Lake Okareka Trophic State Targets

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J C Rutherford
A B Cooper

Prepared for

Environment B·O·P

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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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Reviewed by: *Approved for release by:*

Ian Hawes David Ray

Formatting checked

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Executive Summary

Environment B.O.P has prepared a draft Action Plan for Lake Okareka to improve water quality by reducing nutrient loads. NIWA was asked to help revise the Action Plan and specifically to:

- Re-work Table 4 of the Action Plan and produce water quality targets to achieve an average Trophic Level Index (TLI) = 3 by reducing each sub-index (TLx) by 0.3,

- Re-calculate the target lake water quality and check whether these targets are feasible (based on historic monitoring data from Lake Okareka and elsewhere), and

- Estimate the nitrogen and phosphorus load reductions required to achieve these targets.

The ratio of TN/TP in Okareka is ~ 36 which indicates it is more likely to be phosphorus than nitrogen limited. However, there was general agreement at a meeting of Environment B·O·P staff, NIWA staff and Noel Burns of Lakes Consulting Ltd that the best strategy to reduce algal biomass, and hence increase water clarity, in Lake Okareka is to reduce both nitrogen and phosphorus loads.

It is estimated that average lake concentrations of 5 mgP/m^3 and 183 mgN/m^3 will give an average trophic lake index (TLI) of 3: the target set for Okareka. Lake concentrations are currently 6.5 mgP/m^3 and 230 mgN/m^3, implying that a 21% reduction in nutrient concentration is required. The target lake concentrations fall within the range of observed lake concentrations (1990-2001) and therefore should be achievable.

Historic data from Lake Okareka show only weak relationships between annual average Secchi disc clarity, chlorophyll-*a*, TN or TP concentrations. There is likely to be high variability in clarity and chlorophyll concentration if/when lake TN and TP concentrations are reduced to target levels. Nevertheless the target values conform to the spread of chlorophyll/nutrient relationships seen in existing data and are realistic.

Nutrient loads were estimated from measured lake concentrations using an established model (Hoare 1980, 1987). The nitrogen load of 11.3 tN/yr (range 6.8-16.9) is comparable with estimates made in the draft Action Plan (12.5 tN/yr) but the phosphorus load of 0.32 tP/yr (range 0.19-0.47) is significantly smaller (1.62 tP/yr). We believe the phosphorus load in the draft Action Plan (1.62 tP/yr) is unrealistically high. Load reductions estimated in this study to meet the target TLI of 3 are 2.32 tN/yr (range 1.39-3.47) and 0.07 tP/yr (range 0.04-0.10). The required reductions in this report are larger than in the draft Action Plan (1.23 tN/yr and 0.03 tP/yr respectively) for two reasons:

1. the target sub-index for P is slightly lower than in the Action Plan, and

2. the relationship between load and lake concentration is >1 whereas it was assumed to be 1 in the Action Plan.

1. Introduction

Environment B·O·P has prepared a draft Action Plan for Lake Okareka to reduce lake trophic status by reducing nutrient loads. Noel Burns of Lakes Consulting Ltd provided consultancy advice on use of the trophic lake index (TLI). Bryce Cooper (NIWA) was one of the reviewers and raised concerns about the water quality targets arrived at in the Action Plan.

A meeting was held on 15th July in Hamilton to discuss these concerns. Attending were Paul Dell, Stephen Park and John Gibbons-Davies (Environment B.o.P.), Noel Burns (Lakes Consulting Ltd), Bryce Cooper and Kit Rutherford (NIWA). At the end of the meeting NIWA was requested to:

1. Re-work Table 4 of the Action Plan to achieve an average TLI = 3 by reducing each TLx by 0.3,

2. Re-calculate the target lake water quality and check whether these targets are feasible (based on historic monitoring data from Lake Okareka and elsewhere), and

3. Estimate the nitrogen and phosphorus load reductions required to achieve these targets.

2. Findings

2.1 Target lake water quality

Table 1 is a re-working of Table 4 in the Action Plan. The average lake water quality (line 1) is the average of the annual mean values given in Figure 3.5 of the Environment B·O·P Report (Gibbons-Davies 2001). TLx values are re-calculated using the equations from Burns et al. (1999). Note that the coefficients for the Secchi disk sub-index, TLs, have been changed (as reported by Noel Burns at the meeting on 15th July 2002).

Management of chlorophyll-*a* and water clarity in the current draft Action Plan are dependent on management of TN and TP. Existing annual average data, however, indicate that the relationships between either TN or TP and chlorophyll-*a* is weak (Figure 1). The same is true for Secchi disc clarity (data omitted). Nevertheless, based on experience in other lakes, a reduction in long-term average TN and TP can be expected to lead to a reduction in long-term average chlorophyll-*a* concentration and an increase in Secchi disc clarity.

The current TLn of 3.5 and TLp of 2.6 indicate that the ratio of nitrogen/phosphorus in the water column is higher than is typical in the New Zealand lakes that Burns et al. (1999) examined when deriving the normalising equations used to calculate TLx values from lake water quality.

The ratio of TN/TP in Okareka (based on the long term averages in Table 1) is ~36. Pridmore (1987) plots annual average TN versus TP values for 34 New Zealand lakes (Appendix 1). There are several lakes with a high TN/TP ratio comparable with Okareka. It is asserted by Pridmore that for '…balanced phytoplankton growth…' the ratio of TN/TP should lie in the range 10-17. It can be inferred that in Okareka phytoplankton growth is unbalanced and that phosphorus is in short supply compared with nitrogen.

However, Figure 1 shows that there is a correlation (albeit weak) between annual average chlorophyll and TN concentrations, but not between chlorophyll and TP concentrations. This indicates that as lake TN concentration decreases, so too does chlorophyll-*a* concentration.

The study of White et al. (1986) showed that with a TN/TP ratio of 32, phytoplankton in a sample of Lake Okareka water were lacking in phosphorus but also showed short term responses to nitrogen addition. Regardless of whether phytoplankton respond in the short term to nitrogen or phosphorus additions, there is general agreement that the best way to maintain or improve lake water quality in the long term is to reduce the inputs of <u>both</u> nitrogen and phosphorus (e.g., see Rutherford et al. 1989). The reason is that phytoplankton communities are complex and can adjust to accommodate changes in the balance of water column nutrients. For example, when a lake appears to be nitrogen limited (viz., TN/TP < 10) reducing just nitrogen seems to be the optimal strategy. This is seldom advocated because reducing nitrogen but not phosphorus might favour blue-green algae (that can fix atmospheric nitrogen) and result in a smaller decrease in chlorophyll than expected and a shift to undesirable bloom-forming blue-green species. Similarly, in a lake like Okareka that appears to be phosphorus limited (viz., TN/TP ~ 36) reducing just phosphorus appears to be the optimal strategy. However, as suggested by Noel Burns during discussions on 15th July 2002, in lakes like Okareka phosphorus may be recycled very efficiently even though concentrations are low (see also White et al. 1986). If this is so then reducing just phosphorus may result in a smaller decrease in chlorophyll than expected. There was general agreement at the meeting on 15th July that the best strategy for Okareka is to reduce both nitrogen and phosphorus loads.

The average TLI is currently 3.3 and to achieve the target TLI of 3.0, an average reduction is required of 0.3. Because chlorophyll-*a* and Secchi disc clarity depend on TP and TN concentrations, the various TLx values are correlated. However, there is some uncertainty about exactly what average values chlorophyll-*a* and Secchi disc clarity will attain for given average TN and TP concentrations. Thus it is not clear what values the individual TLx will have if/when the average TLI in the lake has been reduced to the target value of 3.

It was agreed at the meeting on 15th July, that the aim should be to reduce each of the TLx values by 0.3. Table 1 indicates that when this is done, the resulting target TLx values range from 2.3 for phosphorus to 3.6 for chlorophyll with an average TLI of 3.0. Note that the imbalance in TLp and TLn remains. We cannot be certain that the combination of target TLx values shown in Table 1 will occur even if the nutrient loads are reduced to the targets described below. It is possible that some TLx values may decrease by more than 0.3 and some by less than 0.3. However, on the basis of the available information, it was agreed that the best strategy is to aim to reduce each TLx value by 0.3.

The target lake water quality for each variable was then calculated by inverting the equations used to calculate the TLx values. A check was run to ensure that these water quality targets gave the target TLx values (details omitted).

Table 1: Current (1992-2001) and target lake water quality and trophic indices.

	Chla mg/m3	SD m	TP mg/m3	TN mg/m3	
Current Lake Quality	**4.51**	**7.13**	**6.45**	**230.5**	Gibbons-Davies, 2001, Fig 3.5
TLx coefficients	2.22	5.56	0.218	-3.61	From Burns et al. (1999). NB the
TLx coefficients	2.54	2.6	2.92	3.01	coefficients for TLs have been
TLx coefficients		40			modified (see text)
	TLc	TLs	TLp	TLn	
Current TLx	**3.88**	**3.12**	**2.58**	**3.50**	Average TLI = 3.27
					Target average TLI = 3.00
					Average reduction = 0.27
Required reduction	0.30	0.30	0.30	0.30	Reduce all TLx by 0.30
Target TLx	**3.58**	**2.82**	**2.28**	**3.20**	
Target Lake Quality	chla	SD	TP	TN	
	mg/m3	m	mg/m3	mg/m3	
	3.44	**8.82**	**5.09**	**183.2**	Average concentrations

Figure 1 compares current annual average and target average lake water quality plotted in terms of chlorophyll versus nutrient relationships. There is considerable scatter in lake observations, notably one high chlorophyll value in 1996 (9.8 ± 5.1 mg m^{-3}). Nevertheless, the target lake quality (solid black circle) falls within the range of values observed at some time during the period 1990-2001, indicating that they are realistic targets and make limnological sense (i.e., chlorophyll/nutrient relationships are reasonable). Figure 2 compares annual average and target lake chlorophyll, TN and TP plotted as time series. The target values roughly correspond with the minimum values observed in the lake over the period 1990-2001.

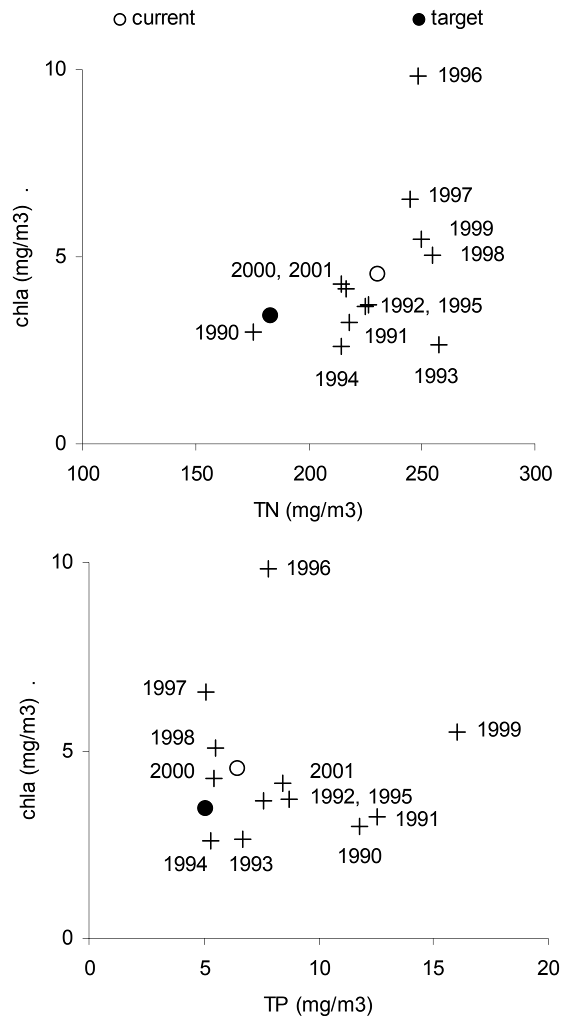

Figure 1: Annual average chlorophyll versus nutrient concentration. Also shown are the overall average 1990-2001 (open circle) and the target values (closed circle).

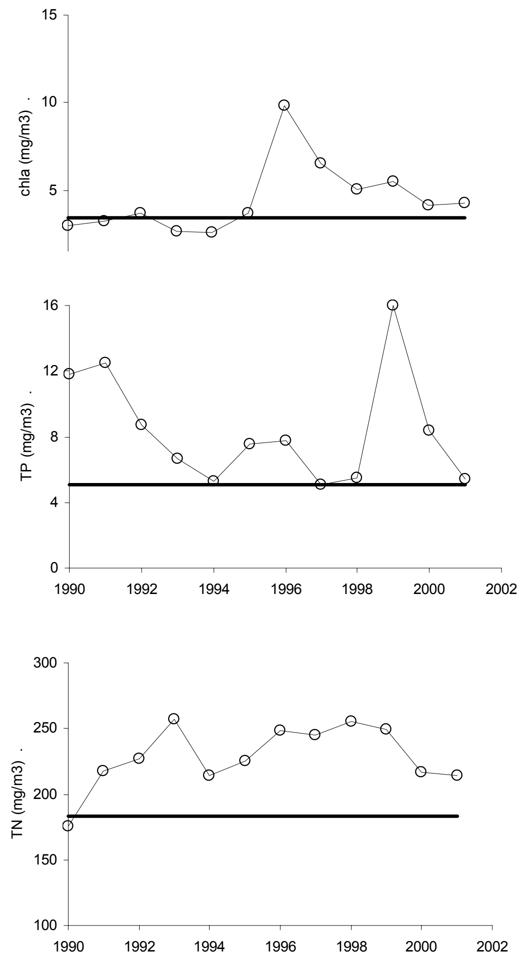

Figure 2: Annual average lake water quality 1990-2001 (circles) and proposed targets (horizontal black line).

2.3 Load reductions

The draft Action Plan estimates the nitrogen and phosphorus loads on Lake Okareka using published information on nutrient yields from catchments with different land uses. This is a standard and valid approach, but there is high variability in published nutrient yield data arising in part because they are measured on a range of different soils, slopes and hydrological regimes.

At the 15th July meeting NIWA advocated 'back calculating' catchment nutrient loads from measured lake nutrient concentrations. Such estimates have the attraction of being based on actual lake concentration measurements in Lake Okareka, although they do depend on accurately estimating nutrient retention in the lake. Nutrient load is 'back calculated' using a well-proven model for nutrient (e.g., that Hoare (1980) applied on Lake Rotorua). The model is a steady-state mass balance formula relating average lake outflow nutrient concentration, C (mg/m^3), to nutrient load, M (mg/yr), outflow rate, Q (m^3/yr) and nutrient retention coefficient, R (dimensionless).

$$C = (1-R)\,M / Q$$

The nutrient retention coefficient, R, is the fraction of the nutrient load that does not leave the lake via its outflow (e.g., by settling onto the lakebed or loss by denitrification). This equation can be rearranged to estimate the nutrient load, M

$$M = CQ / (1-R)$$

The approach requires knowledge of the:

1. annual-average lake outflow nutrient concentration, C,
2. outflow rate, Q, and
3. retention coefficient, R.

Both Q and C (which can be assumed to approximate to the average surface water nutrient concentration) are known for Lake Okareka with moderate precision. The underlying assumption that each of these variables approaches a long-term steady state is supported by Figure 2.

The nutrient retention coefficient, R, for TP has been estimated in a large number of overseas lakes. It has been shown by Nurnberg (1984) to be inversely related to the hydraulic loading rate, Q/A, where A = lake surface area. Thus lakes with a very long residence time (low hydraulic loading) have a value of R that approaches 1 while lakes with a very short residence time have a value of R that approaches 0.

Nurnberg (1984) (as reported in Hoare 1987) derived an equation relating R with Q/A. We used Nurnberg's equation to estimate the likely value of R for Lake Okareka knowing its value of Q/A. The 'best estimate' for Okareka is R = 0.7 but the uncertainties are high and, based on the scatter shown by Hoare (1987), upper and lower bounds of 0.5-0.8 were used in subsequent calculations.

Nurnberg (1984) only considered TP when deriving the relationship between R and Q/A. It is possible that the R value for TN could be different from the R value for TP. However, Hoare (1980) found that, in Lake Rotorua, the retention coefficients for TP and TN were very similar. We assumed them to be identical in Lake Okareka.

Having estimated R for Lake Okareka, we then used the same model to estimate the nutrient load, M*, required to achieve a given 'target' lake concentration, C*.

$M^* = C^*Q / (1-R)$

Predictions are summarised in Table 2. The target nitrogen and phosphorus lake concentrations are 21% lower than the current average lake concentrations and, as expected, the target nutrient loads are also 21% lower than the current loads.

Estimates of current and target nutrient loads are repeated in Table 3.

Table 7 in the draft Action Plan summarises load estimates based on land-use yield coefficients, and estimates of septic tank contributions, rainfall and internal load. The Action Plan estimate for nitrogen load of 12.5 t/yr is close to our estimate of 11.3 t/yr (range 6.8-16.9) based on lake concentration. However, the draft Action Plan estimate for phosphorus of 1.6 t/yr is more than 5-fold our estimated mean of 0.32 t/yr, and 3-fold greater than our upper bound estimate of 0.47 t/yr, based on lake concentration. The reason for this discrepancy and its implications are discussed in the next section.

Mean estimates of load reductions estimated in this study of 2.32 tN/yr and 0.07 tP/yr are approximately 2-fold those in the draft Action Plan (its Table 5) of 1.23 tN/yr and 0.03 tP/yr. The reasons for these differences are that:

1. The target TLp is lower in this report.

2. The relationship between load and lake concentration is >1 in this report (namely 1/(1-R)) whereas it was assumed to be 1 in the draft Action Plan.

Table 2: Estimation of current nutrient loads (based on average lake concentrations 1992-2001) and target nutrient loads to reach proposed target lake concentrations.

	chla mg/m3	sd m	TP mg/m3	TN mg/m3	Notes
Average 1992-2001	4.51	7.13	6.45	230.5	Gibbons-Davies (2001), Fig 3.5
Target lake quality	3.44	8.82	5.09	183.2	
Reduction			21%	21%	
lake area A m2	3,400,000				
lake volume V m3	59,088,000				mean depth = 17.4 m
catchment runoff Q1 m3/yr	11,291,000				Ray & Timpany 2002; rain minus evapotranspiration
Direct rainfall onto lake Q2 m3/yr	3,400,000				Rain-evapotranspiration
total inflow Q = Q1+Q2 m3/yr	14,691,000				
hydraulic loading Q/A m/yr	4.3				residence time = 4 years
predicted retention coefficient R (-)	0.7				Nurnberg (1984) in Hoare (1987)
lower bound R	0.5				R=15/(18+Q/A)
mean R	0.7				
upper bound R	0.8				
			TP	**TN**	
Estimated current load			t/yr	t/yr	Hoare (1980)
lower bound			0.19	6.8	C=(1-R)M/Q hence M=CQ/(1-R)
Mean			0.32	11.3	
upper bound			0.47	16.9	
Estimated target load			t/yr	t/yr	
lower bound			0.15	5.4	
Mean			0.25	9.0	
upper bound			0.37	13.5	
Estimated load reductions			t/yr	t/yr	
lower bound			0.04	1.39	
Mean			0.07	2.32	
upper bound			0.10	3.47	
			21%	21%	

Table 3: Summary of current and target nutrient loads estimated in this study. Mean estimates (with lower and upper bounds).

	Current	Target	Reduction
Phosphorus t/yr	0.32 (0.19-0.47)	0.25 (0.15-0.37)	0.07 (0.04-0.10)
Nitrogen t/yr	11.3 (6.8-16.9)	9.0 (5.4-13.5)	2.32 (1.39-3.47)

2.4 Implications of our findings

1. To achieve the target trophic state for Okareka there is a need to reduce both N and P loadings. As the relative sources of N and P and their pathways to the lake can be different, the effectiveness of reduction strategies needs to be considered on a nutrient-specific basis. Section 6 of the draft Action Plan needs to be re-visited to address this point.

2. To achieve the target trophic state for Lake Okareka requires load reductions approximately 2-fold those in the draft Action Plan, thus Section 6 of that document ("Actions to Reduce Nutrient Load") needs to be re-visited.

3. The estimate of P load to Okareka contained in the draft Action Plan of 1.62 t/yr (its Table 7) needs to be revised downward. We are of the view that the estimate we have made of 0.32 tP/yr (0.19-0.47), based upon in-lake concentration and retention coefficients, is a more reasonable one. There are several pieces of evidence to support this contention:

    - To achieve the target in-lake concentration of TP with a load of 1.62 t/y we would have to postulate a retention rate of 0.95, which is outside the band of observed values shown by Nurnberg (1984).

    - The ratio of N/P in the lake may be expected to reflect the ratio of N/P in the source waters, particularly where in-lake sources such as N-fixation and bottom release are likely to be minor (as in Okareka). This assumes that the R values for TP and TN are similar. Based on Hoare's work in Lake Rotorua (Hoare 1980) this seems a reasonable assumption. The loads estimated in Table 7 of the draft Action Plan lead to an N/P ratio in source waters of 7.7, well below the observed in-lake ratios of 30-40. Because the N loading estimates in the draft Action Plan are in close agreement with our estimate based upon in-lake concentrations, we suggest that the P loading estimates in the draft Action Plan are in error.

- The limited data for inflows to Okareka (Environment B·O·P 1994/95 data, presented in Appendix 2 of Ray and Timpany, 2002) show low P concentrations and high N/P ratios. For example, the Millar Road stream site had an average TP of 0.035 gP/m^3 and N/P ratios in excess of 30. Care needs to be taken in interpreting these data as they were all collected during periods of baseflow (Park, Environment B·O·P, *pers comm*.), and concentrations of TP may be expected to rise during stormflows. Nevertheless, large areas of the Okareka catchment lack surface streams and stormflows are rare, with much of the inflow to the lake being through groundwater. Ray and Timpany (2002) estimated N loads to the lake from annual inflow estimates (based on rainfall-evapotranspiration) and measurements of N in the surface streams and groundwater. A similar calculation can be done to estimate P loads although, in the absence of data on groundwater P (which we might expect to have lower concentrations than streams) and stormflow P (which we might expect to be higher than stream baseflow concentrations), there will be a very large uncertainty. Assuming an overall average TP concentration of 0.035 gP/m^3 for all catchment inflows and an annual catchment inflow of 11,291,000 m^3/yr (Table 2) then a crude estimate of P load to Okareka would be 0.40 tP/yr. This approximates the load of 0.32 tP/yr (0.19-0.47) that we have estimated from in-lake concentration and is considerably less than the 1.62 tP/yr estimated in Table 7 of the draft Action Plan.

Based upon this analysis we suggest that the P export coefficients used in the spreadsheet model for Okareka (Table 7 of the draft Action Plan) need revision downward so that there is reasonable consistency between load estimates. The export coefficients used in the draft Action Plan for pasture (1.67 kg P/ha/yr) and forest (0.12 kg P/ha/yr) appears to have been derived from the study of Cooper and Thomsen (1988) on catchments at Purukohukohu, approximately 50km southwest. It would appear from our analysis that the Okareka catchment is considerably more retentive of P than those study catchments. We suggest that the lower bound of reported P export coefficients be used in a revised spreadsheet model: *viz*., 0.3 kg P/ha/yr for pasture and 0.04 kg P/ha/yr for forest (indigenous, exotic, and scrub). If this is done, then P load to the lake via the spreadsheet is estimated at 0.34 tP/yr, in reasonable agreement with the estimate from in-lake concentration and retention coefficients of 0.32 tP/yr. Such a revised spreadsheet would then provide the basis for a P reduction strategy as part of section 6 “Actions to Reduce Nutrient Load”, Action 1 (convert pasture to forest) which could become:

“Converting pasture to forest results in a reduction in P export from land of 0.26 kgP/ha/yr (i.e., 0.3 minus 0.04). To achieve the desired reduction in P load from the land of 0.07 tonnes (0.04-0.10) would require conversion of 270 ha (154-384) of land from pasture to forest.”

4. We believe that estimation of nutrient loading to lakes based upon in-lake concentrations and calculation of retention coefficients can be used as an independent ‘calibration’ of load estimates based upon information on point sources and export coefficients from differing land uses. This is particularly so in the Rotorua lakes where good information exists on in-lake concentrations but, generally speaking, poor information exists on nutrient inflows.

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