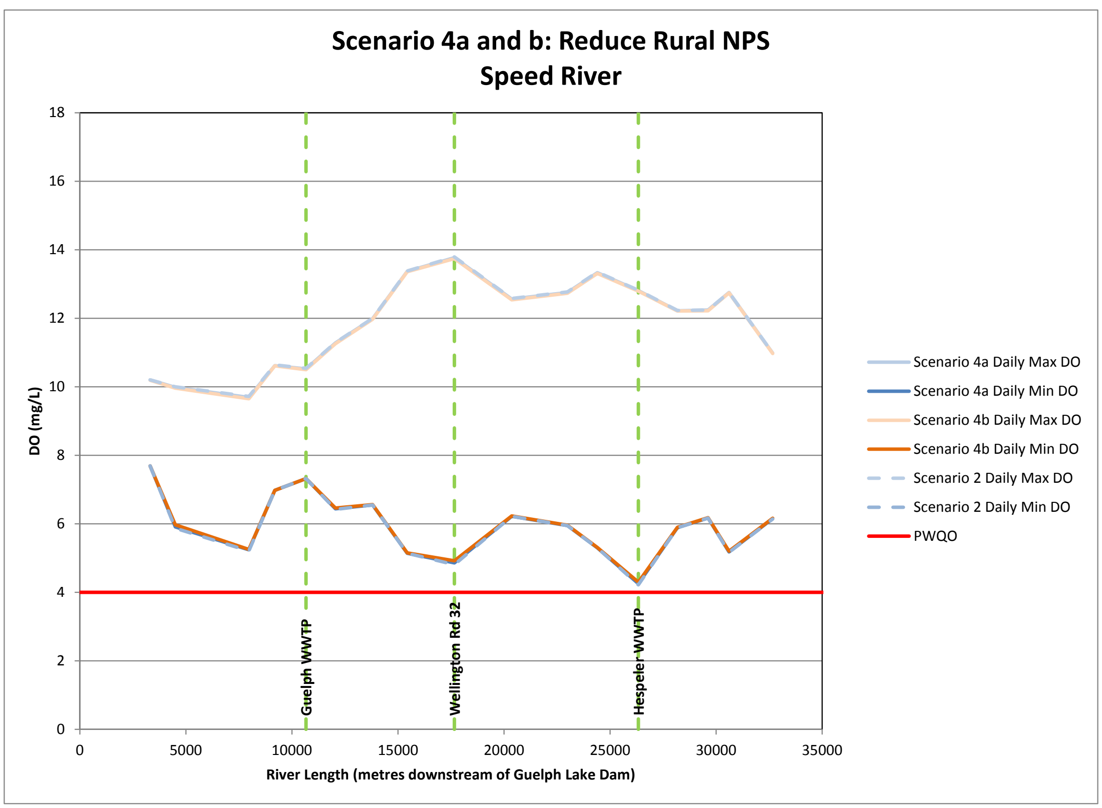
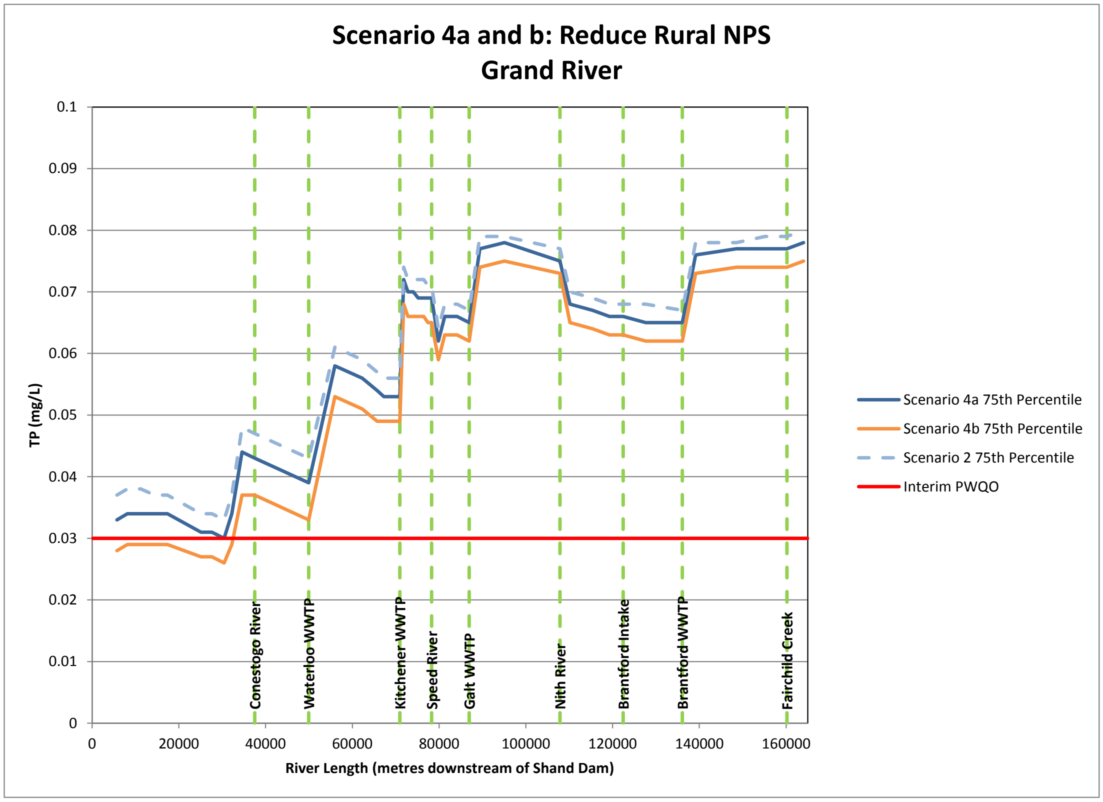


Figure B-14: Scenario 4a and b Results, Low Flow Summer Conditions – Total Phosphorus



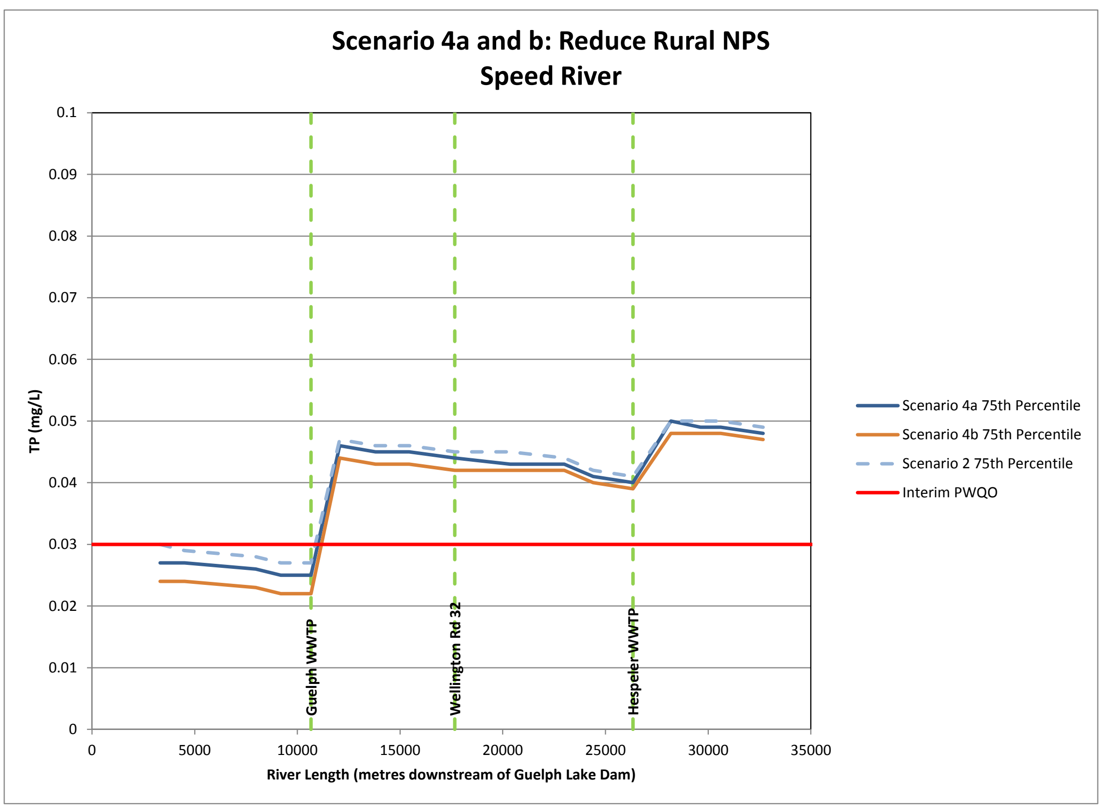
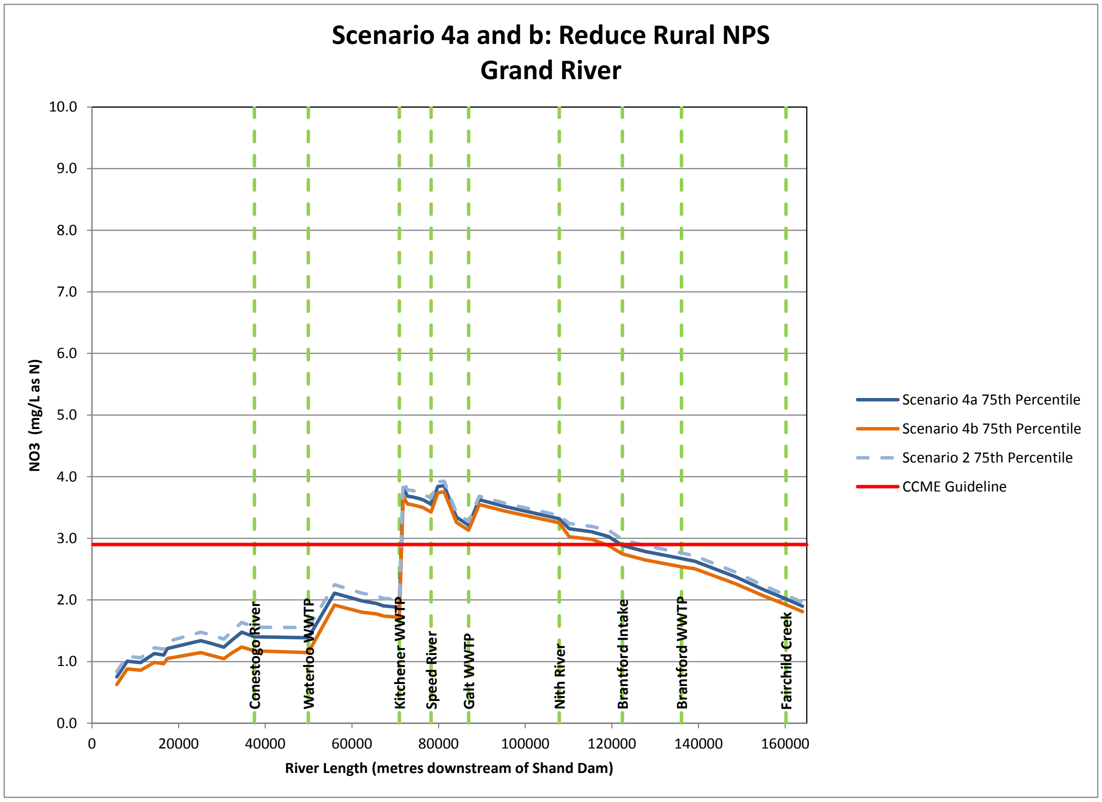


Figure B-15: Scenario 4a and b Results, Low Flow Summer Conditions – Nitrate



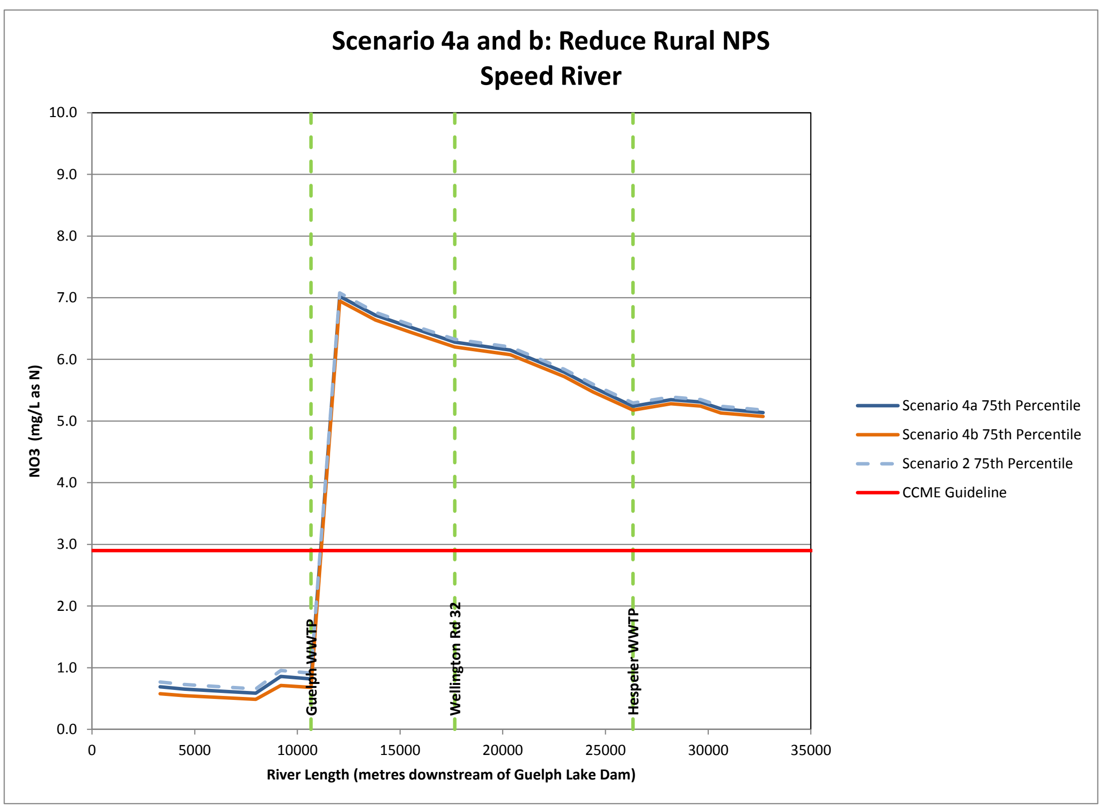
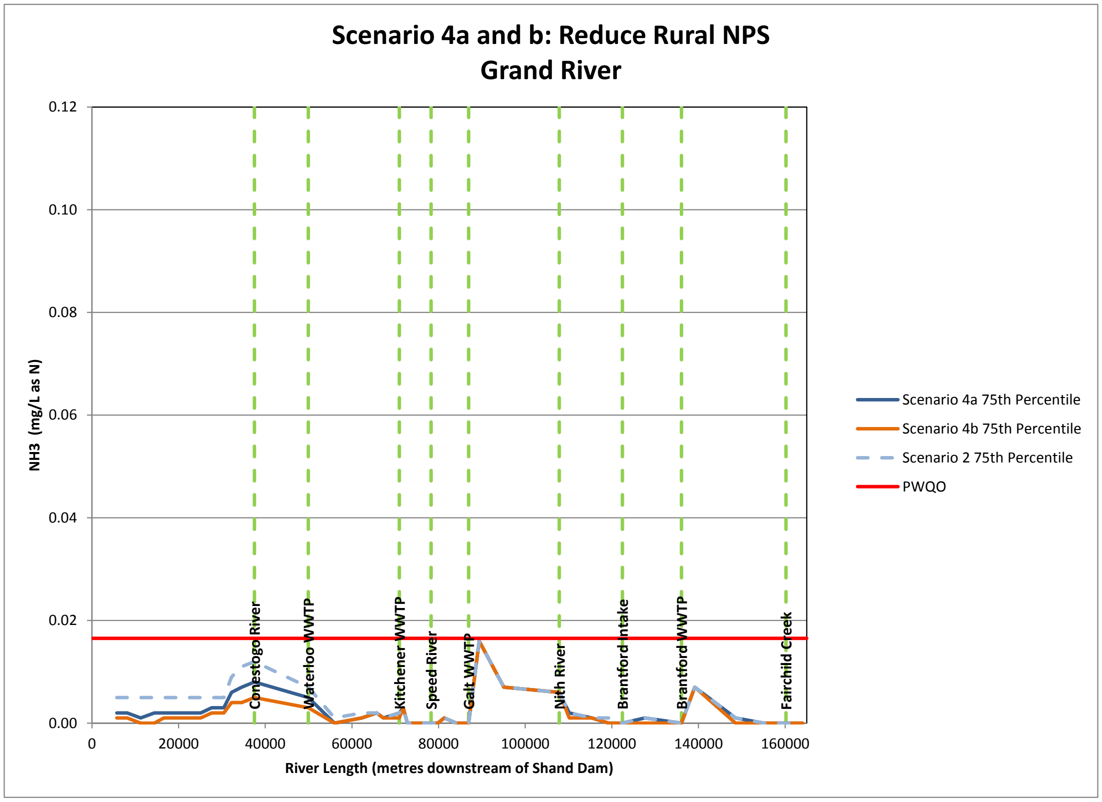


Figure B-16: Scenario 4a and b Results, Low Flow Summer Conditions – Un-ionized Ammonia



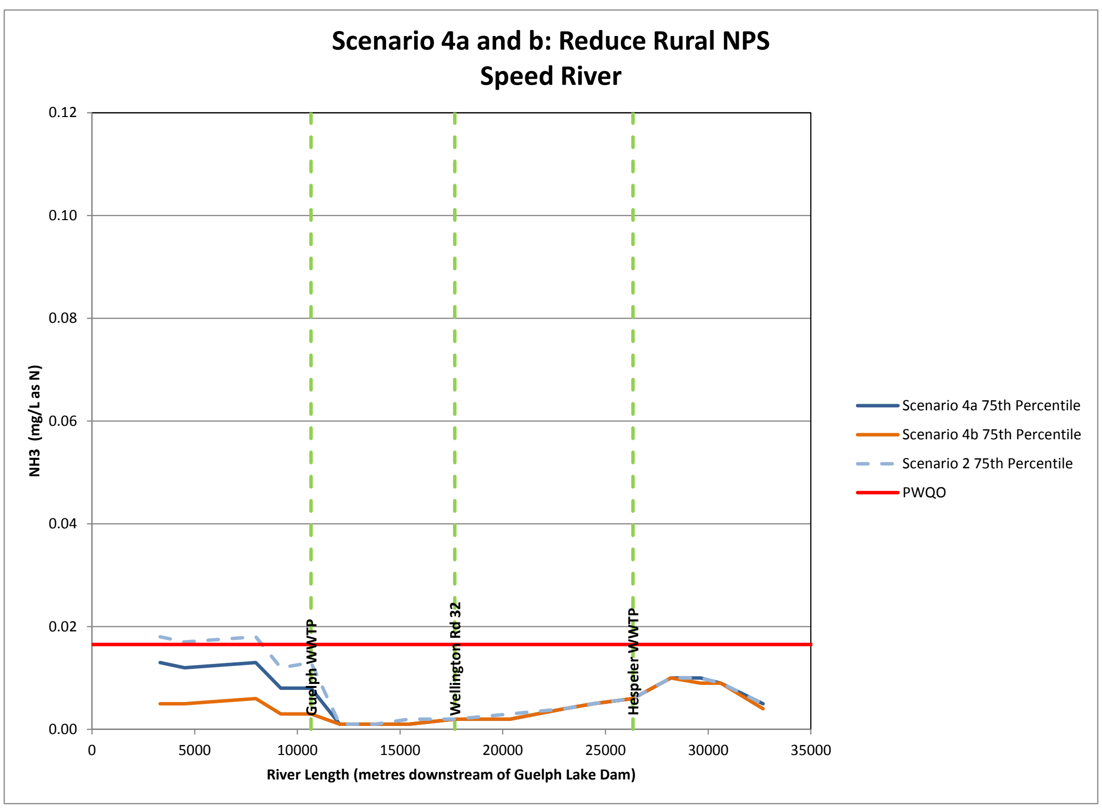
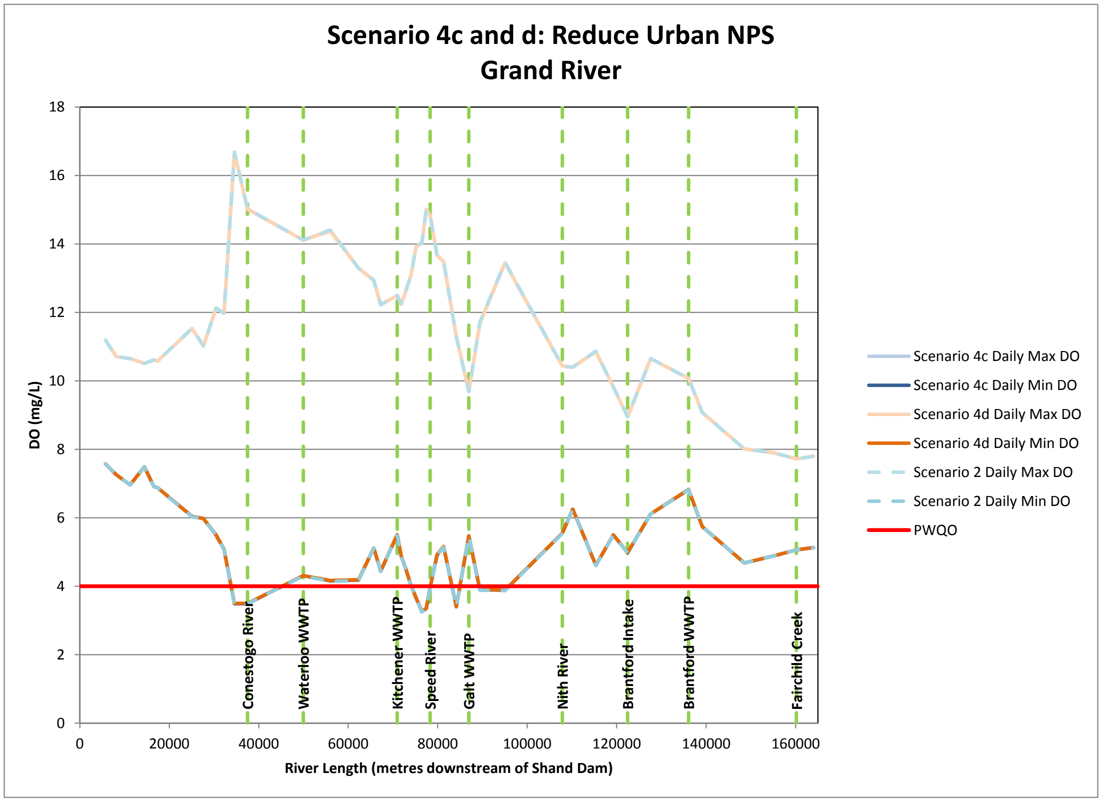


Figure B-17: Scenario 4c and d Results, Low Flow Summer Conditions – Dissolved Oxygen



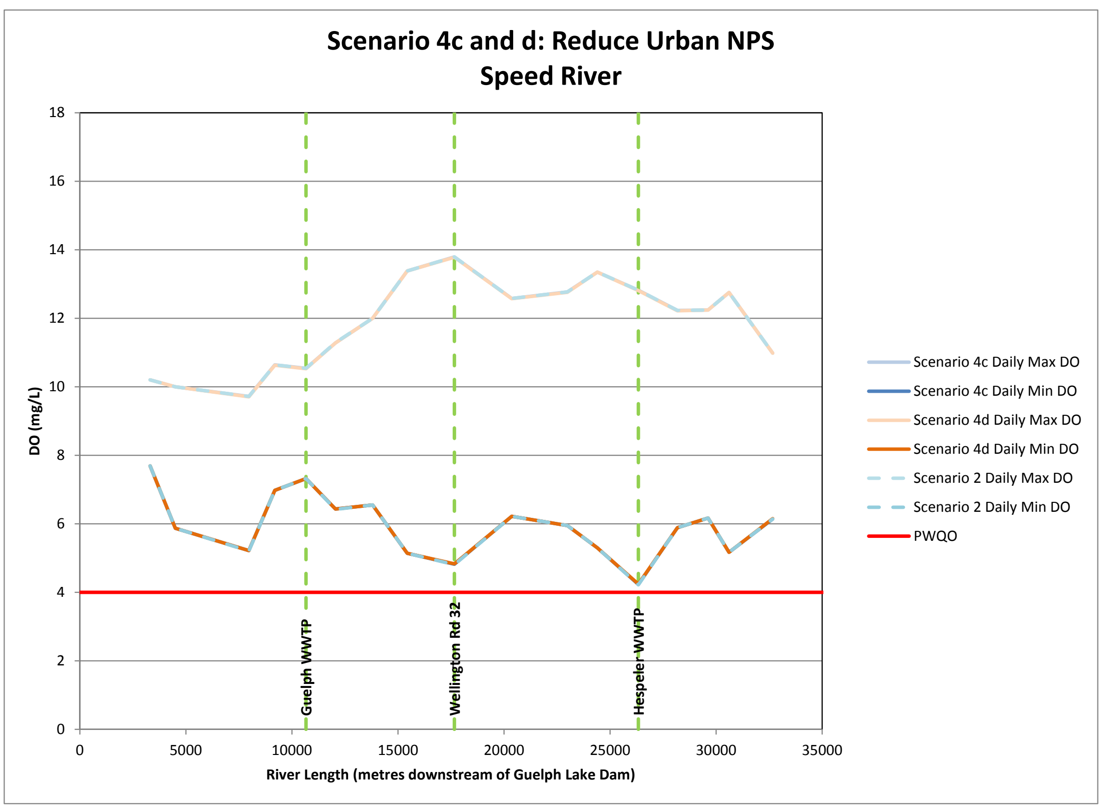
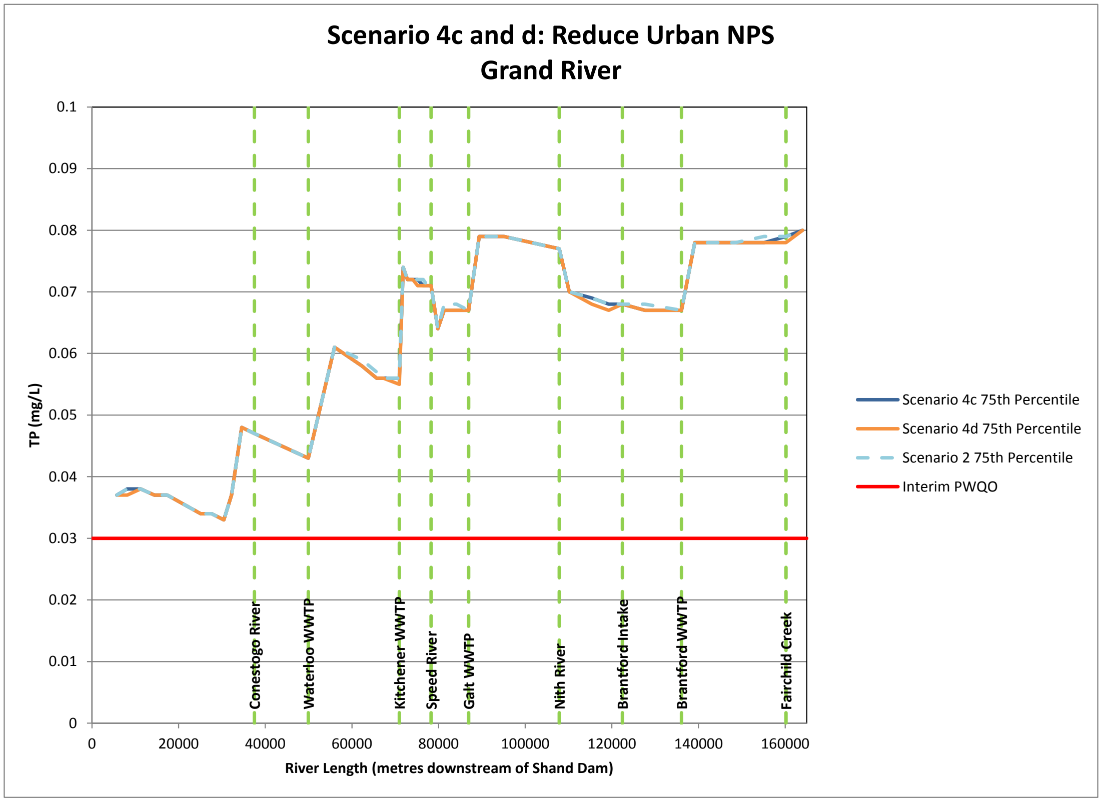


Figure B-18: Scenario 4c and d Results, Low Flow Summer Conditions – Total Phosphorus



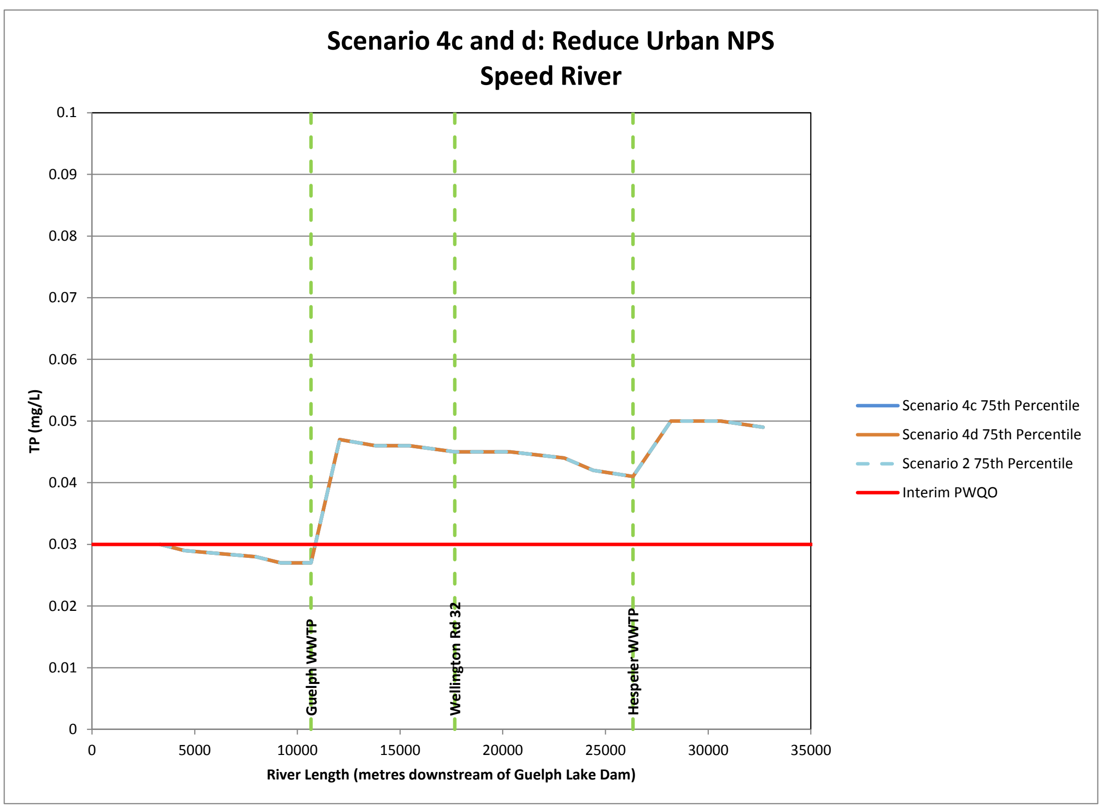
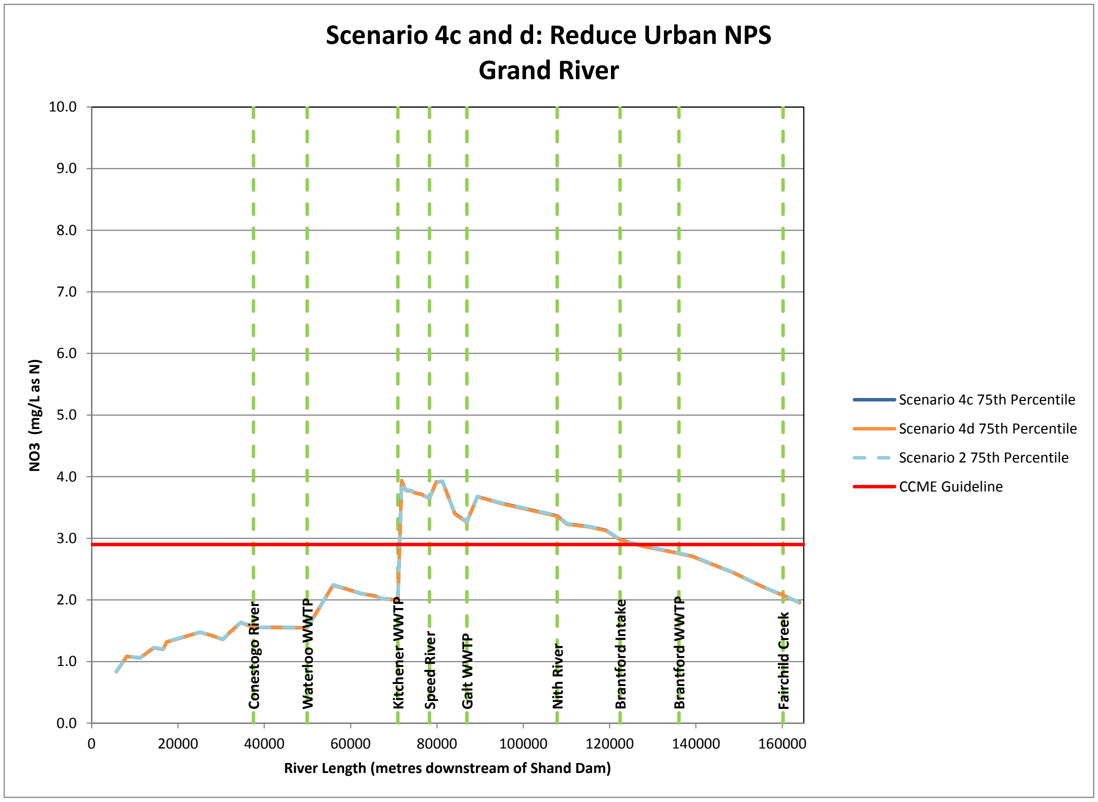


Figure B-19: Scenario 4c and d Results, Low Flow Summer Conditions – Nitrate



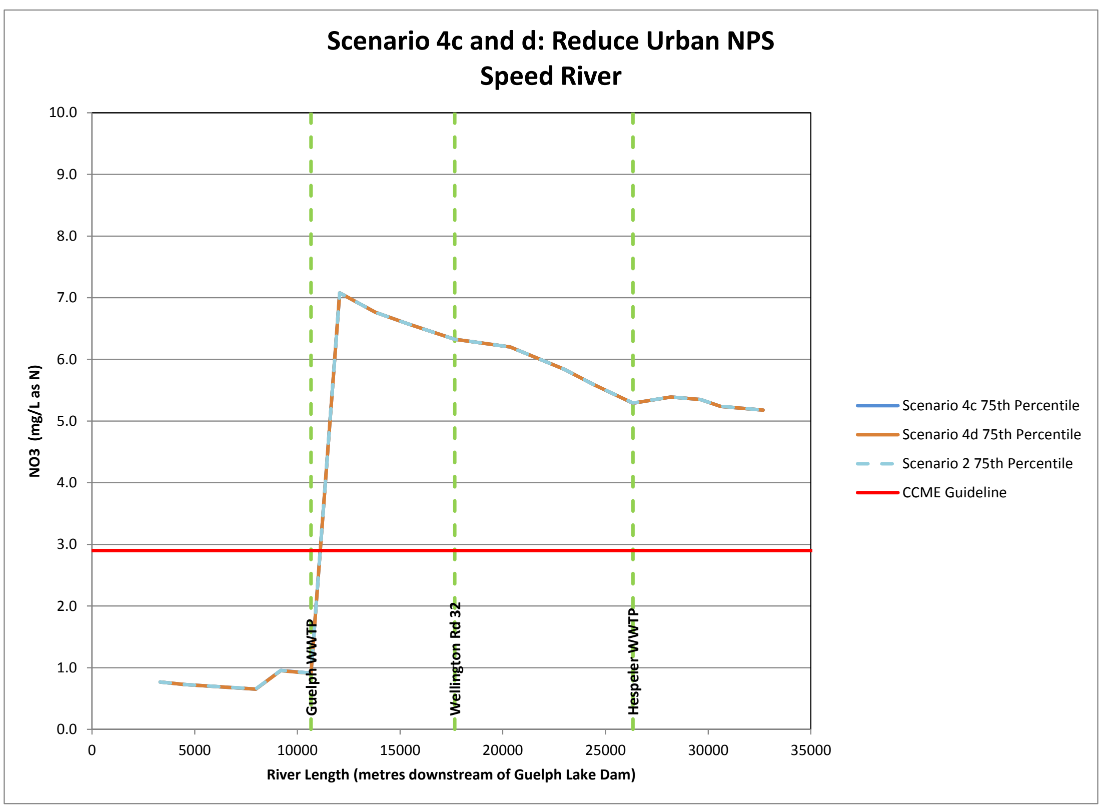
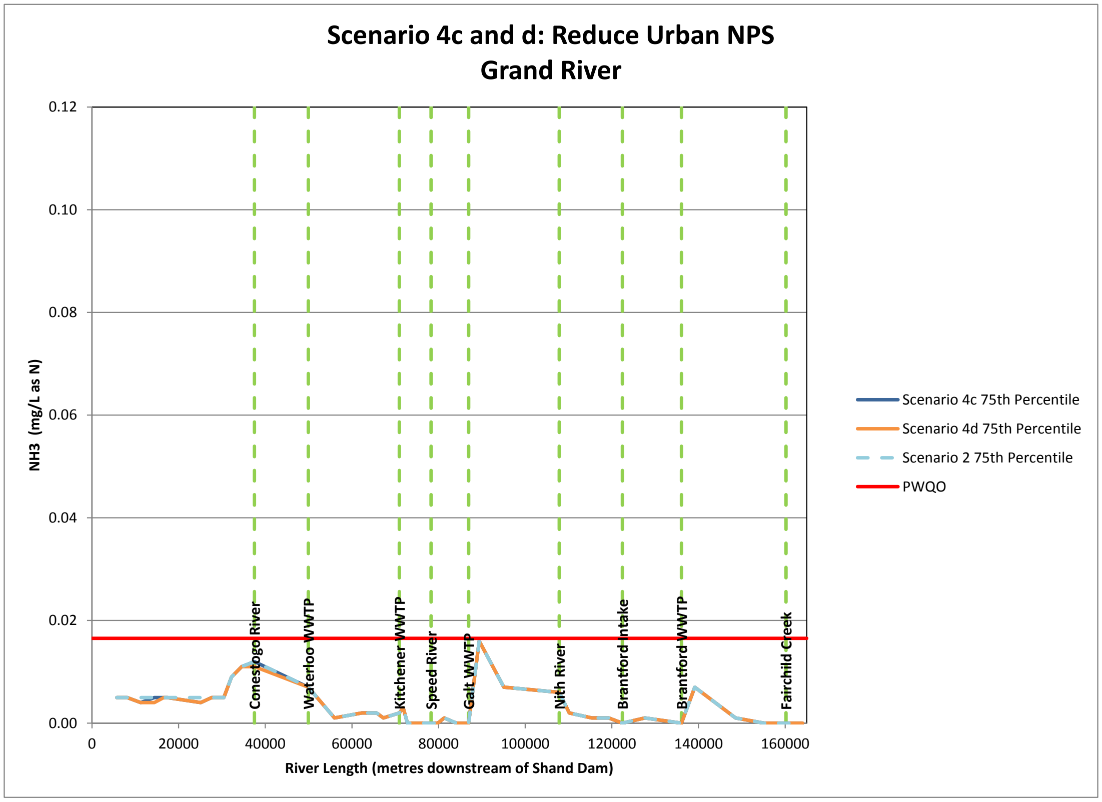


Figure B-20: Scenario 4c and d Results, Low Flow Summer Conditions – Un-ionized Ammonia



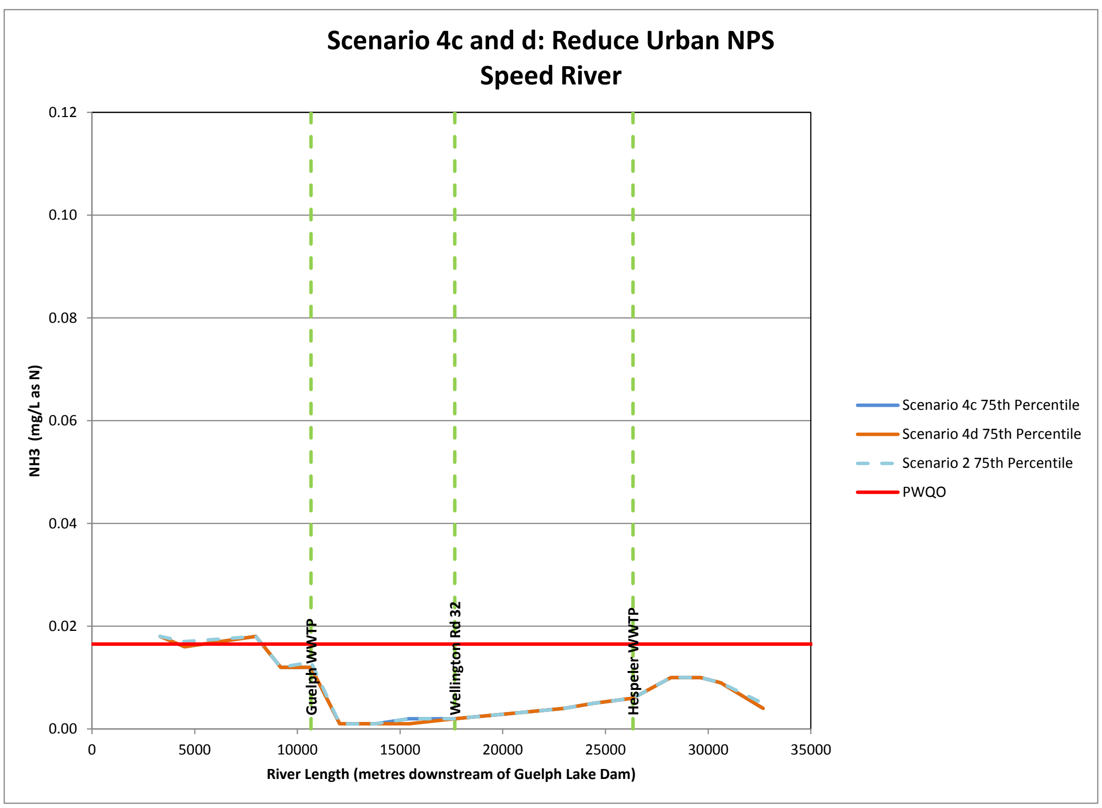
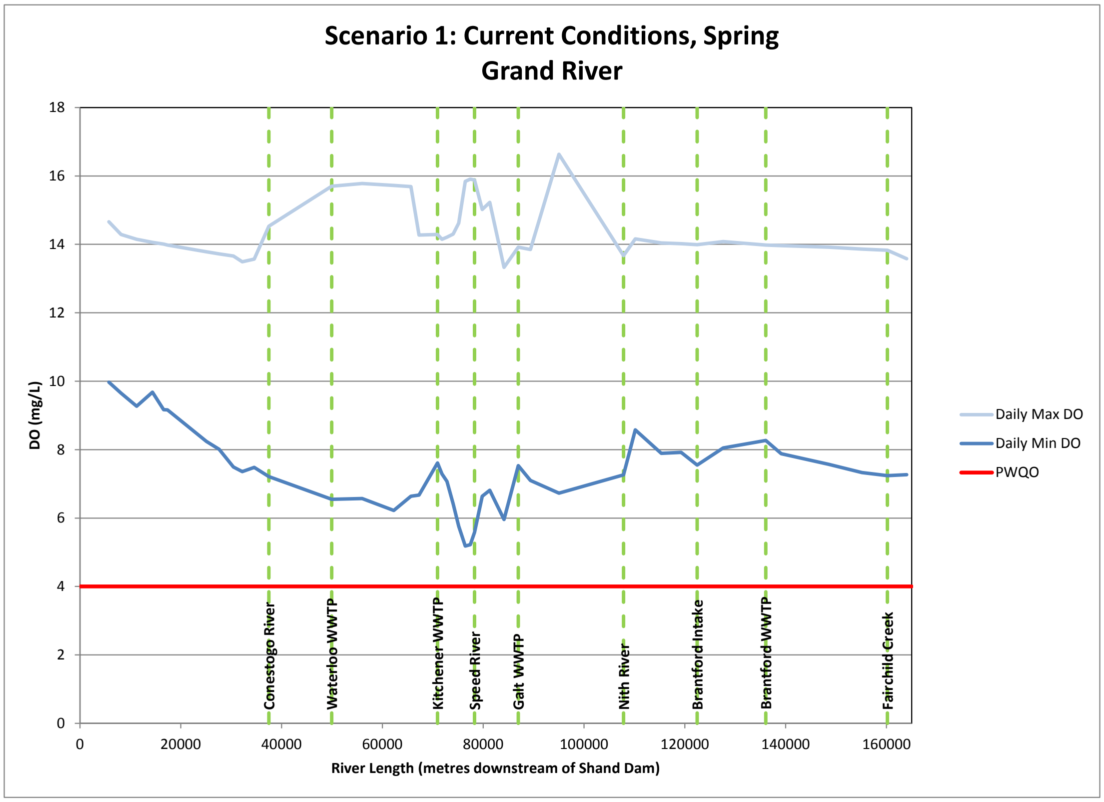


Figure B-21: Scenario 1 Results, Spring – Dissolved Oxygen



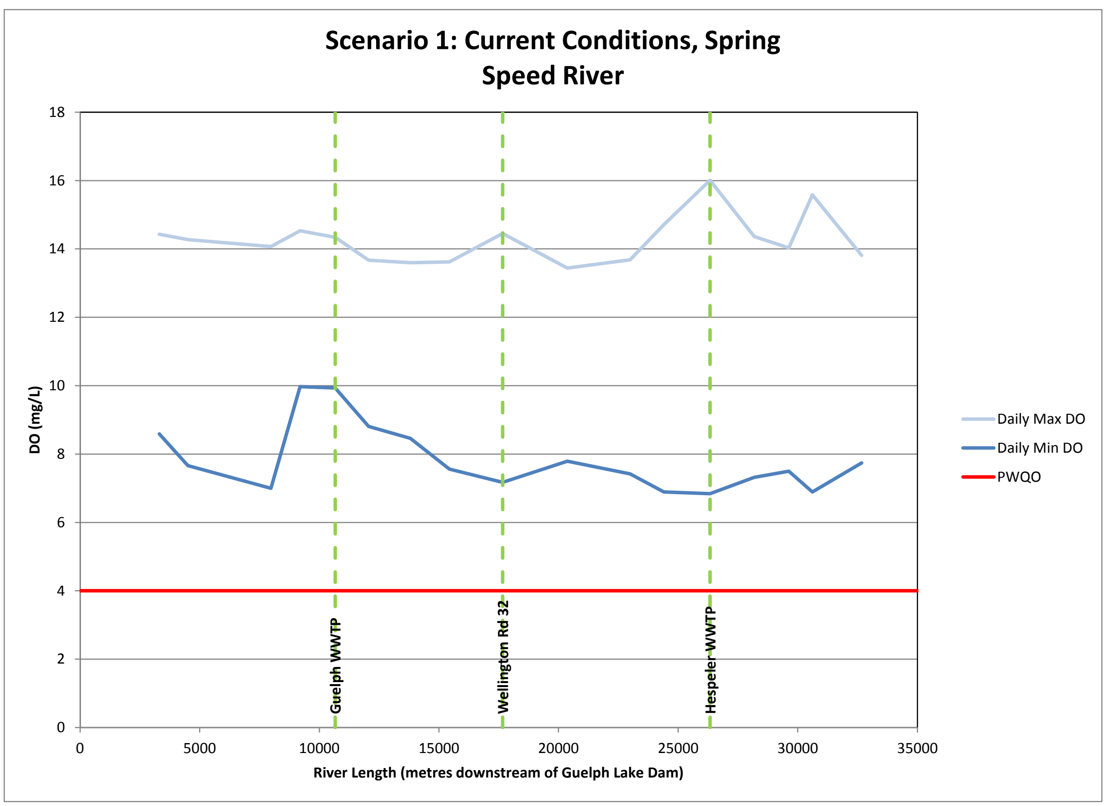
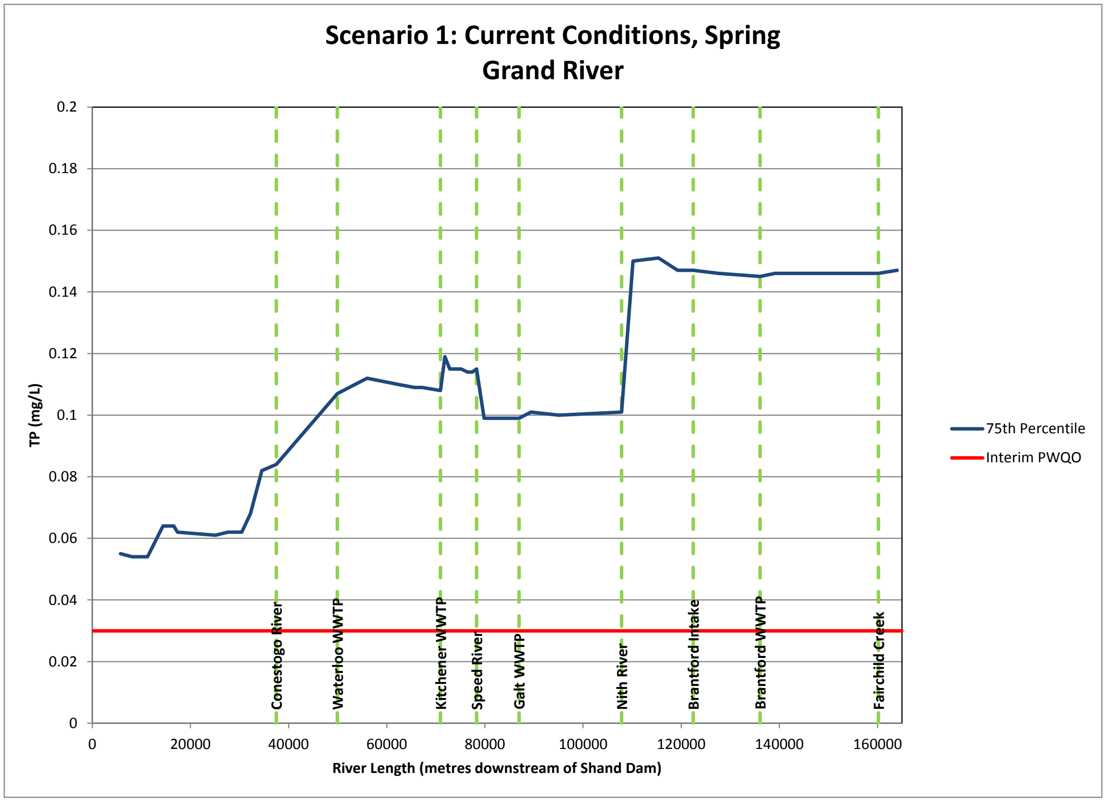


Figure B-22: Scenario 1 Results, Spring – Total Phosphorus



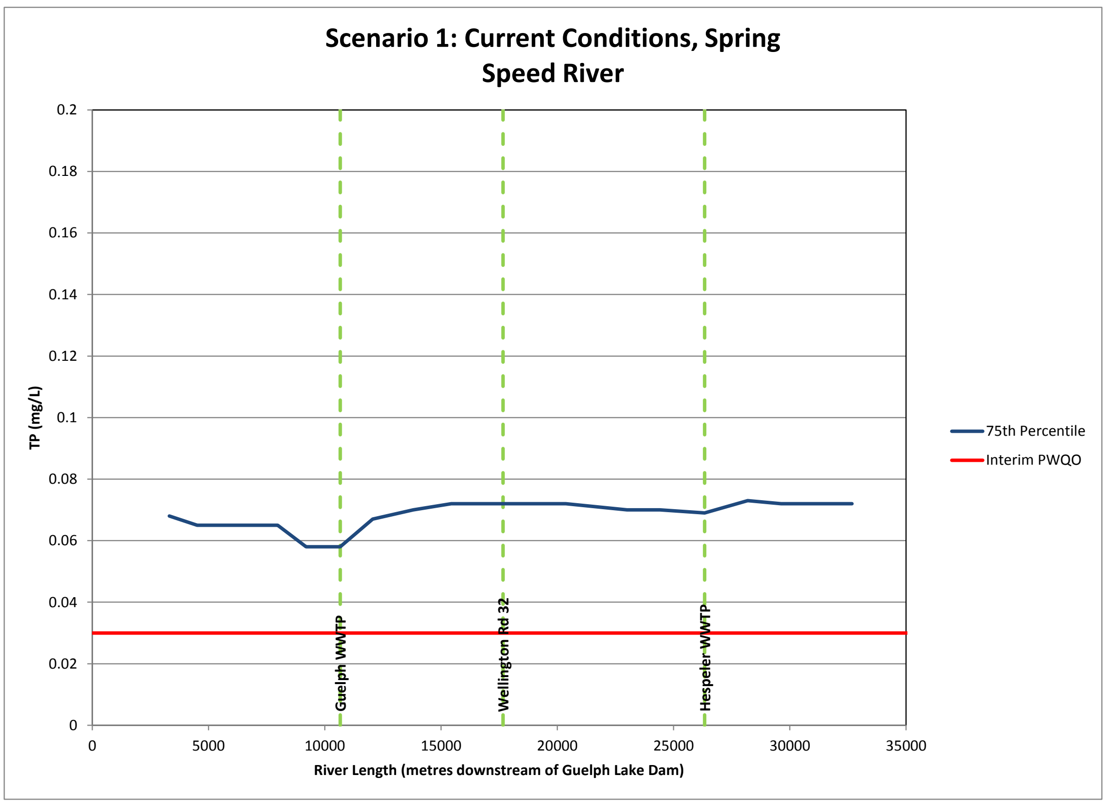
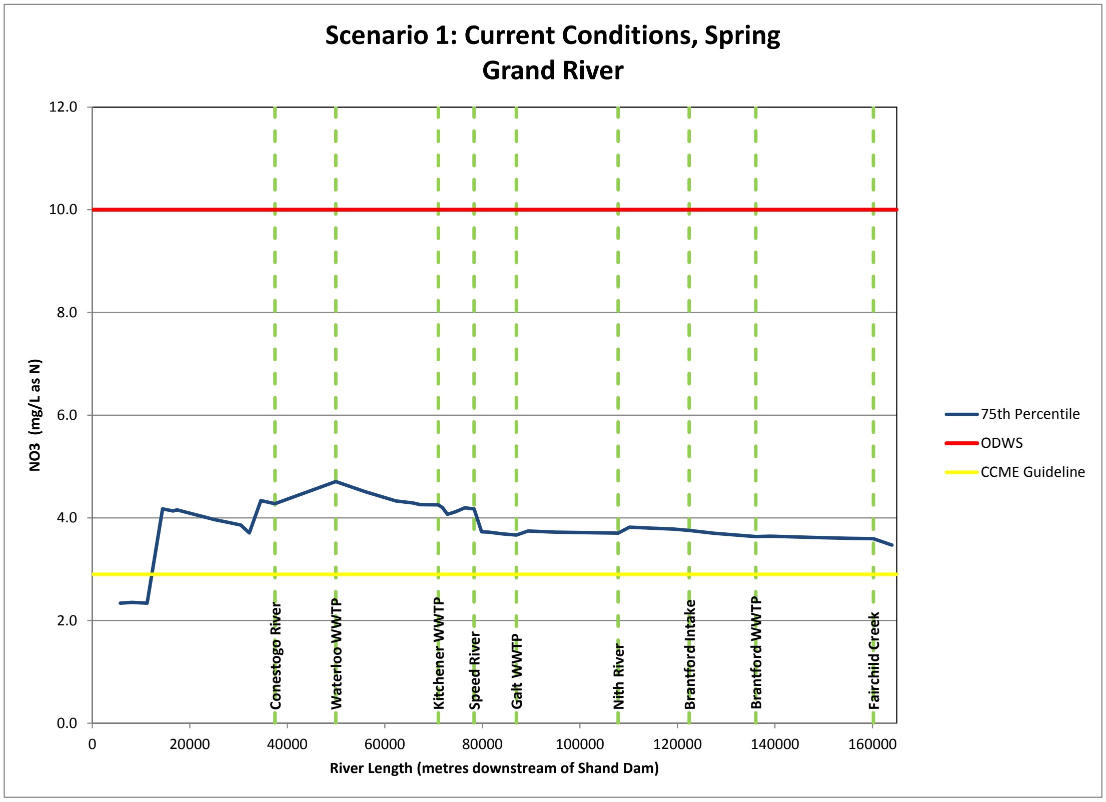


Figure B-23: Scenario 1 Results, Spring – Nitrate



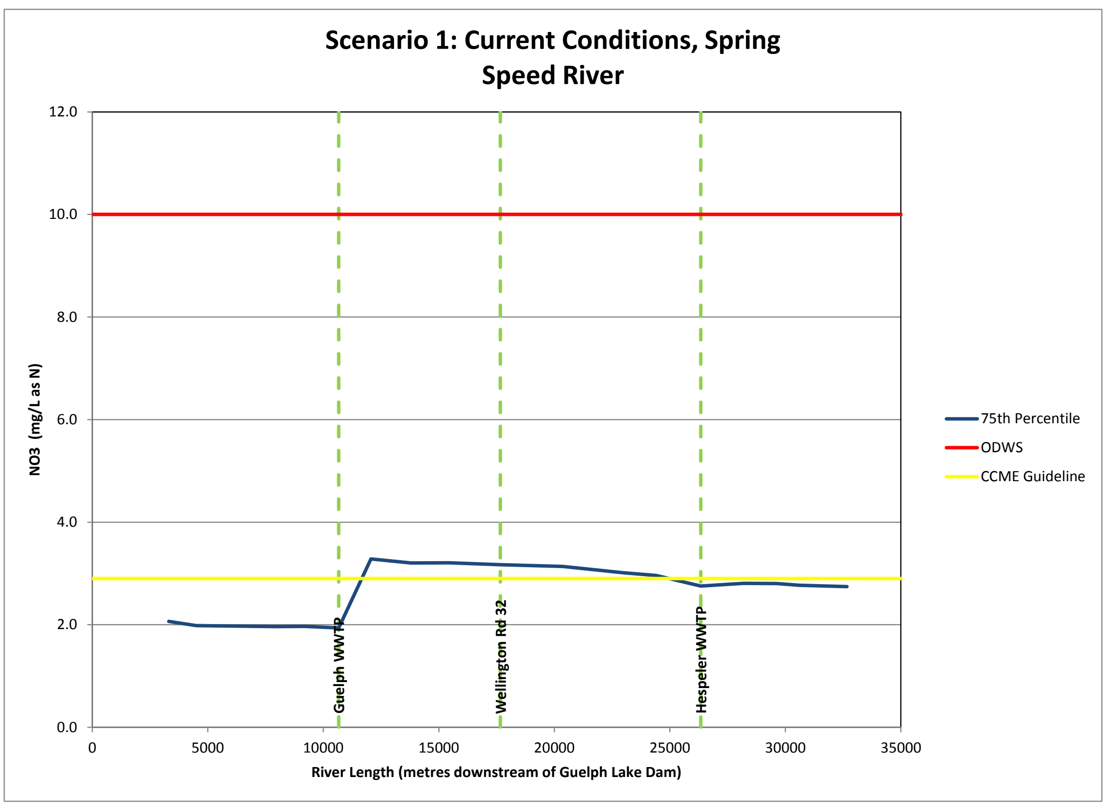
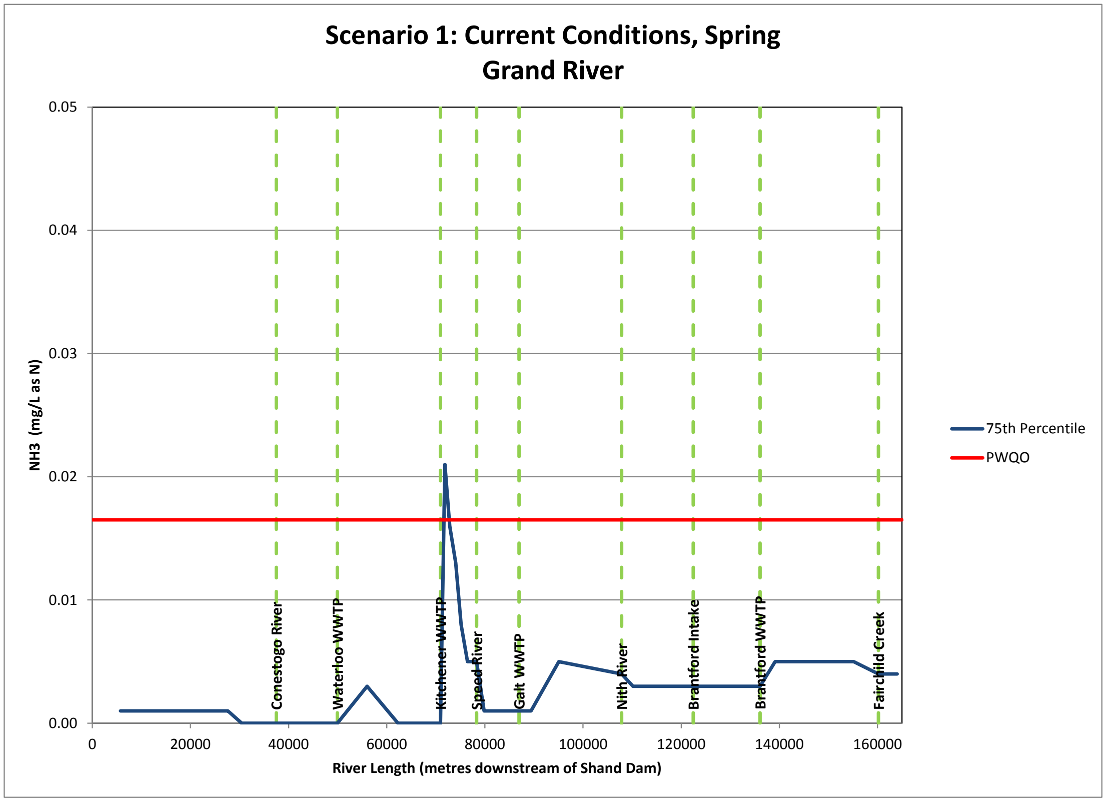


Figure B-24: Scenario 1 Results, Spring – Un-ionized Ammonia



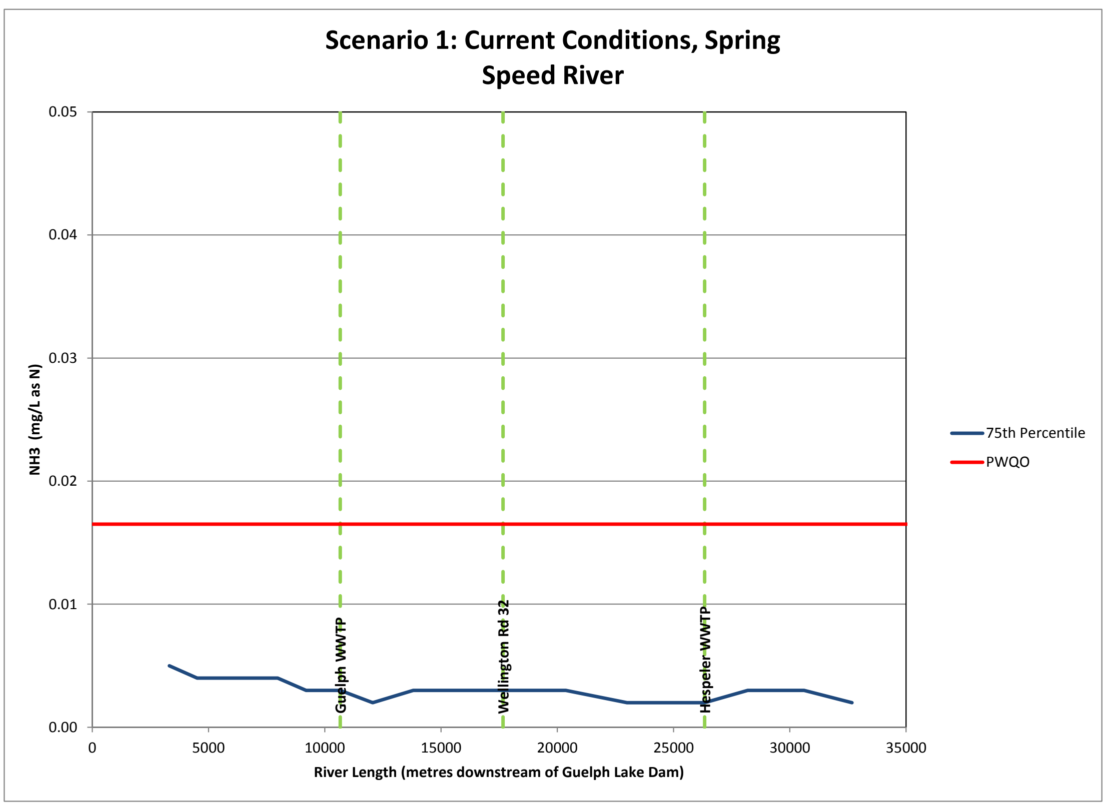
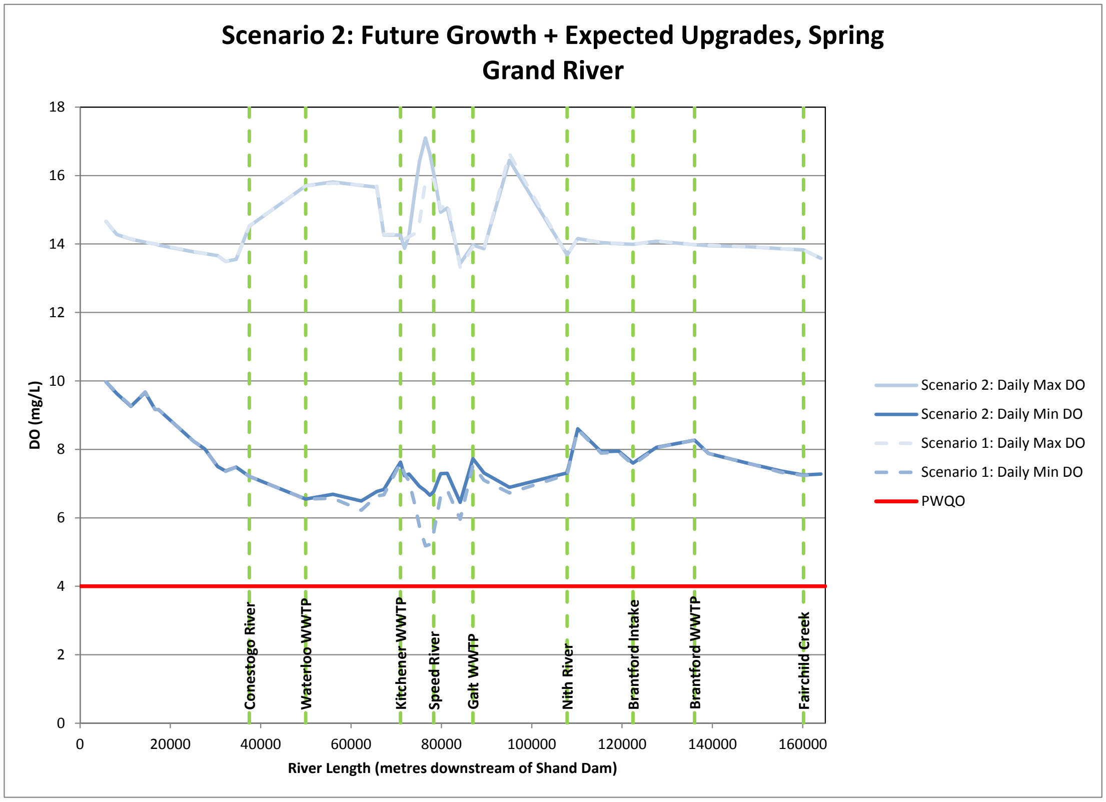


Figure B-25: Scenario 2 Results, Spring – Dissolved Oxygen



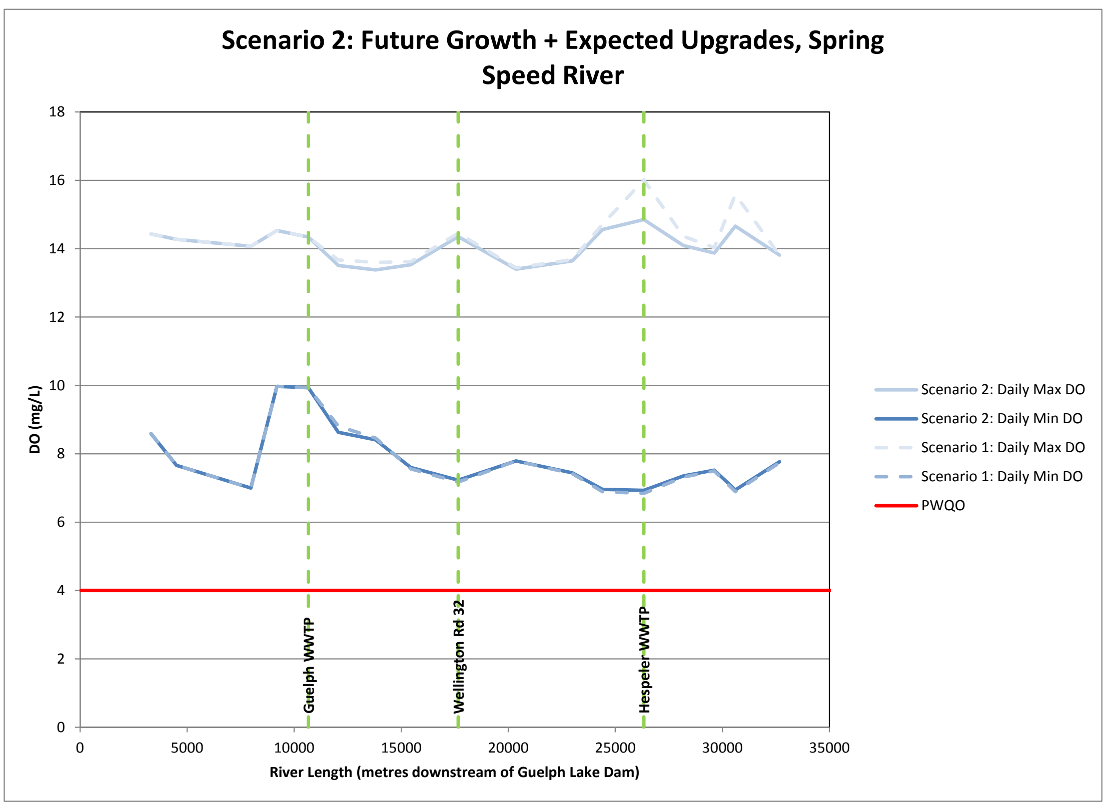
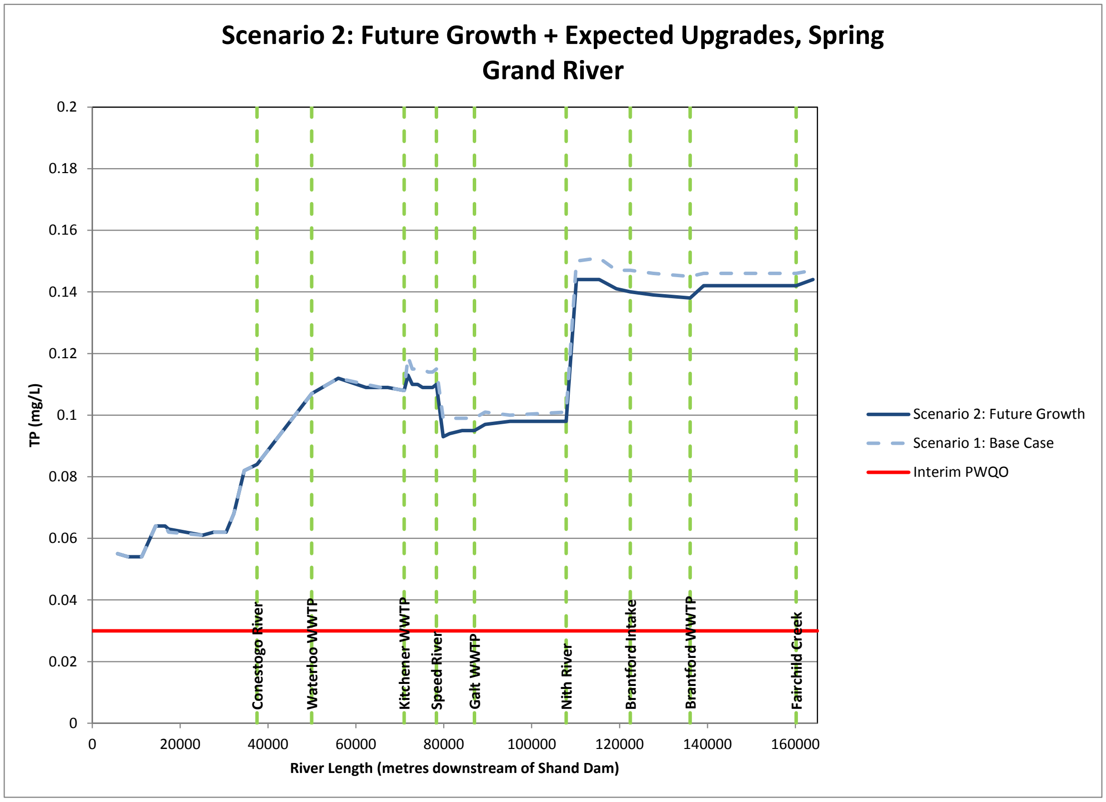


Figure B-26: Scenario 2 Results, Spring – Total Phosphorus



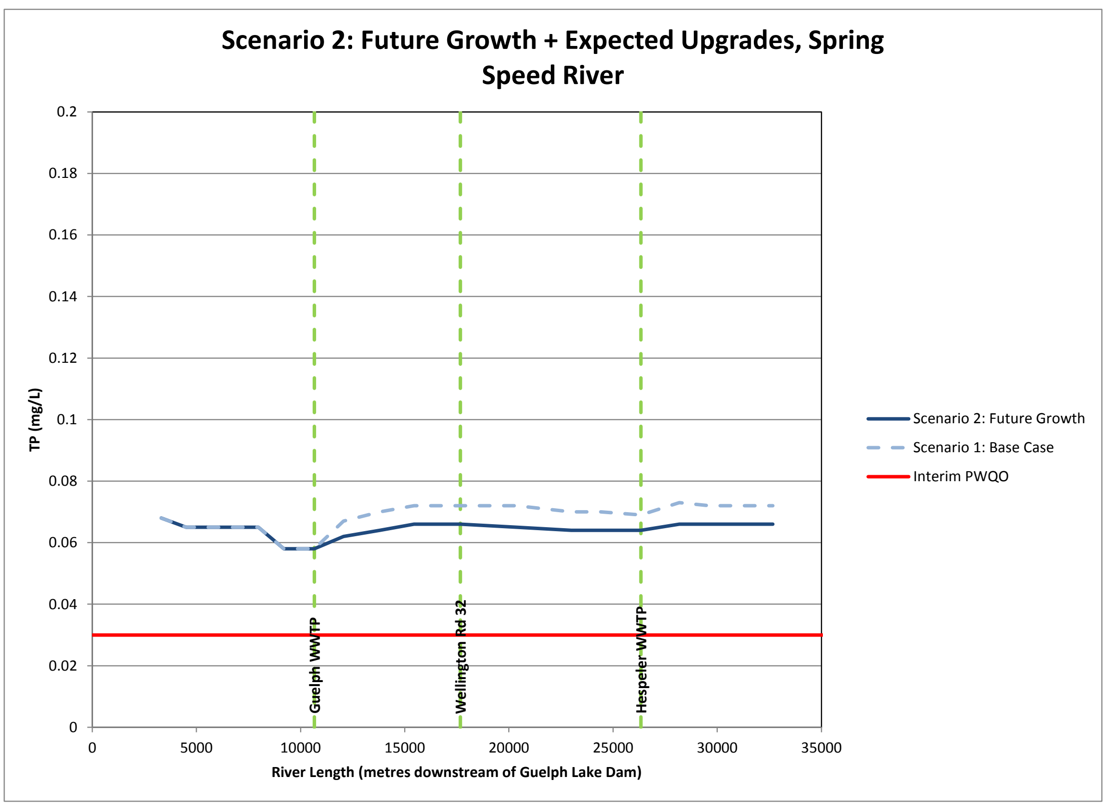
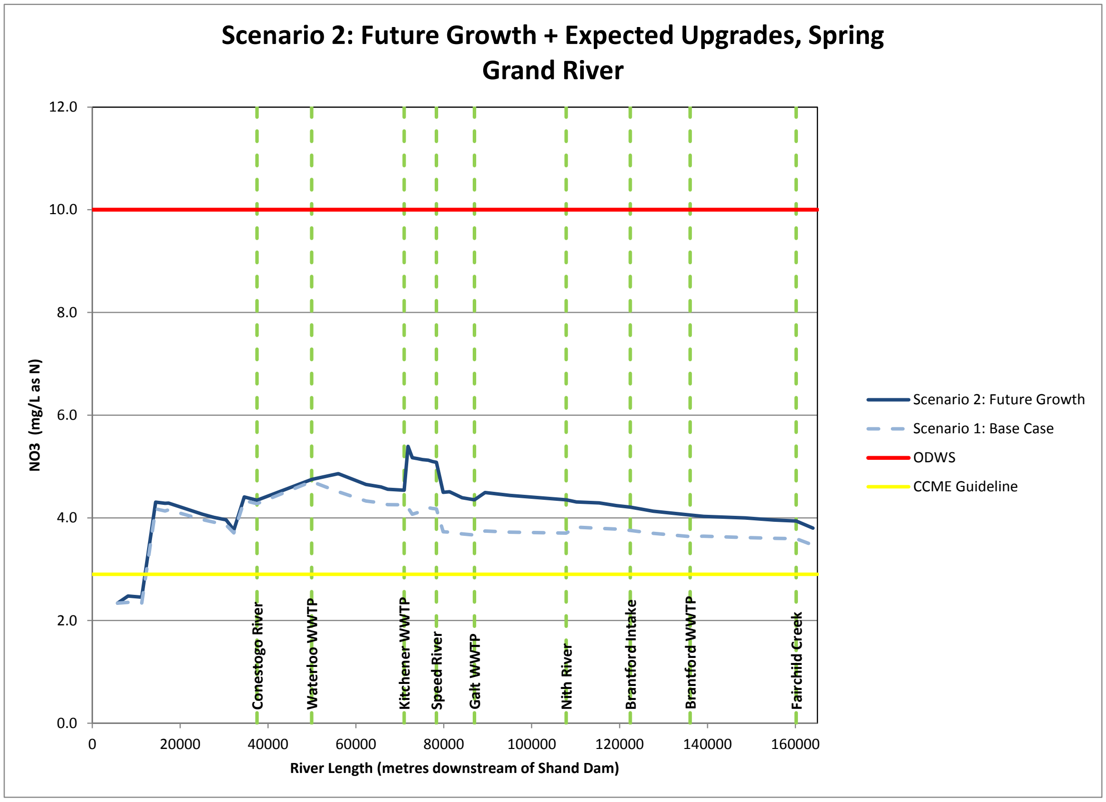


Figure B-27: Scenario 2 Results, Spring – Nitrate



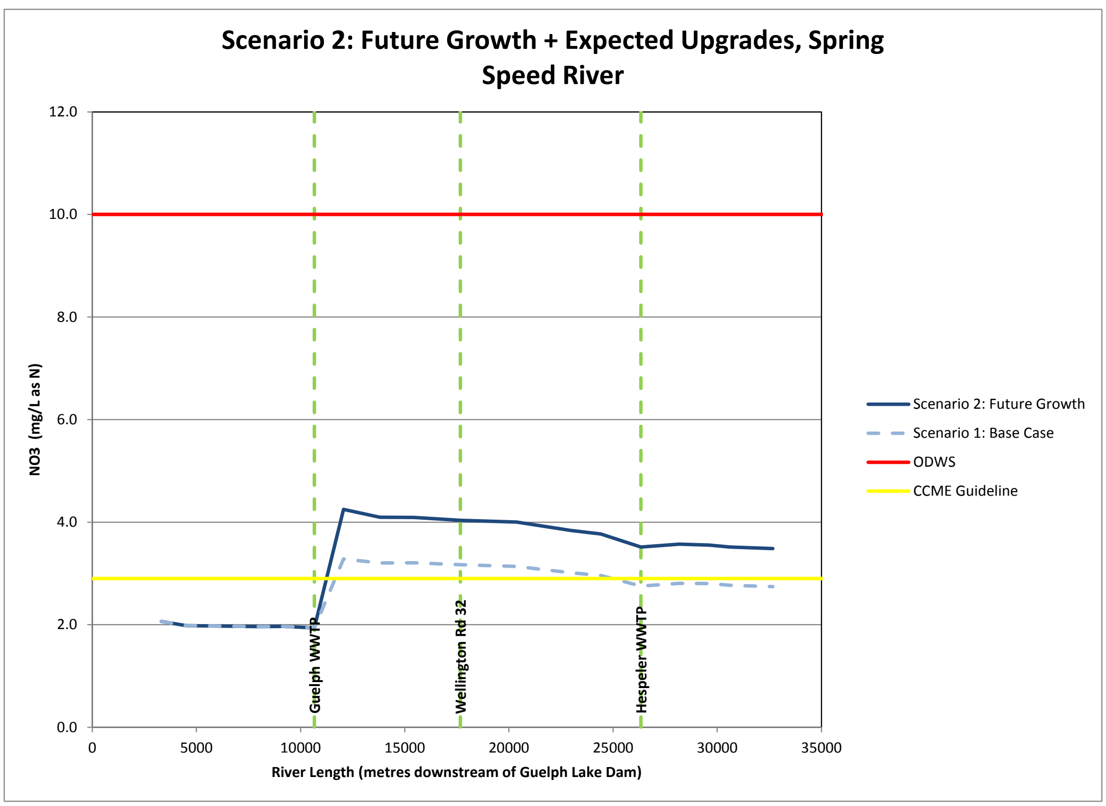
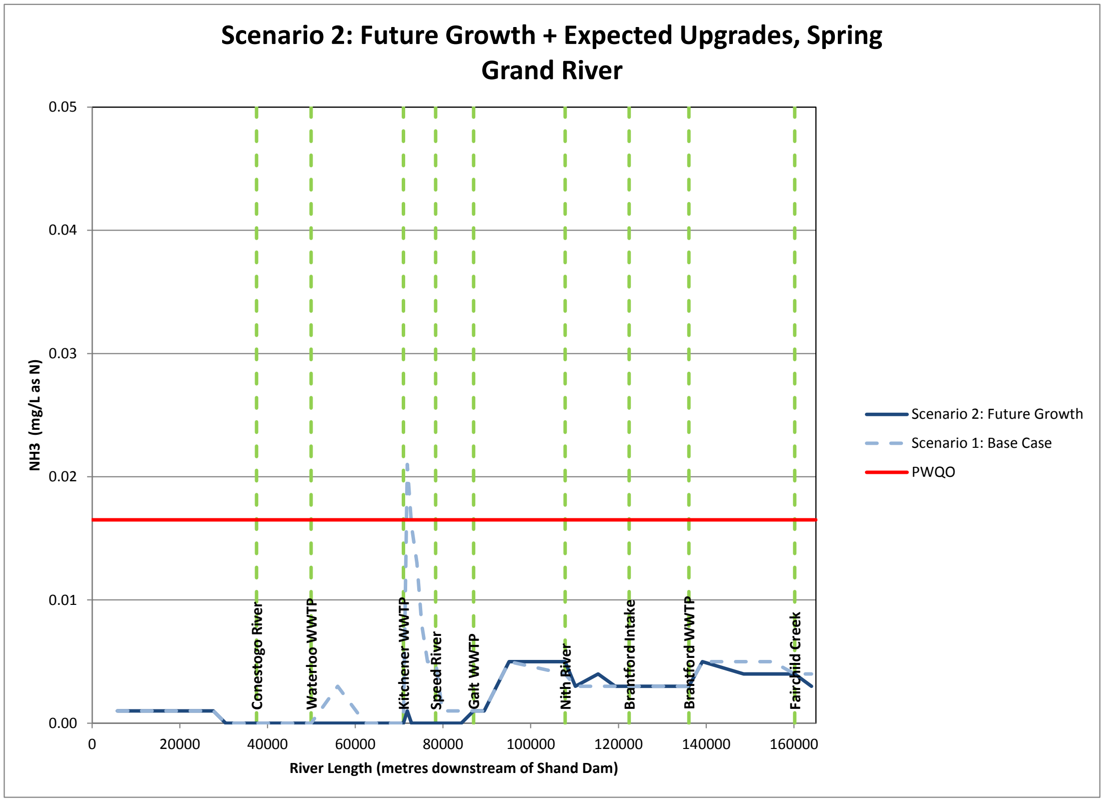


Figure B-28: Scenario 2 Results, Spring – Un-ionized Ammonia



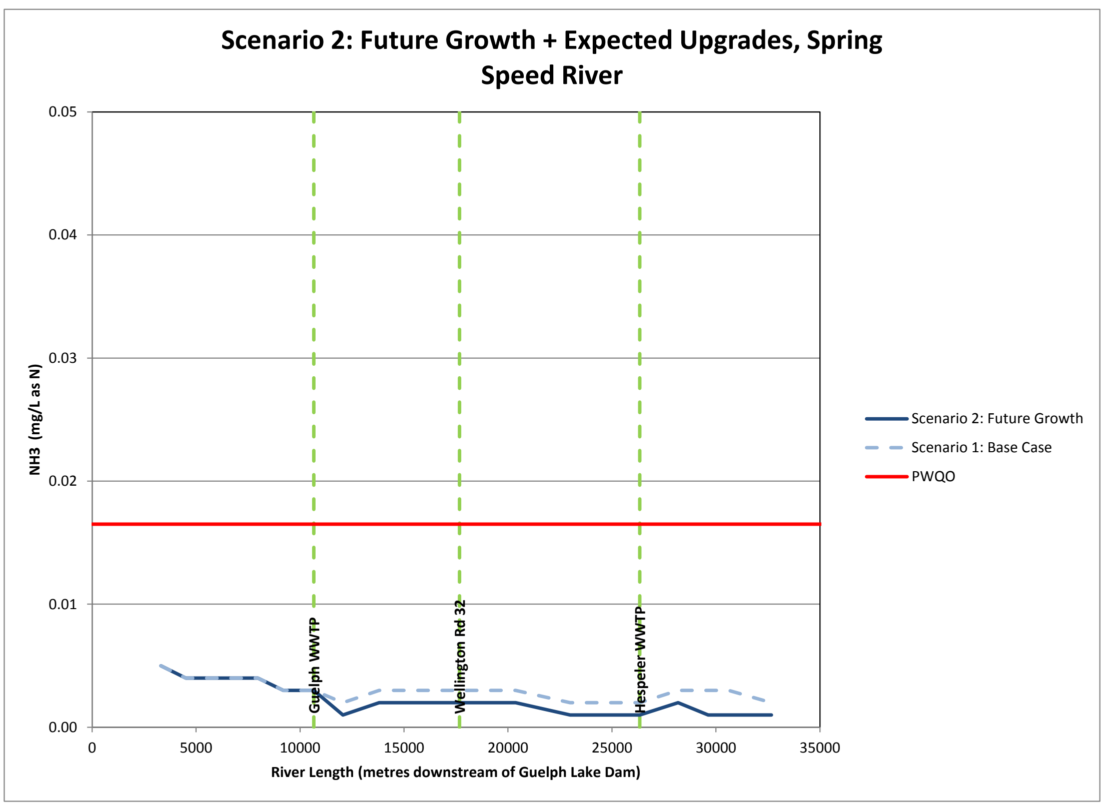
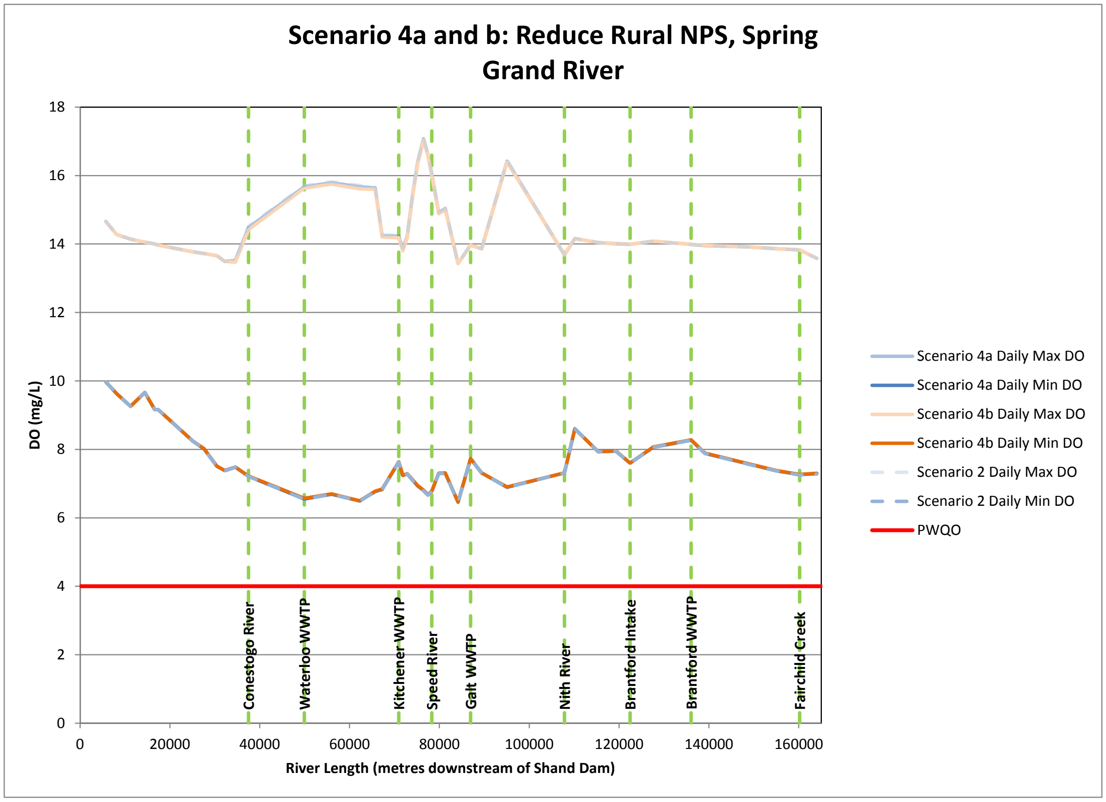


Figure B-29: Scenario 4a and b Results, Spring – Dissolved Oxygen



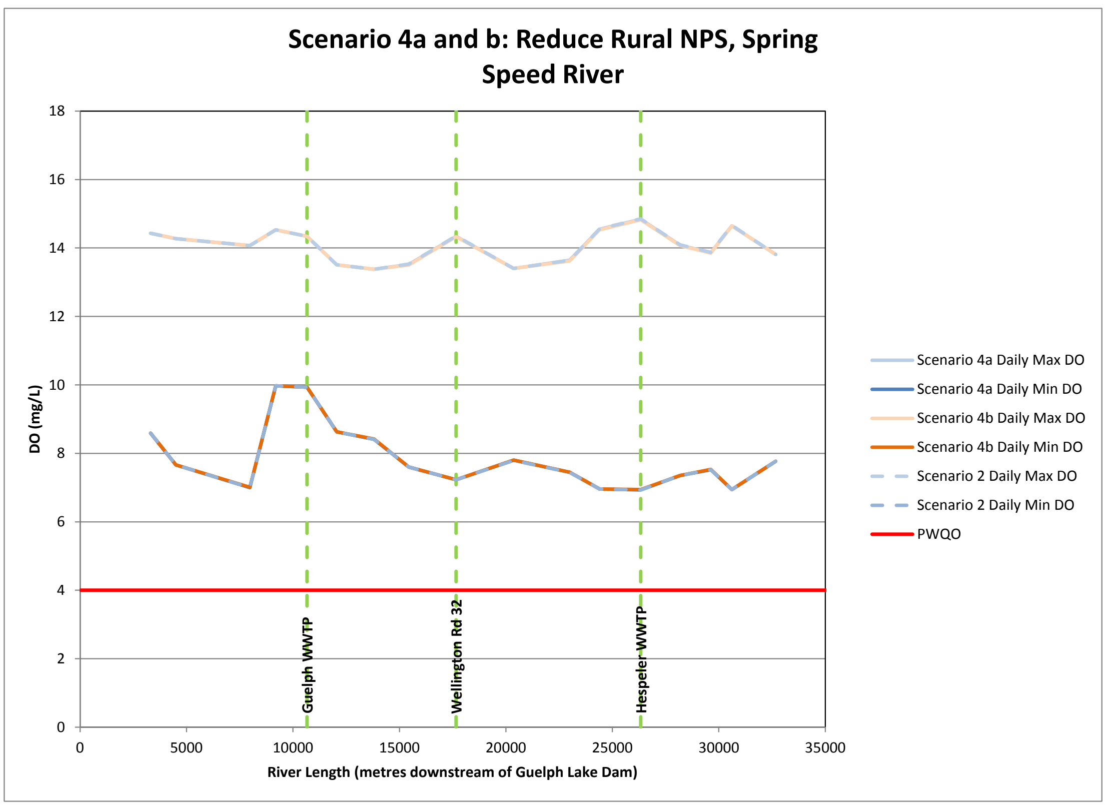
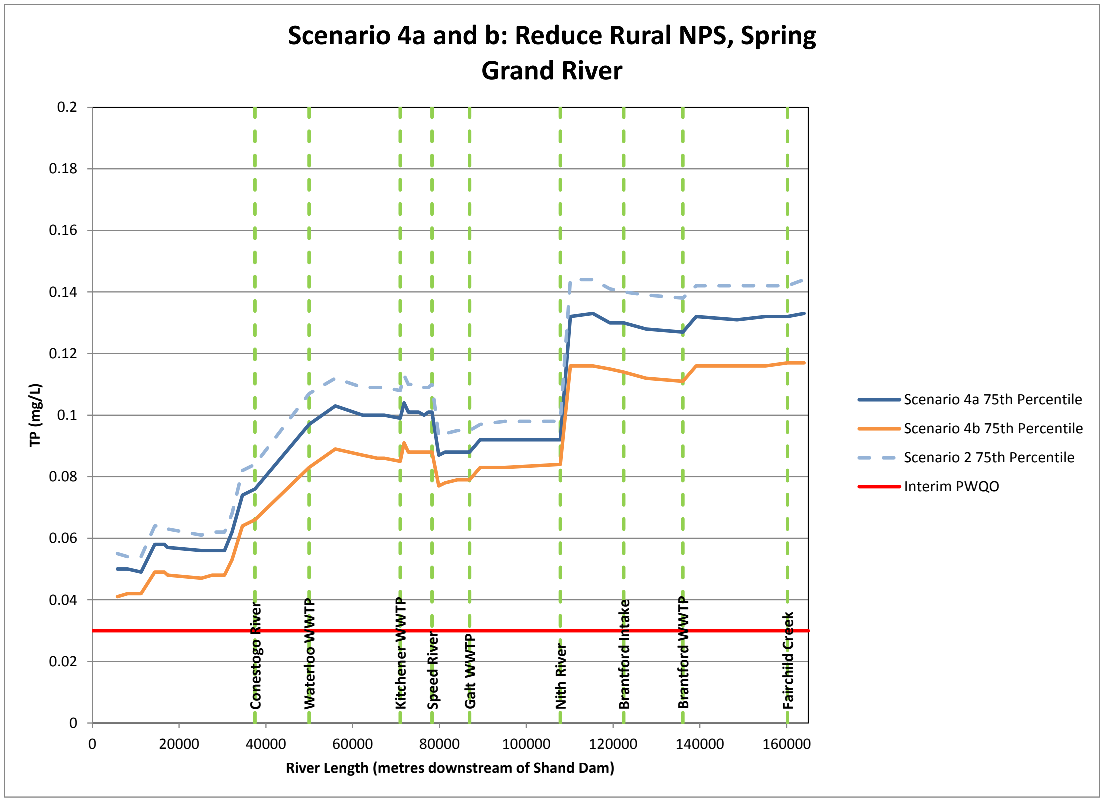


Figure B-30: Scenario 4a and b Results, Spring – Total Phosphorus



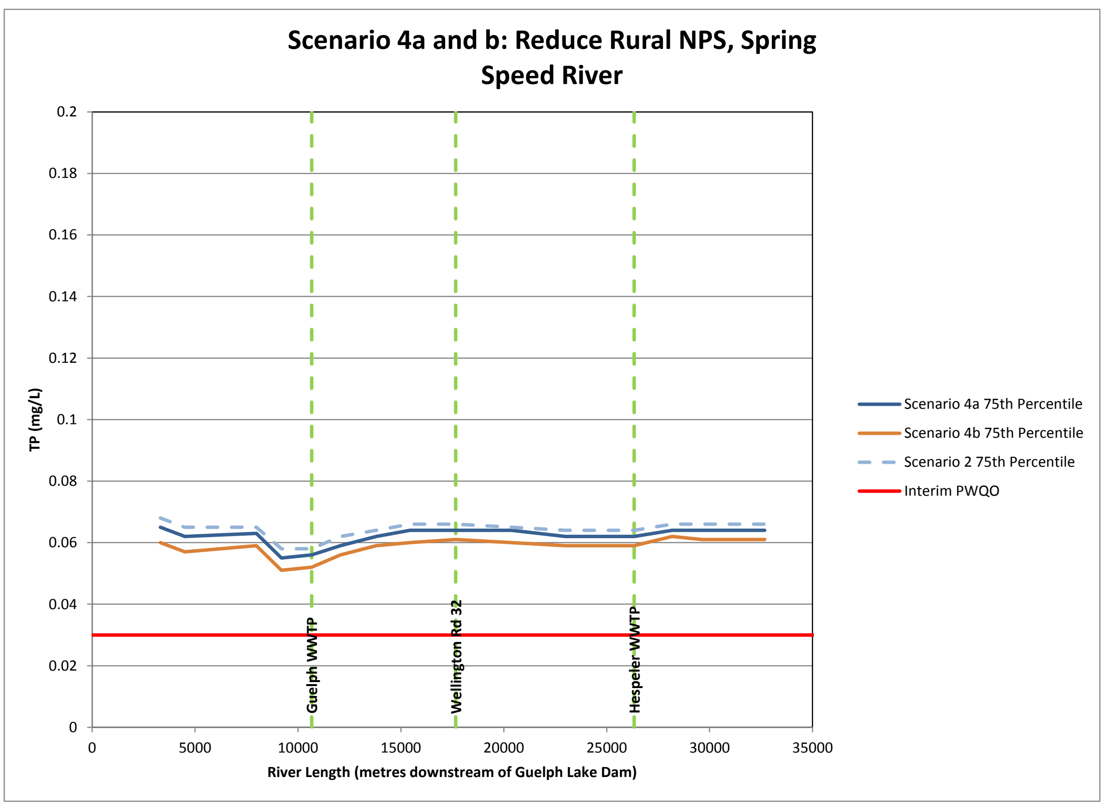
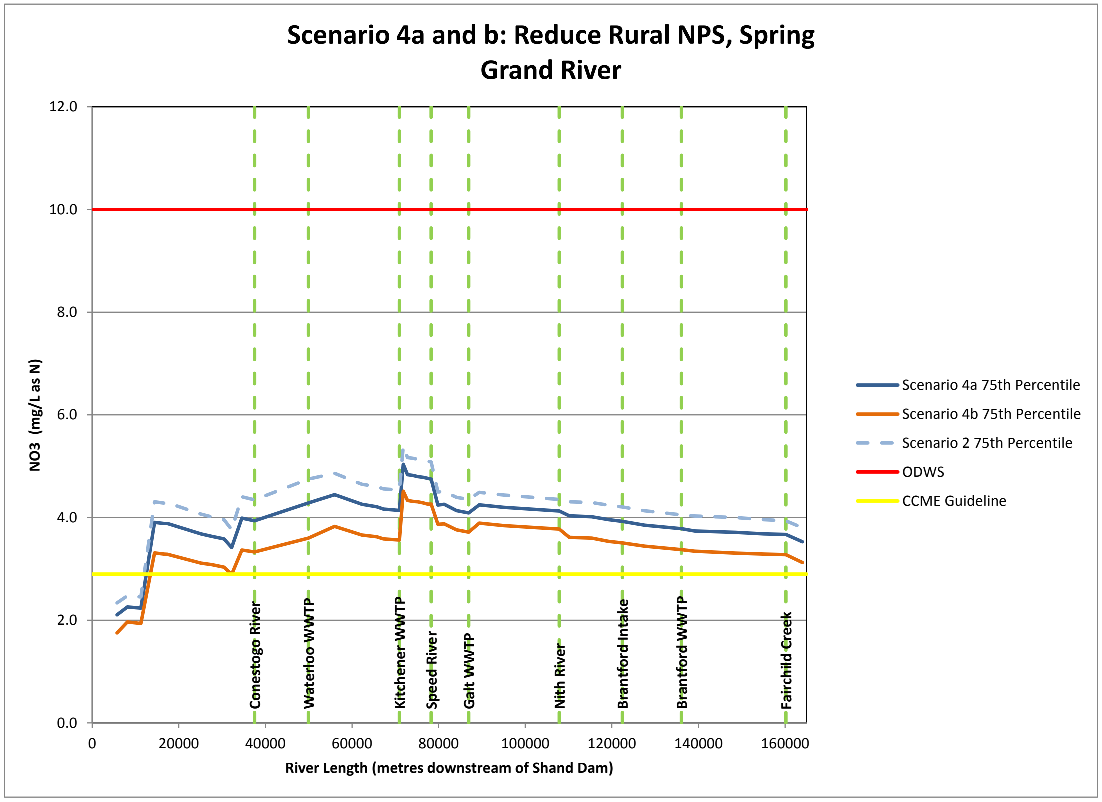


Figure B-31: Scenario 4a and b Results, Spring – Nitrate



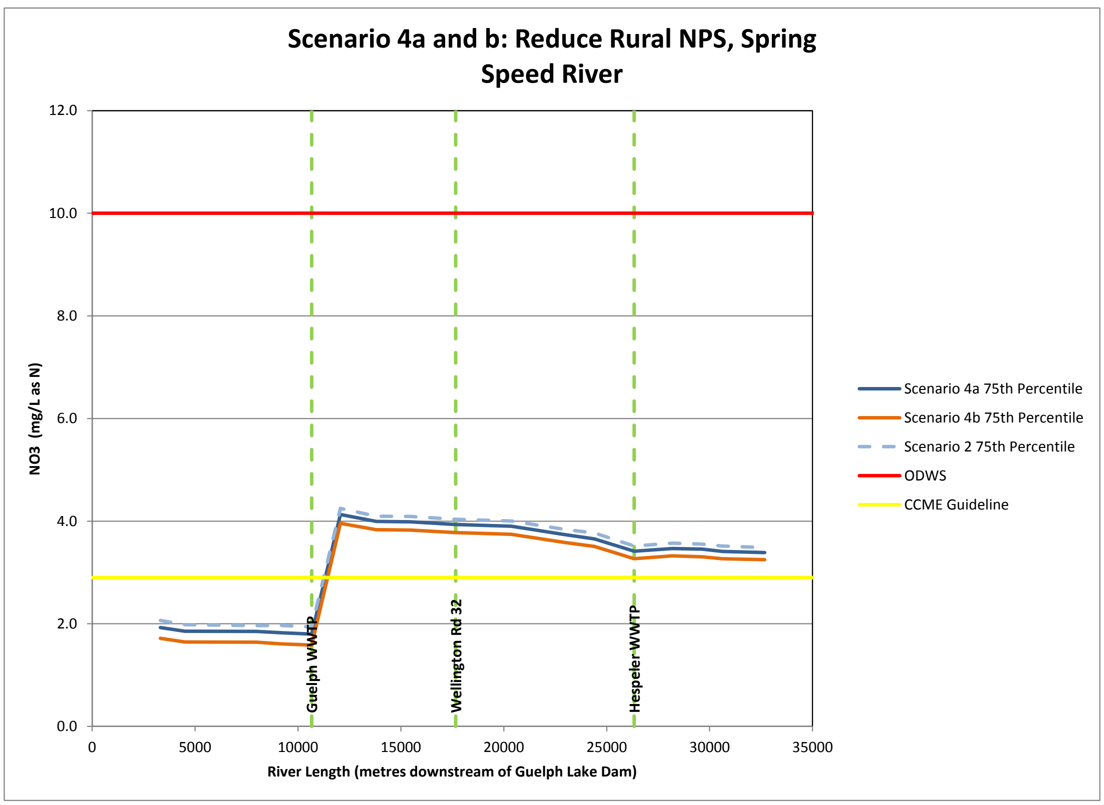
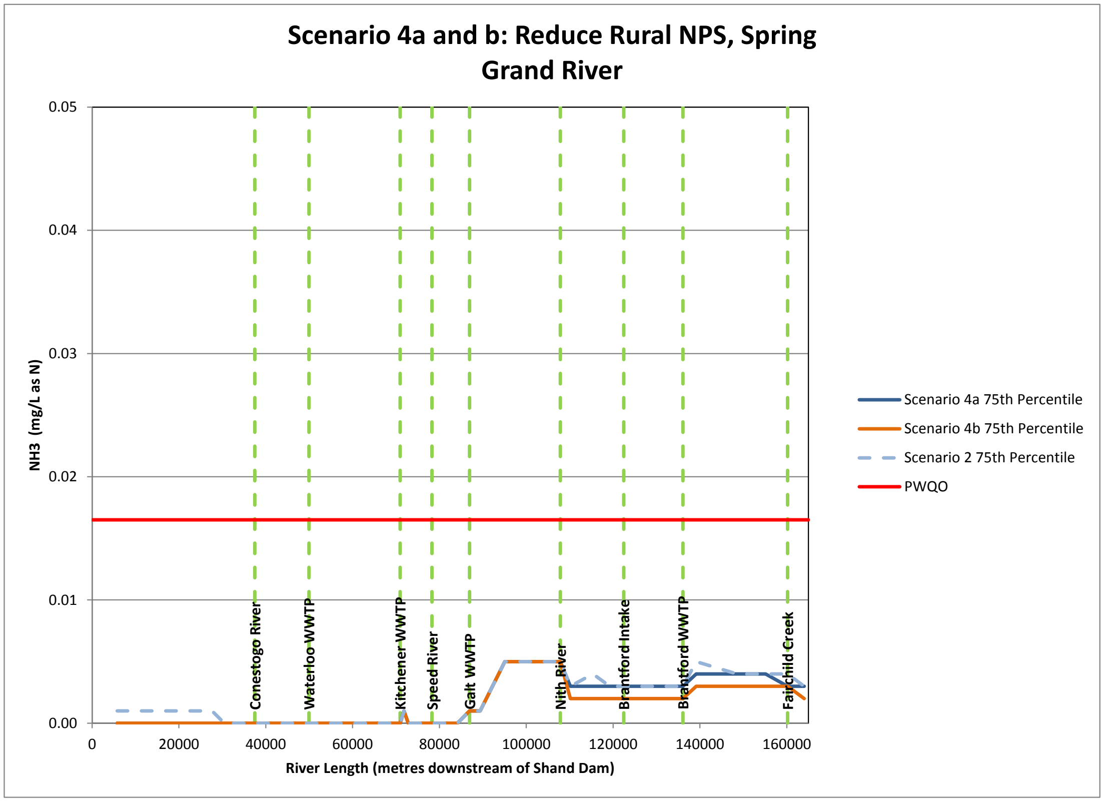


Figure B-32: Scenario 4a and b Results, Spring – Un-ionized Ammonia



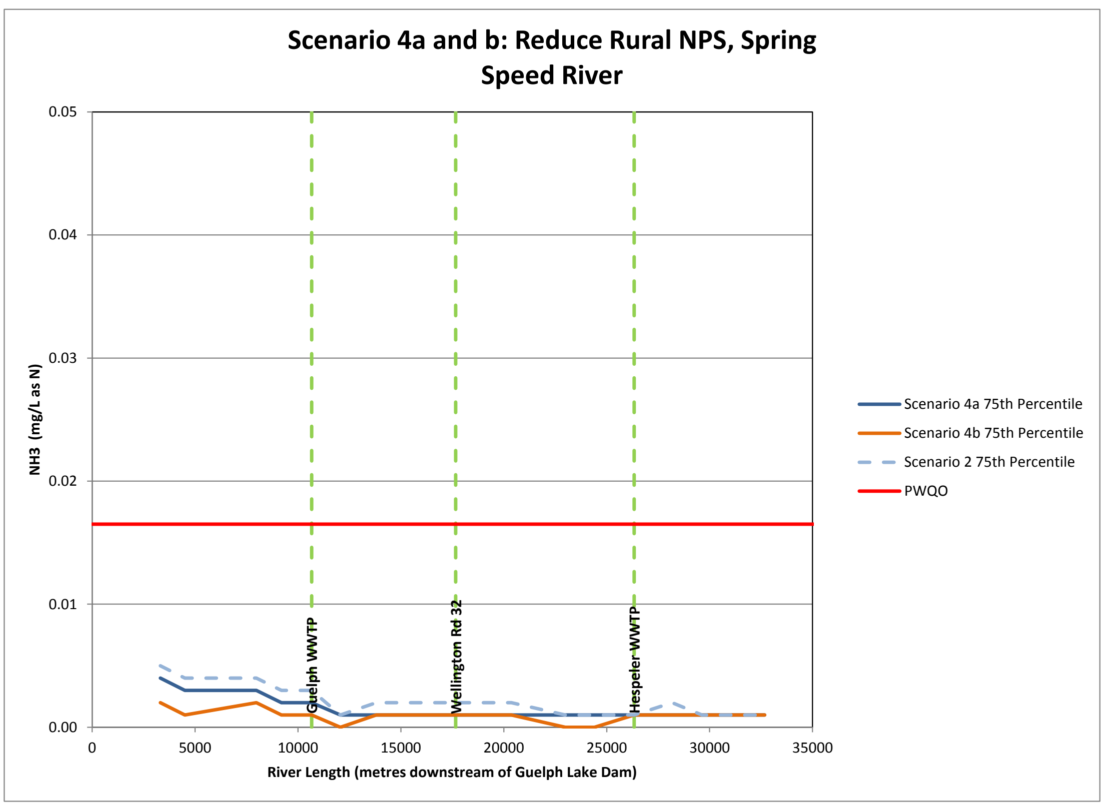
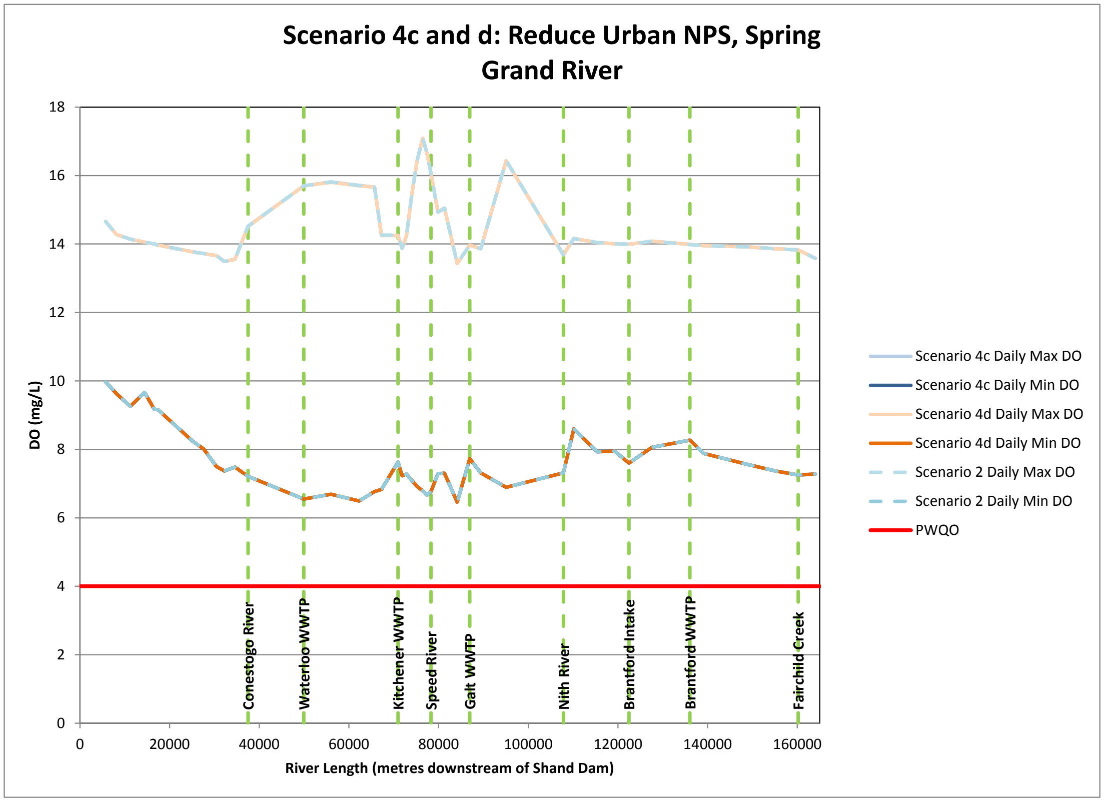


Figure B-33: Scenario 4c and d Results, Spring – Dissolved Oxygen



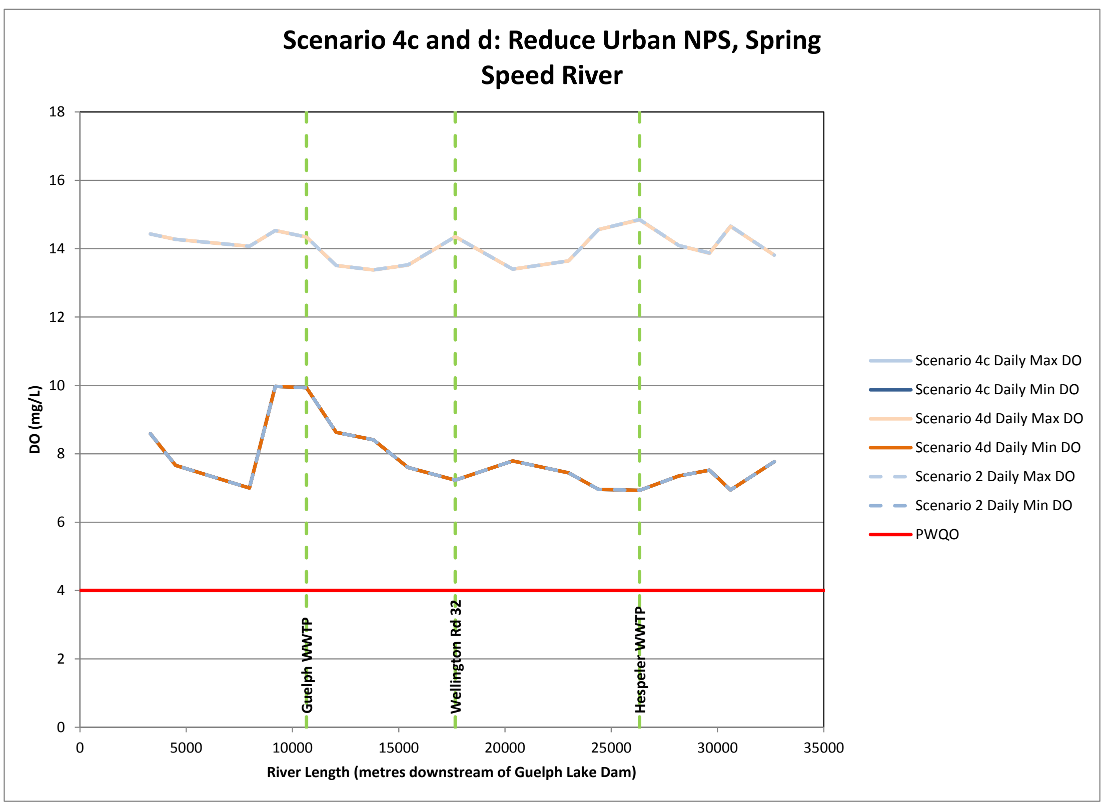
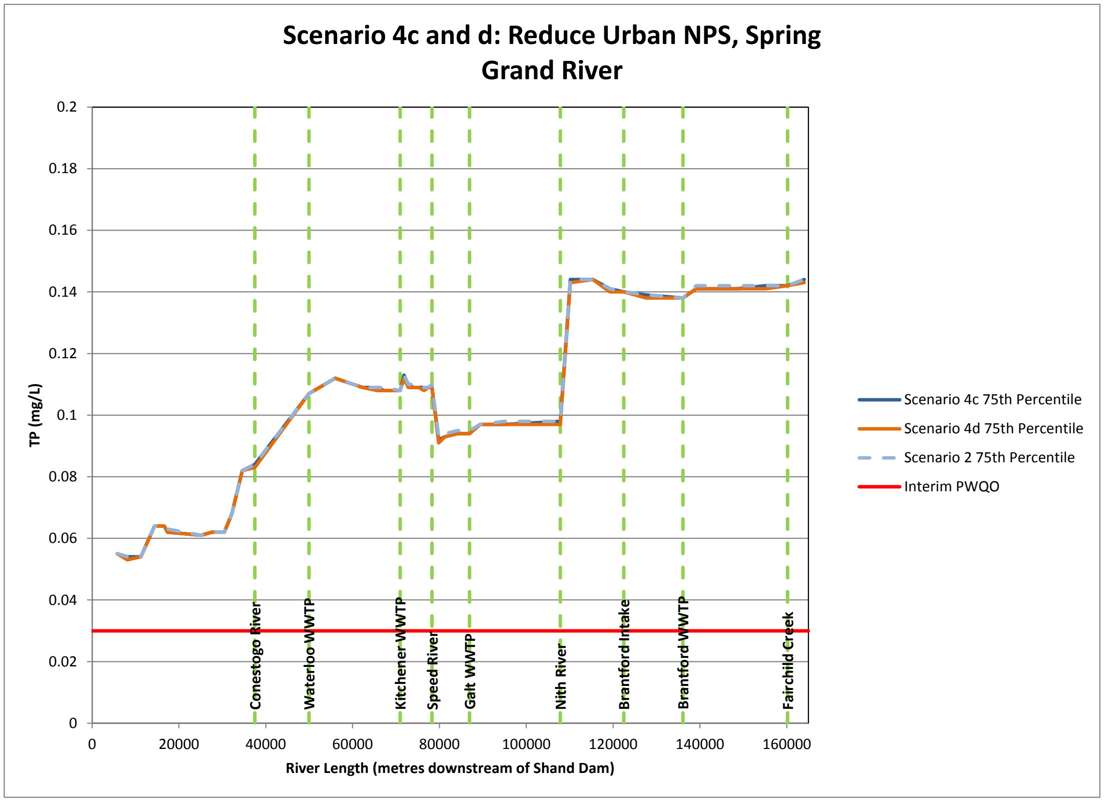


Figure B-34: Scenario 4c and d Results, Spring – Total Phosphorus



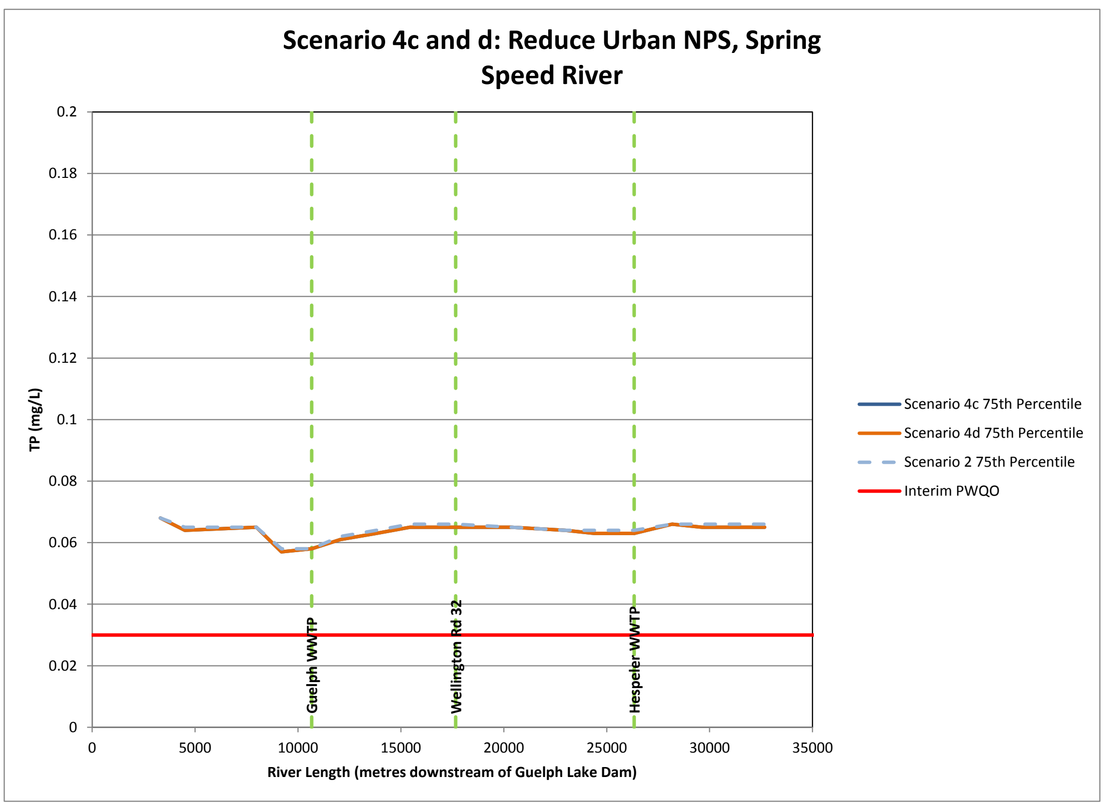
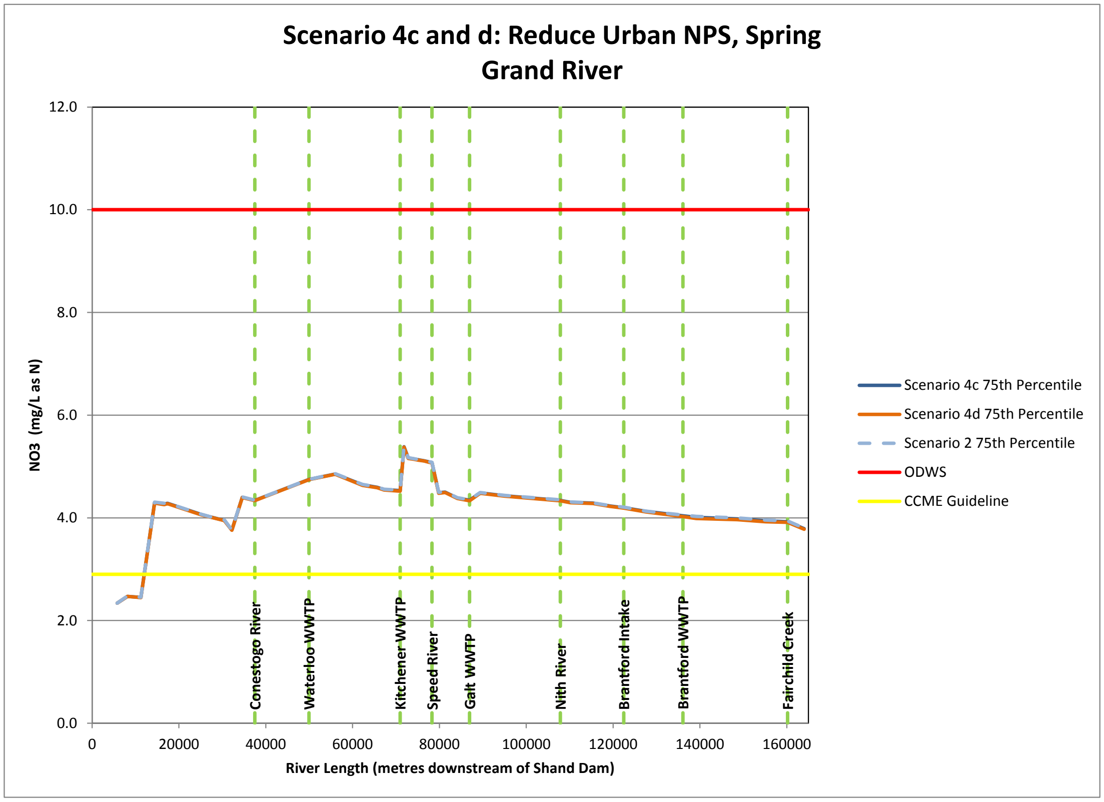


Figure B-35: Scenario 4c and d Results, Spring – Nitrate



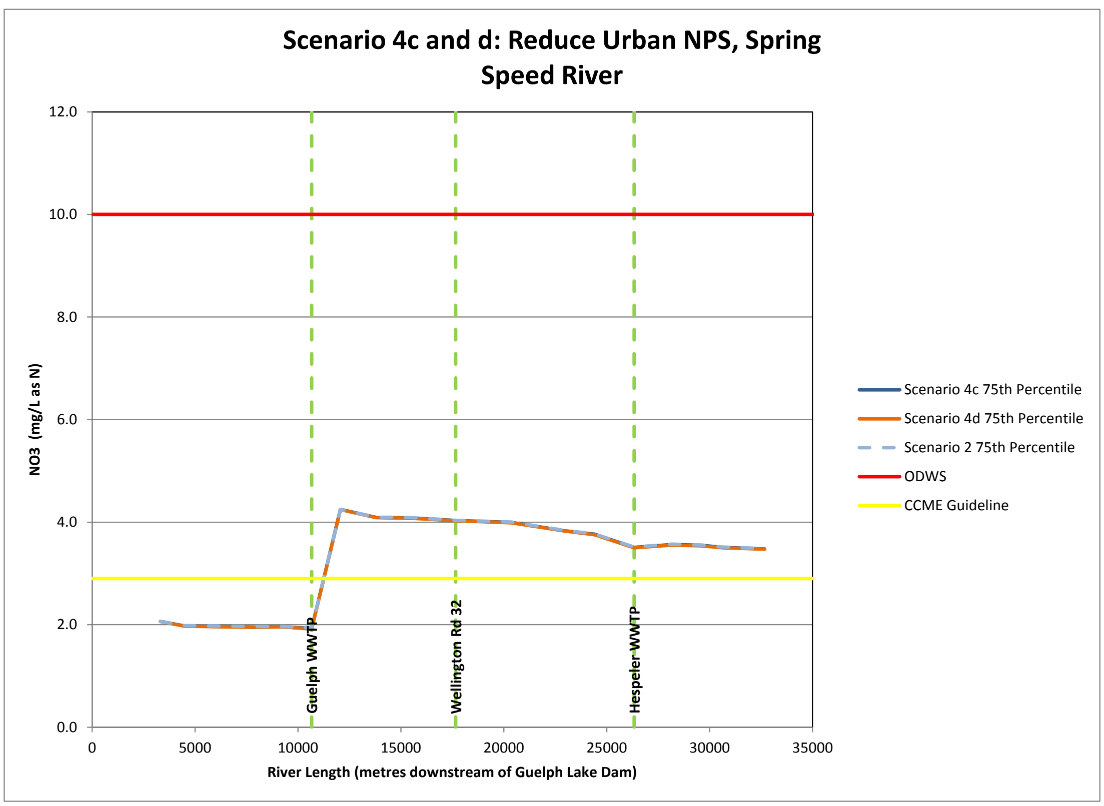
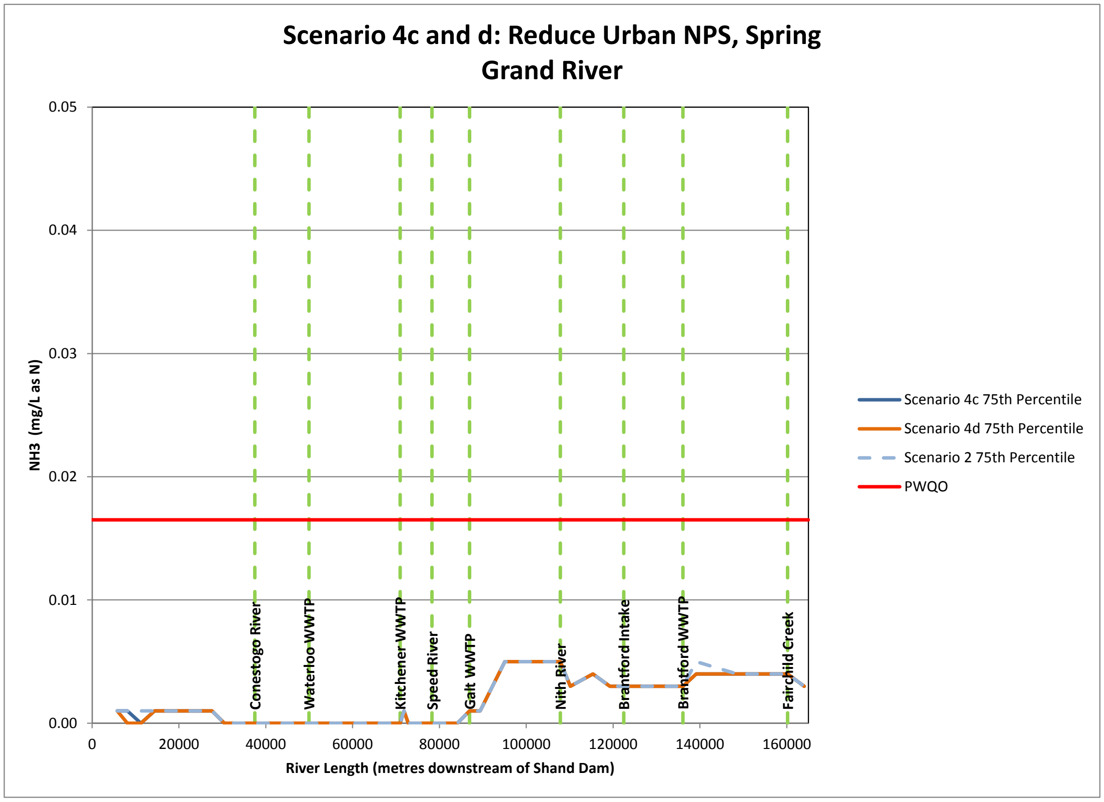


Figure B-36: Scenario 4c and d Results, Spring – Un-ionized Ammonia



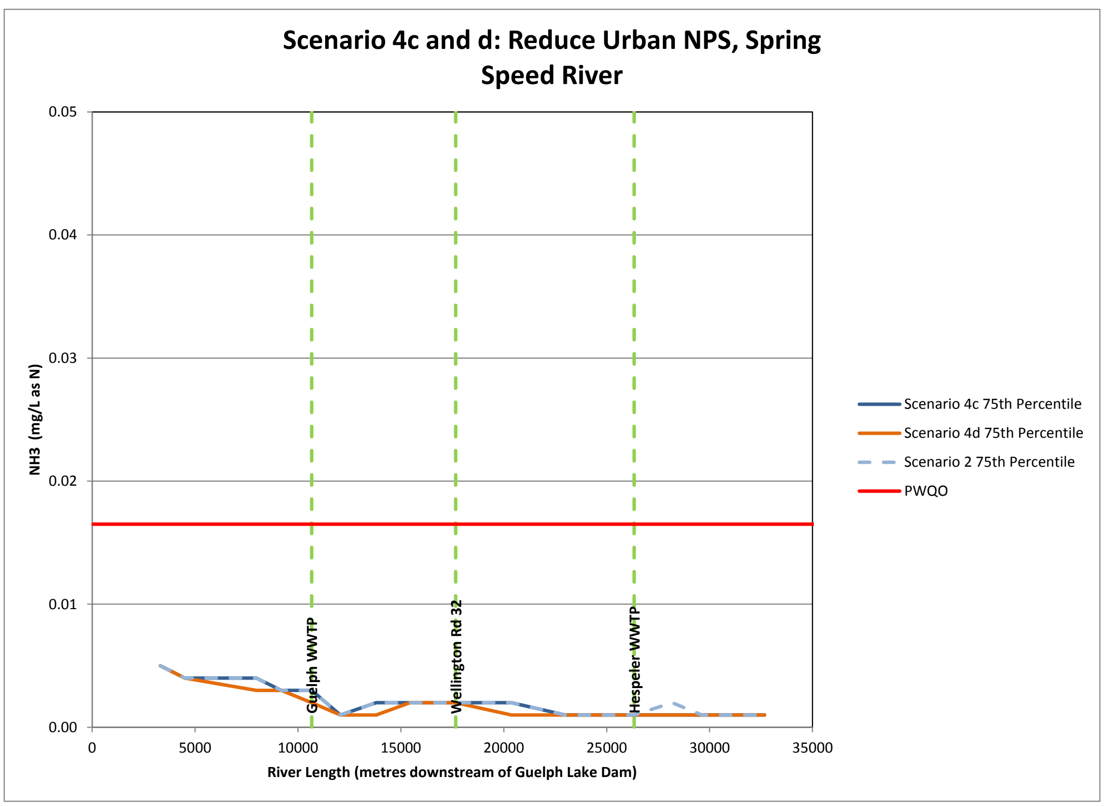
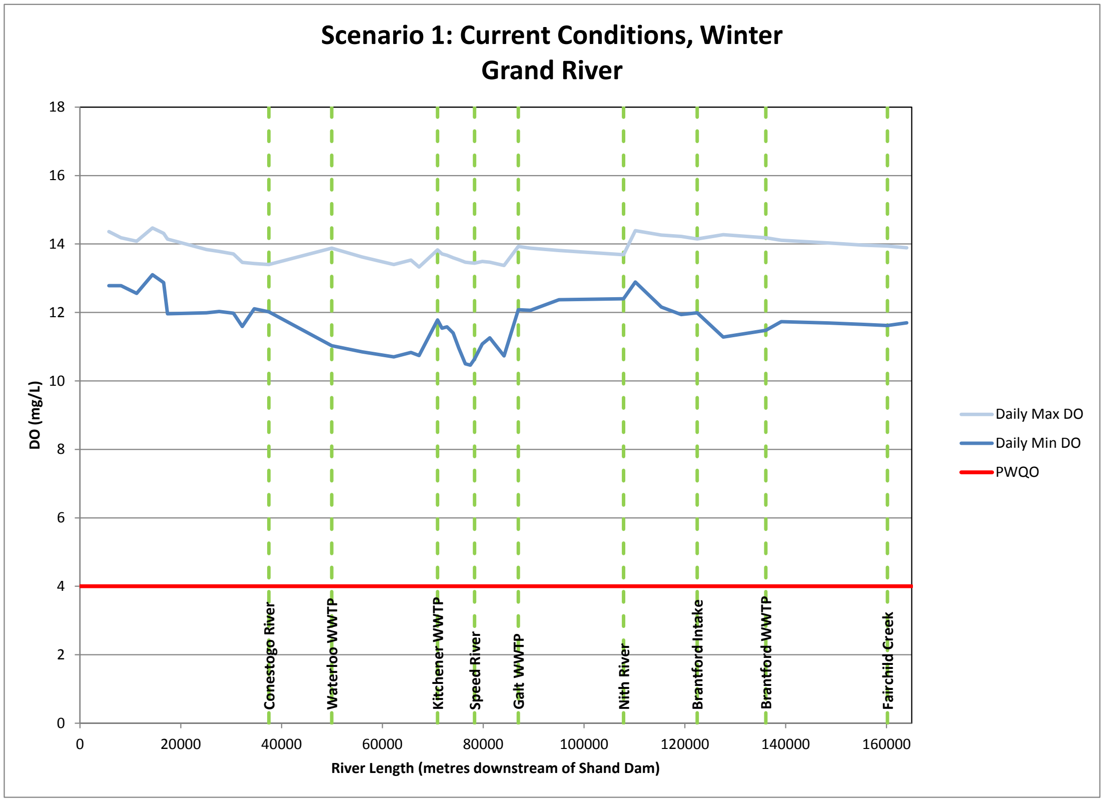


Figure B-37: Scenario 1 Results, Winter – Dissolved Oxygen



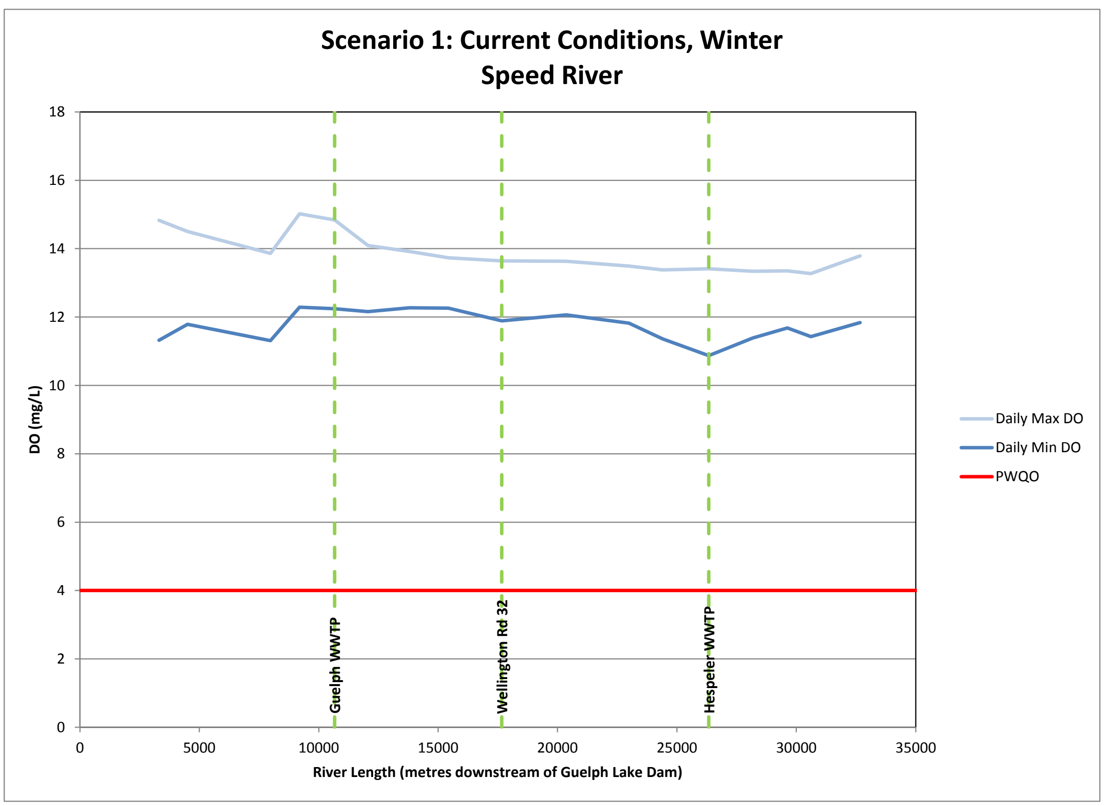
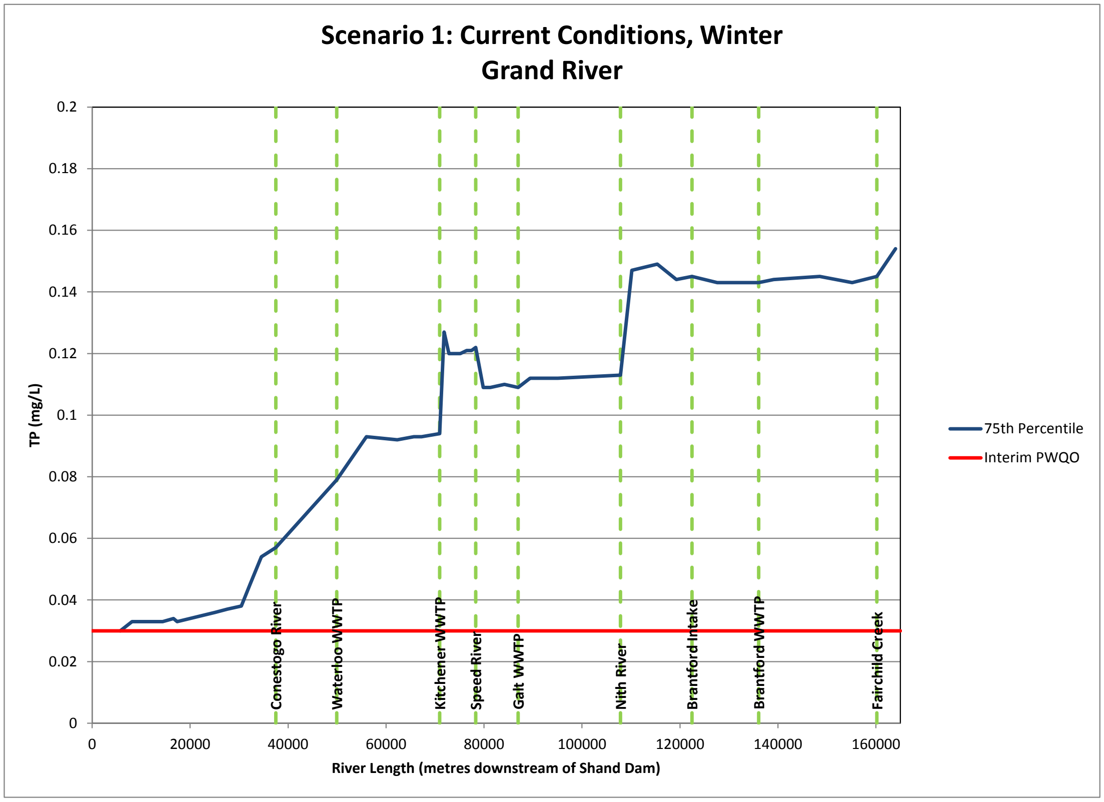


Figure B-38: Scenario 1 Results, Winter – Total Phosphorus



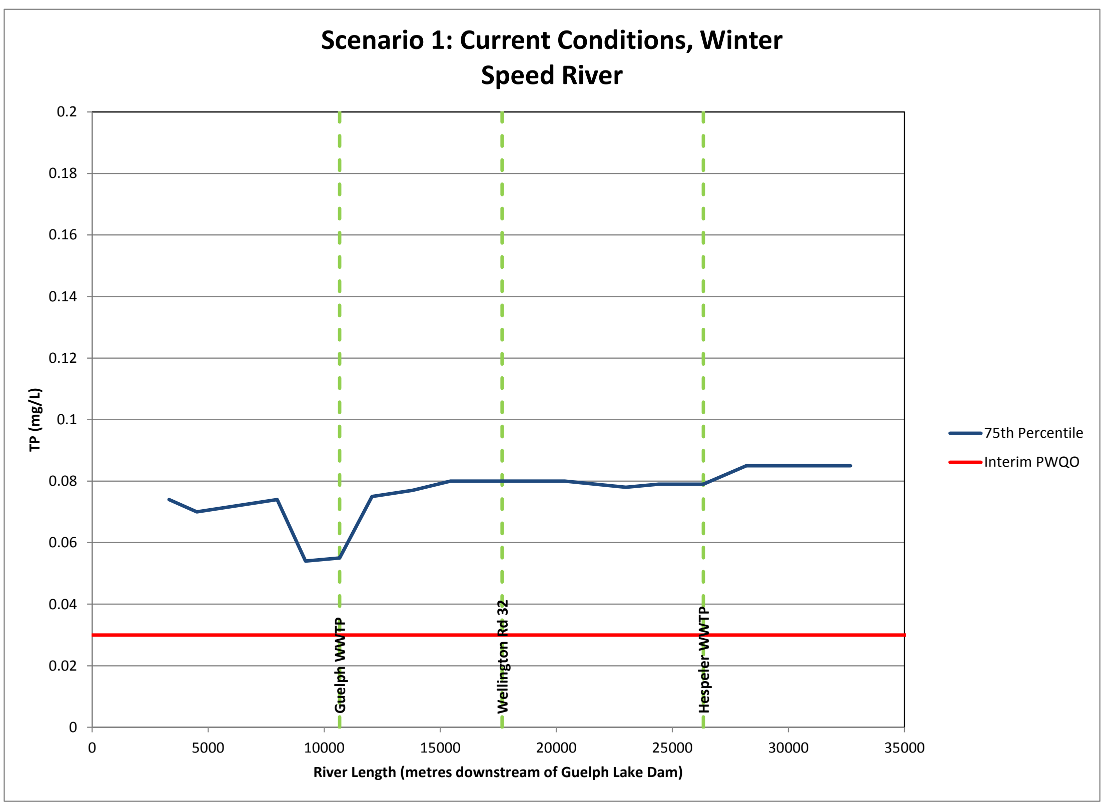
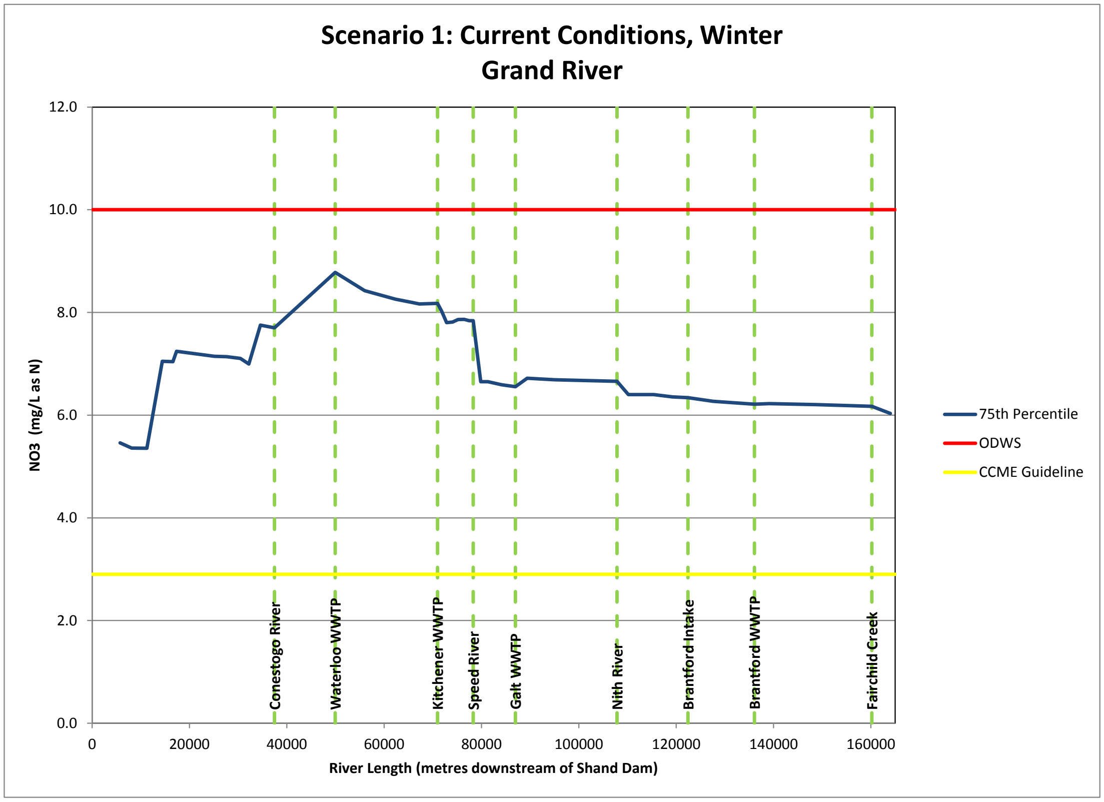


Figure B-39: Scenario 1 Results, Winter – Nitrate



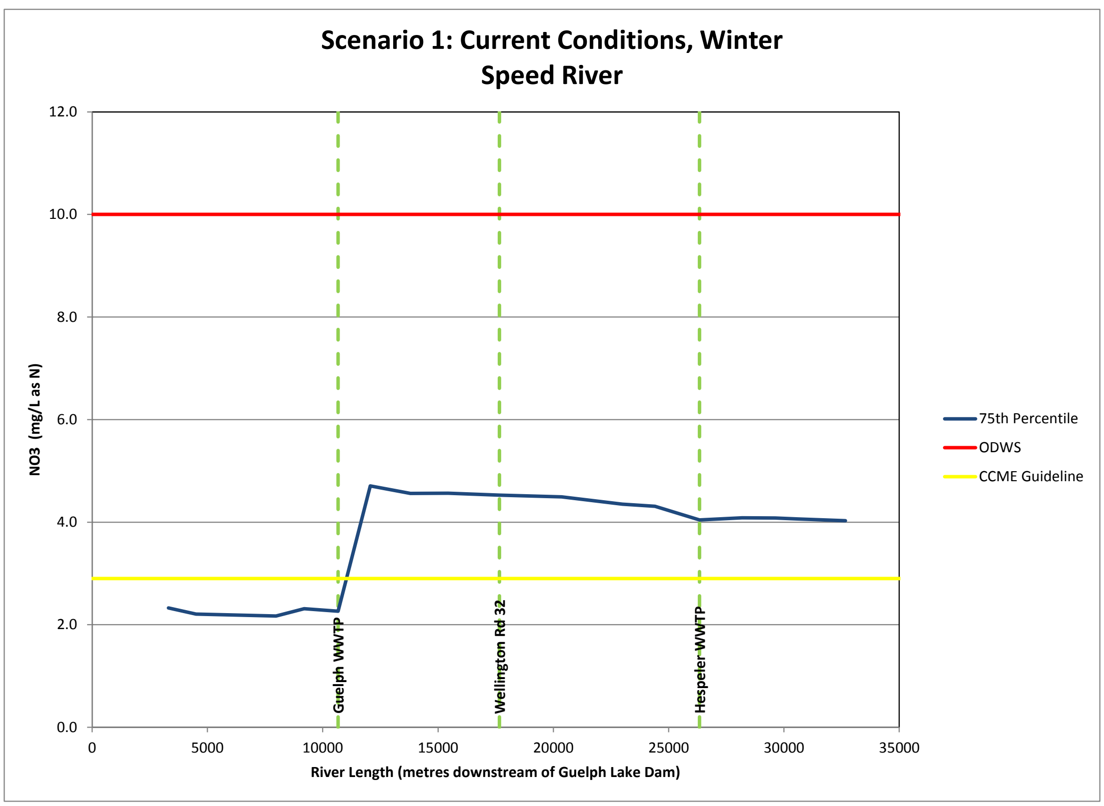
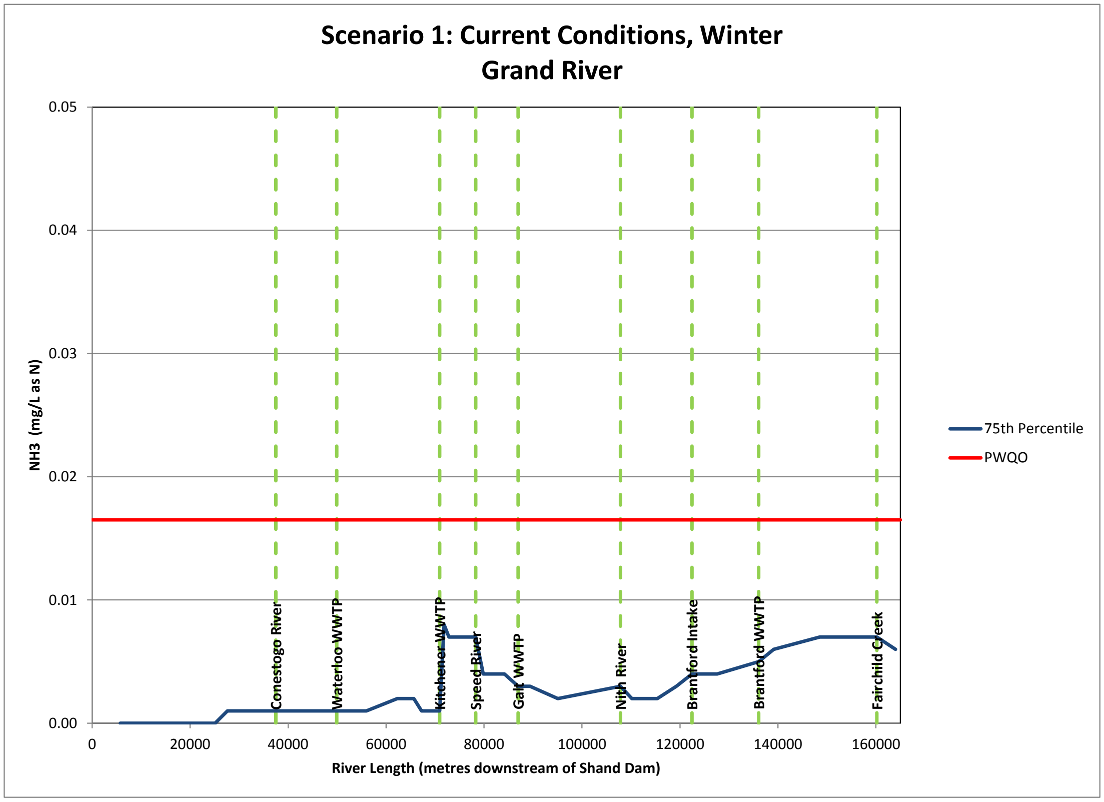


Figure B-40: Scenario 1 Results, Winter – Un-ionized Ammonia



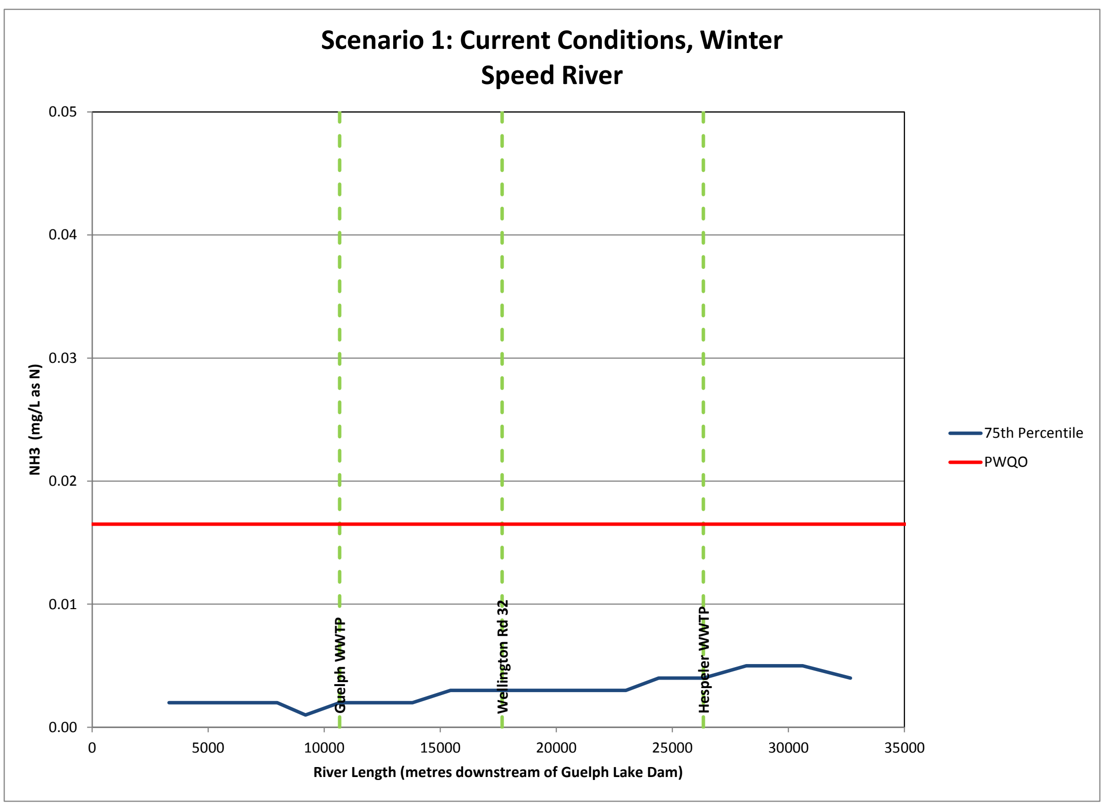
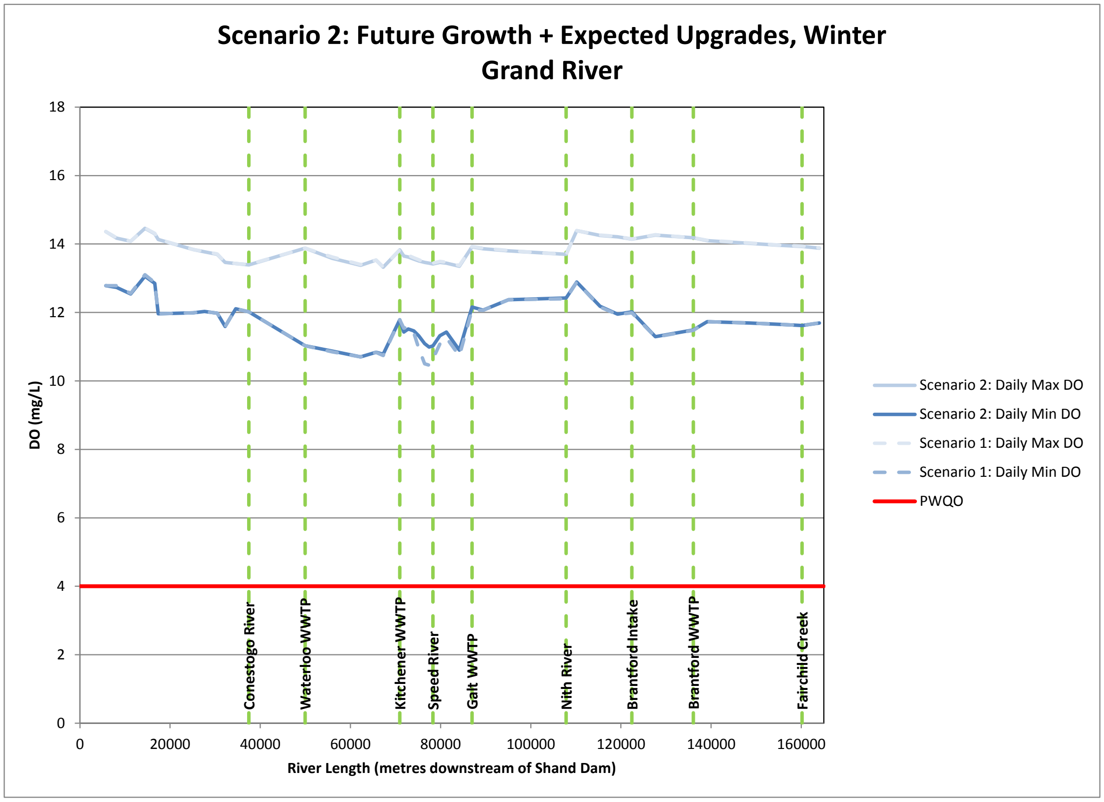


Figure B-41: Scenario 2 Results, Winter – Dissolved Oxygen



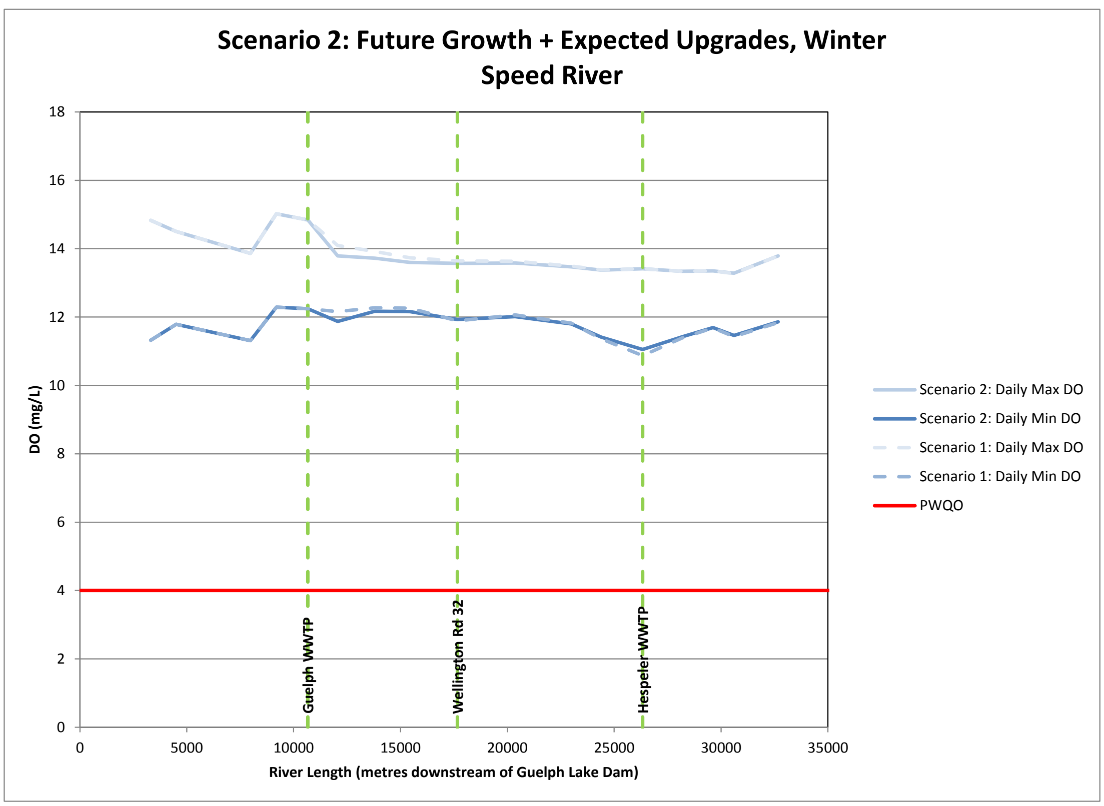
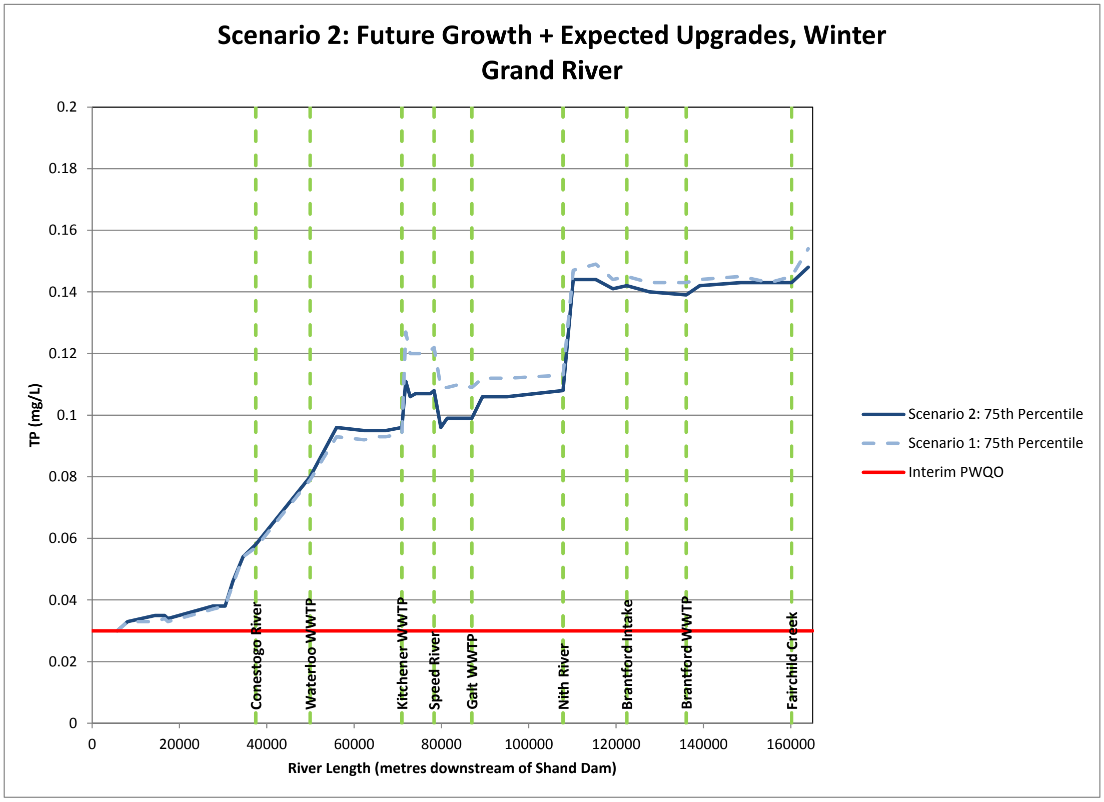


Figure B-42: Scenario 2 Results, Winter – Total Phosphorus



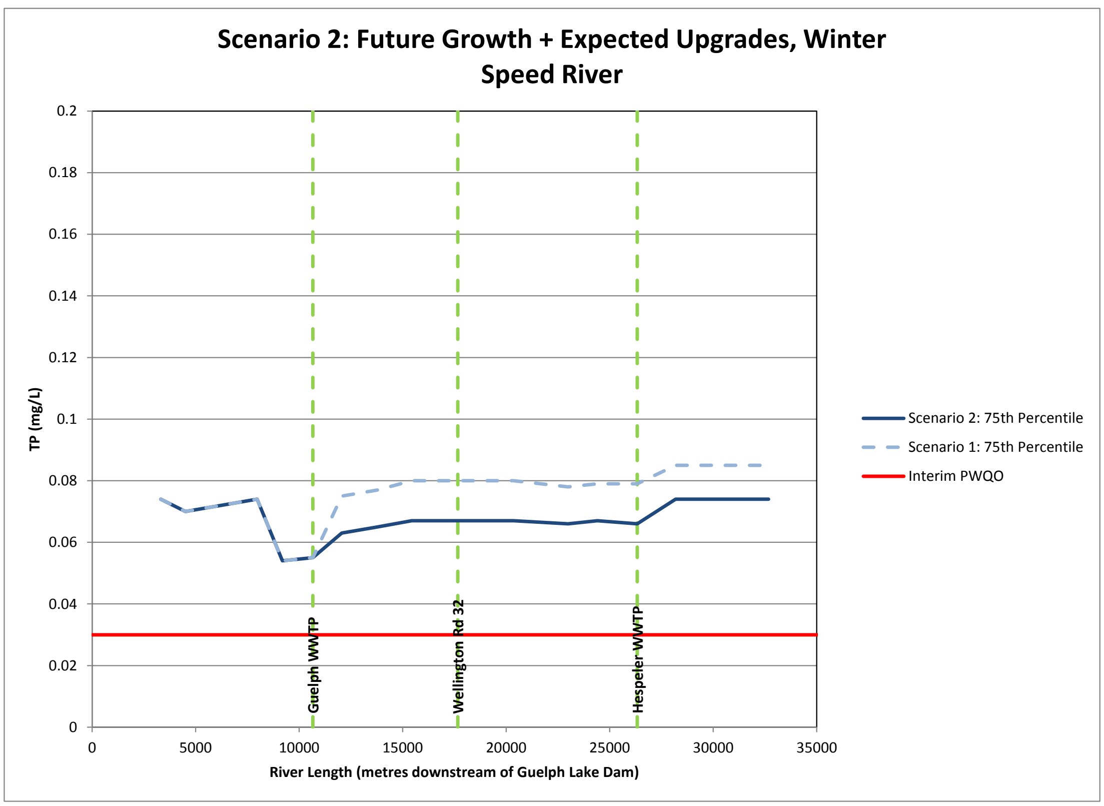
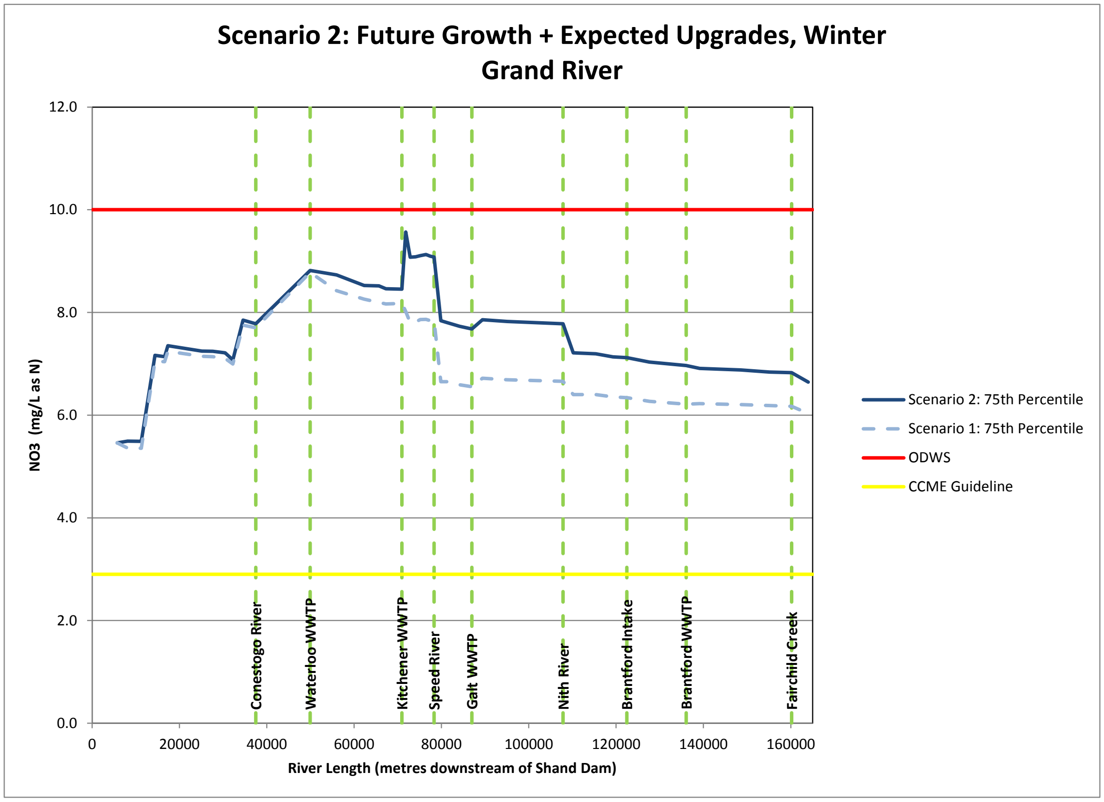


Figure B-43: Scenario 2 Results, Winter – Nitrate



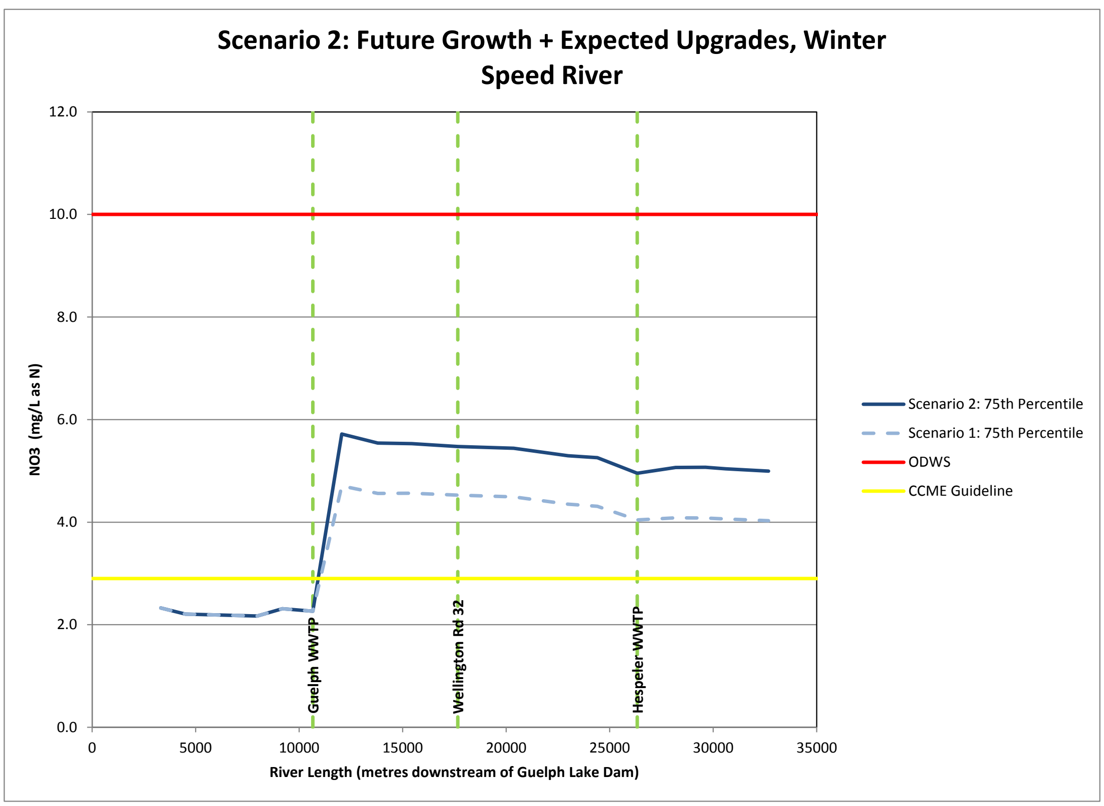


Figure B-44: Scenario 2 Results, Winter – Un-ionized Ammonia