Environment Waikato Technical Report 2005/03

The Effect on Waikato Water Quality of Changes to River Flow and Catchment Land Use, including the December Addendum

Prepared by:
Kit Rutherford (NIWA)

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

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The effect on Waikato River water quality of changes to river flow and catchment land use, including the December addendum

Kit Rutherford

Prepared for

Environment Waikato

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Rob Collins Jim Cooke

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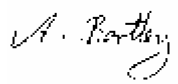


1. Introduction

Environment Waikato has requested NIWA to predict the likely effects on Waikato River water quality of:

1. reductions in the flow of the river at times of low flow; and
2. changes in nutrient loads to the river from dairy conversions;

by making use of an existing Waikato River water quality model (Rutherford et al. 2001). Results are provided as graphs (this report) and MS Excel spreadsheets (enclosed CD). Appendix 1 contains the contract details.

Originally 10 scenarios were detailed for modelling but subsequently an 11th scenario was requested (Appendix 2). Email correspondence to clarify assumptions made in these scenarios is attached (Appendix 2).

Subsequent to the presentation and acceptance of this report, EW requested that we run the model for 5 additional scenarios (cases 12-16). These are presented as an addendum in section 4.

2. Methods

This report relies upon the model calibration described in Rutherford et al. (2001) and no verification of the model has been undertaken in this study (e.g., making use of monitoring data collected since 2001 or by re-examining monitoring datasets). Environment Waikato requested that simulations be made at extreme low flows (viz., at the 5 day low flow (Q_5) which is exceeded 98.5% of the time, see Appendix 2). Consequently the flows modelled in this report are lower than those modelled by Rutherford et al. (2001) and also lower than those at which water quality monitoring has been carried out. For this reason no monitoring results are available to be plotted in Figures 1-11 for comparison with model predictions.

The model was run with a time step of 1 hour. Water temperatures were the average of those measured during summer low flows (viz., those used during calibration). Reduced flows may result in higher water temperatures but it was beyond the scope of this study to predict such changes. Reduced flows were simulated by applying a uniform flow reduction to all tributary inflows plus the flow through the Taupo gates. Note that when flows were reduced (Cases 2-4) no reduction was assumed in the flow or composition of point source discharges (e.g., Kinleith, Hamilton sewage etc.). Changes (decrease/increase) in nutrient loads from point sources (Cases 5-8) were simulated by changing (reducing/increasing) the mean concentration leaving the flow unchanged. Changes (decrease/increase) in diffuse source nutrient load (viz., runoff from the catchment) were simulated in two different ways. In Cases 5-8 the tributary nutrient concentrations were all reduced/increased by a uniform percentage. In Cases 9-11 for each catchment above Lake Ohakuri the area of forest was decreased, and the area of dairy (*past_3*) (Case 9-10) or dairy and sheep/beef (*past_1* = *past_2*) (Case 11) were increased by the same amount. The nitrogen and phosphorus yields are ranked *past_3* > *past_1* = *past_2* > *forest* and so the change in land use caused an increase in tributary nutrient concentration. The nutrient yields and method of calculating stream concentration are described in Rutherford et al. (2001). The nitrogen and phosphorus yields from *past_3*, *past_2*, *past_1*, and *forest* were estimated from Environment Waikato monitoring datasets using linear regression. In the Waikato the predominant landuse on *past_3* is dairying. As discussed by Rutherford et al. (2001) co-linearity between landuse and stocking density made it impossible to derive a satisfactory regression model for predicting the effects of changing the stocking density on landuse class *past_3*. Consequently the derived coefficients best quantify *TN* and *TP* yield from *past_3* with the average stocking density found on such land in the lower Waikato (~280 cows/km^2).

Comments on the assumptions used for cases 12-16 are given in the addendum (section 4).

3. Results

3.1 Base case

At the base case flow (Taupo Gates = 48 $m^3\ s^{-1}$, Waipa = 13.1 $m^3\ s^{-1}$, Mercer = 185 $m^3\ s^{-1}$) with the current land use predicted *TN* and *TP* concentrations follow the same pattern but are higher than those described in Rutherford et al. (2001) (Figure 1). Predicted chlorophyll reaches ~70 mg m^{-3} and Munsell colour drops to ~22 at Mercer (Figure 1).

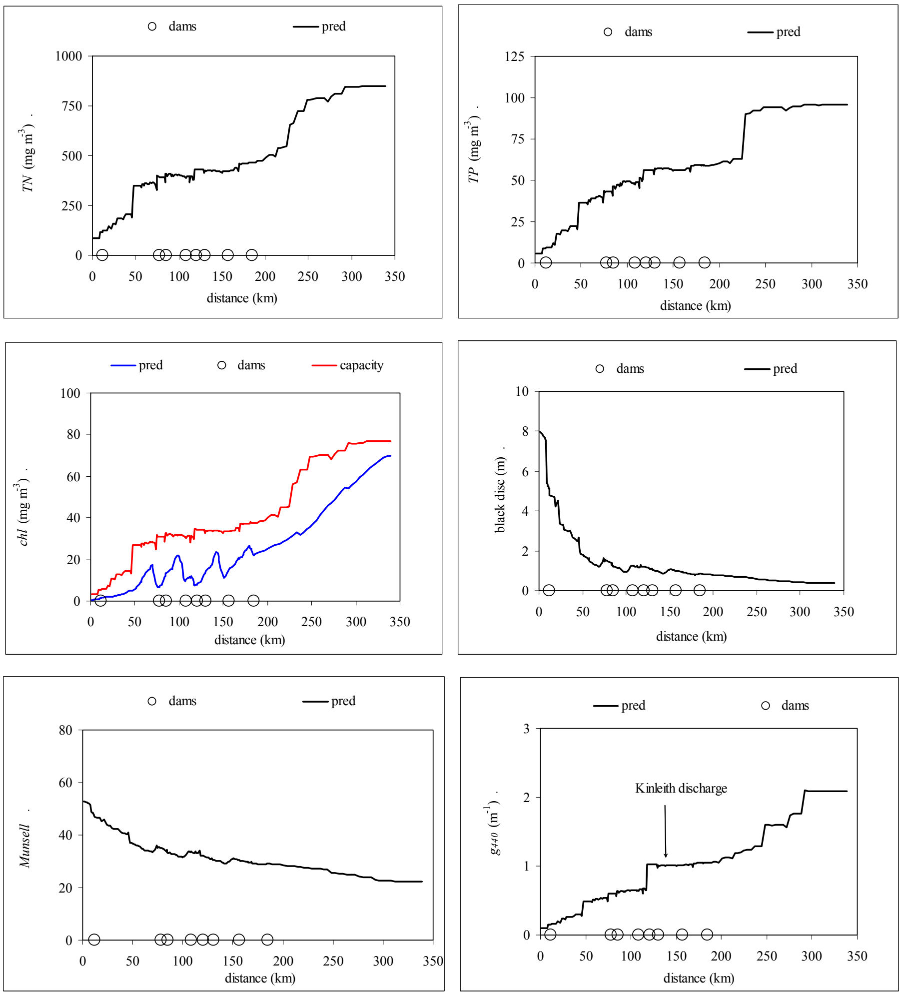
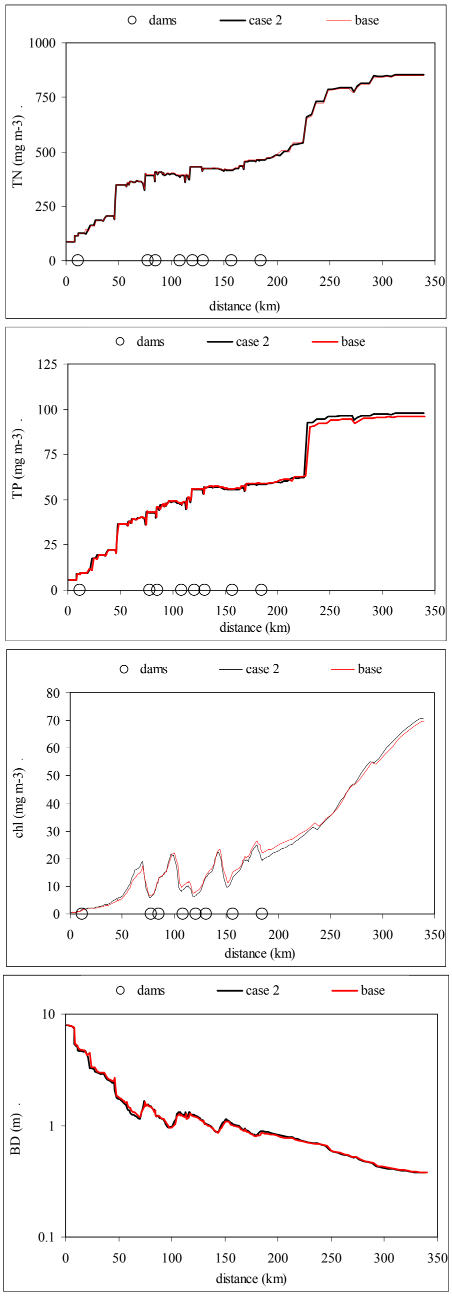


Figure 1: Predicted water quality for the base case (98.5% exceedance low flow and current land use).

3.2 Case 2: flows reduced by 10%

Reducing all tributary inflows by 10% (including the inflow through the Taupo Gates and all tributaries but excluding point sources) is predicted to cause only a small change in *TN* and *TP* concentration in the hydro lakes. This is because *TN* and *TP* settle only very slowly (sinking velocity ~0.1 m d^{-1}) and so the increased residence time that results from reduced flow has no discernible effect. Tributary concentration is unchanged in Case 2, only inflow is reduced. However, river flow (the cumulative sum of tributary inflow) is also reduced and consequently there is no discernible difference in *TN* or *TP* concentration at any of the tributary confluences. The lack of any significant change in *TN* and *TP* in the hydro lakes in Cases 2-4 also reflects the fact that there are no large point-source nutrient discharges in the upper catchment. *TP* concentration is slightly higher below the Hamilton city sewage outfall (227.4 km) because dilution by river flow is lower but the nutrient massflow is unchanged. This is also true for *TN* but the effects are less readily discernible. Compared with the base case chlorophyll concentration is slightly higher in the upper river (0-60 km) because increased residence time allows more phytoplankton biomass to develop in this reach. Chlorophyll concentration then decreases relative to the base case in the hydro lakes because increased residence time allows more settling. In the lower river chlorophyll concentration increases relative to the base case, again because increased residence time allows more phytoplankton biomass to develop. The effects on black disc clarity (*BD*), colour (*Munsell*) and yellow substance (*g440*) are barely discernible.



dams
case 2
base
TN (mg m-3)
1000
750
500
250
0
0
50
100
150
200
250
300
350
distance (km)
dams
case 2
base
TP (mg m-3)
125
100
75
50
25
0
0
50
100
150
200
250
300
350
distance (km)
dams
case 2
base
chl (mg m-3)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
distance (km)
dams
case 2
base
BD (m)
10
1
0.1
0
50
100
150
200
250
300
350
distance (km)

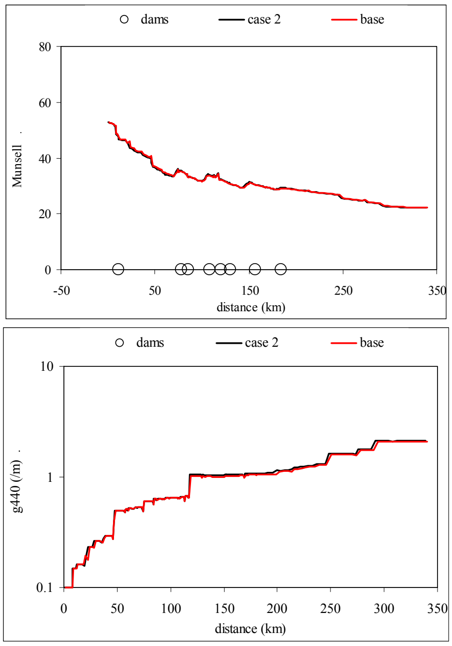
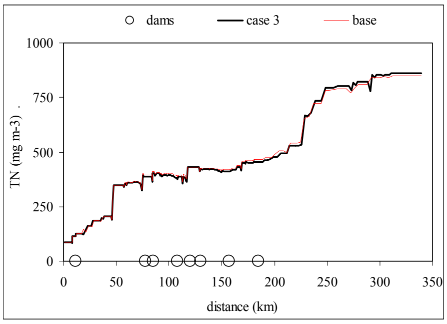
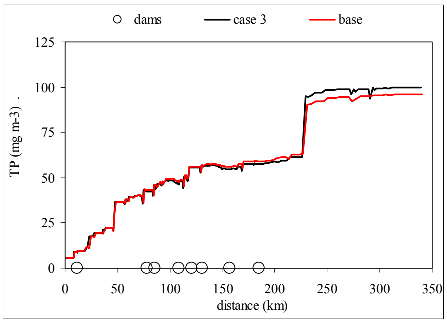


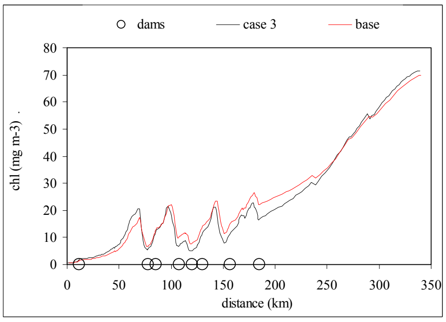
Figure 2: Case 2 compared with the base case.

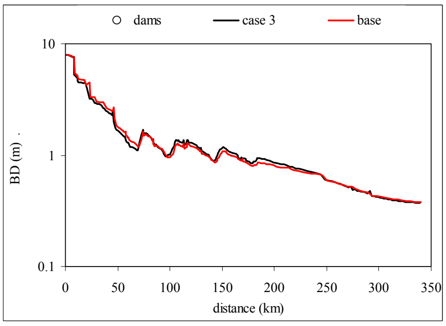
3.3 Case 3: flows reduced by 20%

Reducing tributary inflows by 20% causes larger changes in *TN*, *TP* and chlorophyll than Case 2. In the hydro lakes *TN* and *TP* are lower than for the base case because increased residence time allows more settling. Black disc clarity decreases quickly in the upper river (0-60 km) because chlorophyll concentration increases quickly. The opposite occurs in the hydro lakes because of chlorophyll settling. There is no significant difference in the lower river. Munsell colour is indistinguishable from the base case. Yellow substance (*g440*) is slightly higher in Case 3 than the base case below 120 km because there is less dilution of Kinleith effluent.


dams
case 3
base
TN (mg m-3)
distance (km)


dams
case 3
base
TP (mg m-3)
distance (km)


dams
case 3
base
chl (mg m-3)
distance (km)


dams
case 3
base
BD (m)
distance (km)

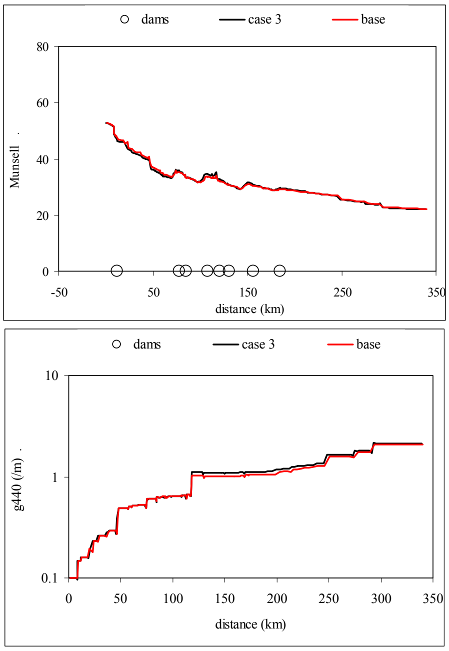
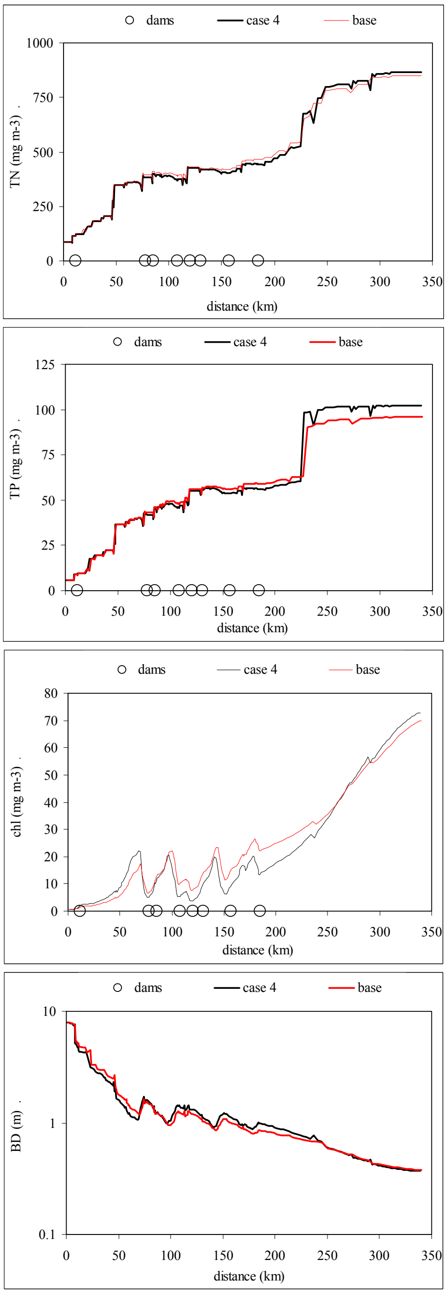


Figure 3: Case 3 compared with the base case.

3.4 Case 4: flows reduced by 30%

Reducing tributary flows by 30% results in similar changes to Case 2 and 3 but the differences are larger. Slight irregularities appear in the *TN* and *TP* concentration profiles which are an artefact of the numerical simulation and should be ignored.


dams
case 4
base
TN (mg m-3)
1000
750
500
250
0
0
50
100
150
200
250
300
350
distance (km)
dams
case 4
base
TP (mg m-3)
125
100
75
50
25
0
distance (km)
dams
case 4
base
chl (mg m-3)
80
70
60
50
40
30
20
10
0
distance (km)
dams
case 4
base
BD (m)
10
1
0.1
distance (km)

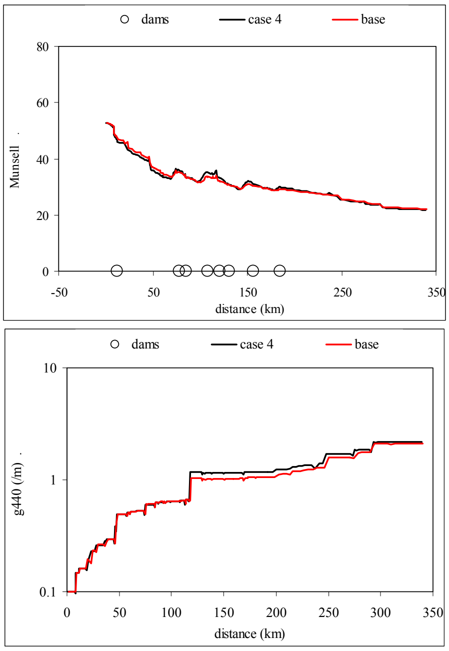
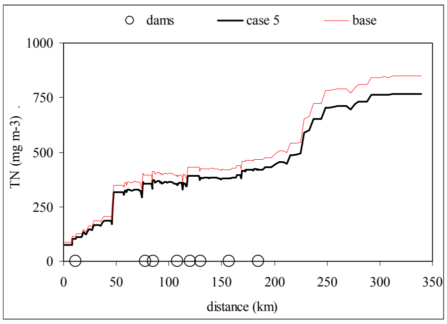
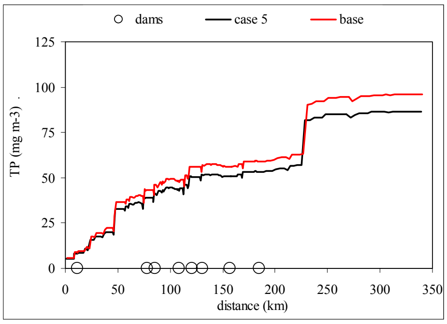


Figure 4: Case 4 compared with the base case.

3.5 Case 5: nutrient inputs reduced by 10%

Reducing all tributary and point source nutrient concentrations by 10% (but assuming base case flows) results in a decrease in *TN* and *TP* concentration of ~10% along the entire length of the Waikato as would be expected. As a result chlorophyll decreases, most noticeably below Karapiro dam, because of reduced growth rate. However, the effect on clarity, colour and yellow substance is barely discernible.





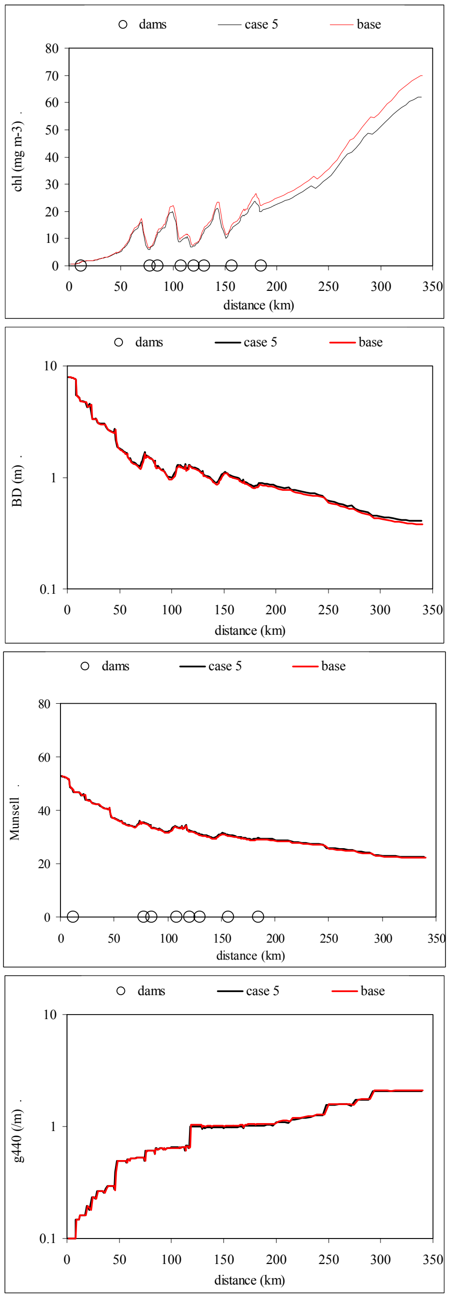
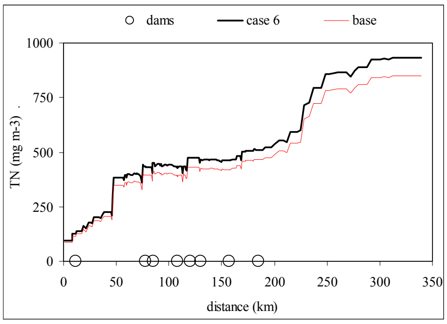
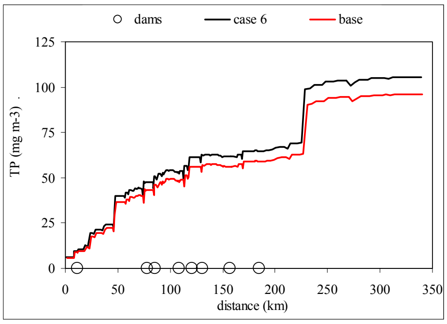


Figure 5: Case 5 compared with the base case.

3.6 Case 6: nutrient inputs increased by 10%

Increasing tributary and point source nutrient concentrations by 10% (but assuming base case flows) results in an increase in *TN* and *TP* concentration of ~10% along the entire Waikato as would be expected. As a result chlorophyll increases, most noticeably below Karapiro dam, because of increased growth rate. There is a slight decrease in clarity but no discernible effect on colour and yellow substance.





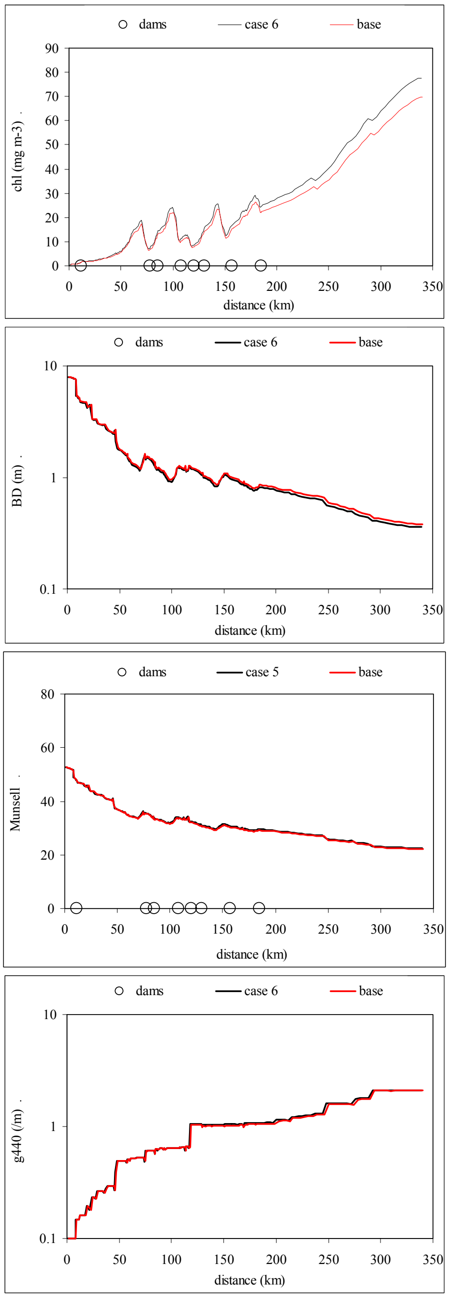
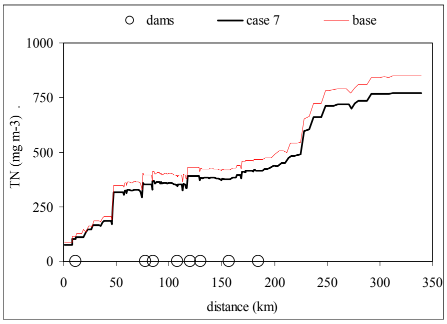
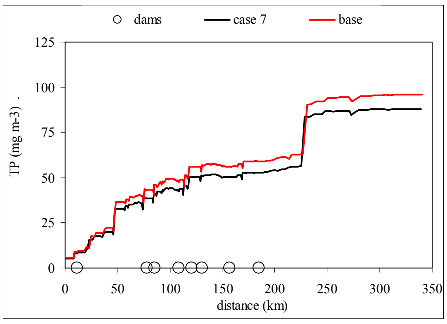


Figure 6: Case 6 compared with the base case.

3.7 Case 7: flows reduced by 10%, nutrient inputs reduced by 10%

Reducing inflows by 10% and decreasing nutrient concentrations by 10% caused significant decreases in predicted *TN* and *TP* concentration as would be expected. This resulted in decreased chlorophyll concentration. Note that the increased residence time in the hydro lakes leads to increased settling that exacerbates the reduced growth rate resulting from lower nutrient concentration. There was a slight increase in water clarity associated with the reduced chlorophyll, but no discernible effect on colour or yellow substance.





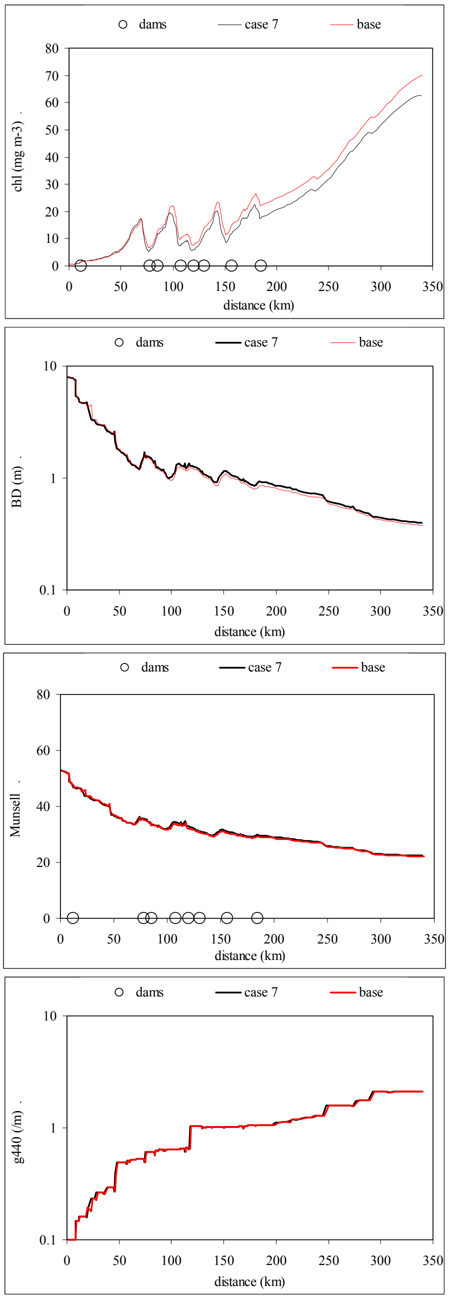
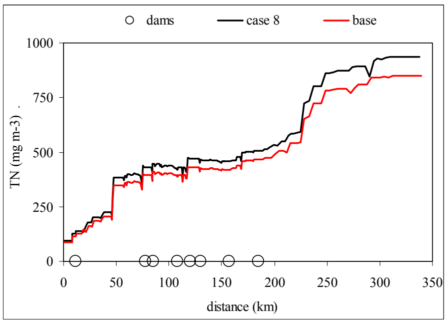
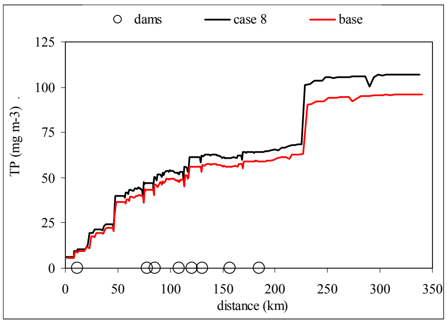


Figure 7: Case 7 compared with the base case.

3.8 Case 8: flows reduced by 10%, nutrient inputs increased by 10%

Reducing inflows by 10% and increasing nutrient concentrations by 10% caused significant increases in predicted *TN* and *TP* concentration as would be expected. This resulted in increased chlorophyll concentration in the lower river. Increased residence time in the hydro lakes led to increased settling that counteracted the increased growth rate resulting from higher nutrient concentration. There was a slight decrease in water clarity associated with the reduced chlorophyll, a slight increase in yellow substance because of reduced dilution but no discernible effect on colour.





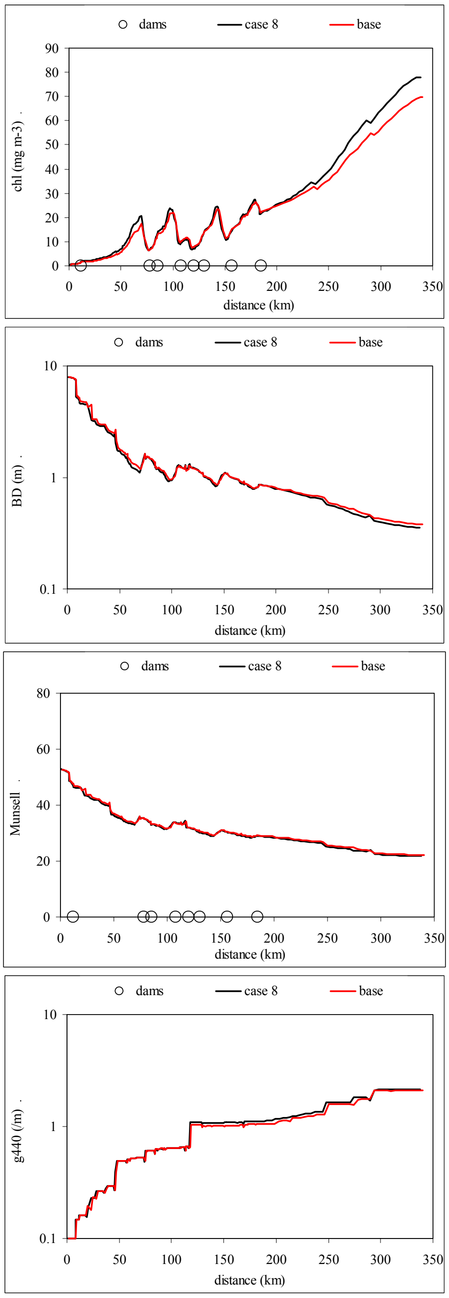
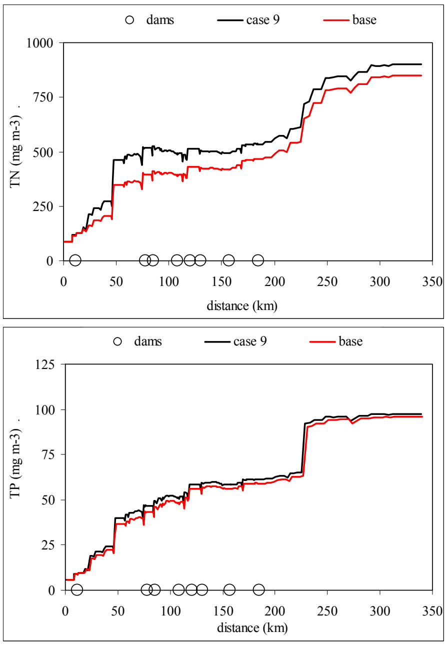


Figure 8: Case 8 compared with the base case.

3.9 Case 9: 20,000 ha pines converted to dairy

Conversion of 20,000 ha above Lake Ohakuri from pine to dairy pasture (~280 cows km^{-2}) increased nitrogen inputs and hence *TN* concentration in the upper river. This caused an increase in chlorophyll concentration in the upper river. Yellow substance showed a significant increase in the upper river as a result of increased chlorophyll. *TP* concentration increased but by a smaller fraction than *TN* because the yield coefficients for forest and dairy pasture do not differ as much for phosphorus as nitrogen. Increased chlorophyll caused slight decreases in Munsell colour and black disc water clarity.



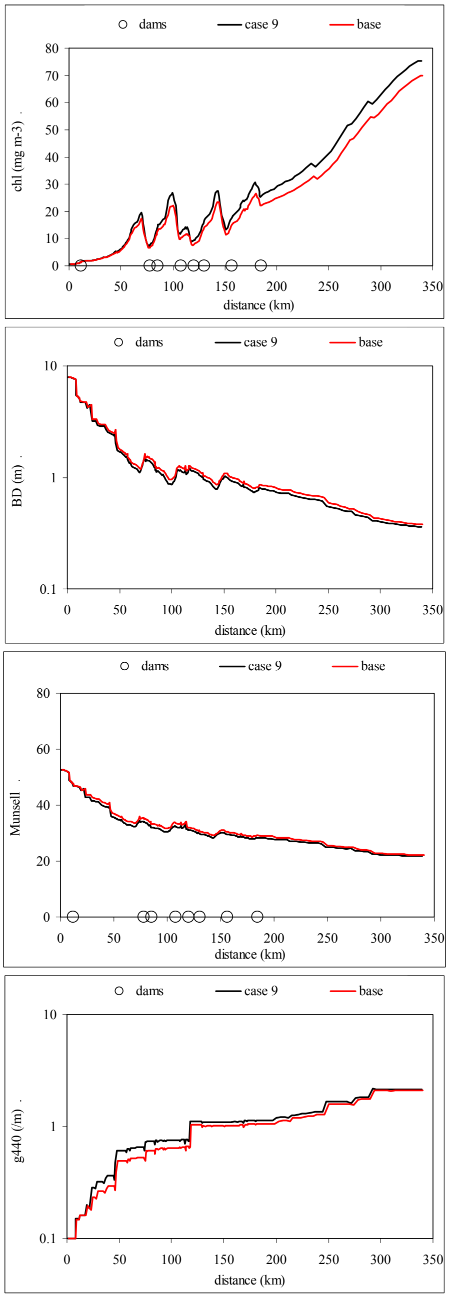
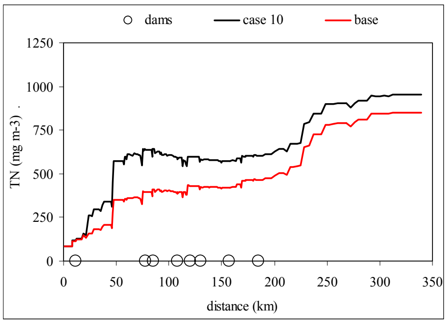
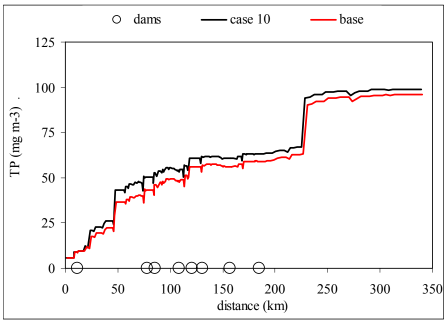


Figure 9: Case 9 compared with the base case.

3.10 Case 10: 40,000 ha pines converted to dairy

Conversion of 40,000 ha above Lake Ohakuri from pine to dairy pasture (~280 cows km^{-2}) increased *TN*, *TP*, chlorophyll and yellow substance in the same pattern but by significantly more than the conversion of 20,000 ha (Case 9). Increased chlorophyll caused significant decreases in Munsell colour and black disc water clarity.





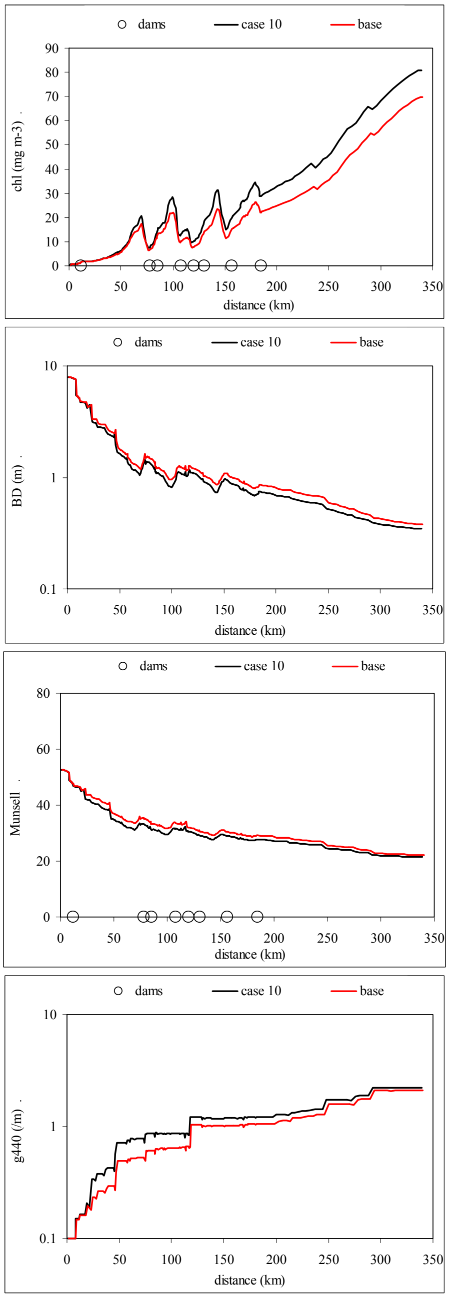
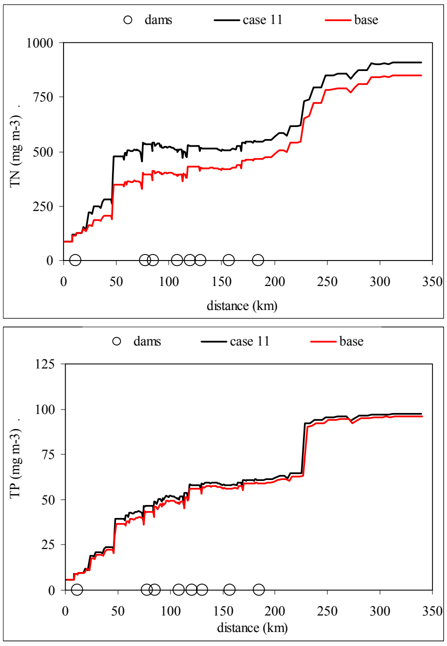


Figure 10: Case 10 compared with the base case.

3.11 Case 11: 40,000 ha pines converted, 50% to dairy and 50% to mixed sheep/beef

Converting 20,000 ha above Lake Ohakuri from pine to dairy (~280 cows km^{-2}) and 20,000 ha from pine to sheep/beef caused *TN*, *TP*, chlorophyll and yellow substance concentrations intermediate between those predicted for Case 9 and Case 10. This is because the nutrient yield from sheep/beef is higher than from forest, but lower than from dairy pasture. Clarity and Munsell colour were both lower than for the base case.



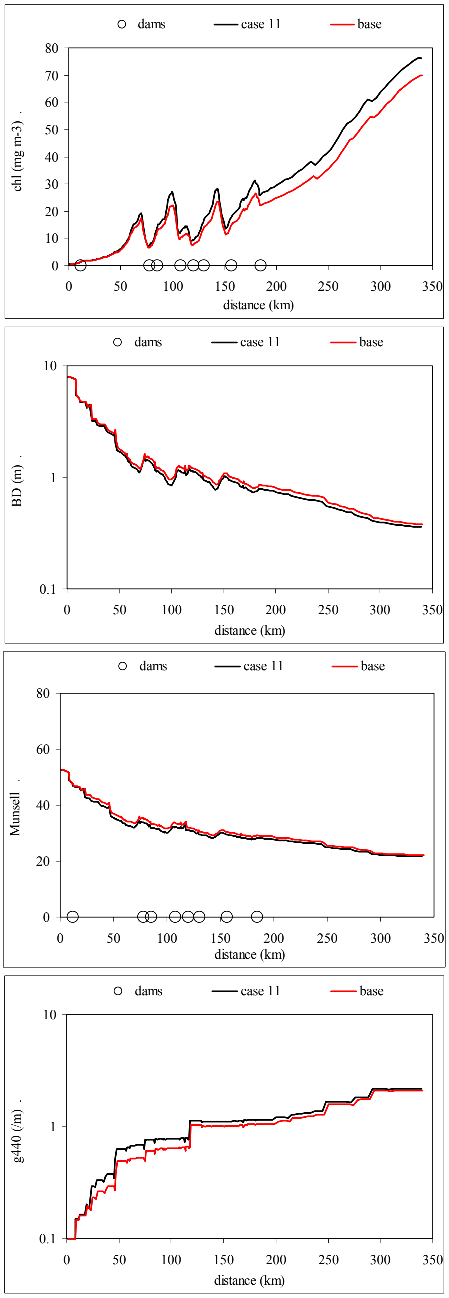


Figure 11: Case 11 compared with the base case.

4. Addendum

4.1 Introduction

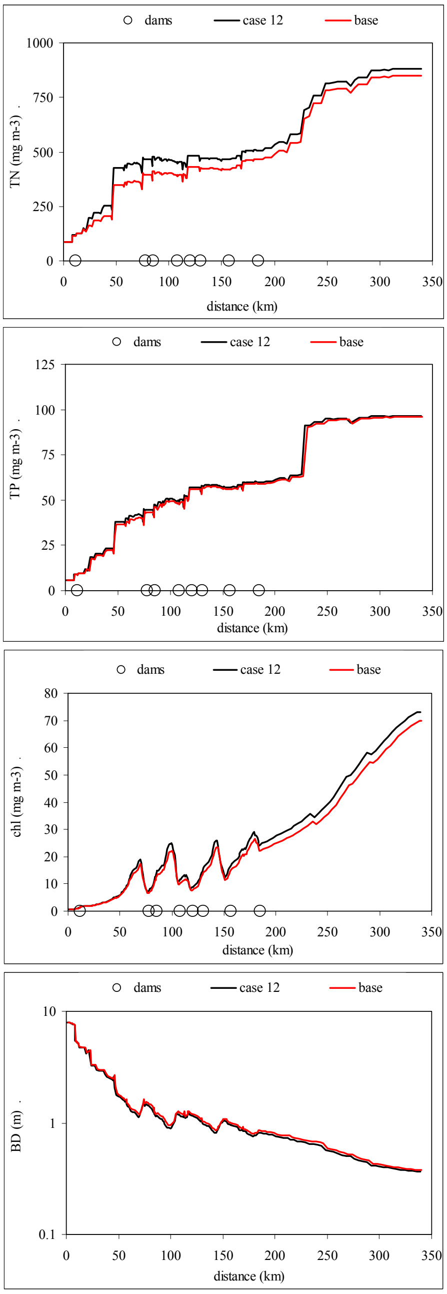
A report detailing Cases 1-11 was completed in November 2004 (Rutherford, 2004). In December 2004 Environment Waikato requested that NIWA undertake five additional model runs termed Cases 12 and 13 (email from Bill Vant, 15th December 2004, Appendix 3) and then Cases 14, 15 and 16 (email from Bill Vant, 16th December 2004, Appendix 3).

Cases 12 and 13 were for the same extreme (98.5% exceedance) low flows as Cases 1-11, namely 48, 13.1 and 185 $m^3 s^{-1}$ at Taupo Gates, in the Waipa River at Ngaruawahia and at Mercer respectively. Cases 14, 15 and 16 were for a higher flow, the 'summer low flow' used in Rutherford et al. (2001), namely 125, 35 and 250 $m^3 s^{-1}$ at Taupo Gates, in the Waipa River at Ngaruawahia and at Mercer respectively. Environment Waikato has pointed out that these flow values have different recurrence intervals (see Appendix 3), 60, 75 and 90% respectively. However, Environment Waikato has requested that these flows be used to maintain consistency with previous modelling.

4.2 Results

4.2.1 Case 12: 22,500 ha pines above Wharekaka converted to 10,000 ha dairy and 12,500 ha mixed sheep/beef.

Compared with the base case *TN* concentrations were elevated, most noticeably in the upper hydro lakes. The difference in *TN* concentration between Case 12 and the base Case decreased below Wharekaka because tributary *TN* was unchanged and dilution plus settling occurred. High *TN* resulted in slightly higher chlorophyll in the hydro lakes for Case 12 than the base case although phytoplankton growth was offset by settling in slow moving regions near the dam walls. Yellow substance concentrations were also slightly higher for Case 12 than the base case but the effects on black disc clarity and Munsell colour were barely discernible. The increases in *TN* and chlorophyll were smaller for Case 12 than Case 9 (20,000 ha pines above Ohakuri to dairy) because less land was assumed converted to dairy and hence the total nitrogen input was lower.


dams
case 12
base
TN (mg m-3)
distance (km)
TP (mg m-3)
distance (km)
chl (mg m-3)
distance (km)
BD (m)
distance (km)

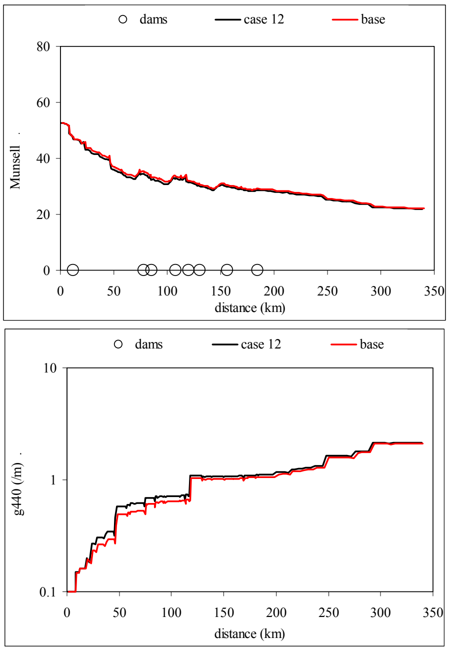
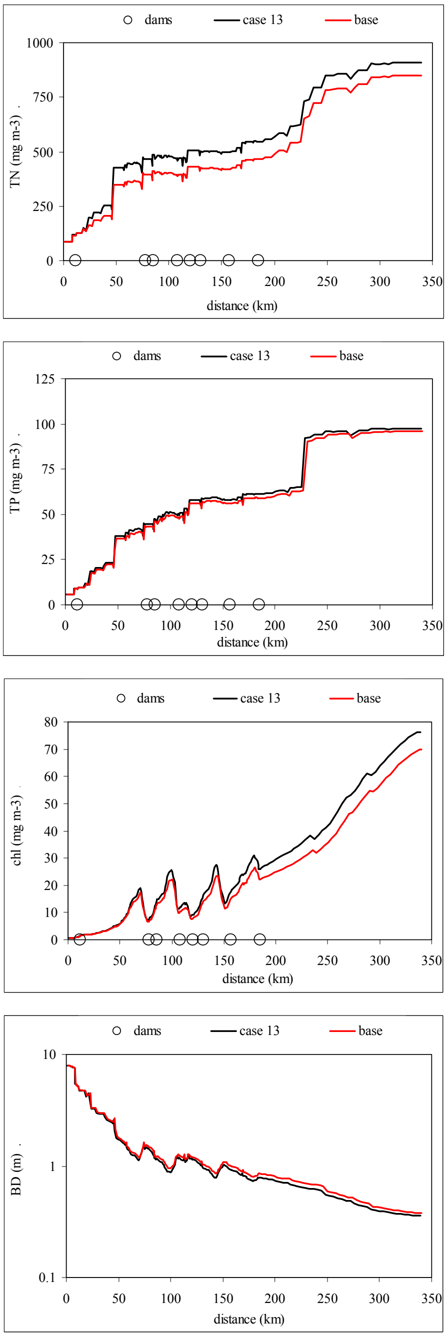


Figure 12: Case 12 compared with the base case.

4.2.2 Case 13: 22,500 ha pines above Wharekaka converted to 10,000 ha dairy and 12,500 ha mixed sheep/beef PLUS 7,000 ha pines between Ohakuri and Maraetai converted to dairy PLUS 7,000 ha pines between Maraetai and Pokaiwhenua converted to dairy.

Compared with the base case *TN* concentrations were significantly increased and this caused a slight increase of chlorophyll in the hydro lakes (where growth was offset by settling) and a larger increase in the lower river (where settling was negligible). The total area of pines converted for Case 13 (36,500 ha) was comparable with the total area converted for Case 10 (40,000 ha). However, dairy conversions above Ohakuri were lower for Case 13 (10,000 ha) than Case 10 (40,000 ha) and as a result *TN* concentrations in the upper hydro lakes were lower for Case 13, and as a result chlorophyll concentrations were also lower above Wharekaka. In Case 13 increased nitrogen loads between Ohakuri and Maraetai resulted in the difference in *TN* between Case 13 and the base Case remaining high in the lower hydro lakes (whereas it dropped in Case 10). The increased nitrogen input to this part of the river offset dilution and the (very slow) settling of nutrient in the hydro lakes. The differences between Cases 13 and 11 were smaller than between Cases 13 and 10 because in Case 11 only 20,000 ha of pines were converted to dairy whereas in Case 10 the conversion was 40,000 ha. However, Case 13 (24,000 ha to dairy) had a higher total nitrogen input than Case 11 (20,000 ha to dairy) and this resulted in slightly higher *TN* and chlorophyll concentrations. The differences in black disc clarity and Munsell colour between the base case, Case 10, Case 11 and Case 13 were barely discernible.


dams
case 13
base
TN (mg m-3)
1000
750
500
250
0
0
50
100
150
200
250
300
350
distance (km)
TP (mg m-3)
125
100
75
50
25
chl (mg m-3)
80
70
60
40
30
20
10
BD (m)
10
1
0.1

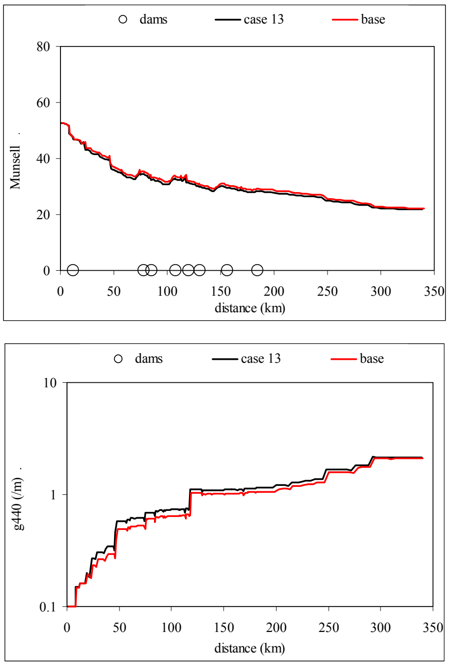
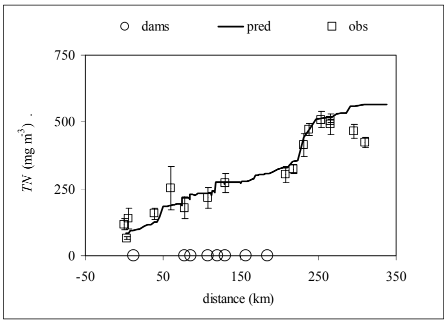


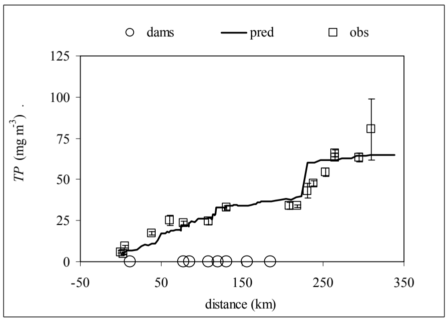
Figure 13: Case 13 compared with the base case.

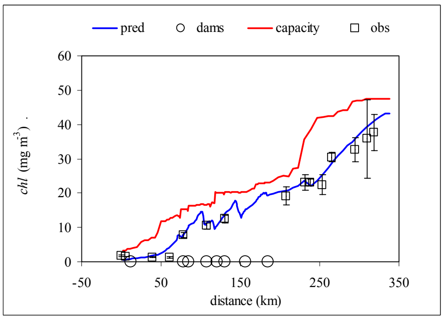
4.2.3 Case 14: summer low flow with current land use

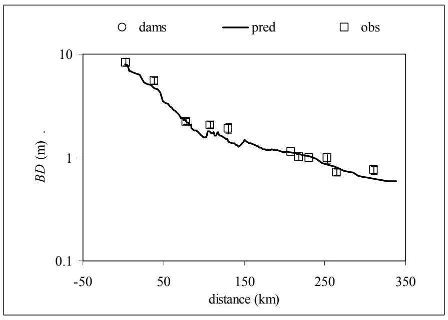
Cases 14-16 used flows of 125, 35 and 250 $m^3 s^{-1}$ Waikato at Taupo Gates, Waipa at Ngaruawahia and Waikato at Mercer respectively. These were the same as the 'summer low flow' case used by Rutherford et al. (2001) to calibrate the model. During model calibration Eq. 25 and 27 were used to calculate tributary *TN* concentration because this minimised the prediction error (see details in Rutherford et al. 2001 p38). During the present study it was found that Eq. 25 and 27 gave unrealistic predictions in some tributaries when there was a significant change in land use. Consequently for Cases 1-13 tributary concentrations were calculated using the regression models summarised in Table 8 of Rutherford et al. (2001). For example tributary *TN* concentration was calculated using Eq. 22 (see details in Rutherford et al. 2001 p38). For consistency the same method of calculating tributary concentrations was adopted for Cases 14-16 as that used for Cases 1-13. Consequently, summer low flow concentrations (Case 14) were re-calculated and hence differ slightly from the 'summer low flow' predictions in Rutherford et al. (2001). The differences are not large enough to invalidate any of the conclusions drawn in this study or in earlier work.

Monitoring data are available at summer low flow, in contrast with the extreme low flows used in Cases 1-13. Figure 14 shows that the model provides a satisfactory fit to summer low flow observations. The main exceptions are Munsell colour (which appears to have been underestimated [less blue] in the upper river) and *TN* (which appears to have been overestimated in the lower river). The reasons for these discrepancies are not clear but it was beyond the scope of this study to recalibrate the model. They are unlikely to significantly affect the main conclusions drawn which focus upon *TN* and chlorophyll in the hydro lakes and middle river.


dams
pred
obs
750
500
250
0
-50
50
150
250
350
TN (mg m-3)
distance (km)


dams
pred
obs
125
100
75
50
25
0
-50
50
150
250
350
TP (mg m-3)
distance (km)


pred
dams
capacity
obs
60
50
40
30
20
10
0
-50
50
150
250
350
chl (mg m-3)
distance (km)


dams
pred
obs
10
1
0.1
-50
50
150
250
350
BD (m)
distance (km)

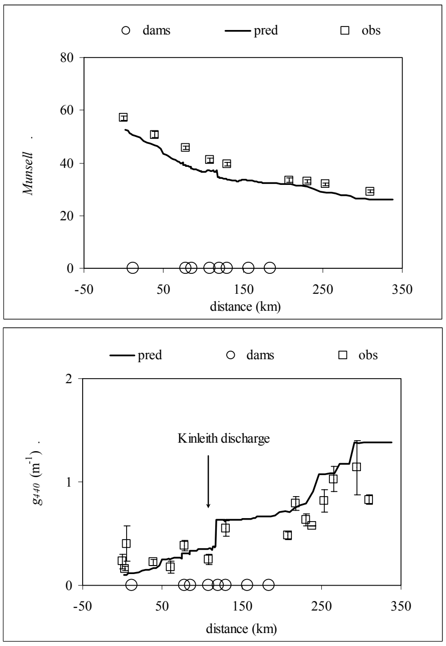
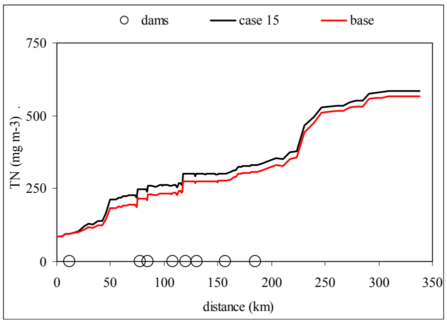
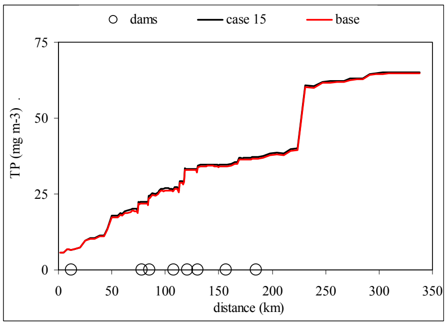


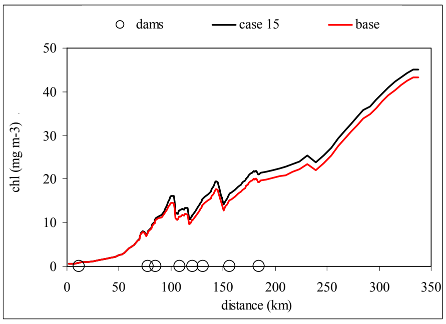
Figure 14: Case 14: summer low flow with current land use. Observations are mean ± standard error from 1993-1995 for flows less than $0.7Q_{mean}$ (see Rutherford et al. 2001 for details).

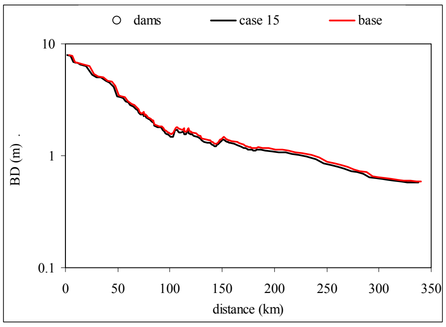
4.2.4 Case 15: 22,500 ha pines above Wharekaka converted to 10,000 ha dairy and 12,500 ha mixed sheep/beef. Summer low flow.

Comparing Cases 14 and 15 land use change increased *TN* concentrations in the upper river and they subsequently remained high throughout the river. Increased *TN* resulted in higher 'carrying capacity' and chlorophyll concentrations in the hydro lakes, and this difference increased progressively downstream. The land use changes were identical to Cases 15 and 12. However, river flow was higher for Case 15 and consequently *TN* concentrations were lower. The *TN* concentration difference Case 15 – Case 14 was also lower than the concentration difference Case 12 – base case because the higher river flow caused greater dilution of tributary loads. Consequently the 'carrying capacity' and chlorophyll concentrations were lower for Case 15 than Case 12. However, the percentage increases in chlorophyll Case 15 – Case 14 were similar to those for Case 12 – base Case. Appreciable chlorophyll settling in the hydro lakes was predicted for Case 15 despite the higher river flow. As with previous simulations, the effects of these land use changes on *TP* concentration, black disc clarity and Munsell colour were barely discernible although there was a slight increase in the concentration of yellow substance.


dams
case 15
base
TN (mg m-3)
750
500
250
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 15
base
TP (mg m-3)
75
50
25
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 15
base
chl (mg m-3)
50
40
30
20
10
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 15
base
BD (m)
10
1
0.1
0
50
100
150
200
250
300
350
distance (km)

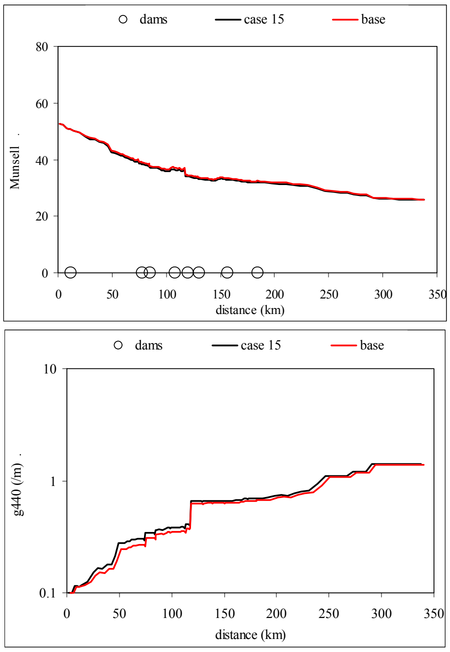
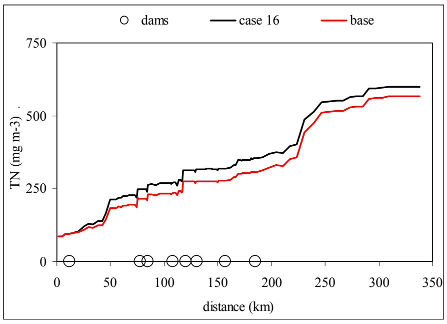
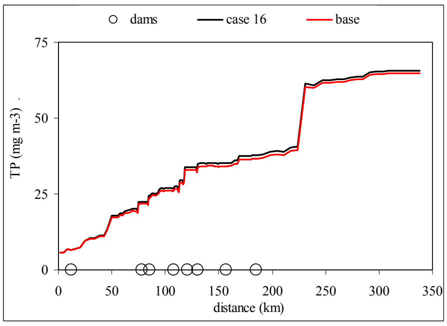


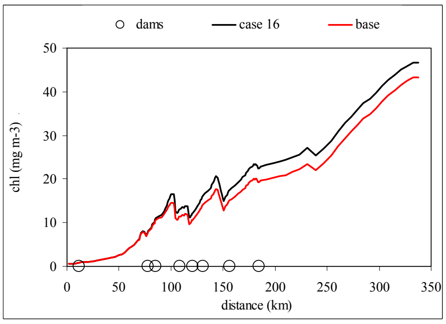
Figure 15: Case 15 compared with Case 14.

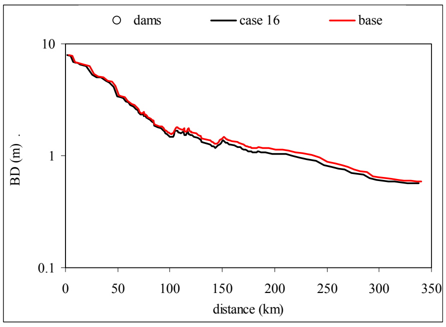
4.2.5 Case 16: 22,500 ha pines above Wharekaka converted to 10,000 ha dairy and 12,500 ha mixed sheep/beef PLUS 7,000 ha pines between Ohakuri and Maraetai converted to dairy PLUS 7,000 ha pines between Maraetai and Pokaiwhenua converted to dairy. Summer low flow.

The land use changes were identical for Cases 16 and 13 but river flow was higher. Comparing Cases 16 and 14 land use changes above Wharekaka resulted in higher *TN* concentrations in the upper river while land use changes between Ohakuri and Maraetai resulted in further *TN* increases in the middle river. This is a similar pattern to Case 13 although, because river flow was higher, *TN* concentrations were lower for Case 16. As in previous simulations the increased *TN* concentrations resulted in higher chlorophyll concentrations in the hydro lakes, and this difference increased progressively downstream. Predicted chlorophyll was lower for Case 16 than Case 13 because there was greater dilution of tributary nutrient inputs, lower river *TN* and hence lower chlorophyll ‘carrying capacity’. Again appreciable chlorophyll settling in the hydro lakes was predicted. As with previous simulations, the effects of these land use changes on *TP* concentration, black disc clarity and Munsell colour were barely discernible although there was a slight increase in the concentration of yellow substance.


dams
case 16
base
TN (mg m-3)
750
500
250
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 16
base
TP (mg m-3)
75
50
25
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 16
base
chl (mg m-3)
50
40
30
20
10
0
0
50
100
150
200
250
300
350
distance (km)


dams
case 16
base
BD (m)
10
1
0.1
0
50
100
150
200
250
300
350
distance (km)

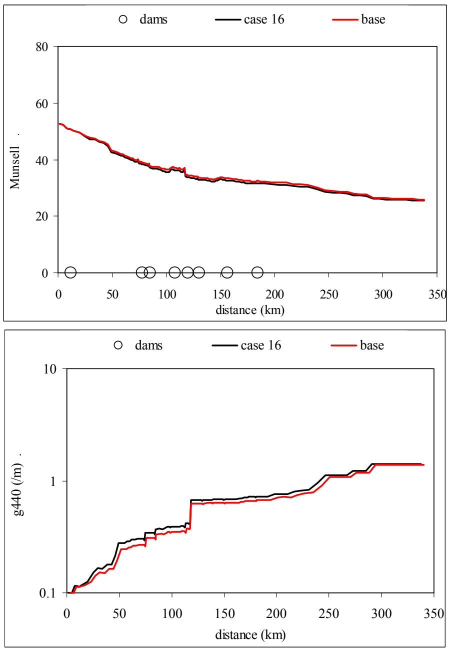


Figure 16: Case 16 compared Case 14.

5. References

Rutherford, J.C.; Williamson, R.B.; Davies-Colley, R.J.; Shankar, U. (2001). Waikato Catchment Water Quality Model. NIWA Client Report: ELE90229/3. August 2001.

6. Appendix 1

WRC Project Code: R209 1 WRC Purchase Order #:

WRC:	Waikato Regional Council	**Contractor for services**:	NIWA
Address: Contact Person: Phone: Fax:	PO Box 4010 Hamilton East Bill Vant (07) 856 7184 (07) 856 0551	Contractor's address for service of notices: Contact Person: Phone: Fax:	PO Box 11-115 Hamilton Jim Cooke (07) 856 7026 (07) 856 0151
Term	From: 26 October 2004 To: 30 November 2004		
Cost of services (excl GST) and terms of payment if different from 5 above.	Total cost $7,600 (invoicing on completion)		
Background information	Environment Waikato wishes to assess the likely effects on Waikato River water quality of (1) reductions in the flow of the river at times of low flow, and (2) changes in nutrient loads to the river from dairy conversions.		
Services: (see attached proposal for details)	Objective: Predict the effects on the water quality of the Waikato River of changes to river flows and catchment land use Services: o Use NIWA's existing Waikato River water quality model to calculate the effects of ten summer low flow scenarios (as attached) o Provide model output as both graphs (similar to Figure 42 in *NIWA Client Report ELE90229/3*) and MS Excel spreadsheets		
Report to:	Bill Vant, WRC		
Investigation Leader	Kit Rutherford, NIWA		

Waikato River scenarios to be modeled by NIWA

NIWA have developed a water quality model for the Waikato catchment.[1] The model takes account of climate, river flows, catchment land use and point source inputs together with in-river processes including particle settling and algal growth to calculate the resulting river water quality throughout the length of the river (Taupo Gates to Port Waikato): nutrients, algal biomass, suspended sediment, colour and clarity.

The model has been calibrated using EW's and other monitoring information, and produces satisfactory estimates of river water quality (e.g., "The model accurately predicts the average chlorophyll concentrations in the hydro lakes at summer low flow which gives us confidence in using it to estimate the effects of land use changes on average water quality", Rutherford et al. 2001, p. 87).

[1] Rutherford, J.C. & others 2001: Waikato catchment water quality model. *NIWA Client Report ELE90229/3*. NIWA, Hamilton.

Environment Waikato has identified the following scenarios that it wishes to have modelled:

1. Summer climate, with flows corresponding to a flow at Mercer of 185 m^3/s (i.e., Q_5). Call this “Base case”.

2. Base case, but with flows across the catchment reduced by 10% (i.e., 10% of Q_5 abstracted).

3. Base case, but with flows across the catchment reduced by 20%.

4. Base case, but with flows across the catchment reduced by 30%.

5. Base case, but with all sources of nitrogen and phosphorus—including point source inputs—reduced by 10%.

6. Base case, but with all sources of nitrogen and phosphorus increased by 10%.

7. Base case, but with flows across the catchment reduced by 10%, and all sources of nitrogen and phosphorus reduced by 10%.

8. Base case, but with flows across the catchment reduced by 10%, and all sources of nitrogen and phosphorus increased by 10%.

9. Base case, but with 20,000 hectares of pine plantation in the catchment upstream of the outflow from Lake Ohakuri converted to dairy (at 280 cows/km^2 as in Rutherford et al.’s “Scenario 4”).

10. Base case, but with 40,000 hectares of pine plantation in the catchment upstream of the outflow from Lake Ohakuri converted to dairy (at 280 cows/km^2 as in Rutherford et al.’s “Scenario 4”).

7. Appendix 2

From: Ed Brown [mailto:Ed.Brown@ew.govt.nz]
Sent: Thursday, 11 November 2004 10:20 AM
To: Rutherford, Kit (CLW, Black Mountain)
Cc: 'j.cooke@niwa.co.nz'; Peter Singleton; Bill Vant
Subject: FW: Flows to model

Hi Kit,
Sorry that you have not received a reply to your email request. Bill is currently off work after injuring his leg in a cycling accident - he is recovering well and should be working part-time starting next week.

1. I am ready to run the scenarios but would like your input first on
Taupo Gates and Waipa flows (see earlier email below).
The flow of 185 cumecs at Mercer is the Q5 flow and corresponds to being exceeded 98.5% of the time between 1994 and 2004. The 98.5 %tile flow at Waipa (Whatawhata) from 1990 to 2004 is 13.1 cumecs and for comparison the Q5 for the last 32 years is 15.1 cumecs. The 98.5 %tile flow at Taupo Gates from 1990 to 2004 is 48 cumecs and for comparison the Q5 at Reids Farm for the last 30 years is 50 cumecs. Data from the last 10 years has been selected as it includes the current regime of discharge from the TPD into Taupo.

2. '...flows reduced by 10% etc...' Do you want me to reduce the Taupo
outflow by 10% as well, or just the tributary inflows?
Have checked with Bill, please reduce flows across the catchments by the 10% etc. as stated in the contract, including Taupo.

I will be away all next week so any other information requirements can be directed to Bill who should be back for some of next week or I can deal with them prior to Friday 12th knock of time.

Hope this helps,
Cheers
Ed.
Dr Edmund Brown
Environment Waikato
PO Box 4010
401 Grey Street
Hamilton East
direct line +64-7-859 0715
phone +64-7-856 7184
email ed.brown@ew.govt.nz

-----Original Message-----
From: Rutherford, Kit (CLW, Black Mountain)
Sent: Thursday, 4 November 2004 11:22 AM
To: 'Bill Vant'
Subject: Flows to model

Hi Bill
Two things
1. I am ready to run the scenarios but would like your input first on

Taupo Gates and Waipa flows (see earlier email below).
2. '...flows reduced by 10% etc...' Do you want me to reduce the Taupo outflow by 10% as well, or just the tributary inflows?

Kit

Kit Rutherford, Ecosystem Modelling
CSIRO Land & Water, GPO Box 1666, Canberra, ACT 2601
phone +61 2 6246 5706, email kit.rutherford@csiro.au

-----Original Message-----
From: Rutherford, Kit (CLW, Black Mountain)
Sent: Tuesday, 2 November 2004 12:16 PM
To: 'Bill Vant'
Subject: Flows to model

Hi Bill
I am lining ducks up to re-run the model. One quick question for you.
Can you please check with your hydro people and then advise me the flows
1. out of Taupo Gates and
2. in the Waipa
corresponding with 185 m3/s at Mercer (Q5). Thanks.

Kit

Kit Rutherford, Ecosystem Modelling
CSIRO Land & Water, GPO Box 1666, Canberra, ACT 2601
phone +61 2 6246 5706, email kit.rutherford@csiro.au

8. Appendix 3

```
From: Bill Vant [mailto:Bill.Vant@ew.govt.nz]
Sent: Wednesday, 15 December 2004 8:05 AM
To: Rutherford, Kit (CLW, Black Mountain); j.cooke@niwa.co.nz
Cc: d.roper@niwa.co.nz
Subject: RE: more scenarios

Many thanks Kit.
The attached file contains two additional scenarios ("12" and
"13"). Please check that they make sense, and if they do, then
please proceed.

Jim: I spoke to Dave in your absence, and we agreed we'd be
able to sort out the contractual details when you return. I
suppose I need to know the cost soonish, but otherwise would
you be prepared simply to invoice me for this additional task
on completion?  Or should we be anticipating that this may not
be the last request for additional scenarios, and arrange
something more general to cover any such?
Thanks again, Bill
```

Two additional Waikato River scenarios to be modelled by NIWA.

In October 2004 Environment Waikato commissioned NIWA to use the existing Waikato River model to predict the effects on water quality of changes to river flows and catchment land use (see EW DOCS #955094). EW now wishes to have two further scenarios addressing land use changes modelled. Let's refer to these as "Case 12" and "Case 13", as follows:

Case 12. Base case, but with 22,500 hectares of pine plantation in the catchment upstream of the point where the Wharekaka Stream enters the river (64.6 km) converted to 10,000 hectares of dairy (at 280 cows/km^2) and 12,500 hectares of sheep and beef.

Case 13. Base case, but with (a) 22,500 hectares of pine plantation in the catchment upstream of the point where the Wharekaka Stream enters the river (64.6 km) converted to 10,000 hectares of dairy (at 280 cows/ km^2) and 12,500 hectares of sheep and beef (as in Case 12), and (b) 7000 hectares of pine plantation in the catchment between the Ohakuri dam (78 km) and the Maraetai dam (120.5 km) converted to dairy (280 cows/km2) and (c) 7000 hectares of pine plantation in the catchment between the Maraetai dam (120.5 km) and the point where the Pokaiwhenua Stream enters the river (169.1 km) converted to dairy (280 cows/ km^2).

(Note that "Base case" refers to the first scenario modelled under the October 2004 contract, as follows: *Summer climate, with flows corresponding to a flow at Mercer of 185* m^3/s *(i.e.* Q_5*). Call this "Base case".*)

```
From: Bill Vant [mailto:Bill.Vant@ew.govt.nz]
Sent: Thursday, 16 December 2004 11:12 AM
To: Rutherford, Kit (CLW, Black Mountain); Bill Vant;
j.cooke@niwa.co.nz
Cc: d.roper@niwa.co.nz
Subject: RE: still more scenarios

Thanks for that Kit. I've decided I would like three additional
runs please (14, 15 and 16). As per the attachment. Many
thanks, Bill
```

Addendum

After-thought (16/12/04)

EW would also like three further scenarios modelled: call these "Case 14", "Case 15" and "Case 16". They are analogous to Cases 1, 12 and 13, but with different summer flow conditions as follows:

Case 14. Summer climate, with flows corresponding to 125 m^3/s at Taupo Gates, 35 m^3/s at Whatawhata and 250 m^3/s at Mercer. This is the same as NIWA's (2001) "summer low flow". Call this "NIWA summer low".

Case 15. NIWA summer low, but with 22,500 hectares of pine plantation in the catchment upstream of the point where the Wharekaka Stream enters the river (64.6 km) converted to 10,000 hectares of dairy (at 280 cows/km^2) and 12,500 hectares of sheep and beef.

Case 16. NIWA summer low, but with (a) 22,500 hectares of pine plantation in the catchment upstream of the point where the Wharekaka Stream enters the river (64.6 km) converted to 10,000 hectares of dairy (at 280 cows/ km^2) and 12,500 hectares of sheep and beef (as in Case 14), **and** (b) 7000 hectares of pine plantation in the catchment between the Ohakuri dam and the Maraetai dam (120.5 km) converted to dairy (280 cows/km2) and (c) 7000 hectares of pine plantation in the catchment between the Maraetai dam and the point where the Pokaiwhenua Stream enters the river (169.1 km) converted to dairy (280 cows/ km^2).

```
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From: Kit.Rutherford@csiro.au [mailto:Kit.Rutherford@csiro.au]
```

Sent: Thursday, 16 December 2004 10:32 a.m.
To: Bill.Vant@ew.govt.nz; j.cooke@niwa.co.nz
Cc: d.roper@niwa.co.nz
Subject: RE: still more scenarios?!

Hi Bill. It is easy enough for me to re-run the model. I can see where you are coming from and agree it is probably worth generating a few extra pictures. If you can confirm the scenarios you want run, I can try and fit them in before Xmas.
Kit Rutherford

From: Bill Vant [mailto:Bill.Vant@ew.govt.nz]
Sent: Thursday, 16 December 2004 7:02 AM
To: Rutherford, Kit (CLW, Black Mountain); j.cooke@niwa.co.nz
Cc: d.roper@niwa.co.nz
Subject: RE: still more scenarios?!

Hello Kit. Many thanks for that. At first reading everything makes sense/seems reasonable. I'll start playing with the numbers shortly. I greatly appreciate the speedy turn-around: my compliments!

But on reflection (!), I realize EW's original desire to have some scenarios modelled was initially driven by the water allocation issue (i.e., effects of allocating >10% of Q5). So naturally it made sense (to me at least) that "base case" be Q5. Since then I've wondered whether this is perhaps a bit extreme, especially since phytoplankton losses through settling in the hydrolakes is high in this case. So I've been wondering "what if we made base case Kit's summer low flow (250 m3/s at Mercer), or even Kit's summer mean flow (360 m3/s at Mercer: predicted Chla shows no marked settling-induced dips in the hydrolake reach, see your Fig 31)"? And repeated Cases 12 and 13 against one or both of these revised baselines. Your thoughts?

My guess at this stage is that if we were to re-do cases 12 and 13 compared to your summer low flow base for example, then the relative changes would be similar to those already calculated (e.g. TN and Chla would increase by similar proportions). But unless we do it, I won't know for sure! So I think it's worth doing; how about you?

As an aside, there's a minor detail we'd have to sort out before taking this further, namely the relativity of the 98.5% exceedance flows EW specified for our original base case, namely 48, 13 and 185 m3/s at Taupo Gates, Whatawhata and Mercer, compared to that of the values you used, namely 125, 35 and 250 m3/s. For the period 1994-2004 these represent exceedances of about 60, 75 and 90% at the relevant sites. There may be a can of worms here; I recall feeling I would probably have been satisfied if you'd specified all catchment flows for my original base case as simply being 185/250ths of

the corresponding values in your summer low flow scenarios.
Thanks, Bill

From: Kit.Rutherford@csiro.au [mailto:Kit.Rutherford@csiro.au]
Sent: Wednesday, 15 December 2004 5:27 p.m.
To: Bill.Vant@ew.govt.nz; j.cooke@niwa.co.nz
Cc: d.roper@niwa.co.nz
Subject: RE: more scenarios

Hi Bill. In the interests of you getting away for Xmas, I enclose the unchecked results of running Cases 12 and 13. Please note they have not been checked by anyone else yet! Please contact me if there are any problems. Jim: if and when you get back from Oz, could you please get this Addendum reviewed, reformatted and sent to EW officially. Kit Rutherford, Ecosystem Modelling, CSIRO Land & Water, GPO Box 1666, Canberra, ACT 2601. phone +61 2 6246 5706, email kit.rutherford@csiro.au
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